Examining risk literacy in a complex decision-making environment: A study of public avalanche bulletins

by

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Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

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Abstract

Each winter, approximately 140 individuals die in avalanches in North America and Europe during recreational outings in mountainous backcountry terrain. To help recreationists manage the risks of avalanches, avalanche warning services publish daily bulletins which detail current and forecasted avalanche conditions. The effectiveness of these bulletins depends on whether the risk information they contain is accurately understood and sensibly acted upon by recreationists as they plan and conduct their backcountry trips. This study builds on existing research in risk literacy to present a comprehensive framework for evaluating avalanche bulletin literacy in relation to the needs and practices of different recreational user types. The responses of 3,198 participants to an online survey offer valuable insight on recreationists' avalanche bulletin literacy skills, how these skills relate to each other, and which background factors, such as avalanche training and backcountry experience, have an influence on how bulletins are comprehended. The results from this research provide actionable recommendations for the design and implementation of future interventions.

Keywords: Avalanche safety; risk communication; winter backcountry recreation; decision-making; conditional inference trees

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Chapter 1. Introduction

When faced with situations that involve uncertainty or risk, individuals typically seek to obtain and process relevant information to help guide future decisions and avoid harm or loss (Griffin, Dunwoody, & Neuwirth, 1999). Risk literacy, the practical capacity to understand and evaluate risk-related information (Gigerenzer, 2012, 2015), is an essential prerequisite for competent decision-making: information must first be understood before it can be acted-upon appropriately (Finucane et al., 2002). Having an accurate understanding of risk literacy is of critical importance for both the individuals making decisions in the face of risk and risk communicators that aim to facilitate these decisions with targeted information. To determine how much the public understands about a hazard or to evaluate how effective a risk communication has been, an appropriate measure of risk literacy is needed (Weinstein, 1999).

As citizens are increasingly being placed at the helm of complex risk management decisions involving health, finances, cyber security and natural hazards, the topic of risk literacy has become increasingly important, and there is a growing body of scholarly research on the topic (e.g., Allan, Ripberger, Ybarra, & Cokely, 2017; Cokely, Galesic, Schulz, Ghazal, & Garcia-Retamero, 2012; Garcia-Retamero & Cokely, 2017; Gigerenzer, 2008, 2012, 2015). To offer meaningful insight for risk communicators and educators, a measurement tool for literacy must shed light on what subgroups within a population encounter challenges with what information, and provide actionable recommendations on what needs to be done to address any evident gaps in comprehension (Okan, Bauer, Levin-Zamir, Pinheiro, & Sørensen, 2019). Existing efforts to measure and explain individual differences in risk literacy have primarily focused on individuals' capacity to make sense of probabilities and interpret statistical information (e.g., Cokely et al., 2012; Wegwarth, Gaissmaier, & Gigerenzer, 2009). One of the most widely used and well-established risk literacy scales is the Berlin Numeracy Test; a short psychometrically robust instrument containing a maximum of three questions that evaluates statistical reasoning skills (Cokely et al., 2012).

Winter backcountry recreation in mountainous terrain represents a unique context for studying risk literacy. While activities like backcountry skiing, out-of-bounds skiing, mountain snowmobile riding, snowshoeing or ice climbing can offer rewarding and fulfilling recreational experiences in pristine mountainscapes, these activities are also associated with serious risks. Each winter, avalanche accidents claim an average of 40 lives in North America (Avalanche Canada, 2019; CAIC, 2019; Jekich et al., 2016) and 100 lives in Europe (Techel et al., 2016). Ninety percent of these fatalities are non-professional members of the public engaging in self-directed recreation (Avalanche Canada, 2019; CAIC, 2019). It is further suspected that many more recreationists are involved in avalanche accidents that could have easily resulted in fatalities (Vanpoulle, Vignac, & Soulé, 2017).

Avalanches are a dynamic mountain hazard that continuously evolves throughout the winter in response to interactions between the seasonal snowpack, local weather conditions and terrain (McClung & Schaerer, 2006). The main threat to people is dry-snow slab avalanches where a cohesive slab of snow slides as a unit on the snow underneath. Slab avalanche release results from a sequence of fracture processes, which include failure initiation in a weak layer underneath the cohesive slab, dynamic crack propagation through the weak layer, and tensile failures at the edges of the slab (Schweizer, Reuter, Van Herwijnen, & Gaume, 2016). If the slope is sufficiently steep, the slab will subsequently slide downhill. While many avalanches release naturally during storms, avalanches that involve people are typically triggered by the individuals caught or somebody in their group (Jamieson, Haegeli, & Gauthier, 2010). Since avalanche conditions vary dramatically in space and time, personal avalanche risk is managed by developing an accurate perspective on the existing conditions and carefully choosing when and where to expose oneself to the hazard (Statham, Haegeli, et al., 2018).

To assist recreationists in their personal risk management practices, avalanche warning services publish daily bulletins during the winter on websites and mobile apps. These bulletins are available to the public and provide information about current avalanche conditions. In North America, the main agencies that produce daily avalanche bulletins are Avalanche Canada and Parks Canada in Canada, and the Colorado Avalanche Information Center and various forecasting centers of the US Forest Service in the United States. As well as checking the relevant avalanche bulletin information before their backcountry trips, recreationists can also partake in avalanche awareness courses which are typically a few days long and provide teachings on the skills needed to assess conditions in the field so that trip plans can be adjusted if necessary. Due to the rapidly expanding trends of participation in winter backcountry recreation (Winter Wildlands Alliance, 2017) avalanche warning services and avalanche awareness courses are having to account for a growing audience and one that is notably wide-ranging in terms of its needs, motivations and perspectives (St Clair, 2019).

Another critical challenge that hinders efforts to promote safe avalanche risk management practices among recreationists is the “wicked” conditions for learning in the winter backcountry environment. Unlike “kind” learning environments that provide rapid, regular and accurate feedback as to which decisions or actions will result in positive outcomes, mountainous backcountry terrain is notorious for showing ambiguous, deceptive or non-existent correlations between outcomes and specific decisions (Bonini et al., 2018). These types of wicked learning environments preclude the development of effective risk management routines through meaningful experiential learning (Hogarth, 2001). This challenge is further exacerbated by the fact that ‘successful’ but critically unsafe perceptions and behaviors can be reinforced by emotionally rich rewards of spectacular mountainscapes or thrilling descents through fresh powdered snow. If an accurate feedback signal were to eventually materialize, it could be in the form of a fatal avalanche. In the absence of reliable mechanisms to observe and learn from the outcomes of erroneous decision-making, it can be extremely difficult to form accurate self-assessments of competence (Hogarth, Lejarraga, & Soyer, 2015).

An additional item on the list of factors that increase the risks of winter backcountry recreation is the susceptibility of human decision-making to biases and mental shortcuts, or heuristics, which are known to catch out even the most experienced of individuals (Tremper, 2013). Studies in the field of judgement and decision-making have provided a useful framework for conceptualizing these intellectual tendencies, namely the categorization of cognition into two primary modes of thought: System 1 and System 2 (Kahneman, 2011). The slow, effortful and calculating System 2 allows us to gather and observe evidence for or against one idea or another and is useful in situations when abstract thinking is required. The fast, automatic and emotionally driven System 1 is always functioning in the background and has generally served us extremely well throughout evolutionary history. However, in the complex conditions that are present in the winter backcountry environment, there are certain components of System 1 that can be dangerously misleading. For example, the ‘expert halo’, the ‘role of familiarity’ and ‘herding instincts’ are all types of heuristic traps that have been identified as potential reasons for past avalanche accidents (McCammon, 2004). Developing the necessary skills to avoid the use of these unconscious habits in an environment that seldom provides corrective feedback is extremely challenging, and generally requires years of dedicated training (Tremper, 2013).

To improve the conditions for learning and decision-making in the avalanche safety context, both backcountry recreationists and avalanche risk communicators would benefit from being able to measure avalanche risk literacy in a reliable and meaningful way. Previous studies focused on the comprehension of avalanche bulletin information have used online surveys with self-report measures (e.g., Burkeljca, 2013; Fitzgerald, Kay, Hendrikx, & Johnson, 2016), in which participants were required to provide an assessment of their own competence or proficiency. While self-report measures are commonly used in survey research, they also typically lead to overestimations of competence (Short et al., 2009), and can limit the insight provided to researchers on the reasoning behind participants' selections (Au & Johnston, 2014). Other research examining user comprehension of avalanche bulletin information has combined self-report measures with more objective methods of assessment (Engeset, Pfuhl, Landrø, Mannberg, & Hetland, 2018; Hallandvik, 2017). However, the objective measures in these studies included pre-defined, closed-ended responses, and administered the same evaluative questions to all study participants. For example, Hallandvik et al. (2017) examined whether 209 Norwegian skiers were able to accurately judge the complexity of a specific mountainous terrain feature using a multiple-choice question with three response options; *simple*, *challenging* and *complex*.

To assess avalanche risk literacy meaningfully, it is important to understand that depending on the recreational objective, the risk from avalanches can be managed at different levels of sophistication. For some recreational users, it is completely legitimate to consult avalanche bulletin information to make simple, large-scale decisions, such as whether or not to go out on a given day based on the danger rating alone (St Clair, 2019). Other more advanced users require more nuanced insights to inform small-scale management of personal exposure to avalanche risk (St Clair, 2019). This range of legitimate approaches for personal avalanche risk management makes it challenging to assess avalanche risk literacy in a meaningful way by asking all users the same skill questions. While the informational needs and literacy requirements for various individuals may differ substantially, the same underlying condition applies to everyone who consults the avalanche bulletin: if critical components of avalanche bulletin information are misunderstood, this increases the probability of poor decision-making, which in turn could increase the risk of experiencing a fatal avalanche.

Being risk literate as a winter backcountry recreationist extends beyond the capacity to handle probabilities. In contrast to most risk communication contexts, in which the quantitative likelihood of an adverse event occurring tends to play a central role (Lipkus, 2007), only qualitative risk assessments can be produced for the likelihood of avalanches (Schweizer, 2008). These probability estimates form one of the four fundamental questions for assessing avalanche hazard: (1) What type of avalanches are expected? (2) Where are these avalanches located in terrain? (3) How likely are they to occur? and (4) How big will the avalanches be? (Statham, Haegeli, et al., 2018). For end users, probability estimates are generally seen as secondary in importance compared with other avalanche information components such as the danger rating assignments or recommendations for precautionary behavior (Klassen, Haegeli, & Statham, 2013). Due to the diminished importance of likelihood information in the avalanche context, it is unlikely that conventional approaches for measuring risk literacy, such as The Berlin Numeracy Test (Cokely et al., 2012), would produce meaningful results.

The objective of this research is to build on existing research in risk literacy and develop a framework for assessing avalanche risk literacy that can provide meaningful and actionable insight for avalanche warning services. Using responses to a large online survey on avalanche bulletin use, I will present an approach that evaluates a broad range of relevant competencies and comprehension skills involved with personal avalanche risk management. The research is divided into three distinct components. First, I examine participants' self-reported avalanche bulletin routines. Second, I use objective assessment measures to evaluate whether participants are capable of demonstrating the necessary literacy skills for their self-identified levels of bulletin use sophistication. Finally, I undertake a demographic exploration of literacy performance to provide insights on which segments of the winter backcountry recreational audience encounter the most significant literacy challenges. While this study generates valuable insight for avalanche warning services on the effectiveness of their avalanche bulletin products, the ideas and concepts presented are applicable for studying risk literacy in other complex risk management contexts as well.

Chapter 2. Background

2.1. Avalanche Bulletins

During the winter, avalanche forecasting centers in Canada and the US publish daily avalanche bulletins to provide the public with the information they need to make informed trip planning decisions about backcountry travel. While there are some aesthetic differences between the avalanche bulletins produced by separate forecasting centers across North America, all avalanche bulletins generally contain the same essential features. On the home page of the bulletin, backcountry recreationalists will typically select the area they plan to travel in from a range of bulletin regions shown on a map (Figure 2.1a). This will bring up the contents of the bulletin which is typically structured using an Information Pyramid comprised of three tiers. The most condensed and synthesized information is found at the top, and each step down represents an escalation in the degree of skill required to form proper interpretations (Winkler & Techel, 2014).

The first tier of information presented in public avalanche bulletins is the danger rating (Figure 2.1b), which provides a general measure of avalanche danger for a given bulletin region, over a given period (Statham et al., 2010). Danger ratings are typically provided for the upcoming day as well as the two days that will follow. The danger rating is a color-coded ordinal scale containing 5 signal words: *low*, *moderate*, *considerable*, *high* and *extreme*. The corresponding colors used for each level are green, yellow, orange, red and black. In North America, avalanche bulletins typically include danger ratings for three separate elevations; alpine, treeline and below treeline; enabling users to make broad-scale travel strategies that avoid areas subject to greater risk (Statham et al., 2010).

The second tier of information found in public avalanche bulletins is the avalanche problems (Figure 2.1c), which provide a more detailed account of the specific nature of expected avalanches (Klassen et al., 2013; Statham, Haegeli, et al., 2018). Avalanche problems are comprised of a set of four factors that describe avalanche hazard: type, location, likelihood and size. Avalanche problem types are distinct and repeatable patterns in avalanche characteristics that result from different combinations of snowpack structures and weather conditions (Statham, Haegeli, et al., 2018).

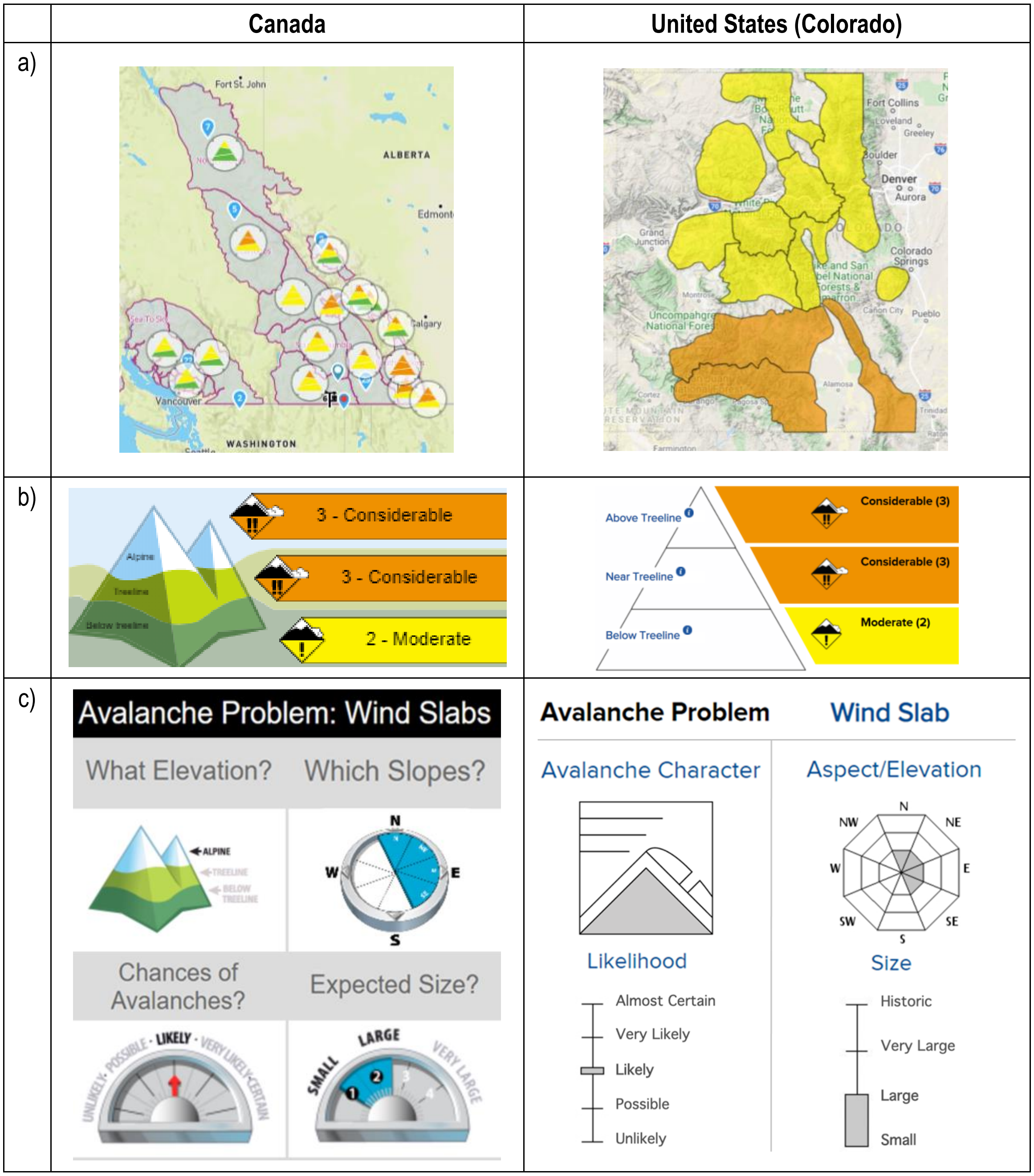

Figure 2.1. **Comparison of the features in a Canadian and a US avalanche bulletin. Both contain a) a map displaying the forecast regions, b) danger rating information, c) avalanche problem information and a detailed weather and snowpack summary. Sources: Avalanche Canada, Colorado Avalache Information Center.**

Wind slab avalanches, for example, result from wind events that deposit dense slabs of broken snow crystals on the lee side of terrain features that act as natural wind-fences, such as ridges, ribs or isolated stands of trees. These types of avalanche are relatively easy to manage since they are associated with well defined locations and typically stabilize within days after significant wind events (Haegeli, Atkins, & Klassen, 2010). Persistent slab avalanches, on the other hand, are much more difficult to forecast and require a patient and conservative approach to travel in avalanche terrain. The persistence in the name is a reference to the associated structural weaknesses in the snowpack that are typically preserved for weeks. During this extended period, large avalanches can be produced in response to human triggers. One of the primary purposes of including the avalanche problems in avalanche bulletins is to encourage pattern recognition by recreational users. The hope is that the problem types will facilitate the identification of hazardous situations at an early stage and help to point out which observations and travel strategies are most suitable given the current conditions (Haegeli et al., 2010). Accordingly, there are a set of specific travel strategies recommended for mitigating avalanche hazard in each avalanche problem scenario (Haegeli et al., 2010; Wagner & Hardesty, 2014). Avoiding warmer, or sun-affected areas, for example, is recommended when there are wet slab avalanches forecasted. The number of avalanche problems used in bulletins differs between countries. While Canadian avalanche bulletins outline the avalanche conditions using eight separate problems, each with its own unique set of characteristics, avalanche forecasting centers in the US also include glide avalanches as a ninth avalanche problem type.

The avalanche bulletin's third tier contains a detailed summary of weather and snowpack information. These text-based descriptions, which are intended for more advanced users, provide a summary of the supporting evidence for the assigned danger rating and avalanche problem conditions. This detailed section also typically includes an account of recent avalanche observations from the area, to give a sense of current trends in avalanche activity over a finer spatial scale than the rest of the bulletin's broader assessments.

Avalanche forecasting centers are tasked with producing this sophisticated hierarchy of information in a format that is digestible and actionable for an audience that varies widely in terms of its skills, knowledge and experience. While explicit data on winter backcountry use is missing, industry experts generally agree that backcountry recreation has increased dramatically over the last decade and is likely to continue growing (Ng, Smith, Wheeler, & McIntosh, 2015; Winkler, Fischer, & Techel, 2016). The evident trends of expansion in winter backcountry recreation necessitate the need to evaluate whether avalanche bulletins are continuing to serve the needs of the backcountry recreational community and whether there are specific components of avalanche bulletin information that users commonly struggle to interpret correctly.

2.2. Existing Research on Avalanche Bulletins

A variety of topics have been explored in attempts to evaluate the effectiveness of the avalanche bulletin as a risk communication tool. These research endeavors can be broadly categorized under three main themes. First, a series of studies have focused on the production end of avalanche risk communication by examining consistency and bias in the delivery of avalanche bulletin information (Clark, 2019; Lazar, Trautmann, Cooperstein, Greene, & Birkeland, 2016; Statham, Holeczi, & Shandro, 2018; Techel et al., 2018). Producing avalanche bulletins requires judgemental assessment that is susceptible to interpretation and bias (Statham, Holeczi, et al., 2018). This presents a challenging public safety issue since inconsistent messaging can lead to conflicting information and confusion for backcountry users. Research in both the European Alps and North America has helped to identify inconsistencies in the assignments of danger ratings (Clark, 2019; Lazar et al., 2016; Techel et al., 2018) and avalanche problems (Statham, Holeczi, et al., 2018) both within and between avalanche forecasting centers. Accordingly, efforts are being made to enhance the consistency of avalanche forecaster training and to encourage avalanche forecasting centers to analyze their own forecasting data to help reduce the effects of bias (Statham, Holeczi, et al., 2018).

Other studies have focussed more on the receiving end of avalanche risk communication, examining how recreationists' use avalanche bulletin information. Some of this research has used intercept surveys in the backcountry to evaluate whether recreationists could remember details from the avalanche bulletin on a given day (Fitzgerald et al., 2016; Procter et al., 2014; Sykes, Hendrikx, Johnson, & Birkeland, 2018). Studies such as these provide valuable insight into actual behavior in the field and help to include participation from those potentially less interested in avalanche research. Efforts have also been made to examine how people incorporate bulletin information into their decision processes using hypothetical terrain choices in online survey environments (Haegeli, Gunn, & Haider, 2012; Haegeli & Strong-Cvetich, 2018; Mannberg, Hendrikx, Landrø, & Ahrland Stefan, 2018). These experiments enable the detection of strengths and weaknesses in the avalanche risk management practices of end users and help to determine the factors that are associated with riskier attitudes and perceptions.

Another important research focus in avalanche risk communication is the study of avalanche bulletins themselves and the explicit quality of communication they provide. To help improve the quality and usability of avalanche bulletins in Switzerland, one study used an online survey to compare user preferences before and after design revisions had been made (Winkler & Techel, 2014). This enabled the various preferences and perceptions of different users of the bulletin to be characterized. A separate study in Canada used qualitative interviews (n=45) to highlight distinctive patterns of avalanche bulletin use among a diverse sample in the lower mainland of British Columbia (St Clair, 2019). In her analysis, St Clair (2019) identified a 5-level avalanche bulletin use typology that categorized users according to the specific bulletin components they typically focus on and the sophistication of trip planning decisions they tend to make. Those with less sophisticated avalanche bulletin routines solely incorporate the danger rating information into simple decisions that span large scales, such as whether or not to head into the backcountry on a given day. Those with a higher degree of sophistication in their avalanche bulletin practices consult the avalanche problem information to make more nuanced decisions than span finer scales. St Clair's (2019) classification of the typical approaches used for interacting with avalanche bulletin information present a novel opportunity to evaluate whether current bulletin products are serving the needs of users at each level. These are but two among a sparse number of studies that have attempted to explicitly examine the quality of risk communication provided by public avalanche bulletins. This leaves an important gap which the present study aims to fill. Here, the aim is to capitalize on the outcomes from St Clair's research by evaluating whether winter backcountry recreationists are able to accurately interpret and sensibly act upon the avalanche bulletin information most relevant to their personal decision routines.

Chapter 3. Methods

3.1. Survey design

The research instrument of this study is a custom-built online survey focused on avalanche bulletin practices. The design of the survey drew upon existing human dimensions research in avalanche safety (Gunn, 2010; Hallandvik, Andresen, & Aadland, 2017; Strong-Cvetich, 2014), with a particular focus on St Clair's (2019) study of avalanche bulletin user types. Consultations with avalanche industry experts helped to review the survey for structure and content, ensuring the perspectives and challenges of avalanche risk communicators were included in the design. The survey questions used to examine avalanche bulletin literacy were constructed using Bloom's taxonomy of educational objectives (Bloom, 1956). Literacy questions incorporated the taxonomy's first three tiers; *knowledge recall*, *comprehension* and *application*, which are most relevant and applicable for evaluating the use and understanding of avalanche bulletin information.

3.1.1. The Slope Choice Scenario

To assess participants' ability to synthesize avalanche bulletin information and apply their interpretations into a decision about the suitability of terrain for backcountry travel, a slope choice exercise was included in the survey. This task was presented early to avoid learning effects from the other survey questions. In Canada, the avalanche bulletin's first page presents the danger rating information and additional information about the avalanche problems is only revealed if the reader clicks the necessary tab. To maintain consistency with this structure, the **Slope Choice** question provided the danger rating information initially (Figure 3.1) and participants were only shown additional problem information (Figure 3.2) if they clicked the 'Problems' tab at the top. Participants were asked to state whether each of four separate slopes were appropriate for travel given the forecasted avalanche conditions. All participants were presented with the same slopes: two slopes in the alpine; one facing west (slope A) and one facing south-east (slope C) , and two slopes below treeline; one facing south-east (slope B) and the other facing south-west (slope D). Participants that recreate in Canada and the US were shown bulletin iconography that was most representative of the avalanche bulletins in their country (see Figure 2.1 for an example of US bulletin iconography).

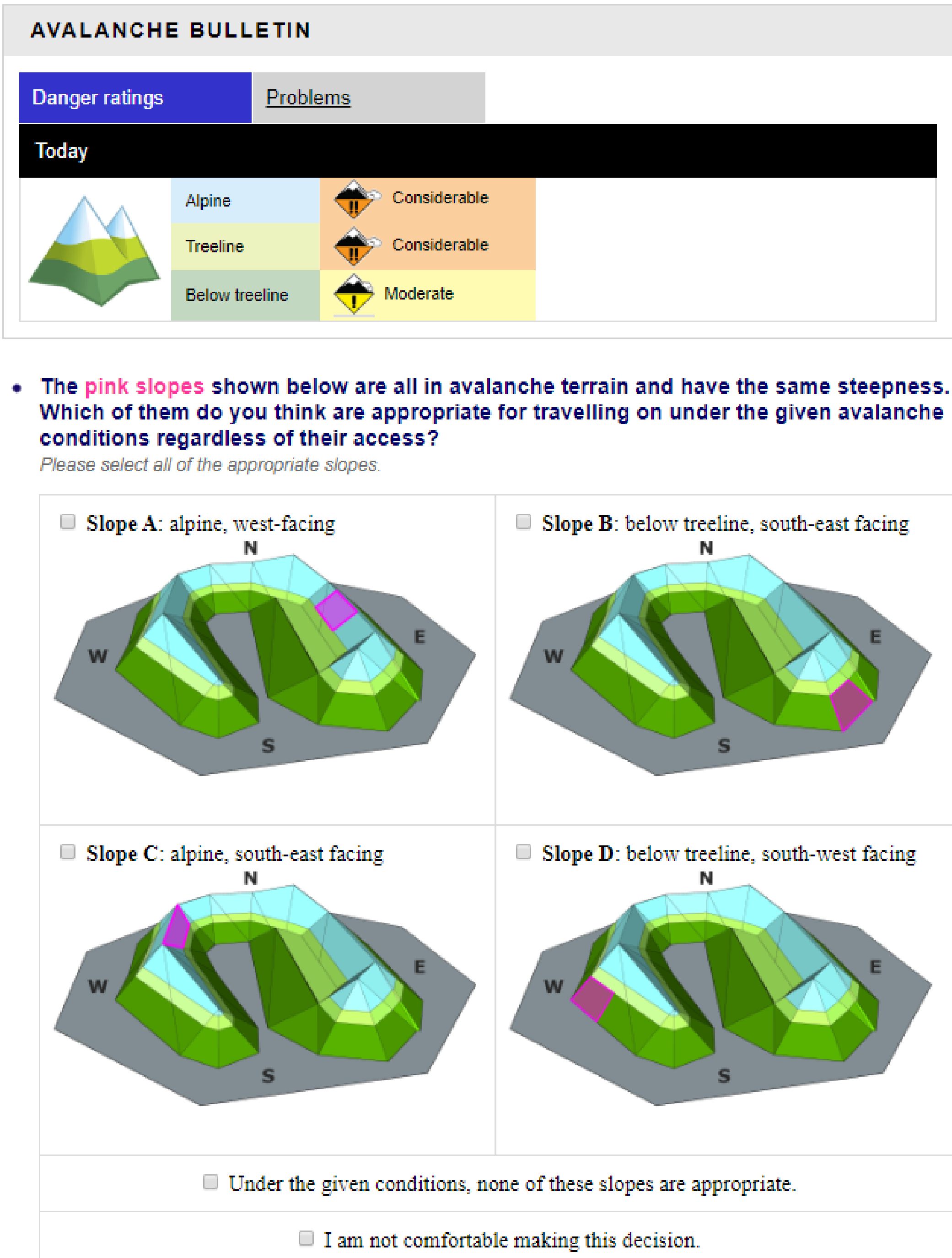

Figure 3.1. The slope choice exercise. Participants that did not click the 'Problems' tab at the top were only presented with the danger rating information, which is displayed above. Format displayed to those that recreate in Canada.

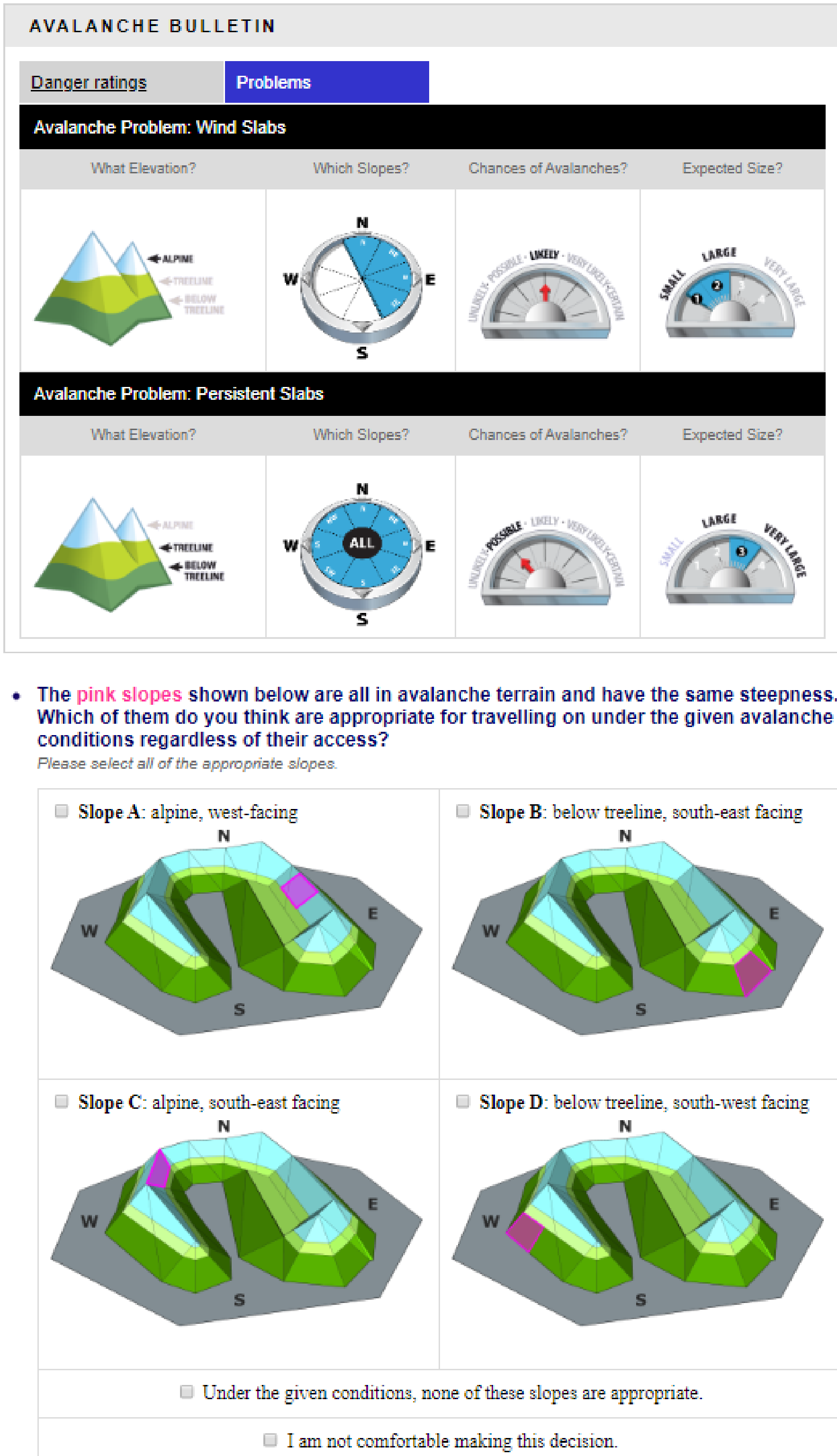

Figure 3.2. **The slope choice exercise. Participants that clicked the 'Problems' tab were presented both the danger rating information and additional information about the nature and location of avalanche problems. Format displayed to those that recreate in Canada.**

The **Slope Choice** question tested whether participants were able to extract relevant avalanche bulletin information, integrate their interpretations into a coherent decision rule, and apply this decision rule consistently. The grading of participants' responses depended upon the bulletin information they had available. If participants only looked at the danger rating information (*considerable* danger in the alpine and at treeline, and *moderate* danger below treeline), an example of a logical decision rule would be "Avoid *considerable* danger and travel on slopes where the danger is *moderate*". The consistent application of this decision rule would have involved selecting both below treeline slopes (slopes B & D) as 'appropriate' but leaving the alpine slopes (slopes A & C) unselected as 'inappropriate'. Clicking on the avalanche problems tab revealed that a wind slab problem was present in the alpine on North, Northeast, East and Southeast aspects (Figure 3.2). The problem information also showed that there was a persistent slab problem at treeline and below treeline on all aspects. If participants had interpreted this information accurately, they would have been able to determine that the wind slab problem in the alpine was present on slope C, but not slope A, and that the persistent slab problem was present on both slopes below treeline (slopes B & D). An example of a logical decision rule in this instance would be "Avoid all slopes where avalanche problems are present". To apply this decision rule consistently, participants would have needed to select the west-facing alpine slope (slope A) as 'appropriate' and have left all the other three slopes (slopes B, C & D) unselected as 'inappropriate'.

If participants' slope choice selections did not match either of the two decision rules described above, a follow-up question was displayed (Figure 3.3), which asked participants to provide reasoning for each of their four slope choice decisions. The response options presented were dependent upon whether the slopes had been chosen or not, and whether the participant had seen the avalanche problem information or not. The reasoning provided in the follow-up question enabled each participants' slope choices to be categorized as either having successfully demonstrated the application of a coherent decision rule or as having failed to do so. For example, if participants only saw the danger rating information (Figure 3.1) and did not select any of the four slopes as 'appropriate', this could have been justifiably supported by the conservative decision rule: "All *considerable* and *moderate* danger slopes are unacceptable". Alternatively, if participants saw both the danger rating and avalanche problem information (Figure 3.2), and selected slopes A, B & D as 'appropriate' but not slope C, a more advanced

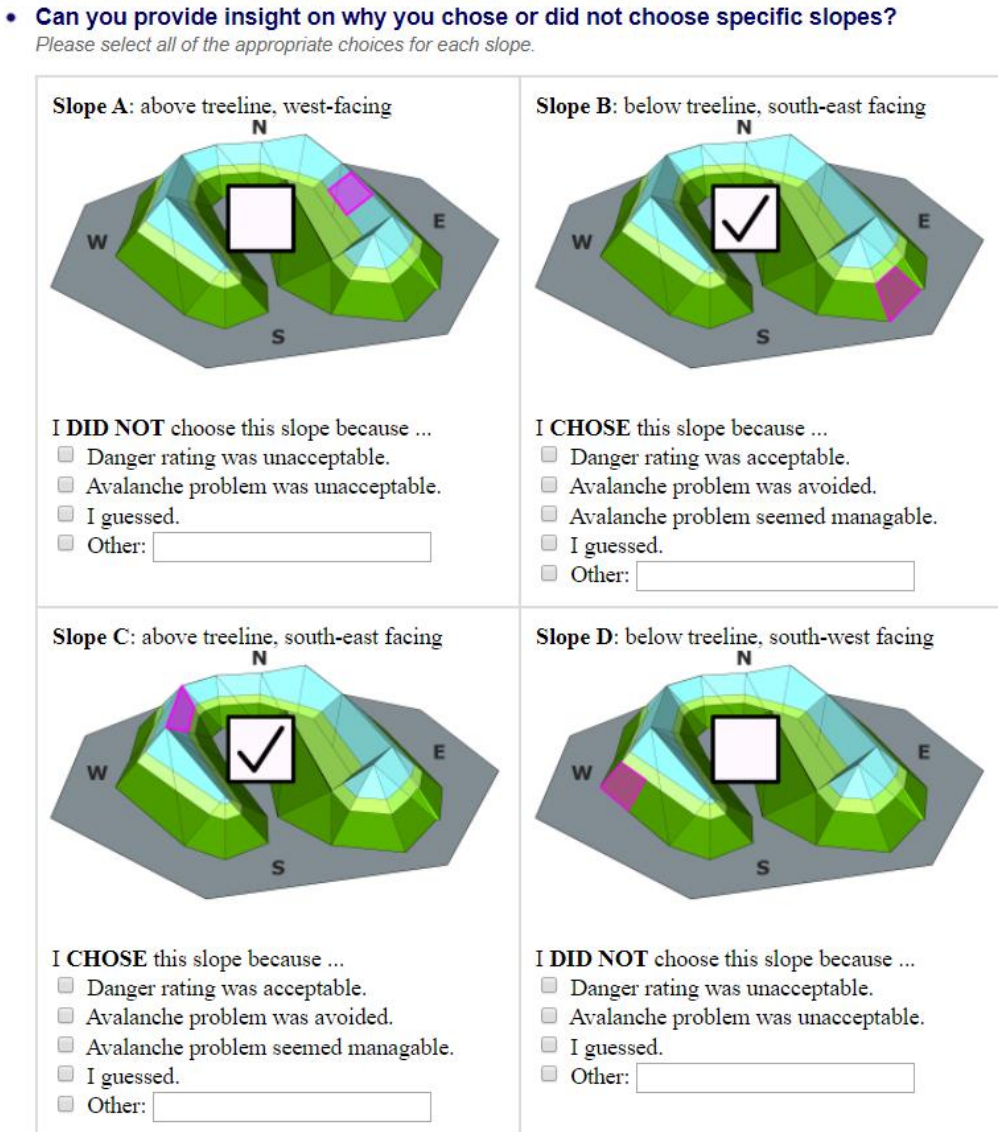

Figure 3.3. The slope choice follow up exercise. If participants' initial selections did not match a predefined expected response, they were asked to provide justification for their selections.

decision rule that would be acceptable here is: "Avoid the wind slab in the alpine and travel below treeline but manage the persistent slab with caution". An example of an inconsistent response would be if a participant only looked at the danger rating information, and selected one of the alpine slopes (e.g. slope A) as 'appropriate' for travel, but not the other (e.g. slope C), even though these slopes had the same danger rating assignment. If the follow up reasoning for this response stated that the danger rating was unacceptable on slope A but acceptable on slope C, this would further indicate an inability to accurately interpret and apply avalanche bulletin information.

3.1.2. Danger Rating Literacy Questions

Following the Slope Choice scenario was a series of questions that evaluated participants' understanding of the North American Public Avalanche Danger Scale (Statham et al., 2010). The **Danger Rating Order** question was used to determine whether entry level participants were able to place the five danger rating terms in the correct order. This question was only presented to those that do not typically use avalanche bulletins. All other participants were asked a series of more challenging questions about the danger rating terms. First, the **Danger Rating Recall** was a prompted recall question that evaluated participants' familiarity with the danger scale by asking them to type out the danger rating terms from memory. Next, the **Danger Rating Conditions Management** question, a multiple-choice question, evaluated participants' comprehension of the scale by asking them which of the danger rating assignments is most challenging to manage. It is broadly accepted that *considerable* is the hardest danger rating to manage: the heightened degree of uncertainty at this level warrants careful management of decision making & terrain (Blake, 2004). *Moderate* can also be challenging to manage since this rating sometimes involves low-probability, high-consequence hazards. Typically, *low*, *high* and *extreme* avalanche danger conditions involve less uncertainty, and so avalanche risk management decisions tend to be less complex (Tremper, 2018). The final literacy question related to the danger rating was the **Elevation Band Management** question. While the three danger ratings provided in the avalanche bulletin describe the conditions in the respective elevation bands, the hazard from above must be considered when crossing large avalanche paths at lower elevations (Jamieson, 2000). This question used the concept of overhead avalanche hazard to examine participants' ability to properly use the danger rating information.

3.1.3. Avalanche Problem Literacy Questions

If participants stated that they never check the avalanche problem section of the bulletin, they were not presented with any of the avalanche problem literacy questions. For all other participants, this section of the survey started with the **Avalanche Problem Recall** question which asked participants to type out the avalanche problem terms from memory. While Canadian avalanche forecasts include eight avalanche problem types, avalanche forecasting centers in the US use an additional ninth problem type (glide avalanches). To accommodate these differences the survey provided US participants with an extra text box for their responses. However, to make the results of this question comparable across countries, glide avalanches were excluded from the analysis. In the next literacy question, half of the sample were presented with a multiple-choice question that evaluated comprehension of the aspect icon and the other half were asked a similar question related to the size icon. In the **Aspect Icon** question, participants were presented with a hypothetical aspect icon and were asked to identify the correct mountain faces on which forecasted avalanche problems were present. Similarly, in the **Size Icon** question, participants were presented with a hypothetical size icon and were asked to identify the largest possible avalanches within the highlighted range of sizes presented. While the Canadian size icon is able to display predicted avalanche sizes above a size four, the highest the US icon can go is up to but not past size four avalanches (see Figure 2.1 for differences between Canadian and US size icons). Therefore, the mark scheme used for the **Size Icon** question allowed US participants to select a size four or a size five avalanche when the maximum range was displayed. However, given that the Canadian size icon does not imply that a size four is the largest size on the scale, only the selection of a size four avalanche was accepted for Canadian participants when the maximum size range was displayed. Whether participants saw the aspect or size icon question was chosen at random. The incentive for presenting these two icon questions to only half of the sample, instead of presenting both to all participants, was an attempt to reduce total survey duration and the risk of incompletion.

The final literacy question related to the avalanche problems was the **Avalanche Problem Mitigation** question, which was a multiple-choice question that evaluated participants' ability to identify the most appropriate risk mitigation behaviors in specified avalanche problem conditions. For each avalanche problem there are a series of specific travel strategies and observational approaches that can be used to reduce exposure to avalanche risk (Wagner & Hardesty, 2014). Participants that saw the question were randomly assigned two avalanche problems out of Wind Slab, Persistent Slab, Wet Slab, Storm Slab and Loose Dry. They were then asked to state whether each terrain and travel strategy from a list of six were 'Highly applicable', 'Somewhat applicable' or 'Not applicable' for managing their two assigned avalanche problems. This enabled the identification of participants that were not able to recognize suitable mitigation techniques in given avalanche problem conditions.

Table 3.1. Survey questions that were used to evaluate avalanche bulletin literacy

Question Name	Question Text	Correct response	Response format	Which participants saw the question?	How many saw the question?	
					n	%
Slope Choice Scenario	*The pink slopes shown below are all in avalanche terrain and have the same steepness. Which of them do you think are appropriate for travelling on under the given avalanche conditions regardless of their access?*	Demonstration of a consistent and logical decision rule	Closed: check box (feedback was check box combined with free text)	All participants	3,198	100%
DR – Order	*The danger scale uses the five terms shown below to describe the general severity of avalanche conditions. Please use the dropdowns to order the levels from the least to the most severe. Please note that the terms are presented in random order.*	Low, Moderate, Considerable, High, Extreme	Closed: drop-down box	Only non-bulletin users	42	1.3%
DR – Recall	*Please write out the danger rating levels that you can recall from the least to the most severe.*	Low, Moderate, Considerable, High, Extreme	Open: free text	All bulletin users except those that never check the danger rating	3,133	98.0%
DR - Conditions Mgmt.	*Based on your understanding of the danger scale, which of the levels is the most challenging for making avalanche safety decisions when travelling in the backcountry?*	Considerable or Moderate	Closed: multiple choice (choose one answer)	All bulletin users except those that never check the danger rating	3,133	98.0%
DR - Elevation Band Mgmt.	*Imagine you're planning a backcountry trip where you primarily travel below treeline, but occasionally cross large open slopes. Which danger ratings would you consider in your planning process?*	All three elevations	Closed: multiple choice (choose all that apply)	All bulletin users except those that never check the danger rating	3,133	98.0%

Question Name	Question Text	Correct response	Response format	Which participants saw the question?	How many saw the question?	
					n	%
Avalanche Problems – Recall	*Avalanche bulletins use 8 different avalanche problem types to describe the nature of the avalanche hazard. Please list any avalanche problem type you may recall. (Eight are used in Canada, nine are used in the US).*	Wind Slab, Storm Slab, Persistent Slab, Deep Persistent Slab, Wet Slab, Loose Wet, Loose Dry, Cornice, (Glide)	Open: free text	All bulletin users except those that never check the avalanche problems	3,130	97.9%
Avalanche Problems – Aspect Icon	*If you were presented with the graphic shown below, on which aspects do you think the avalanche problem would be present?*	The compass directions highlighted in the displayed icon	Closed: multiple choice (choose all that apply)	Half of the bulletin users (except those that never check the avalanche problems) chosen at random	1,630	51.0%
Avalanche Problems – Size Icon	*If you were presented with the graphic shown below, how harmful do you believe the largest potential avalanches are?*	The size at the top of the highlighted range in the displayed icon	Closed: multiple choice (choose one answer)	Half of the bulletin users (except those that never check the avalanche problems) chosen at random	1,568	49.0%
Avalanche Problems – Mitigations	*How applicable are the following mitigation approaches for managing the two avalanche problems displayed?*	The correct applicable approach for both avalanche problems	Closed: multiple choice (choose one answer)	All type C-F bulletin users, except those that never check the avalanche problems.	2,942	92.0%

3.1.4. Other Critical Background Information

In addition to the avalanche bulletin literacy questions, the survey instrument collected a variety of background information from participants. At the very beginning of the survey, participants were asked to state the order of the three winter backcountry activities they most closely associate with. The survey logic used the responses from this question to make the onward survey experience personal: the wording of questions directed participants to answer in the context of their primary activity. Since it was anticipated that ice climbers would be underrepresented in the sample, all participants that selected ice climbing as their primary or secondary activity were asked to answer the survey questions from the perspective of their experience as an ice climber. Other background questions included in the survey targeted participants' years of experience in the backcountry, their average number of days spent recreating each winter, their level of formal avalanche awareness training and the backcountry regions they most frequently visit. Due to differences in iconography used between Canadian and US avalanche bulletins, the information about typical regions of use enabled each participant to be presented with survey questions containing the bulletin iconography they were most familiar with.

One of the most critical questions in the survey asked participants to choose from a list of statements according to the one that best described their use of avalanche bulletins when they are planning for backcountry trips (Table 3.2). These statements, which were based on findings from St Clair's (2019) qualitative interview study, comprise an avalanche bulletin user typology, with each level increasing in terms of the sophistication of decisions made and the breadth of avalanche bulletin information incorporated. The resulting hierarchy ranges from recreationists who do not typically use public avalanche bulletins or know that they exist (Type A), all the way up to those that use the bulletin as a starting point for their own continual assessment of avalanche conditions in the backcountry (Type E). In recognition that some professionals have access to alternative sources of avalanche information and so might not typically use public avalanche bulletins on their outings, participants who had indicated they were professionally trained on a previous page in the survey were not shown option A, and had the option to choose statement F instead. All other respondents were required to choose between statements A-E. The survey logic used the responses to this background question to target participants with relevant questions and to reduce dissatisfaction by ensuring that entry level users were not asked complex questions about topics they were unfamiliar with. The survey included several additional questions about related topics, such as social media use and perceptions of social norms, that were not included in this analysis. Respondents were also asked to provide feedback on their experiences using avalanche bulletin products, detailing their level of satisfaction, possible suggestions for improvements and if applicable, their reasoning for not using avalanche bulletin products. The final section of the survey sampled demographic characteristics.

Table 3.2. Statements used to describe the typical avalanche bulletin routines of each of the user types describes in St Clair (2019)

User type	Characterization statement
A	It is not typical for me to consult the avalanche bulletin or public forecast online (website or mobile app) when making backcountry travel plans.
B	I typically use the bulletin to check the danger rating which informs my decision of whether or not it's safe to travel in the backcountry.
C	I typically combine the danger rating from the bulletin with knowledge of how avalanche prone an area is to determine where to travel in the backcountry.
D	I typically make a decision about where or when to go based on the specific nature of the avalanche problem conditions reported in the bulletin and whether I feel that I can manage my travel in the terrain given these conditions.
E	I typically use the available information about the specific nature of the avalanche problem conditions from the bulletin as a starting point for my continuous assessment in the field to confirm or disconfirm the information where I am travelling.
F	It is not typical for me to consult public avalanche bulletins or forecasts because I have access to professional information sources (e.g., InfoEx) that offer more detailed insight into current conditions.

3.1.5. Survey Pretesting

The initial version of the survey was pretested in person with ten residents in Vancouver, Canada, using one-on-one verbal protocols ("think-alouds") in which participants were asked to talk about their impressions while reading and responding to the survey (Ericsson & Simon, 1993). Following revisions based on the think aloud interviews, the survey was programmed online and pretested a second time by seven individuals with differing levels of experience, ranging from first time avalanche bulletin users to avalanche forecasting directors. This second round of testing revealed that the survey was too comprehensive, too lengthy and overly complicated, particularly for novices. Accordingly, some questions were removed, and the survey's logic was altered so that entry level users would see fewer, simpler questions, and only the most competent and experienced participants would see the more complex questions (see Appendix A for screen shots of the published version of the survey).

3.2. Survey Implementation

One of the primary objectives of this study was to incorporate the views and perspectives of a wide range of participants with differing levels of avalanche and backcountry experience. The lack of a reliable means for obtaining a representative sample of the entire population of winter backcountry recreationists in North America necessitated the use of an opportunity sampling approach with self-selected participants. Recruitment efforts commenced in November 2018, when a series of avalanche skills education providers began promoting the research to students during the classroom component of their courses (see Appendix B for promotion materials). Backcountry recreational clubs, snowmobile manufacturers, outdoor gear rental providers, trail-head booth organizers and mountain guiding operations also helped by encouraging customers and members to participate. These organizations were asked to include a notice about the survey in their email lists and in newsletters. In some instances, post-cards and posters were mailed to promotional partners to enhance recruitment efforts. Throughout recruitment, concerted efforts were made to encourage meaningful participation. These included a clear specification of how the survey's results would eventually benefit the end user, the demonstration of sponsorship and endorsement from legitimate and trusted organizations in the avalanche safety community, the inclusion of interactive and thought-provoking questions and the use of cash incentives to encourage reciprocity (Dillman, Smyth, & Christian, 2014).

At the start of April 2019, approximately 200 responses were obtained to confirm survey functionality and basic data quality. Once checks were complete, the survey website was made public and full data collection proceeded. Two months of sampling lasted until the end of May 2019. During data collection, a link to the survey website was distributed extensively on social media and on the websites of several avalanche forecasting centers across North America (see Appendix B for details). Preliminary analysis of the dataset indicated that backcountry skiers and highly trained individuals were comparatively overrepresented, and so entry level users, snowmobilers, snowshoers and ice climbers became the target of recruitment campaigns. Respondents that completed the survey before the 15th May 2019 were entered into a prize draw with the chance of winning one of 6 cash prizes (three prizes of $100, two prizes of $200 and one prize of $500 Canadian dollars). Data collected from the survey was automatically stored in an online database and participants remained anonymous.

Respondents were excluded from analysis if they participated in backcountry recreation outside of North America, if they completed the survey in less than ten minutes, or if their reported primary recreational activity was not relevant for the study, (e.g. trail running or mountaineering). For those that were included in the final sample, the median survey duration was 30 minutes. The number of incomplete records that were discarded from analysis was 1,332 (drop out rate of 19.3%). Once data collection and filtering were complete, the number of completed survey records included in the final sample was 3,198.

3.3. Analysis Approach

All the analysis for this study was conducted in the statistical environment *R* (v3.6.1, R Core Development Team, 2019). Results from statistical comparisons with p values of less than 0.05 were considered significant throughout. Initial exploratory analysis of the dataset was used to generate a general overview of patterns and relationships between participants' background characteristics, starting with an examination of the demographic makeup of each of the different bulletin user types. Next, summary statistics were generated to examine participants' responses on each of the avalanche bulletin literacy questions across the entire sample. The sample was then split up into separate bulletin user types, and an avalanche bulletin literacy framework with targeted grading criteria was used to provide a meaningful evaluation of avalanche bulletin literacy.

3.3.1. Avalanche Bulletin Literacy Framework

To make the responses to the various literacy questions comparable, all the possible responses were coded onto an ordinal scale containing the grades: *problematic*, *insufficient*, *sufficient* and *excellent*. While it is common among studies of literacy to apply the same evaluation criteria to all the individuals in a sample (e.g., Joshi et al., 2014; Sorensen et al., 2015), this study used separate grading criteria for each of the separate groups in St Clair's (2019) avalanche bulletin user typology. This was to account for the different levels of sophistication in the avalanche risk management decisions made by individuals in each user type. Participants at each of these levels were only graded according to the literacy questions from the survey that were most relevant for their specified decision-routines. For example, Type C users typically consult the danger rating information to select appropriate destinations for backcountry travel on a given day (St Clair, 2019). Therefore, grades for Type C users were exclusively based on the literacy questions that related to the danger rating. Type D users, however, incorporate the avalanche problem information to make more nuanced decisions about the specific types of terrain that should be avoided on any given backcountry trip. Accordingly, Type D users' grades were only based on the avalanche problem literacy questions. Type E bulletin users are defined by their capacity to critique the information provided in public avalanche bulletins using their own interpretations and observations in the field. Since it would require several in depth questions to meaningfully examine these types of skills in an online survey, a complete evaluation of the capabilities of this user group is beyond the scope of this study. Given that each stage of the avalanche bulletin user typology builds on the last, essential literacy skills for entry-level and intermediate users are still critically important for those that are more advanced. Therefore, in this analysis, Type E users were subjected to the same grading criteria as the Type D users. Type F participants—the most expert users in the sample—were also evaluated using the same grading criteria as Type Ds.

In the Slope Choice Scenario, some identifiable decision rules were considered to be *sufficient* for lower bulletin user types but *insufficient* for those that were more advanced. Leaving all four slopes unselected as 'inappropriate' for example, was considered to be acceptable for Type B and C users, who solely depend on the danger rating. However, the Type D and E users, who consult the avalanche problem information, should have been able to determine that slope A was not subject to heightened avalanche hazard. Selecting appropriate slopes for travel was unlikely to be typical for the trip planning routines of Type A users. However, they were presented with the **Slope Choice** question nonetheless, since it was thought that their capacity to conduct this exercise would be insightful, given their lack of familiarity with avalanche bulletin information. Type As were subject to the same grading criteria as Type B users in the **Slope Choice** question.

The most critical threshold in the grading criteria for all the literacy questions was that between *insufficient* and *sufficient*. Answers below this threshold did not demonstrate the level of comprehension required to make safe and informed decisions consistently, due to an evident gap in understanding related to the concept being evaluated. Responses graded as *problematic* were indicative of a serious misconception or a substantial lack in understanding. To be graded as *excellent,* responses needed to demonstrate a level of comprehension that strongly affirmed users could operate safely at or above their self-identified level. Grading criteria were organized into an evaluative framework (Table 3.3) that enabled a 'sufficiency' grade to be assigned for each participant on each relevant literacy question. Multiple consultations with avalanche industry experts as well as the incorporation of insight from seminal avalanche safety literature (Tremper, 2018), helped to inform, develop and refine the avalanche bulletin literacy framework.

To explore the relationships between performance on the different avalanche bulletin literacy questions, Spearman's rank correlation coefficients were calculated between performance on each pair of questions for the separate bulletin user types. The next phase of analysis evaluated how performance on each of the individual literacy questions related to participants' background variables. The final phase of analysis involved generating a more comprehensive measure of avalanche bulletin literacy for each participant. All grades for the literacy questions were converted into numerical values (*problematic* = 1, *insufficient* = 2, *sufficient* = 3 & *excellent* = 4), and the sums of scores for each question were used as a measure for each participant's overall literacy performance. Using the maximum and minimum possible total scores for each user type, summed scores for each participant were transformed onto a scale between 0 and 1. These values were then used as the dependent variable to examine the influence of participants' background characteristics on overall literacy performance. Since only half of the sample answered the **Aspect Icon** question and the other half answered the **Size Icon** question, these two questions could not be included in the overall literacy scores calculated for each participant.

Table 3.3. Avalanche bulletin literacy grading criteria

Bulletin User Type	Question	Problematic	Insufficient	Sufficient	Excellent
A	Danger Rating Order	n/a	n/a	n/a	n/a
A & B	Slope Choice Scenario	In the slope choice they: • Made an error, guessed OR Their follow-up reasoning was: • Ambiguous, inconsistent, missing	n/a	• Didn't select any slopes as appropriate	• Demonstrated the application of a coherent decision rule. • Reasoning was based on the avalanche problems or the danger rating info
B	Danger Rating Recall	n/a	• Stated levels in wrong order • Stated <2 correct terms • Stated that they didn't understand the question • Stated that they didn't know any levels	• Recalled 2 or 3 terms in the correct order	• Recalled 4 or 5 DRs in the correct order
C	Slope Choice Scenario	In the slope choice they: • Made an error, guessed OR Their reasoning was: • Ambiguous, inconsistent, missing	n/a	• Didn't select any slopes as appropriate	• Demonstrated the application of a coherent decision rule. • Reasoning based on the avalanche problems or the danger rating info
	Danger Rating Recall	• Recalled 2 or less in the correct order • OR had terms in the wrong order	• Stated a range (end terms), but incorrectly (I.e. not "Low, Ext") • Could recall 3 terms in the correct order • Provided information about current conditions	• Recalled 4 DRs in the correct order	• Recalled all 5 DRs in the correct order

Bulletin User Type	Question	Problematic	Insufficient	Sufficient	Excellent
	Danger Rating Elevation Band Management	n/a	• All other answers	• All elevations	n/a
	Danger Rating Conditions Management	• DNK/Low/Extreme	• High	• Moderate/Considerable	n/a
D	Slope Choice Scenario	In the slope choice they: • Made an error, guessed OR Their reasoning was: • Ambiguous, inconsistent, missing	• Didn't select any slopes as appropriate	• Demonstrated the application of a coherent decision rule AND • Reasoning was based on the danger rating info	• Demonstrated the application of a coherent decision rule AND • Reasoning was based on the avalanche problems info
	Avalanche Problem Recall	• <2 recalled correctly	• Missing any of *Storm*, *Wind* or *Persistent* OR • ≥2, <4 recalled correctly	• Answers included *Storm*, *Persistent* & *Wind* AND • ≥4, <6 recalled correctly	• Answers included *Storm*, *Persistent* & *Wind* AND • ≥ 6 recalled correctly
	Avalanche Problem Aspect Icon	• Made 2 or more aspect selection errors	• Made 1 aspect selection error	• Made no errors	n/a
	Avalanche Problem Size Icon	• Size selected was >1 level above the icon's displayed range OR was below the icon's displayed range	• Size selected was 1 level above the icon's displayed range	• Size selected was within the icon's displayed range	n/a
	Avalanche Problem Mitigations	• Selected 'not applicable' for the appropriate strategies for both assigned Av Probs	• Selected 'somewhat' or 'highly applicable' for the appropriate strategy for one assigned Av Prob	• Selected 'somewhat' or 'highly applicable' for the appropriate strategies for both assigned Av Probs	n/a
E & F	Same as type D	Assessed using type D criteria. Evaluating skills specific to Es & Fs was beyond the scope of this survey.			

3.3.2. Conditional Inference Tree Analysis

Conditional inference trees (CTrees) are a multivariate statistical approach that can be used to efficiently extract significant statistical relationships between a dependent variable (e.g., avalanche bulletin literacy scores) and a series of potential predictor variables (e.g., background characteristics). The CTree framework is well-suited to the structure of the dataset in this study, since predictor variables can be measured at nominal, ordinal, discrete and continuous scales (Hothorn & Zeileis, 2015). In addition, classification tree approaches naturally account for interactions between independent variables that would have to be explicitly specified in other analysis methods (e.g., regression analysis). Conducting separate statistical comparisons for every possible association between the background variables and avalanche bulletin literacy scores would have been inefficient and challenging for sample-wide comparisons. The CTree method streamlines this process by testing for all possible associations in the dataset and produces a classification tree that not only displays all the most significant splits, it also highlights their relative importance; the higher up in the tree a split appears, the more significant it is.

The CTree algorithm works by recursively splitting a dataset into smaller and smaller subgroups that are maximally different from each other according to their distributions of the chosen dependent variable (Hothorn, Hornik, & Zeileis, 2006). The CTree model first identifies the most significant binary split in the data (e.g., whether age is greater or less than 35), creating two child nodes or sub-populations. Once the initial split is statistically validated, the model searches for the next best predictors and corresponding cutoff values that split each of the two child nodes into two subsequent groups, such that the dependent variable is significantly different between the two emerging nodes (Hothorn, Hornik, Van De Wiel, & Zeileis, 2006). This process is repeated, and the decision tree grows as more splits are identified until it cannot find any partition that leads to significantly different groups. Given that multiple predictors are considered at each stage, the Bonferroni correction is used to counteract the problem of multiple comparisons (Hothorn & Zeileis, 2015). The final tree is characterized by a minimum of variation within terminal nodes and a maximum of variation across terminal nodes.

Since the CTree algorithm uses a statistical stopping criterion to determine when further splitting is no more required (typically $p < 0.05$), the method is less prone to overfitting than similar statistical approaches, such as Classification and Regression Trees (CARTs), which use an information criterion (e.g., Gini index). Overfitting refers to the issue of statistical models unnecessarily capturing random errors or minor fluctuations in the data which results in poor generalization and prediction (Salis, Kliem, & O'Leary, 2014). Thanks to the statistical grounding of CTrees, 'pruning' of branches is not required when using this classification method (Hothorn, Hornik, & Zeileis, 2006). This removes the potential bias introduced from having to manually select which nodes and corresponding branches should be 'pruned'. In CTree models, the minimum sample size in each terminal node also acts as a criterion as well, which is conventionally a minimum of one percent of the entire sample (Hothorn & Zeileis, 2015).

In this research, CTree models were used in a variety of ways to explore the relationships between avalanche bulletin use, bulletin literacy and the background variables collected for each participant. All the CTree analyses in this study used the same seven background predictor variables: Age, Gender, Nationality, Primary Activity, Level of Avalanche Training, Years of Experience and Average Number of Days of Backcountry Recreation per Winter. The first CTree model examined the relationship between the self-selected bulletin user types and background variables across the entire dataset to shed light on the characteristics of the different bulletin user types. To better understand the factors affecting avalanche bulletin literacy, separate CITs comparing participants, performance on individual literacy questions with their background variables were conducted for each of the different bulletin user types. Finally, the overall literacy scores for each participant were compared with background variables to see which characteristics had the most significant influence on overall avalanche bulletin literacy. All CTree models were conducted using R's 'partykit' package (Hothorn & Zeileis, 2015).

To augment the CTree analyses, various additional univariate comparisons were performed using appropriate statistical tests, including Pearson's chi-squared tests for the comparison of nominal variables between two or multiple groups, Wilcoxon rank-sum tests for the comparison of ordinal variables between two groups, and Kruskall-Wallis tests for the comparison of ordinal variables between more than two groups.

Chapter 4. Results

This chapter provides an overview of who took part in the survey, focussing first on participants' sociodemographics and their backcountry-related background characteristics. Results are then provided for how participants self-reported on their avalanche bulletin routines and how they performed on the bulletin literacy questions.

4.1. Sample Overview

4.1.1. Demographics

The total number of completed surveys included in the final sample was 3,198. This included 2,343 participants who self-described as male and 802 participants who self-described as female (Table 4.1). While the age group with the largest number of participants was the 25- to 34-year old's (38.8%), the sample also included a substantial number of individuals that were over the age of 44 (28.5%). Representation was relatively even between Canada and the United States.

Table 4.1. Sociodemographics of the suvery sample

Variable	Quantity	Proportion
Gender	**n**	**%**
Male	2,343	73.3
Female	802	25.1
Prefer not to say	28	0.9
Prefer to self-describe	7	0.2
Non-binary/third gender	3	0.1
No answer	15	0.5
Age		
Under 20	51	1.6
20 - 24	254	7.9
25 - 34	1,240	38.8
35 - 44	725	22.7
45 - 54	419	13.1
Over 55	492	15.4
No answer	17	0.5
Country of Residence		
Canada	1,447	45.2
United States	1,751	54.8

4.1.2. Participants' Geographic Origins

Participation predominately came from western North America where most of the continent's hubs for winter backcountry recreation exist, and where there are more towns and cities close to large mountain ranges (Figure 4.1). The survey was also advertised more prominently in the west of the continent. The sample included representation from 32 US states and 11 Canadian provinces. The most highly represented states and provinces were British Columbia (n=929), Colorado (n=752), Alberta (n=460) and Washington (n=369). In total, survey participants accessed the avalanche bulletins provided by 29 separate avalanche forecasting centers. Collectively, these forecasting centers produce avalanche bulletins for 102 backcountry regions in North America.

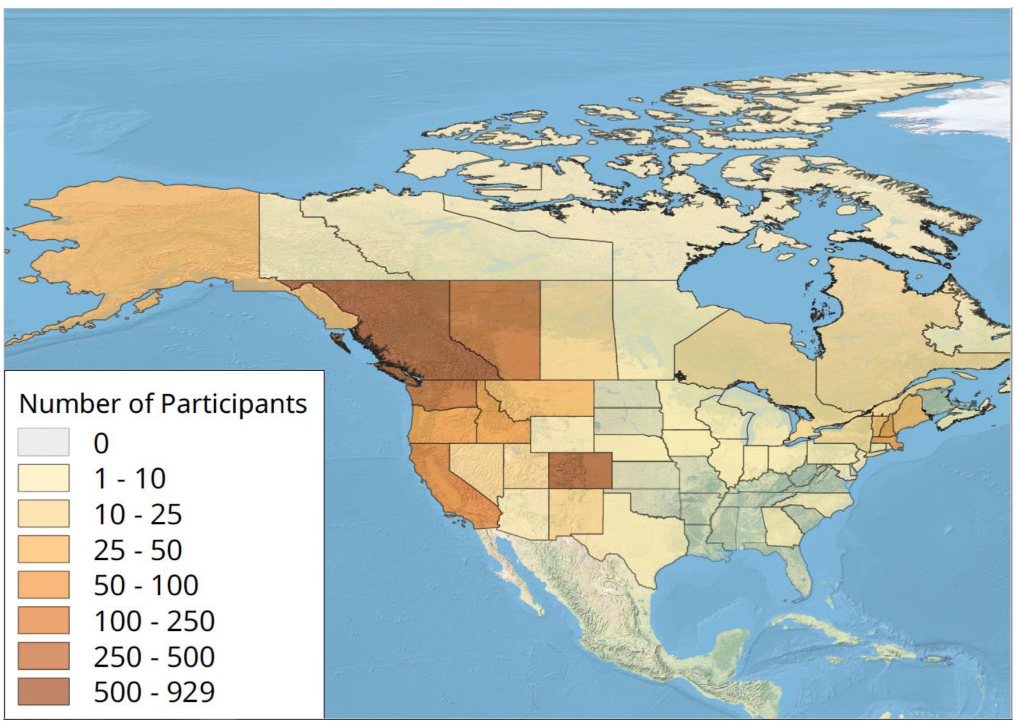

Figure 4.1. Map of survey participants' states/provinces of residence.

4.1.3. Backcountry Activities, Experience and Avalanche Training

A large majority of the sample stated that the winter backcountry activity they most closely associate with involved skiing (Table 4.2). Three quarters of participants (76.0%) participated primarily in backcountry skiing or backcountry snowboarding, 5.8% primarily engaged in out-of-bounds skiing or snowboarding and 1.8% stated that they typically use a snowmobile to access terrain for backcountry skiing. Despite the large predominance of skiers, the sample also included substantial representation from other backcountry activities, with 18.1% of the sample stating that their primary activity type was mountain snowmobiling, snowshoeing or ice climbing. A large number of participants (78.7%) stated that they engage in more than one backcountry activity. Participating in multiple activities was most common for the participants whose primary activity was out-of-bounds skiing or snowboarding (91.5%) or backcountry skiing accessed via snowmobile (84.5%) and was least common for the participants whose primary activity was snowshoeing (55.1%) or mountain snowmobiling (61.9%).

More than four fifths of the sample (81.9%) stated that they had undertaken formal avalanche awareness training, which involves both a theory-based classroom component and practical, field-based component. A much smaller proportion had attended an avalanche education/awareness event that did not involve a practical component (3.0%), and 14.8% had not attended any form of avalanche training or awareness event. Of those that stated they had been formally trained, 57.0% had completed their most recent set of training in the 2-year period before data collection (since 2017). The portion of participants that had undertaken professional training (15.1%) included those that had taken part in an avalanche course designed for people with the aspiration of becoming an avalanche professional. Therefore, while these individuals were categorized as being professionally trained, it is not necessarily the case that all of them were practicing avalanche professionals at the time of data collection.

The number of years of experience that participants had in the backcountry was relatively evenly distributed among the sample (Table 4.2). While there was a significant portion of participants that had more than 20 years of experience (20.5%), a much larger portion had five or less years of experience (39.4%). A strong correlation was found between years of experience and participants’ age categories (Spearman’s Rank Correlation: rho = 0.61; $p < 0.001$). The number of days that participants typically spent in the backcountry each winter was also spread quite evenly across categories (Table 4.2). Just over half of the sample (52.1%) stated that they participate in winter backcountry recreation on less than 20 days each winter season. The modal response for days per winter was 21-50 days (30.1%).

Table 4.2. Avalanche and backcountry related characteristics of the sample

Variable	Quantity	Proportion
Primary Backcountry Activity	**n**	**%**
Backcountry skiing/snowboarding (BC)	2,429	76.0
Snowshoeing (SS)	243	7.6
Snowmobiling (SM)	194	6.1
Out-of-bounds skiing from resorts (OB)	165	5.2
Ice climbing (IC)	109	3.4
Backcountry skiing accessed with a snowmobile (SMBC)	58	1.8
Avalanche awareness training		
None	473	14.8
Seminar/Classroom (Seminar)	95	3.0
Level 1 avalanche awareness course (Lev. 1)	1,520	47.5
Level 2 avalanche awareness course (Lev. 2)	617	19.3
Professionally trained	482	15.1
No answer	11	0.3
Years of experience		
1st year	164	5.1
2-5 years	1,098	34.3
6-10 years	661	20.7
11-20 years	592	18.5
20+ years	655	20.5
No answer	28	0.9
Avg. no. of days recreation per winter		
1-2 days	66	2.1
3-10 days	710	22.2
11-20 days	888	27.8
21-50 days	964	30.1
50+ days	486	15.2
No answer	84	2.6
Avalanche bulletin user type (self-reported)		
Type A	43	1.3
Type B	195	6.1
Type C	528	16.5
Type D	907	28.4
Type E	1,457	45.6
Type F	68	2.1

4.1.4. Avalanche Bulletin User Types

Participants generally self-reported towards the higher end of the avalanche bulletin user typology scale (Table 4.2). The more advanced options of D, E and F were chosen by 76.1% of the sample. In the initial CTree analysis, which examined the influence of background variables on self-reported bulletin user types across the entire dataset, the most significant split was between users with different levels of avalanche awareness training (Figure 4.2). Participants whose level of avalanche training was more than a Level 1 avalanche awareness course, self-reported significantly higher than those with lower levels of training ($p < 0.001$, n=3,198). Among those with lower levels of avalanche training, the next most significant split in the dataset was between users of different activity types, with out-of-bounds riders and snowshoers self-selecting significantly lower in the avalanche bulletin typology than the other four activity types ($p < 0.001$, n=2,096). The average number of days of recreation per winter also caused several significant splits in the dataset. Those with more frequent visits to the backcountry consistently self-rated as higher among both the more and less advanced bulletin user types. There were no significant splits in this CTree model according to differences in participants' years of experience in the backcountry.

To provide additional insight into the demographic differences between each of the different bulletin user types, a series of basic statistical comparisons, contingency tables and proportional bar plots were used (Figure 4.3). Firstly, males self-reported significantly higher than females (Wilcoxon rank-sum test: $p < 0.001$). Females comprised nearly half of the Type As (48.8%) and Type Bs (47.7%), however, with each upward step in the typology, this proportion reduced; females made up 27.3% of the type Cs, 25.7% of the type Ds, 21.1% of the type Es and 10.3% of the type Fs (Figure 4.3c). Most of the activity types were dominated by males (~75-85% for all), apart from the snowshoers, most of whom were females (53.5%).

There were also significant differences between activity types in terms of how they self-reported in the avalanche bulletin typology (Kruskal-Wallis test: $p < 0.001$). Snowshoers consistently self-reported as significantly lower in the bulletin user typology than all other activity types (all pairwise comparisons with Wilcoxon rank sum test: $p < 0.001$). In contrast, Backcountry skiers self-reported at significantly higher bulletin user type levels than all other activity types (pairwise comparisons with Wilcoxon rank sum test: $p < 0.001$), apart from those that access terrain for backcountry skiing via snowmobile (pairwise comparison with Wilcoxon rank sum test: $p = 1.000$).

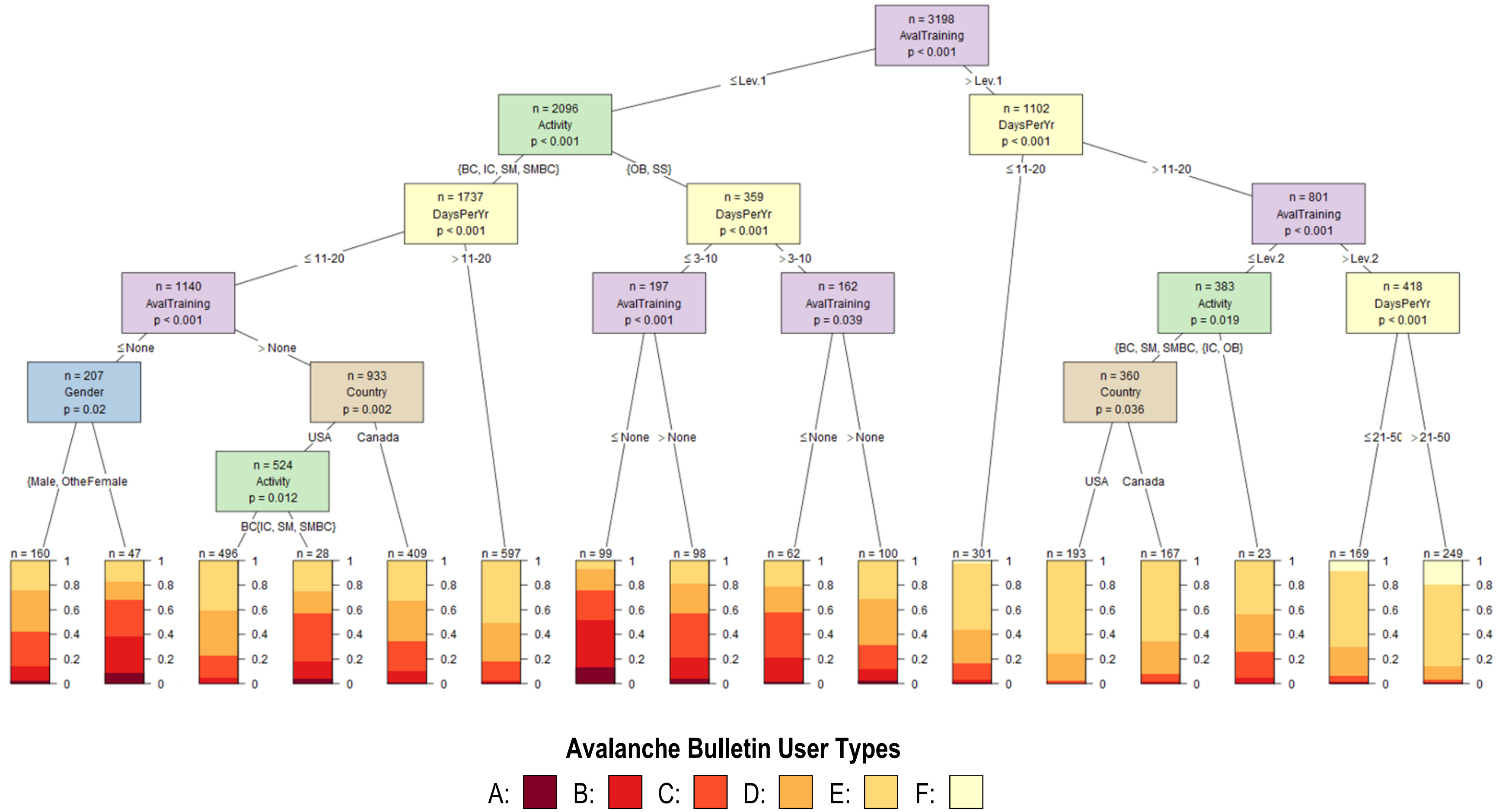

Figure 4.2. **Conditional inference tree displaying the interaction between self- identified avalanche bulletin user types and participants' background variables.**

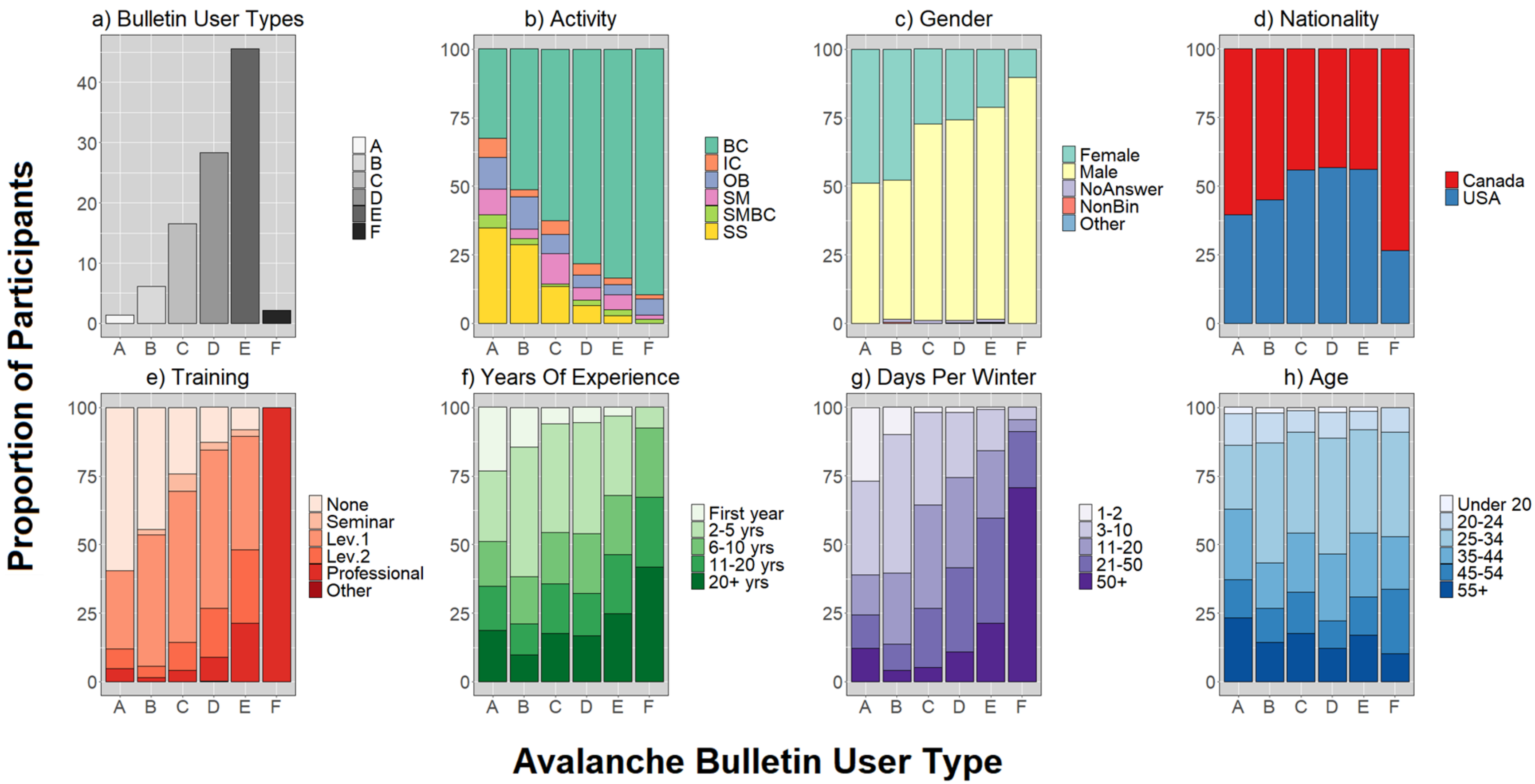

Figure 4.3. **Proportional bar charts displaying the relationships between self-reported avalanche bulletin user types and background demographic variables.**

4.2. Avalanche Bulletin Literacy Performance

4.2.1. Sample-wide Performance, Individual Questions

The Slope Choice Scenario

In the Slope Choice Scenario, a relatively small proportion of the sample (18.9%, n=605) did not click the avalanche problems tab and so were only presented with the danger rating information in the mock avalanche bulletin. The rest of the sample (81.1%, n=2,593), *did* click the avalanche problems tab, which meant that these participants also had access to the avalanche problem information to help inform their four slope choice decisions.

Among the participants that did not click the avalanche problems tab, the most common decision rule that was consistently applied was to “avoid slopes where *considerable* danger exists and select the slopes with *moderate* danger as ‘appropriate’ for travel” (35.0%, n=212). However, it was slightly more common for participants in this group to provide a response that did not demonstrate the consistent application of a coherent decision rule (35.4%, n=214), due to inconsistencies, errors or incomplete explanations in their responses. In the group of participants that clicked the avalanche problems tab, the most common decision rule that participants successfully applied was to only select the one slope where no avalanche problems were present (slope A) as ‘appropriate’ for travelling on (26.9%, n=697). However, a much larger proportion of this group (42.9%, n=1,113), provided responses that did not align with a coherent decision rule.

Across the entire sample, a substantial proportion of participants made a systematic error of judgement in their initial slope choice selections or in their supportive reasoning (21.0%, n=673). For example, 6.2% (n=199) of participants clicked the avalanche problems tab and then selected one or more of the three slopes where avalanche problems existed (slopes B, C & D) as ‘appropriate’ for travelling on. Then in the follow-up question, they stated that the slope was appropriate because avalanche problems had been avoided. Another common issue that was observed related to inconsistencies in the reasoning provided for separate slopes with similar conditions. For example, slopes B and D, were subject to the same danger rating and avalanche problem conditions. However, 8.9% (n=284) of participants selected one of these two slopes as ‘appropriate’, but not the other, and did not provide a justifiable reason for why.

Danger Rating Literacy Questions

The **Danger Rating Order** question was only presented to Type A recreationists (non-bulletin users). Within this group, 27 participants (64.3%) were able to correctly place all five terms in the correct order without making any mistakes. However, 13 participants (30.9%) ordered the terms incorrectly and two participants (4.7%) correctly placed some of the danger rating terms and left others blank.

The proportion of participants that ordered terms incorrectly in the **Danger Rating Recall** question was much lower (1.0%) than in the **Danger Rating Order** question. Around two thirds (65.7%) of the sample were able to recall all five terms in the correct order (Figure 4.4a). Response types that were accepted as correct included the exact labels of each danger rating signal word, as well as the assigned colors and number equivalents of each of the five terms. Out of all five danger rating terms, *moderate* (92.1%) and *considerable* (87.9%) were recalled correctly the most frequently. The term that participants were able to recall least frequently was *High* (79.2%) (Figure 4.4b). It is worth noting that the two most commonly recalled danger rating levels were those presented in the **Slope Choice** question.

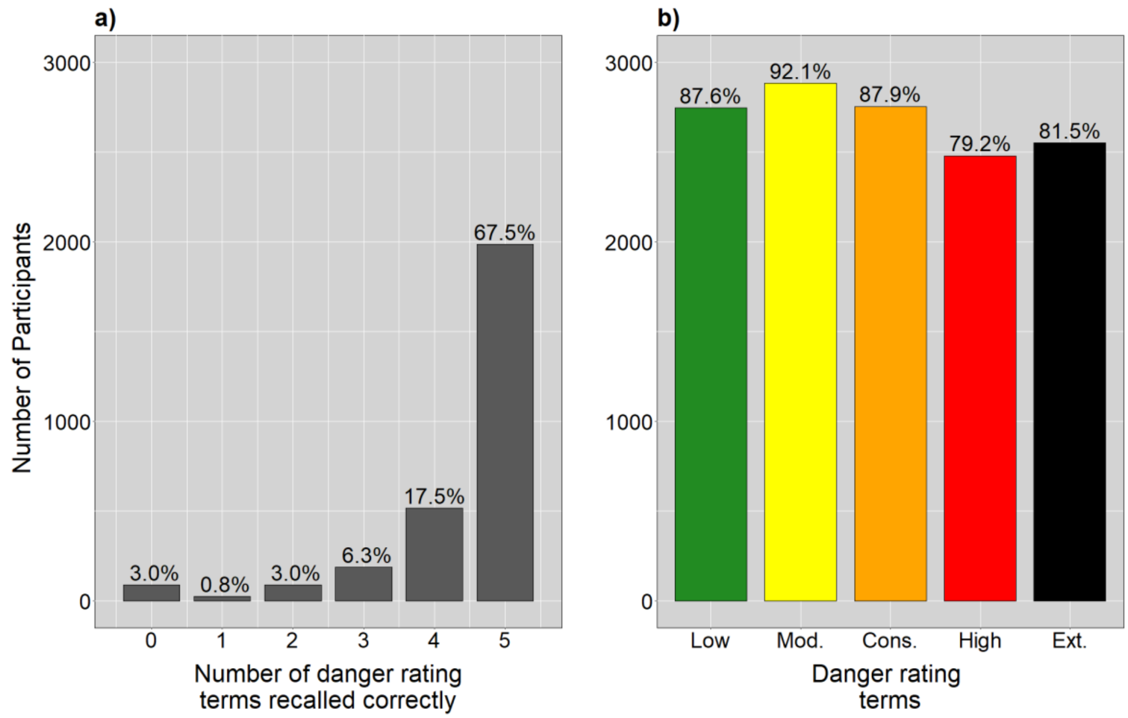

Figure 4.4. The Danger Rating Recall question. a) The number of danger rating terms that participants were able to recall correctly, b) The proportions of the sample that were able to correctly recall each of the five terms. Numbers above each bar represent the proportions of the sample.

In the **Danger Rating Conditions Management** question, a large majority of participants correctly stated that avalanche conditions are hardest to manage when the assigned danger rating is *Moderate* (24.4%) or *Considerable* (67.9%) (Figure 4.5). In the **Elevation Band Management** question, when participants were asked about which of the three danger rating assignments they check if their planned route involves crossing large, open avalanche paths, the correct answer (all three elevation bands) was selected by 70.0% of the sample (n=2,238).

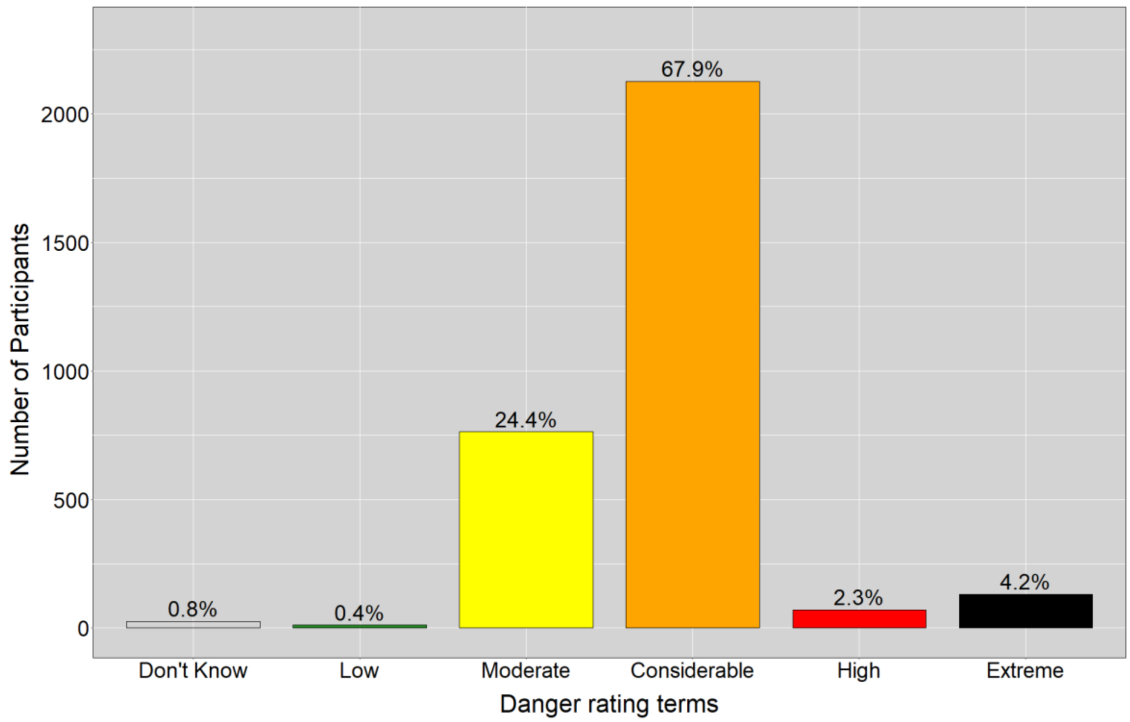

Figure 4.5. Danger rating conditions management question: "which danger rating is most challenging to manage?" Proportions of the sample that selected each of the different danger ratings. Participants were only able to select one option.

Avalanche Problem Literacy Questions

In the **Avalanche Problem Recall** question, 8.6% of the sample were able to recall all eight of the avalanche problem types correctly (Figure 4.6a). Wind Slab (85.5%) and Persistent Slab (72.0%) were the two problems that participants were able to recall most frequently (Figure 4.6b). Similarly to the danger rating recall, these are the problem types that were included in the **Slope Choice** question. The problems that were recalled least frequently by participants were Cornice (36.5%) and Loose Dry (35.8%). Out of the US participants, who had the option to provide an additional and ninth response, 21.6% were able to recall Glide. Even though glide avalanches are not used in Canadian Bulletins, 5.3% of the Canadian participants still listed Glide as one of their eight avalanche problem types in the **Avalanche Problem Recall** exercise.

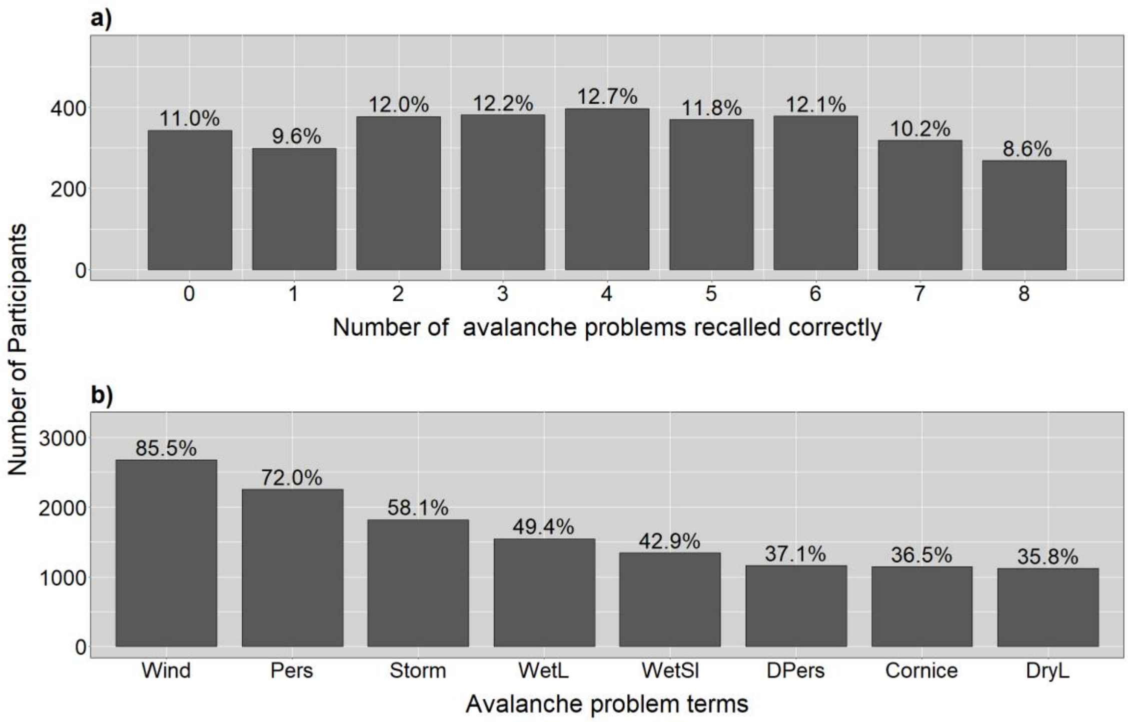

Figure 4.6. Avalanche problem recall question. a) % of the sample that were able to recall each quantity of avalanche problems correctly, b) % of the sample that were able to recall each avalanche problem correctly.

In the **Aspect Icon** question, participants were presented with a hypothetical aspect icon and were asked to select the mountain faces (compass directions) on which they thought the avalanche problems existed. In all, 86.8% of those that saw the question made no mistakes: they selected all the compass directions that were highlighted, and they did not select any of the compass directions that were not highlighted. There were a range of different types of error made among the 215 participants (13.2%) that did not get this question correct. Most of the errors made were because participants slightly misinterpreted the position of the aspects highlighted; 64 participants (3.9%) were incorrect on one of the eight compass directions and 79 participants (4.8%) were incorrect on two compass directions. A much smaller number of participants (n=5, 0.3%) inverted the intended perception of the diagram and only selected the compass directions that had not been highlighted in the icon.

In the **Size Icon** question, the proportion of participants that correctly selected the largest size in the displayed range was 74.4%. An additional 6.9% selected the lower size within the displayed range in the icon. All other participants' selections in this question were either above or below the displayed range presented in the question.

In the **Avalanche Problem Mitigation** question, 78.4% of the sample identified the appropriate mitigation strategies for both of the avalanche problems they were shown (Figure 4.7a). Just under thirteen percent of participants identified the correct mitigation strategy for one of the two problems and 9.0% did not provide the correct answer for either of the problem types. The rate at which the **Avalanche Problem Mitigation** question was answered correctly differed significantly between the different avalanche problem types (Figure 4.7a). Survey participants answered the risk mitigation questions for storm and wind slab avalanche problems significantly better than for loose dry and persistent slab avalanche problems, whereas their performance was worst for wet slab avalanche problems. The p-values of pairwise Wilcoxon rank-sum tests was 1.000 within these groups of avalanche problems and < 0.001 between them.

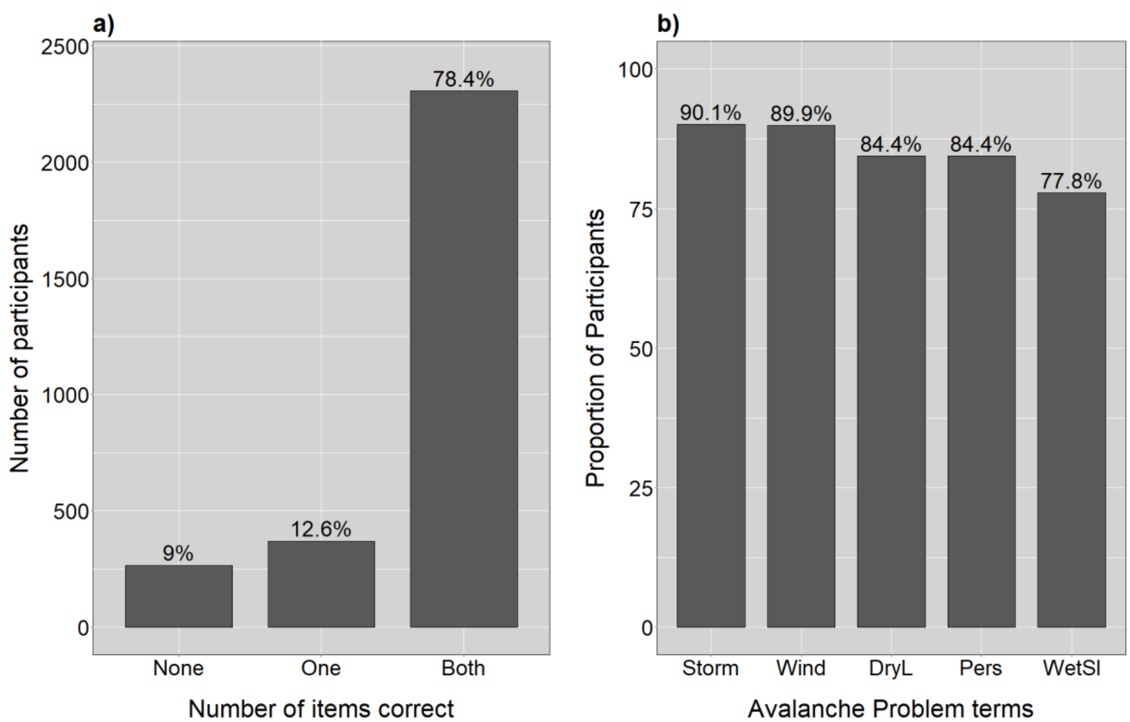

Figure 4.7. The Avalanche Problem Mitigation question. a) How many of the avalanche problem mitigation scienarios did participants get correct? b) Proportions of participants that were able to identify the correct mitigation strategies for each of the five avalanche different avalanche problems used in the question.

4.2.2. Avalanche Bulletin User Type Literacy Grades

The only avalanche bulletin literacy question that Type A users were evaluated for was the **Slope Choice** scenario. Despite having backcountry travel routines that do not typically involve consulting the avalanche bulletin, 27.9% of the Type As were graded as *excellent* in this question and 7.0% were graded as *sufficient*. A much larger proportion (65.1%) were graded as *problematic*.

Type B recreationists are heavily dependent upon the danger rating information for their avalanche risk management decisions. On the **Danger Rating Recall** question, 18.8% of Type B users were graded as *insufficient*, 45% as *sufficient* and 36.1% as *excellent*. In the Slope Choice Scenario, almost two thirds of the Type B participants (65.1%), were graded as *problematic*, whereas 33.2% of this user group achieved a grade of *sufficient* or *excellent* (Figure 4.8).

Four questions were used to evaluate the avalanche bulletin literacy of Type C recreationists (Figure 4.8). The proportion of Type Cs that were able to achieve a grade of either *sufficient* or *excellent* was 79.2% in the **Danger Rating Recall** and 88.4% in the **Danger Rating Conditions Management** question. The majority of Type C users (60.6%) achieved a grade of *sufficient* in the **Elevation Band Management** question. However, when faced with the more challenging task of applying avalanche bulletin information in the **Slope Choice** scenario, a much larger proportion of Type C participants were graded as *problematic* (52.5%).

Type D, E and F users were all evaluated using the same five literacy questions that related to avalanche problem information (Figure 4.8). Performance was generally very high on the **Aspect**, **Size**, and **Avalanche Problem Mitigation** questions. On all three of these exercises, each of which targeted comprehension skills, more than 80% of participants among Type Ds, Es and Fs achieved the maximum grade of *sufficient*. On the **Avalanche Problem Recall** question, the proportion of participants that achieved a grade of *sufficient* or *excellent* was 60.4% for Type Ds, 64.3% for Type Es and 90.5% for Type Fs. The question that caused the most significant challenges for participants in these more advanced user types was the **Slope Choice** question. Almost two thirds of the Type D users (64.6%), and more than half of the Type E users (56.7%) were graded

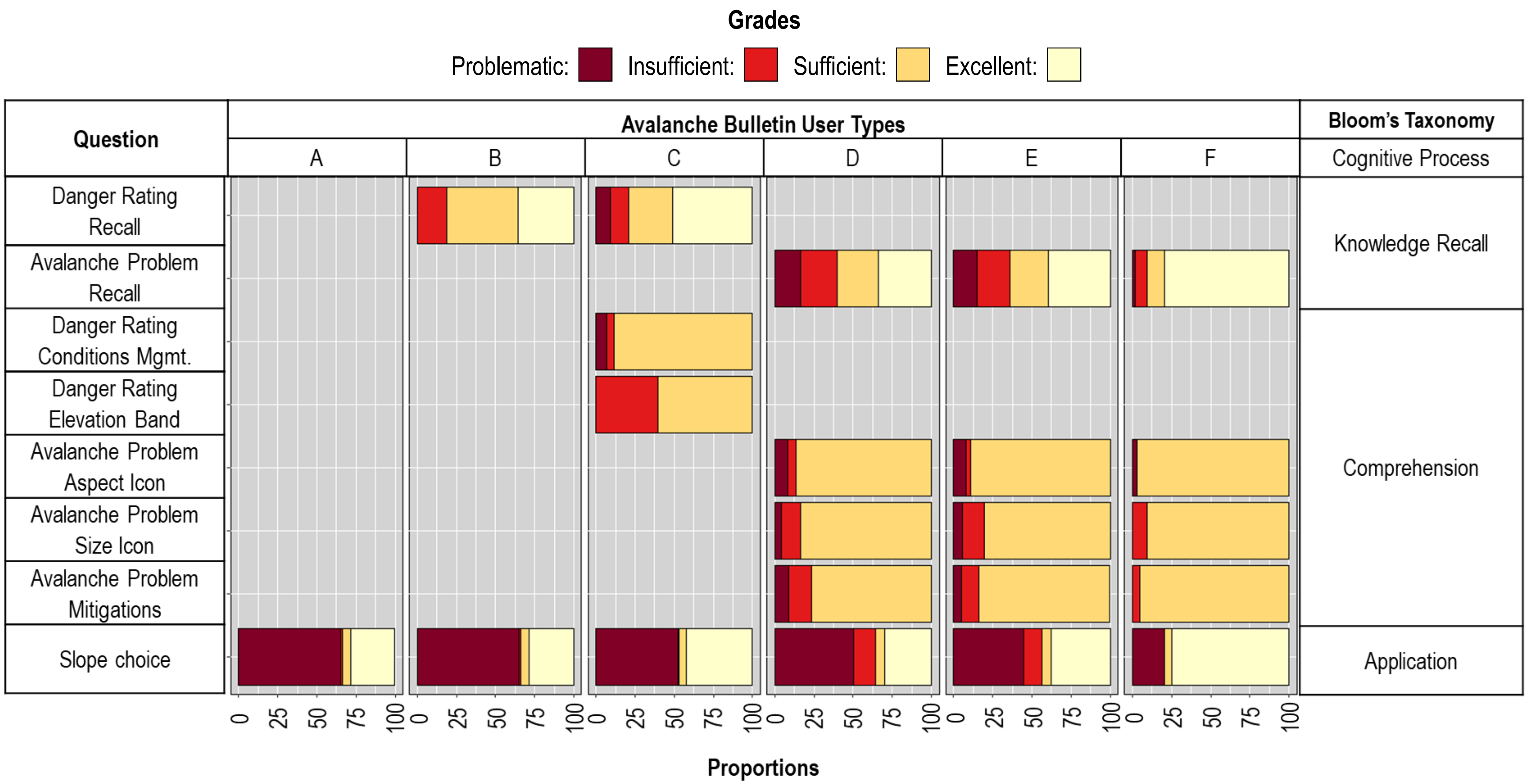

Figure 4.8. **Performance on the avalanche bulletin literacy questions by each avalanche bulletin user type. For each of the eight questions, the bar widths represent the proportions within each user type that achieved each grade.**

as *problematic* or *insufficient* in the **Slope Choice**. This proportion was much smaller (20.6%) among the Type Fs, who performed significantly better than the Type Ds (pairwise Wilcoxon rank-sum test $p < 0.001$) and the Type Es (pairwise Wilcoxon rank-sum test $p < 0.001$) on the slope choice scenario.

4.2.3. Comparing Performance on the Different Literacy Questions

To examine the relationships between performance on each of the different avalanche bulletin literacy questions, Spearman's rank correlation coefficients were calculated for participants within each of the separate avalanche bulletin user types. While nearly all the correlation coefficients were positive, the associations between the performances on the different literacy questions were generally very weak. Among Type C users, for example, the strongest correlation was between performance on the **Danger Rating Recall** question and the **Danger Rating Conditions Management** question (Spearman's Rank Correlation: rho = 0.19; $p < 0.001$) (Figure 4.9). Correlations between performance on the **Slope Choice** question and on other questions were consistently weak among each of the different bulletin user types (Spearman's Rank Correlation: range of rho: -0.01 to 0.25) (See Appendix C for all correlations plots).

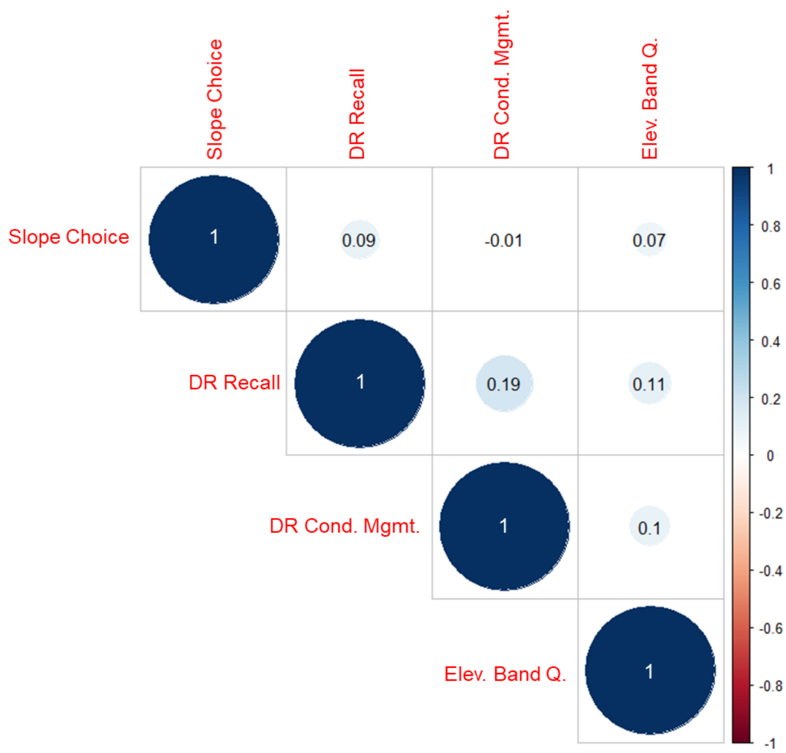

Figure 4.9. Correlation plot displaying the relationships between performance on the avalanche bulletin literacy questions among Type C users.

4.2.4. Comparing Literacy Performance with Background Characteristics

Individual Questions

Type As

The CTree model conducted on Type A users' performance on the **Slope Choice** question did not return any significant splits in the data.

Type Bs

In a CTree analysis used to compare the **Danger Rating Recall** performance of the Type B users with their background characteristics, the only significant split in the dataset was between users with different levels of avalanche training (See Appendix D for all CTree plots). The distributions of performance on the **Danger Rating Recall** among those that had received no formal avalanche awareness training was significantly lower than all those that had undertaken some form of training ($p = 0.036$, n=191). The CTree model conducted on Type B users' performance on the **Slope Choice** question did not return any significant splits.

Type Cs

In the CTree analysis comparing Type C users' **Danger Rating Recall** performance with their background characteristics, the most significant split in the data set was participants' level of avalanche awareness training ($p < 0.001$, n=528). The distributions of performance on this question were significantly lower among those that had no formal avalanche awareness training. Among those with higher levels of training, participants' age group was the next most significant split. Those over the age of 54 performed significantly worse on this question compared to younger participants ($p = 0.008$, n=304). The only significant split between performance on the **Danger Rating Conditions Management** question was between activity types, with snowmobilers and snowshoers achieving significantly lower grades than the other activity types ($p = 0.02$, n=528). The CTree analysis on the **Elevation Band** question for Type C users only computed two significant splits in the dataset (Figure 4.10). The first and most significant split was between activity types, with snowmobilers performing significantly lower than the rest of this user group ($p = 0.002$, n=528). Among the Type

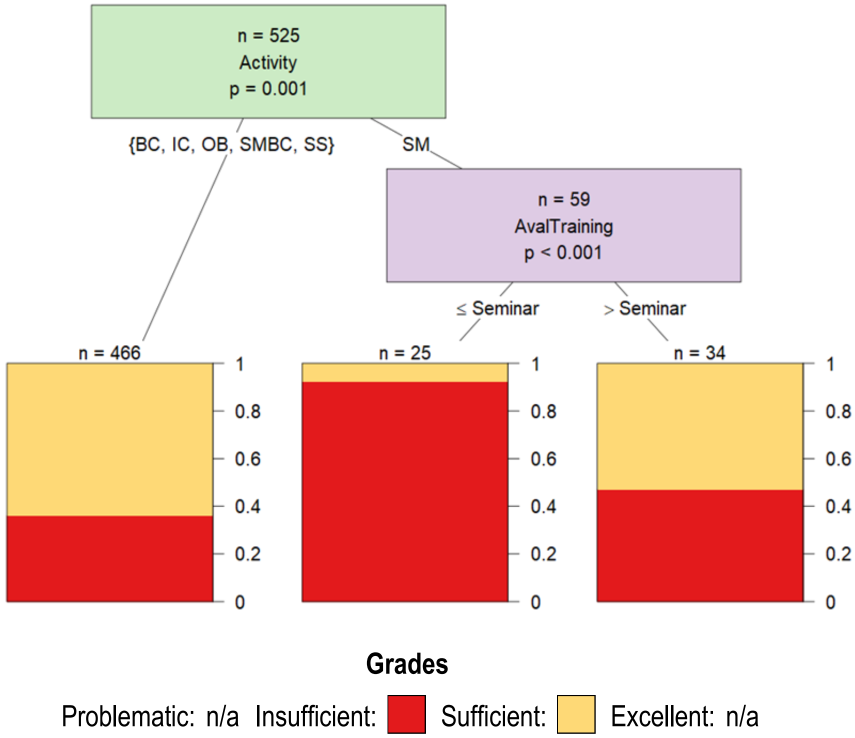

Figure 4.10. Conditional inference tree displaying the interaction between Type C users' performance on the Elevation Band question and their background variables.

C users that were snowmobilers, there was another significant split between those that had undertaken formal avalanche awareness training and those that had not. The proportion of trained Type C snowmobilers that achieved a grade of *sufficient* was 52.9%, whereas the proportion of *sufficient* grades was only 8% ($p = 0.008$, $n=59$) among those who were not formally trained. The CTree conducted on type C users' performance on the **Slope Choice** question did not return any significant splits.

Type Ds

To evaluate how Type D users' performance on the literacy questions compared with their background characteristics, CTree analyses were conducted on each of the five literacy questions related to avalanche problem information. In the **Avalanche Problem Recall** question, the first and most significant split was between participants of different ages. Those under the age of 45 were able to recall significantly more of the avalanche problems than those among older age categories ($p < 0.001$, $n=907$). Among those below the age of 45, the US participants performed significantly better than Canadians on the Avalanche Problem Recall question ($p < 0.001$, $n=707$). The CTree

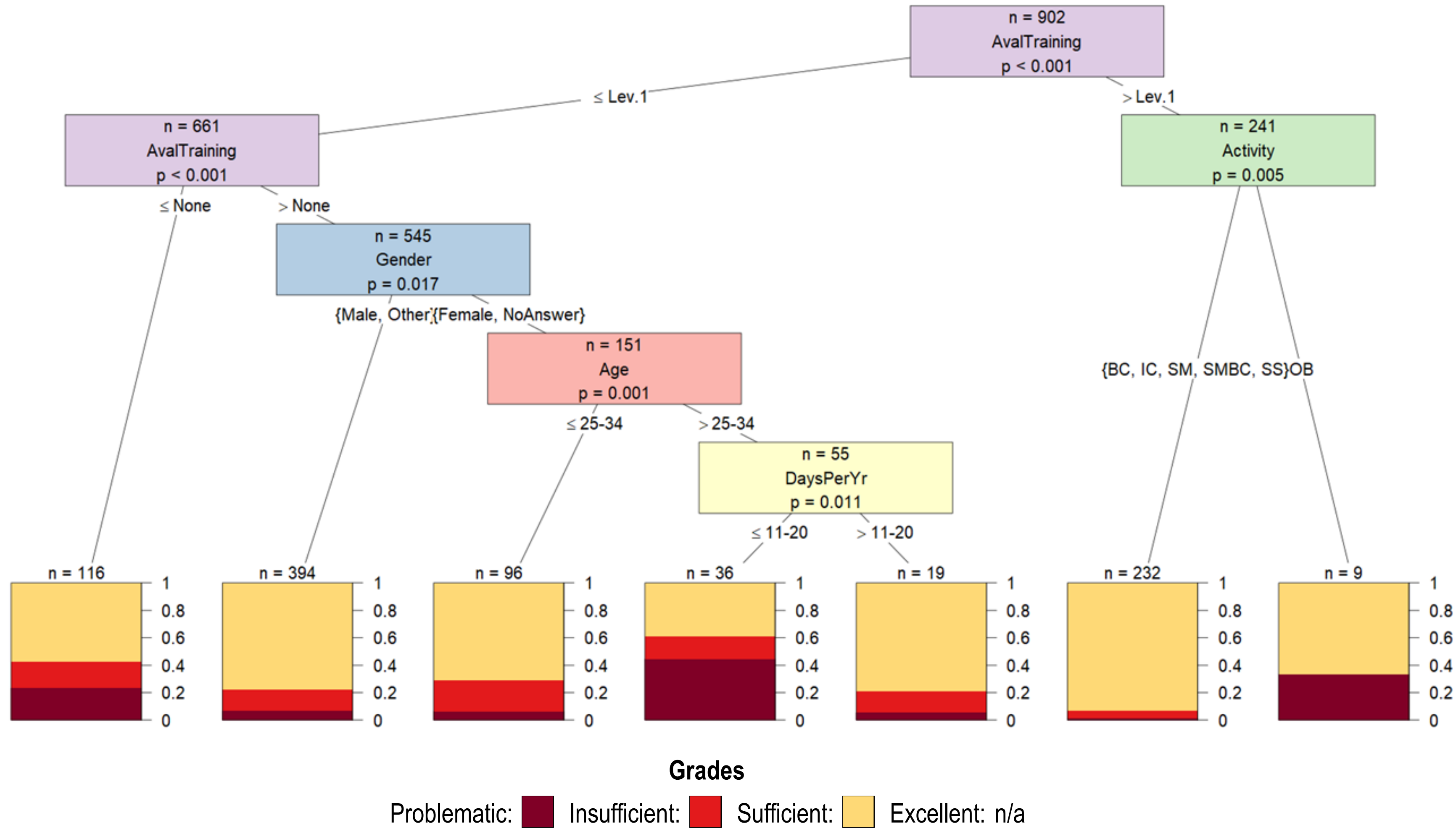

Figure 4.11. Conditional inference tree displaying the interaction between Type D users' performance on the avalanche problem mitigation question and their background variables.

analysis conducted on the Type Ds performance on the **Aspect Icon** question computed two significant splits in the dataset. The most significant split was between activity types, with snowmobilers and snowshoers achieving significantly lower grades than the other activity types ($p = 0.001$, n=434). The only other significant split was between genders, with females and those that provided no answer on their gender performing significantly better than males ($p = 0.009$, n=385). The CTree analysis conducted on the **Size Icon** question for Type D users did not compute any significant splits in the dataset. On the **Avalanche Problem Mitigation** question, Type D users that had undertaken avalanche training higher than a recreational Level 1 avalanche awareness course performed significantly better than those with lower levels of training ($p < 0.001$, n=907) (Figure 4.11). All activity types among this more highly trained group performed significantly better on this question than the out-of-bounds skiers and snowboarders. This CTree analysis further highlighted that Females above the age of 34 with intermediate levels of training and who recreated on less than 20 days a year on average, performed significantly worse than those with the same demographic characteristics that recreate more than 20 days per winter ($p = 0.01$, n=55). The CTree conducted on type D users' performance on the **Slope Choice** question did not return any significant splits.

Type Es

The same five questions were used in a series of CTree analyses on Type E avalanche bulletin users. In the CTree analysis of performance on the **Avalanche Problem Recall** question, eight significant splits were computed in the dataset (Figure 4.12). The first and most significant split was between participants with different levels of avalanche training, with those professionally trained performing significantly better than those that had less training ($p < 0.001$, n=1,457). The next most significant splits among both emerging child nodes was among different age groups, with those below the age of 45 being able to recall significantly more of the avalanche problems than their older counterparts, both among those that were professionally trained ($p<0.001$, n=304) and those with lower levels of training ($p < 0.001$, n=1,133). The lowest performing terminal node for the **Avalanche Problem Recall** question was participants with lower than a Level 2 avalanche awareness course who were over the age of 44, 39% of whom achieved a grade of *problematic*, and 31% of whom achieved a grade of *insufficient*. The CTree analysis conducted on Type E users' performance on the **Aspect Icon** question only revealed two significant splits in the dataset. The first and most significant split was between participants of different nationalities ($p < 0.001$, n=781). A significantly higher proportion of US participants achieved a grade of *sufficient* than Canadians (94.2% vs 82.8%). The only other significant split was between different age groups among the Canadians, with those above the age of 54 performing significantly worse on this question compared with those among lower age groups. There were no significant splits calculated in the CTree analysis conducted on the **Size Icon** question for Type E users.

The CTree model that examined Type E users' performance on the **Avalanche Problem Mitigation** question computed four significant splits in the data. The first and most significant split was between users who recreate for different numbers of days each winter, with those who recreated for ten days or less performing significantly worse ($p < 0.001$, n=1,449). Among the Type E users that recreate more frequently, the most significant split was between users of different activity types, with out-of-bounds riders, snowmobilers and snowshoers performing significantly worse than the other three activity types ($p < 0.001$, n=1,227). The CTree analysis that evaluated Type Es performance on the **Slope Choice** question computed three significant splits in the dataset. In the first and most significant split, those that were professionally trained achieved significantly higher grades than those with lower levels of training ($p < 0.001$, n=1,457). The Type E users with no formal avalanche training were the group that achieved the lowest grades on this question; 50.2% were graded as *problematic* and 20.5% were graded as *insufficient*. Among those who had undertaken formal avalanche training but were not professionally trained, the individuals above the age of 44 performed significantly worse than younger individuals ($p = 0.01$, n=998).

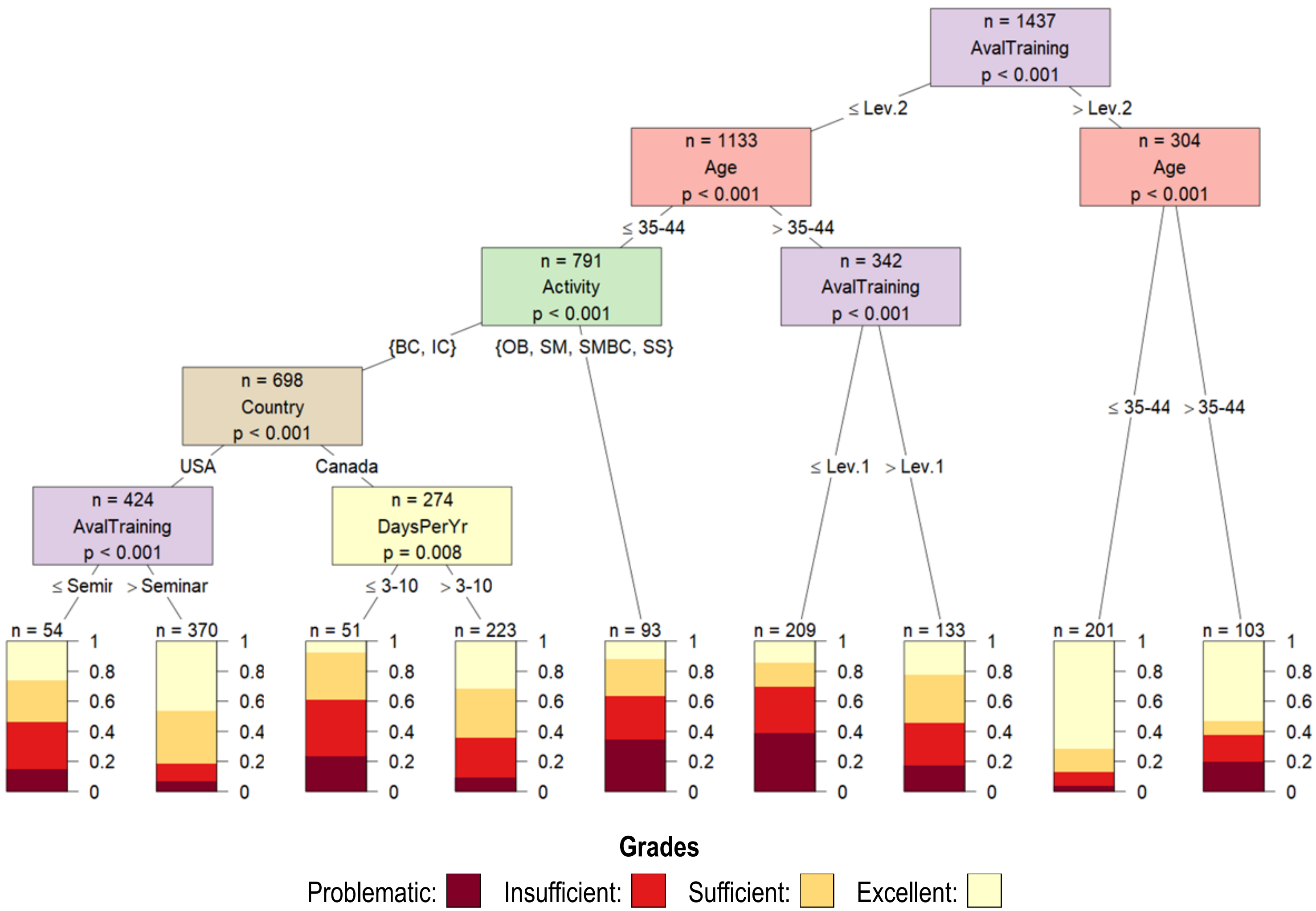

Figure 4.12. Conditional inference tree displaying the interaction between Type E users' performance on the Avalanche Problem Recall question and their background variables.

Total Scores Across Literacy Questions

Type As & Type Bs

Since the Type As only answered one question, they were not included in this section of the analysis. The CTree model conducted on Type Bs' summed scores from the **Danger Rating** Recall and the **Slope Choice** questions did not compute any significant splits (n=528).

Type Cs

The CTree analysis that evaluated the influence of Type C's background variables on their overall summed literacy scores computed three significant splits in the dataset (Figure 4.13). The most significant split was between participants with different levels of training, with those that had not been formally trained performing significantly worse than participants with at least a Level 1 avalanche awareness course ($p < 0.001$, n=524). The next significant split showed that participants over the age of 54 performed significantly worse overall than the younger individuals within the group. Finally, among the younger participants with higher levels of training, participants that get more than ten days of winter backcountry recreation in per season performed significantly better than those who recreated less often ($p = 0.03$, n=301).

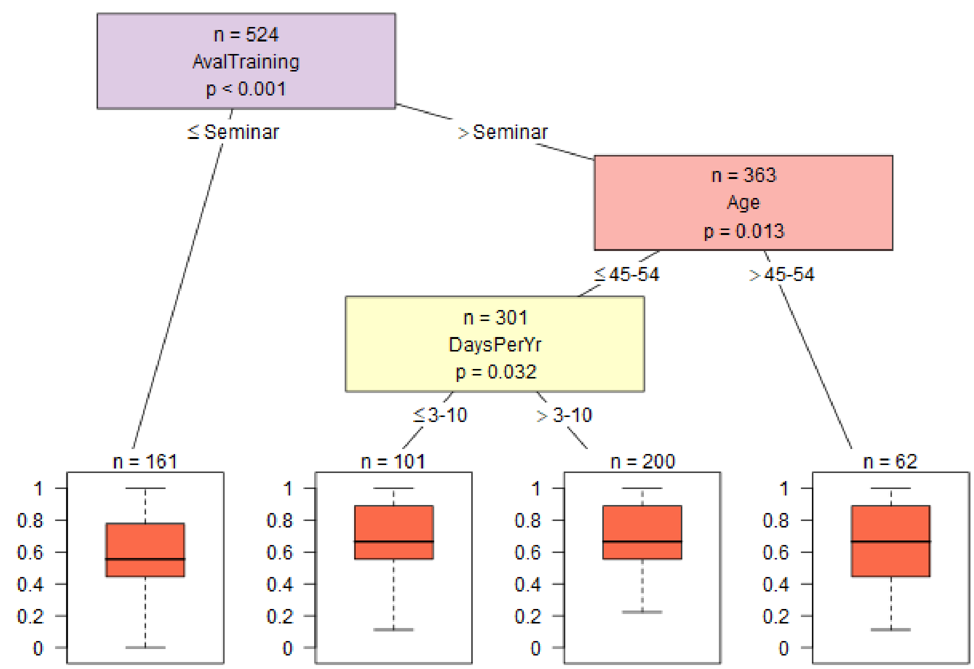

Figure 4.13. Conditional inference tree displaying the interaction between Type C users' overall scores on the literacy questions and their background variables.

Type Ds

The CTree analysis run on Type Ds users' overall scores of avalanche bulletin literacy computed six significant splits in the dataset (Figure 4.14). Just as was seen with the Type Cs, the most significant split in this group was between users with and without formal avalanche awareness training ($p < 0.001$, n=897). Among the lower trained individuals, males achieved significantly higher overall scores than the females ($p = 0.016$, n=140) with the median score for males being 0.5 and only 0.25 for females. The next significant split among those that were more highly trained was between users of different age groups. Participants over the age of 44 performed significantly less well than those in younger age categories ($p < 0.001$, n=757).

Type Es

The final CTree analysis compared the overall scores of type E users with their background characteristics (Figure 4.15). The first and most significant split was between individuals with different levels of avalanche training, with professionally trained individuals achieving significantly higher scores than those with lower levels of avalanche training ($p < 0.001$, n=1,437). This model also revealed that older participants generally performed worse than younger participants. Among the Canadian participants that had undertaken a recreational Level 1 or Level 2 avalanche awareness course, the out-of-bounds riders, snowmobilers and snowshoers achieved significantly lower grades compared with other activity types ($p = 0.011$, n=302).

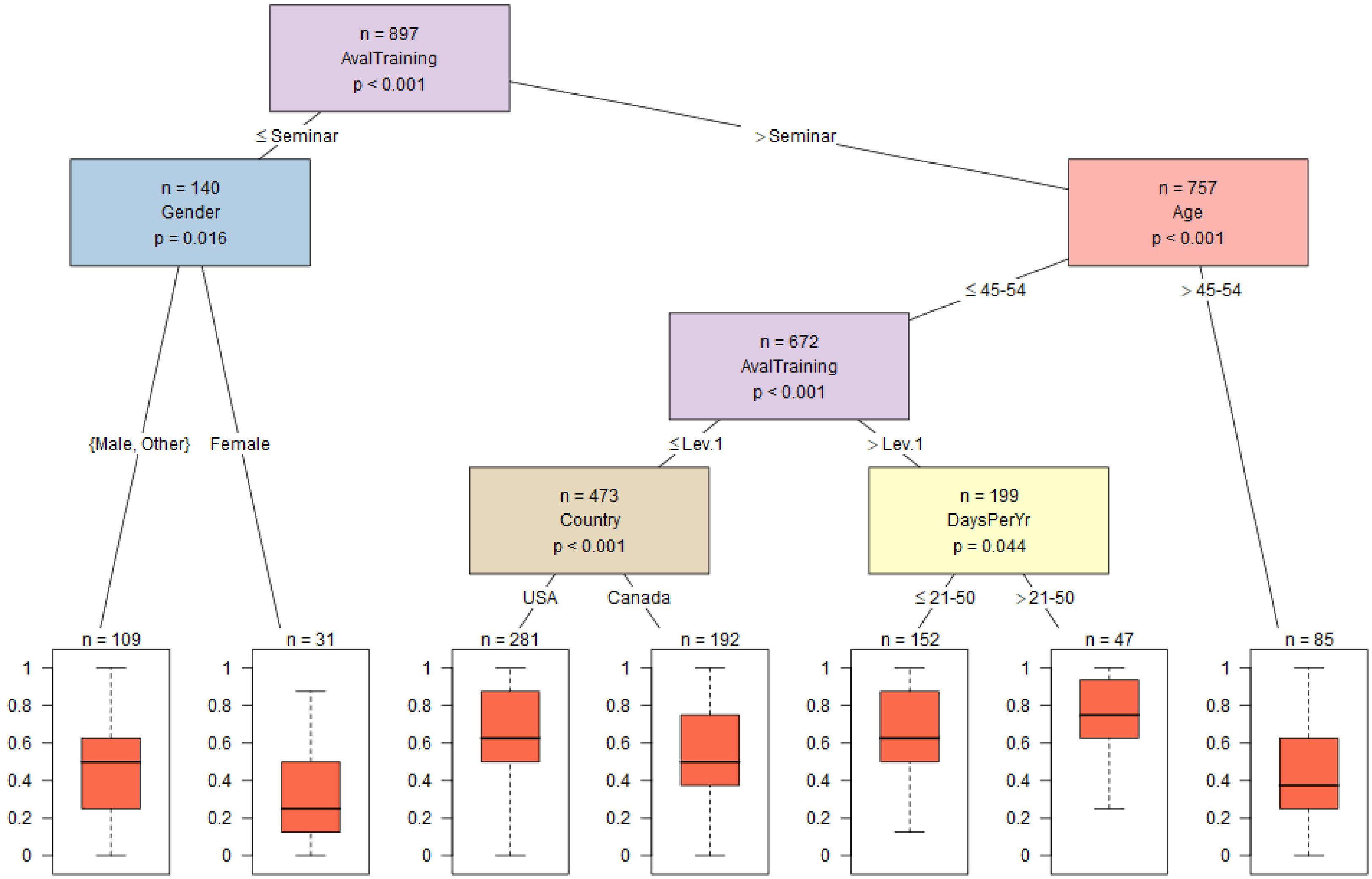

Figure 4.14. Conditional inference tree displaying the interaction between Type D users' overall scores on the literacy questions and their background variables.

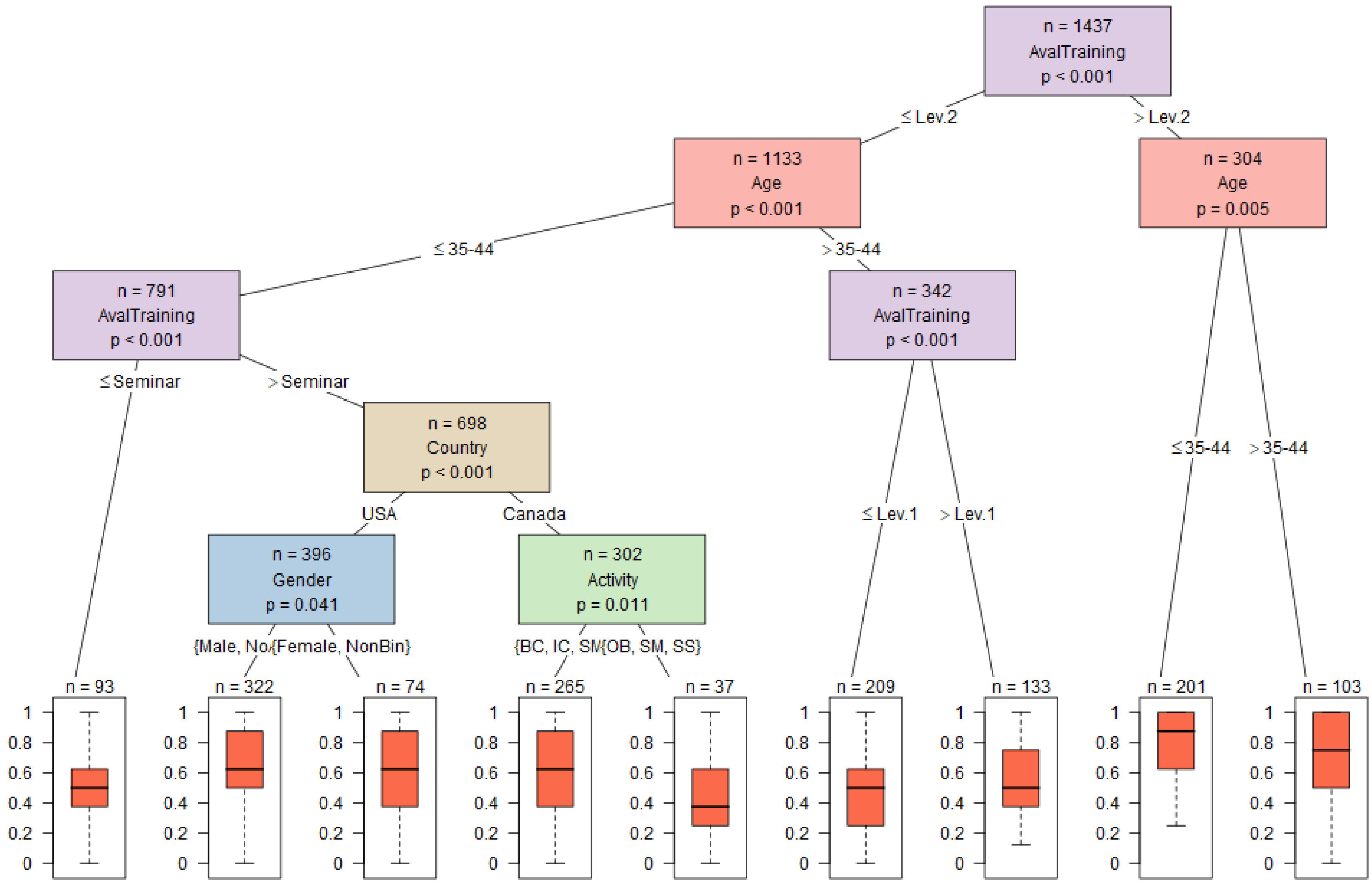

Figure 4.15. Conditional inference tree displaying the interaction between Type E users' overall scores on the literacy questions and their background variables.

Across all CTree analyses, the background variable that caused the most significant splits was avalanche awareness training (Table 4.3). While difference in age was only the cause of one of the models' most significant splits, it featured as a significant split in lots of other splits lower down in each model. Differences in years of experience in the backcountry did not cause a single significant split in any of the CTree models.

Table 4.3. Summary of CTree analyses on the avalanche bulletin literacy questions. The most significant splits calculated in each model. The cutoff value underneath each significant split displays the group(s) that performed significantly worse in that CTree analysis

Question	Avalanche Bulletin User Types					
	A	B	C	D	E	F
Danger Rating Recall		Avalanche Training: < Lev. 1	Avalanche Training: < Lev. 1			
Avalanche Problem Recall				Age: > 44	Avalanche Training: < Prof.	No signif. splits
Danger Rating Conditions Mgmt.			Activity: SM, SS			
Danger Rating Elevation Band			Activity: SM			
Avalanche Problem Aspect Icon				Activity: SM, SS	Country: Canadians	No signif. splits
Avalanche Problem Size Icon				No signif. splits	No signif. splits	No signif. splits
Avalanche Problem Mitigations				Avalanche Training: < Lev. 2	Days/Year: < 11-20 days	No signif. splits
Slope choice	No signif. splits	No signif. splits	No signif. splits	No signif. splits	Avalanche Training: < Prof.	No signif. splits
Overall Score	No signif. splits	No signif. splits	Avalanche Training: < Lev. 1	Avalanche Training: < Lev. 1	Avalanche Training: < Prof.	No signif. splits

4.3. Feedback

The final page in the survey included an optional question that asked participants to provide feedback on their experiences using (or not using) avalanche bulletins and their overall comments on the survey too. One of the recurring themes in these responses was the desire for more interactive tools and quizzes to be incorporated into bulletin products. These tools would be able to provide users with feedback on any potential gaps in their knowledge. While I did not conduct a formal analysis on the content of the survey comments, the example quotes below are included to illustrate the general sentiment of the feedback.

> “I hope you'll send feedback on travel decisions I made in the survey”

> "I really liked having my knowledge tested through this survey and during my avy class. Is there an online forum that does this (has practice questions and quizzes) but gives feedback on the accuracy of the response? That would be a great resource to create or advertise if it exists”

> “Would love an interactive route planning tool for trip planning in real time that would give you instant feedback about route selection and ski line selection.”

> “That was fun! something interactive like this at the beginning of the season would be great”

> “Is there an online forum that has practice questions and quizzes but gives feedback on the accuracy of the response?”

> “I'm very curious to hear the findings of all this information, and would even be interested to discuss my responses for a learning opportunity.”

> “Could link to resources for people to learn more at the end, since this survey made me re-evaluate my level of knowledge”

> "Would love to learn more!!"

Chapter 5. Discussion

This chapter synthesizes the results of my analyses into an overall picture of avalanche bulletin literacy among recreational backcountry users and develops recommendations for avalanche safety initiatives and avalanche risk communication. The first two sections include a summary of how recreationists self-reported on their own avalanche bulletin routines and a review of performance on the avalanche bulletin literacy questions. The following section discusses the implications of these findings for avalanche bulletin design, avalanche awareness education and risk literacy research. The final section discusses the limitations of the methods used in this study.

5.1. Avalanche Bulletin Use Patterns

It is critical for avalanche warning services to have an in-depth understanding of how the avalanche bulletin is used and by who. There was a strong tendency among the participants in this study to self-report as having highly sophisticated avalanche bulletin use routines. It is likely that this finding was largely driven by a bias in the survey sample in which advanced backcountry users are over-represented due to their heightened interest in avalanche safety initiatives and the relative ease with which they can be recruited to take part in this kind of research. Considering this trend, it is important to evaluate the factors that determine self-reported bulletin use, and how these factors might be related to people's perceptions of their own bulletin use routines.

Some of the factors that significantly contributed towards self-reported bulletin use in this study have an obvious causal link. For example, individuals that recreate in the backcountry more frequently are more likely to have repeated exposure to avalanche bulletin information which helps to explain the selection of more advanced levels among those with a higher number of days spent recreating per winter. A similar pattern observed among those with higher levels of avalanche awareness training could be explained by the components on best practices for avalanche bulletin use that are typically included in avalanche awareness courses. However, other factors that had a significant influence on self-reported bulletin use routines are less intuitive to explain such as the differences between activity types. Among the survey participants with formal avalanche awareness training, ice climbers and out-of-bounds skiers self-reported significantly lower levels of avalanche bulletin use. Among participants without formal training, ice climbers, snowmobile riders and backcountry skiers that use snowmobiles to access the backcountry were identified as lower level users. This could have been the result of a wide range of social and cultural factors, such as differences in perceptions of social norms regarding avalanche safety practices or alternative beliefs about the value and relevance of avalanche bulletin information. Whether the specific nature of the relationship between each background demographic variable and self-reported avalanche bulletin use can be easily interpreted or not, having a clearer understanding of who makes up each user type can facilitate the tailoring of targeted avalanche safety initiatives in the future.

5.2. Avalanche Bulletin Literacy

When a sample generally identifies as being highly competent, it is important to consider whether individuals possess the necessary skills to operate at their self-declared levels of competence and what the implications might be if they do not. In the literacy questions that focused on individual concepts related to the danger rating and avalanche problems, most of the participants in each bulletin user type were graded as *sufficient* or *excellent*. Somewhat surprisingly, this was more common on the comprehension questions (~80-90%) than it was on the knowledge recall questions (~60-80%). This finding does not align with the structure of Bloom's taxonomy, in which comprehension tasks are classified as more challenging than simple knowledge recall, since they require a deeper level of cognition (Bloom, 1956).

Another noteworthy result from the recall questions was observed when comparing the performance of more advanced and less advanced users. The proportion of participants that achieved a grade of at least *sufficient* was higher among the Type Bs and Cs on the **Danger Rating Recall** question than the Type Ds and Es on the **Avalanche Problem Recall** question. More than a third of users among Type Ds and Type Es failed to recall one or more of the three most common avalanche problems (Wind Slab, Storm Slab and Persistent Slab) and so were graded as *insufficient* on the **Avalanche Problem Recall** question. This result implies that these individuals who failed to achieve a grade of *sufficient* had not regularly thought about, discussed or properly incorporated the avalanche problem information despite stating in the avalanche bulletin user type question that this was the primary information source they used to inform their trip planning decisions. Additionally, around a fifth of Type D and Type E users were graded as *insufficient* or *problematic* on the **Avalanche Problem Mitigation** question. The observed challenges that participants encountered on these avalanche problem questions are consistent with a number of previous studies that have found winter backcountry recreationists to generally struggle when handling avalanche problem information (e.g, Haegeli & Strong-Cvetich, 2018; Klassen et al., 2013; Wagner & Hardesty, 2014).

One realm of study that offers potential avenues for increasing the awareness and understanding of avalanche problem types is social marketing. A possible strategy from this domain of research that might elicit greater familiarity with each of the avalanche problems could be to activate the specific character of each avalanche problem type using “brands” of avalanches (Evans, 2006; Keller, 1998). Using this type of branded marketing strategy and bringing the character of each avalanche to life might also help end users to understand the most suitable precautionary behaviors for each avalanche problem type.

In the **Danger Rating Order** question, which was only shown to non-bulletin users, more than 30% of participants were unable to state the order correctly. This indicates that perhaps the sequencing of the danger ratings’ signal words is not completely intuitive and that the use of a separate system for entry level users that only incorporates numbers or colours, could be more effective. Overall, most of the sample demonstrated that they were literate with regard to individual avalanche bulletin components.

In contrast, participants consistently seemed to encounter challenges with the integration and application of multiple avalanche bulletin components in the **Slope Choice** scenario. The results from this question suggest that more than half of all recreational users, both entry level and advanced individuals, do not possess the avalanche bulletin literacy skills required for conducting safe and consistent trip planning decisions. The consistently weak correlations between performance on the **Slope Choice** question and other literacy skills indicates that despite the relatively strong performance on the individual literacy items, lots of users encounter challenges when attempting to bring the various components together. While it is somewhat surprising that 20.6% of the Type Fs were graded as *problematic* in this question, other studies that have evaluated the capacity of professional doctors, journalists, and politicians to handle statistical and risk-related information, have also found an unexpectedly large proportion of experts do not understand what statistics mean or draw wrong conclusions from statistical or risk-related information without noticing (e.g., Gaissmaier & Gigerenzer, 2008; Gigerenzer, Gaissmaier, Kurz-Milcke, Schwartz, & Woloshin, 2007; Gigerenzer & Gray, 2011; Tremper, 2013). Experts do not get it right all the time and after reviewing the follow-up reasoning provided by Type Fs in the **Slope Choice** question, it can be said with confidence that these grades were justified.

It is possible that the integration and application challenges encountered in the **Slope Choice** question by most of the sample were at least in part the result of participants being overwhelmed by the complexity and volume of information presented in this exercise. Best practices in risk communication emphasize the need to account for our limited attention capacities and the challenges that humans typically encounter when attending to many things simultaneously (Wogalter, DeJoy, & Laughery, 2005). Indeed, a reasonable assumption for communication design is that people should not be required to attend to more than one thing at a time (Wogalter et al., 2005). Challenges on the **Slope Choice** question were especially pronounced among entry level users which points towards the need to either simplify avalanche bulletin information or to make it easier for recreationists to put the different pieces together. Implementing these changes to future avalanche risk communication could enable those that are currently overwhelmed by the complexity of avalanche bulletins to incorporate more System 2 thinking and to engage in a more deliberate and thoughtful consideration of the available information.

5.3. Implications for Avalanche Bulletin Design

A number of recommendations for improvements to avalanche bulletin design can be generated by the findings from this study. One of these recommendations arises from the analysis of the **Aspect Icon** question, which provided a useful opportunity to compare the effectiveness of different visual designs. The CTree analysis of Type E users' performance on the **Aspect Icon** question demonstrated that the US icon was significantly superior to the Canadian icon in helping users to identify the mountain faces on which avalanche problems exist. Insights from risk literacy research have demonstrated that well-designed visual aids can dramatically improve risk communication, comprehension and skilled decision-making among diverse individuals (Garcia-Retamero & Cokely, 2017; Garcia-Retamero, Okan, & Cokely, 2012). Visual aids tend to be most effective when they are “transparent” – that is, when they promote representative, or unbiased understanding (Garcia-Retamero & Cokely, 2013). It is possible that the reduced comprehensibility of the Canadian aspect icon is due to its 3D layout, which, compared to 2D designs, like the US aspect icon, can add unnecessary spatial cues and distort perceptions (Ware, 2019). The results from this study suggest that there is room for improvement in the visual presentation of the aspect information in Canadian avalanche bulletins.

Another possible design alteration that could enhance the effectiveness of avalanche bulletins, would be to incorporate interactive exercises that constructively demonstrate where users’ misconceptions existed. The large number of individuals that self-identified towards the top of the avalanche bulletin user typology, combined with the poor performance of most users on the **Slope Choice** scenario, suggests some of the participants in this study are likely to have unrealistic positive self-evaluations. As research in educational theory suggests, if self-perceptions are positively biased, learners may not detect their learning needs and thus inefficiently self-regulate their learning processes (e.g., Dunlosky, Hertzog, Kennedy, & Thiede, 2005; Schunk, 2008; Thiede, Anderson, & Therriault, 2003). If tasks like the **Slope Choice** scenario were incorporated into avalanche bulletins and were combined with feedback detailing how participants’ responses compare with best practices, this would enable users to self-evaluate their own competencies realistically and accurately. Self-monitoring skills such as these are considered to be important prerequisites for meaningful learning (Dunning, Heath, & Suls, 2004; Kruger & Dunning, 1999). The integration of interactive exercises in avalanche bulletins, coupled with the routine nature of avalanche bulletin use, could generate regular and repeated learning opportunities that neither avalanche awareness courses, nor the backcountry environment, are able to provide.

5.4. Implications for Avalanche Safety Initiatives

The findings from this research shed valuable insight on the segments of the backcountry population whose bulletin skills would benefit the most from targeted interventions. Firstly, regarding activity types, snowshoers, snowmobilers and out-of-bounds riders were found to consistently perform less well than other activity types in the avalanche bulletin literacy questions. One strikingly apparent difference between activity types was observed in the results of the **Elevation Band** question, which suggested that Type C snowmobilers have a significantly lower awareness of overhead avalanche hazard that other activity types. Another demographic group that would likely benefit from targeted education initiatives in the future is older backcountry recreationists, who consistently performed worse than those in younger age categories. This finding carries greater weight when coupled with the outcomes from a recent study by Peitzsch et al. (2020), who found that the median age of those killed in avalanche accidents has increased from 27 to 33 in the US over the last 70 years. One of the most surprising results from the CTree analyses was that years of experience in the backcountry was the background variable that had the least significant influence on avalanche bulletin literacy. This suggests that backcountry experience does not necessarily lead to a more in-depth use of public avalanche bulletin information. The absence of a significant relationship between years of experience in the backcountry and avalanche bulletin literacy skills contradicts a general theme in avalanche safety literature, whereby experience in the backcountry environment is thought to be one of the most critical components of becoming an all-round competent and routine mitigator of avalanche hazard (Jamieson, 2000; Tremper, 2018).

The current study also provides evidence for broader trends on the effectiveness of avalanche education and elucidates more general insufficiencies in knowledge that could be addressed in future curriculum design. It is promising to have found that participants' level of avalanche awareness training was repeatedly the most significant factor influencing performance on the avalanche bulletin literacy questions. The CTree analysis on self-reported bulletin use types also suggests that avalanche awareness education is having a significantly positive influence on the sophistication of winter backcountry recreationists' avalanche bulletin routines. Based on the strong performance of trained individuals on the recall and comprehension questions, it seems as though avalanche awareness courses are having a beneficial impact on the backcountry audience's familiarity with, and general understanding of, core bulletin components. However, the results of the **Slope Choice** question suggest a lot could be gained from placing more of a focus on helping students to learn and practice the integration and application of avalanche bulletin information.

Incorporating these sorts of activities that involve more active participation from students is a challenging task for teachers in classroom settings. It is much more common for educators to place a disproportionately large focus on knowledge recall and information comprehension (Gershon, 2018). These basic cognitive processes are more efficient to evaluate and more straightforward to demonstrate, which makes it easier to evidence progress of learning (Krathwohl & Anderson, 2009). It is much more challenging to design and analyse outcomes from simulations that require learners to incorporate their understanding into actions and decisions. This lack of attention to application skills can be severely limiting, since, in order to be successful, learners typically need to not only acquire knowledge, they need to also use it and apply it in real world settings in order to achieve better performance and outcomes (Dror, 2011). The infrequent or oftentimes non-existent opportunities for avalanche bulletin users to practice information application in a low-stakes, feedback-rich learning environment, likely means that mistakes and misconceptions will commonly go unnoticed, unless perhaps, they result in the triggering of an avalanche. Avalanche education should continue in its pursuit to lessen the wicked nature of the learning environment for winter backcountry recreationists by maximizing opportunities for students to implement their understandings in novel settings. This could include the application of bulletin information into terrain selection scenarios or trip planning simulations in which a strong emphasis is placed on showing learners whether their interpretations of the bulletin information were accurate, and whether their chosen travel strategies were safe.

5.5. Implications for Risk Literacy Research

For other studies attempting to examine risk literacy in complex decision-making environments, there are several important lessons learned from the comprehensive and targeted evaluation approach used in this research. Any public risk communication tool that attempts to communicate somewhat complex information is likely to have an audience that varies widely in terms of its capacity to use, understand and act upon the presented content. The use of separate grading criteria in this study that were based on the sophistication of recreationists' decision routines, highlighted the specific literacy skills that users tend to struggle with at each level, as well as the demographic groups that were associated with these challenges. While the inclusion of free-text questions required a time-intensive coding process, it also provided a higher degree of insight compared with more conventional multiple-choice survey items. Bloom's taxonomy provided a useful structure for the development of the avalanche bulletin literacy framework which enabled the identification of the specific step in cognition at which avalanche risk communication typically breaks down. Using this study's approach for evaluating risk literacy could be particularly useful in contexts where individuals are required to incorporate a wide variety of information types into personal risk management decisions, such as health literacy or cyber security. Overall, the approach was successful in generating meaningful and actionable insight for avalanche risk communication and avalanche awareness education.

5.6. Limitations

While this study provides valuable insights for examining risk literacy in a complex decision environment and for improving avalanche risk communication, there are several limitations that need to be considered when interpreting the results. In general, the complex and variable nature of the winter backcountry environment makes it challenging to measure and account for all the physical and emotional nuances involved with personal avalanche risk management decisions. However, unlike similar studies that used hypothetical decision-making scenarios for backcountry decisions in the field (e.g., Gunn, 2010; Haegeli, 2018) this survey was focussed on the use of avalanche forecast information for trip planning. This process is generally carried out at home prior to departure, in environments that are far less dynamic and uncertain than avalanche terrain. Nevertheless, there are still factors that affect the processing of avalanche bulletin information that surveys cannot account for or measure as accurately as methods of direct observation. The aim of presenting information in the survey in the same order that information is provided in avalanche bulletins was to mimic the environment of typical avalanche bulletin use as closely as possible.

Being literate with avalanche bulletin information involves a large number of factors and skills, some of which were unaccounted for in this survey. Having a grasp of weather-related information for example, is considered critical for high-end avalanche bulletin users, as is the capacity to use and interpret maps. It would be interesting for future studies of avalanche bulletin literacy to evaluate how background characteristics relate to the avalanche bulletin literacy skills that were not examined in this study. To ensure the survey in the current study was not overly arduous and long, selections had to be made, and Bloom's taxonomy provided a meaningful structure to ensure that fundamental concepts and skills related to avalanche bulletin literacy were included. The final selection of questions included enabled the users to be evaluated at each of the separate levels in the avalanche bulletin user typology.

It is possible that the abstract nature of the **Slope Choice** scenario and certain design features might have contributed to the consistently poor performance observed in this question. However, the strong grades achieved by the Type F users in comparison with recreational participants reinforces the legitimacy of the insights provided by this exercise. Additionally, the inclusion of the follow-up feedback question allowed participants to justify their decisions and provided a clearer perspective on whether their reasoning was consistent and logical. Including this additional exercise helped to minimize the chances that participants would be graded incorrectly.

Several challenges were encountered in the design and analysis of the **Avalanche Problem Mitigation** question. While there is general consensus about the specific terrain and travel mitigations that are applicable in given avalanche problem scenarios, it is also possible to think of situations where the rule for each of these strategies does not apply. Therefore, the additional option of 'Somewhat applicable' was added to the range of possible answers for this question alongside 'Highly applicable' and 'Not applicable'. Given that answers of 'Somewhat applicable' and 'Highly applicable' were graded as *sufficient*, if selected for the correct problem, this is likely to have contributed to the relatively strong performance observed in this question compared to what the result might have been if only binary answer options were provided. However, in a similar outcome to the **Slope Choice** question, the higher proportion of Type Fs that performed well on the **Avalanche Problem Mitigation** question compared with other users provides strong evidence that the question structure and grading criteria were effective in examining this component of bulletin literacy.

Controlling for learning effects in the survey and preventing participants from incorporating the knowledge they might have gained from previous questions was unavoidable. The **Slope Choice** question was purposely positioned at the beginning of the survey to help prevent learning effects from influencing the results of this question. This likely means that literacy performance on some of the individual skills questions was better than the literacy skills of these participants in reality. The desire to keep the learning effects of the **Slope Choice** question consistent between participants is what drove the decision to only use one scenario, instead of multiple scenarios that were randomly assigned.

While there was a certain degree of subjectivity in the grading criteria included in the avalanche bulletin literary framework, the incorporation of expert opinion and seminal avalanche safety literature in the design of this framework helped to make the thresholds between each grade as objective as possible. Furthermore, limiting the grading scale of each question to a maximum of four levels also helped to reduce the potential effects of subjectivity.

The process of converting the ordinal literacy grades into numerical values and summing them to produce overall literacy scores also has several shortcomings (Wittkowski, Lee, Nussbaum, Chamian, & Krueger, 2004). This is because the relative importance of each variable, the relative distance between each ordinal grade and the contribution of each literacy skill to the overall latent factor of avalanche bulletin literacy are unknown. In reality, the only assumption that can be made without issue is that the grades for each literacy question have an orientation, i.e. that if performance on all other literacy questions were held constant, an increase in the grade on one chosen literacy question would result in an improvement in overall avalanche bulletin literacy. The method of summing scores for the final CTree analyses requires the additional assumption that all increases in literacy grades provide an equal contribution to avalanche bulletin literacy, which is highly unlikely to be true. While there are statistical methods for examining the nature of the individual literacy scales and combining them into an overall score in more sophisticated ways, they all require their own assumptions. Hence the summing of numerical scores was considered to be the simplest and most transparent method for obtaining an overall literacy score for each participant.

Perhaps the most significant limitation of this study was the relatively smaller numbers of novice users in the sample. It is arguably these individuals that would benefit the most from having their literacy capabilities evaluated and their informational needs more closely met through targeted interventions. The concerted promotional efforts to recruit participation from those less involved or interested in avalanche safety initiatives, and the tailored design of the survey, meant that there were at least some entry level users included in the sample.

Chapter 6. Conclusion

The limited foundation of evidence documenting the avalanche bulletin literacy skills of winter backcountry recreationists, makes it challenging for avalanche warning services to inform the decisions of their target audience effectively. To address this gap, the present study conducted a comprehensive evaluation of avalanche bulletin literacy to identify the skills that users commonly struggle with, and to highlight the demographic groups that stand to benefit the most from future interventions. The findings from this research provide an actionable set of recommendations for efficiently targeting the avalanche risk communication challenges where improvements are needed the most.

The predominant pattern among the survey participants to self-report as having highly sophisticated avalanche bulletin routines, suggests that the sample contained a large proportion of individuals with advanced avalanche risk management skills. This trend was consistent with the relatively strong performance on the literacy questions that evaluated knowledge recall and comprehension. However, when tasked with the integration and application of multiple bulletin components in a terrain selection scenario, more than half of the recreational users at all levels in the bulletin user typology failed to provide a *sufficient* answer. This result suggests that the informational outcomes of the winter backcountry audience could be significantly enhanced if a stronger emphasis were placed on helping end users to learn and practice their application skills.

The CTree analyses provided a strong indication that avalanche awareness courses are highly beneficial in facilitating the development of avalanche bulletin literacy skills for users at all levels in the typology. The CTree analysis also suggests that older backcountry recreationists are the age group that struggle the most with avalanche bulletin information, and that snowmobilers, snowshoers and out-of-bounds riders are the activity types that most frequently encounter literacy challenges, particularly among intermediate users. Against expectations, more experienced backcountry users were not found to be more literate with avalanche bulletin information; participants' years of experience did not cause a single significant split in any of the CTree analyses on the avalanche bulletin literacy questions.

The traditional communication dynamic that avalanche bulletins provide has been one of unidirectional delivery of information about current conditions; users typically visit the bulletin website to extract information relevant to their trip plan. The results from this study provide an exciting opportunity to re-envision the way that avalanche bulletin engagement occurs. While recreationists typically only take avalanche courses once or twice in the entirety of their backcountry career, the avalanche bulletin is in a unique position to reach a wide-ranging audience on a routine basis. Recreationists' consistent application challenges and their desire for more feedback highlights the immense potential for avalanche bulletin websites to play more of an active role in avalanche awareness education. If designed effectively, directly integrating interactive tools into avalanche bulletin websites could foster a more constructive learning environment that provides accurate and reliable indicators for recreationists on their level of competence and any evident gaps in their understanding.

There are several areas in which future studies can capitalize meaningfully on the results from this study. Now that subgroups with literacy challenges have been identified, avalanche bulletin messaging can be created or adapted to increase the literacy of specific audiences. Future research could test message design alternatives to see which ones most effectively address the literacy challenges identified in the present study. Onward research efforts will also help to define the optimal approaches for measuring avalanche bulletin literacy accurately and efficiently. This will be particularly important if future avalanche bulletins are to adopt a more tailored approach with separate products for users that operate at separate levels of sophistication. Ultimately, efforts to improve avalanche bulletin literacy will help to prevent avalanche accidents and empower individuals to gain a sense of control through understanding the risks they encounter on their backcountry trips.

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Appendix A. Online Survey Screenshots

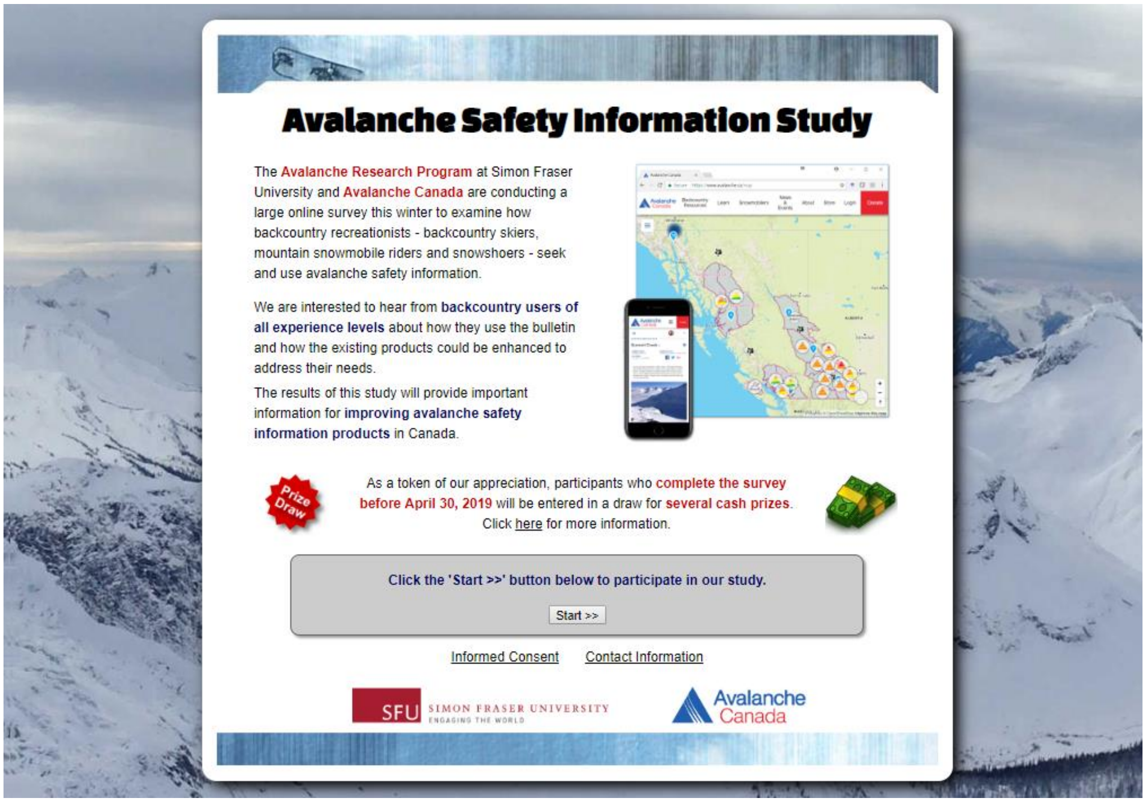


Figure A.1. Survey landing page

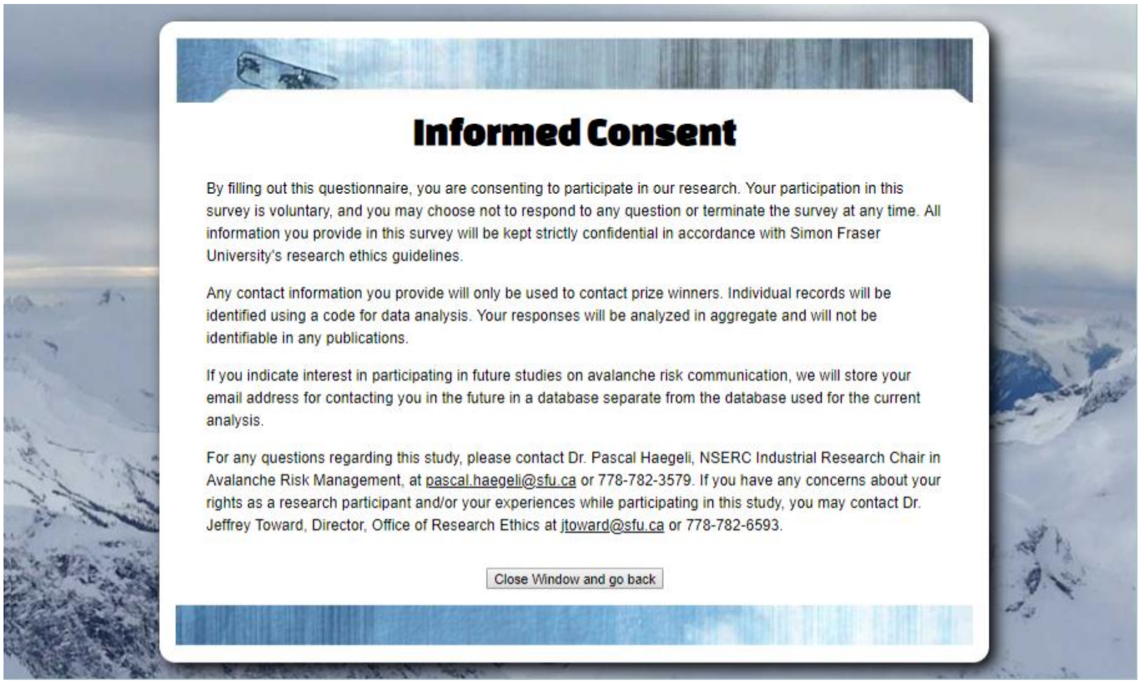


Figure A.2. **Statement of informed consent**

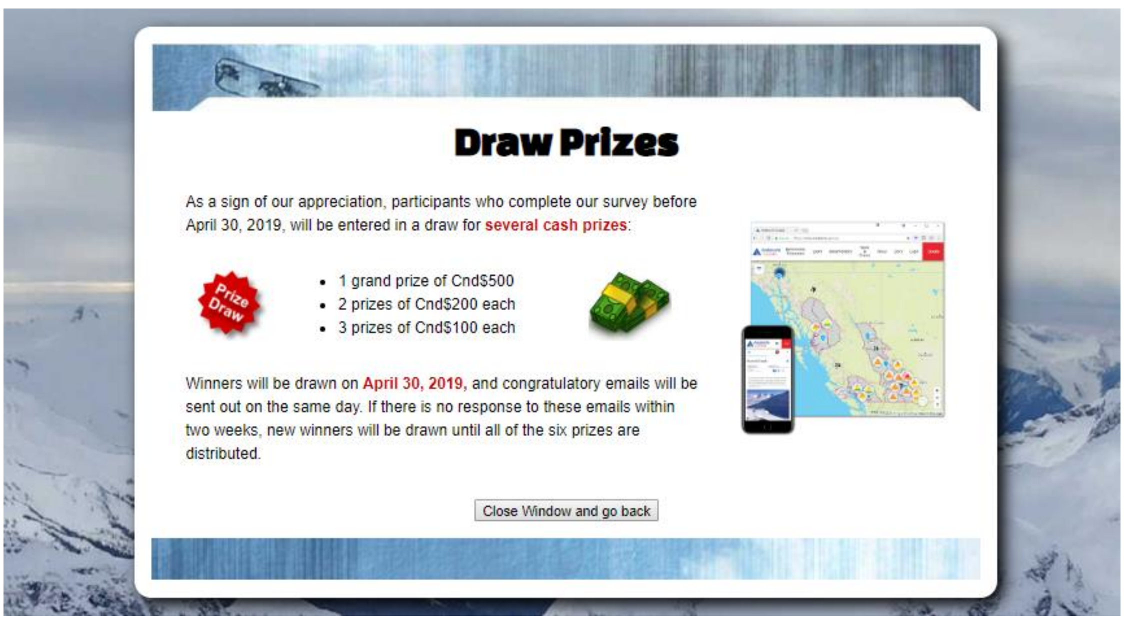


Figure A.3. **Draw prize information**

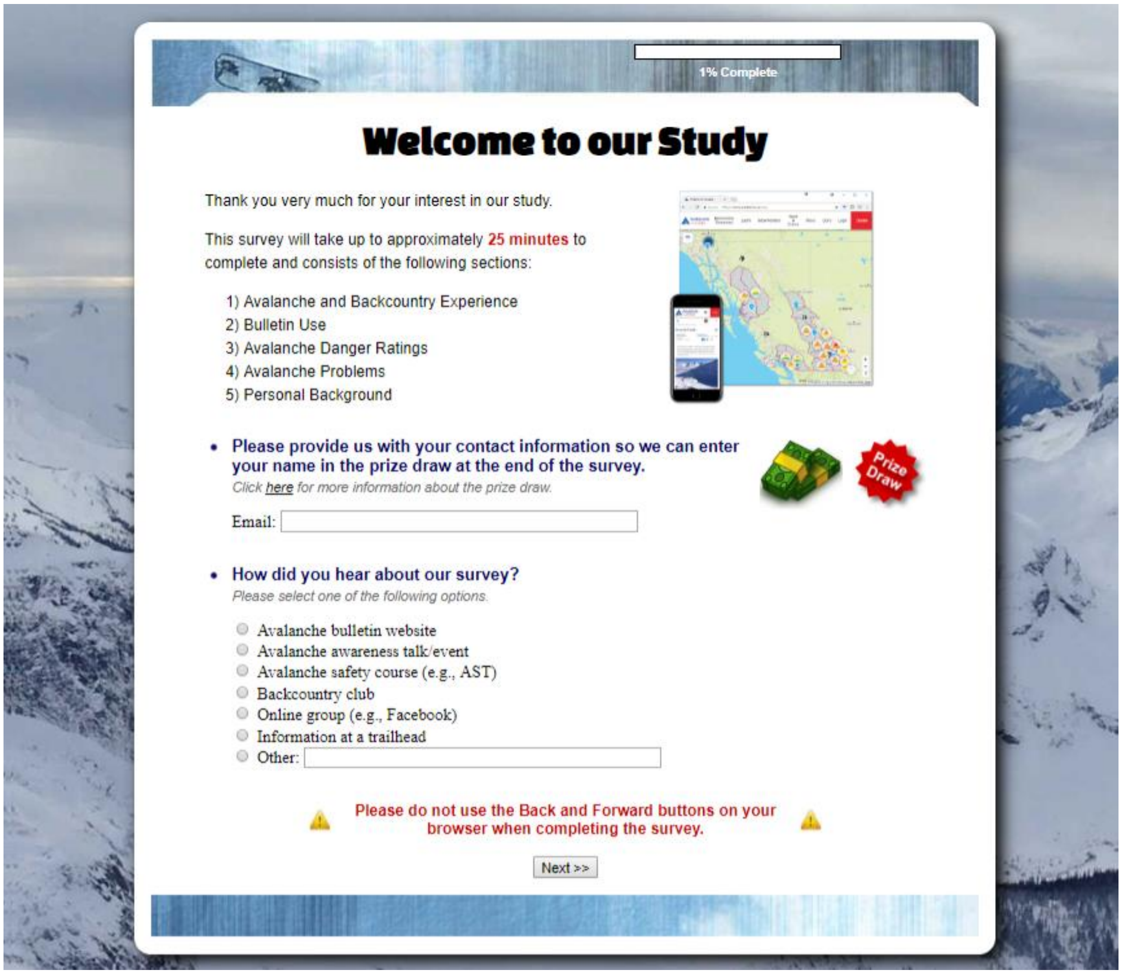


Figure A.4. **Survey introduction**

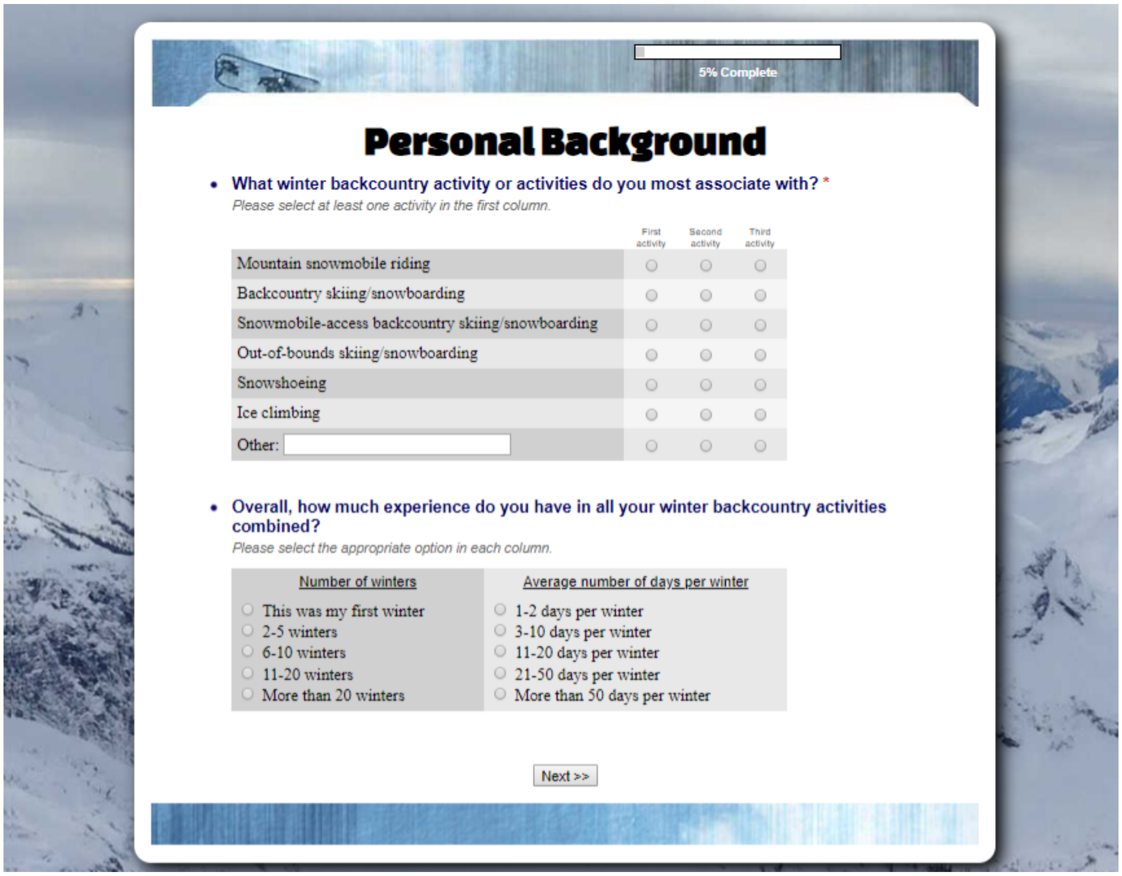
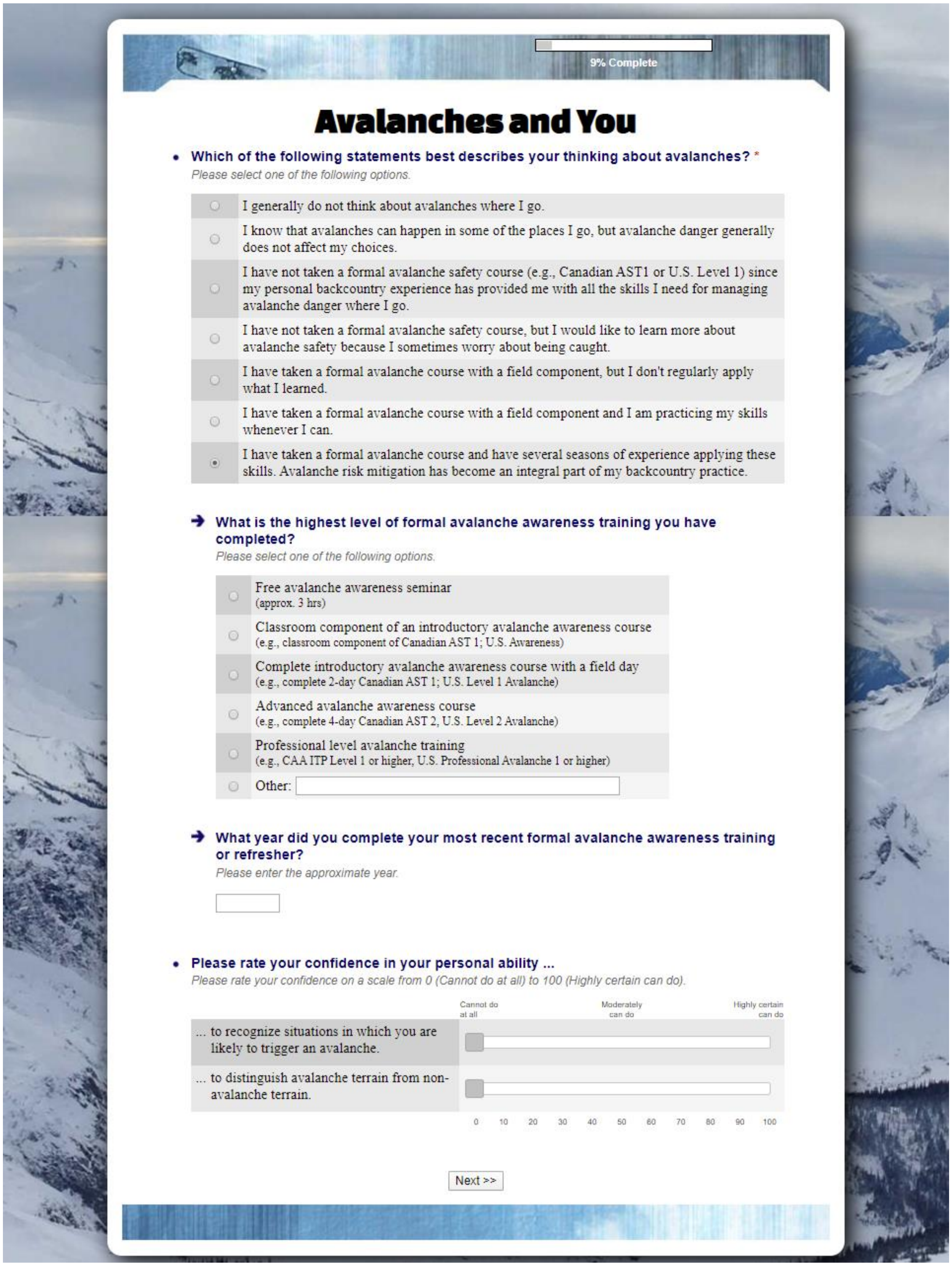


Figure A.5. **Backcountry activities, days per winter and years of experience**



9% Complete

Avalanches and You

- **Which of the following statements best describes your thinking about avalanches?** *

Please select one of the following options.

- I generally do not think about avalanches where I go.
- I know that avalanches can happen in some of the places I go, but avalanche danger generally does not affect my choices.
- I have not taken a formal avalanche safety course (e.g., Canadian AST1 or U.S. Level 1) since my personal backcountry experience has provided me with all the skills I need for managing avalanche danger where I go.
- I have not taken a formal avalanche safety course, but I would like to learn more about avalanche safety because I sometimes worry about being caught.
- I have taken a formal avalanche course with a field component, but I don't regularly apply what I learned.
- I have taken a formal avalanche course with a field component and I am practicing my skills whenever I can.
- I have taken a formal avalanche course and have several seasons of experience applying these skills. Avalanche risk mitigation has become an integral part of my backcountry practice.

→ **What is the highest level of formal avalanche awareness training you have completed?**

Please select one of the following options.

- Free avalanche awareness seminar (approx. 3 hrs)
- Classroom component of an introductory avalanche awareness course (e.g., classroom component of Canadian AST 1; U.S. Awareness)
- Complete introductory avalanche awareness course with a field day (e.g., complete 2-day Canadian AST 1; U.S. Level 1 Avalanche)
- Advanced avalanche awareness course (e.g., complete 4-day Canadian AST 2, U.S. Level 2 Avalanche)
- Professional level avalanche training (e.g., CAA ITP Level 1 or higher, U.S. Professional Avalanche 1 or higher)
- Other:

→ **What year did you complete your most recent formal avalanche awareness training or refresher?**

Please enter the approximate year.

- **Please rate your confidence in your personal ability ...**

Please rate your confidence on a scale from 0 (Cannot do at all) to 100 (Highly certain can do).

	Cannot do at all	Moderately can do	Highly certain can do
... to recognize situations in which you are likely to trigger an avalanche.			
... to distinguish avalanche terrain from non-avalanche terrain.			

0 10 20 30 40 50 60 70 80 90 100

Next >>

Figure A.6. Avalanche training and personal confidence indicators

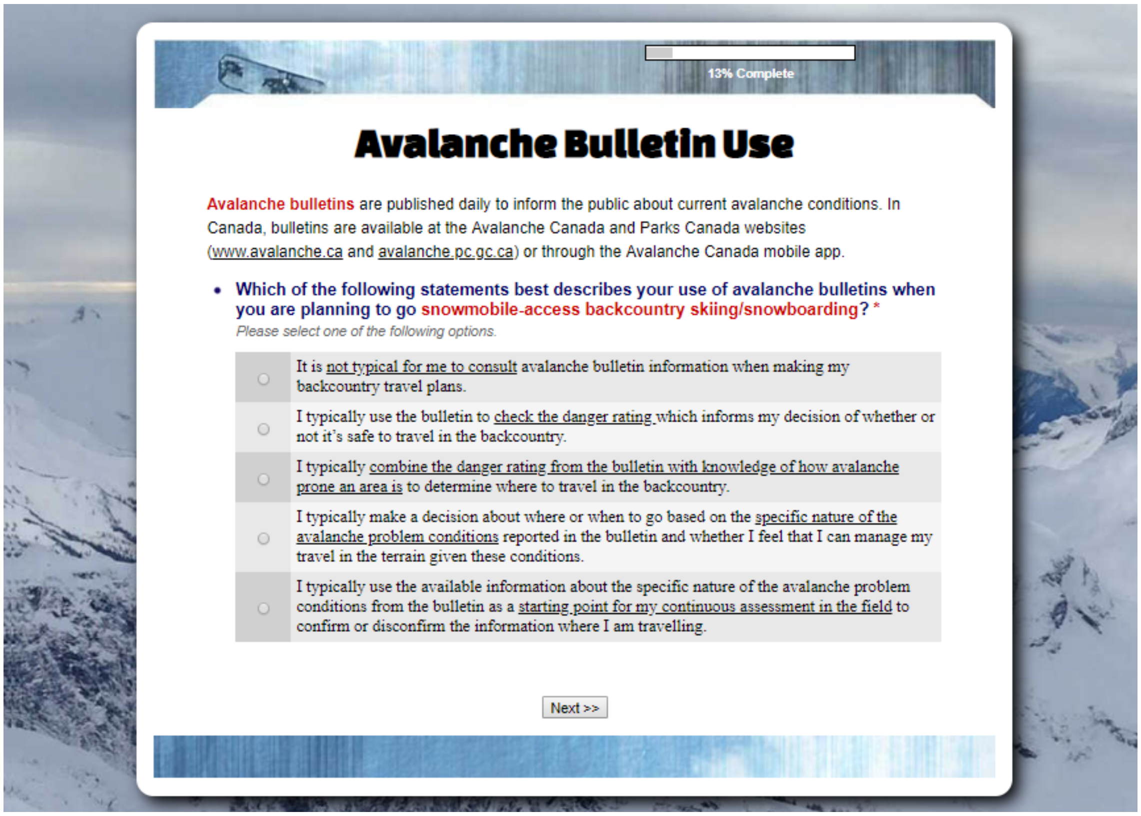


Figure A.7. **The avalanche bulletin user type question (this screen shot does not show the option for Type F)**

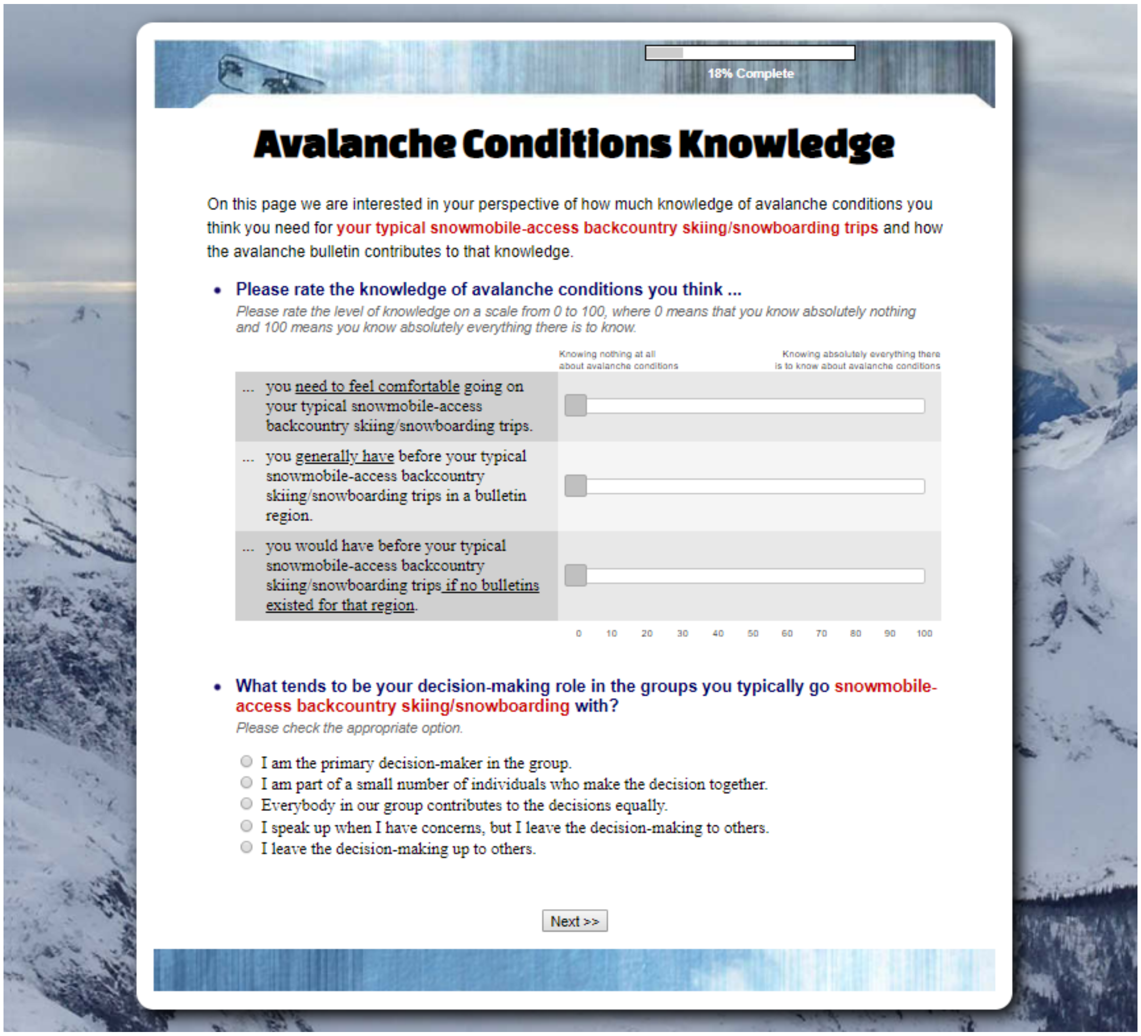


Figure A.8. **Information insufficiency questions and typical group roles, version 1, for avalanche bulletin users**

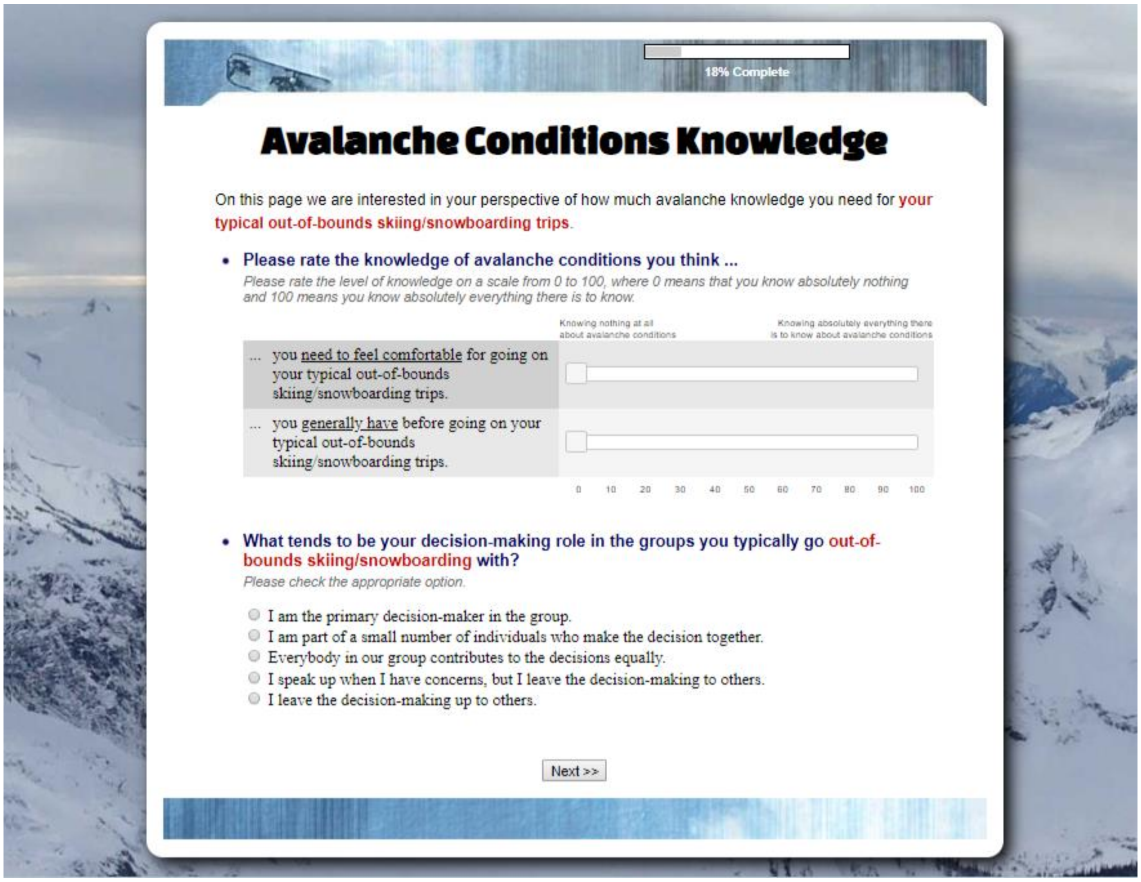


Figure A.9. **Information insufficiency questions and typical group roles, version 2, for non-avalanche bulletin users**

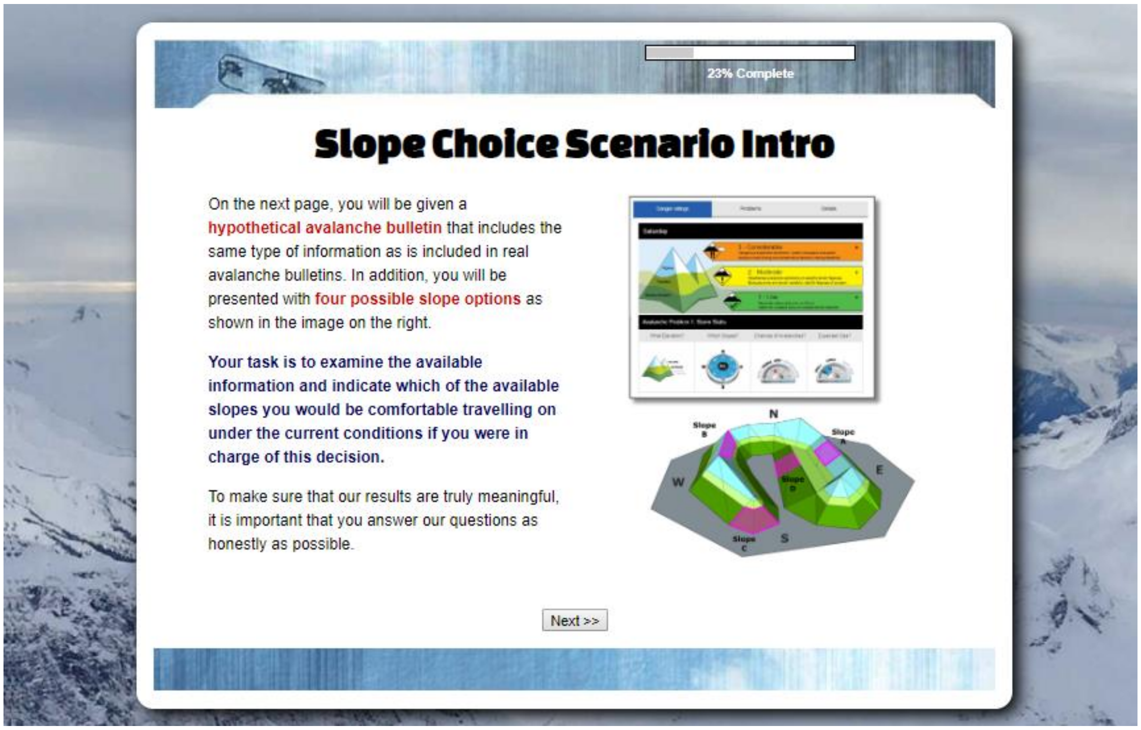


Figure A.10. Slope choice scenario introduction, version 1, for avalanche bulletin users

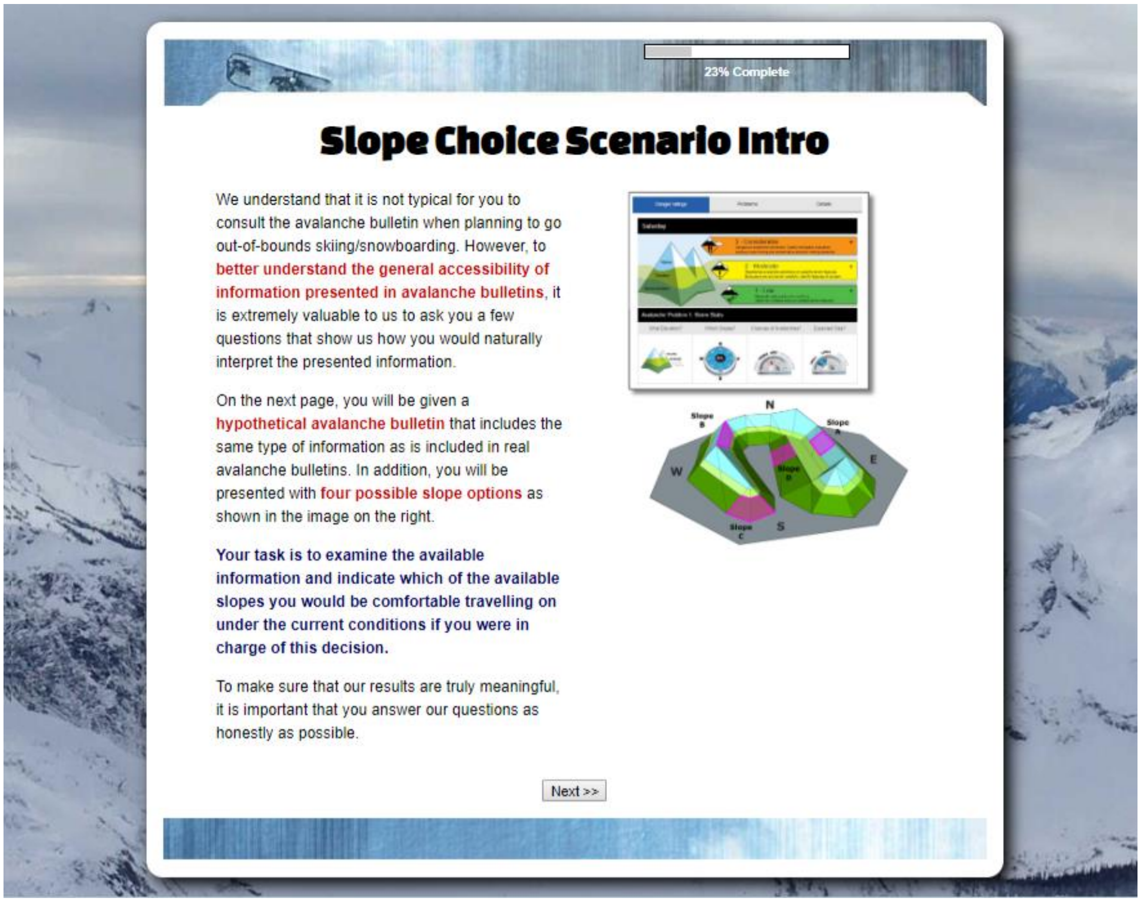


Figure A.11. Slope choice scenario introduction, version 2, for non-avalanche bulletin users

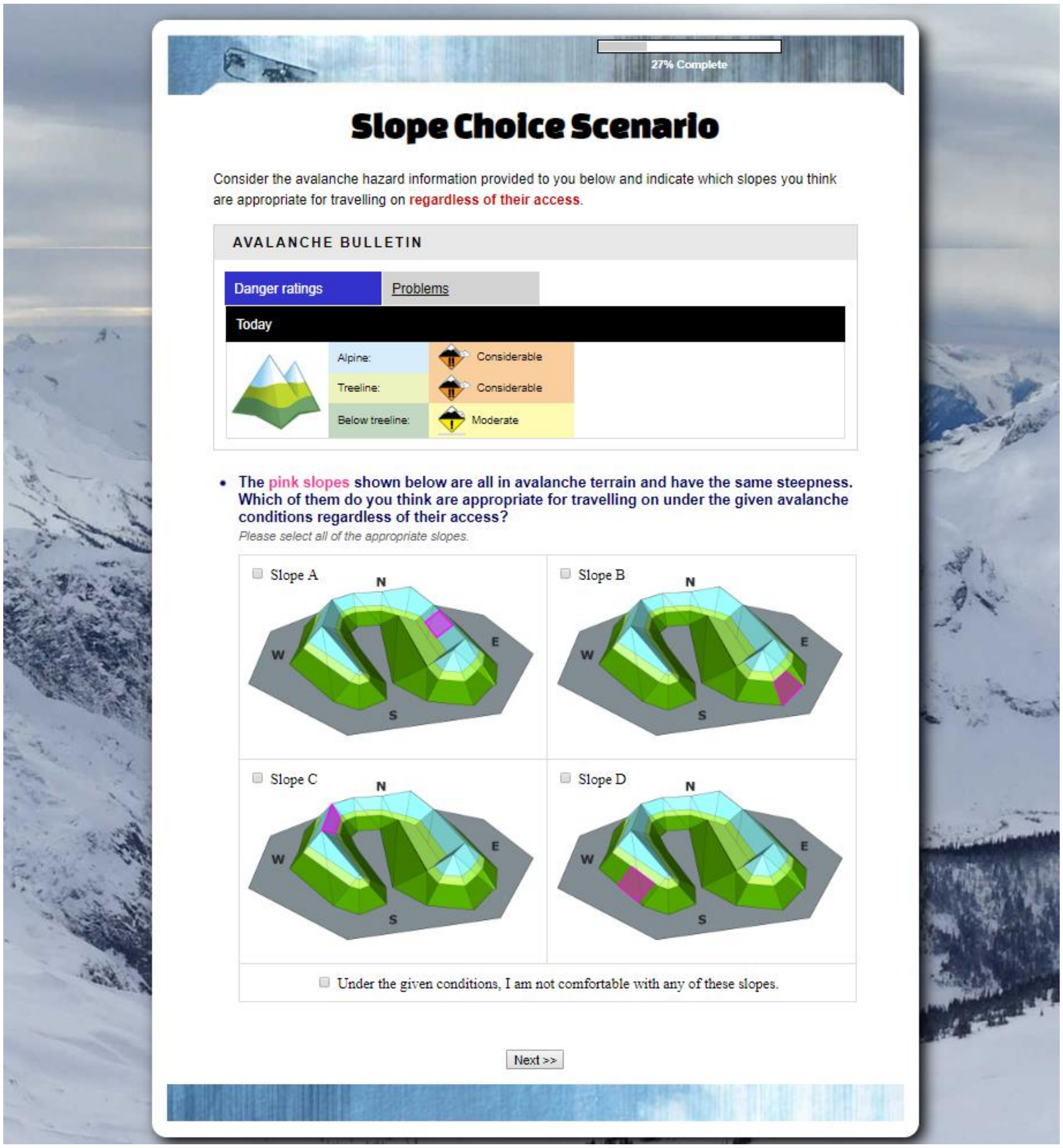


Figure A.12. Slope choice question. Note: only the danger rating information is displayed in this screenshot

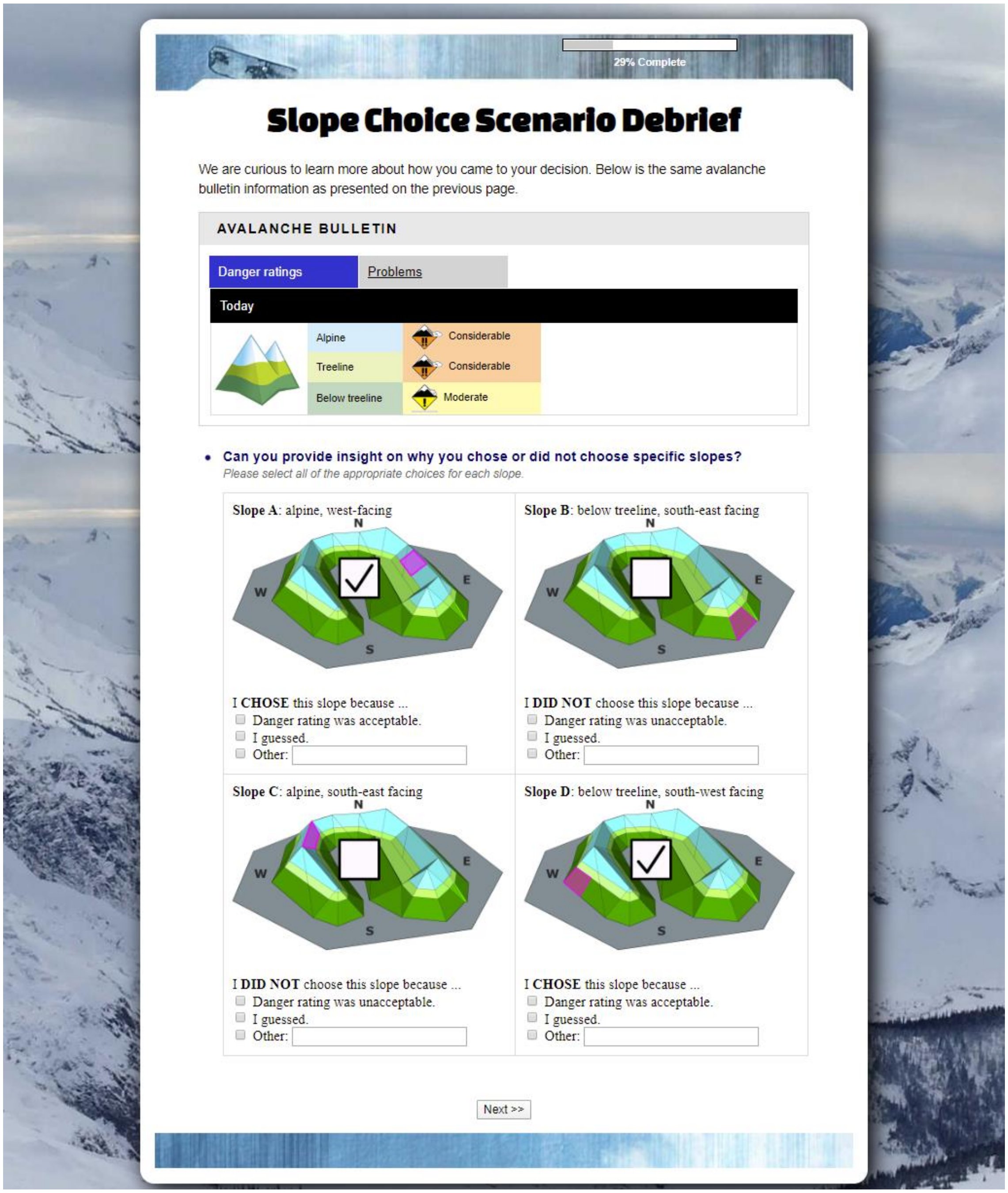
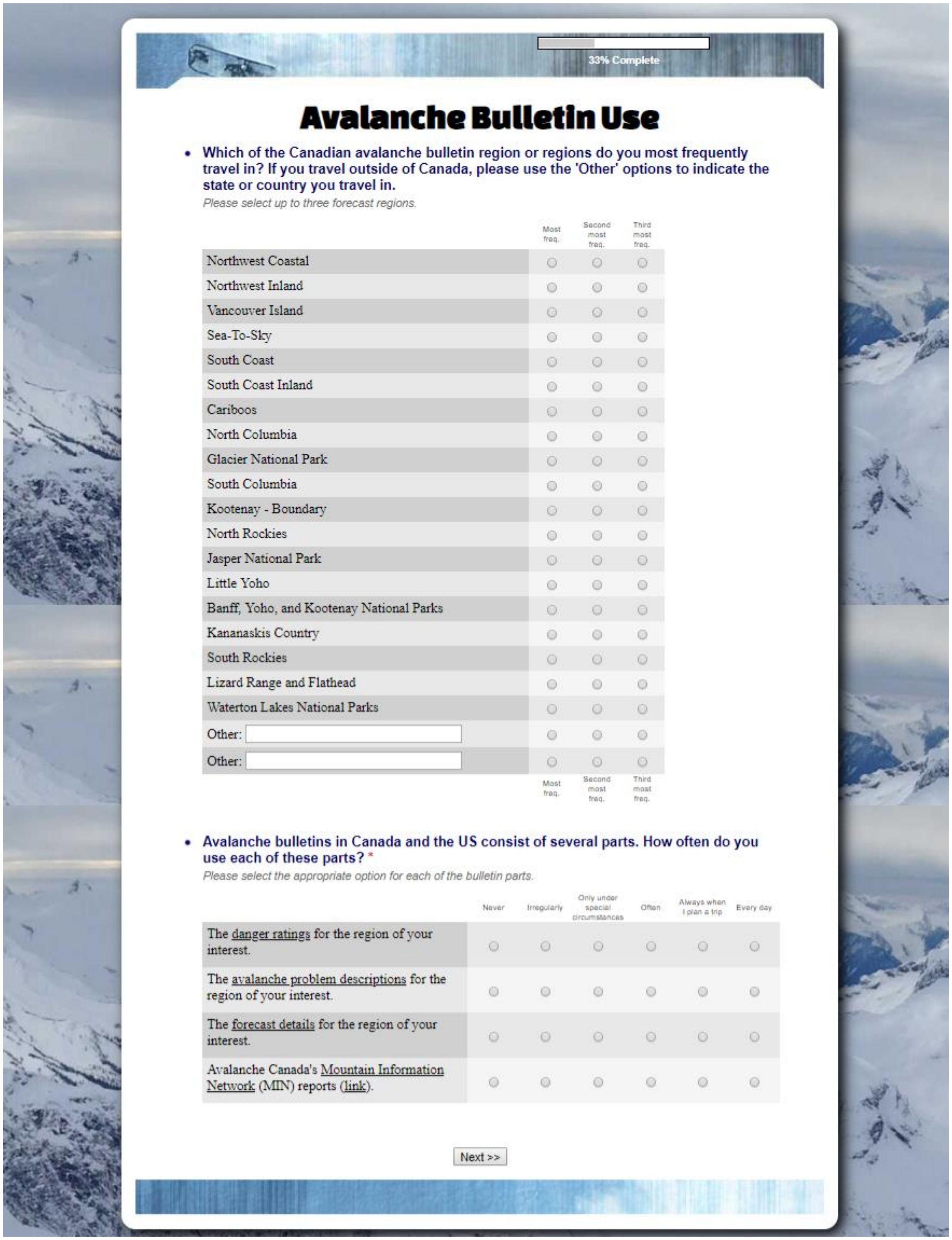


Figure A.13. Slope choice follow-up question



33% Complete

Avalanche Bulletin Use

- **Which of the Canadian avalanche bulletin region or regions do you most frequently travel in? If you travel outside of Canada, please use the 'Other' options to indicate the state or country you travel in.**

Please select up to three forecast regions.

	Most freq.	Second most freq.	Third most freq.
Northwest Coastal	○	○	○
Northwest Inland	○	○	○
Vancouver Island	○	○	○
Sea-To-Sky	○	○	○
South Coast	○	○	○
South Coast Inland	○	○	○
Cariboos	○	○	○
North Columbia	○	○	○
Glacier National Park	○	○	○
South Columbia	○	○	○
Kootenay - Boundary	○	○	○
North Rockies	○	○	○
Jasper National Park	○	○	○
Little Yoho	○	○	○
Banff, Yoho, and Kootenay National Parks	○	○	○
Kananaskis Country	○	○	○
South Rockies	○	○	○
Lizard Range and Flathead	○	○	○
Waterton Lakes National Parks	○	○	○
Other:	○	○	○
Other:	○	○	○
	Most freq.	Second most freq.	Third most freq.

- **Avalanche bulletins in Canada and the US consist of several parts. How often do you use each of these parts? ***

Please select the appropriate option for each of the bulletin parts.

	Never	Irregularly	Only under special circumstances	Often	Always when I plan a trip	Every day
The danger ratings for the region of your interest.	○	○	○	○	○	○
The avalanche problem descriptions for the region of your interest.	○	○	○	○	○	○
The forecast details for the region of your interest.	○	○	○	○	○	○
Avalanche Canada's Mountain Information Network (MIN) reports (link).	○	○	○	○	○	○

Next >>

Figure A.14. Backcountry regions of use

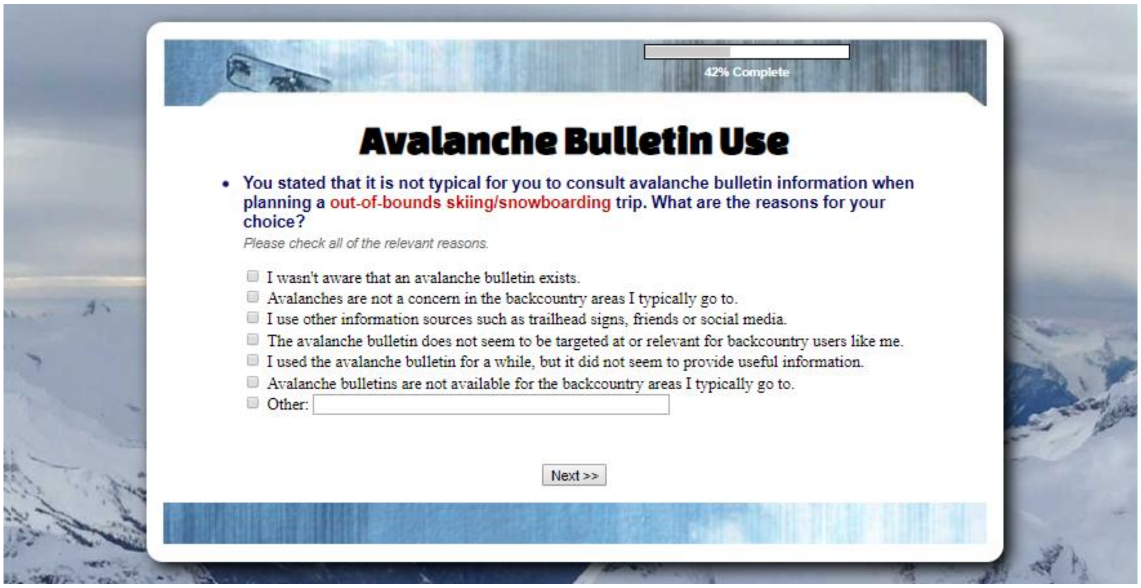


Figure A.15. Reasons for not using the avalanche bulletin (only non-avalanche bulletin users saw this question)

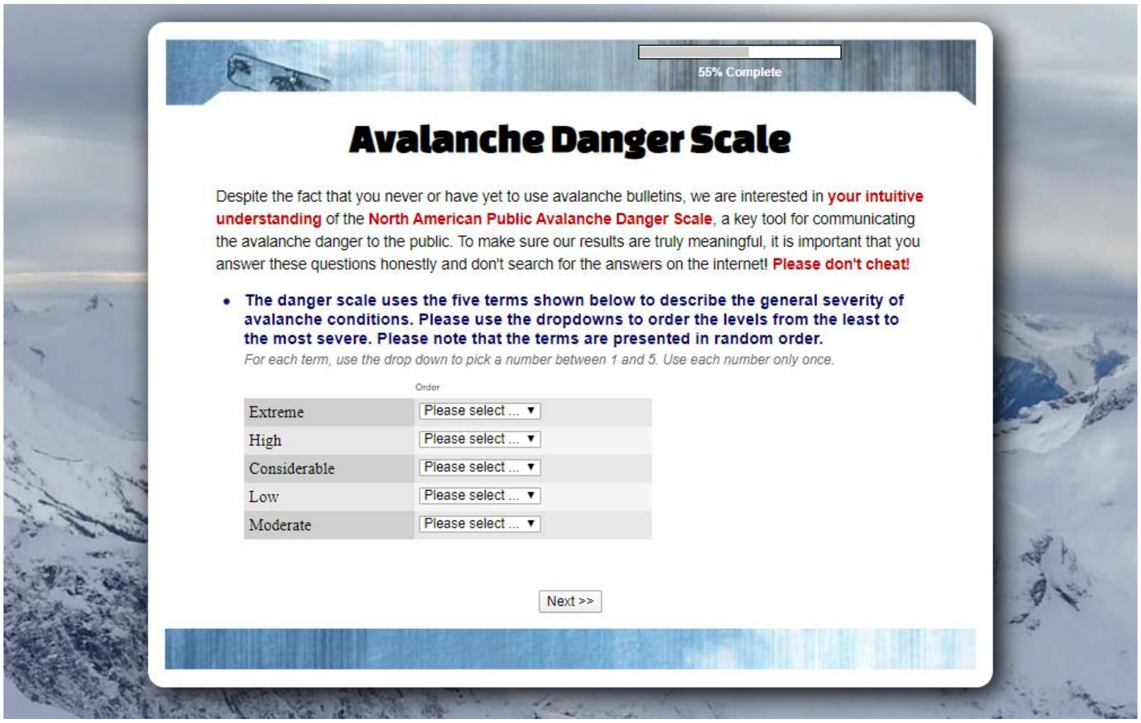


Figure A.16. Danger rating order question (only non-avalanche bulletin users saw this question)

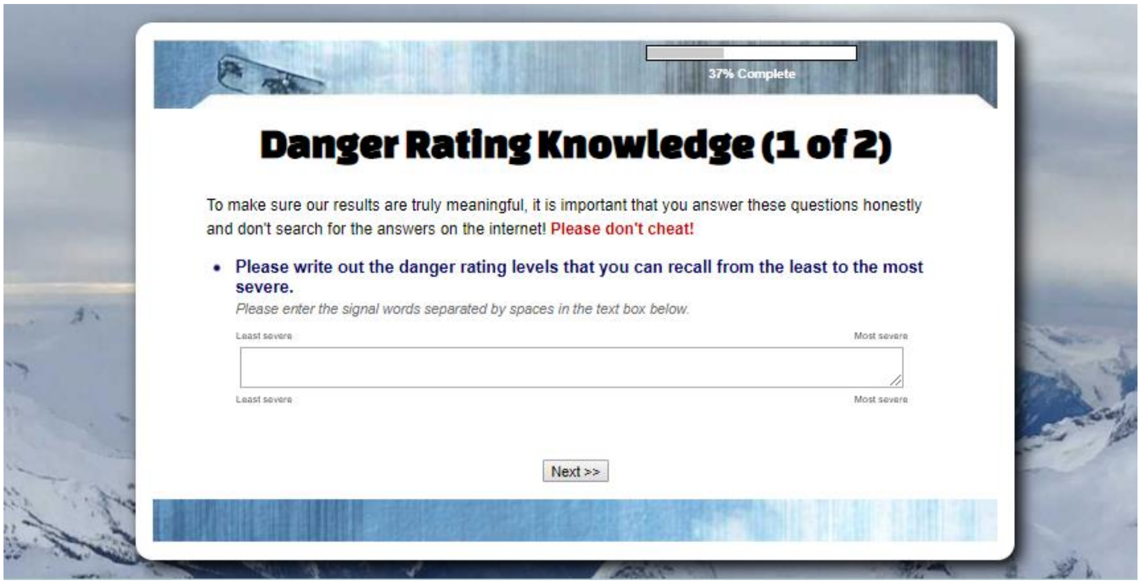


Figure A.17. Danger rating recall question

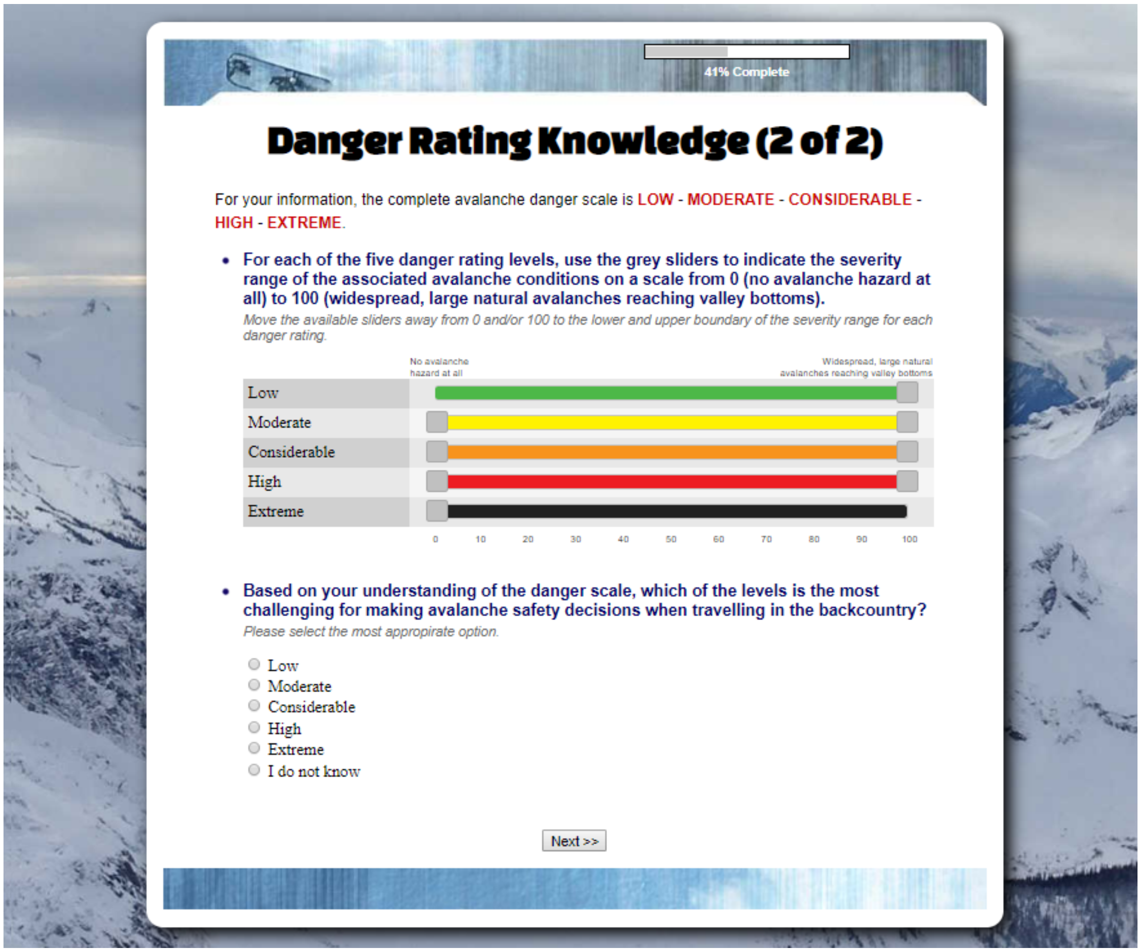


Figure A.18. Danger rating severity perception question

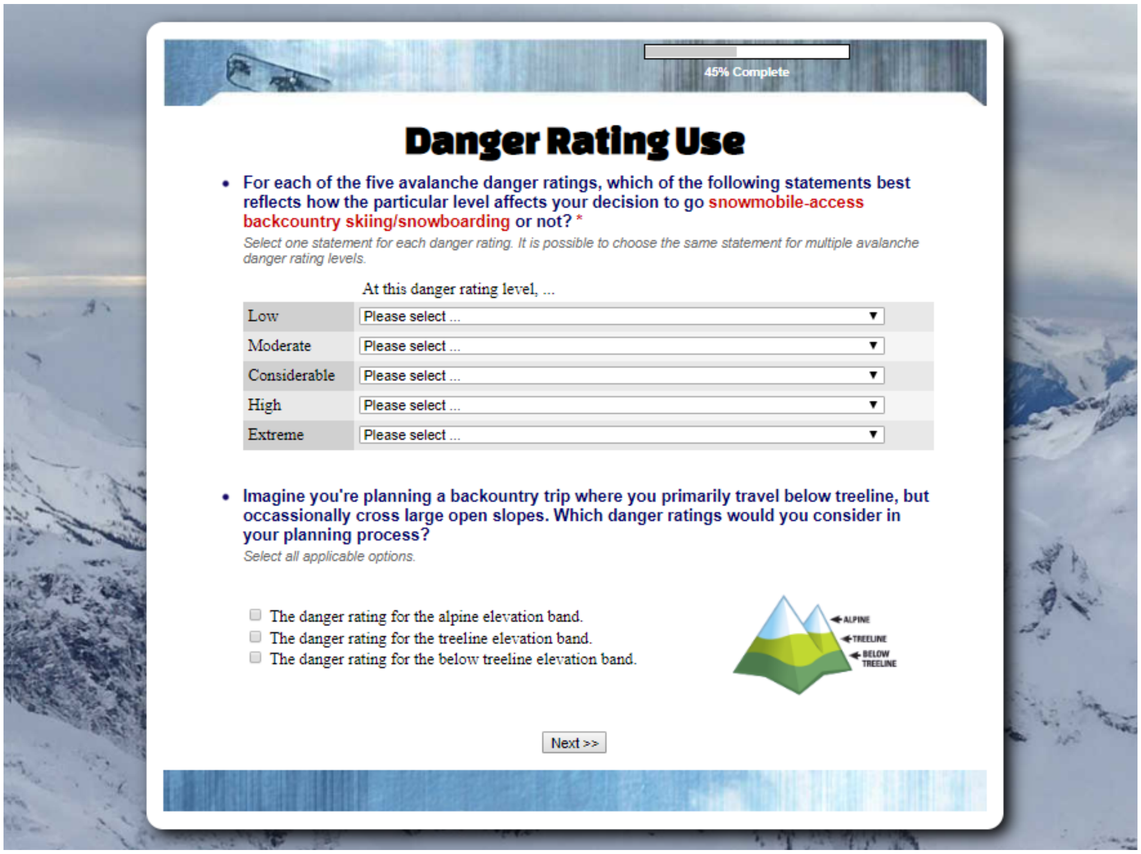


Figure A.19. **Danger rating: 1st question- danger rating decision question 2nd question- danger rating conditions management question**

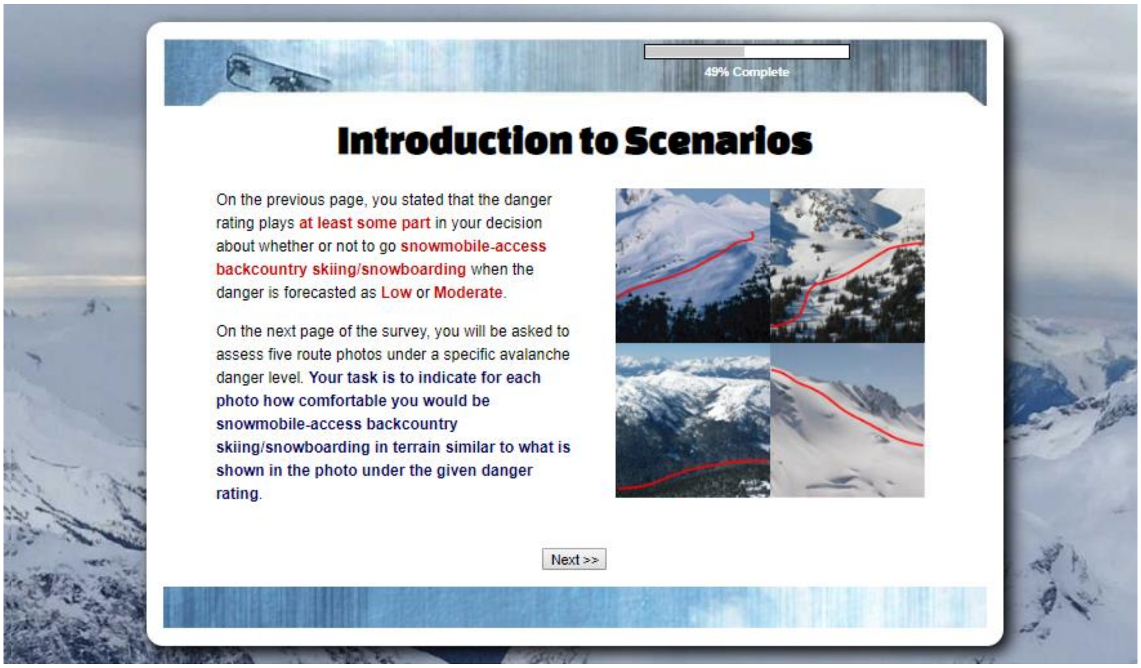


Figure A.20. **Introduction to the danger rating application question**

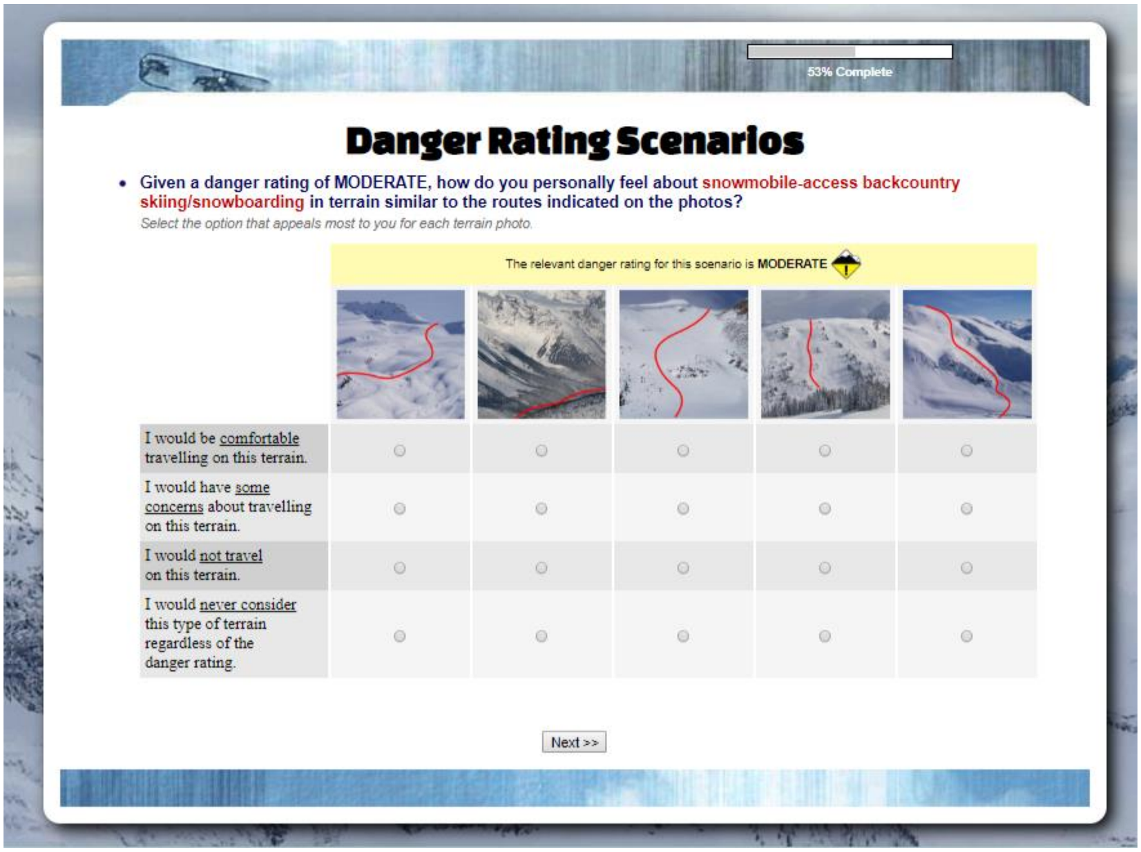
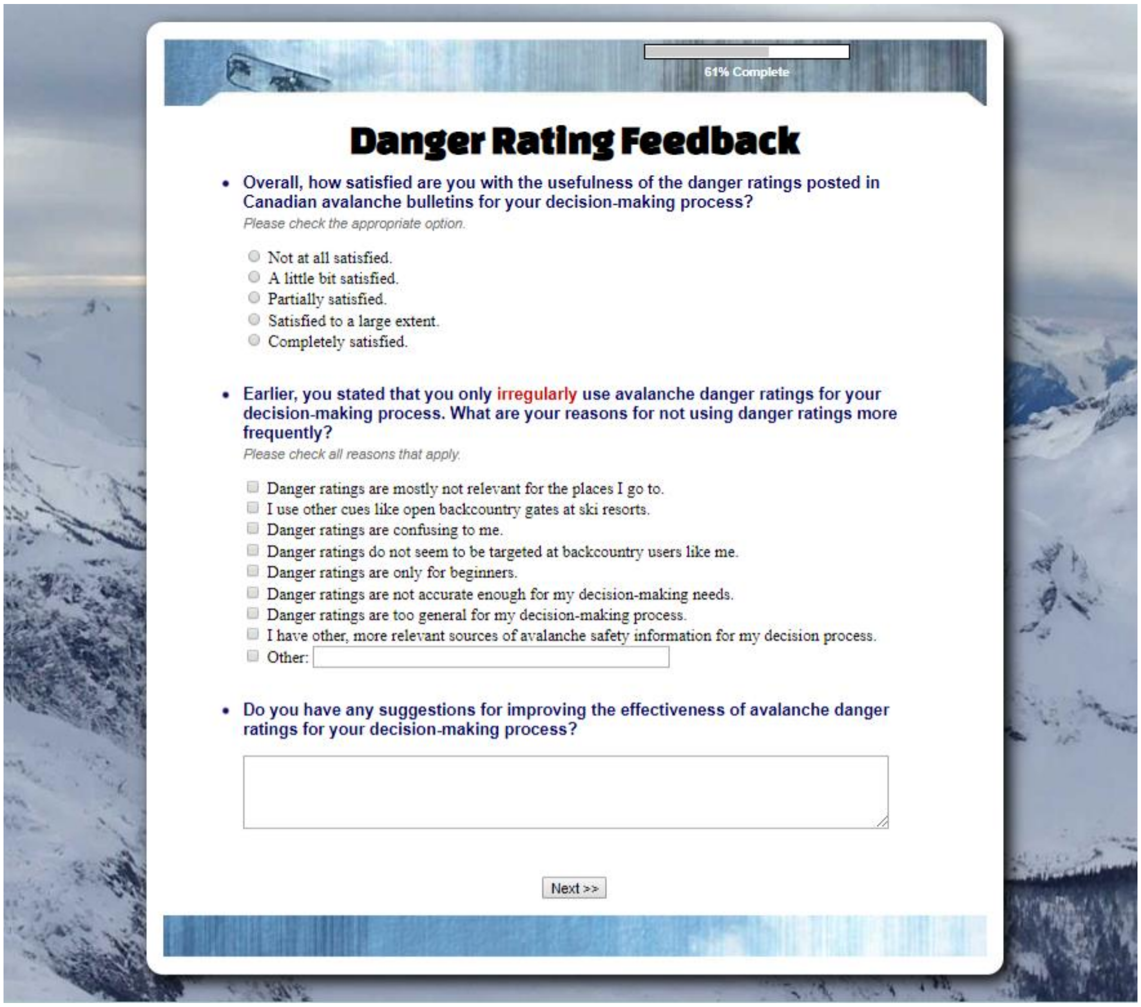


Figure A.21. Danger rating application question


61% Complete

Danger Rating Feedback

- **Overall, how satisfied are you with the usefulness of the danger ratings posted in Canadian avalanche bulletins for your decision-making process?**
  Please check the appropriate option.
  - Not at all satisfied.
  - A little bit satisfied.
  - Partially satisfied.
  - Satisfied to a large extent.
  - Completely satisfied.

- **Earlier, you stated that you only irregularly use avalanche danger ratings for your decision-making process. What are your reasons for not using danger ratings more frequently?**
  Please check all reasons that apply.
  - Danger ratings are mostly not relevant for the places I go to.
  - I use other cues like open backcountry gates at ski resorts.
  - Danger ratings are confusing to me.
  - Danger ratings do not seem to be targeted at backcountry users like me.
  - Danger ratings are only for beginners.
  - Danger ratings are not accurate enough for my decision-making needs.
  - Danger ratings are too general for my decision-making process.
  - I have other, more relevant sources of avalanche safety information for my decision process.
  - Other:

- **Do you have any suggestions for improving the effectiveness of avalanche danger ratings for your decision-making process?**

Next >>

Figure A.22. Danger rating feedback

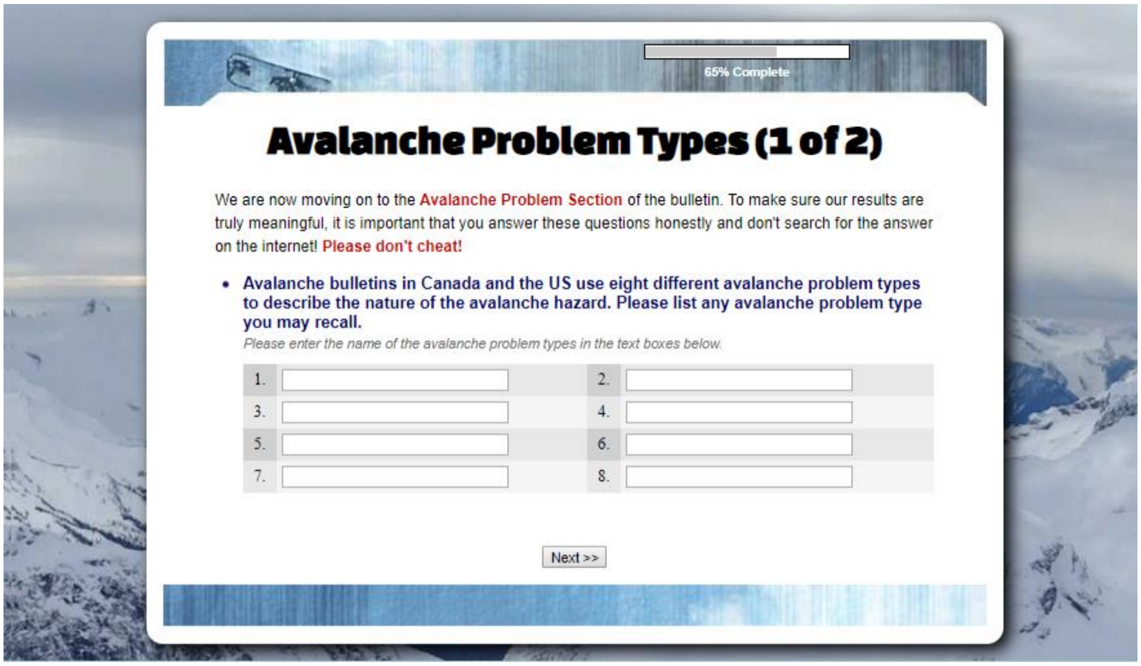


Figure A.23. Avalanche problem recall question (note: US participants were presented with nine free-text boxes)

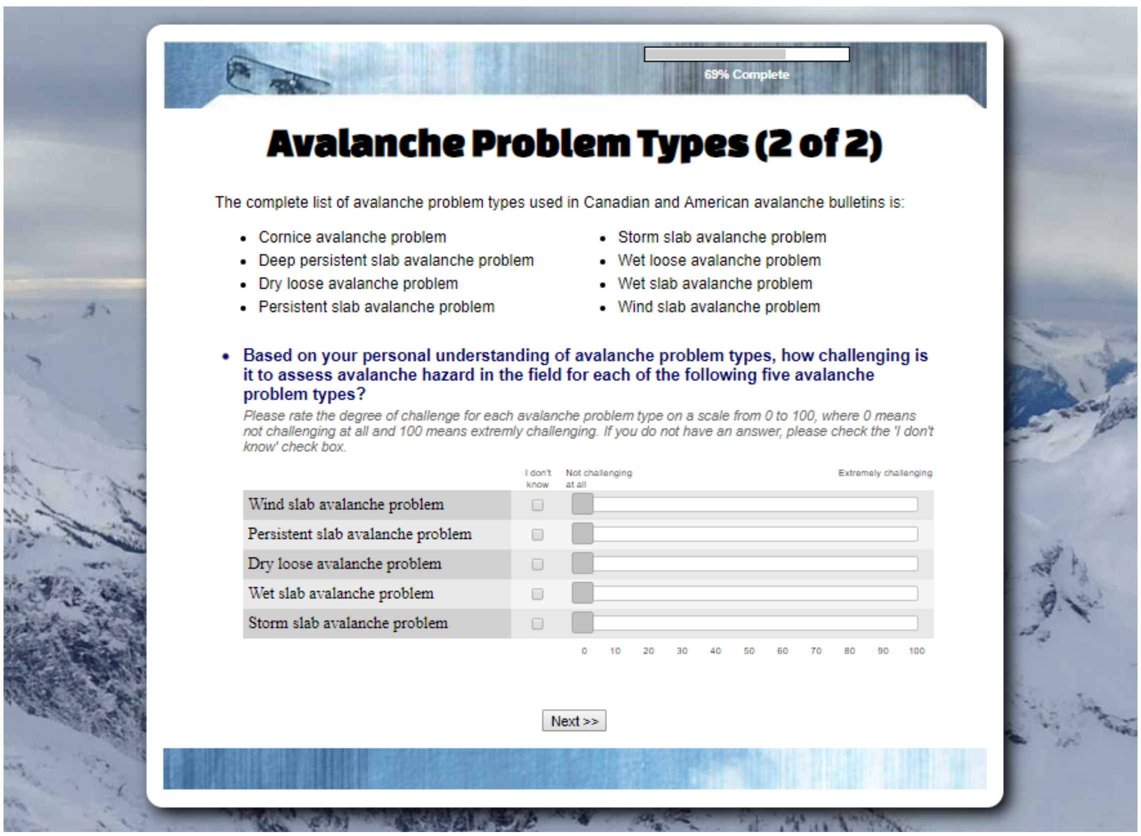


Figure A.24. Avalanche problem perception question

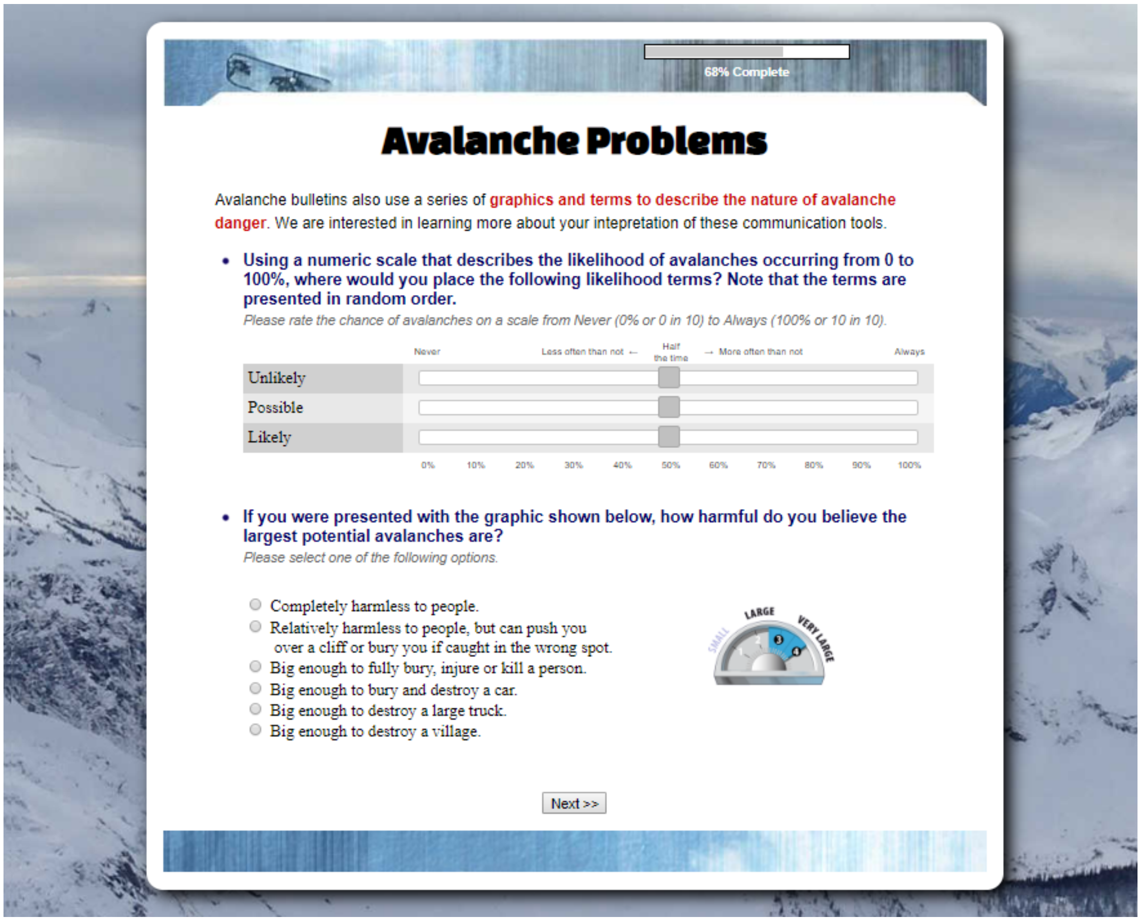


Figure A.25. Avalanche problem components (version 1): 1st question- likelihood indicator perception, 2nd question- size icon question. Note: half the sample were shown the size icon question, and half were shown the aspect icon question in the following figure

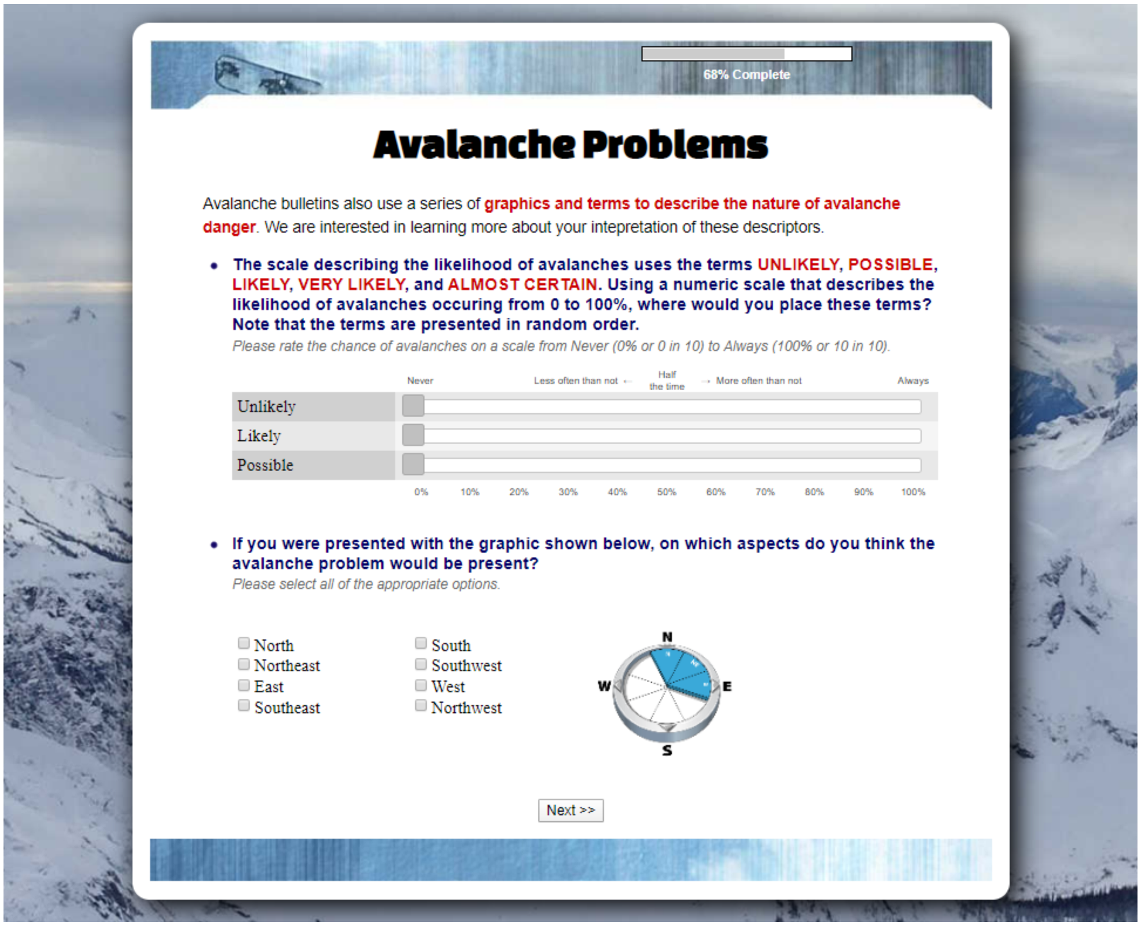


Figure A.26. **Avalanche problem components (version 2): 1st question- likelihood indicator perception, 2nd question- aspect icon question. Note: half the sample were shown the aspect icon question, and half were shown the size icon question in the previous figure**

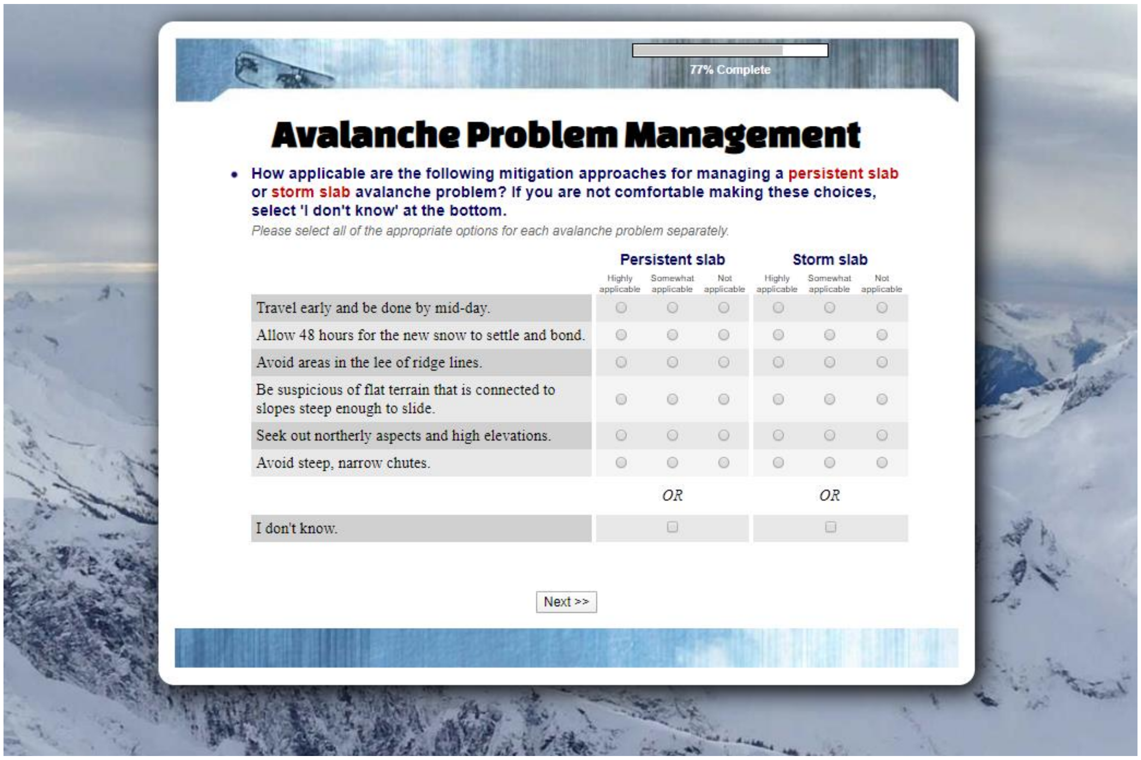


Figure A.27. Avalanche problem mitigation question

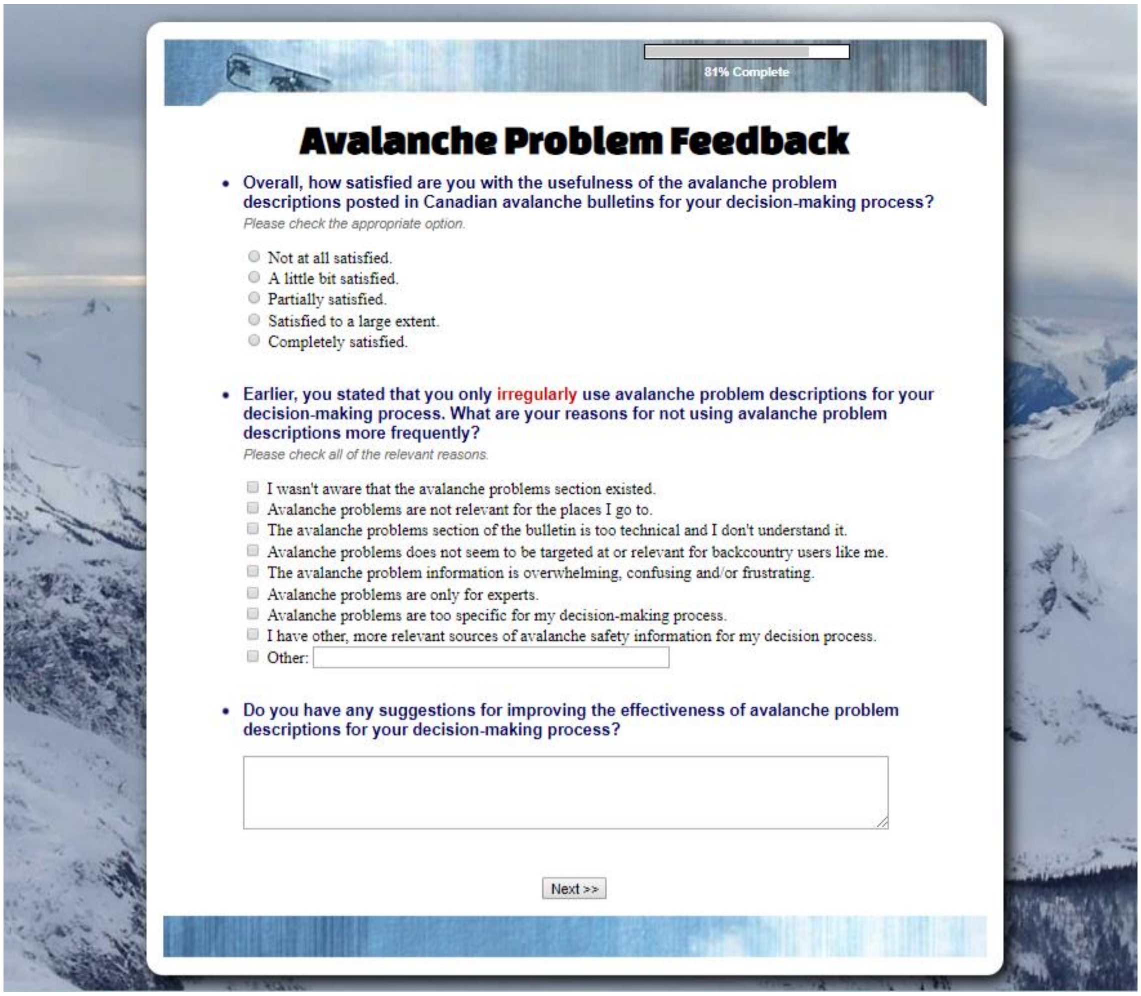


Figure A.28. Avalanche problem feedback question

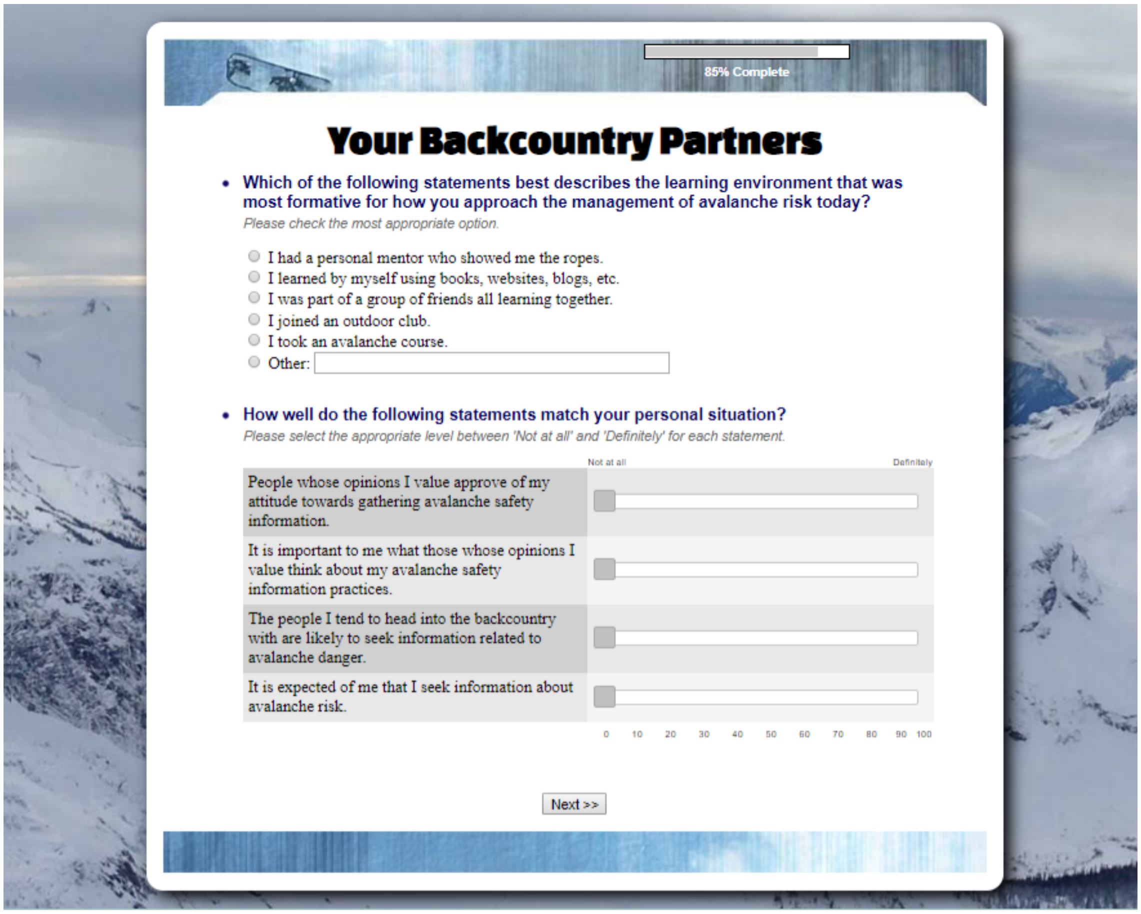


Figure A.29. Others in the backcountry: 1st question- most meaningful learning source, 2nd question- informational subjective norms questions

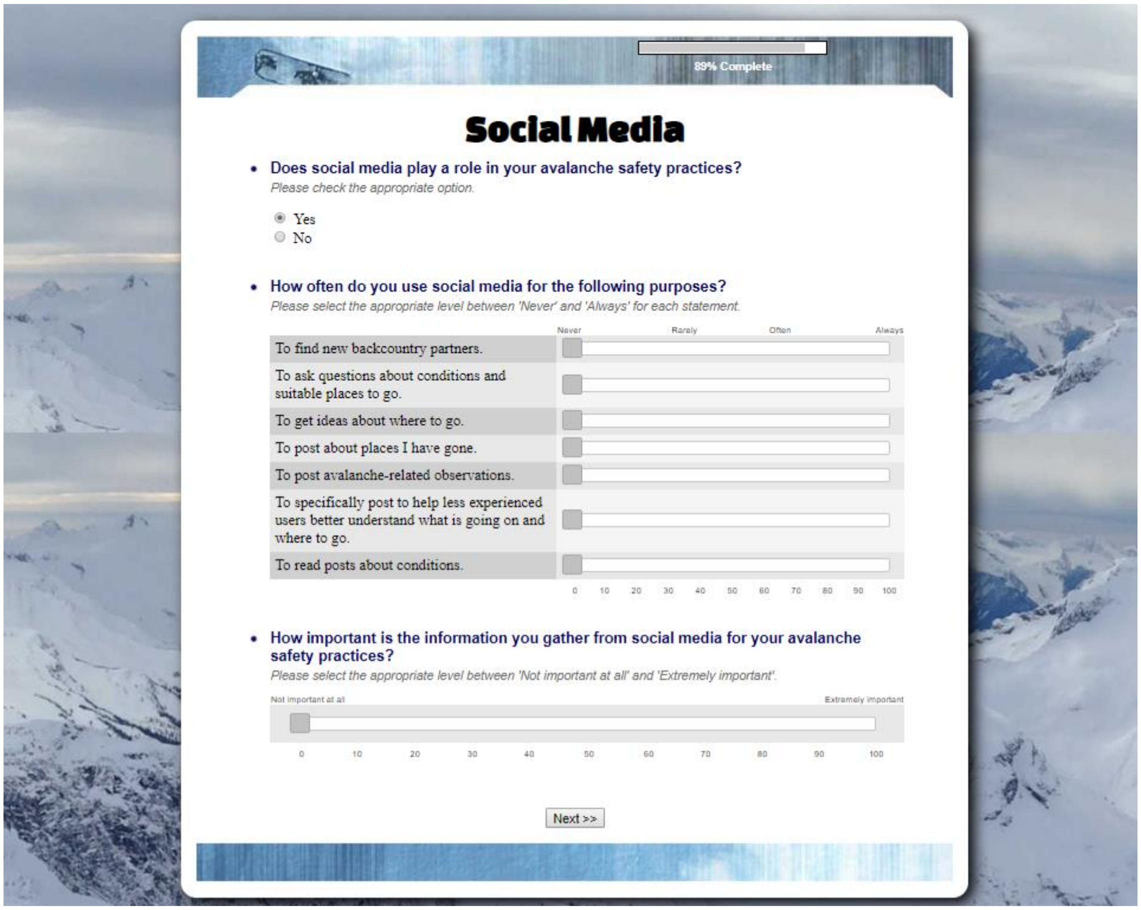
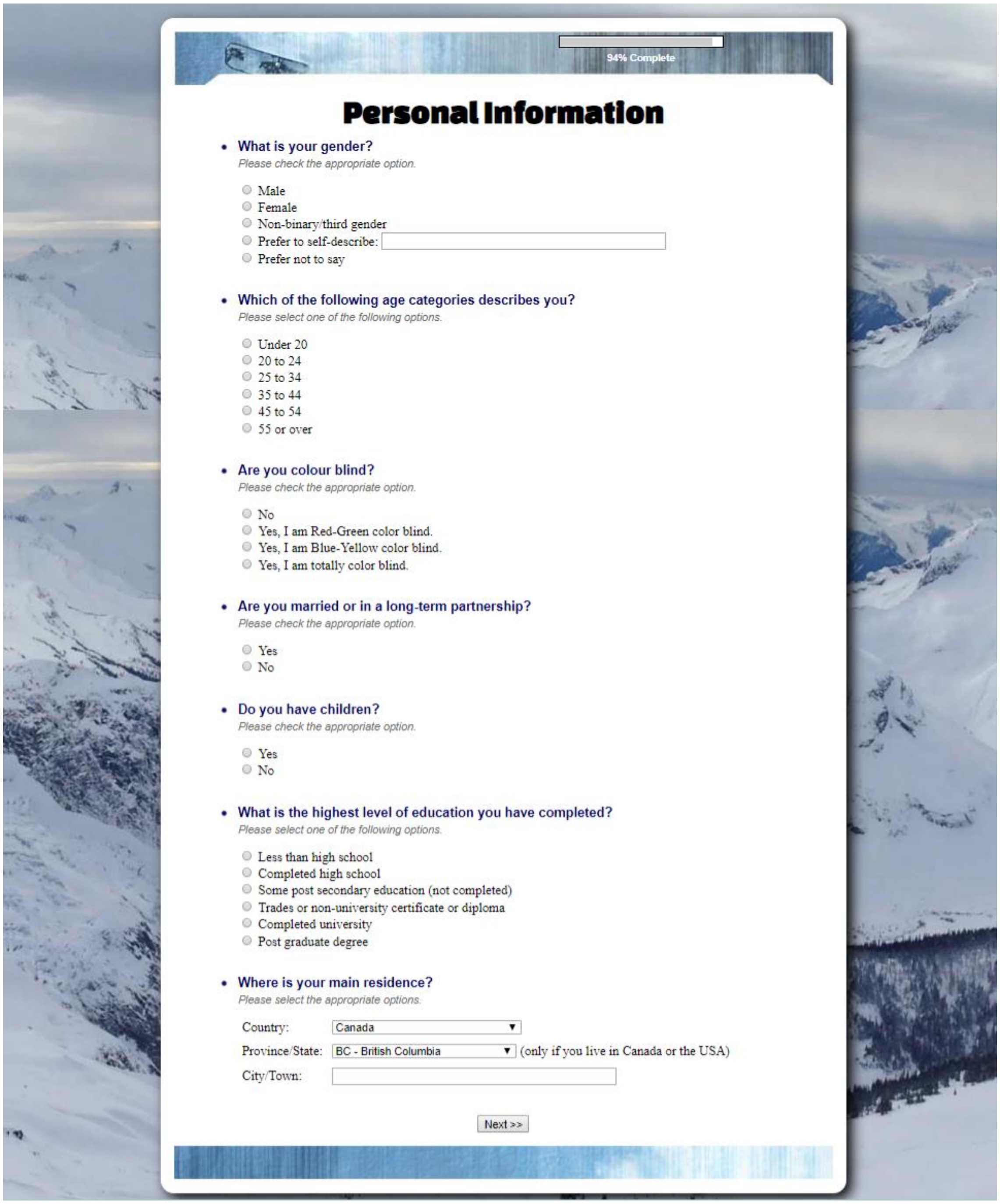


Figure A.30. Social media questions



94% Complete

Personal Information

- **What is your gender?**
  Please check the appropriate option.
  - Male
  - Female
  - Non-binary/third gender
  - Prefer to self-describe:
  - Prefer not to say

- **Which of the following age categories describes you?**
  Please select one of the following options.
  - Under 20
  - 20 to 24
  - 25 to 34
  - 35 to 44
  - 45 to 54
  - 55 or over

- **Are you colour blind?**
  Please check the appropriate option.
  - No
  - Yes, I am Red-Green color blind.
  - Yes, I am Blue-Yellow color blind.
  - Yes, I am totally color blind.

- **Are you married or in a long-term partnership?**
  Please check the appropriate option.
  - Yes
  - No

- **Do you have children?**
  Please check the appropriate option.
  - Yes
  - No

- **What is the highest level of education you have completed?**
  Please select one of the following options.
  - Less than high school
  - Completed high school
  - Some post secondary education (not completed)
  - Trades or non-university certificate or diploma
  - Completed university
  - Post graduate degree

- **Where is your main residence?**
  Please select the appropriate options.

Country: Canada
Province/State: BC - British Columbia (only if you live in Canada or the USA)
City/Town:

Next >>

Figure A.31. Demographic questions

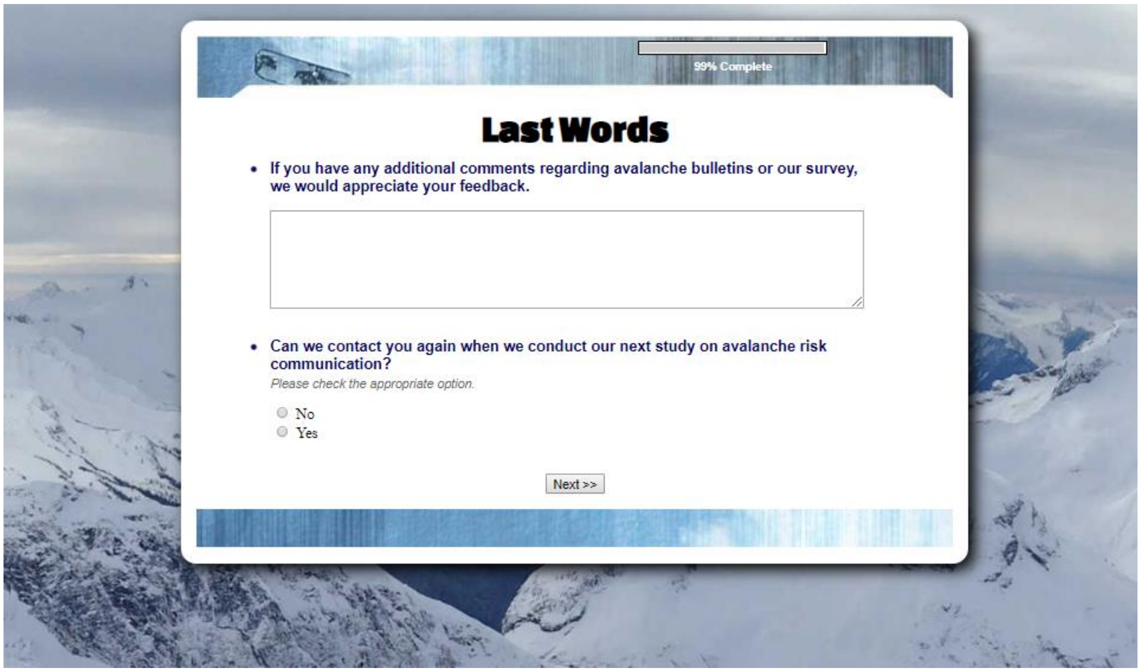


Figure A.32. Final feedback

Appendix B. Recruitment Materials & Promotion Efforts

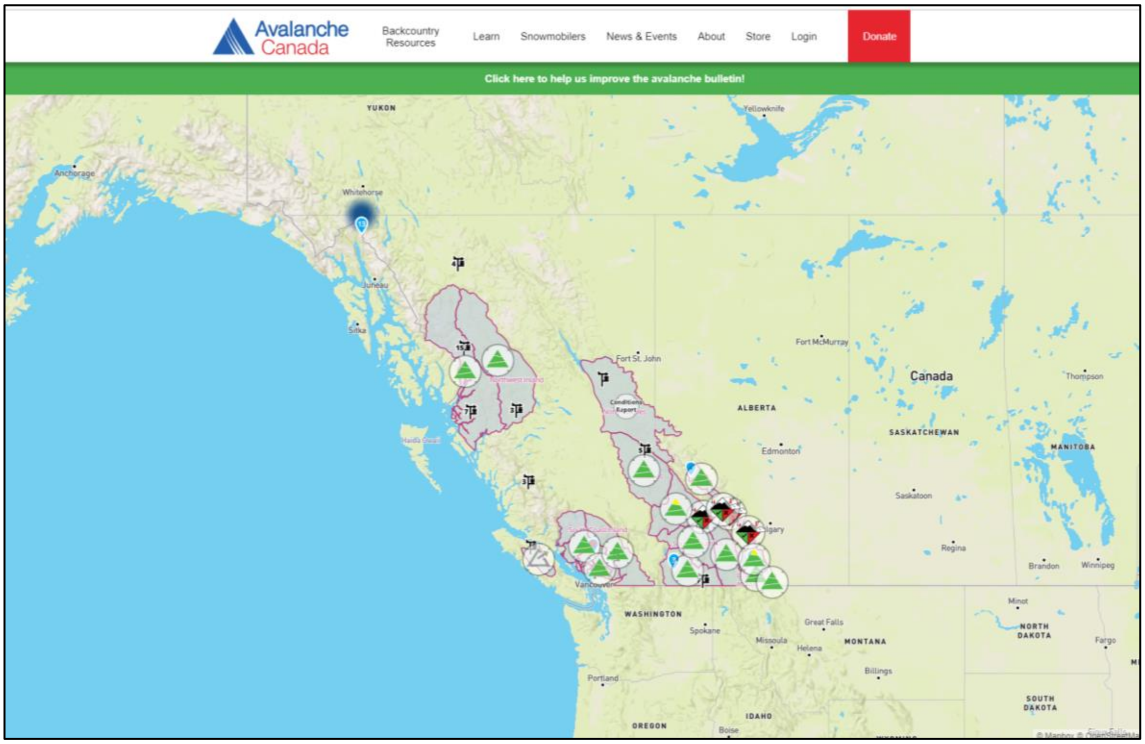


Figure B.1. Clickable banner link to the survey on Avalanche Canada's avalanche bulletin website

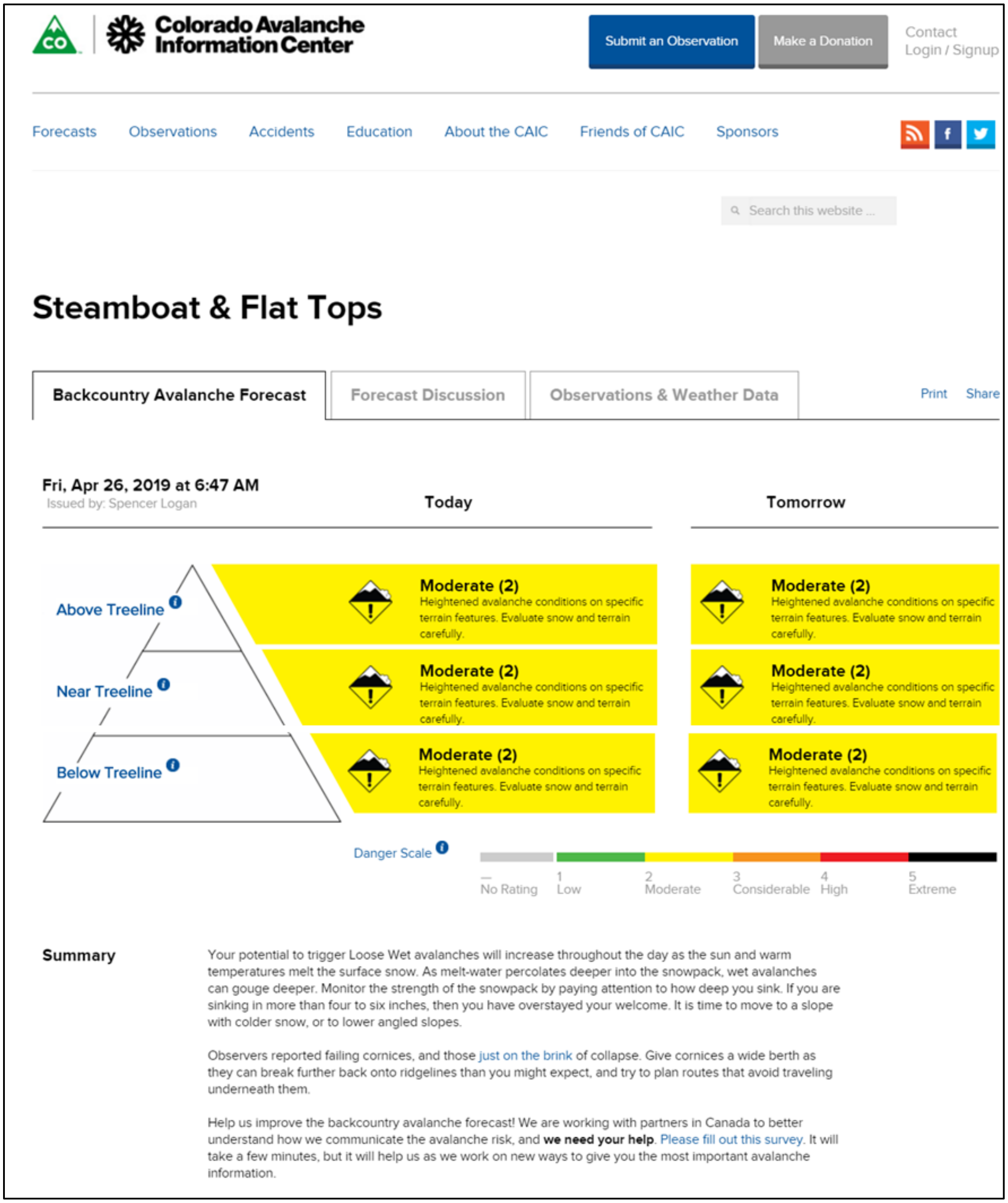


Figure B.2. Clickable link to the survey at the bottom of the avalanche bulletin provided by Colorado Avalanche Information Center

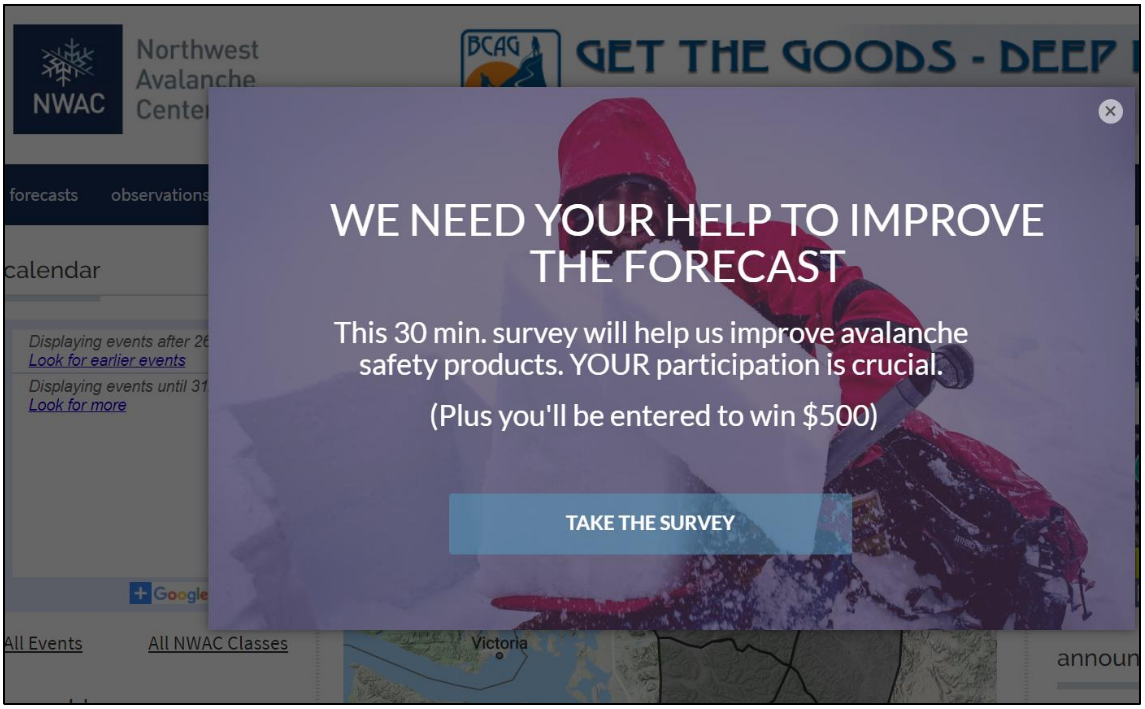


Figure B.3. **Clickable link to the survey on the Northwest Avalanche Center's avalanche bulletin website (Washington & Oregon)**

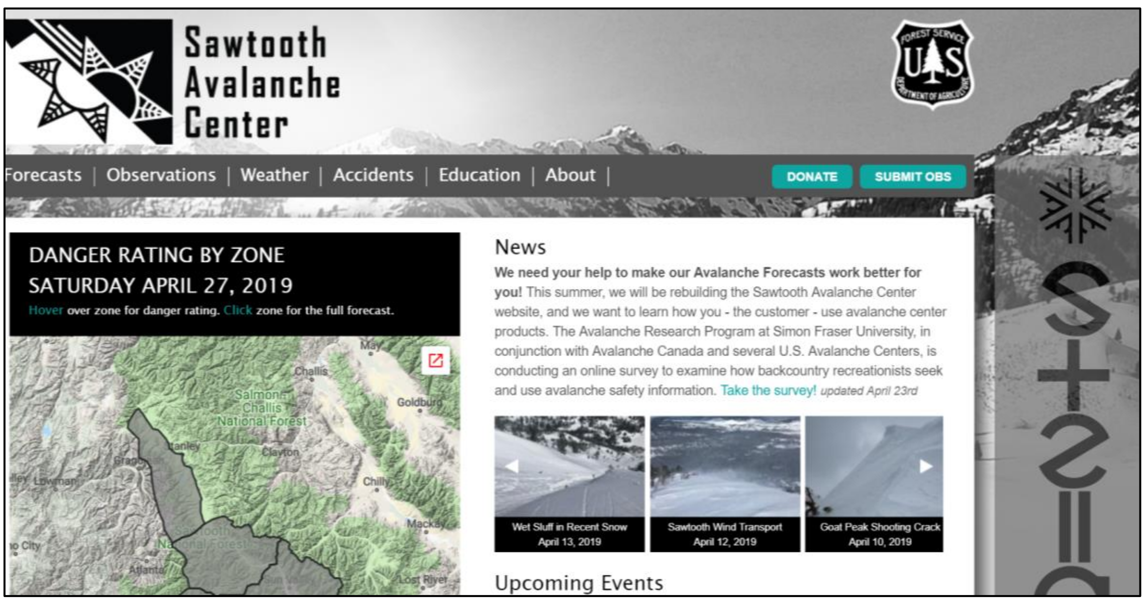


Figure B.4. **Clickable link to the survey on the Sawtooth Avalanche Center's avalanche bulletin website (Idaho)**

Figure B.5. **Recruitment slide used in smowmobiling avalanche awareness courses before survey sampling began**

Figure B.6. **Recruitment slide used in avalanche awareness courses for backcountry skiing, snowshoeing and ice climbing before survey sampling began**

Figure B.7. **Recruitment postcard for snowmobilers provided to snowmobiling avalanche awareness course providers and snowmobiling clubs (front and back)**

Figure B.8. **Recruitment postcard provided to Mountain Equipment Co-op stores in Canada (front and back)**

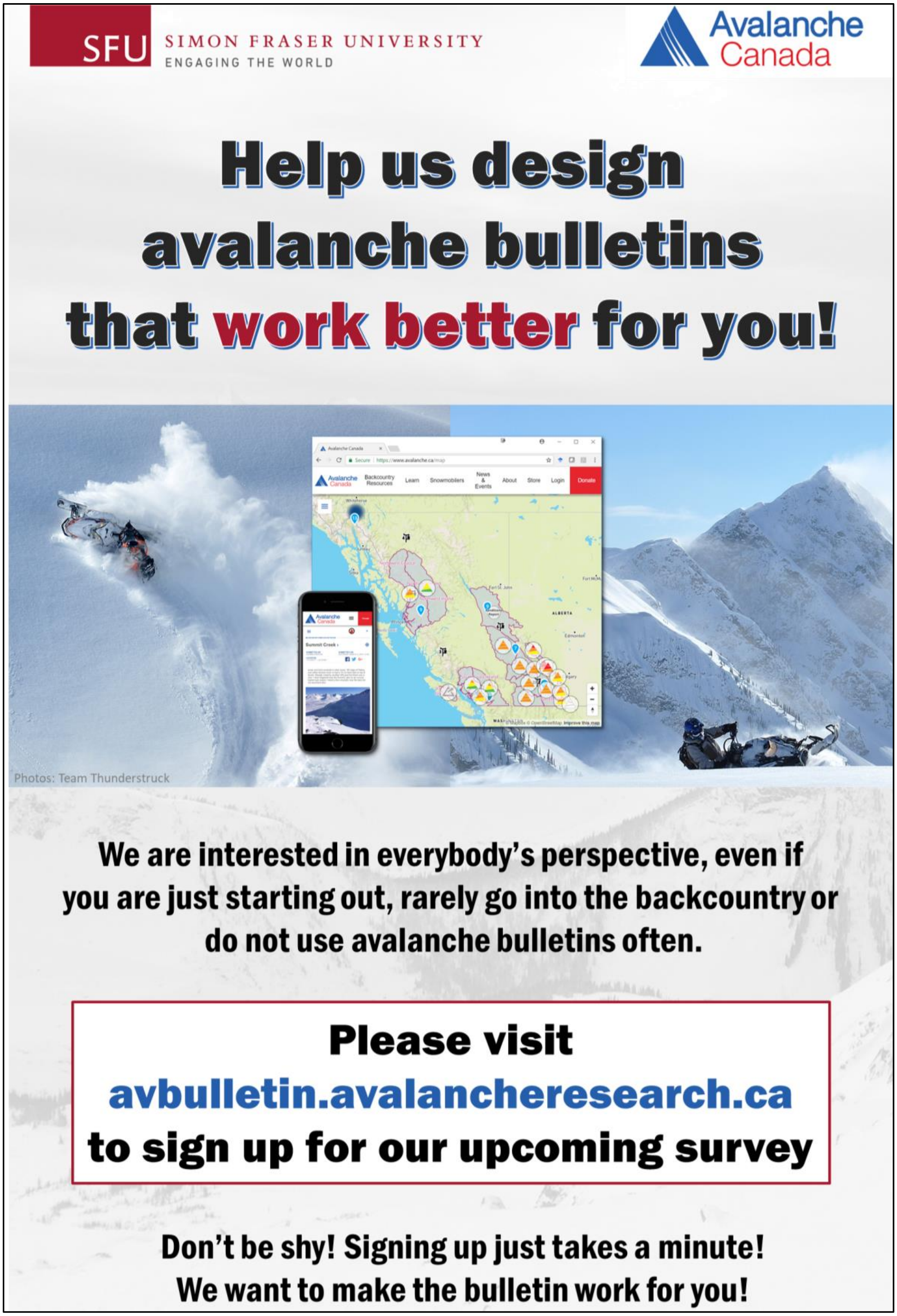


Figure B.9. Recruitment poster for snowmobilers

Appendix C. Correlation Plots

This appendix includes correlation plots showing how sufficiency grades on each of the different avalanche bulletin literacy questions were related to each other. Bulletin user types included: Type C, Type D and Type E.

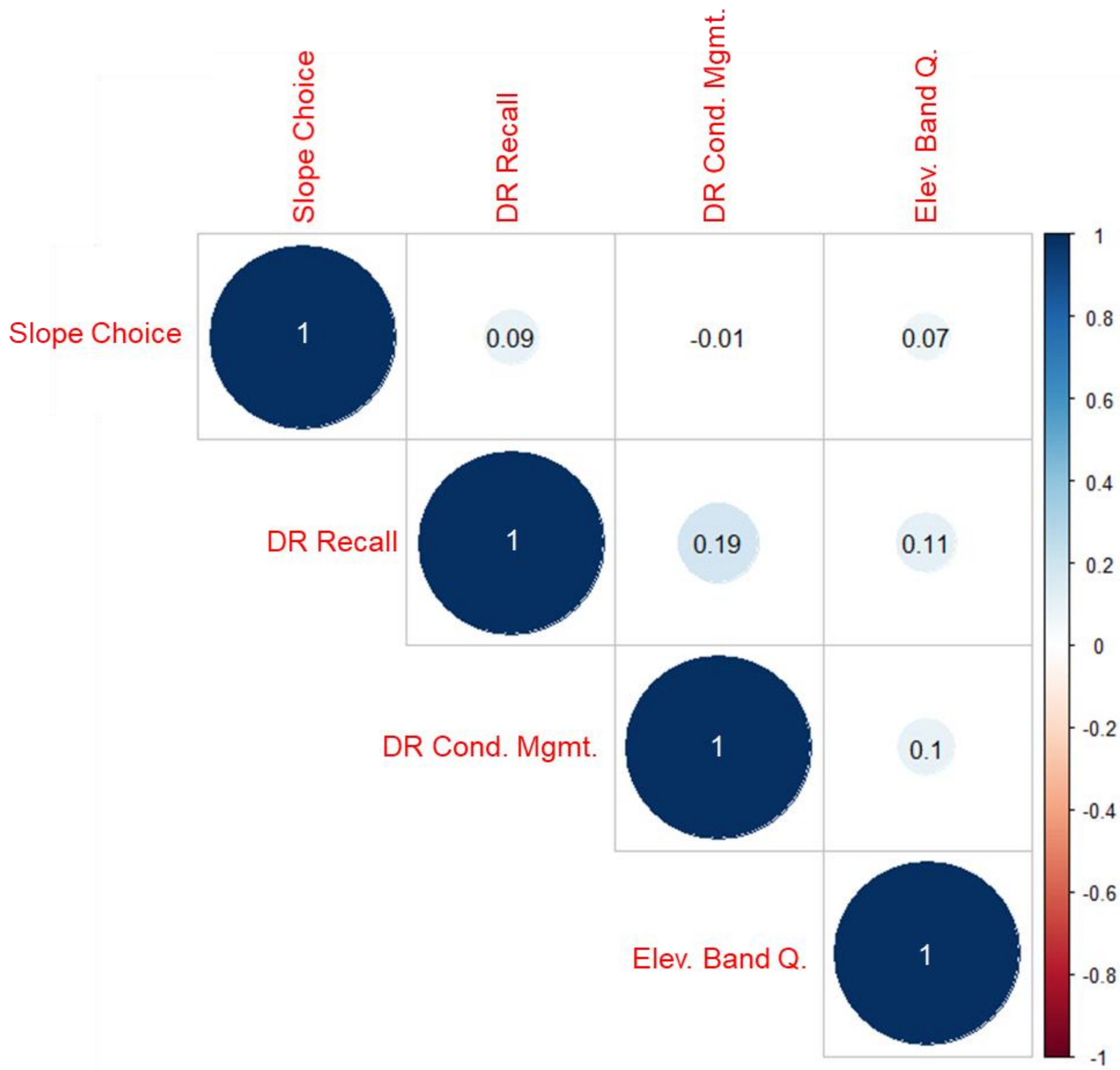


Figure C.1. Type Cs (n=528). Correlation plot displaying the relationships between performance on the avalanche bulletin literacy questions

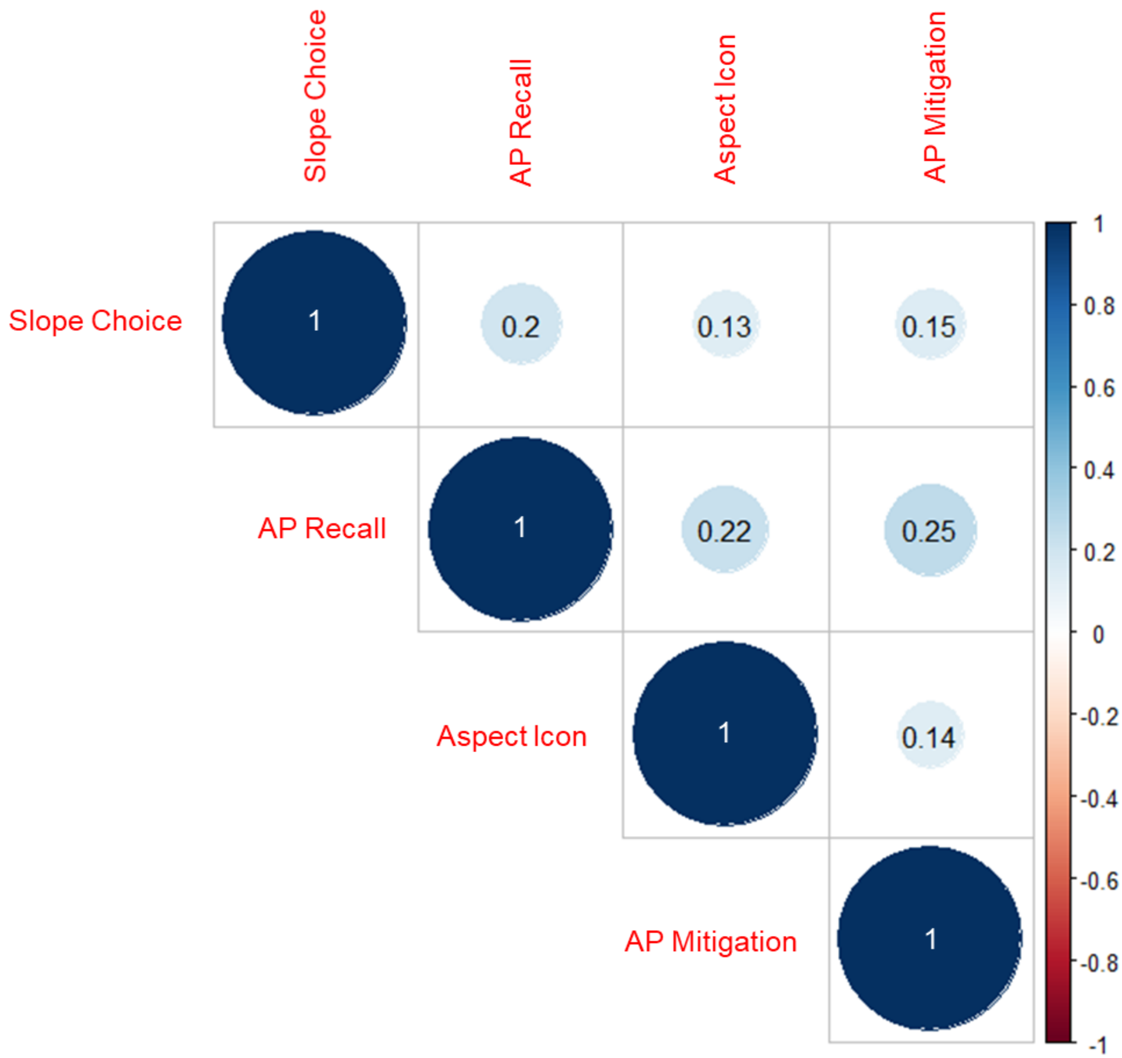


Figure C.2. **Type Ds who saw the aspect question (n=434). Correlation plot displaying the relationships between performance on the avalanche bulletin literacy questions**

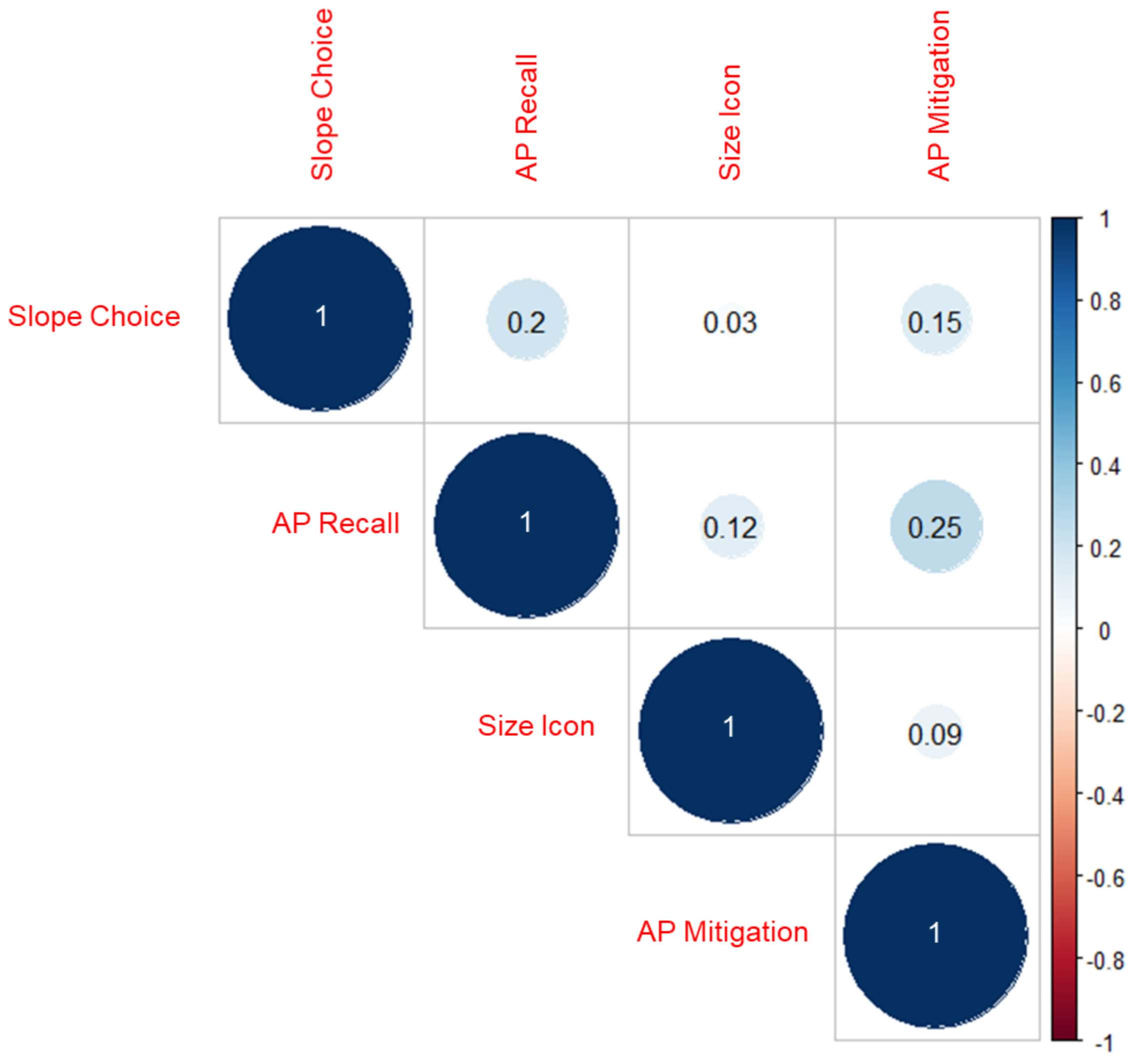


Figure C.3. **Type Ds who saw the size question (n=471). Correlation plot displaying the relationships between performance on the avalanche bulletin literacy questions**

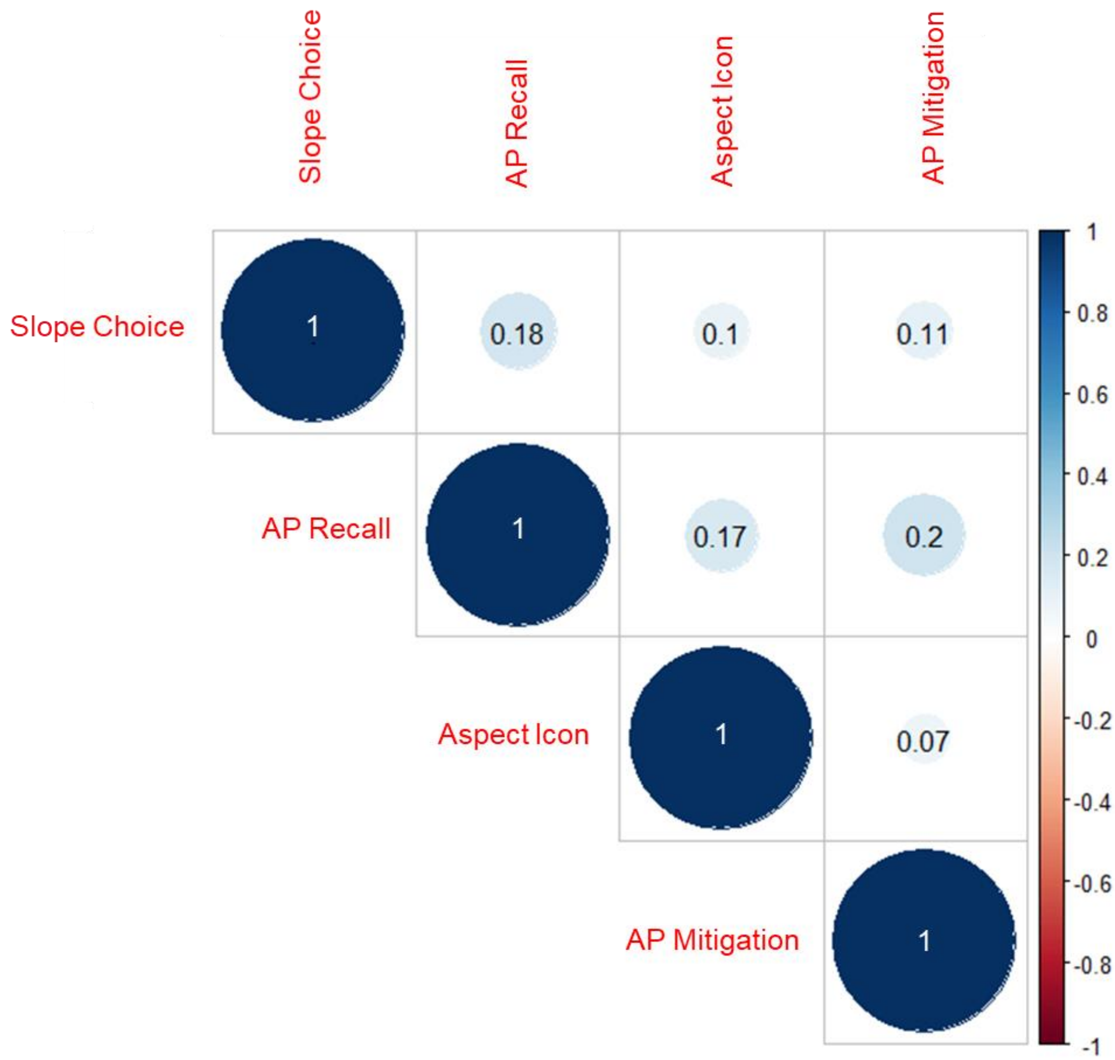


Figure C.4. **Type Es who saw the aspect question (n=771). Correlation plot displaying the relationships between performance on the avalanche bulletin literacy questions**

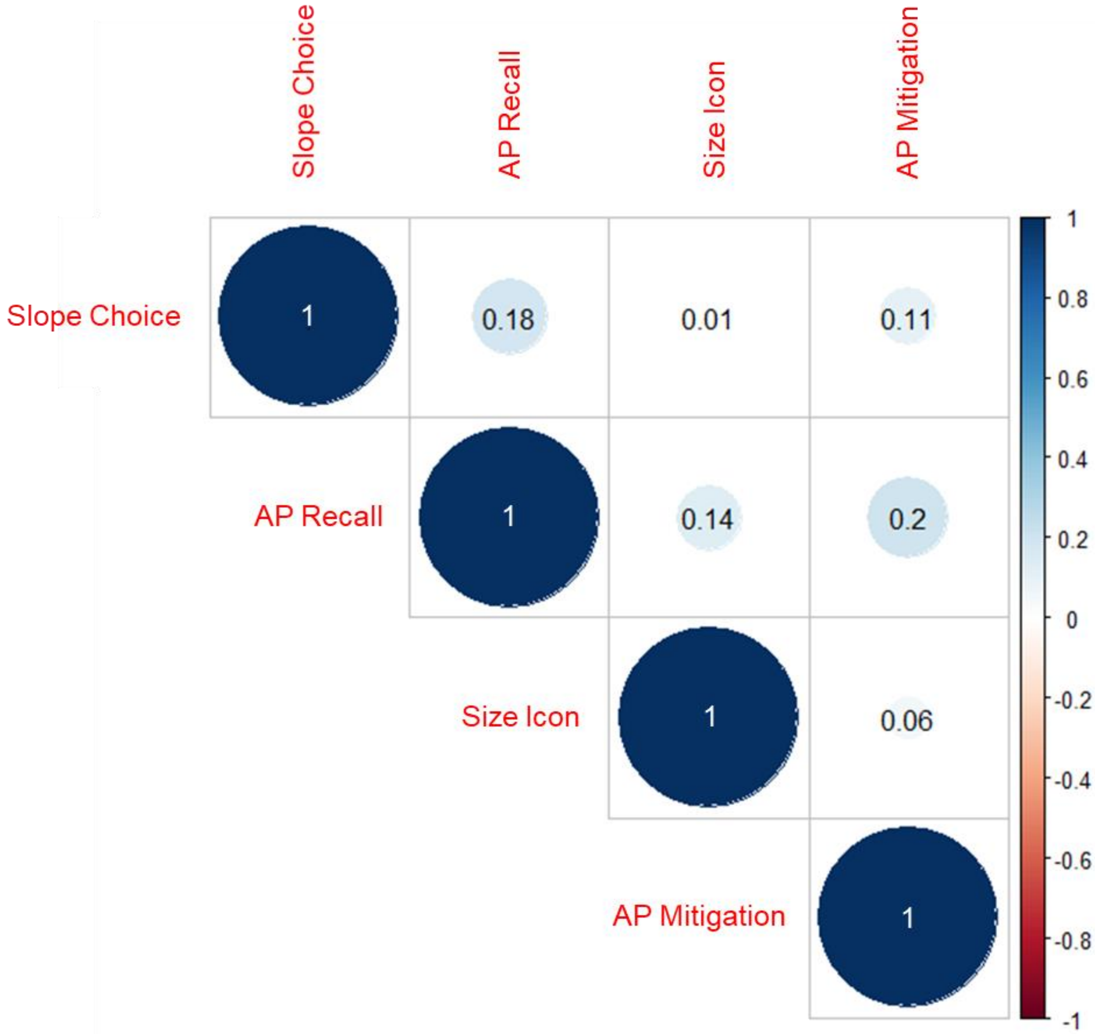


Figure C.5. **Type Es who saw the size question (n=685). Correlation plot displaying the relationships between performance on the avalanche bulletin literacy questions**

Appendix D. Conditional Inference Tree Plots

This section displays the plots for all the conditional inference tree (CTree) models that computed significant splits in the data but that were not included in the results section.

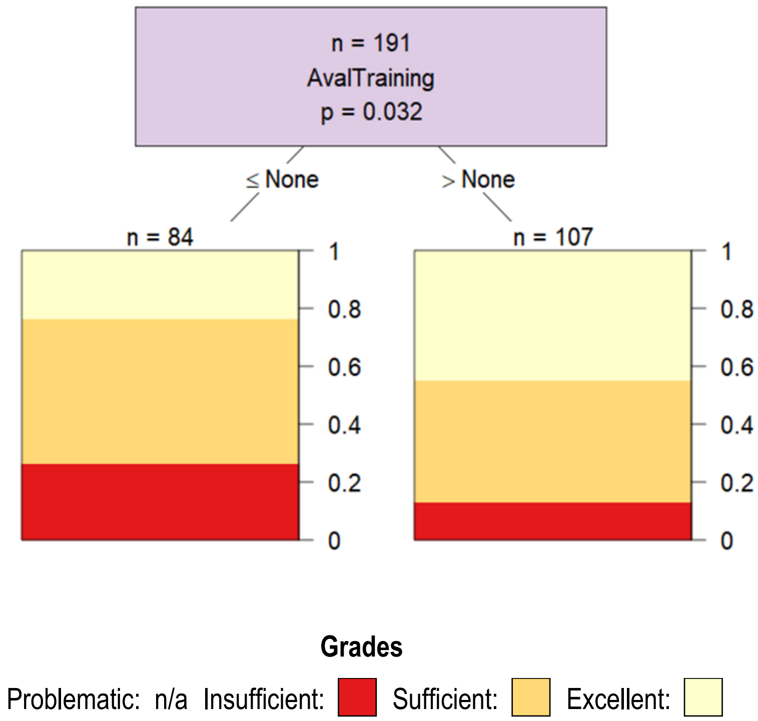


Figure D.1. Conditional inference tree displaying the interaction between Type B users' performance on the Danger Rating Recall question and their background variables.

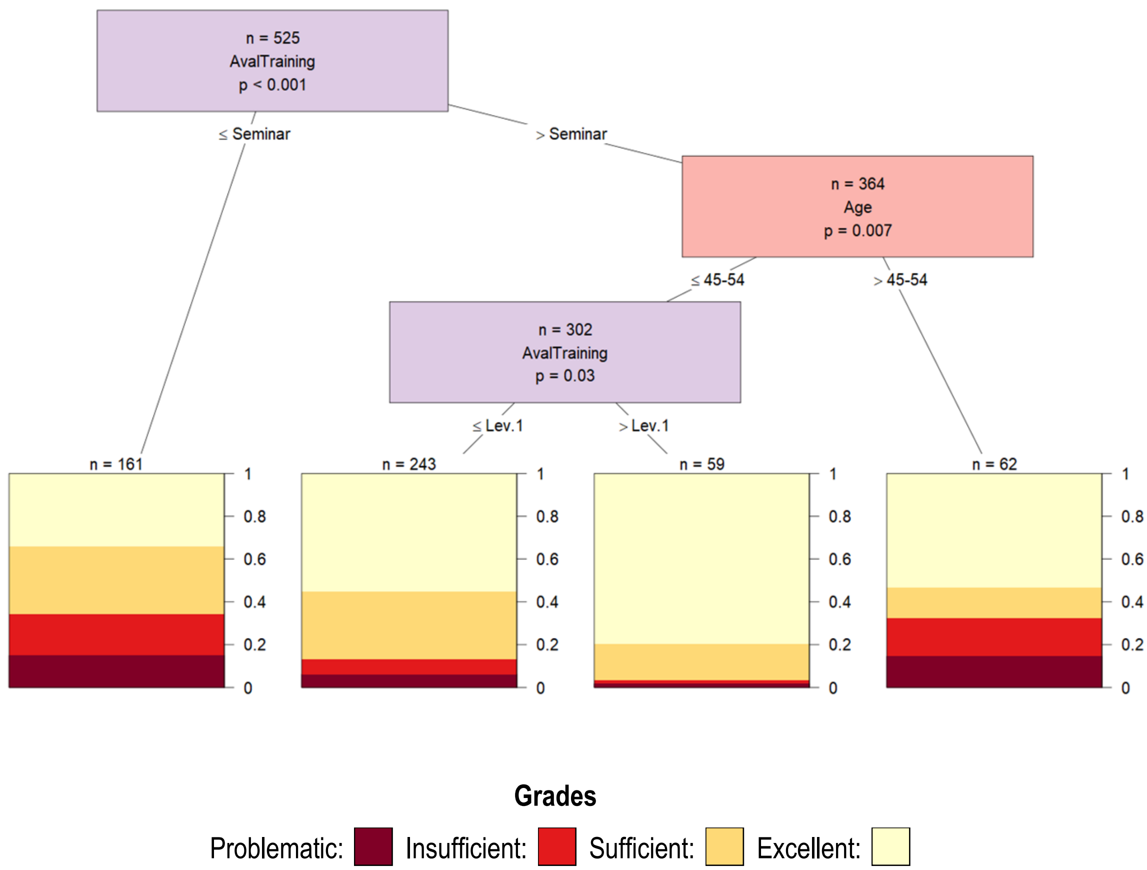


Figure D.2. **Conditional inference tree displaying the interaction between Type C users' performance on the Danger Rating Recall question and their background variables.**

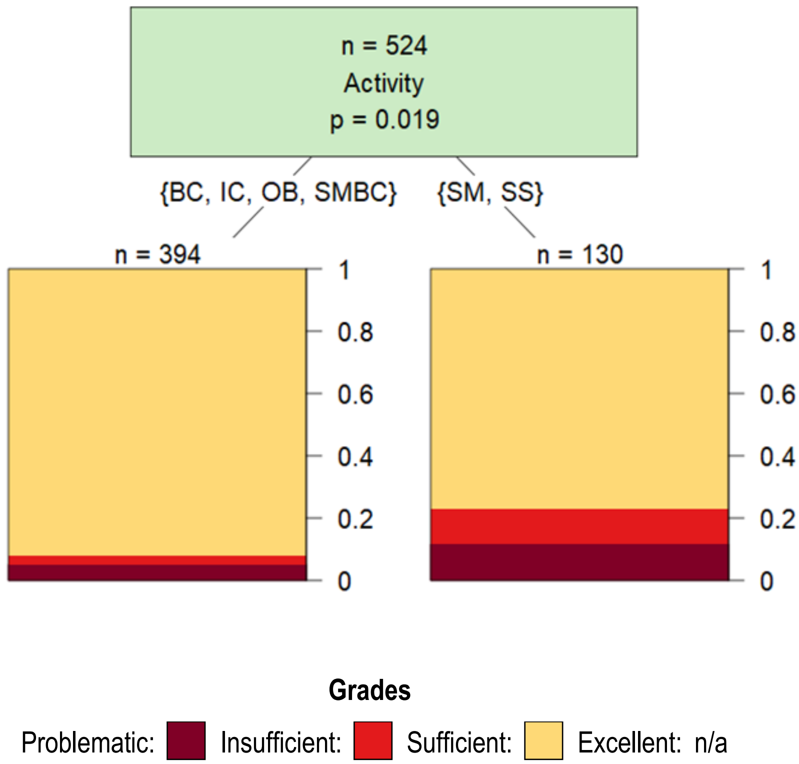


Figure D.3. **Conditional inference tree displaying the interaction between Type C users' performance on the Danger Rating Conditions Management question and their background variables.**

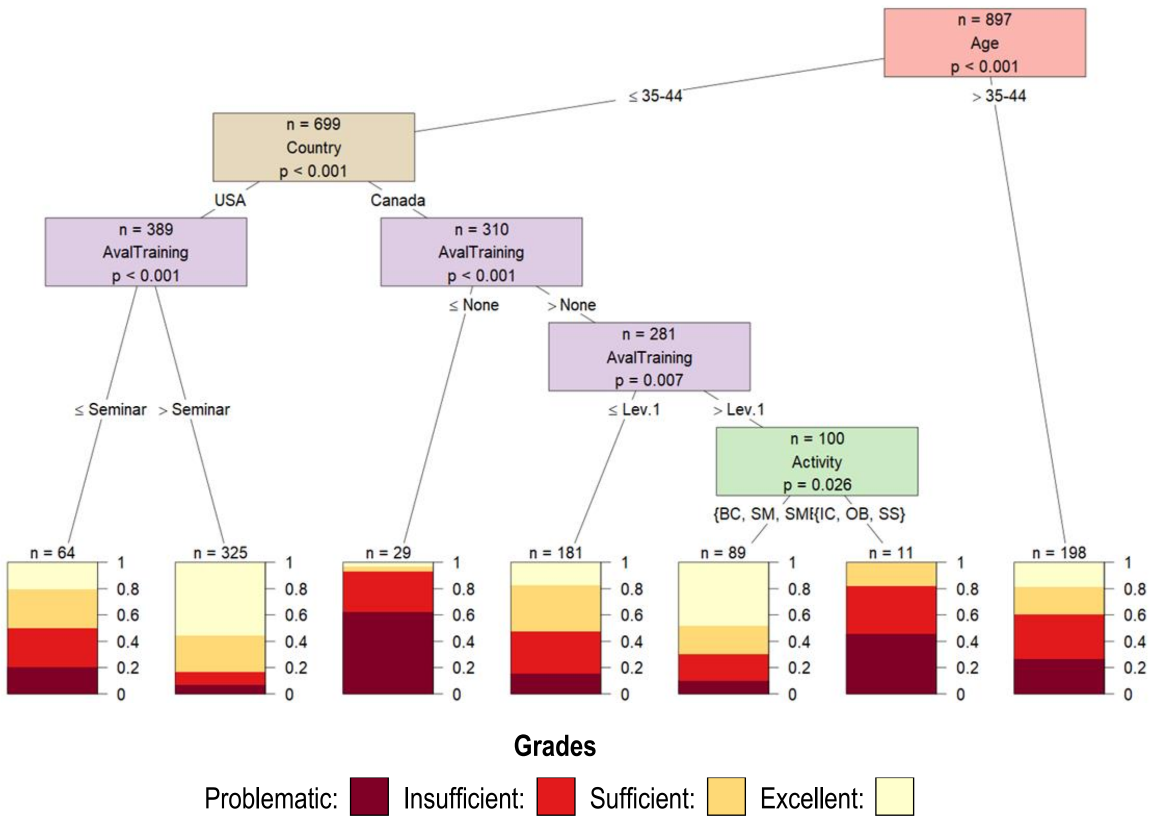


Figure D.4. **Conditional inference tree displaying the interaction between Type D users' performance on the Avalanche Problem Recall question and their background variables.**

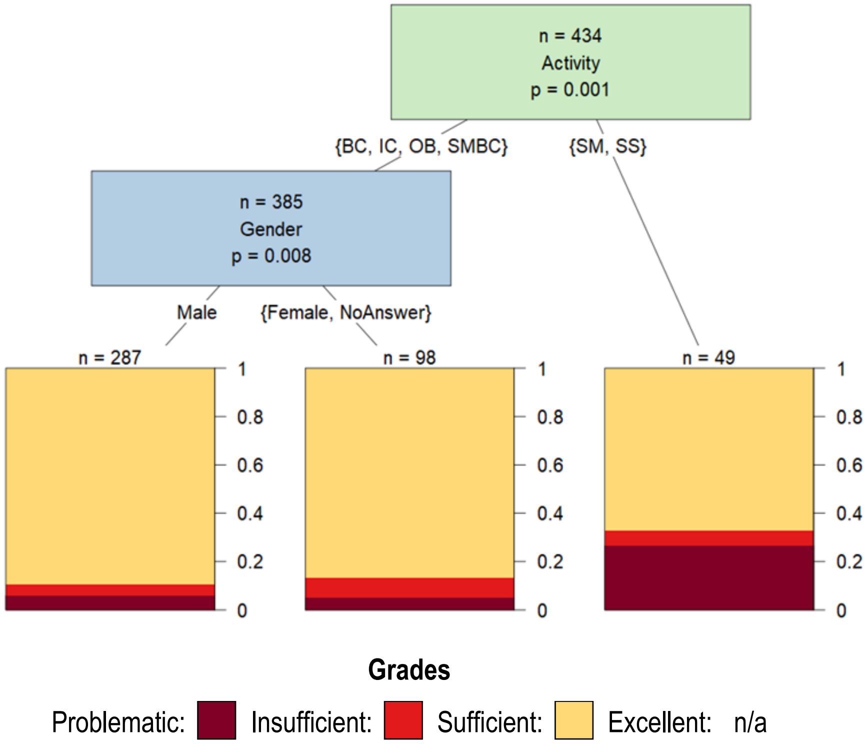


Figure D.5. **Conditional inference tree displaying the interaction between Type D users' performance on the Aspect Icon question and their background variables.**

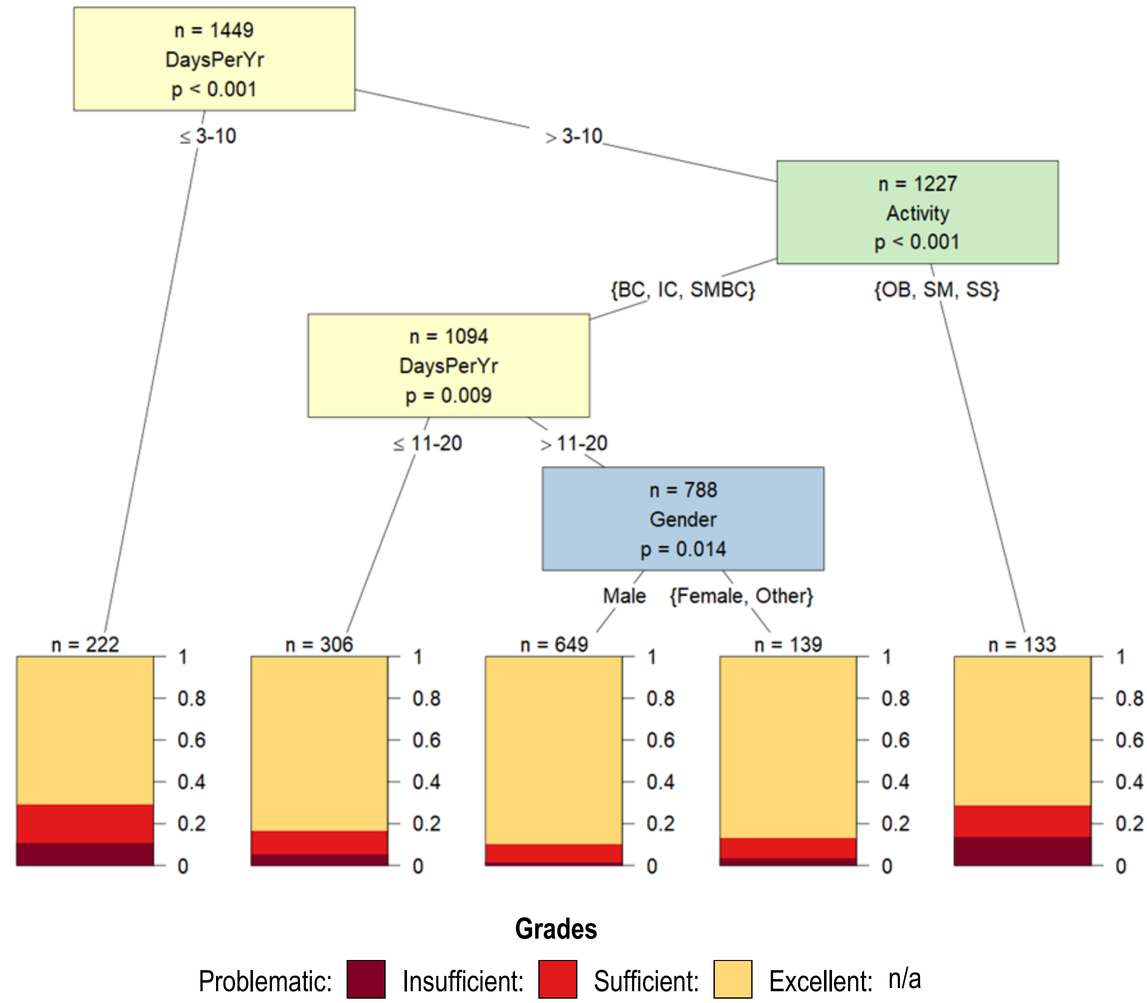


Figure D.6. **Conditional inference tree displaying the interaction between Type E users' performance on the Avalanche Problem Mitigation question and their background variables.**

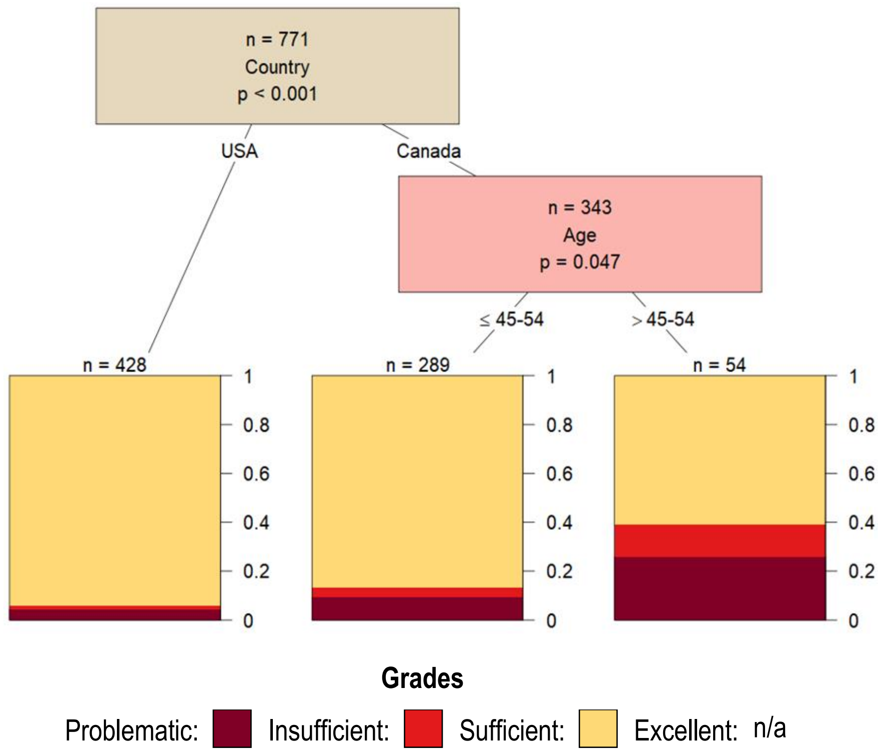


Figure D.7. **Conditional inference tree displaying the interaction between Type E users' performance on the Aspect Icon question and their background variables.**

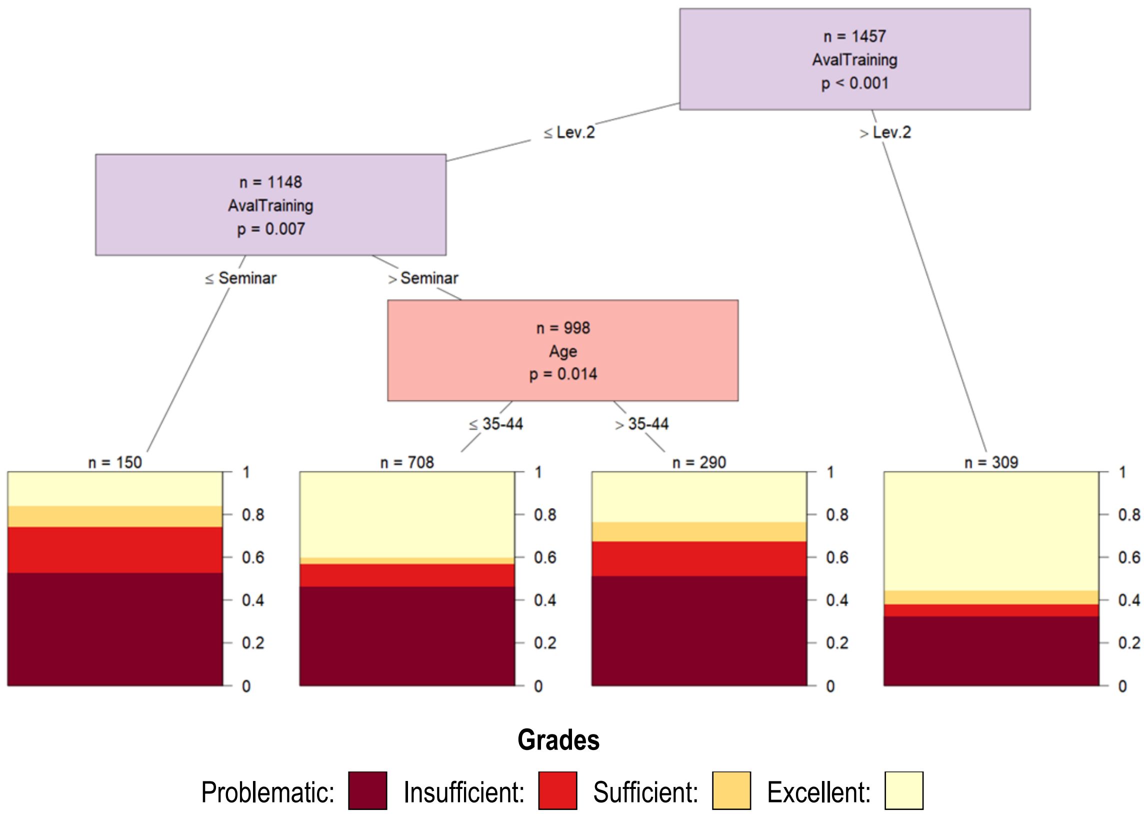


Figure D.8. **Conditional inference tree displaying the interaction between Type E users' performance on the Slope Choice question and their background variables.**