EXPLORING LARGE-SCALE TERRAIN PREFERENCES FOR MANAGING AVALANCHE RISK IN A COMMERCIAL BACKCOUNTRY SKIING OPERATION

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ABSTRACT: Guides of commercial backcountry skiing operations manage the physical risk from avalanches by assessing the local avalanche hazard and carefully choosing terrain and travel procedures to keep the residual risk at an acceptable level. A daily evaluation of predefined ski runs by the guiding team about whether the particular terrain is open or closed for guest skiing under the expected avalanche conditions represents the foundation for all subsequent guiding decisions during the daily skiing program. This study uses daily hazard assessments and run list records from a heli-skiing operation to quantitatively explore patterns in large-scale terrain preferences under different avalanche hazard conditions. Our data set spans four winters (2012/13 to 2015/16) with a total of 339 days and 93,647 documented run list ratings. The patterns in the daily terrain preferences revealed by our analysis provide interesting insights on how professional mountain guides deal with different avalanche situations. Our visualization of the 2013/14 winter season shows that both daily run list ratings for different terrain categories and run usage were closely linked to the avalanche hazard rating and avalanche character. Different ski line categories on a run were progressively opened or closed with decreasing and increasing hazard level, respectively. Using the entire data set of four winters, we show that runs with more options are skied earlier in the season and more frequently skied for the rest of the season. Contrasting run use on days with and without persistent avalanche problems, we see that both repeated use of terrain that was skied previously and the number of run passes per group on the same ski run are higher on days with persistent avalanche problems and groups tend to use the same runs more frequently.

KEYWORDS: avalanche risk management, terrain selection, decision making, helicopter skiing, conceptual model of avalanche hazard

1. INTRODUCTION

Guides of commercial backcountry skiing operations manage the physical risk from avalanches by assessing the local avalanche hazard and carefully choosing appropriate terrain and travel procedures to keep the residual risk at an acceptable level while providing a high quality skiing product. The entire process is iterative in nature and occurs at multiple spatial and temporal scales (Hendrikx et al., 2016).

Israelson (2015) describes the terrain selection process as a series of decision filters to decide on suitable terrain to ski on any given day. Avalanche hazard is an important factor in this process, but other factors such as weather and flying conditions, flight economics, skiing quality, guest preferences, and skiing abilities also play an important role (Israelson, 2015).

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The terrain choice process at a mechanized skiing operation starts with the daily hazard assessment in the morning, resulting in a large scale avalanche forecast for the entire tenure for the day. Subsequently, a list of predefined ski runs is evaluated by the guiding team to decide what type of terrain is open or closed for guiding under the expected avalanche conditions. The resulting 'run list' has established itself as a critical component in the risk management process of many commercial backcountry skiing operations. This large-scale, consensus-based terrain assessment represents the foundation for all subsequent guiding decisions during the daily skiing program. In most helicopter skiing operations, helicopters commonly serve multiple groups of skiers, each of them led by a guide. It is common practice that the guide of the first group serviced by the helicopter (known as the 'lead guide') decides what runs the groups of this helicopter ski. How exactly the particular run is skied by a group is the responsibility of the guides of the individual groups. The described sequence of (a) run list by entire guiding team, (b) run choice by lead guide and (c) ski line within run by individual guide, highlights the hierarchical and iterative nature of the terrain selection process. At

each level, the decisions are adjusted based on new avalanche hazard related observations, operational constraints and guest needs.

While traditionally avalanche safety research has primarily focused on improving our understanding of avalanche hazard, the terrain selection process of professional guides has received relatively little attention. Examples of studies in this area include Grimsdottir and McClung (2006), who interviewed professional guides to elicit factors influencing terrain choices or Haegeli ands Atkins (2010) who explored the terrain assessment expertise of mountain guides through hypothetical decision scenarios in an online survey. Hendrikx et al. (2013) and Hendrikx et al. (2016) recorded terrain choices with GPS trackers and examined terrain preferences by comparing terrain characteristics (e.g., aspect, incline) of skied terrain among different hazard ratings. However, due to the multitude of influencing factors, identifying meaningful patterns is challenging. A more in-depth understanding of existing terrain management strategies is critical for improving our understanding of decision-making in the avalanche risk management context.

To address this research gap, we document and explore the process of terrain selection at a commercial backcountry helicopter skiing operation by examining patterns in their run list records. In particular, we (a) visualize terrain choices at the run list scale, (b) explore patterns in run list ratings and run usage, (c) contrast run usage with available terrain options on a run, and (d) contrast run usage under conditions with and without persistent avalanche problems. The results of this paper provide initial insight into the larger topic of terrain selection by showing how large-scale terrain choices at the run list level correlate with two specific components of the Conceptual Model of Avalanche Hazard (Statham et al., under review).

2. STUDY SITE

For this study, we have collaborated with Northern Escape Heli Skiing (NEH), a commercial helicopter skiing company based out of Terrace, BC, Canada. NEH has a tenure of nearly 6,000 km^2 of skiing terrain, divided into 13 operating zones. The elevation of the available skiing terrain ranges from 450 m to 2450 m covering all three elevation bands (alpine, treeline and below treeline). The character of the local snow climate is maritime with storm slab avalanche problems mostly during or immediately following storms being the primary avalanche hazard concerns and warm temperatures promoting rapid stabilization (McClung and Schaerer, 2006).

NEH has an inventory of 351 mapped and named ski runs. For each of the ski runs helicopter landings, pick-ups and common ski lines have been identified (Fig. 1). Ski lines have been classified according to the severity of their exposure to potential avalanche hazard using a modified Avalanche Terrain Exposure Scale (ATES, Statham et al., 2006) rating system.

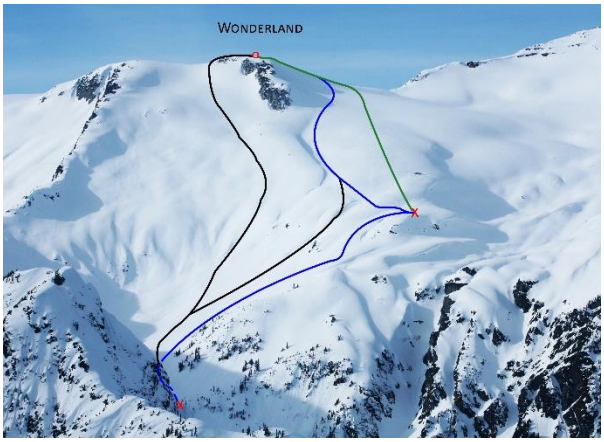

Fig. 1: Example of predefined ski lines on a run with their avalanche severity category (green/blue/black) as well as helicopter landings and pick-ups. Photo: Northern Escape Heli Skiing.

The modified classification scheme is based on personal terrain knowledge of experienced guides at NEH and rates ski lines as green (least severe terrain), blue or black (most severe terrain) considering the following factors (Israelson, 2015):

- Slope angle
- Max. avalanche size possible
- Exposure to overhead hazards
- Forest density
- Terrain traps
- Slope shape
- Escape options

Of the 351 predefined runs in the run list of NEH, 88 runs have green ski lines options (25% of runs), 144 runs have blue ski line options (41%) and 167 runs have black ski line options (48%).

During the morning meetings of the guides at NEH, each type of terrain on a run is evaluated and according ski lines are opened or closed for guest skiing separately. On a typical skiing day, NEH uses up to three helicopters each serving two to three groups.

3. DATA SET

The data set used in this study consists of daily avalanche hazard information and operational records of the terrain choices with run list and run usage for the winter seasons 2012/13 to 2015/16.

The daily operational avalanche hazard information available from NEH follows the Conceptual Model of Avalanche Hazard (Statham et al., submitted). The data set also includes the weather, field and avalanche observations that were used to produce the avalanche hazard assessment. In the present study we focus on the hazard ratings, which are given for each elevation band, and the avalanche problem type of daily avalanche concerns. Avalanche hazard and avalanche problem information is available for 272 days during the four seasons.

Records of daily run list ratings of open and closed runs represent the large-scale terrain choices of the guiding team. The run list data set consists of 93,647 individual run ratings of 339 days.

The terrain choice data set also includes daily records of skied runs. In total, this part of the data set consists of 11,585 individual ski run passes on 290 days. While the records include which group skied the run, they do not specify which specific ski line was skied on the particular run.

4. DATA ANALYSIS

4.1 Visualization and qualitative description

Due to the exploratory nature of this study, we first visualized avalanche hazard conditions together with the run list rating and the run usage to facilitate the visual identification of potential patterns between avalanche hazard and terrain choices at the run level. In this paper, we only show the visualization of the 2013/14 winter season (Jan. 1 to Mar. 31) focused on the "Promised Land" operating zone as an example (Fig. 2). With its 79 runs (23%) it is the most frequently used zone of NEH. The visualization consists of the following charts:

a) *Avalanche hazard*: The avalanche hazard ratings for three elevation bands (alpine, tree line and below tree line) are shown together with the avalanche problem type(s) of concern.
b) *Run list ratings*: Daily ratings for each run are shown with the color of the avalanche exposure scale rating of the most severe class of ski line considered open on that day (green/blue/black). If none of the lines were considered open for guiding, the run is shown in red. Black squares indicate the runs skied during the particular day. The plotting order of the runs reflects the dates when the runs were first skied in that season. The percentages in the column with the yellow to red color coding on the right of the panel indicates the percentage of days a run was used after it had been skied for the first time. Available elevation bands and type of available ski line classes are plotted on the left of the graph as background information about the character of each run.
c) *Terrain class summary*: This graph shows the daily percentage of open runs for each terrain category (green/blue/black).
d) *Total number of runs used*: This graph shows the daily number of runs used split between the core operating zone "Promised Land" (dark grey) and all other operating zones (light grey).
e) *Repeated run usage*: This graph illustrates the percentage of runs skied in relation to when they were skied previously. The different colored bars indicate (i) runs already skied the previous day (darkest blue), (ii) two days ago, (iii) between three and seven days ago, (iv) skied at least once this season, and (v) skied for the first time this season (white).

4.2 Statistical examination of specific patterns

The run usage patterns identified for the 2013/14 winter season (Fig. 2) were subsequently statistically assessed with the complete run usage data (2012/13 to 2015/16). Statistical analyses were performed in the statistical software R (R Core Team, 2015) and test results were only considered statistically significant with p-values < 0.05.

Effect of terrain options on run usage

For examining the relationship between number and type of terrain options and run usage, we assessed the following hypotheses:

1. Runs with more terrain options are skied more often during a season.
2. Runs with more terrain options are skied earlier in the season.

For this analysis we classified all runs according to their number of avalanche terrain exposure classes as a proxy for the number of available terrain options. This results in a number of 1 (green only, blue only, black only), 2 (green and blue, green and black, blue and black) or 3 (green, blue and black) for each run. In addition to the number

alone, the classes of available terrain can offer further insight into the reasons for the terrain choices. First, we assessed whether mean run usage count of a run for each season differs based on the number and type of different terrain options on the run. For the second hypothesis, we used the mean number of the operational day when a run was first skied in a season (i.e., date first skied minus date of the first day of the season) as the dependent variable.

Given the non-normal character of the target variables (number of days skied, day first skied in the season) and the fact that we are comparing more than two groups, we used the non-parametric Kruskal-Wallis test for these analyses.

Effect of persistent avalanche problems on run usage

For examining the relationship between persistent avalanche problems and run usage we examined the following hypotheses:

1. On days with persistent avalanche problems, run use tends to focus on runs that have been skied more recently than during days without any persistent avalanche problems.
2. On days with persistent avalanche problems, individual groups tend to ski the same runs more often than on days without any persistent avalanche problems.
3. On days with persistent avalanche problems, groups tend to ski the same runs more frequently than on days without any persistent avalanche problems.

For examining these hypotheses, we first collapsed the ski run pass records into run use records, which represents whether a run was used on a day regardless of how many times it was skied. We also calculated how many groups used it and how many times each group used it on that day. Subsequently we divided the daily records into two groups based on whether a persistent or deep persistent avalanche problem was present on the particular day. The resulting daily run use data set (runs used, number of run passes, number of groups using the run) consisted of 2,090 records, 863 (41%) on days with persistent avalanche problems present and 1,227 (59%) on days without any persistent avalanche problems.

For assessing the first hypothesis, we also coded each daily run use record according to when the particular run was skied last as described in Section 4.1e.

Finally, to eliminate the effect of more or fewer groups skiing on a particular day on the assessment whether different groups skied more similar runs during periods with persistent avalanche problems we normalized the number of groups on the same run by the number of groups per day to calculate the fraction of daily groups skiing on a particular run.

Given the ordinal character of the data, we used the non-parametric Wilcoxon-Rank-Sum test to test these hypotheses.

5. RESULTS

5.1 Run list and run usage analysis of the 2013/14 winter season

Weather and avalanche hazard conditions

The 2013/14 winter season was characterized by generally favorable avalanche conditions during early season and more challenging ones in the second half of the winter. The dramatic change in conditions was brought on by a 12-day storm period starting on Feb. 10, which deposited roughly 120 cm of new snow on top of a layer of well-developed surface hoar on a variety of hard surfaces (crust, faceted crystals). The rest of the winter was characterized by an extended period of high avalanche hazard and persistent and deep persistent avalanche problems (Fig. 2a).

Run list patterns

Our analysis shows that daily run list ratings were closely linked to avalanche hazard and avalanche character (Fig. 2a & 2c). During the first half of the season, most of the different ski lines on a run were open: up to 94% of all runs with green ski lines, up to 88% of all runs with blue ski lines and up to 70% of all runs with black ski lines. The extended storm period starting on Feb. 10 resulted in a dramatic shift in the percentage of closed runs of all terrain classes. While the percentage of open green terrain only dropped to 56% during the 11-day period of highest hazard, the percentage of open blue and black terrain dropped to 19% and 2% respectively. The percentage of open green and blue ski lines progressively increased again after the period of high hazard. The percentage of open green ski lines remained generally between 78-94% throughout the rest of the season with the exception of March 8 (high hazard) and the percentage of open blue ski lines remained between 19-62%. In contrast, the percentage of black ski lines remained low (2-10%) despite the improving hazard rating due to the persistent and deep persistent avalanche concerns.

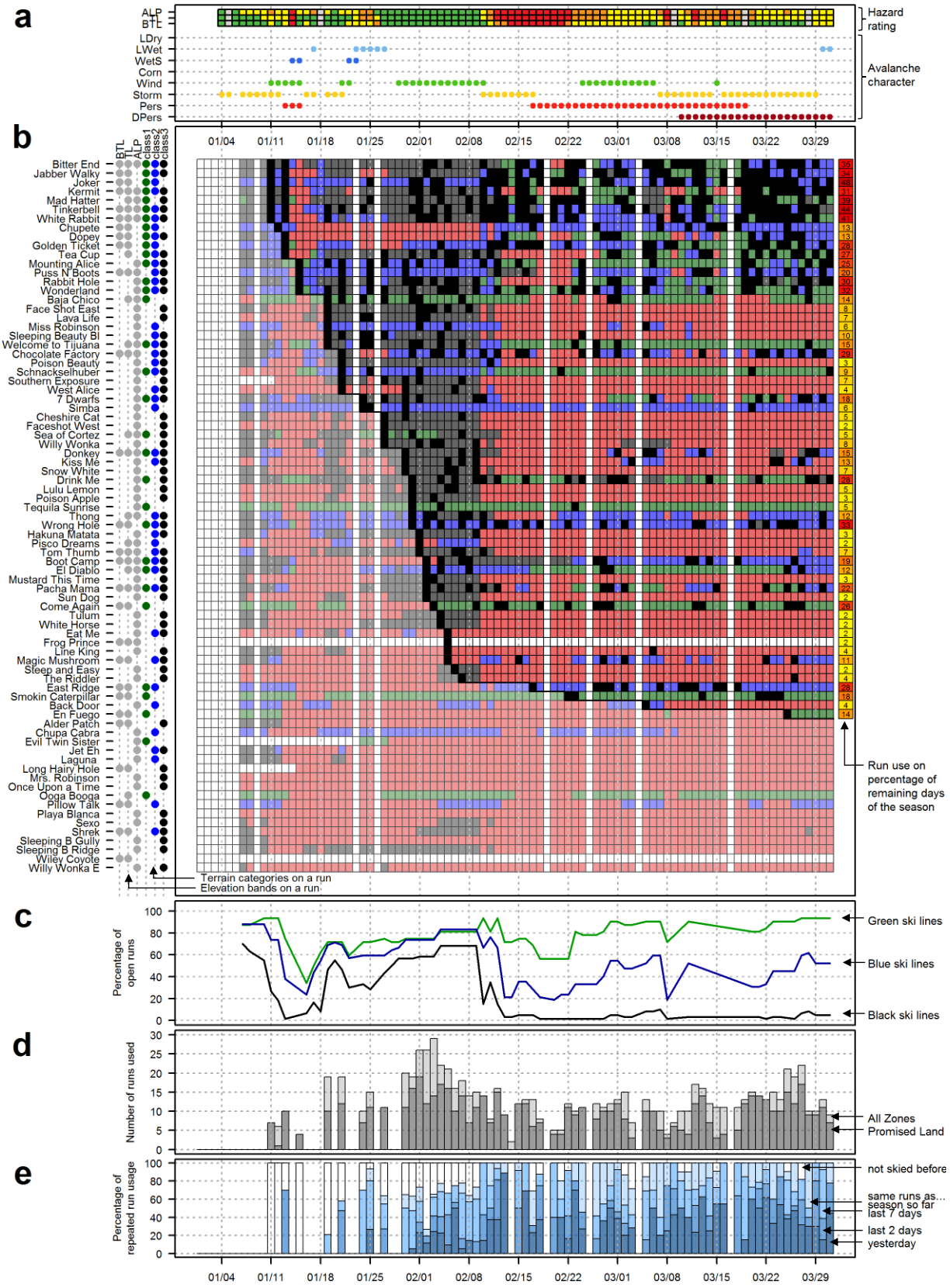

Fig. 2: Visualization of the 2013/14 winter season with (a) avalanche hazard, (b) run list ratings, (c) terrain class summary, (d) total number of runs used and (d) repeated run usage.

On runs with ski lines of multiple avalanche terrain exposure categories (green, blue, black), the different levels were gradually opened or closed with decreasing and increasing hazard level respectively (Fig. 2b). This pattern can most easily be seen with the uppermost runs where the most severely exposed ski line category which was open changed from black to blue to green and vice versa with the avalanche hazard level.

While ski lines of the same exposure scale category were usually open or closed at similar times, there are some notable exceptions to this general pattern. For example, deviations from that pattern can be found in the period Feb. 10-12 where the black ski line options on some runs remained open for a few additional days, while the majority of the black lines were closed immediately on Feb. 10.

Run usage patterns

Not all runs that were open during the season were actually skied (Fig. 2b). By the end of the season 62 of 79 runs (78%) in the "Promised Land" operating zone were skied at least once. A visual inspection of the run usage pattern shows that runs that were open during the challenging second part of the season but not skied only have green or blue ski line options and are located at the far end of the operating zone.

We can see that initial skiing of new runs mostly happened before Feb. 7 (Fig. 2b). Out of the 62 skied runs, 58 (94%) were skied by Feb. 7 before the major shift in hazard conditions. Throughout the rest of the season, no new black runs were skied. During the second half of the season, run usage focused almost exclusively on core runs at the top of the Fig. 2b, which had been skied numerous times from the very beginning of the season.

Some runs were clearly skied much more often than others during the season 2013/2014 (see percentage heat map on the right of Fig. 2b). Once opened, 12 runs were skied more often than every third day with one run being skied on 52% of the days of the season since it was skied first. All of these runs were skied consistently both early in the season and during the second half of the season. Many of these runs seem to be attractive for skiing because of the higher number of options they provide with respect to avalanche terrain exposure categories and elevation bands.

Similarly, runs skied early in the season seem to have more ski line options with different exposure categories on a run. Out of the first 15 skied runs in the season 2013/14, 10 have all three terrain options, 5 have two options and none has only one option (Fig 2b).

The number of different runs skied per day varied across the season likely in response to avalanche hazard (Fig. 2d). While up to almost 30 different runs were skied on days during the favorable situation before Feb. 7, typically only 10-15 runs were skied in the second half of the season. Towards the very end of the season, this number slightly increased again to a maximum of 22 different runs. In addition, we can see that during the challenging period (Feb. 10 to Mar. 1), run usage was initially almost completely limited to the "Promised Land" operating zone.

The run usage data indicates repeated use of previously skied runs during the period with challenging avalanche conditions (Fig. 2e). If we compare the first with the second part of the 2013/14 season, we can observe that run usage after Feb. 10 generally shows a higher daily percentage of runs that had been skied more recently.

5.2 Effect of terrain options on run usage

Our statistical examination of the complete 2012/13 to 2015/16 data set confirms that there is a significant relationship between the average number of days a run is skied per season and the number and types of available terrain categories (Kruskal-Wallis test: $p < 0.001$; Fig. 3a).

On average, runs with all three terrain categories were more frequently skied over a season than runs with less ski line options. Furthermore, the average number of days a run is skied varies depending on the types of available terrain categories. Runs with green/blue/black or green/blue options were more frequently skied over a season than the other categories. Within the group of runs with only one terrain category there is no statistical difference in average run usage (Kruskal-Wallis test: $p = 0.48$; Fig. 3a).

Our statistical analysis also confirms that the average operational day a run is first skied differs among the categories of available terrain options (Kruskal-Wallis test: $p < 0.001$; Fig. 3b). We see that green/blue/black runs and green/blue runs were generally skied earliest in a season, whereas runs with only one option were generally skied later in the season (Fig. 3b). Within the latter group of runs, there is no statistical difference in average operational day of initial skiing (Kruskal-Wallis test: $p = 0.79$; Fig. 3b).

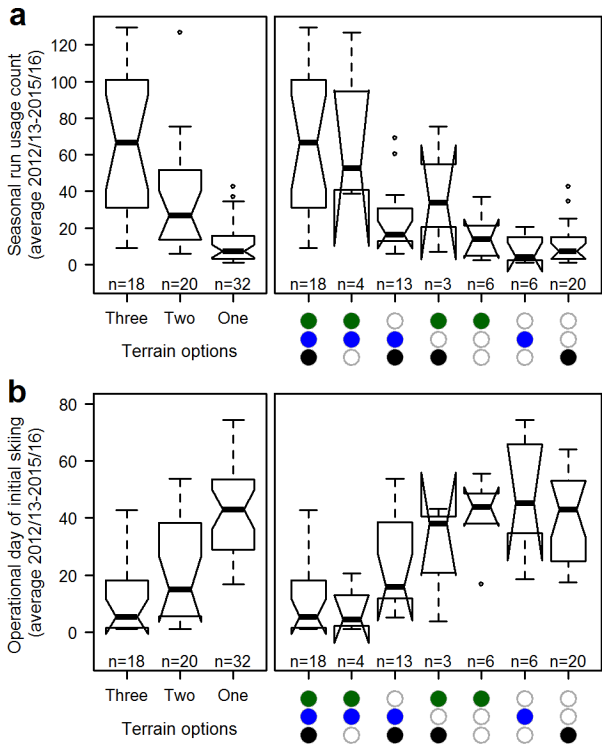

Fig. 3: Effect of terrain options on run usage with (a) average seasonal run usage count and (b) average operational day of initial skiing of a run.

5.3 *Effect of persistent avalanche problems on run usage*

Our statistical analysis of the complete 2012/13 to 2015/16 data set confirms that the distribution of lag times between repeated run use was shifted towards shorter lag times during days when persistent or deep persistent avalanche problems were present (Wilcoxon-Rank-Sum test: p-value < 0.001; Fig. 4a).

The statistical analysis of run usage data also shows a significantly higher number of passes on the same run by individual groups on days with persistent avalanche problems (Wilcoxon-Rank-Sum test: p-value < 0.001; Fig. 4b). This result is somewhat surprising as the median number of passes is the same for both categories (median = 1 run passes per group). However, the statistical difference can be explained by the fact that the distribution of the run passes on the days with persistent or deep persistent avalanche problems is skewed towards higher numbers above the median as illustrated in Fig. 4b.

Finally, our analysis showed that more groups used the same runs (Wilcoxon-Rank-Sum test: p-value < 0.001) on days with persistent avalanche problems compared to days without persistent avalanche problems (median = 0.5 and 0.4 respectively; Fig. 4c).

6. DISCUSSION

We used the 2013/14 winter season as an example to illustrate that both daily run list ratings for different avalanche terrain exposure categories used at NEH and run usage are closely linked to avalanche hazard rating and avalanche character. However, operational factors which also influence run choices (e.g., flight economics, weather changes, skiing conditions) during the course of a day were not considered in the present analysis. Moreover, the run usage data set currently does not provide information about which ski line options were actually used based on the run list. Despite these limitations, the present study is an important first step in exploring large-scale terrain preferences.

An important finding of our run list rating analysis is that the documented terrain choices are closely linked to the avalanche problem of concern. While most of the green ski lines stayed open during the majority of the season, the percentage of black lines remained low due to the persistent and deep persistent instabilities despite the improving hazard rating during the second half of the season. This clearly highlights the value of including avalanche problem types in the characterization of avalanche hazard.

However, the observed patterns of different opening and closing of ski lines within the same avalanche terrain exposure categories in the run list warrants further research on run characterization that more comprehensively captures the special character of certain runs. This can include a more detailed technical terrain characterization (e.g., localization and characterization of cruxes such as overhead hazard or wind loaded entries), but could also include other operational or run use aspects that make a run unique.

The analysis of run usage confirmed that repeated use of previously skied terrain occurs more frequently during periods with persistent avalanche problems. During such periods, our analysis also shows that the same runs are skied more often per day by the same group. We interpret these patterns as strategies for reducing uncertainty during challenging avalanche problems by repeated skiing of known terrain.

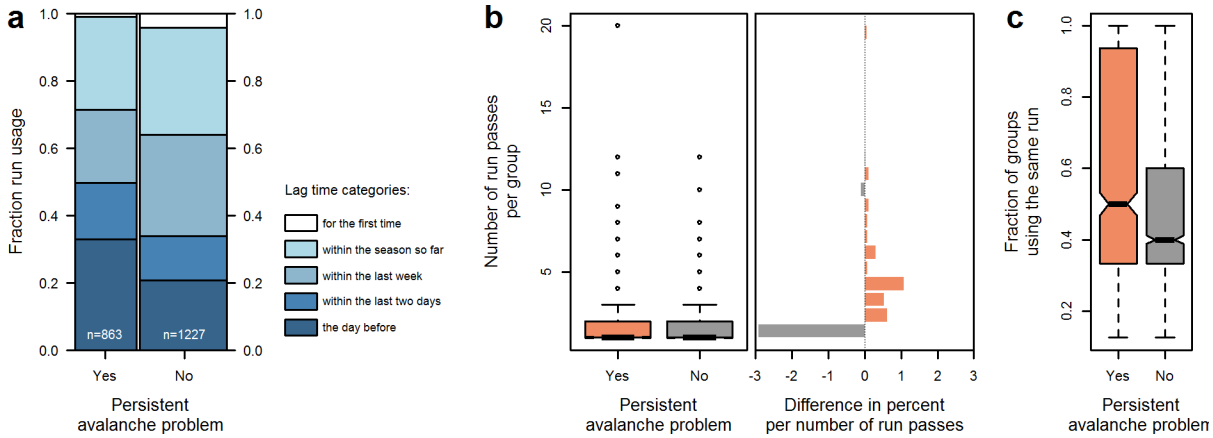

Fig. 4: Effect of persistent avalanche problems on run usage, with (a) fractions of run usage for different lag times, (b) passes per individual group on the same run and (c) fraction of groups per day skiing on the same run. All figures contrast run usage during periods with persistent problems with run usage during periods without persistent problems.

7. CONCLUSIONS

In this paper, we used an operational data set of large-scale terrain choices made at Northern Escape Heli Skiing identify patterns in large-scale terrain choices. We subsequently analyzed the identified patterns statistically and draw conclusions how terrain choices may be used to mitigate avalanche hazard. These results provide interesting first insights into this part of the risk management process at commercial backcountry skiing operations at the run scale and highlight which type of runs might be more suitable for skiing under different avalanche conditions. The management of the physical risk from avalanches at mechanized skiing risk operations is certainly a lot more complex and multifaceted than presented in this paper, but we believe that the results of this research provide a valuable first step for the development of operational decisions aids that can assist operations to manage the physical risk from avalanches more effectively and efficiently.

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REFERENCES

Grimsdottir, H. and McClung, D.M. (2006): Avalanche Risk During Backcountry Skiing – An Analysis of Risk Factors. Natural Hazards 39: 127-153.

Haegeli, P. & Atkins, R. (2010): Insights into the 'It depends' – Quantitative explorations of the assessment expertise of mountain guides. Proceedings of the International Snow Science Workshop, Anchorage, USA,130-132.

Hendrikx, J., Johnson, J., & Southworth, E. (2013): Understanding Travel Behaviour in Avalanche Terrain: A New Approach. Proceedings of the International Snow Science Workshop, Grenoble, France.

Hendrikx, J., Shelly, C. & Johnson, J. (2016): Using GPS tracking to explore terrain preferences of heli-ski guides. Journal of Outdoor Recreation and Tourism 13, 34-43.

Israelson, C. (2015). A suggested conceptual model for daily terrain use decisions at Northern Escape Heliskiing. The Avalanche Journal. 110. 39-43.

McClung, D., Schaerer, P., 2006. The Avalanche Handbook, 3rd ed. Mountaineers Books, Seattle, WA.

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Statham, G., Haegeli, P., Greene, E., Birkeland, K., Israelson, C., Tremper, B., Stethem, Ch., McMahon, B., White, B., and Kelly, J. (submitted). The Conceptual Model of Avalanche Hazard. Submitted to Natural Hazards on March 21, 2016.

Statham, G., McMahon, B., & Tomm, I. (2006): The Avalanche Terrain Exposure Scale. Proceedings of the International Snow Science Workshop, Telluride, CO, USA, 491-497.