HOW DO EXPERTS INTERPRET AVALANCHE TERRAIN FROM A MAP?

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ABSTRACT: Planning ski tours with accurate topographic maps is today a standard procedure. When a specific avalanche-prone slope has to be evaluated, the perception of the terrain from the map varies due to subjective interpretation. The question arises: How do experienced backcountry skiers assess avalanche terrain from a map? To gain a better understanding, we conducted a survey among 26 experts. They were asked to evaluate 24 avalanche-prone locations considering a given avalanche situation. First, they had to delineate the slope area they considered relevant for assessing the terrain. Second, they had to rate the hazard in terms of avalanche triggering probability and the consequences of being caught. The participants were also encouraged to describe their assessment in qualitative terms. Depending on the specific location, the assessments among the participants varied, whereas the agreement between the qualitative explanations was higher. The criteria most frequently mentioned to rate the terrain were slope angle, slope size, terrain traps, homogeneity of the slope and proximity to ridges. The results confirm that assessing avalanche terrain from a map is not a straightforward task. Nevertheless, the survey helps quantifying subjective expert knowledge. For instance, the data can be useful for designing algorithms to classify potential avalanche terrain, as it provides a set of well-studied terrain situations.

KEYWORDS: Avalanche terrain perception, ATES, Avalanche Terrain Exposure Scale, Backcountry Skiing.

1. INTRODUCTION

1.1 Background

Among the main factors for avalanche formation are snowpack stability and terrain. Snowpack stratigraphy and stability are complex factors varying in time and space, whereas terrain features remain constant and can be observed easily. Therefore, avoiding or minimizing the exposure to avalanche terrain is an effective approach to minimize avalanche risk. Hence, trip planning with accurate topographic maps and optimal route selection are crucial. Yet, interpreting terrain in an avalanche context is still intuitive.

In order to support backcountry skiers in interpreting avalanche terrain, Parks Canada proposed 2006 the Avalanche Terrain Exposure Scale (Statham et al., 2006). It is based on eleven terrain criteria and classifies terrain into three (alternatively four) categories.

Subsequently several attempts were undertaken to classify avalanche terrain semi-automatically (Delparte, 2008; Campbell and Gould, 2013) or full-automatically Schmudlach and Köhler, 2016). Recently, Harvey et al. (2018) presented an approach to classify avalanche terrain and created avalanche terrain maps for winter backcountry touring. An obvious question they asked at the beginning was how experienced backcountry skiers assess avalanche terrain from a map. Terrain features, such as slope angle, shape of terrain, slope size, terrain trap etc., are typically taken into account for terrain assessment and decision making. But little is known how experienced backcountry skiers perceive and evaluate terrain features and to what extent terrain interpretation differs from expert to expert. In order to fill this gap we conducted a survey among 26 experts.

1.2 Scope of the Survey

We defined three scopes of the survey:

1. Gaining qualitative knowledge about the terrain perception of backcountry skiers.
2. Gaining a common understanding of 24 terrain situations covering the range of typical terrain on backcountry tours.
3. Gaining some quantitative data about the perceived hazard at the locations.

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The knowledge gained in the survey may support the development of terrain classification algorithms.

From the beginning it was clear that the survey had rather a qualitative then a quantitative character.

2. SURVEY DESIGN

2.1 Locations

Backcountry skiing takes place in a wide range of terrain. Typical terrain features are: Uniform slopes, sharp ridges, gentle ridge, gullies, foot of a slope, upper edge of a slope etc. We chose 24 locations that cover the range of typical terrain features. The locations are placed in two popular backcountry skiing areas, 12 locations in Engstligenalp and 12 locations in Davos. The maps in Fig. 1 and 2 show all 24 locations; the type of terrain feature is given in parentheses.

2.2 Participants

The survey was conducted among 26 experienced backcountry skiers, mainly mountain guides. The participants had to fulfill three criteria:

- Many years of experience in avalanche danger and avalanche risk assessment.
- Many years of backcountry skiing experience.
- Skills to evaluate terrain from topographic maps.

2.3 Questions

We provided the participants with two topographic maps (of scale of 1:25K), each of it with 12 marked locations. The participants were assigned the following two tasks:

1. Delineation of Relevant Slope Area (RSA): The participants had to delineate on the map the slope area they considered relevant for the hazard at each point. Participants had to neglect the consequences of being caught by an avalanche.
2. Quantification of hazard: The participants had to quantify the level of hazard at each point. In contrast to the first task, the participants were allowed to include the consequences into their terrain assessment. In order to specify the level of hazard participants had to use the scale described in Tab. 1.

In addition to the quantitative tasks the participants were encouraged to comment on their reasoning.

The different handling of the consequences had a particular background: Mainly we wanted to focus on avalanche release probability and not on avalanche consequences. However, we supposed it was unlikely that the participants could exclude avalanche consequences from the second task.

Table 1: Terrain hazard scale

Class	*Value*	*Description*
A ±	*1, 2, 3*	*No hazard: No avalanche terrain.*
B±	*4, 5, 6*	*Low hazard: Untypical avalanche terrain.*
C±	*7, 8, 9*	*Elevated hazard: Typical avalanche terrain.*
D±	*10, 11, 12*	*High hazard: Very typical avalanche terrain.*

2.4 Snow and avalanche situation

Terrain perception depends on the prevailing snow and avalanche conditions. Thus the following snow and avalanche scenario was provided to the participants:

- The forecasted danger level is in the range of “2: Moderate” to “3: Considerable”.
- Avalanche triggering by skiers is possible. Remote triggering is also possible, but limited to some dozens of meters.
- Natural avalanches are not to be expected.
- No further information about the prevailing avalanche problem is available.
- The expected fracture depth is about 50 cm.
- The described situation applies to all elevations and aspects.

The assumed snow and avalanche scenario corresponds to a common backcountry skiing situation.

Participants got provided with a web map link, supplying topographic maps up to a scale of 1:10K and a slope angle layer.

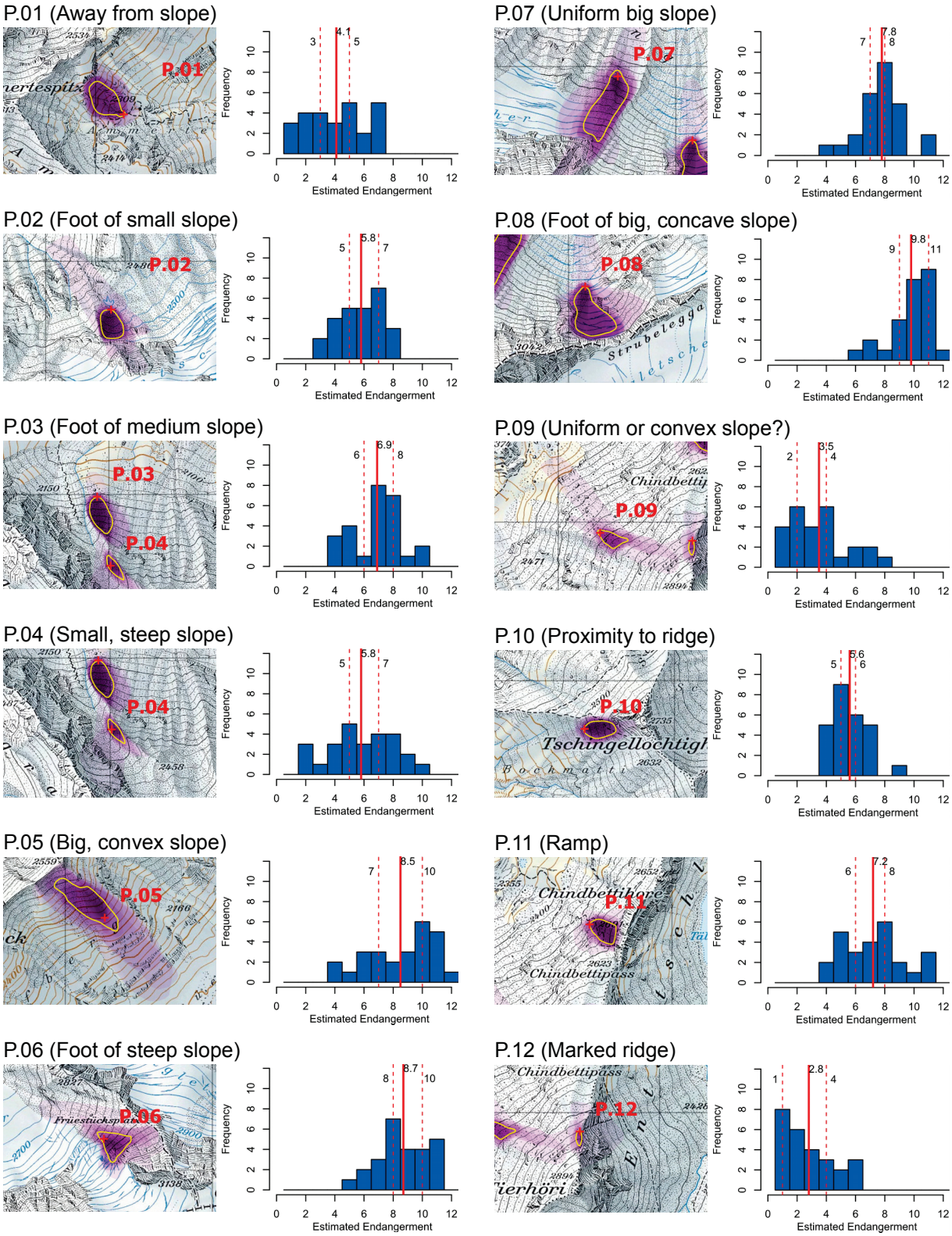

Fig. 1: Survey locations "Engstligenalp"

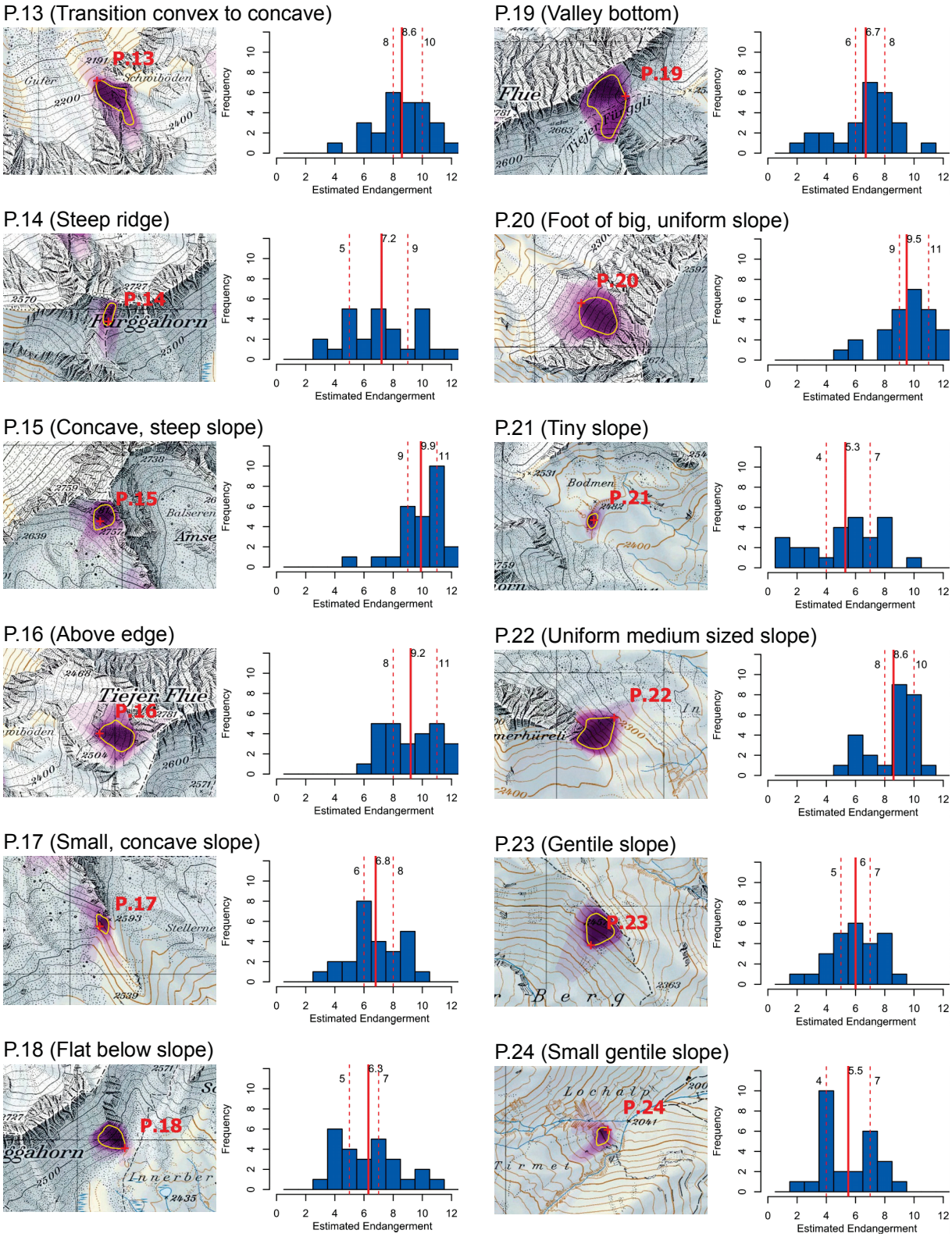

Fig. 2: Survey locations "Davos"

2.5 Terrain hazard scale

The second task required the introduction of a scale that allows quantifying the perceived hazard. In contrast to ATES the scale focuses exclusively on the avalanche hazard induced by the terrain and neglects the technical difficulty.

The scale consists of four principal classes. Each class can be further specified by optionally adding a plus or minus sign. Thus the ordinal scale contains 12 different levels.

3. RESULTS

The RSA polygons of each participant were scanned and vectorized. They are given in Fig. 1 and Fig. 2. The quantitative hazard estimates are listed in Tab. 2. The distribution of the 24 estimated hazard values are summarized in the histograms of Fig. 1 and 2.

3.1 Relevant Slope Area

The Relevant Slope Areas (RSA) are marked with purple color (Fig. 1 and 2). The transparency of the color enables the identification of areas with high and low agreement among the participants.

The yellow line indicates the average polygon. The average polygon for each location was calculated as follows:

- The maximal extent of the location (union of all 26 polygons) was rasterized with cell size 5 m.
- For each cell and participant a “deepness” value was calculated. This value expresses how far the cell is located from the outline of the participant’s polygon.
- The average of the deepness values of each cell was used to build a deepness raster.
- The deepness raster was vectorized. The resulting yellow polygon is shown on the maps in Fig. 1 and 2.

Table 2: Estimated hazard values of all participants A to Z. For statistical output the following abbreviations were used: M=Mean, MdN=Median, s=Standard Deviation, d=Abs(Mean-Median)

	P001	P002	P003	P004	P005	P006	P007	P008	P009	P010	P011	P012	P013	P014	P015	P016	P017	P018	P019	P020	P021	P022	P023	P024
A	6.00	5.00	5.00	7.00	6.00	7.00	8.00	11.00	1.00	4.00	5.00	5.00	9.00	8.00	9.00	8.00	6.00	5.00	8.00	8.00	6.00	9.00	6.00	4.00
B	7.00	7.00	9.00	6.00	11.00	8.00	8.00	7.00	4.00	5.00	8.00	2.00	7.00	9.00	10.00	8.00	7.00	8.00	9.00	10.00	5.00	9.00	6.00	7.00
C	5.00	3.00	8.00	6.00	12.00	9.00	9.00	11.00	1.00	6.00	11.00	3.00	10.00	11.00	11.00	12.00	8.00	9.00	9.00	10.00	6.00	10.00	8.00	7.00
D	2.00	7.00	4.00	10.00	4.00	8.00	8.00	9.00	3.00	4.00	8.00	3.00	4.00	5.00	12.00	8.00	9.00	10.00	3.00	5.00	8.00	5.00	2.00	4.00
E	6.00	7.00	7.00	4.00	11.00	8.00	9.00	11.00	4.00	6.00	7.00	3.00	8.00	7.00	10.00	7.00	6.00	6.00	8.00	10.00	6.00	9.00	5.00	4.00
F	7.00	8.00	10.00	4.00	9.00	10.00	8.00	10.00	7.00	9.00	11.00	3.00	12.00	10.00	11.00	10.00	10.00	10.00	11.00	11.00	5.00	10.00	8.00	6.00
G	7.00	5.00	7.00	4.00	9.00	8.00	7.00	10.00	8.00	6.00	6.00	2.00	11.00	3.00	10.00	10.00	6.00	5.00	7.00	10.00	5.00	10.00	8.00	5.00
H	3.00	6.00	8.00	8.00	7.00	11.00	8.00	9.00	4.00	7.00	8.00	2.00	10.00	6.00	11.00	9.00	9.00	7.00	7.00	10.00	7.00	9.00	7.00	8.00
I	2.00	4.00	5.00	2.00	8.00	5.00	6.00	11.00	2.00	4.00	5.00	1.00	11.00	10.00	11.00	12.00	3.00	4.00	3.00	11.00	2.00	6.00	5.00	2.00
J	5.00	4.00	4.00	5.00	10.00	8.00	9.00	10.00	4.00	6.00	5.00	6.00	11.00	10.00	9.00	7.00	7.00	3.00	7.00	11.00	7.00	6.00	6.00	7.00
K	7.00	5.00	8.00	5.00	7.00	11.00	8.00	11.00	2.00	5.00	7.00	1.00	8.00	5.00	8.00	8.00	6.00	8.00	7.00	10.00	1.00	11.00	8.00	4.00
L	4.00	8.00	7.00	9.00	10.00	11.00	11.00	7.00	6.00	5.00	11.00	4.00	9.00	3.00	12.00	11.00	6.00	7.00	8.00	12.00	8.00	9.00	6.00	8.00
M	5.00	7.00	8.00	7.00	6.00	9.00	9.00	10.00	3.00	5.00	7.00	1.00	8.00	8.00	9.00	6.00	8.00	6.00	7.00	9.00	4.00	9.00	4.00	6.00
N	7.00	7.00	10.00	7.00	10.00	8.00	11.00	11.00	7.00	6.00	7.00	6.00	6.00	10.00	11.00	11.00	9.00	6.00	8.00	11.00	7.00	10.00	9.00	9.00
O	1.00	5.00	7.00	8.00	7.00	11.00	7.00	10.00	2.00	7.00	9.00	1.00	8.00	8.00	11.00	10.00	9.00	11.00	6.00	9.00	8.00	10.00	6.00	7.00
P	3.00	7.00	8.00	6.00	10.00	10.00	7.00	11.00	3.00	7.00	8.00	1.00	10.00	7.00	11.00	11.00	4.00	7.00	7.00	9.00	3.00	10.00	4.00	4.00
Q	1.00	6.00	7.00	3.00	6.00	9.00	8.00	10.00	2.00	4.00	6.50	1.00	9.00	7.00	9.00	8.00	5.00	4.00	6.00	8.00	3.00	10.00	5.00	7.00
R	1.00	5.00	7.00	5.00	8.00	10.00	4.00	9.00	2.00	4.00	9.00	5.00	6.00	5.00	10.00	11.00	8.00	7.00	4.00	9.00	8.00	10.00	5.00	4.00
S	5.00	8.00	4.00	7.00	4.00	8.00	7.00	11.00	4.00	5.00	5.00	2.00	9.00	4.00	5.00	7.00	6.00	4.00	8.00	10.00	1.00	8.00	4.00	5.00
T	4.00	6.00	8.00	8.00	11.00	7.00	7.00	8.00	4.00	7.00	6.00	4.00	7.00	5.00	9.00	7.00	5.00	4.00	4.00	6.00	8.00	6.00	7.00	4.00
U	2.00	4.00	6.00	2.00	11.00	6.00	8.00	10.00	1.00	5.00	4.00	1.00	10.00	7.00	10.00	10.00	6.00	5.00	5.00	12.00	1.00	7.00	7.00	4.00
V	3.00	4.00	8.00	5.00	11.00	10.00	9.00	12.00	5.00	7.00	8.00	4.00	8.00	10.00	11.00	11.00	7.00	7.00	9.00	12.00	5.00	9.00	8.00	4.00
W	3.00	6.00	7.00	9.00	9.00	11.00	6.00	6.00	3.00	6.00	8.00	2.00	6.00	5.00	11.00	9.00	9.00	8.00	8.00	9.00	10.00	9.00	6.00	7.00
X	2.00	7.00	5.00	8.00	5.00	6.00	8.00	11.00	2.00	5.00	10.00	1.00	9.00	7.00	11.00	9.00	7.00	5.00	7.00	8.00	6.00	9.00	7.00	3.50
Y	5.00	3.00	7.00	2.00	10.00	9.00	5.00	10.00	1.00	5.00	4.00	2.00	10.00	12.00	9.00	12.00	4.00	4.00	2.00	11.00	2.00	7.00	3.00	8.00
Z	4.00	6.00	5.00	5.00	10.00	7.00	7.00	9.00	6.00	5.00	5.00	6.00	8.00	6.00	7.00	7.00	6.00	4.00	6.00	6.00	6.00	6.00	5.00	4.00
M	4.12	5.77	6.88	5.85	8.54	8.65	7.77	9.81	3.50	5.58	7.25	2.77	8.62	7.23	9.92	9.19	6.77	6.31	6.69	9.50	5.31	8.58	5.96	5.48
Mdn	4.00	6.00	7.00	6.00	9.00	8.50	8.00	10.00	3.00	5.00	7.00	2.00	9.00	7.00	10.00	9.00	6.50	6.00	7.00	10.00	6.00	9.00	6.00	5.00
d	0.12	0.23	0.12	0.15	0.46	0.15	0.23	0.19	0.50	0.58	0.25	0.77	0.38	0.23	0.08	0.19	0.27	0.31	0.31	0.50	0.69	0.42	0.04	0.48
s	2.05	1.50	1.70	2.26	2.34	1.72	1.56	1.47	2.00	1.24	2.09	1.73	1.88	2.49	1.57	1.83	1.80	2.17	2.13	1.84	2.53	1.65	1.73	1.84

Participants submitted qualitative comments describing the applied RSA delineation criteria. Many of the comments rather described the terrain. However, some of the comments relate to the terrain criteria applied. They can be split into three categories:

1. Connected area with slope angle above 30°.
2. Area with homogeneous plan and profile curvature. A typical example often mentioned was a significant change in terrain characteristics at the top, bottom or to the side of the RSA.
3. Terrain sector within a certain maximal distance from the supplied location: Although participants were aware, that a specific terrain sector was connected to the RSA, they would not take it into account, if it was far away.

The average polygon (yellow line) reflects all three comments to a certain extent.

3.2 Hazard

Beside the maps in Fig. 1 and 2 a histogram shows the distribution of the estimated hazard values. The x-axis depicts the terrain hazard scale [1..12], the y-axis shows the frequency of the quoted hazard.

The estimated terrain hazard varies among the 24 locations with standard deviations from 1.24 to 2.53 (Tab. 2). The absolute differences between the means and medians are low and are between 0.32 and 0.77. Fig. 1 and 2 show the mean value (red line) and a 95% sign test confidence interval for the median (dashed red line). The confidence interval is in most cases less than three hazard scores.

The participants also submitted qualitative comments describing the applied criteria during the quantification of the hazard. Similar to the first exercise most comments refer to a general terrain description. The remaining comments can be grouped into the following categories:

1. Slope angle.
2. Slope size.
3. Concave plan curvature indicating hazard, rather than convex plan curvature.
4. Consequences: High burial depth or critical trajectory in case of a fall.
5. Proximity to ridge.

4. CONCLUSIONS

The verbal feedback from the participants reflected a high agreement on two issues: The survey was time-consuming and perceived to be difficult. Nevertheless, several participants remarked that the reasoning process was productive.

It remains unclear, whether all participants understood the tasks in the same way. That refers in particular to the exclusion/inclusion of the avalanche consequences.

The difficulty of the tasks can be recognized in the relatively high variation of the estimated hazard (standard deviation=1.88). However, the interpretation should take into account the following two survey settings:

- The terrain hazard scale has quite a high number of levels (12 levels).
- The sites to be evaluated were deliberately selected at locations where it was not obvious how to assess the hazard. Hence, they had the potential to reveal disagreement.

Although the variation of the estimated hazard is relatively high, the average confidence interval of ±1.1 shows that the mean values are relatively robust.

The RSA polygons converge reasonably. Nevertheless each location shows individual outliers. Some of them are eventually due to a lack of a common understanding of the task.

There is a higher agreement among the qualitative criteria. Partly that may be due to the subjective nature of qualitative information. Most of the mentioned criteria were to be expected. However, for the first time these criteria could be systematically collected and prioritized.

The survey turned out to be useful for the subsequent development of a terrain classification algorithm (Harvey et al., 2018). With respect to the scope of the survey the following can be concluded:

- Qualitative knowledge: we got familiar with the 24 locations and gained knowledge on how experts assess terrain from a map. That was useful for visual inspection of results from automatic classifications.
- Quantitative data: The 24 mean values are comparable to the output of terrain classification algorithms. Nevertheless two issues limit the significance: First, it

is not clear whether the algorithm measures on the same scale as the survey does. Second, the amount of 24 points is too small for a proper validation of classification algorithms.

The main output of this survey are the 24 maps and histograms presented in Fig. 1 and 2. Their significance can be captured only through a meticulous location study.

It would be interesting to see how the experts would assess the terrain at these locations in a real outdoor situation.

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