ACCEPTABLE RISK FOR BACKCOUNTRY SKIERS AND RIDERS FROM AVALANCHE HAZARDS: DIFFERENCES IN UPHILL AND DOWNHILL TERRAIN SELECTION

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ABSTRACT: Backcountry skiers and riders move through terrain differently depending on whether they are traveling uphill, downhill or along rolling or flat terrain. For example, skiers often follow ridgelines or travel through denser tree cover when ascending but select more open and often steeper terrain when descending. The movement characteristics of a recreationist affects exposure to avalanche terrain hazard. Using a GPS point dataset (n=433,555 points from 687 individual tracks) of winter recreationist movement patterns from Colorado, USA, collected between 2011 and 2013, this analysis tested if it is possible to measure whether backcountry skiers and riders increased their exposure to terrain-related avalanche risk when traveling downhill, compared with traveling uphill. In other words, was backcountry skier/rider terrain selection more conservative when ascending? GPS points were segmented into uphill/downhill using an adapted Douglas-Peucker-Ramer generalization algorithm. Physical terrain variables including elevation, slope angle, slope curvature, slope position, aspect, terrain roughness, heat loading, and percent tree canopy cover for each point were used to characterize differences between the uphill and downhill portions of the trip. As a proxy for avalanche risk from snowpack conditions, differences in the forecasted avalanche danger (from North American scale of Low to Extreme) were tested as well. Results provide practitioners and researchers with insights into terrain selection and risk exposure for non motorized-assisted backcountry skiers/riders.

KEYWORDS: Terrain selection, GPS tracking, Recreation, GIS, Danger scale

1. INTRODUCTION

The use of a GPS receiver to quantify winter recreationist movement patterns offers an objective record of terrain selection. It is becoming increasingly common in winter recreation studies (e.g., Bielański et al. 2018; Miller et al., 2017; Olson et al., 2017; D'Antonio et al., 2010), including in studies specifically recording guided and unguided recreation in avalanche terrain (e.g., Hendrikx and Johnson, 2016; Hendrikx et al., 2015; Thumlert and Haegeli, 2018).

Recreationist terrain selection is only one part of complex set of interactions between snow, weather, terrain and human factors that all together characterize avalanche hazard. However, objectively measuring how recreationists move through avalanche terrain sheds light on underlying drivers of terrain selection and help to improve our understanding of exposure to terrain-related hazards.

Previous research suggests recreationists move through a landscape differently depending on their mode of travel (Olson et al., 2017). For example snowmobilers and hybrid motorized-assisted skiers/riders penetrate much deeper into the backcountry and away from maintained roads compared with backcountry skiers/riders. And overall skiers select steeper slopes than snowmobilers (Olson et al., 2017).

Research is lacking on differences in recreation movement patterns within one mode of travel. Field observation suggests backcountry skiers/riders move through a landscape differently depending on whether they are traveling uphill or downhill. For instance, in steep mountainous terrain, skiers/riders will often lay in a skin track up ridge features and ski down open slopes or slide paths (see Figure 1, for example). But these observations remain largely untested.

Here we use common terrain variables such as elevation, slope angle, slope curvature, tree cover and aspect—fundamentals to the Avalanche Terrain Exposure Scale (Statham et al., 2006; Thumlert and Haegeli, 2018)—in addition to terrain variables more common in ecological research, including slope position, heat load index and terrain roughness to quantify differences in uphill vs. downhill terrain selection among skiers/riders. Since exposure is related to time spent in avalanche terrain, we also approximate the differences in time spent moving uphill vs. moving

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downhill in the steepest terrain used by back-country skiers/riders sampled in the study.

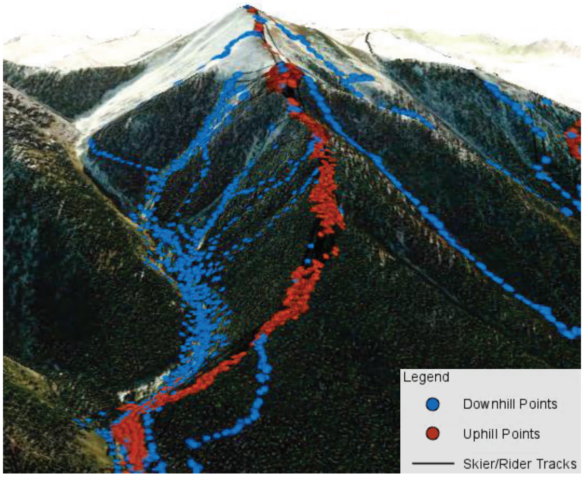

Figure 1: Example of skier/rider GPS locations segmented by downhill (blue) and uphill (orange) portions of trip.

2. METHODS

For this analysis, we used recreation data that were captured between 2011 and 2013 as part of a larger recreation and wildlife study in Colorado. Technicians approached recreationists at back-country access portals in the San Juan range of southwest Colorado, USA (Figure 2) and asked them if they would voluntarily carry a small passive GPS device (Qstarz, model BT-Q1300, position accuracy <10m, logging frequency of 5-sec) for the trip duration. GPS units were collected from drop-boxes at the end of each day and data downloaded as point locations. Only one GPS unit was carried per group, but group size was documented for each track. For a full account of sampling methodology, see Olson et al. (2017).

2.1 Data pre-processing

Data were analyzed using a combination of ArcGIS Desktop and Python scripts. For this analysis, a total of 433,555 points (from 687 individual skier/rider tracks) were segmented into uphill and downhill portions of the backcountry tour. Points were then assigned physical terrain variables based on their location, from a 10m DEM (USGS NED), which included elevation, slope angle, down-slope and across-slope curvature, slope position (from Evans et al. (2014) terrain position index at a local 30m and a medium 125m scale), terrain roughness, aspect (linearized for analysis into measures of eastness and northness), heat loading (a folded aspect by McCune (2007) where high values are steeper southwesterly sunny aspects, and low values are darker northeasterly aspects) and percent tree canopy cover from the 30m national land cover database (Homer et al., 2015). Points were also assigned the forecasted danger rating (North American Scale: Low (1) to Extreme (5)) for the day the point was recorded and for the combination of aspect and elevation for the location of the point from the avalanche forecast released by the Colorado Avalanche Information Center (CAIC).

2.2 Segmentation algorithm

We used an adapted Douglas-Peucker-Ramer algorithm to segment the points into their uphill and downhill portions. The original algorithm—introduced independently by Ramer (1972) and Douglas and Peucker (1973) was used for 2D line generalization on the x and y coordinates of vertices along the line. Here, we adapt it for 3D usage by applying the accumulated xy inter-point distance of all points along a track to the algorithm's x coordinate and the elevation of the point to the algorithm's y coordinate. The iterative algorithm identifies transition points where elevation change along the track reverses (from uphill to downhill and vice versa) if a user-input threshold elevation is exceeded, allowing segmentation of all points along a track as either uphill or downhill.

This adapted algorithm is effective at uphill and downhill segmentation even when terrain is undulating since it looks for significant elevation changes over the track. Skiers/riders often lap terrain several times during their trip, which the algorithm also effectively captures. Figure 2 provides an overview map of the data used in analysis and examples of the segmented points.

2.3 Data analysis

Once points were processed, we compared variable distributions between the uphill points and the downhill points with a one-way ANOVA (at $p < 0.05$). We also compared distributions on steep slopes—in the 95th percentile of slope angle distribution (Hendrikx and Johnson, 2016) and measured differences in the time spent on the uphill vs. downhill portions of the recreationist's trip.

3. RESULTS

All variables had statically significant differing means, however the effect sizes were small (largest were aspect (northness) with adjusted r^2 of .013 and heat load index with adjusted r^2 of .012). Since points were recorded every five seconds when moving and skiers/riders move more slowly uphill than downhill, 67% of the points were uphill points and 32% were downhill points. In other words, skiers/riders spent on average two thirds of their moving time traveling uphill compared with one third of the time moving downhill. The mean moving speed of uphill points was 2.7kph, compared with 7.16kph for downhill points.

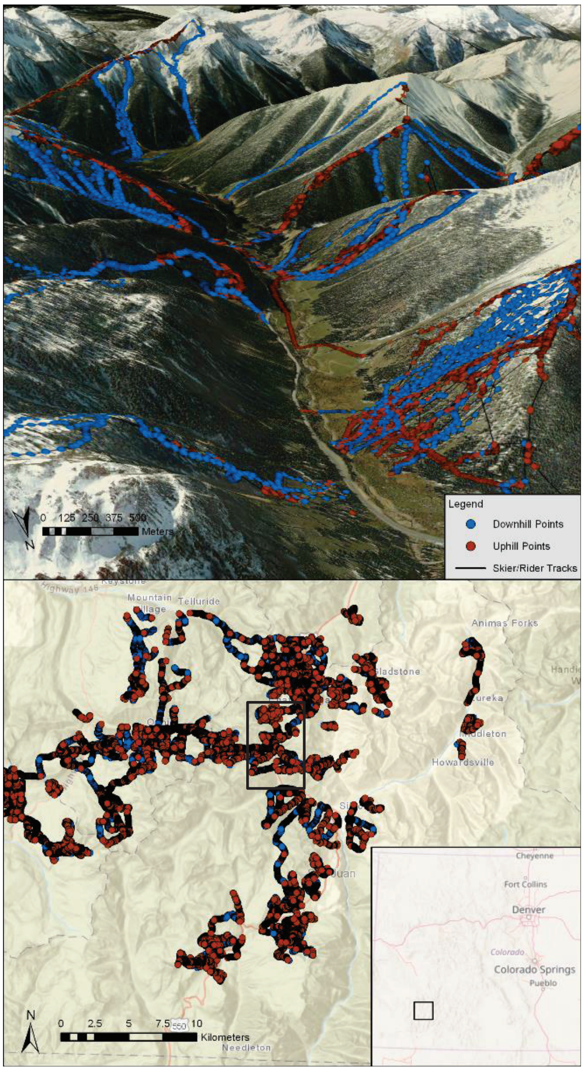

Figure 2: Backcountry skier/rider data from San Juan range in southwest Colorado, USA segmented by downhill (blue points) and uphill (orange points) portions of trip. Top scene shows example data, bottom map shows all data used in analysis. Basemaps: Esri. Note: Scale bar in scene is linear distance at center of the scene.

While there are differences in the terrain features (e.g., ridge vs. gulley) that characterize uphill vs. downhill travel, these differences are small and hard to detect since skiers/riders move through a range of terrain features throughout their trip. But when we look specifically at the points located on the steepest slopes (95th percentile of steep slope angles recorded in dataset, or slopes greater than 33.5deg), some clearer differences emerge. First, both measures of aspect and the heat load index suggest skiers/riders more often select southwesterly aspects while moving uphill vs. easterly aspects while moving downhill (Figure 3).

The head load index measures a slope's angle towards the sun (high values, correspond with sunnier, southwesterly steep slopes and low values correspond with darker, north easterly steep

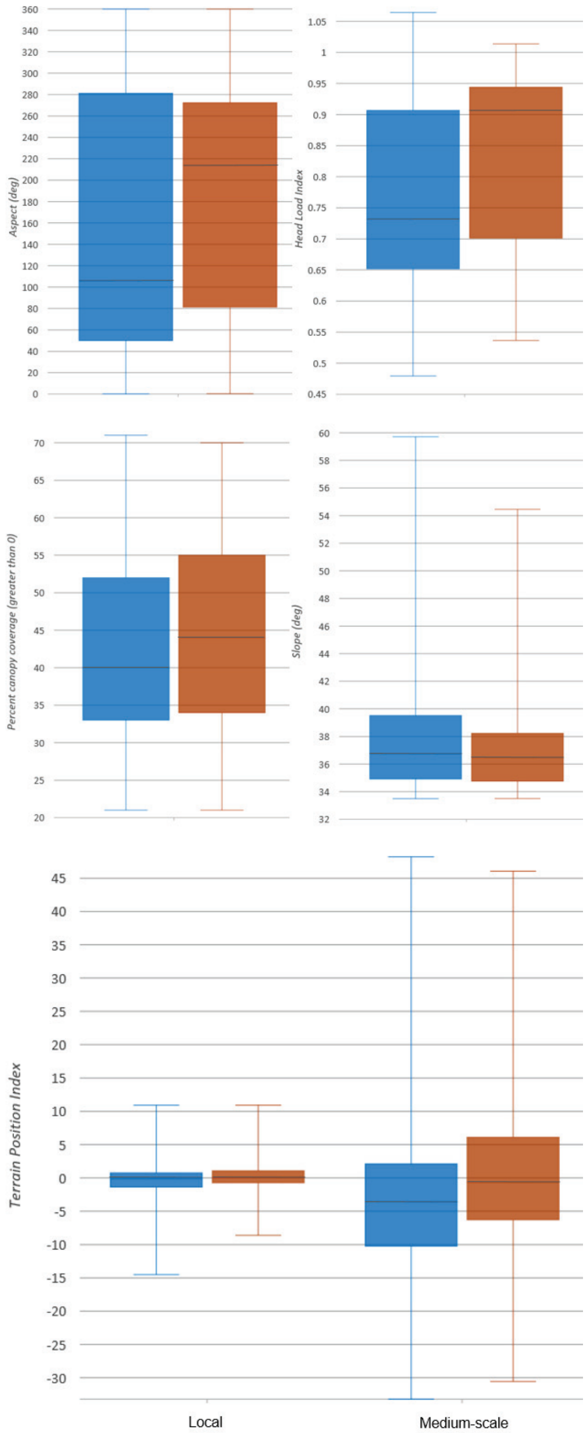

Figure 3: Example boxplot distributions (median, 25th and 75th quartiles, range) for data from the steepest slopes (95th percentile) to highlight differences in downhill (left, blue) and uphill (right, orange) points. Clockwise from top left: Aspect, heat load index, slope angle, local and medium-scale terrain position index and percent tree canopy cover.

slopes. Downhill points have a wider distribution of aspects. Also, skiers/riders moving uphill select slightly more concave features (medium-scale TPI such as ridges) but skiers/riders moving downhill cover a wider range of slope convexity/concavity. In both cases, the distributions are skewed towards more concave features at a local and medium scale-measure.

Finally, there was minimal difference in the forecasted avalanche danger between uphill and downhill points when looking at all points (downhill mean of 2.4 and uphill mean of 2.42), but on the steepest slopes that spread increases. The mean forecasted danger rating was 2.35 for downhill points and 2.46 for uphill points. There were 243 individual tracks (35% of all tracks) that included points in the steepest 5% of terrain when the forecasted danger was considerable or high.

4. DISCUSSION AND FUTURE RESEARCH

The results of this analysis highlight important differences in the ways in which skiers/riders select terrain when moving uphill compared with downhill. The differences in terrain selection are for the most part small. However, clearer differences emerge for the portions of the trip on the steepest slopes. And, the results have implications for skier/rider exposure to terrain-related avalanche hazards in the backcountry.

On the steepest slopes, backcountry skiers/riders traveling downhill will select steeper, more northeasterly, and more convex slopes compared with their uphill portions of the trip. These results fit with field observations. The question of whether skiers/riders are willing to accept a higher level of risk when traveling downhill are harder to see from these results. It is important to note that 70% of the individual tracks in this analysis included points in the steepest 95% of slopes in the dataset, suggesting most skiers/riders move through a wide range of terrain.

Terrain selection is more complex than can be measured by the terrain variables presented here. The availability and location of access portals to the backcountry and the presence of established skin tracks, the seasonal snowpack and the recreationist demographics and familiarity with the terrain are all important drivers to the real-time decision making of exactly where a recreationist goes in the backcountry. However this analysis provides an important, objective documentation of how skiers/riders use a landscape.

Researchers and practitioners interested in improving public messaging about decision making in avalanche terrain may find these results interesting for two reasons. First, a small proportion of skiers/riders move through steep terrain even when forecasted danger is considerable or high. Accepting the limitations of the resolution of the DEM available for analysis and the accuracy of the GPS units, our data show an average moving time of more than two minutes on the steepest 5% of slopes for data from the 243 individual tracks. In other words, more than a third of skiers/riders sampled spent some time on steep slopes with considerable or high forecasted danger. More investigation is necessary to determine if there is a pattern to where these points are located.

Second, while terrain variables measured here suggest that skiers/riders may select slightly more hazardous terrain when traveling downhill, this is balanced by the fact that they spend less time traveling downhill. It highlights the importance of encouraging conservative terrain selection for both downhill and uphill travel. More research is needed on exactly where recreationists are willing to accept the highest terrain-related risk.

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