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Topographic setting of archaeological survey in the Boreal Forest of Alberta

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ABSTRACT

The archaeological record of the Canadian Boreal Forest is dominated by shallowly buried sites with little to no datable artifacts or stratigraphy. This has led to characterizations of the region as an area of low scientific interpretive value. However, the factors that underlie this skew to shallow sites are rarely formally examined. Here we use a geomorphon-based terrain classification to assess the role of topographic setting in the placement of archaeological survey points. Our results show that there is considerable bias in current archaeological survey methods towards landforms that disperse sediment. This reduces the likelihood of finding deeply buried or stratified sites and calls into question the assertion that datable sites are largely absent from the region. We recommend that increased sampling of low-lying terrain should be a regular component of Boreal Forest survey methodology.

KEYWORDS

Boreal Forest, archaeological survey, geomorphon, topography

1. Introduction

A source of bias in Boreal Forest archaeological survey is preferential sampling of high relief landforms such as ridges and hilltops. This pattern contributes to overrepresentation of mixed component and shallowly buried sites in the archaeological record because these landforms are more likely to erode sediments than to accumulate deeply buried or stratified depositional sequences (Hamilton, 2000; Bereziuk et al. 2021). These types of sites are difficult to date because they rarely contain datable material and lack stratigraphic context (Woywitka 2016; Ives 2017; Poletto 2019). This lack of temporal information has led to characterization of the Boreal Forest archaeological record as one of low interpretive value. Whether or not this characterization is justified has been questioned (Hamilton 2000), but few studies have attempted to quantify effects of survey bias in the region. An analysis of patterns in the Lower Athabasca River drainage of northeastern Alberta found that over 90% of shovel tests were placed on high-relief landforms, even though low-lying terrain elements yielded sites at similar rates (Woywitka and Froese 2020). These results, combined with the occurrence of datable sites on the margins of wetlands (Ives 2017; Woywitka et al. 2022), suggest that there is overlooked potential for archaeological sites in lower topographic settings in the Lower Athabasca region. In this paper we expand on the methods of Woywitka and Froese (2020) to assess whether or not a similar bias is evident in the Boreal Forest of northern Alberta as a whole.

This study is an examination of just one of the primary variables used in archaeological predictive modeling: topography. Our work here does not present a detailed model of where archaeological sites can occur in the Boreal Forest. Instead, we assess how archaeologists have used topographic parameters to guide placement of survey areas and discuss how this affects cultural resource management (CRM) practices and the types of sites that are found. Although our observations can inform models of site distribution, they cannot explain past land use patterns on their own.

2. Study area

Our study area is delineated by the intersection of the Boreal ecoregion, as defined by Downing and Pettapiece (2006), with available Light Detection and Ranging (LiDAR) coverage (Figure 1). We omit adjacent Foothills ecoregions (e.g., eastern slopes of the Rocky Mountains, Swan Hills, Pelican Mountain) because the higher elevation and increased topographic ruggedness is markedly different than the lowlands and requires different survey strategies.

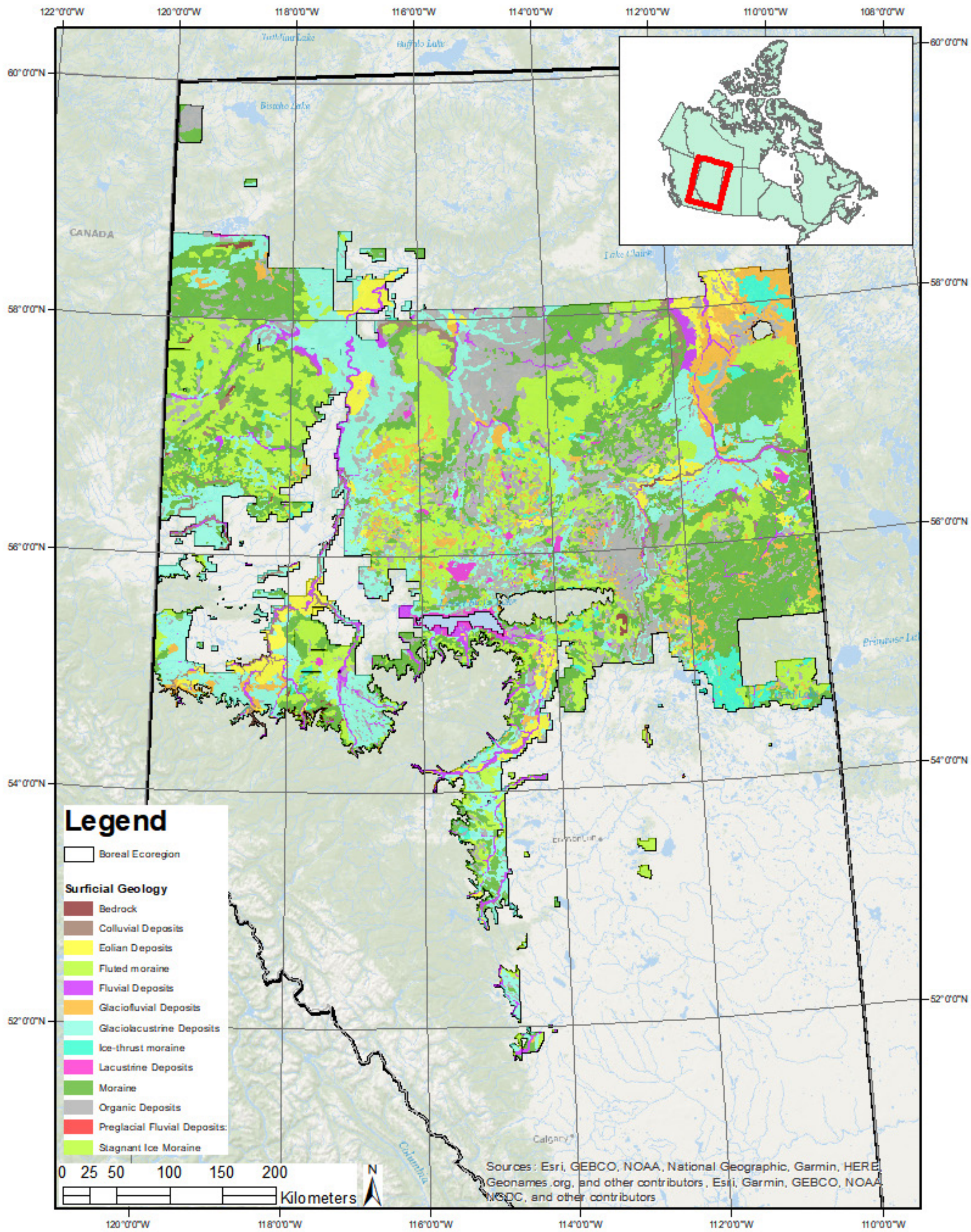

Figure 1. Study area with surficial geology.

The Boreal ecoregion is the largest in Alberta, covering 58% of the province and enveloping much of its northern land base. Our study area overlaps a considerable portion of the Boreal ecoregion (212,500 square kilometres). Vegetation is typified by the presence of extensive coniferous, deciduous, and mixed-wood forests interspersed with expansive wetlands and numerous lakes (Downing and Pettapiece 2006). The region is transected by several large rivers (e.g., North Saskatchewan, Athabasca, Mackenzie, Peace) and numerous associated tributaries.

The topography of the Boreal ecoregion is level to gently undulating and characterized by large tracts of wetlands. This allows subtle positive-relief features to appear more pronounced on the landscape and these landforms serve as focal points for animals, humans, and the scientists that study their ecologies and movements. The surficial geology of the study area is characterized by Late Pleistocene-aged deposits related to glacial and deglacial processes (Fenton et al. 2013). Various moraine deposits (e.g., fluted, stagnant-ice, and ordinary moraines), represent 48% of the surface area. Other Late Pleistocene-aged deposits (e.g., glaciolacustrine, glaciofluvial, and preglacial deposits) take up 24% of the region. The remainder are Holocene-aged surficial deposits; eolian (4%), fluvial (3%), organic deposits (16%), and colluvial deposits (2%). Holocene deposition occurs largely in river valleys, waterbody shores, wetlands, and mass movements.

3. Data and methods

We evaluate current sampling patterns by comparing shovel test and subsurface exposure data with a geomorphon-derived terrain classification (Jasiewicz and Stepinski 2013). The geomorphon approach calculates intervisibility along eight lines-of-sight to determine relative heights from a focal pixel. The different permutations of the local relief on the eight lines-of-site are then classified into ten common landforms (Table 1, Figure 2; Jasiewicz and Stepinski, 2013). Summits, ridges, shoulders, and spurs are characterized by convex curvatures that are more likely to shed than collect sediment. We refer to this group of elements as dispersing landforms (Table 1). Flat areas are stable, whereas slopes are characterized by sediment movement driven by gravity or surface runoff. Hollows, footslopes, valleys, and depressions have concave curvature and serve as receiving areas for transported sediment. These latter four categories are the most likely elements to contain deeply buried or stratified archaeological sites. We refer to this group of elements as sediment traps (Table 1). We chose the geomorphon terrain classification system because it is more computationally efficient than traditional moving window terrain classifications (e.g., Pennock et al. 1987; Wood 1996; MacMillan and Shary 2009). This enabled us to calculate a terrain classification for the entirety of the Boreal ecoregion in Alberta using a high-resolution LiDAR digital elevation model (DEM).

Table 1. Geomorphon classes grouped by sediment flux characteristics.

Number	Landform Element Name	Landform Element Group
1	Flat	Stable
2	Summit	Dispersing
3	Ridge	Dispersing
4	Shoulder	Dispersing
5	Spur	Dispersing
6	Slope	Movement
7	Hollow	Sediment trap
8	Footslope	Sediment trap
9	Valley	Sediment trap
10	Depression	Sediment trap

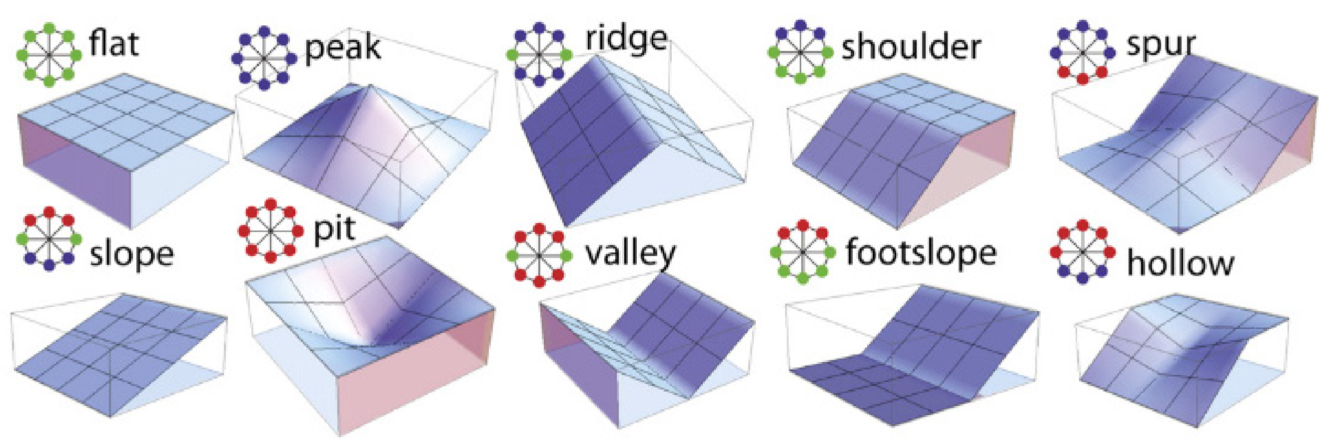

Figure 2. Illustration of geomorphon classes (from Jasiwicz and Stepinski 2013).

Our analysis is completed in four steps:

1) Determination of the scales of spatial clustering in shovel test and subsurface exposure locations by spatial autocorrelation analysis;

2) Classification of the study area into landform elements at the clustering scales identified in Step 1. Landform elements are calculated using the geomorphon approach;

3) Assessment of scale effects on landform element classifications using image change detection;

4) Analysis of the distribution of test locations relative to landform elements and sedimentary context by statistical and spatial analyses.

3.1 Data

Archaeological survey data were acquired in March 2022 from the Archaeological Survey of Alberta. The dataset was subsampled to include only data that were recorded after 2015. This filter was used because 2015 represents the first full year that standardized geospatial data formats were required by the Archaeological Survey of Alberta. This reduces spatial error associated with digitization of data from paper maps and potentially inaccurate Global Positioning System (GPS) data. Our analysis therefore covers only the most recent six years of archaeological survey in the Boreal Forest. There are a total 115,771 points in the data set, consisting of shovel tests, subsurface exposures, and excavation blocks. The data were provided as an ArcGIS feature service.

LiDAR data were provided by the Government of Alberta. In its original form, the data have 1 x 1 metre horizontal grid size, with a vertical accuracy of ±0.60 metres. We used a resampled 12 x 12 metre horizontal grid size version of these data to derive geomorphons and to produce hillshades for mapping. The resampling was done in ArcMap 10.5, using bilinear interpolation. Multidirectional hillshades were used to visualize terrain in order to minimize shadowing and other illumination artifacts.

3.2 Step 1: Identifying the scale of spatial clustering in survey data

The scale of geomorphon analysis must be consistent with the phenomena being examined. For example, using a 1 kilometre resolution DEM and a search radius of 3 kilometres would result in landform elements far too large to detect anthills. Similarly, using a sub-metre resolution DEM and a search radius of 3 metres would divide the landscape into far too much detail to meaningfully portray Mount Everest for the purpose of choosing a climbing route. Geomorphons can be derived at different spatial scales by varying DEM resolution and the size of the outer search radius used to calculate landform elements (Jasiewicz and Stepinski 2013). The outer search radius represents the maximum length along the line-of-sight calculations that the algorithm will use to calculate the output. Coarser DEM resolutions and larger search radii result in classifications that represent the landscape at broader scales. Finer resolutions and radii will create results at more detailed scales. For this study we use the size of shovel test areas in the Boreal Forest to determine our scalar "sweet spot."

We determined the size of shovel test areas using the Incremental Spatial Autocorrelation tool in ArcGIS Pro 2.8. This tool measures the degree of spatial autocorrelation (i.e., the tendency of features that are close together to have similar values) by calculating Global Moran's I (Getis and Ord 1992) at varying distances. A z-score is calculated for each distance, with higher z-scores indicating increased spatial clustering. Peaks in z-score indicate distances at which clustering is particularly pronounced. In this study, these distances serve as a proxy for the spatial scale that archaeologists have used when deciding the location and shovel test intensity at a survey location. For computational efficiency, we ran this tool on a subset of 3,545 shovel tests, all from within the NTS 84A Mapsheet. Because the tool cannot be run on single incidence points, the shovel test data were aggregated. Aggregation was achieved by dividing the mapsheet area into a 10 metre grid, and then assigning a shovel test count to each grid cell via a spatial join with the shovel test point data. Two peaks were observed in the data, one at ~70 metres and another at ~170 metres (Figure 3).

3.3 Step 2: Geomorphon classification

We ran geomorphon calculations using the nearest odd-number outer radii to the clustering distances identified in Step 1 using the r.geomorphon add-on in GRASS GIS 7.8.7. For the 12 metre DEM, this translates to search radii of five pixels (60 metres; Run A, Table 1) and 15 pixels (180 metres; Run B, Table 1). Figures 4 and 5 show examples of a geomorphon classification using a five-pixel radius.

In addition to the outer search radius discussed above, there are three other parameters that control the output of the r.geomorphon module: inner search radius, flatness threshold, and flatness distance (Table 2). The inner search radius serves as a "skip" radius; the function of this parameter is to exclude small irregularities and reduce noise in the output. The flatness threshold allows the user to control what is considered a flat surface and is dependent on the type of analysis

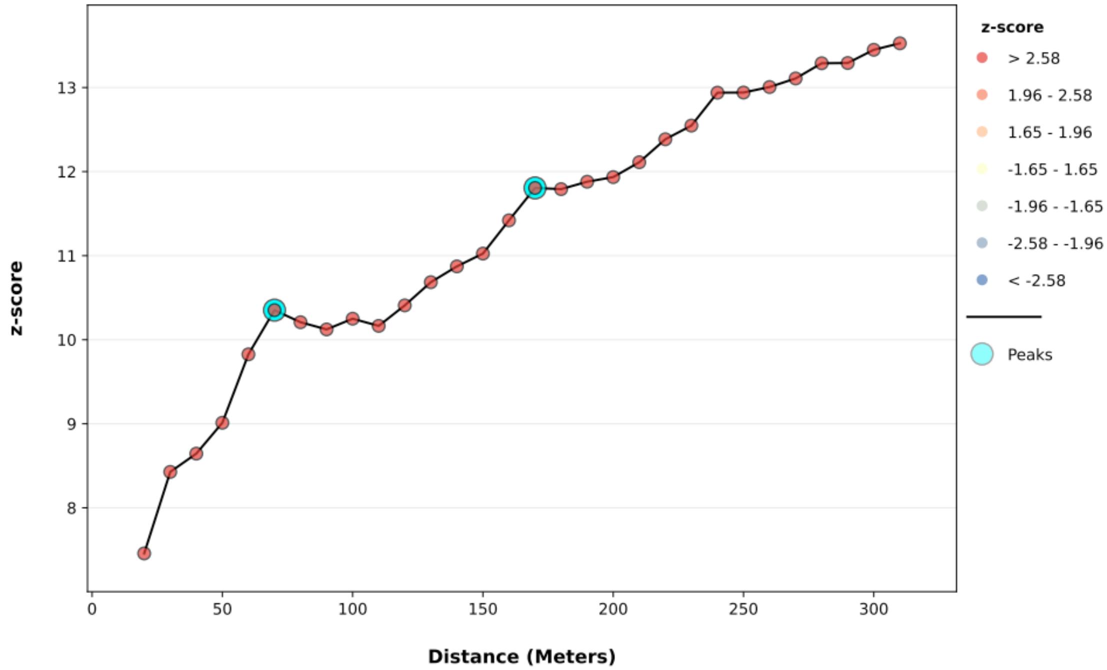

Figure 3. Incremental spatial autocorrelation results. Peaks at 70m and 170m indicate distances of the most pronounced spatial clustering of shovel tests.

being performed. Flatness distance is used to constrain the effects of apparent low relief in low resolution DEMs. This parameter is not used in our analysis because we are using a higher resolution elevation product. In this study, we used trial and error and visual assessment of outputs to determine appropriate inner radii and flatness thresholds.

Table 1. Geomorphon classes grouped by sediment flux characteristics.

Parameter	Run A	Run B
Outer radius (m)	60	180
Inner radius (m)	0	36
Flatness threshold (°)	1	1
Flatness distance (m)	n/a	n/a

3.4 Step 3: Assessment of scale effects on geomorphon calculations

Percent area was calculated for each landform element category to compare regional scale effects between the two runs. Pixel-by-pixel changes between Runs A and B were calculated to assess local changes and the categories most affected by varying geomorphon parameters. This was achieved by first creating a multidimensional change detection raster in the Change Detection Wizard module of ArcGIS Pro. This product does not provide pixel counts per change category, so "flat" change detection raster using the Compute Change Raster had to be computed. The raster attribute tables of these two change detection datasets were then joined on the "value" field to calculate summary statistics.

3.5 Step 4: Analysis of the distribution of test locations relative to landform elements

All subsurface test and surface exposure point data were intersected with the two geomorphon classifications using the Extract Values to Points tool in ArcGIS Pro. A chi-squared test ($\alpha p = 0.05$) was performed to assess whether or not test locations are distributed proportionally among the different landform elements in the study area. The null hypothesis in this test is that shovel tests will be distributed in proportion with the area of each landform element in the study area. For example, if slopes account for 35% of the total study area, then 35% of tests will occur within the slope category. The alternative hypothesis is that tests are not proportionally distributed by landform element area. The chi-squared test, descriptive statistics, and charts were created in Microsoft Office Excel.

Variable response curves generated with the Maxent habitat suitability modeling software (Phillips et al. 2022) were also used to investigate the associations between subsurface inspection points and landform elements. Two suitability models were created using a single categorical variable: landform element. One model included only negative points, and the other one included only positive points. These curves provide an approximation of how much of the final model can be attributed to each landform category, scaled from 0 to 1. In this application the results indicate which landform elements best explain the existing distribution of subsurface tests.

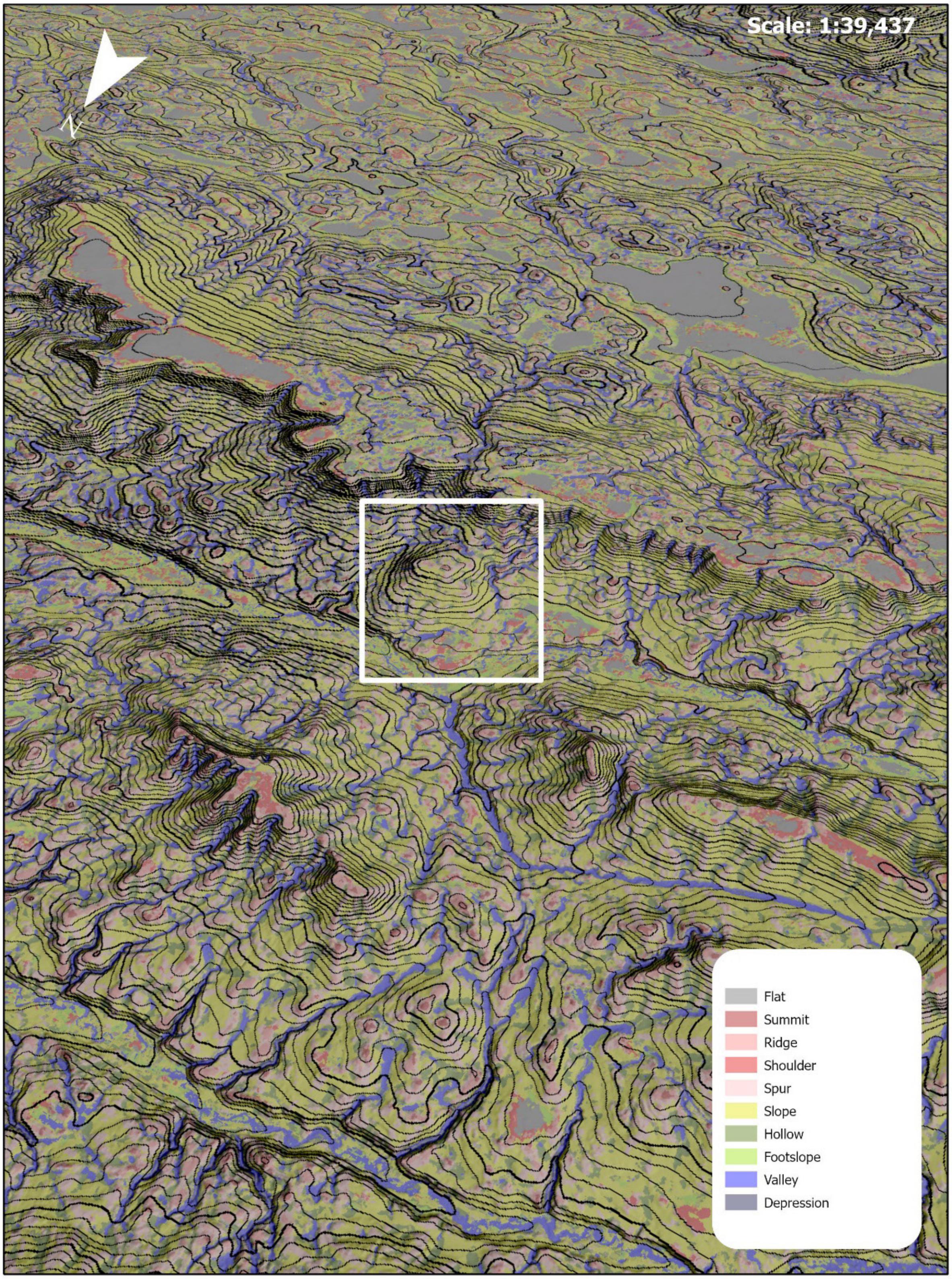

Figure 4. Oblique view of a geomorphon classification near Swan River, Alberta. Areas in red shading indicate elements that are likely to be characterized by erosion, areas in grey shading are flat and likely to remain stable, yellow areas are slopes that are characterized by sediment transport, while green-shaded areas are likely to collect sediment. White box indicates extent of Figure 5. Contour interval is 10 metres.

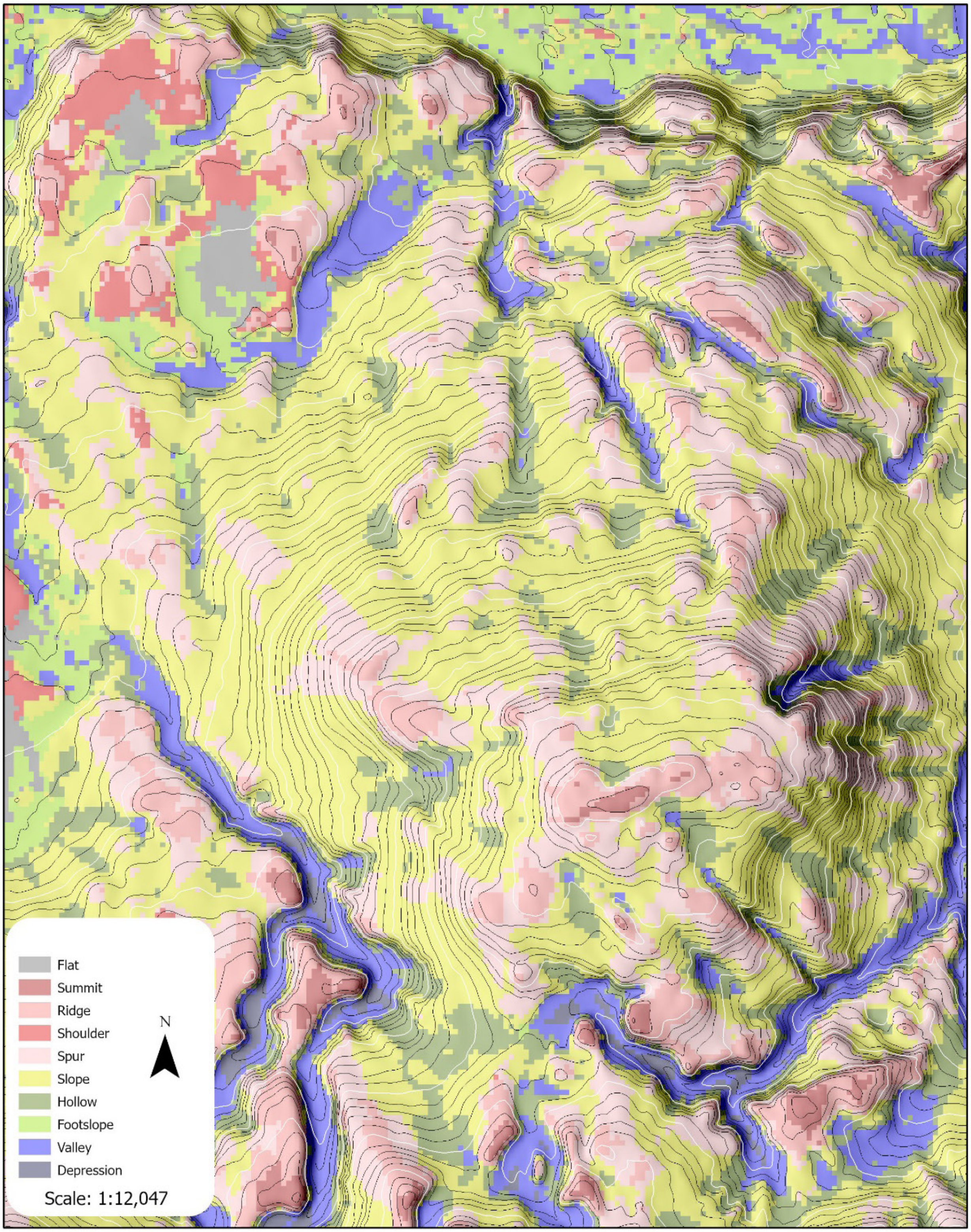

Figure 5. Plan view of a geomorphon classification near Swan River, Alberta. Areas in red shades indicate convex elements that are likely to be characterized by erosion, grey shades are flat and likely to remain stable, yellow areas are slopes characterized by sediment transport and green shades indicate concave areas likely to collect sediment. Contour interval is 5 metres.

4. Results

4.1 Scale effects

The two geomorphon runs returned relatively consistent landform element proportions across the study area (Figure 6). Run B returned larger areas for most landform elements, except for the slope category, which saw a 7% increase in Run A over Run B. The slope category occurred in 55% of all changed pixels, mostly transitioning to spurs, hollows, and footslopes (Figure 6).

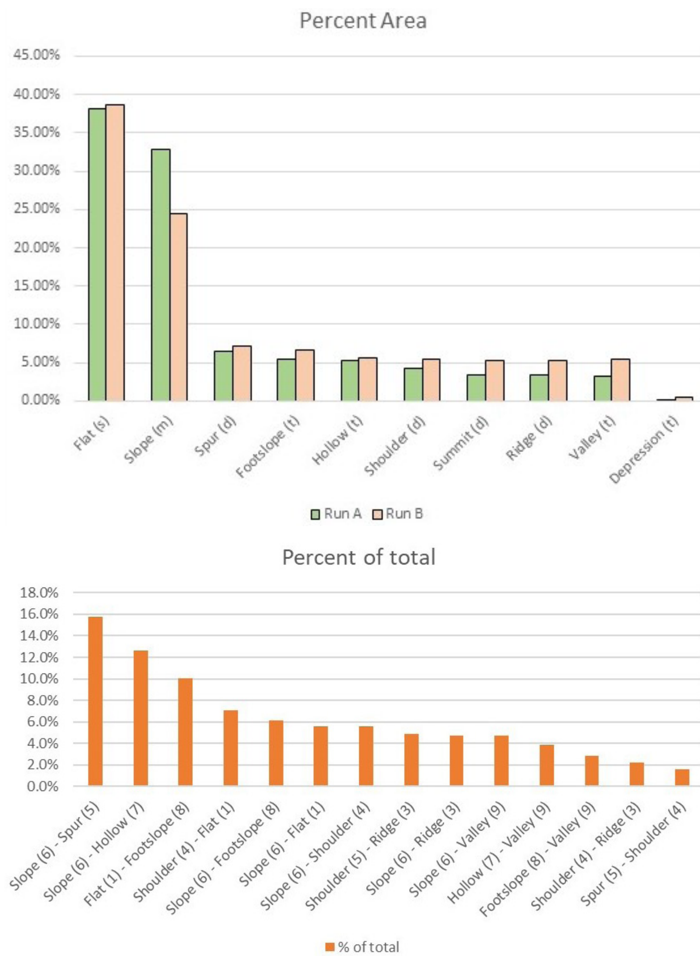

Figure 6. Percent area of each landform element in Run A and Run B (top) and the most common pixel transitions between Run A and Run B (bottom).

4.2 Distribution of test locations relative to landform elements

4.2.1 Geomorphon Run A (60 metre search radius)

Landform elements that disperse sediment account for 67.4% of all subsurface tests in Run A, while slopes account for 25.7%, traps combine for 4.3% and stable, flat areas 2.7% (Figure 7) The chi-squared test yielded a value of 425437.1178 (αp = 0), indicating that tests are not distributed in proportion to landform element area. Elements that disperse sediment all exceed expected proportional values (140% to 881%; Figure 8). Slopes are tested 49%, flat areas 90% and sediment traps 57-90% less than expected proportional values (Figure 8).

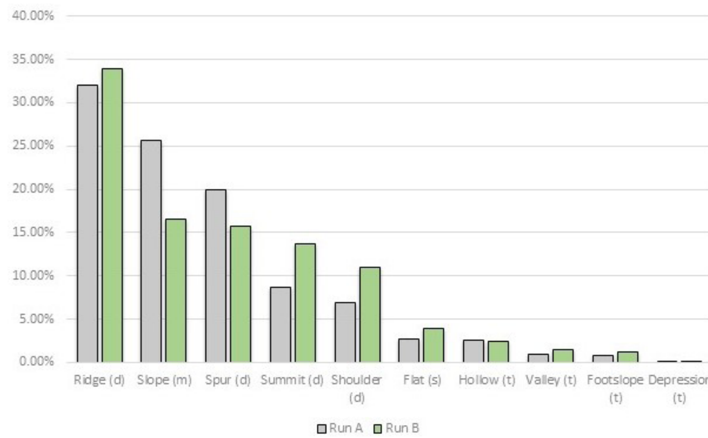

Figure 7. Proportion of shovel tests by landform element (n=115,771). Letters in brackets indicate the character of sediment movement; d = dispersal, m = movement, s = stable, t = trap.

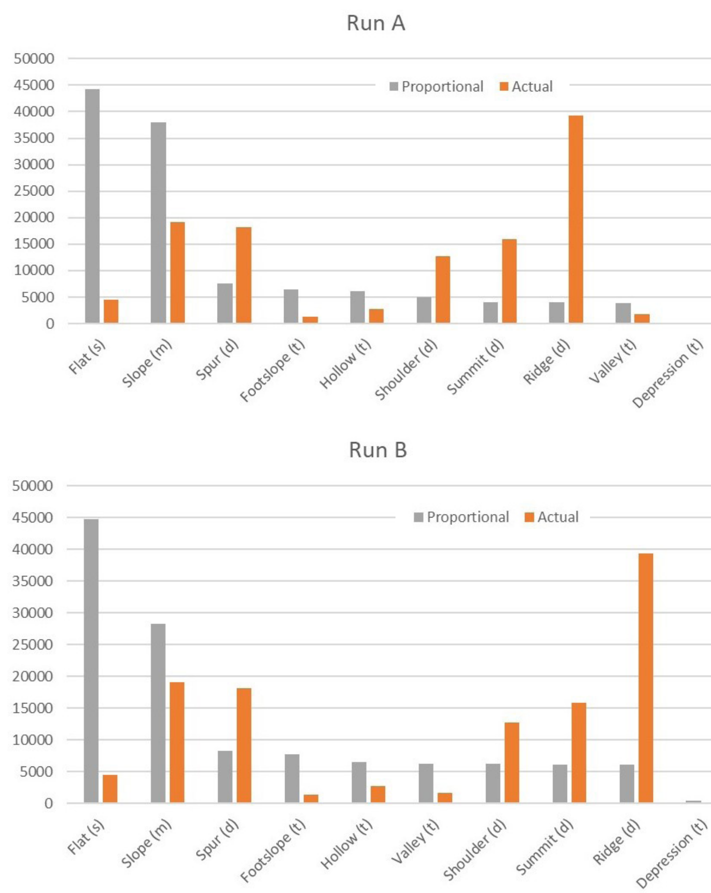

Figure 8. Comparison of actual subsurface tests with expected values if testing was proportional to the percent area of landform elements in the study area.

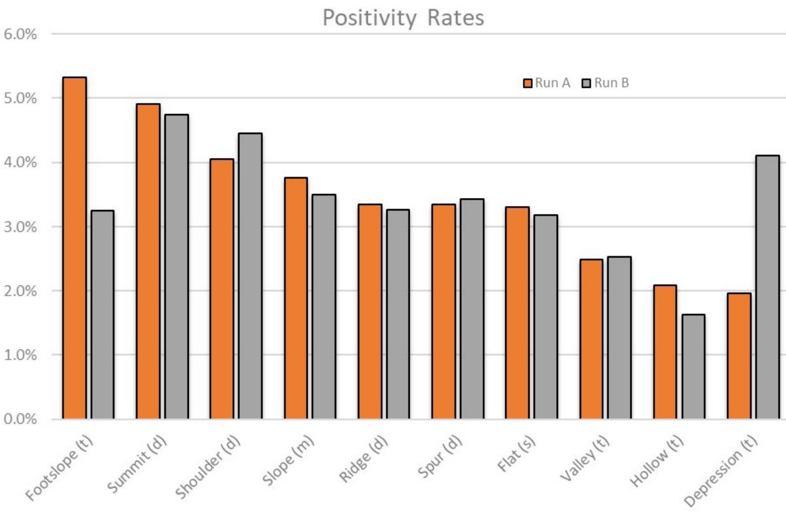

Figure 9. Positivity rates per landform element (n=4,177).

A total of 4,177 (3.6%) subsurface tests returned positive results. Positivity rates in Run A range from 2.0 to 5.3%, with footslopes, summits, and shoulders returning the highest rates (4.1-5.3%; Figure 9). Slopes, ridges, spurs, and flat areas return positivity rates of 3.3–3.8%, while valleys (2.5%), hollows (1.6%) and depressions (2.1%) return the lowest positive returns (Figure 9). The Maxent results indicate that negative and positive tests are most strongly associated with summits, ridges, and spurs (Figures 10 and 11). Negative tests have intermediate association with slopes, shoulders, and depressions and low association with flat areas, valleys, hollows, and footslopes. Positive tests follow this same pattern with the exception of depressions, which have low association (Figures 10 and 11).

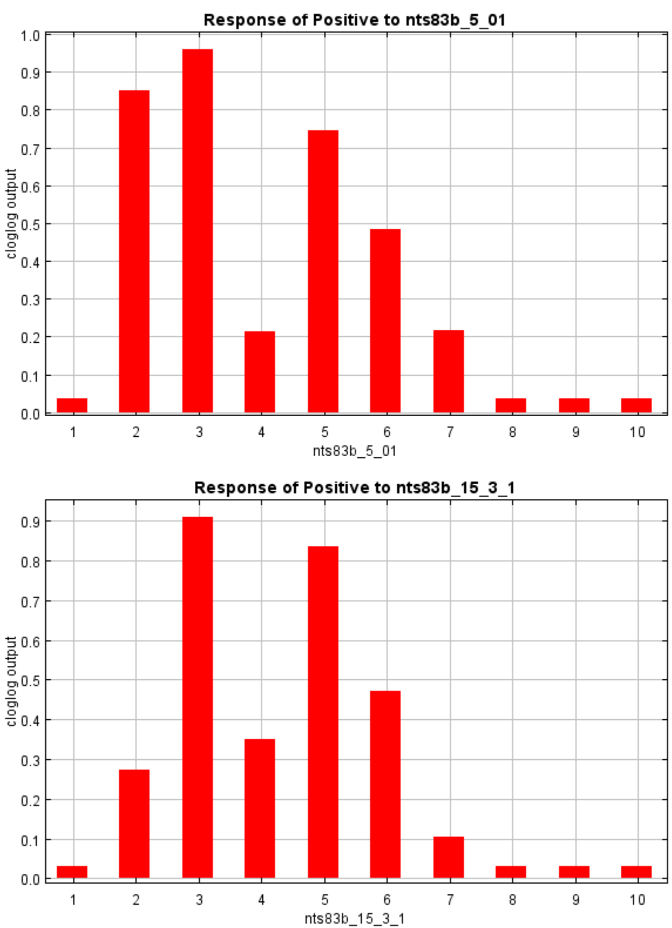

Figure 10. Maxent results for negative tests for Run A (top) and Run B (bottom).

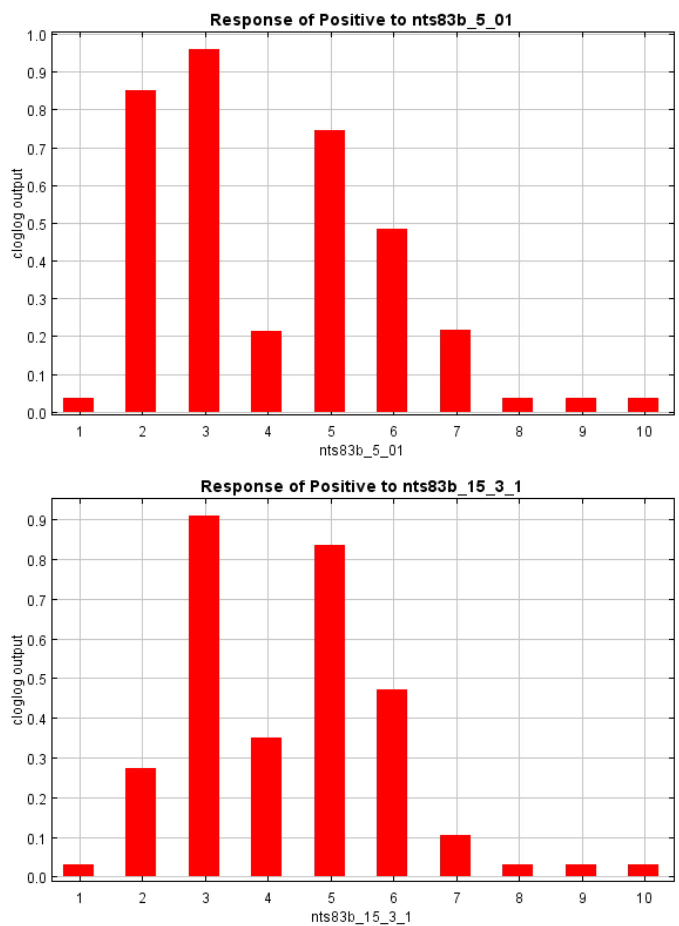

Figure 11. Maxent results for positive tests for Run A (top) and Run B (bottom).

4.2.2 Geomorphon Run B (180 metre search radius)

Landform elements that disperse sediment account for 74.4% of all subsurface tests in Run B, while slopes account for 16.6%, traps combine for 5.2% and stable, flat areas 3.9% (Figure 7) The chi-squared test yielded a value of 262,894 (αp = 0), indicating that tests are not distributed in proportion to landform element area. Elements that disperse sediment all exceed expected proportional values (104% to 540%; Figure 8). Slopes are tested 32% less than expected proportional values and sediment traps are tested 57-90% less than expected (Figure 8).

Positivity rates in Run B range from 1.6 to 4.7%, with summits, shoulders, and depressions returning the highest rates (4.1-4.7%; Figure 9). Ridges, spurs, footslopes, and flat areas return positivity rates of 3.2–3.5%, while valleys (2.5%) and hollows (1.6%) return the lowest positive returns (Figure 9). The Maxent results mimic Run A, with some slight variation in values, but the same overall trends (Figures 10 and 11).

5. Discussion

5.1 Geomorphons and survey patterns

The clustering of shovel tests at ~70 metres and ~170 metres identified in the incremental spatial autocorrelation analysis (Figure 3) could represent variations in testing approaches, with the smaller patch size representing well defined, polygonal landforms like hilltops, and the larger patch size representing long, linear features like ridges associated with valley edges. This interpretation should be treated with caution because archaeological data are a poor fit for this type of autocorrelation analysis. Global Moran's I calculations are more accurate when the phenomenon being measured is normally distributed on the landscape (Getis and Ord 1992); this is not the case for shovel test locations. Based on visual assessment of the resulting classifications we are confident that these scales roughly match the scale at which archaeologists make survey targeting decisions. However, statistical analyses that account for the non-normal distributions of archaeological data should be used in future work to corroborate our preliminary assessment.

The mostly consistent proportions of landform elements in Run A and Run B indicate that changes in search radius had limited effect on regional geomorphon results at our chosen analytical scales (Figure 6). The smaller proportions of the slope category in Run B are likely explained by the implementation of a 36 metre skip radius in the analysis. This parameter may have smoothed noisy returns in complex terrain characterized by the presence of small, isolated areas of sloped topography that remained intact in the finer resolution Run A. The change vectors shown in Figure 6 indicate that most switches occurred in localized areas near transitions at the tops (i.e., spurs, ridges, summits, shoulders) and bottoms (i.e., hollows, footslopes, valleys) of slopes. Our results suggest that geomorphon classifications using 60-180 metre outer search radii would produce classifications useful for archaeological modeling. We favour the larger radius because the results are less noisy, but image filtering could also reduce noise in smaller radii classifications.

Our chi-squared results indicate that archaeological testing has not occurred in proportion to the distribution of landform elements in the study area. Landform elements that disperse or transport sediment have been tested in far greater proportion than their occurrence on the landscape and in greater proportion than all other elements except for slopes (Figures 7 and 8). Testing rates vary in concert with changes in geomorphon classifications between Runs A and B, suggesting that many of these tests are located near transitions of sloped terrain with adjacent landform elements, especially dispersing ones (Figure 7). This is consistent with traditional sampling techniques in the Boreal Forest, in which prominent, high-relief landforms are targeted regularly (Hamilton 2000; Bereziuk et al. 2022).

Positivity rates show that most positive shovel tests occur on dispersing landform elements, and that these elements generally return archaeological material at higher rates than slopes or sediment traps (Figure 9). The Maxent results confirm that the relationship between dispersing landforms and positive tests is strong in the entire sample population (Figures 10 and 11). However, footslopes had the highest positivity rate in Run A, and depressions had the third highest return rate in Run B (Figure 9). Although these rates may be influenced by changes in the spatial arrangement of elements between runs, transitions from footslopes and depressions to higher relief elements are not common (Figure 6). They are more likely to occur adjacent to flat terrain, sloped areas, or other sediment traps (Figure 6). There is a discrepancy between positivity rates and Maxent results for depressions, with the latter indicating low association with positive tests, and former indicating higher positivity rates. This may be a result of the large difference in the raw number of tests in each category, but further work is needed to confirm this. Overall, our results provide some indication that sediment traps have returned archaeological sites at higher rates than traditionally thought, a finding consistent with patterns identified in the Lower Athabasca River drainage (Woywitka and Froese 2020).

5.2 Implications

Our results confirm that archaeologists have not representatively sampled the full suite of landform elements in the Boreal Forest. This is logical and expected; survey target area selection is not solely dependent on topography and there are obstacles to adequately testing low-lying terrain (e.g., heavy ground cover, thick organic layers, high water tables). However, our analysis shows that low-lying areas do hold potential for archaeological sites. The only way to more fully understand the occurrence of archaeological material in sediment traps like footslopes, hollows, and depressions is to test them more frequently. Many of these areas are deemed to be of low potential in archaeological assessments, and intersecting developments are usually recommended for approval. It is possible that well-preserved sites occur in saturated sediments within or at the base of wetlands, and that additional stratified sites like Quarry of the Ancestors (Saxberg and Robertson 2017; Woywitka et al. 2022) occur in these topographic contexts. The underrepresentation of these landform elements in current sampling strategies biases the archaeological record to shallow and difficult to interpret sites and may contribute to unwitting destruction of extremely significant locations.

It is not reasonable to expect fully randomized stratified sampling in Boreal Forest archaeology; the practicalities of fieldwork and methodological freedom in regulatory systems preclude this. Based on our informal observations, there is also healthy skepticism among Alberta CRM professionals of quantitative survey approaches that were advocated for in the 1970s (e.g., Conaty 1979) and that are currently used in other jurisdictions. But increased sampling of lower relief landform elements is necessary to help ensure significant archaeological sites are not being missed in surveys. There are now remote sensing data like LiDAR digital elevation models and their derivatives (e.g., Wet Areas Mapping; White et al. 2012) and non-invasive techniques such as ground penetrating radar that may alleviate some of the logistical problems previously associated with testing low, wet terrain (Gabler et al. 2021). Increased monitoring of muskeg removal and drainage ditch excavations can also provide survey opportunities in these sedimentary settings. Incorporation of these approaches in archaeological permit methods and regulatory approvals will aid in providing a more robust understanding of the distribution of archaeological sites in the Boreal Forest. Even if it turns out that significant sites are uncommon in low-relief settings, impact assessment recommendations will be made with increased certainty. Alberta archaeologists owe this to the development of their science and to the descendants of the Indigenous groups who left their archaeological signature on the land.

6. Conclusion

We used a geomorphon-based terrain classification to assess the topographic setting of archaeological survey points in the Boreal Forest of Alberta. Spatial autocorrelation assessment of existing survey data indicate that terrain classifications calculated at roughly 60 metre and 180 metre scales will produce results consistent with the size of terrain units used by archaeologists to assess archaeological potential in the field. Our results show that there is considerable bias in current archaeological survey methods towards landforms that disperse sediment, reducing the likelihood of finding deeply buried or stratified sites. We recommend that increased sampling of low-lying terrain should be a regular component of future Boreal Forest survey methodology.

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