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# **Bioturbation by grizzly bears in relict solifluction features of Glacier National Park, Montana, USA: A case study**

**Carol F. SAWYER<sup>1\*</sup>, Clayton J. WHITESIDES<sup>2</sup>, Melanie B. STINE<sup>3</sup>**

<sup>1</sup>University of South Alabama, Department of Earth Sciences, Mobile, Alabama, 36688, United States of America

<sup>2</sup>Coastal Carolina University, Department of Anthropology and Geography, Conway, South Carolina, 29528, United States of America

<sup>3</sup>University of Texas-San Antonio, Department of Political Science and Geography, San Antonio, Texas, 78249, United States of America. Present affiliation: Independent scholar

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\*Correspondence to: Carol F. SAWYER, e-mail: [sawyer@southalabama.edu](mailto:sawyer@southalabama.edu)

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## ABSTRACT

Grizzly bears are an integral part of the northern Rocky Mountains ecosystem, where their foraging and denning leaves a measurable impact on the landscape. The purpose of this project was to evaluate the erosional effect of grizzly bears on relict solifluction tread and riser environments in the alpine tundra of Glacier National Park, Montana, USA. Grizzly bear excavation sites and material removed from vegetated risers and deposited downslope by bears was classified into either recent or decaying (i.e., not the current season) excavations, measured, and the volume of each excavation was calculated to determine the magnitude of disturbance by grizzly bears in this alpine environment. Grizzly bear activity was found at only one of four sample sites, where grizzlies removed 1.1727 m<sup>3</sup> of material (new excavations = 0.6974 m<sup>3</sup>, old excavations = 0.4754 m<sup>3</sup>). The width of treads and risers was also measured to determine if there were differences in the dimensions of solifluction features where bear activity was observed. Although one of the study sites did have statistically wider treads and narrower risers than the other study sites, no grizzly bear activity was observed at that site, suggesting that excavations are related to factors intrinsic to solifluction features. A conceptual model of the degradation of turf was developed based on observations of vegetation and soil removed by bears, illustrating how foraging activity in a tread and riser environment may produce micro-scale changes in the landscape over time.

**KEYWORDS** Zoogeomorphology; Grizzly bears; Bioturbation; Relict solifluction; Glacier National Park

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## 1. Introduction

In subalpine and treeline regions, grizzly bears (*Ursus arctos horribilis*) forage by digging for plant roots and bulbs (Butler, 1992; Mattson, 1997; Tardiff and Stanford, 1998), cutworm moths (White et al., 1998), and small mammals (Doak and Loso, 2003). These foraging activities have resulted in grizzly bears being cited as substantial erosional agents in these environments (Butler, 1992).

Grizzlies have been documented in alpine areas above treeline, but their geomorphic effects have often been cursory and the existing literature is contradictory. Hamer and Herrero (1987) stated that the alpine environment was unimportant as a food source for grizzly bears, despite numerous sightings of grizzlies above 1829 m during summer months in Glacier National Park, Montana, USA (GNP; Martinka, 1972). Butler (1992) noted that grizzly bears in GNP foraged in the alpine zone, and in the Canadian Rockies it has been suggested that "during the summer months, the bears spend most of their time digging for food above the treeline" (Hall et al., 1999, p. 437).

Although grizzly bears dig deep into the soil when in pursuit of ground squirrels, digging for plant-based food, including roots, results in removal of only the top layer of sod (Doak and Loso, 2003). In some alpine and subpolar environments, sod may be limited to turf-banked terraces, described as linear step-like features with unsorted stone treads and vegetated turf risers (Benedict, 1970; Butler et al., 2004). These relict solifluction features protect underlying fine-grained sediments (Walsh et al., 2003). When the turf bank is disturbed, however, by bears, ungulates, or frost heaving (Benedict, 1970; Pérez, 1993; Grab, 2002), the terraces may become susceptible to other erosional processes (Walsh et al., 2003).

The environment wherein both turf-banked terraces and grizzly bears occur in GNP provides an ideal venue to assess the potential for grizzlies to modify relict solifluction features, which are likely relatively stable features that resist erosion, despite active surface movement (Sawyer, 2007).

From a zoogeomorphic perspective, grizzly bears have the ability to modify directly the alpine tundra by trampling, digging for food, and con-

structing dens (Butler, 1995). In a subalpine environment, Butler (1992) calculated 0.3 m<sup>3</sup> of material had been removed by a grizzly bear digging for food; furthermore, he estimated that a single grizzly bear may be responsible for 6.8 m<sup>3</sup> yr<sup>-1</sup> of erosion in GNP from denning, digging, and foraging. White et al.'s (1998) analysis of grizzly bear feeding in the alpine of GNP focused on grizzly bear consumption of cutworm moths in talus slopes, not turf-banked terraces. Although the focus of their research was not zoogeomorphology per se, White et al. (1998) concluded that approximately 0.22 m<sup>3</sup> of talus debris was excavated from 30 oval pits dug by grizzly bears. Tardiff and Stanford (1998) evaluated the effect of grizzly bear digging on nitrogen availability in subalpine meadows of GNP and estimated that a single foraging event covered an area of >15 m<sup>2</sup> and was characterized by overturned chunks of soil and plant roots to a depth of approximately 10 cm. In the Rocky Mountains of Canada, Hall et al. (1999) identified the erosional impact of grizzly bears above treeline to be as much as 0.4958 m<sup>3</sup> per m<sup>-2</sup>.

Scant knowledge exists of the change, modification, or recovery of turf-banked terraces following surficial disturbances by large mammals. In alpine areas, needle ice (small filaments of ice that form in freezing temperatures) has been attributed to turf exfoliation, or the process of destroying "a continuous ground vegetation cover by removing the soil exposed along small terrace fronts" (Pérez, 1992, p. 82).

Needle ice can disturb soil and prevent vegetation growth (French, 1996). Previous research (Pérez, 1992, 1993; Grab, 2002; Butler et al., 2004), however, has suggested that for needle ice to cause turf exfoliation, another process is first needed to disrupt the thick turf and expose the underlying soil. Pérez (1993), Grab (2002), and Butler et al. (2004) suggested that animals could interrupt turf cover by trampling or pawing at the ground.

Any behaviour by animals, including burrowing and digging for food, also has the ability to disturb turf. A possible consequence of grizzly bear digging along turf-banked terraces is terrace retreat through erosion of risers.

## 2. Methods

### 2.1 Study Area

GNP (Figure 1) contains a stable grizzly bear population and relict solifluction-related turf-banked terraces containing treads and risers (Hayward, 1989; Butler et al., 2004). The vegetation within these alpine turf-banked terraces is mostly *Dryas octopetala* (Bamberg and Major, 1968), which, where present, provides a nearly continuous protective vegetated cover.

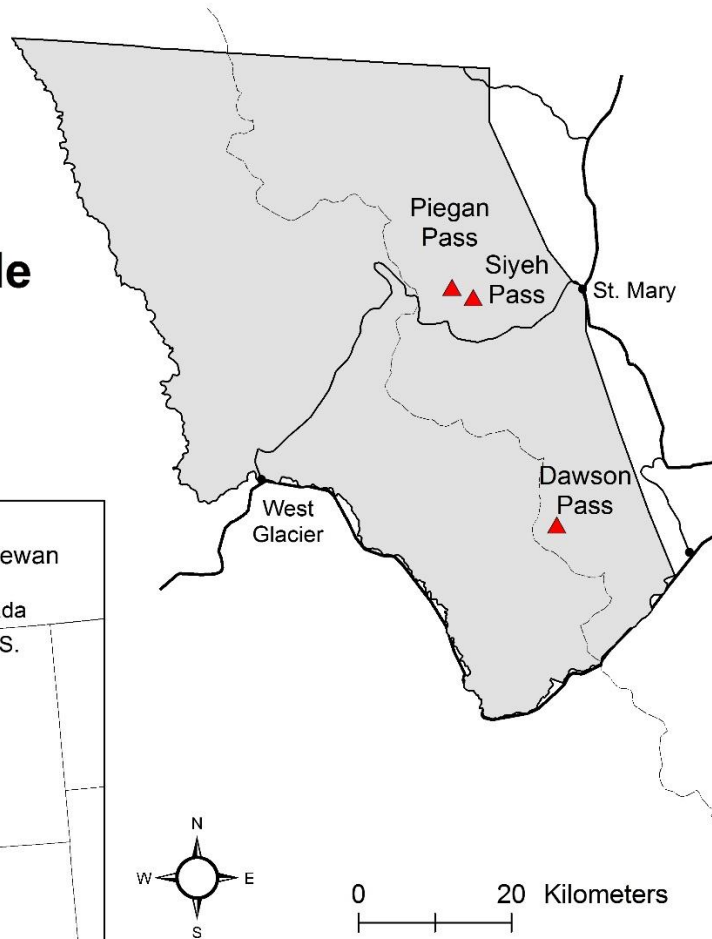
Four study sites were selected (Table 1), using aerial imagery, personal observation, and published literature (Bamberg and Major, 1968; Butler and Malanson, 1989; Tardiff and Stanford, 1998; White et al., 1998; Butler and Malanson, 1999; Resler et al.,

2005; Butler et al., 2009; Butler, 2011). The primary criterion for inclusion was the presence of well-developed, vegetated solifluction treads and risers; the sites were not chosen because of known grizzly bear presence.

All study sites were located on or east of the Continental Divide, ensuring similar precipitation and temperature patterns. Diurnal freezing is possible during all months of the year, with mean monthly temperatures below freezing for 6 months (November to April). Precipitation averages 677 mm per year, with the driest month (August) recording 43 mm and the wettest month (June) receiving 90 mm. Snowfall is possible all months of the year (WRCC, n.d.).

### Legend

- ▲ Study Sites
- Glacier NP
- Continental Divide
- Towns
- Local Roads



**Figure 1** Study area map illustrating the location of study sites in Glacier National Park, Montana, USA. The sites were located above treeline, on or east of the Continental Divide

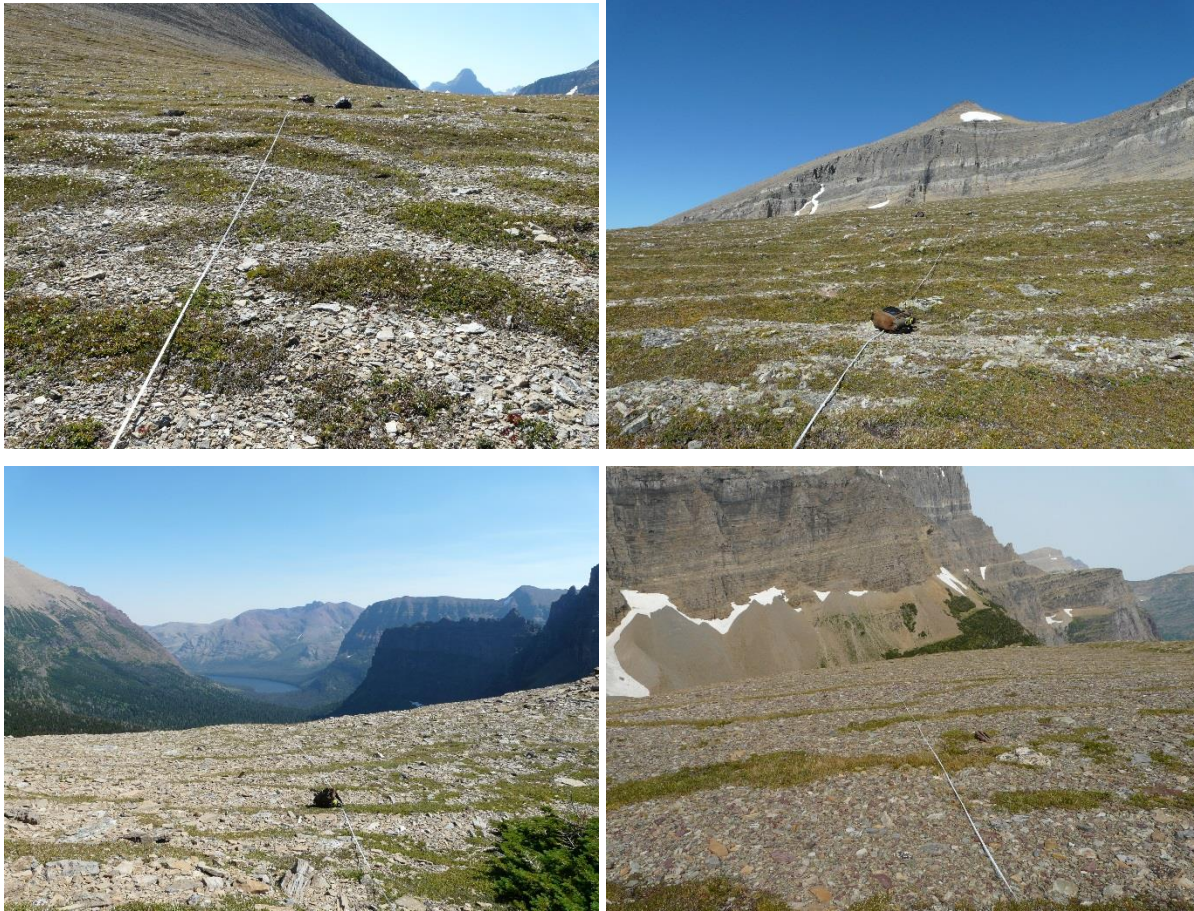
**Table 1** Characteristics of study sites

Site	Surficial deposit	Elevation (m)	Aspect
Siyeh Pass 1 (SP 1)	Solifluction frost rubble	2362	SE
Siyeh Pass 2 (SP 2)		2389	E-NE
Dawson Pass (DP)		2286	E
Piegan Pass (PP)		1900	N-NW

## 2.2 Data Collection and Analysis

We identified inactive solifluction treads and risers above alpine treeline at Siyeh Pass that contained grizzly bear diggings as well as two other sites, Dawson Pass and Piegan Pass, where no bear activity was observed, despite similar site conditions

among all locations (Figure 2). Field visits and data collection occurred during the summers of 2010 and 2011 and two separate field visits occurred in 2011 (mid-July and mid-September) to document seasonal excavation by bears. No new excavations, however, were observed in September 2011.



**Figure 2** Photos of study sites: clockwise from upper left: Siyeh Pass 1; Siyeh Pass 2; Piegan Pass; Dawson Pass. Each site was located on a ridge above a cirque



**Figure 3** Photo of bear excavations (arrows) from vegetated solifluction risers with spoils deposited on downslope treads at Siyeh Pass

At Siyeh Pass, chunks or wedges of vegetation and soil resting on adjacent, downslope tread surfaces characterized recent grizzly bear excavations (Figure 3). Grizzly bears were considered responsible because our observations paralleled those of Hall et al. (1999) who noted, "it was possible to discern the digging effect in four instances of a single paw" (p. 437). Moreover, other mammals that reside near or frequent the alpine tundra (e.g., marmots (*Marmota* sp.), bighorn sheep (*Ovis canadensis*), and mountain goats (*Oreamnos americanus*) create different patterns of disturbance and are not known to dislodge turf from risers. Differentiation between fresh (i.e., dug that summer) and older digs was evident by sediment infilling, vegetation establishment within older depressions (Gutterman et al., 1990; Doak and Loso, 2003), and degradation of the shape of the excavated material. Determining the age of depressions older than one year was not possible because

of varying rates of excavated sod decay and infilling of depressions (Tardiff and Stanford, 1998). Excavation depths for 30 recent (dug that summer) and 30 decaying (older than one year) depressions were recorded in the center of excavated holes found within two 30 x 30 m quadrats that were randomly placed on the landscape. The long and short axes of each excavation were measured, resulting in length, width, and depth data for each grizzly bear disturbance. Measurements of freshly excavated material and older spoils were taken during the same site visit to eliminate any size differences between visits. Although we cannot guarantee that all content removed from the hole was still present in downslope spoil mounds, the reinsertion of excavated material into their original holes suggested that most material was present and had not yet eroded. Volume was calculated by the cuboid formula (Butler, 1992),

using the long and short axes of the excavated material and the depth of the hole in the riser.

In an effort to determine if micro-site characteristics explained why grizzly bear activity was present at Siyeh Pass and not at Dawson Pass and Piegan Pass, the widths of the solifluction treads and risers were recorded at the four study sites by placing three 30–50 m transects perpendicular to the con-

tours of the slope. The height of each riser was recorded with a measuring tape placed perpendicular to the tread below the riser, measured to the top of the riser. Transect lengths were 50 m, unless the tread and riser topography did not extend for a full 50 m, in which case, 30 m transects were used. Inferential and descriptive statistics were used to analyse the data.

**Table 2** Mean, standard deviation, and median of old and new diggings

	Mean ± Standard deviation (median)			
	Length (cm)	Width (cm)	Depth (cm)	Total Volume (m <sup>3</sup> )
Old diggings (n=30)	49.73±20.97 (42.5)	36.47 ±14.98 (33)	7.85±1.76 (7.75)	0.4754
New diggings (n=30)	49.30±19.86 (41.5)	34.20±9.55 (33)	12.55±3.69 (11.5)	0.6974

### 3. Results and Discussion

Recent excavations (i.e., dug that season; M = 12.55, SD = 3.69) were significantly deeper than decaying (old) excavations ((M = 7.85, SD = 1.76); t (29) = 7.086, p ≤ 0.001). Despite differences in age and the appearance that fresh excavations better retained their shape, the lengths of new (M = 49.30, SD = 19.86) and old (M = 49.73, SD = 20.97) excavations were surprisingly similar and non-significant (t(29) = -0.080, p = 0.937)), which was also the case for widths of new (M = 34.20 ; SD = 9.55) and old (M = 36.47; SD = 14.98) excavations (t(29) = -0.668, p = 0.509; Table 2). The total volume of soil removed from the 60 samples was 1.1727 m<sup>3</sup> (recent = 0.6974 m<sup>3</sup>, decaying = 0.4754 m<sup>3</sup>). A one-way ANOVA revealed a statistical difference between riser widths at the study sites (F(3, 385) = 4.6001, p = 0.004), and a Tukey's HSD post-hoc test indicated that the statistical difference existed between Siyeh Pass and Dawson Pass (p = 0.017, 95% C.I. = -41.15, -2.85) and between Piegan Pass and Dawson Pass (p = 0.008, 95% C.I. = -44.07, -4.73). Similar significant differences were found for tread widths (F(3, 368) = 14.137, p ≤ 0.000), where Piegan Pass had significantly wider treads than either site at Siyeh Pass (p ≤ 0.000, 95% C.I. 20.82, 65.18; p ≤ 0.000, 95% C.I.

15.44, 64.56) or Dawson Pass (p ≤ 0.000, 95% C.I. = 32.77, 83.23; Table 3). In addition, a one-way ANOVA showed that riser heights were also found to be significantly different (F(3, 358) = 53.9, p ≤ 0.000) between study sites. A Tukey's HSD post-hoc test indicated that significant statistical differences existed with the riser heights between all study sites with six relationships tested: SP1:SP2 (Q = 9.20, p ≤ 0.000); SP1:DP (Q = 8.93, p ≤ 0.000); SP1:PP (Q = 5.46, p ≤ 0.001); SP2:DP (Q = 18.13, p ≤ 0.000); SP2:PP (Q = 3.74, p = 0.043); DP:PP (Q = 14.39, p ≤ 0.000).

The depth of bear excavations in risers appeared to be greatest in the initial year, with infilling over time due to secondary erosional processes (e.g., fluvial, aeolian, etc.). The length and width of both new and old excavations were not statistically different. Butler (1992) estimated 0.3 m<sup>3</sup> of material was excavated while digging for food at a subalpine site whereas our data indicated that almost 0.7 m<sup>3</sup> had been excavated at an alpine site, which is logical as vegetation provides a non-continuous cover in the alpine region, requiring bears to excavate more area for food. Alpine vegetation may be worth the extra energy expenditure, however, as plants at higher elevations in the Rocky Mountains have been shown to have higher caloric content than plants at

lower elevations in the Appalachian Mountains (Andersen and Armitage, 1976). This trend is consistent with increased nutrient concentration at

higher elevations at several global sites (Körner, 1989).

**Table 3** Mean and standard deviation of riser heights and widths, as well as tread widths. All measurements are in centimetres

Site	Mean $\pm$ Standard deviation (n)		
	Riser heights	Riser widths	Tread widths
Siyeh Pass 1 (SP 1)	26.1 $\pm$ 10.7 (n=113)	99.2 $\pm$ 48.5 (n=113)	118 $\pm$ 58.1 (n=117)
Siyeh Pass 2 (SP 2)	13.4 $\pm$ 5.4 (n=78)	111 $\pm$ 55.1 (n=78)	121 $\pm$ 82.6 (n=79)
Dawson Pass (DP)	38.56 $\pm$ 24.5 (n=71)	113.4 $\pm$ 61.4 (n=71)	103 $\pm$ 51.8 (n=72)
Piegan Pass (PP)	18.6 $\pm$ 5.7 (n=100)	89 $\pm$ 32.2 (n=100)	161 $\pm$ 61.0 (n=104)

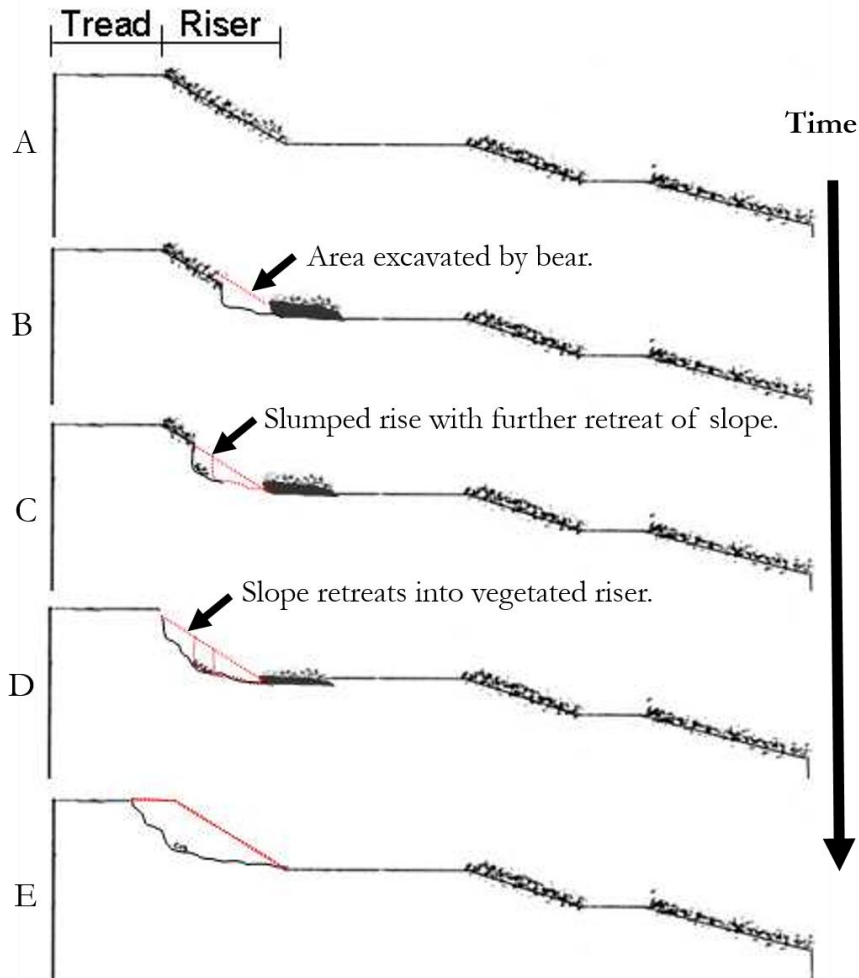
It has been suggested that locations where bears dig for ground squirrels were determined more by a bear's presence in the alpine than by specific micro-site characteristics (Doak and Loso, 2003). Grizzlies may use alpine environments as travel corridors and take advantage of convenient food sources while in transit. Insects are readily transported by aeolian processes and deposited in alpine environments. High mountain snowbanks serve as catchment areas for these insects, which remain stranded on the snow (Van Dyke, 1919) and have been cited as a food source for bears (Gurney, 1953 and references therein). Insects deposited on exposed rock and tundra vegetation have also been documented in large quantities in the White Mountains of California (Spalding, 1979) and insect activity in western Montana during summer months has been shown to increase with elevation (Chapman, 1954), where grizzlies have been observed feeding on ladybird beetle and army cutworm populations at elevations above 3000 m (Chapman et al., 1955). Although Piegan Pass did have statistically wider tread and nar-

rower riser widths than most of the other study sites, our measurements were comparable with other solifluction features in eastern GNP (Butler et al., 2004). Additionally, grizzly bear activity was not observed at Piegan Pass, suggesting that regardless of the reason for grizzly bear presence in the alpine (e.g., transit, food), their excavations appear to be related to factors intrinsic to solifluction features, whether significant or not, not solely the presence of the bears, which is contrary to the findings reported by Doak and Loso (2003).

Our findings suggest that grizzly bears have potential to modify the microscale geomorphology of alpine tundra through excavation. As noted above, debris was located downslope from the excavated site with no excavated debris found upslope from the excavation. A conceptual model of possible microscale response to a single excavation (Figure 4) illustrates how the removal of turf from a riser, through grizzly bear excavation, facilitates erosion, contributing to the overall decay of relict solifluction treads and risers. For the reason that alpine tundra

vegetation is slow to re-establish following disturbance (Bell and Bliss, 1973; Ebersole, 2002), fine-scale slope retreat may occur as the riser erodes. It has been argued that the geomorphological features of dynamic upland environments in Scotland were

“crucial in maintaining habitat diversity and dynamic equilibrium” (Gordon, et al. 2001, p. 327), and this habitat diversity is apparent in conifer seedling establishment within solifluction features in GNP (Butler et al., 2004; Resler et al., 2005; Resler, 2006).



**Figure 4** Conceptual model illustrating how a riser may be modified following excavation by a bear

Additionally, disruptions in solifluction turf-banked terraces may provide sites for conifer establishment above current treeline (Walsh et al., 2003), and fine-scale disturbances, especially those adjacent to treeline, have significantly higher rates of conifer germination (Whitesides and Butler, 2016; Kambo and Danby, 2018). Despite mentions of animal activity within the tread and riser environment (sensu Butler, 1995; Walsh et al., 2003), scant research exists on the factors that degrade relict solifluction features and how degradation may affect vegetation dynamics and the longevity of these landforms, particularly in an era of changing climate.

#### **4. Conclusions**

This case study suggests that grizzly bear activity above alpine treeline is occurring within specific landforms and grizzlies should be considered erosional agents contributing to the degradation of relict solifluction features. These findings also contribute to and corroborate the limited existing literature on grizzlies as geomorphic agents above treeline. Alpine tundra may become increasingly important to bears as the effects of climate change alter vegetation throughout GNP (Hall and Fagre, 2003) and other mountainous regions. Continued



study of bear activity on fine-scale solifluction features is necessary to reveal and monitor the extent of these geomorphic agents on the fragile alpine environment.

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