Catena 145 (2016) 107–117

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Biogeomorphic disturbance: A case study on associations and methods after fire within the alpine treeline ecotone

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ARTICLE INFO

Article history:
Received 31 August 2014
Received in revised form 31 May 2016
Accepted 1 June 2016
Available online 8 June 2016

Keywords:
Biogeomorphology
Fire
Field methods
Alpine treeline ecotone
Glacier National Park

ABSTRACT

Biogeomorphology is an increasingly popular field of study, but the approaches to biogeomorphic research and methods are not yet well developed. This research evaluated ecologic and geomorphic interactions after fire within the alpine treeline ecotone of Glacier National Park, Montana. Associations between soil conditions and vegetation, the effect of vegetation edges on soil characteristics, and the influence of quadrat size on select vegetation and soil variables were evaluated with the use of fieldwork and statistics. Of the 11 ecologic/soil variables compared, three were significantly correlated – soil compaction and krummholz density, soil loss and percent vegetation, and soil loss and burn severity. The ecologic edge between burned and unburned krummholz had significant influence on soil compaction, clast size, and effective soil depth patterns. Quadrat size did not have much influence on average results for either soil or vegetation variables. These findings highlight both the potential biogeomorphic interactions as well as interesting results that were not significant, and will contribute to the advancement of biogeomorphology. The results also provide novel information on alpine treeline ecotone response after fire.

1. Introduction

Biogeomorphology is the study of the interactions between organisms and geomorphology (Viles, 1988), and is a growing sub-field within numerous disciplines, including geography, engineering, and environmental science (Renschler et al., 2007; Marston, 2010; Stine and Butler, 2011; Pavel, 2012). Taking into account both biotic and abiotic processes and interactions is becoming increasingly important in conditions of climate change, environmental degradation, and ecosystem restoration. Biogeomorphology is especially vital after disturbance events, because disturbances – such as floods, fires, and volcanic eruptions – often affect both biotic and abiotic factors, and subsequently how ecologic and geomorphic factors respond to a disturbance (Stallins, 2006; Viles et al., 2008). The overall goal of this study was to evaluate several aspects of coupled vegetation – geomorphic response after fire within the alpine treeline ecotone, specifically focusing on potential relationships between vegetation and soil conditions. The treeline ecotone is an ideal system in which to conduct this study because the harsh conditions heighten the dependencies between geomorphic and ecologic factors (Resler, 2006; Resler et al., 2005) and a great need exists for data on the effects of fire within this system (Coop et al., 2010; Sass et al., 2012).

A concurrent aim of this research was to evaluate methods that may be used to collect data on vegetation and geomorphic conditions. The interactions between geomorphic and ecologic processes are often challenging to determine because of the different scales at which geomorphic and ecologic processes operate (Phillips, 1995; Post et al., 2007; Renschler et al., 2007; Pavel, 2012). I addressed this issue by 1) collecting field data on both geomorphic and ecologic variables after fire, 2) selecting sites that have burned within a timeframe that encompasses both ecologic and geomorphic processes, and 3) synthesizing the overall results from a coupled geomorphic–ecologic framework. I selected sites that experienced fire between 5 and 10 years before field data collection, a timeframe in which geomorphic conditions and processes are still evident and occurring because the fires were relatively recent, but also allowing enough time for seedlings to have begun establishing.

Several approaches are used in this paper to evaluate a broad scope of variables, potential interactions, and methods. The first topic is on vegetation conditions, including herbaceous vegetation and krummholz burn severities, and how they compared to select soil conditions. The second topic is on the burned/unburned vegetation edge and how soil conditions change in relation to the ecological edge. The third topic evaluates the influence of plot size on results. Averages for variables of

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http://dx.doi.org/10.1016/j.catena.2016.06.001

clast size, soil penetrability, krummholz density, and total basal area are compared among eight plot sizes ranging from 1 m^2 up to 100 m^2.

2. Study area

I selected three study sites that had experienced fires at alpine treeline in Glacier National Park, Montana (GNP). Glacier National Park is situated in the Northern Rocky Mountains in northwestern Montana. The Continental Divide extends north–south along the long axis of the Park, and serves as a dividing line between the more vegetated western side of the Park and the drier eastern side. Two sites were located on Divide Mountain – Upper Divide and Lower Divide – and one on Swiftcurrent Mountain (Fig. 1), all east of the Continental Divide. Soils are predominantly sedimentary with parent material of Altyn limestone on Divide Mountain and Grinnel Argillite on Swiftcurrent Mountain. The most common krummholz species within treeline in GNP are *Abies lasiocarpa* (subalpine fir), *Picea angelmannii* (Engelmann spruce), and *Pinus* sp. (five-needle pine).

The region of GNP was heavily glaciated during the Pleistocene Glaciation and the steep mountain sides, deep U–shaped valleys, and sharp peaks bear witness to this past. Two major mountain ranges, the Lewis and Livingston Ranges, run parallel with the roughly north–south long axis of the Park. The Continental Divide splits the Park into two distinct climate zones – a wetter western side and a drier eastern side. This difference in precipitation amounts is evident with the vegetation. The western part of the Park contains abundant, lush forests, whereas the eastern side is more of a mosaic of meadows, bare rock, alpine tundra vegetation, in addition to forests.

Three study sites were selected based on locations that had experienced fire within alpine treeline in the ten years prior to data collection.

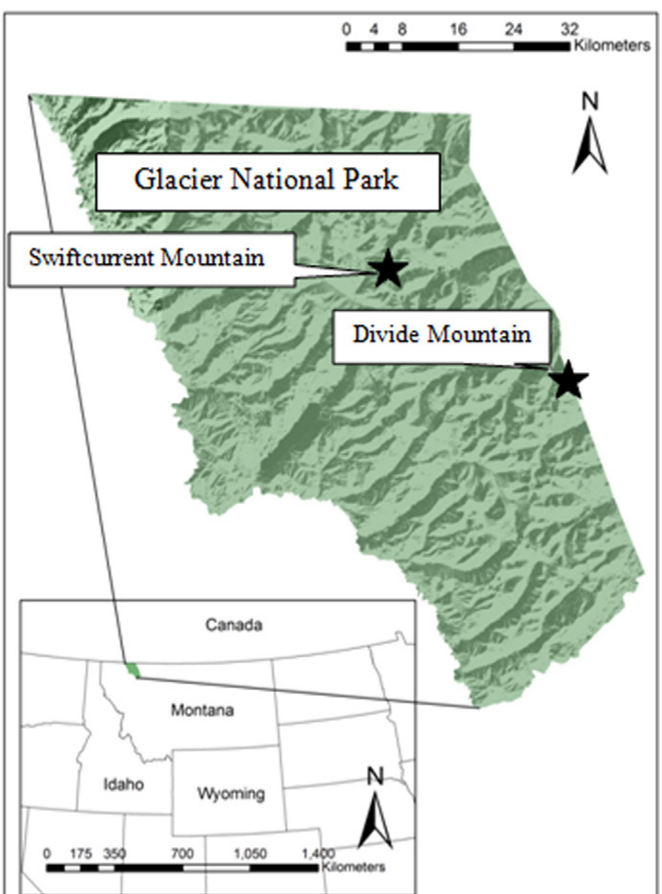

Fig. 1. Study site locations within Glacier National Park, Montana.

Divide Mountain and Swiftcurrent Mountain experienced high severity fires, the Red Eagle Fire on Divide in 2006, and the Trapper Fire on Swiftcurrent Mountain in 2003. One of the sites on Divide Mountain, Upper Divide (UD) (elevation 2200 m), was about 100 m above a second site, Lower Divide (LD) (elevation 2100 m). Upper Divide was located on a saddle feature (with east- and west-facing slopes) extending between Divide Mountain and Whitecalf Mountain on the eastern edge of the Park. Lower Divide was on a north-facing slope. The Swiftcurrent site (SC) (elevation 2340 m) was situated on a south-facing slope just east of the Continental Divide.

Sites were divided into sub-sites based on fine-scale topographic variation within each site. The sub–sites, presented by their relative west to east location, were Upper Divide West (UDW), Upper Divide Ridge (UDR), Upper Divide East (UDE), Upper Divide Islands (UDI), and Upper Divide Far East (UDF). Each sub-site displayed distinct and different characteristics, degree slope, and/or slope aspect. UDW was located on a west-facing slope in a broad gully slightly downslope from the crest of the saddle that extends between Divide Mountain and Whitecalf Mountain. Krummholz had established within the gully, extending up from the sub-alpine forest. UDR was located immediately downslope on the eastern side of the saddle. A narrow (about 5 to 10 m in width) strip of krummholz extended along this ridge. UDE was positioned east of the ridge within a slight depression. The patches were found leeward of boulders on the eastern side of the saddle, east of UDE and west of UDF. UDI was similar in degree slope and aspect to UDE, but the burned patches were distinctly different because they were smaller patches (about 5 × 5 m) of krummholz that had burned and were located leeward of boulders. UDF was the eastern-most site on Upper Divide and was located on an east-aspect slope with an average degree slope of 29°. The islands on Upper Divide had the lowest degree slope with an average of 4°, followed by UDE with an average of 5°. Quadrats within a sub-site were further identified as 1, 2, 3, etc. (UDE1, UDW3, for examples).

Only two sub-sites were identified for Lower Divide, and these were similar in both degree slope and slope aspect. The difference was their respective settings within vegetation – Lower Divide North (LDN) was a burned patch of krummholz that was situated within a larger patch of krummholz that had not burned. The burned patch extended downslope, into the subalpine area. The sub-site contained little topographic variation. The other identified sub-site – Lower Divide Gully (LDG) – was comprised of two gullies that were lined with burned krummholz within an area of low-lying tundra vegetation. The gullies had apparently served as a protective depression for the establishment of krummholz and then fire extended up from the subalpine forest into the treeline ecotone via krummholz within the gullies.

The Swiftcurrent site was located on a south-aspect slope on Swiftcurrent Mountain. Average degree slope for this site was 29.3° and ranged from 28 to 30°. Swiftcurrent did not have the topographic variability found on Divide Mountain, but was rather a relatively uniform, steep slope. Each 5 × 20 m quadrat was designated as SC1 (upper-most quadrat), SC2, and SC3 (lowest in elevation).

3. Methods

To assess potential relationships among krummholz density and soil conditions, erosion, and burn severity, a total of 17, 5 × 20 m and 11, 5 × 5 m quadrats were randomly placed in burned areas within the three sites. The number of quadrats per site was dependent upon the topographic variability of the site. Upper Divide had the greatest topographic variability, and therefore, had the greatest number of quadrats. Quadrat placement was determined with a pin toss, which served as the right-hand, upslope corner of a quadrat. Quadrats measuring 5 × 20 m were used, except when changes to slope or aspect within the sampling area occurred, in which cases, a 5 × 5 m quadrat was then placed.