



The Beartooth Alliance is a non-partisan organization of citizens - based in the Cooke City area of Montana - who are committed to influencing environmental and social issues affecting their quality of life. By anticipating problems, providing information and directing resources, the Alliance can ensure the welfare and vitality of the area. Our members and supporters come from all walks of life and have deep roots in our community. The Alliance brings people who love this region together to find ways to protect and enhance our unique mountain environment.

August 21, 2025

Gardiner Ranger District
805 Scott Street W
Gardiner, MT 59030

Re: Cooke City Fuels and Forest Health Project Objection

To Gardiner Ranger District:

The Cooke City Fuels and Forest Health Project will directly affect the residents and property owners of the Cooke City-Silver Gate community, who are members of Beartooth Alliance. Beartooth Alliance members and supporters have a strong interest in management decisions that impact the local national forest adjacent to our community, homes, and businesses. The Custer Gallatin National Forest's robotic response of "*Comment considered but no changes needed*" stated throughout the Final Environmental Assessment to the concerns of the citizens who are immediately impacted undermines the relationship between stakeholders and government agencies.

Beartooth Alliance members desire to protect and enhance the unique Greater Yellowstone Ecosystem we are fortunate to reside in. Some members live year-round in the Cooke City-Silver Gate community; others return year-after-year, drawn to the refuge-like intact ecosystem that abounds with native flora and fauna. The Forest Service's disregard of those most impacted confirms the use of current political changes to force unclear agendas at the public's expense.

The Cooke City Fuels and Forest Health Project uses the fear of intense wildfire to create a logging and timber sale program. Additional public meetings have been requested to attempt to build a working relationship; however, the forest service failed to meet with the public once directly affected citizens had the proper time to become informed of the project and its implications to the community.

Beartooth Alliance submitted written concerns for both the scoping and Draft Environmental Assessment. Our concerns have not been addressed. Beartooth Alliance files this objection to the proposed Cooke City Fuels and Forest Health Project.

Reasons for the objection:

- The Executive Order titled "Immediate Expansion of American Timber Production," dated April 3, 2025, is included in the Appendix, as the Cooke City Fuels and Forest Health Project appears to stem directly from the language and actions in this document. The intent of the order is stated in the title. Except for meeting minimum legal requirements, the document shows no concern to invite a conversation with citizens who will be impacted most and who know the treatment areas best. This has been the format throughout the Cooke City Fuels and Forest Health Project. The process has been circumnavigated and concerns have been dismissed with unsubstantiated evidence.

- o The first stated goal of the Executive Order—*Support rural economies and forest product industry partners*—is a false claim for the Cooke City-Silver Gate community. Cooke City is one of the most remote locations in the lower 48 states. Our rural economy is based on tourism. Tourists from all over the country and world visit with the purpose of recreating in mountains that have not been affected by timber harvest. They come to see the wildlife and enjoy the solitude of the mountains with pristine views (Jorgenson et al., 2013).
 - The Cooke City Fuels and Forest Health Final Environmental Assessment states scenic views have been taken into account. Beartooth Alliance members who recreate and live in the area year-round disagree. The commercial logging and mechanical treatments to occur on Republic Creek and Woody Creek and the mechanical treatments along the north aspect of Republic Mountain and the north aspect slopes above the Soda Butte Creek campground will be visible from every listed High Scenic Integrity Objective Areas stated to be taken into consideration in the Cooke City Fuels and Forest Health Project: *Critical viewing platforms in the project area are Clark's Fork trailhead, Colter campground, Soda Butte campground, Highway 212, Lulu Pass Road, Daisy Pass Road, and Round Lake Road* (p.102). Every viewpoint will be negatively impacted, including Miller Road, which was not listed. Wildlife will be impacted as the forest canopy and forest floor will be abruptly changed for decades.
- Planned mitigation of future winter activity conflicts between motorized and non-motorized recreation must be more substantial. This concern was not addressed. Historically, because of the density of the forest within the Woody Creek and Republic Creek drainages (Units 42, 44, 45, 99, 113), non-motorized use has dominated the area; however, this project plans to open up the spacing between dense stands of trees that will permit motorized use and potentially invite increased misuse of non-motorized areas
 - o The response to this concern was the following: *Units 44, 45, 99 and 113 are located within an area designated for both motorized and non-motorized use according to the OSVUM travel decision. This area will be managed as it has been historically in the area with signage and Forest Service employee patrols. Unit 42 is located in a motorized closure area. This area will also be managed as it has been historically with signage and Forest Service patrols.*
 - Historical forest service management and signage is not sufficient. Frequent misuse of land and boundaries occurs during the winter and summer seasons. Forest service patrols are not present. With decreased funding, patrols will be even less frequent. I have stopped off-road vehicles from driving in the upper Stillwater River. I have encountered off-road vehicle tracks within the wilderness boundary at Goose Lake. While backcountry skiing, I have had close calls with snowmobiles while tree skiing. In February of 2021, eight snowmobilers were rescued at Granite Lake, which is well-within the wilderness boundary. Despite having snowmobiled in the area four or five times, one rider stated “they had no idea where they were entering was illegal” (see appendix for news article). Signage does not work. Forest service patrols are not present. New openings created by fuels treatments will invite winter and summer motorized recreationists to misuse the areas.
- Prior to the start of any approved work within a treatment unit funds must be secured to monitor the spread of non-indigenous plant species for a minimum of 5 years following treatments. This concern was not addressed.
 - o Non-indigenous plant species begin at disturbances to the landscape, especially human-disturbed sites, such as fire treatment areas (Rew et al., 2006). The presence of noxious weeds within and surrounding the treatment sites is known. Houndstongue and thistle are present in Units 34 & 35. Houndstongue, thistle, and knapweed are in and around Unit 13. Freshly opened areas to motorized and non-motorized travel will bring people, pets, and motorized vehicles, all of which transport invasive species, which will take hold within the newly disturbed treatment units.
- The project encompasses a vast and varied 3,218 acres, with seven different treatment types. This project is too large. Funding to complete this project is not stated nor is a timeline of completion provided.

- The forest service has not been transparent as to how this project will be funded. There are over 3,000 acres that are not commercially harvested, yet intense silviculture treatments will be conducted with machinery and by hand within steep and remote terrain. A new logging-worthy bridge was installed in July of 2025 on upper Woody Creek. This bridge leads to nothing except mature tree stands on forest service land. What is the forest service's intent? Included in the Appendix are photos of the new bridge.
 - There is real concern work could begin and abruptly end, without work being completed within treatment units. Unfinished work would leave hazardous slash debris and piles throughout popular winter recreation areas for backcountry skiing and snowmobiling.
 - No timeline for the completion of the project is provided. The small Cooke City-Silver Gate community and wildlife could be impacted by noise, heavy equipment, dust, and closures for 10-15 years. All of which negatively impacts tourism, which the community is dependent on.
- The Final Environmental Assessment does not properly address the benefit of maintaining as many trees as possible. No commercial logging should occur. The Regeneration Harvest treatments leave only 10 percent of the regrowth from the 1988 fires, which only adds carbon to the atmosphere. These trees have just reached a maturity to have become carbon sinks and the project will remove them with new trees that will not become carbon sinks for 20 plus years. This new growth needs to be managed with prescribed burns, which is not a treatment in this project (Mildrexler, 2023; Ripple, 2024).
- The best climate adaptation efforts to create a more fire resilient landscape use a mixture of thinning and prescribed burning (Churchill, 2022; Cansler, 2022; Johnston, 2021). Commercial logging will require prescribed burns and thinning within 10-20 years of completed logging to address regenerative growth and maintain effectiveness of the original treatment Units (Churchill, 2022). Wind events continue to increase in the area. Single mature trees remaining on the landscape, without the support of the grove protection the trees grew in fall over. The silviculture treatments that occurred at Reef Creek in Wyoming along Chief Joseph Highway are an example of the significant amount of live-standing trees that will fall post treatment.
- Photos of before and after treatments in the Final Environmental Assessment do not match. The locations of the before and after photos are different; therefore, comparisons cannot be accurately made. The Final Environmental Assessment has not corrected this error, nor does the document show all treatment types.
 - This concern has never been addressed. No public meetings were organized outside of the first meeting in July 2024, before citizens had a chance to review the scoping document or were allowed access to KMZ files of the intended project.
- The concern that dead-standing Whitebark pine trees will remain on the landscape has not been addressed. At the July 2024 field trip meeting with the forest service, attendees were told whitebark pine trees, deadstanding or alive, could not be removed, since they are listed as threatened species under the U.S. Environmental Species Act. Yet, the response provided to Beartooth Alliance's concern of dead-standing and live-standing whitebarks being removed, the FEA response is the following:
 - *Dead trees with diameter at breast height larger than 8 or 9 inches would be retained on the landscape. Smaller trees may need to be removed to meet fuels objectives. Research on whitebark pine and its response to various silvicultural and fuels treatments is not comprehensive nor is it always consistent. This is not surprising given the wide range of the species and its ecological settings as well as the fact that it has only begun to be studied relatively recently unlike other commercial tree species. In the absence of such research, standard silvicultural practices which have a long history of research behind them are the resource best used to develop treatments (p. 117).*
 - Whitebark pines with a breast height diameter of 8-9 inches and larger are rare. Therefore, the conclusion made is that most dead-standing whitebark pine trees will be removed. This is unacceptable.
 - Units with Whitebark pine trees should be entirely removed from the project until current science-based data can be provided that indicates treatments will definitively benefit one

of the healthiest whitebark regions remaining within the Greater Yellowstone System. The FEA provides unconvincing information regarding its suggestions of treatments for whitebark pine areas. On pages 31-32, the FEA uses the words “speculative, unknown, unclear, not all damage may be preventable” when referring to suggested whitebark pine treatments. Whitebark pine areas are too important to risk inconclusive treatments.

- Please refer to comments provided by Jesse Logan for additional, in depth analysis of the impacts of this project on whitebark pine and recommendations.
- The planting of blister-rust resistant whitebark pine seedlings should be incorporated into the project.
- The following has never been addressed. This is the third mention of the concern. Misuse at this site continues.
 - On a daily basis, from May-October, tourists are camping in their personal vehicles at the large orientation site (signage pullout) on the southside of Hwy 212, just east of the northeast entrance to Yellowstone National Park. Piles of unburied human feces and soiled toilet paper can be found within the first 200’ of the Forest Service land nearest to this heavily used pullout. The proposed project will cause temporary closure of Soda Butte Campground and eliminate use of Forest Service areas typically used by dispersed campers. A permanent pit toilet needs to be installed at this site or at a minimum a porta potty be placed here, throughout the duration of any project work. The EA states recreationists will be displaced due to campground closures and treatments taking place on Forest Service Roads. Therefore, it is even more imperative for this situation to be addressed.

The Beartooth Alliance members and supporters have a strong interest in management decisions that impact the local National Forest adjacent to our community, homes, and businesses, as well as the Greater Yellowstone Ecosystem. At this time, the Cooke City Fuels and Forest Health Project appears to use the cover of fire protection to create a logging and timber sale program. The Forest Service’s unsubstantiated responses to the legitimate concerns of local residents have deteriorated the trust and relations between the Forest Service and community stakeholders. Beartooth Alliance objects to the Cooke City Fuels and Forest Health Project.

Sincerely,



Lara Belice
Chair, Beartooth Alliance

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APPENDIX

Upper Woody Creek Bridge completed July 2025



Widening of road to upper Woody Creek Bridge





File Code: 1300
Route To:

Date: April 3, 2025

Subject: Implementation of Secretarial Memo 1078-006

To: Regional Foresters and Deputy Chiefs

The Forest Service has a rich history of managing America's forests for the public good. Established in 1905, our agency has evolved significantly, adapting to changing societal needs and environmental challenges.

Today, we enter a new era marked by pressing issues like a growing demand for domestic lumber and wildfire resilience. The Executive Order titled “Immediate Expansion of American Timber Production” identifies these issues and set us on a path to overcome them. To address these challenges, we need to increase our active forest management to improve both the prosperity of rural America and the health of our forests. Our efforts will lead to an increase in America’s wood independence, a thriving wood products economy, and the protection of our water supply. The value of wood products derived from projects on national forests will play a crucial role in driving economic growth while supporting essential efforts to reduce wildfire risk and promote forest health. Our efforts will also result in a better return on investment for the public we serve by covering more of the costs of the timber program through revenue generated.

The goals we will seek to achieve in actively managing our forests are:

- Support rural economies and forest product industry partners
- Reduce the risk of destructive wildfire by creating and sustaining healthy and resilient forests and watersheds
- Build capacity through workforce alignment and partnerships

To achieve these goals, I am directing the following actions, within current capacity constraints, to be taken to make initial progress:

I am directing the Deputy Chief for the National Forest System, in consultation with other Deputy Chiefs, Regions and Forests, to develop a national strategy that outlines our agency’s goals, objectives and initial actions related to increasing active forest management. This will be completed in 30 days.

I am directing all Regional Foresters to develop 5-year strategies, tiered to the national strategy, to increase their timber volume offered, leading to an agencywide increase of 25% over the next 4-5 years. These regional timber strategies will include an assessment of their current 5-year



program of work (POW) that includes timber volume, opportunities to expand that POW, a wood utilization facility risk assessment, barriers to achieving a 25% increase in volume (including information beyond funding needed), and potential solutions to overcoming those barriers. As part of your regional strategy, you'll be required to explore the opportunity to designate *Sustained Yield Units* required for industry investments where active management is needed. Strategies must be completed in 60 days following the release of the national strategy.

I am delegating the authorization to use timber designations by prescription (DxP) and designations by description (DxD) to Forest Supervisors. These types of timber designations should be the default approach in implementing timber projects. Exceptions to these designations must be made in consultation with a Regional Forester. Additionally, virtual boundaries should be used in lieu of marked boundaries whenever possible.

Further, I am directing District Rangers and Forest Supervisors to, in addition to regular timber sale solicitations, utilize direct timber sale opportunities with interested purchasers operating on and around forests. Line officers with interested partners must initiate industry engagement within 60 days to integrate these opportunities into your short- and long-term programs of work.

Finally, all agency timber sales will use base rates or minimum rates, where appropriate, based on the Emergency Authorizations outlined by the Secretary. In addition, within 90 days, Regions will establish standard appraisal rates that can be applied and used over a geographic area where similar conditions exist. The Washington Office is available to assist in this process.

Within the next 24 months, I expect each Regional Forester to establish 2 years' worth of "shelf stock" of timber volume coming from project decisions for out-year implementation of their timber related program of work. These decisions should be in place within the next 24 months. As a part of this, within the next 3 months, and every 6 months thereafter, Districts with suitable timber base and active industry partners will develop projects that can be analyzed using appropriate Categorical Exclusions (CEs) to address active forest management needs. These projects will not only reduce fire risk and support local economies but also result in timber volume sold. National assistance will be made available where needed through the Planning Services Organization and Field Services and Innovation Center (FSIC).

I further direct all Line Officers to use innovative and efficient approaches to meeting the minimum requirements of the National Environmental Policy Act (NEPA), Endangered Species Act, National Historic Preservation Act, and other environmental laws, including categorical exclusions, emergency authorities (including the Secretary's recent expanded Emergency Situation Determination), condition-based management, determinations of National Environmental Policy Act (NEPA) adequacy, and staged or tiered decision-making. In addition, I direct compliance with the NEPA statutory time limits for, completing environmental assessments and environmental impact statements.

To this end, I am directing the Deputy Chief of the National Forest System through the Director of Ecosystem Management Coordination, within 14 days, to release direction for using Emergency NEPA, Endangered Species Act (ESA), and other regulatory authorities to streamline and simplify our permitting processes. This guidance will include mandatory

minimum approaches to scoping, extraordinary circumstances analysis and decision documentation requirements.

We will align our workforce to be efficient in active forest management delivery. I am directing the National Forest System Natural Resources Director to streamline or reduce certification requirements and processes. In the next 4 months, all Forest Supervisors, Regional Forester Teams, and appropriate Washington Office staff will attend a national active forest management meeting to align the goals, objectives and actions associated with the program, followed by regular engagements to ensure continued progress and shared leadership. Within 12 months, all current line officers will complete or refresh Forest Management for Line Officers training. New line officers will complete this training within 12 months of their effective date as a line officer.

There have been significant improvements within the Washington Office with integration of the hazardous fuels, Wildfire Risk Reduction Infrastructure Team (WRRIT), and forest management teams over the last several years and their combined efforts have delivered record accomplishments. Based on the guidance in the Executive Order, I am asking for additional integration to continue building on those successes and chart a new, completely seamless program. Therefore, I am directing the Deputy Chiefs of National Forest System and State, Private and Tribal Forestry to develop a proposal for integration of the teams and funding structures at the Washington Office within 30 days. Additionally, I am directing the same group, in consultation with the Regional Foresters, to develop a strategy field level integration, inclusive of regions and forest, within 6 months.

I expect line officers to work with States, Tribes and Counties to establish priorities and identify opportunities to share resources for execution of regional and national active forest management strategies. I expect this to result in an increase in what region's accomplish through Good Neighbor Agreements. We will emphasize work with industry partners to identify needed, feasible projects on national forests and increase the use of G-Z and A-Z contracting, as well as stewardship agreements and other implementation tools.

We will also find additional opportunities to work with states, counties, tribes and non-governmental partners to increase our active forest management activities on the ground. Internal coordination to build capacity will include increasing commercial product delivery in projects that focus on hazardous fuels reduction, implementing direct financial support programs to industry (Wood Innovation Program and Hazardous Fuels Transportation grants), and identifying opportunities to re-direct existing funds toward active forest management.

The agency will fund up to \$50 Million in Good Neighbor Authority Agreements that will fund road and bridge maintenance and reconstruction for active forest management projects. This work will emphasize the *minimum* standards necessary for safety and removal of wood products.

Finally, it is imperative that we plan and execute salvage and reforestation projects as these disturbances happen to accelerate post-wildfire recovery and reestablish healthy and resilient

forests. We have many critical successes to anchor to, including expanded hazard tree removal efforts along roadways, post fire shaded fuel break construction, and Memorandum of Understandings (MOUs) with key industry partners that have helped us model success at local levels. But we need to do more, and as such, I am directing line officers to prioritize and address salvage opportunities, including leveraging opportunities to work with states, tribes, counties, private industry, and partners to increase the pace and scale of recovery and share in achieving cross-boundary results. I'm also directing the use of existing frameworks and tools, such as Potential Operational Delineations (PODS) and the National Alliance of Forest Owners (NAFO) MOU to capitalize on the opportunity to move quickly, capitalize on value, and restore the areas to more fire resilient conditions. Regions, in consultation with the Washington Office and Forests, will integrate their regional 10-year reforestation implementation strategies with the national active forest management strategy. To the maximum extent practicable, use existing and new categorical exclusions for timber stand improvement, salvage, and other site preparation activities for reforestation, consistent with applicable law. I expect that active management, reforestation and stand improvement activities will reduce wildfire risk, ensure sustainable timber supply, promote forest health, and protect our communities and their water supply.

I want to express my sincere appreciation for your trust and support in these matters. Rest assured, we are committed to our mission, value your service and we will continue to exemplify excellence in stewarding public lands for the American people.

CHRISTOPHER B. FRENCH
Acting Associate Chief

Attachment 1: Regional Specific Actions

https://www.codyenterprise.com/news/local/article_f574023c-7874-11eb-9982-8f46e011e2ba.html

TOP STORY

Search & Rescue evacuates trapped snowmobilers

By LEO WOLFSON leo@codyenterprise.com

Mar 1, 2021

1 of 2



Search and rescue members help load snowmobilers into a waiting helicopter. (SAR photo)

Park County Search and Rescue volunteers had a busy week last week.

On Thursday, members assisted, for the second time in a week, in rescuing stranded snowmobilers.

“It was a lot of team effort,” said Park County SAR member Robert Lind. “Because of the most recent back-to-back events we had all hands on deck.”

The rescue involved dropping a radio from a helicopter to communicate with the stranded riders.

Last Wednesday at around 11 p.m., the Park County Sheriff's Office Dispatch Center received a report of eight snowmobilers from Minnesota and Wisconsin that headed into the Beartooth Mountains and had not returned. The reporting party further stated that acquaintances of the men back in Minnesota had received a text from one of them earlier in the day indicating they were in the Maryott Lake area of the Beartooth Wilderness.

Victim Randy Ernest said they had left from the Pilot Creek trailhead and had driven into the Wilderness area to spread their late friend's ashes. He said he did not know rescue had been called for them until they arrived.

The group illegally accessed this Wilderness area where snowmobiles are not allowed. SAR member and BLM ranger Robert Lind said the U.S. Forest Service is actively investigating this incident.

Ernest said they had no idea where they were entering was illegal. He said he has been snowmobiling in the area four or five times in the past.

Park County Search and Rescue, assisted by members of the Cody Country Snowmobile Association, immediately mobilized for the search. However, due to not knowing the exact location of the missing people and the late hour, rescuers decided to wait to deploy until daylight.

SAR was able to use a cell phone photo taken by the group to lock down the general coordinates of where the group was stranded.

SAR member Dr. Elise Lowe said after calling it a night at about 2 a.m., they were back at the SAR facility preparing to launch the rescue around 5 a.m.

Around 6 a.m. Thursday, the ground search teams went to the Island Lake warming hut to plan and begin a search. At 7 a.m., SAR launched an airplane to begin searching the Maryott Lake area. Upon reaching the search area, a spotter in the plane reported seeing multiple snowmobile tracks leading

south from Maryott Lake in the general direction of Granite Lake.

At 8 a.m., AIR-1 located an abandoned snowmobile on the surface of Granite Lake along with multiple tracks. The tracks led to the very southwest corner of the lake where a single rider on a snowmobile was spotted that seemed to be circling the area. When this rider spotted the search plane, he began waving and eventually AIR-1 spotted the rest of the lost party.

The riders had gotten themselves into an extremely rugged area with steep drops, deep snow and downed timber. In addition, one of their vehicles became disabled.

They were unable to find a way out and eventually ran out of fuel. They then built a fire and hunkered down for the night.

The terrain was so hazardous that even the most experienced riders from the CCSA ground teams were unable to reach the victims. It was then decided to use helicopter resources to evacuate them. A helicopter from Guardian Flight in Cody and a helicopter from Teton County Search and Rescue were launched to assist in the rescue when AIR-1 had to return because of some internal damage.

“Teton County was phenomenal,” Lind said.

At 11:45 a.m., Guardian Flight located the victims and landed near them to render any needed medical assistance.

They were located about six miles from the warming hut, Lowe said.

“The biggest issue was they were out farther than they should have been,” Lowe said.

Guardian staff dropped a radio inside a plastic bag down to the victims because they had been unable to engage communication with them. It turned out the group did have radios, but they were on the wrong channel.

All eight subjects were uninjured and in good spirits.

“They were very fast, very efficient, very polite,” Ernest said of the rescue workers.

At 1:30 p.m., Guardian departed the area and the helicopter from Teton County began transporting the subjects, three at a time, to the Island Lake warming hut. There, the Cody Regional Health Wilderness Response Team was waiting to treat the victims, although none were injured.

“It was just an amazing amount of coordination in the field,” Lowe said.

From there, they were taken to the Pilot Creek parking area where they met up with friends who took them back to Cooke City.

Sheriff Scott Steward took the opportunity to remind residents and visitors that it is illegal to ride snow machines or any other mechanized mode of travel into designated wilderness areas, with substantial fines possible if found guilty for these crimes.

“These areas are designated wilderness for a reason,” Steward said. “They are filled with downed timber, steep ascents, deep draws and sheer cliff faces. Much of these areas are unexplored and can be extremely dangerous if you are unfamiliar or unprepared for emergencies should they arise.”

Lind credited the effort made by both the snowmobile staff on the ground, and those who volunteered back in Cody at the SAR dispatch center, with nearly every member involved in some way with the event.

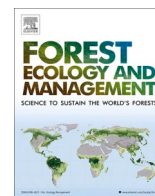
“They are the heart and soul of the operation,” he said. “We have such an awesome set up here in Park County. That’s why SAR here is a well-oiled machine is because of residents like this.”

Although he said the staff was still a little fatigued from the rescue earlier in the week, Lind said SAR used the second rescue as an educational opportunity.

“We were tired by all means, but we refined things from the prior Search and Rescue event and applied them,” Lind said.

Lind thanked the CCSA team that responded to the incident which included members Dustin Rosencranse, Justin Kelly, Brad Metzler, Tony Simek, Dana Buttemeier, Scott Kincheloe, Trinity Schultz and Mike Kelly.

“Those guys are so critical in searching of the ground,” Lind said. “They’re the best there is.”



Previous wildfires and management treatments moderate subsequent fire severity

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ARTICLE INFO

Keywords:

Burn severity
Mixed-conifer forest
Prescribed fire
Thinning
Reburning

ABSTRACT

We investigated the relative importance of daily fire weather, landscape position, climate, recent forest and fuels management, and fire history to explaining patterns of remotely-sensed burn severity – as measured by the Relativized Burn Ratio – in 150 fires occurring from 2001 to 2019, which burned conifer forests of northeastern Washington State, USA. Daily fire weather, annual precipitation anomalies, and species' fire resistance traits were important predictors of wildfire burn severity. In areas burned within the past two to three decades, prior fire decreased the severity of subsequent burns, particularly for the first 16 postfire years. In areas managed before a wildfire, thinning and prescribed burning treatments lowered burn severity relative to untreated controls. Prescribed burning was the most effective treatment at lowering subsequent burn severity, and prescribed burned areas were usually unburned or burned at low severity in subsequent wildfires. Patches that were harvested and planted <10 years before a wildfire burned with slightly higher severity. In areas managed within 5 years after an initial fire, postfire harvest and planting reduced prevalence of stand-replacing fire in reburns. However, overall, postfire management actions after a first wildfire only weakly influenced the severity of subsequent fires. The importance of fire-fire interactions to moderating burn severity establishes the importance of stabilizing feedbacks in active fire regimes, and our results demonstrate how silvicultural treatments can be combined with prescribed fire and wildfires to maintain resilient landscapes.

1. Introduction

1.1. Background

Fire regimes in many seasonally-dry, temperate forest ecosystems have been altered by past grazing, harvest, and fire suppression (Table 1 of Hagmann et al., 2021 and references therein). This has resulted in a fire deficit in forested landscapes throughout the western US (wUS, Lutz et al., 2009; Haugo et al., 2019; Parks et al., 2015b), relative overabundance of high-severity fire (Haugo et al., 2019; Mallek et al., 2013; Parks and Abatzoglou, 2020), and increasingly large high-severity

patches (Cansler and McKenzie, 2014; Stevens et al., 2017). Strong relationships between increased annual drought and increased large fire frequency, greater burned area, and higher fire severity have been documented in temperate forests of western North America (western North America, Holden et al., 2018; Littell et al., 2009; Parisien et al., 2020; Parks and Abatzoglou, 2020; Westerling, 2016). These relationships, along with observed and projected increases in drought and fuel aridity, support the observation that fire regimes in forested ecosystems of western North America are will increase in fire frequency, area burned, and fire severity (Abatzoglou and Williams, 2016; Vose et al., 2018). Hence, the major question for fire researchers and forest

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managers today is how can they adapt forest landscapes to these rapidly changing fire regimes?

Past management (Agee and Lolley, 2006; Agee and Skinner, 2005; Hessburg et al., 2015; Schwillk et al., 2009) and prior fires (Parks et al., 2015a; Prichard et al., 2017; Stephens et al., 2009; Stevens-Rumann et al., 2016) influence the spread, intensity, and severity of subsequent fires. Silviculture and fire, including both prescribed and wildfire, are thus the main tools that managers can use to restore ecological resilience and resistance, and direct ecosystems toward conditions that will be more resilient under future climates (Hessburg et al., 2021; Millar et al., 2007; Schuurman et al., 2020). In the inland Pacific Northwest the composition, structure, pattern, and functions of low and mid-elevation forests have changed since EuroAmerican colonization (Hessburg et al., 2015, 2005, 2000; Hessburg and Agee, 2003). Throughout this region, the early 21st century correspondingly featured rapidly changing burn conditions. A century of fire exclusion – which continues to be a primary management response – has created a severe fire deficit in historically fire-frequent and moderately fire-frequent forests (Haugo et al., 2019). As a result, many of these forests are overly dense with high fuel loads, making them susceptible to high-severity burns (Hessburg et al., 2005).

Presently, a larger proportion of the frequent-fire, low and mid-elevation elevation pine and mixed-conifer forests burning with higher severity than would be expected under historically active fire regimes (Haugo et al., 2019). Moreover, recent wildfires are creating large high-severity patches in dry and moist mixed-conifer forests (Cansler and McKenzie, 2014) that had low- or mixed-severity (i.e., a mix of low, moderate, and high burn severity burn patches) fire regimes prior to Euro-American colonization (Agee, 1998, 1996). Consequently, broad-scale plans to increase forest resilience and resistance to future wildfires and climatic changes through management (e.g., WADNR, 2020) have been developed. Plans recommend either restoring historical forest structural and species composition patterns, or modifying historical conditions using future climate projections to re-establish resilient forest conditions that match future climates (Churchill et al., 2013; Hessburg et al., 2019, 2021; Prichard et al., 2021). Needed now is specific information about how past management and fire history now influence wildfires under the modern climate (Coen et al., 2018; Haugo et al., 2019; Kane et al., 2019; Mallek et al., 2013). Improved knowledge on the types and influence longevities of effective silvicultural and fire treatments can increase consensus on strategies that can successfully

promote resilience and adapt forests to future climates.

We examined determinants of burn severity for fires that burned from 1985 to 2019 in northeastern Washington State, USA. We considered drivers of burn severity and their interactions across a range of management treatments, reburn histories, annual climatic conditions, landscape positions, and forest communities. Our research questions were to identify: 1) co-factors controlling burn severity in untreated long-unburned and reburned areas; and 2) discover the influence of prefire and postfire forest management treatments on burn severity of later wildfires.

2. Methods

2.1. Study area definition

Our study area focused on state, federal and tribally managed lands within the Northern Cascades ecoregion and the Okanogan Highlands ecoregion of Washington State, USA. It included lands managed by the US Forest Service (i.e., Okanogan-Wenatchee NF and the Colville NF), the National Park Service, Confederated Tribes of the Colville Reservation, and the Washington State Departments of Fish and Wildlife (WDFW), and Natural Resources (WA DNR). These ecoregions contain a broad range of biogeoclimatic settings including shrub-steppe, grassland, and sparse woodland communities at lower elevations (approximately 250 m to 1500 m); woodlands and dense pine and mixed-conifer forests at middle elevations (approximately 350 m to 2900 m); and subalpine forests, parklands, and alpine heathlands at the highest elevations (approximately 700 m to 3000 m).

Fires occurred in dry, moist, and cold forest types—as mapped by the Landfire program (Fig. 1)—from the lower to upper montane reaches of the Cascade Range and Kettle River Range, which vary by dominant tree species, historically active fire regimes, precipitation, temperature, climatic water deficit, and evaporative demand placed on tree establishment and growth (Table 1). Elevational gradients in northeastern Washington are steep, and the topography is complexly dissected, especially in the most western parts of our study area (Cansler and McKenzie, 2014), such that the local climate, dominant species, forest structural condition, and fire history can vary over relatively short distances.

Table 1

Summary of potential vegetation groups (PVGs) within the eastern Washington study area, their dominant coniferous species, and 30-yr climate normals. Climate variables are mean annual temperature (MAT; °C), mean annual precipitation (MAP; mm), annual climatic water deficit (DEF; mm), and annual evapotranspiration (AET; mm), for the period 1981–2010. Quantiles are P₅₀ [P₂₅, P₇₅]. Table reproduces climatic summaries from Povak et al. (2020a).

PVG	USFS PVT ¹	Fire regime ²	Dominant species	MAT ³	MAP ³	DEF ^{3,4}	AET ^{3,4}
Dry-mixed conifer	Dry Douglas-fir Dry Mixed Conifer Ponderosa pine	Frequent, low-severity surface fire	<i>Pinus ponderosa</i> <i>Pseudotsuga menziesii</i> <i>Abies grandis</i> <i>Pinus contorta</i>	6.6 [5.3,7.8]	667 [536,828]	290 [212,337]	255 [235,283]
Moist-mixed conifer	Moist Mixed Conifer Cedar/Hemlock	Mix-severity fire	<i>Pseudotsuga menziesii</i> <i>Pinus ponderosa</i> <i>Abies grandis</i> <i>Thuja plicata</i> <i>Tsuga heterophylla</i> <i>Pinus contorta</i>	6.5 [5.6,7.2]	884 [773,942]	270 [207,301]	258 [237, 285]
Cold-dry conifer	Mtn hemlock-Cold/ Dry Subalpine fir-Cold/ Dry	Infrequent, high-severity surface and crown fire	<i>Pinus contorta</i> <i>Abies lasiocarpa</i> <i>Tsuga mertensiana</i> <i>Tsuga heterophylla</i> <i>Pseudotsuga menziesii</i>	3.7 [2.8,4.6]	848 [710,1023]	148 [121,226]	266 [233, 317]

¹ See Table 2.1 in Burcsu et al. (2014) for detailed descriptions of each PVT

² Agee (Agee, 1996)

³ PRISM Climate Group, URL... ⁴ Appendix A

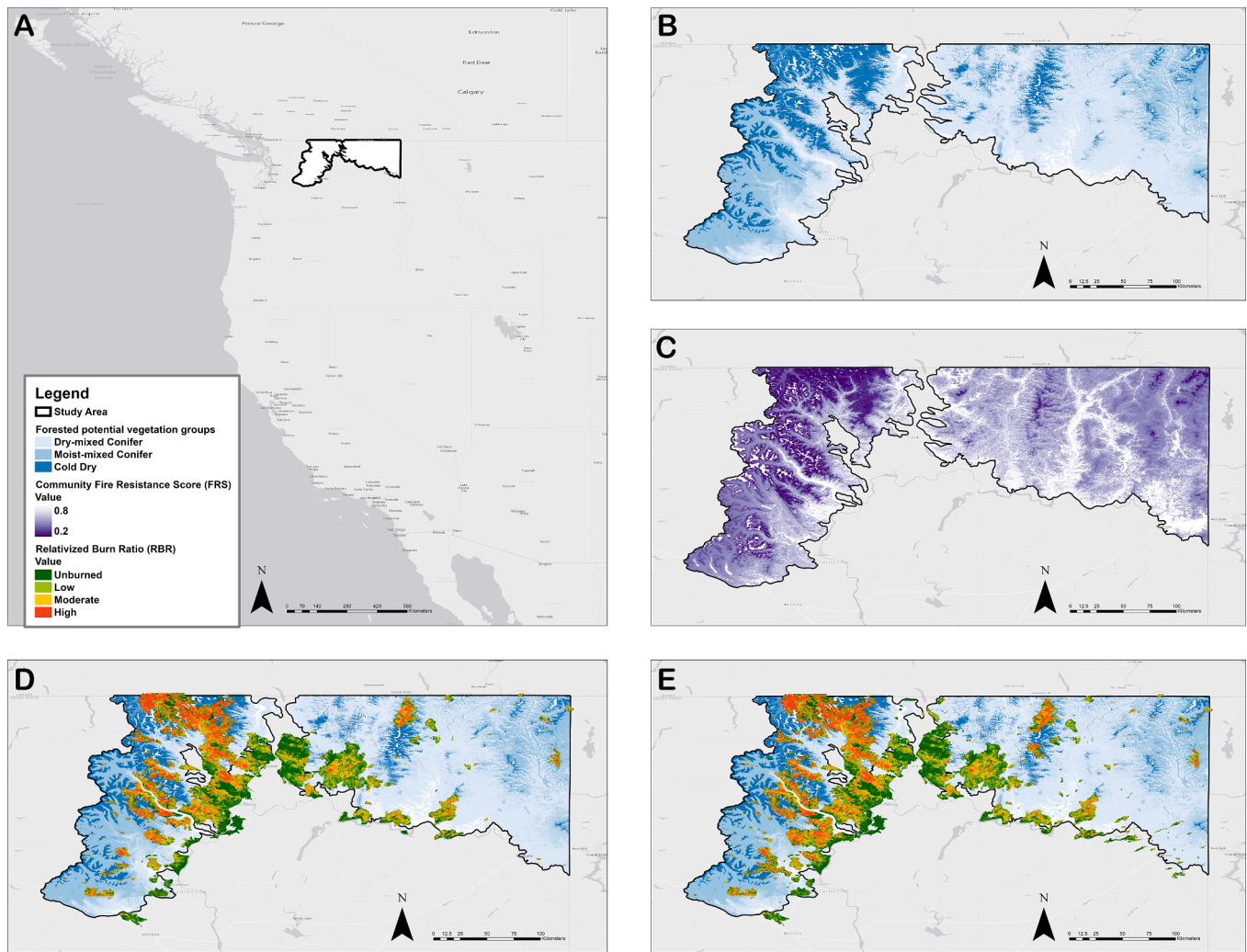


Fig. 1. Maps of study area in northeastern Washington State, USA. (A) The study area was in eastern Washington in North Cascades and Okanogan Highlands ecoregions. (B) We also restricted our analysis forested potential vegetation groups (i.e., dry-mixed conifer, moist-mixed conifer, and cold-dry conifer groups described in Table 1). (C) The community fire resistance score (FRS; Stevens et al. 2020) captures broad-scale gradients in conifer tree species community composition, as reflected in species' fire adapted traits, across the study area. (D) Response data were classified Landsat-based burn severity, as measured by the Relative Differenced Burn Ratio (RBR) within fires occurring from 2001 to 2019, with at least 40 ha in conifer forest, and where there were at least 5 MODIS burn detections. (E) Burn severity of fires from 1985 to 2000, and from all fires from 2001 to 2019, including those that were not included as a response, are shown here. These fires were included as predictors in the models predicting the severity of reburns when they predated another fire. Our response data (D) included most, but not all, of the area burned since 1985 (E).

2.2. Response data

2.2.1. Burn severity

We spatially attributed our burn severity response variable for all sampled wildfire burned areas using Landsat derived Relativized Burn Ratio data (RBR; Parks et al., 2014). Fire perimeters from the WA DNR, as corroborated by the US National Monitoring Trends in Burn Severity (MTBS) program (Eidenshink et al., 2007) were used to identify all mapped perimeters for areas that had burned between 1985 and 2019, and burn severity spatial patterns within all fire perimeters were mapped, for a total of 437 fires occurring across 35 years (Fig. 1c). The use of RBR (Parks et al., 2014) provided a relatively accurate measurement of wildfire effects, which in our experience improved spatial accuracy over the commonly-used RdNBR index, especially in the low to moderate range of burn severities (Furniss et al., 2020; Parks et al., 2014). We calculated RBR in Google Earth Engine (GEE) using composites of prefire and postfire images, following the methods of (Parks et al., 2018b) based on the updated GEE script dated July 2021 (Parks, 2021).

Because very low and very high RBR values may be caused by

reflectance errors, we removed extreme values below and above the 0.5 and 99.5 percentiles (i.e., <-114 and >605 reflectance values, respectively) of all observed RBR values before analysis. For interpretation and predicting reburn severity, we transformed RBR to three fire response classes; high, low-moderate, and unburned refugia (Table 2). Note that based on how our unburned class is defined, it likely captures ephemeral fire refugia, which only last through a single fire, and persistent fire refugia, which remain unburned or are altered little through multiple fires (Meddens et al., 2018). These classes were calculated based on the average class threshold across fires in the Pacific Northwest and Northern Rocky Mountains, provided in Table 3 of Parks et al. (2014), which were derived from field measurement of burn severity using the Composite Burn Index (Cansler and McKenzie, 2012; Key, 2006). For interpretation, we also provide thresholds for 2% and 98% mortality in Table 1, based on data from Saberi and Harvey (2021), and regression methods in Saberi (2019) and Saberi et al. (2020).

All data used to model burn severity response were from fires that took place between 2001 and 2019, which reflects our improved ability to accurately map fire spread using MODIS satellite data beginning in

Table 2

Fire effects response classes and estimates of percent basal area loss derived from RBR, identified based on Parks et al. (2018b). Two additional thresholds related to tree basal area loss were supplied by Saberi et al. (2020) based on field data from fires in the Pacific Northwest region, USA, and statistical methods (zero and one inflated beta regression) described in Saberi (2019).

Burn severity class	RBR range	Composite Burn Index	Estimated % basal area loss
Burn severity classes modeled with random forest			
Refugia	< 69	0–0.1	< 23 (13–37)
Low-moderate	≥ 69 & < 332	0.1–2.25	≥ 23 (13–37) & < 88 (77–98)
High	≥ 332	> 2.25	≥ 88 (77–98)
Additional burn severity thresholds for data interpretation			
All trees survive	< –31		< 2.0 (0.025 – 5.8)
Stand replacing fire	≥ 453		≥ 98 (94–100)

about 2001 (Parks, 2014). We limited response data to forested pixels (i.e., dry-mixed conifer, moist-mixed conifer, and cold-dry conifer potential vegetation groups described in Table 1), with at least 40 ha in forest, and where there were at least 5 MODIS burn detections. We considered a fire to be a “reburn” if any fire burning between 2001 and 2019 fire burned an area previously burned in a fire occurring between 1985 and 2018. Burn severity of fires burning from 2001 to 2019 comprised the response variable dataset for reburns. This resulted in a total response sample from 150 fires, 138 of which had sufficient samples to analyze wildfire effects on long-unburned areas, and 65 of which allowed reburn sampling; 53 fires had separate areas included in both the long-unburned and reburn analysis.

2.3. Predictor data

2.3.1. Temporally varying predictors

Day-of-burning for each sample location (e.g., a 30-m pixel; defined further below in the *Statistical Methods* section) was estimated using MODIS satellite data via the interpolation method of Parks (2014). Any fires with fewer than five MODIS observations (the minimum needed for the Parks (2014) method) were excluded. After estimating the day of burning for each sample in each fire, we acquired daily weather data from gridMET (Abatzoglou, 2013). Daily fire weather variables included spatially interpolated observations based on weather station data (e.g., vapor pressure deficit, wind speed), as well as derived indices related to fire behavior (e.g., energy release component, 1,000-hour fuel moisture) (Table 3). During exploratory analyses, we assessed variables both measured on the day of the burn, and as a five-day average (two days on either side of the estimated burn day), but few differences between approaches were found, and hence we used day-of-burn observations.

Annual climate variables for the period 1981 to 2010 were obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM; <https://prism.oregonstate.edu/>; Daly et al., 2008, 2002, 1994) by averaging monthly data in the year leading up to each fire. Climate variables included precipitation, mean temperature, minimum monthly vapor pressure deficit, and maximum monthly vapor pressure deficit (Table 3). We identified climate anomaly years by differencing yearly summaries from the 30-year climate normals.

2.3.2. Spatially varying predictors

Bioclimatic variables can provide as a proxy for existing vegetation and biomass potential (Table 4). We used actual evapotranspiration (AET) and climatic water deficit (deficit) because they are strongly related to vegetation composition (Stephenson, 1998). We calculated them using the Priestley-Taylor equation (Priestley and Taylor, 1972), following methods of Dobrowski et al. (2013). Along with elevation and latitude, the Priestley-Taylor equation uses albedo, solar radiation, relative humidity, and minimum and maximum temperatures to

estimate potential evapotranspiration (PET) for a given day of the year. Precipitation, temperature, and relative humidity data, downscaled to 90 m, were obtained from Climate NA version 6.0 (Wang et al., 2016). Full methods are described in Appendix A.

Three potential vegetation groups (PVGs) were used to classify mixed-conifer forests. The forest types (PWG) were: dry mixed-conifer (DMC), moist mixed-conifer (MMC), and cold-dry forests (CDF; Table 1.), which were reclassified from U.S. Forest Service potential vegetation classifications (Burcsu et al., 2014), following classification scheme in Povak et al. (2020a). Tree species fire resistance traits were captured using the fire resistance score (FRS) of Stevens et al. (2020) (Fig. 1). The FRS was developed by combining relativized tree morphology and litter flammability traits of 29 western North American conifers. Morphological traits included bark thickness, plant height, and capacity for self-pruning; litter flammability traits included flame length, percent consumption, and flame duration under documented burn conditions, with higher scores indicating greater resistance (Stevens et al., 2020). The geospatial map of FRS used in this analysis measure the community-scale FRS. It was calculated based on the relative abundance of each species, based on modeled and mapped basal area of each species (Stevens et al., 2020; Wilson et al., 2013).

Topographic variables were calculated using a 30 m resolution digital elevation model (DEM), created from a 1/3 arc second (approx. 10-m) DEM from the USGS 3DEP program, resampled to 30 m grids to match the resolution of our other data. Variables included a topographical position index (TPI) calculated at 500 m and 2000 m scales, slope, and aspect (Table 4; McGaughey, 2021). We also included topographic variables in initial models that have been shown to be predictors of fire refugia in the neighboring western Cascades as a function of vegetation composition and structure, short-term fuel moisture, and wind exposure (Meigs et al., 2020).

We used imputed 30-m rasters of forest structure variables (Table 4) from the Landscape Ecology, Modeling, Mapping and Analysis program (<https://lemma.forestry.oregonstate.edu/>; LEMMA) to approximate basal area, canopy cover, quadratic mean diameter of trees, and a diameter diversity index for the year 2000, the start of our study period. These forest structure variables were interpolated across the landscape based on field-sampled regional inventory plots and the canonical relationships between the plot data and several wall-to-wall Landsat imagery datasets, using the gradient nearest neighbor (GNN) imputation procedure described in Ohmann and Gregory (2002).

2.3.3. Reburns: Fire history and severity predictor data

All fires in the burn severity atlas (1985 – 2019) were used to establish fire history for the period (Fig. 1e; Table 4). For all burn severity response data where a previous fire had burned since 1985, we calculated time since the last fire, maximum previous severity (maximum RBR), and the number of previous fires. Areas that had burned two or three times between 1985 and the most recent fire (e.g., twice and thrice reburned) were excluded from the analysis due to low sample sizes.

2.3.4. Management history

Areas where silvicultural or fuel management treatments had occurred from 1991 to 2017 were identified using the U.S. Forest Service-Forest Activity Tracking System (FACTS) database (<https://data.fs.usda.gov/geodata/edw/datasets.php>). We first condensed FACTS database treatments into four broad categories: prescribed fire, mechanical thinning, planting, and timber harvest. In locations where more than one of the four treatment categories occurred, we considered the combined treatments as separate categories (e.g., we also assessed “thinning and harvest”, “harvest and planting”, “prescribed fire and harvest”, and “prescribed fire, harvest, and planting”). Prefire planting primarily occurred within two non-adjacent timeframes, so we divided the prefire planting into “old” (≥20 years before the fire) and “recent” (≤10 years before fire) categories. There were limited observations of

Table 3

Spatially-varying predictor variables used in final Random Forest machine learning models to predict burn severity. Methods for calculating AET and CWD normals are described in Appendix A.

Variable	Expected relationship with fire severity	Modeling steps used	Units or range	Description and methods	Grain (m)	Citation
Bioclimatic setting Actual evapotranspiration climate normals (AET)	Increase	Removed during variable reduction	mm	Actual evapotranspiration is related to the amount of photosynthesis that can actually occur, given water imputes and soil conditions. Calculated following methods described in Appendix A. Variable represent the 30-year mean actual evapotranspiration.	90	Appendix A
Climatic water deficit normals (deficit)	Decrease	Removed due to multicollinearity	mm	Climatic water deficit represents the amount of evaporative demand that cannot be met because soil water has been depleted during the summer dry period. Calculated following methods described in Appendix A. Variable represent the 30-year mean 30-year mean climatic water deficit	90	Appendix A
Community fire resistance score (FRS)	Increase	Final model	continuous numeric	A single fire resistance score for all mature trees at a location, calculated used community-weighted averaging of species' traits to estimate the fire resistance scores of different forest communities, using interpolated species distribution and relative abundance data.	30	Stevens et al. (2020)
Potential vegetation group (PVT)	Lowest in DMC, highest in CDF.	Removed due to multicollinearity	Dry mixed conifer (DMC), moist mixed conifer (MMC), cold-dry forests (CDF)	Potential vegetation groups: Dry mixed conifer (DMC), moist mixed conifer (MMC), cold-dry forests (CDF). These represent climax vegetation types reflecting common species assemblages, site productivity, and disturbance regimes, which could have many different successional states and forest development structures in them.	30	Burcsu et al. (2014)
Topography Topographical position index, at 500 m scale (TPI 500)	Highest at large values, which represent local ridgetops that would be more exposed to the wind.	Removed due to multicollinearity	Continuous numeric index	Smaller, negative values represent valley bottoms and depressions, and larger positive values represent ridgetops and hilltops. Calculated using the terrain() function in R's raster package based on a 30 m resolution ground model	30	Hijmans and van Etten (2012)
Topographical position index, at 2000 m scale (TPI 2000)	Highest at middle values, which represent mid-slope positions of large landscape features.	Final model	Continuous numeric index	Smaller, negative values represent valley bottoms and depressions, and larger positive values represent ridgetops and hilltops. Calculated using the terrain() function in R's raster package based on a 30 m resolution ground model	30	Hijmans and van Etten (2012)
Local slope	Increases	Removed due to multicollinearity	radians	Calculated using the terrain() function in R's raster package.	30	Hijmans and van Etten (2012)
Local aspect	Increases	Removed during variable reduction	Cosine transformed radians	Cosine transformed radians. -1 = South, 1 = North, and values near 0 are East and West. Calculated using the terrain function in R's raster package based on the USGS 3DEP ground model resampled to a 30 m resolution to aid processing time	30	Hijmans and van Etten (2012)
Catchment slope	Increases	Final model	radians	Mean slope of the catchment area. Calculate in R's RSAGA package	30	Brenning and Bangs (2016)
Catchment area	Decreases	Removed due to multicollinearity	square meters	Hydrological catchment extent. Calculate in R's RSAGA package.	30	Brenning and Bangs (2016)
Catchment flow path	Decreases	Removed during variable reduction	meters	Length of hydrologic flow path (m). Calculate in R's RSAGA package	30	Brenning and Bangs (2016)
Relative position	Increases	Removed during variable reduction	numeric (0-10)	Relative topographic position (0–10); lower to higher elevation within 500 m radius; captures the landscape position of a given site. Calculate in R's RSAGA package	30	Brenning and Bangs (2016)
Forest structure Basal area	Increase	Final model	m ² /ha	Interpolated basal area of live trees >=2.5 cm dbh in the year 2000	25	Ohmann, and Gregory (2002)
Canopy cover	Increase	Removed due to multicollinearity	percent	Interpolated canopy cover of all live trees in the year 2000	25	Ohmann, and Gregory (2002)
Quadratic mean diameter	Increase		cm		25	

(continued on next page)

Table 3 (continued)

Variable	Expected relationship with fire severity	Modeling steps used	Units or range	Description and methods	Grain (m)	Citation
Diameter diversity index	Decrease	Removed during variable reduction Removed during variable reduction	numeric continuous	Interpolated quadratic mean diameter of all dominant and codominant trees in the year 2000 Interpolated diameter diversity index in the year 2000. DDI is a measure of the structural diversity of a forest stand, based on tree densities in different DBH classes.	25	Ohmann, and Gregory (2002) Ohmann, and Gregory (2002)

Table 4

Temporally-varying predictor variables used in final Random Forest machine learning models to predict burn severity. Methods for calculating AET and CWD normals are described in Appendix A.

Variable	Expected relationship with fire severity	Modeling steps used	Units or range	Description and methods	Grain (m)	Citation
Annual antecedent weather anomalies						
Annual precipitation anomaly	Decrease	Removed during variable reduction	mm	The sum of annual precipitation for the 12 months proceeding the July of the fire, minus 1981–2020 normals	4000	Daly et al. (2002) ; http://prism.oregonstate.edu , created 4 Feb 2004.
Annual monthly temperature anomaly	Increase	Final model	C	The average monthly temperature for the 12 months proceeding the July of the fire, minus 1981–2020 normals	4000	Daly et al. (2002) ; http://prism.oregonstate.edu , created 4 Feb 2004.
Annual mean monthly minimum vapor pressure deficit anomaly	Increase	Final model	mm	The average monthly minimum vapor pressure deficit for the 12 months proceeding the July of the fire, minus 1981–2020 normals	4000	Daly et al. (2002) ; http://prism.oregonstate.edu , created 4 Feb 2004.
Annual mean monthly maximum vapor pressure deficit anomaly	Increase	Removed during variable reduction	mm	The average monthly maximum vapor pressure deficit for the 12 months proceeding the July of the fire, minus 1981–2020 normals	4000	Daly et al. (2002) ; http://prism.oregonstate.edu , created 4 Feb 2004.
Daily fire weather Burning Index	Increase	Removed during variable reduction	continuous numeric index	The burning index is derived from the spread component (SC), a relative index of rate of fire spread, and the energy release component (ERC), a relative index of the amount of heat released per unit area in the flaming zone of an initiating fire. The BI is expressed as a numeric value related to potential flame length in feet multiplied by 10..	4000	Abatzoglou (2013); also see: https://www.fs.fed.us/rm/pubs_int/int_gtr169.pdf
Energy Release Component	Increase	Removed due to multicollinearity	continuous numeric index	Modeled mean daily energy release component. A relative index of the amount of heat released per unit area in the flaming zone of an initiating fire. with larger values representing greater potential heat release	4000	Abatzoglou (2013); also see: https://www.fs.fed.us/rm/pubs_int/int_gtr169.pdf
Wind Speed	Increase		m/s	Modeled mean daily windspeed	4000	Abatzoglou (2013)
Mean vapor pressure deficit	Increase	Removed due to multicollinearity	mm	Modeled mean daily mass of water vapor per volume of moist air relative to the maximum humidity the air could hold at the same temperature	4000	Abatzoglou (2013)
100-hour dead fuel moisture	Increase	Removed due to multicollinearity	percent	Modeled daily fuel moisture for dead woody surface fuels 2.54–7.62 cm in diameter. 1,000-hour timelag fuel moisture is a good indicator of the severity of a medium term (4- to 6-month) drought event	4000	Abatzoglou (2013); also see: https://www.fs.fed.us/rm/pubs_int/int_gtr169.pdf
1000-hour dead fuel moisture	Increase	Final model	percent	Modeled daily fuel moisture for dead woody surface fuels 7.62–20.32 cm in diameter. 1,000-hour timelag fuel moisture is a good indicator of the severity of a medium term (4- to 6-month) drought event	4000	Abatzoglou (2013); also see: https://www.fs.fed.us/rm/pubs_int/int_gtr169.pdf
Minimum relative humidity	Decrease	Removed due to multicollinearity	percent	Modeled lowest daily mass of water vapor per volume of moist air relative to the maximum humidity the air could hold at the same temperature	4000	Abatzoglou (2013)
Maximum relative humidity	Decrease	Removed during variable reduction	percent	Modeled highest daily mass of water vapor per volume of moist air relative to the maximum humidity the air could hold at the same temperature	4000	Abatzoglou (2013)

planting from 10 to 20 years before fire, so we excluded that time frame from the analysis. We assessed fires occurring from 2001 to 2018, with the start year matching the availability of MODIS fire spread and daily fire weather data, which we used for pairing controls (see below), and 1 year after the latest available FACTS data record at the time of analysis.

We analyzed combinations of treatments and fires occurring in three combinations, with the response variable always being the RBR burn severity of the most recent fire. We identified areas where: (1) treatments occurred before a fire (hereafter, *treatment-fire*, nine types), and (2) treatments occurred before two successive fires (hereafter, *treatment-fire-fire*, two types), and (3) areas where treatment occurred after a first fire (hereafter, *fire-treatment-fire*; three types) but before a reburn (Table 6). *Fire-treatment-fires* were limited to treatments that took place ≤ 5 years of the first fire, because we were specifically interested in treatments implemented in response to the fire. Treatment types that did not include at least 550, 30-m pixels (~ 50 ha) were excluded from analysis. Some prescribed fires were also present in our burn severity atlas. For this analysis, if a prescribed fire occurred before a wildfire, that area analyzed as a *treatment-fire*.

2.3.5. Spatial autocorrelation

We represented spatial autocorrelation using principal coordinates of neighbor matrices analysis (PCNM) (Borcard and Legendre, 2002; Dray et al., 2006). The PCNM procedure uses principal coordinates analysis on a matrix of points within a predefined distance, resulting in eigenvectors that maximize Moran's index of autocorrelation. Low-order vectors represent larger-scale spatial autocorrelation, and high-order vectors represent local-scale spatial autocorrelation (Borcard and Legendre, 2002). We followed methods of Povak et al. (2020b) for application of the PCNM method to predictive modeling of burn severity with random forests (described in the next section). We used truncated distance matrices with a threshold distance of 10,000-m to calculate lower-ordered (1–10) PCNM vectors and included the first six vectors as predictors (Table 5). We refer readers to Povak et al. (2020b), and the associated online [supplementary information](#) for a full discussion of how inclusion of PCNM eigenvector decreases spatial autocorrelation of model residuals and explains how they are used as predictors. PCNM eigenvectors were calculated in R using the *vegan* (Oksanen et al., 2019) and *RSpectra* packages (Qiu Y, 2018).

2.4. Statistical methods

2.4.1. Identifying co-factors controlling burn severity in untreated long-unburned areas and reburns

Because burn severity is controlled by a number of drivers that can

have non-linear, contingent relationships (Dillon et al., 2020; Kane et al., 2015a, 2015b; Meigs et al., 2020; Povak et al., 2020b), we use random forest (RF) modeling (Breiman, 2001) to predict RBR. For this analysis, we resampled the 30-m scale RBR and associated predictor data with a 270 m grid, and then randomly sampled 20,000 of these 270-m grid cells for modeling. Most of the predictor data is captured at finer native scales (25, 30, or 90-m scale), with the exception of the annual climate and fire weather data, which have a 4-km native resolution. We used this 270 m resampling approach to decrease the influence of fine-scale spatial autocorrelation in our models, and because analyzing every 30-m burn severity pixel was computationally intractable. We chose the 270-m grid size based on explicit testing of a range of sampling scales and recommendations by Povak et al. (2020b), and our observation that a 270-m grid cell adequately samples the unburned class, while decreasing prevalence of fine-scale spatial autocorrelation.

We modeled burn severity in long-unburned areas separately from reburns. Areas that burned where silvicultural and mechanical fuel treatments had occurred were excluded from this analysis and are addressed below in a separate analysis. Each model predicted occurrence of three burn severity classes: refugia, low-moderate severity, and high-severity (Table 2).

We determined predictor variable inclusion in the RF models through a multi-step process, with the goal of identifying a parsimonious variable set that allowed direct comparison of predictors between long-unburned and reburn models. We began by assessing multi-collinearity among predictors prior to variable reduction using Spearman's rank correlations ($r < |0.7|$). Among correlated variables, those with the strongest correlation with continuous values of RBR were retained. Next, we developed an RF model with the reduced set of predictors and a 10-fold cross-validation procedure to identify the best *meta*-parameters and assess model stability and robustness to prediction. In machine learning, *meta*-parameters or hyper-parameters are configurations that are external to the model, but are used to estimate model parameters (Boehmke and Greenwell, 2019), and in RF models these include the number of decision trees in the forest, and the criteria used to split each node. We conducted separate cross-validations for differing burning periods and fires to prevent model overfitting to large fire-spread days and allow for model transferability to other events.

Third, using the identified meta-parameters, we reduced variables in the RF models using backwards stepwise reduction, until we found the minimum model that maintained at least 95% of the cross-validated accuracy of the full model. Based on the variable reduction results for the two models (long-unburned areas and reburns), we selected a final set of predictors, which include the set of predictors for each model, without any highly correlated variables, and at least one variable in each

Table 5

Fire history and spatial autocorrelation predictor variables used in final Random Forest machine learning models to predict burn severity. Methods for calculating AET and CWD normals are described in Appendix A.

Variable	Expected relationship with fire severity	Modeling steps used	Units or range	Description and methods	Grain (m)	Citation
Fire history						
Time since last fire	Increase	Final model	years	Based on the fire ignition year of the fire	30	Based on data from fire perimeters geospatial layers from the US national Monitoring Trends in Burn Severity (MTBS) program (Eidenshink et al., 2007), WA DNR, and United States Forest Service (USFS)
Previous RBR	Decrease	Final model	numeric index (see Table 2)	Relativized Burn Ratio or previous fire; calculate for all mapped fires since 1985	30	Parks et al. (2018b, 2014)
Spatial autocorrelation						
Principal coordinates of neighbor matrices (PCNM 1–6)	No expectation	Final model (PCNM 1–3); Removed during variable reduction (PCNM 4–6)	numeric continuous	Low-order PCNM vectors represent broad-scale SA, while higher-order vectors represent more fine-scaled SA	30	Borcard and Legendre (2002)

Table 6

Treatment in mixed-conifer forest in Northeastern Washington state that occurred before wildfire. Wildfires and reburns occurred from 2001 to 2019, and treatments took place from 1982 to 2017. In reburns, previous fires occurred from 1985 to 2018.

Treatment	Total area (ha) in class ¹	Total samples (n) ²	Control samples within environmental range of treated cases (n)	Sub-sample analyzed (n) ³	Unique fires + burn periods in treated subsample	Unique fires + burn periods in control subsample
Untreated areas						
Untreated wildfires (control)	505,510	69,343	NA	19,254	1,385	NA
Untreated reburns (control)	51,919	7,122	NA	6,313	421	NA
<i>Treatment-fire</i>						
Thinning	427	4,742	11,316	4,742	58	501
Thinning + harvest	429	4,772	9,015	4,772	58	494
Harvest ²	8,908	98,982	17,505	5,835	942	275
Harvest + planting ²	2,958	32,864	16,826	5,608	177	623
Planting (old; ≥ 20 years before fire)	291	3,235	8,521	3,235	61	507
Planting (recent; ≤ 10 years before fire) ²	449	4,992	10,193	4,992	26	608
Prescribed fire ²	2,130	23,670	17,551	5,850	100	511
Prescribed fire + harvest	819	9,101	11,307	9,101	101	720
Prescribed fire + harvest + planting	137	1,524	1,375	1,375	8	128
<i>Treatment-fire-fire</i>						
Harvest + planting	122	1,351	2,290	1,351	29	220
Planting	319	3,544	3,943	3,544	40	285
<i>Fire-treatment-fire</i>						
Harvest	62	690	1,881	690	15	116
Harvest + planting	327	3,632	3,010	3,010	43	318
Planting	1,230	13,664	4,007	4,007	59	306

¹ For untreated areas, the area in the table represents the total burned area represented by the sample, not the area of samples.

² Untreated areas were sampled on a 270 m grid, which was then randomly down sampled to 20,000 points. Extreme RBR values above and below the 0.5 and 99.5 percentiles were also trimmed from all datasets. Treated areas were sampled on a 30 m grid, matching the resolution of the RBR data.

³ To create subsamples either the cases or controls were subsampled, based on the best matched environmental variables. For Harvest, Harvest and Planting, Plantings (recent), and Prescribed fire computational limitations required us to subsample both groups before creating matched controls and cases. We subsampled the cases to the listed subsample size, and subsampled the controls to 3 times that amount, then drew environmental matched samples from that subsample.

variable category (Table 3). Fire history variables were not included in models of long-unburned areas. Using this final set of variables, we ran two separate models for both the long-unburned and reburns models: (1) a final cross-validation, with the best *meta*-parameters to determine final cross-validated accuracy and a kappa statistic, and (2) a final model without cross-validation, in which we increased the number of RF trees from 1000 to 5000. Using the latter, we identified final out-of-bag (OOB) error and calculated class probabilities and variable importance.

All analyses were conducted in R version 3.6.3 (2020-02-29, R Core Team, 2020) using the *ranger* package version 0.12.1 (Wright and Ziegler, 2015), and the *caret* package, version 6.0-86 (Kuhn, 2008) for cross-validation and *meta*-parameter tuning, and the *tidyverse* package for data manipulation and visualizations (Wickham et al., 2019). For all RF model runs, we set the sample fraction to take equal samples from each of the predicted burn severity classes within each bootstrap to create balanced random forest modeling conditions (Chen et al., 2004), with the sample fraction of the largest class set to a maximum of 68% of the total sample. For model interpretation, we created one- and two-variable partial dependence plots to assess the correspondence between variables and burn severity, using the *pdp* package in R, version 0.7.0 (Greenwell, 2017). Two-variable whisker plots allowed us to look for interactions and nonlinearities between predictors.

We used class probability predictions for each observation to calculate accuracy statistics for binary classes: refugia vs. non-refugia, low- and moderate-severity vs. other severities, and high- vs. other burn severities. This allowed us to compare model accuracy and direction of errors for fire effects classes for different management priorities. We calculated model accuracy using the area under the receiver operator characteristic curve (AUC, Bradley, 1997), and the confidence interval around the AUC. The AUC provides an average estimate of the discriminatory ability of any model to predict the probability of being in

one of two classes, with AUC values ≥ 0.5 indicating better discrimination than by random chance selection (Hosmer et al., 2000). The higher the AUC, the stronger is model discrimination between two classes. We also calculated model sensitivity in several ways. We estimated model sensitivity to identifying:

- 1) true positives, where $(\text{truepositives} \div (\text{truepositives} + \text{falsenegatives}))$; e.g., for high severity, the proportion of high severity observations correctly predicted),
- 2) true negatives, where $(\text{truenegatives} \div (\text{truenegatives} + \text{falsepositives}))$; e.g., for high severity, the proportion of unburned or low-moderate severity observations correctly predicted),
- 3) model positive predictive value $(\text{truepositives} \div (\text{truepositives} + \text{falsepositives}))$; e.g., for high severity, the proportion of predicted high severity that is actually high severity),
- 4) model negative predictive value $(\text{truenegatives} \div (\text{truenegatives} + \text{falsenegatives}))$; for high severity, the proportion of predicted “not high severity” severity that is actually not high severity), and
- 5) model overall accuracy (total correct as a proportion of total observations).

We used the package *pROC* version 1.17.0.1 in R (Robin et al., 2011) to calculate accuracy statistics with the 10,000 bootstrap samples used to calculate AUC confidence intervals.

2.4.2. Establishing the influence of prefire and postfire forest treatments on the burn severity of later wildfires

Management treatments (both prefire and postfire) occurred on 3.6% of the total area burned in the study area landscape, across an area burned by 44 unique fires in the interval between 2001 and 2019.

Treatment-fire samples occurred on 3.1% of the once-burned landscape, and *fire-treatment-fire* samples made up 3.0% of the reburned area. Treatments also took place in differing forest types, where treatments that included prescribed fire were primarily conducted in dry frequent-fire forests, and FRS generally exceeded 5.0 (Figure B.4, B.5, and B.6). Because of their small areas, and relatively small sample size (Table 6), we did not include them in the landscape scale modeling. In treated areas, a census of the 30-m pixels (0.09 ha) in all treated areas was compiled. Controls—untreated wildfires and untreated reburns—were drawn from the same dataset as used in the RF modeling above, sampled on a 270-m grid. To assess the impacts of treatments on burn severity, we tested for differences between treated and untreated controls, after subsampling treatment and controls to match bioclimatic setting and fire weather for each treatment type.

To match the distributions of the controls to each treatment type we removed the control observations within fires that were outside the range of the treatment values of FRS, 1,000-hr fuel moisture on the day of burning and mean annual temperate anomalies in the year proceeding the fire. For post-fire pre-reburn treatments, we also matched previous burn severity and time between fires. Next, we used the `matchControls` function from the *e1071* package, version 1.7–6 in R (Meyer et al., 2020) to subsample the control sample to the treatment sample, using pairwise dissimilarities to match as closely as possible the FRS and 1,000-hr fuel moisture for prefire treatment. For postfire pre-reburn treatments we also matched previous burn severity, and time between fires. Sample sizes varied by treatment types, and for treatments with very large samples (e.g., > 9,000 pixels) we took a random sample of the available data (Table 6), to allow for the “`matchControls`” to run. For *fire-treatment-fire* samples, where there were more treatment points than control points, we subsampled treatments to match the available controls. We tested for statistical differences between control and treatment distributions using a niche overlap index to quantify the degree of distribution overlap, and two-sided Kolmogorov–Smirnov tests (K–S) (Conover and Iman, 1981; Marsaglia et al., 2003) to test for significant differences. We plotted subsampled treatment and control RBR distributions to visualize differences.

3. Results

3.1. Co-factors controlling burn severity in untreated long-unburned and reburn areas

The final model predicting three classes of burn severity in long-unburned areas had an out-of-bag (OOB) error rate of 0.305 (Table 7). The model performed best at predicting the high severity (AUC = 0.846), and worst at predicting low-moderate severity (AUC = 0.702) outcomes. The final model predicting burn severity in reburns performed better than the model for long-unburned areas, with an OOB error rate of 0.355 (Table 8). The same patterns of higher prediction accuracy for high severity and unburned areas were found within reburns.

The most important predictions in our RF models were related to large-scale gradients across the study area (Fig. 2). Variables measuring the spatial autocorrelation of the burn severity data were strong predictors in both models. Specifically, the first three PCNM eigenvectors were had the highest variable importance in long-unburned areas and

the highest variable importance after time since the last fire among reburned samples. These three PCNM eigenvectors are representative of larger-scale spatial autocorrelation. The FRS score of the sample consistently influenced burn severity in both the long-unburned and reburn models, with higher severity being much more likely with FRS below approximately 0.46 (Fig. 3, Fig. 4). Two variable partial dependence plots showing the probability of high severity fire in previously long-unburned areas (Fig. 5) and in reburns (Figure B.3) indicated that fuel moisture, annual temperature anomalies, annual vapor pressure deficit anomalies, forest structure, and topography were stronger explanatory drivers of variation in burn severity in higher elevation forests where lower fire severity occurred, than in low-elevation dry forests with fire-resistant species.

Daily 1,000-hour fuel moisture was also an important predictor in both models (Fig. 2). In long-unburned areas, daily fire weather had the expected relationship: increased fuel moisture was related to reduced likelihood of high-severity fire. Surprisingly, only daily fuel moisture was retained in predictive models, while other fire weather variables explained little additional variance or were too highly correlated with 1,000-hour daily fuel moisture. Of the annual climate variables, only annual minimum VPD had a clear positive relationship. Prefire basal area was the only forest structure variable retained in both models, and it showed a positive relationship with fire severity. Topographic predictors (slope and TPI) were the among the least important predictors in both models. Unexpectedly, the probability of high-severity fire was higher in flatter than steeper catchments. Relations among variables and the probability of unburned areas were generally opposite those for high-severity (Figure B.1), as would be expected. Unburned areas were clearly associated with lower burning indexes, and with east and west aspects.

In reburns, the time between fires was the most important predictor, and previous burn severity showed a negative relationship with subsequent burn severity. In reburns, high-severity fire likelihood slightly increased 10–18 years after fire (Fig. 4d). High-severity fire likelihood strongly decreased in areas that had previously burned with moderate or high-severity (i.e. RBR > 100). We also observed a strong interaction between the time since past fires and FRS, with very low probabilities of high-severity fire when time since the last fire was < 16 years and the FRS was > 0.5; when FRS was > 0.5 high-severity fire became increasingly likely after 25–28 years (Fig. 6).

In reburns, the probability of high severity consistently increased with daily 1000-hour fuel moisture. This may reflect a narrower range of fuel moisture conditions under which reburns occurred, especially in combination with other predictors (Fig. 6). Biophysical predictors showed similar relationships as for fire in long-unburned areas (e.g., the likelihood of high severity decreased with increasing FRS, and increased with basal area). Within reburns, predictor variables generally showed an opposite relationship with likelihood of being unburned in comparison with the probability of high-severity fire (Figure B.2).

3.2. Influence of prefire and postfire forest management treatments on the burn severity of subsequent fires

All *treatment-fire* samples showed statistically different RBR distributions than those of the paired controls (Table 9). The RBR distributions showed that all treatments except for recent planting displayed

Table 7

Accuracy statistics for RF model predicting burn severity of fires in areas that were previously long-unburned. Cross-validation accuracy = 0.575; Cross-validation Kappa = 0.307; OOB error = 0.305. AUC = area under the receiver operator characteristic curve; AUC C.I. = (95%) confidence interval of the AUC; PPV = positive predictive value; NPV = negative predicted value.

Burn severity class	AUC	AUC C.I.	Sensitivity	Specificity	PPV	NPV	Accuracy
Refugia	0.801	0.793–0.808	0.247	0.969	0.698	0.814	0.805
Low-Moderate	0.702	0.695–0.710	0.481	0.775	0.684	0.596	0.627
High	0.846	0.840–0.852	0.698	0.825	0.597	0.881	0.791

Table 8

Accuracy statistics for RF model predicting burn severity of reburns. Cross validation accuracy = 0.575; Cross-validation Kappa = 0.355; OOB error = 0.280. AUC = area under the receiver operator characteristic curve; AUC C.I. = 95% confidence interval of the AUC; PPV = positive predictive value; NPV = negative predicted value.

Burn severity class	AUC	AUC C.I.	Sensitivity	Specificity	PPV	NPV	Accuracy
Refugia	0.856	0.845–0.866	0.701	0.831	0.613	0.879	0.795
Low-Moderate	0.772	0.760–0.783	0.394	0.905	0.840	0.540	0.619
High	0.884	0.874–0.895	0.676	0.880	0.524	0.933	0.847

lower burn severity, with the distribution peaks at lower severity values than the controls (Fig. 7). Thinning, thinning + harvest, harvest, harvest + planting, and old planting (≥ 20 years before the fire) treatments showed strongly overlapping distributions between paired treatments and controls (niche overlap > 0.8), while prescribed fire, and prescribed fire + harvest + planting treatments, had lower overlap of burn severity distributions (niche overlap < 0.54) (Table 9). For treatments that included prescribed fire, the right tail of the distributions was also shifted to lower burn severity values and high-severity fires were uncommon (Fig. 7).

The effect of treatments on decreasing wildfire severity persisted through a second fire, where one occurred. Harvest + planting and planting-alone treatments showed lower severity than reburns with similar time since fire, previous fire severity, fire weather, and bioclimatic setting (Fig. 8). While only two treatments had sufficient samples to be evaluated, the difference between treatments and controls was greater in the *treatment-fire-fire* class (Fig. 7) than in the *treatment-fire* class, meaning that the treatments and the fires had an additive effect on decreasing burn severity in the most recent fire (Fig. 8; Table 9).

Treatments that occurred within 5 years after an initial fire, which were then reburned, did not show as strong a difference in burn severity relative to controls as *treatment-fire* samples revealed (Table 9; Fig. 9). Niche overlap indices for harvest, and harvest + planting treatments were > 0.9 (Table 9). Post-fire harvest + planting and planting-alone treatments experienced less high-severity fire than their paired controls (note the right-tails of the distributions in Fig. 8).

4. Discussion

This study examined factors influencing burn severity across 19 years, 150 fires, and over a large range of forest communities in northeastern Washington state, USA. We found a consistent signal that previous fires—wild or prescribed—and thinning without fire decreased burn severity. Our result for fires in long unburned areas are similar to the results of previous studies modeling burn severity at a given location (e.g., Meigs et al., 2020; Parks et al., 2018a; Povak et al., 2020b), but expand on those studies by highlighting the importance of species traits in determining burn severity, and provide context to our assessment of burn severity in reburns. Our modeling results highlight the importance of spatial autocorrelation, most likely reflecting high spatial autocorrelation in both measured and unmeasured biogeographic drivers of fire severity across different scales, a topic that should be further explored in future research.

4.1. Burn severity in long-unburned areas

Large-scale bioclimatic gradients were the most important drivers of burn severity in long-unburned areas, more so than fire weather, local forest structure, or topography influences. Spatial autocorrelation (as measured by PCNM eigenvectors) and broad patterns of forest resilience to fire (as estimated by the Forest Resilience Score (FRS)), both of which reflect large bioclimatic gradients, were important to predicting the severity of fires that burned previously long-unburned areas. The FRS is associated with the fire resistance traits of species, while other large scale climatic gradients within our study area are associated with the length of the fire season, complexity of topography and land surface

forms, and presence of topographic or edaphic barriers to fire spread (Cansler and McKenzie, 2014). Within our study area, FRS was highly correlated with climatic water deficit (*deficit*; Spearman's $r = 0.75$). Thus, our results correspond with previous research that found AET, deficit, and elevation can be important predictors of burn severity (Dillon et al., 2020; Kane et al., 2015b; Povak et al., 2020b), but contrast with previous studies that found fuel moisture and fire weather variables were the most important predictors (Parks et al., 2018a), and those that highlight the importance of topography (Meigs et al., 2020).

The rather abrupt changes in the probability of high-severity fire along the FRS gradient, and interactions between other variables and FRS (Figs. 6 and 7), indicate that there are distinctive fire regime areas within our study area. While the different fire regimes among different forest communities in the interior Pacific Northwest has long been documented (e.g., Agee, 1996), we see two distinctive fire regimes, one in ponderosa pine and Douglas-fir forests that burned with low-mixed severity and frequent fire prior to Euromerican colonization, and another in higher elevation forests, which where fires were less frequent and tended to burn with higher severity. In the lower-frequency, higher severity fire regimes of the higher-elevation forests, we saw evidence in burn severity was more strongly related to 1000-hour fuel moisture, basal area, slope, and topographical position index (Fig. 5). The spatial map of FRS we used as a predictor is based on community-scale fire resistance traits, but for interpretation within our study area, we note that 0.46 falls in-between the FRS for *Pseudotsuga menziesii* (0.49) and *Abies grandis* (0.42). FRS was positively correlated with deficit and negatively with elevation in our study area (Fig. 1), but unlike deficit and elevation, FRS has a direct functional relationship to burn severity (Stevens et al., 2020). Plot- and tree-scale empirical modeling have demonstrated the importance of fire-adaptive traits such the bark thickness, lower branch pruning, bud protection, and foliage geometry in determining crown scorch and consumption fire effects (Cansler et al., 2020; Hood et al., 2018; Kane et al., 2013; van Wagtenonk et al., 2020). The FRS provides a useful way to connect functional relationships between species traits and fire effects across broad landscapes.

Previous theoretical work has framed a dichotomy where the spatial controls on fire behavior and effects suddenly shift from controls by means of local fuel and topographic conditions during moderate fire weather, to a collapse of local spatial controls during regionally synchronous drought conditions or severe fire weather events (Kennedy and McKenzie, 2010; McKenzie and Kennedy, 2011, 2012; Povak et al., 2018; Turner and Romme, 1994). Our results support the existence of threshold relationships between the probability of high-severity fire and fuel moisture levels during the burn periods of a fire. We found that low fuel moisture and higher vapor pressure deficit conditions were associated with increased probability of high-severity fire. These modeling results align with earlier research supporting the strong influence of fire weather and annual drought on burn severity in northeastern Washington forests (Cansler and McKenzie, 2014; Parks et al., 2018a). The fire weather data exists at a coarser native resolution (4-km) than the response and predictor data (270-m). Some fire weather variables, such as wind, often vary at a much finer spatial scale than 4-km, and in relation to terrain routing and intensification by topography. Thus, although many fire weather variables were not included in the final model, they may be important at finer scales than we could not resolve with the available data. Annual climate variables, on the other hand, did

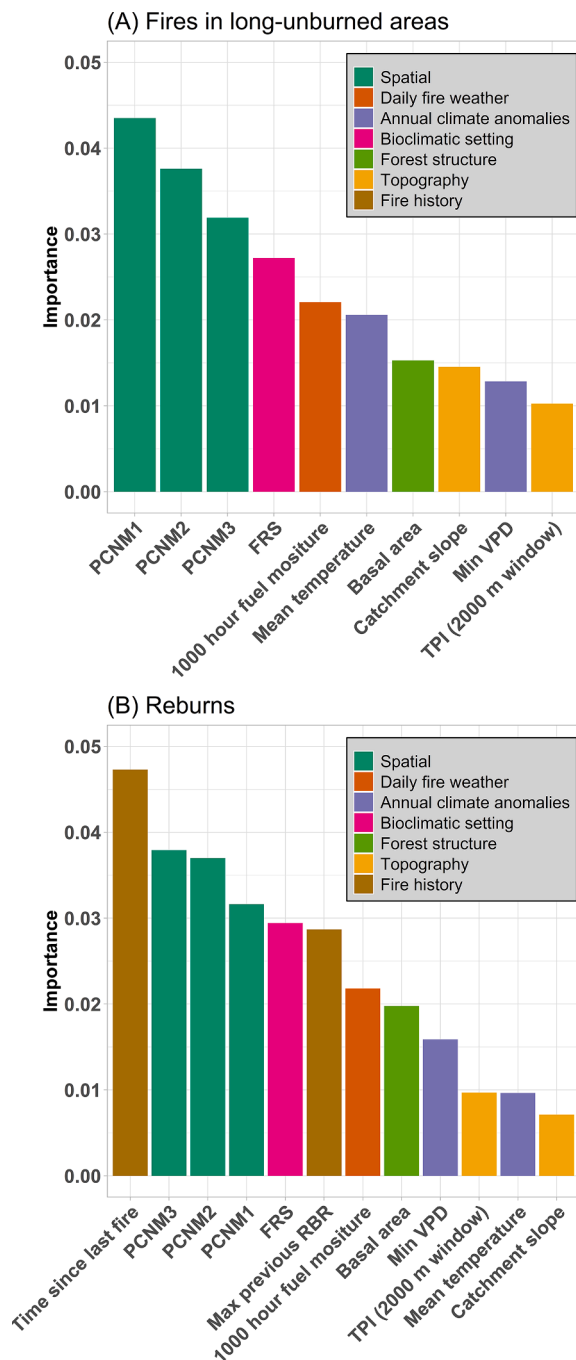


Fig. 2. Variable importance plot from Random Forest models predicting burn severity (relativized burn ratio; RBR) for fire in long-unburned areas (A) and reburns (B). PCNM (principal coordinates of neighborhood matrices) vectors measure spatial autocorrelation with lower-order vectors represent larger-scale spatial autocorrelation, and higher-order vectors represent local-scale spatial autocorrelation. Fire resistance score (FRS) captures community-scale tree species fire resistance traits (Stevens et al., 2020). VPD = annual vapor pressure deficit anomalies. TPI = topographical position index at 2000 m scale. Variable importance is calculate based on how often a variable is used to split predicted outcomes into a correct class. Response data are from wildfires that occurred between 2001 and 2019 in northeastern Washington State, USA. Reburns were previously burned between 1985 and 2018.

not show the consistent relationships with burn severity that we had expected. Specifically, we found that higher temperatures were associated with a lower probability of high-severity fire. In our samples, this could be driven by increased grass and forb growth during cool-wet

springs in the lower elevation portions of our study area, resulting in elevated fine fuel loads during summer (Littell et al., 2009). We note that there was multicollinearity between annual temperature anomalies and annual vapor pressure deficit (Spearman's $r = 0.44$), and complex interactions with annual climate that were difficult to interpret. Nevertheless, the negative association between annual temperature anomalies and burn severity was evident even when based on correlation strength (Spearman's $\rho = -0.15$). Some of the recent large fires, such as the 2014 Carlton Complex and 2015 Lime Belt and Tunk Block fires exhibited large daily growth within grasslands and ponderosa pine woodlands. Since wet cool years are associated with grass and forb production in steppe ecosystems in the Inland Pacific Northwest (Littell et al., 2009), it is possible we are seeing an associated between high severity and cool temperature anomalies due to higher fine fuel production in cool years.

Our predictions of unburned areas, corresponded with the definition of temporally varying fire refugia, not long-term “persistent fire refugia” (Meddens et al., 2018). Past research in this region had identified stable, persistent fire refugia that were associated with topographic constraints (Camp et al., 1997). Our initial set of topographical metrics matched recent research in the western Cascades, which used a relatively larger number of topographic metrics when conducting similar modeling of burn severity with the specific goal of identifying fire refugia (Meigs et al., 2020). That research found that north aspects, steep catchments, and concave topographic positions were associated with refugia there. Either (1) our sampling and modeling methods were not targeted enough to identify persistent refugia, or (2) persistent refugia are no longer persistent in the forested parts of northeastern Washington, due to increased landscape flammability due to fire suppression and climatic changes. The later idea is supported by two studies in this region. First, Kolden et al. (2017), found that persistent fire refugia identified by Camp et al. (1997) burned more severely than non-refugia sites in subsequent fires that took places in 2012. Second, Martinez et al. (2019) found relatively little area remained persistently unburned through more than two fires in the Inland Pacific Northwest and Northern Rocky Mountains, USA, and there were relatively little area unburned by two or more fires in northeastern Washington, compared to other parts of their study area. They also found that persistent fire refugia were associated with sparsely vegetated sites (Martinez et al., 2019), which were likely excluded from this study, since we only analyzed areas classified as having forest cover.

4.2. Reburns

In reburns the relationships we observed were consistent with the concept of stabilizing (negative) feedbacks (Holling, 1973; Johnstone et al., 2016) in active fire regimes: previous fires consume fuels and thus limit the severity of subsequent fires. Previous fires strongly decreased the severity of subsequent fires (a negative feedback to severe fire) for the first decade after a fire. We did not observe any evidence that prior fires led to higher subsequent burn severity (a positive feedback). We found there was a declining resistance to high-severity with increasing time since fire, with a threshold at about 15 years after the previous fire. The stabilizing feedbacks between initial fires and burn severity in subsequent fires probably reflects increasing fire tolerant species composition and more open canopy structure (Halofsky et al., 2011; Prichard et al., 2017; Stevens-Rumann et al., 2016). In other regions, including the Gila National Forest in New Mexico, the south-central Sierra Nevada and the Klamath Mountains, previous high-severity fires increased the probability of high-severity fire when they reburned more than a decade after the previous fire (Collins et al., 2009; Halofsky et al., 2011; Holden et al., 2010; Thompson et al., 2007), reflecting fast regeneration times of highly flammable sclerophyllous shrubs (Halofsky et al., 2011). Although we have observed large patches of high shrub cover in some in some severely burned areas in northeastern Washington, strong shrub responses are localized, and are generally dominated by shrub species adapted to longer fire rotations (e.g., *Ceanothus*

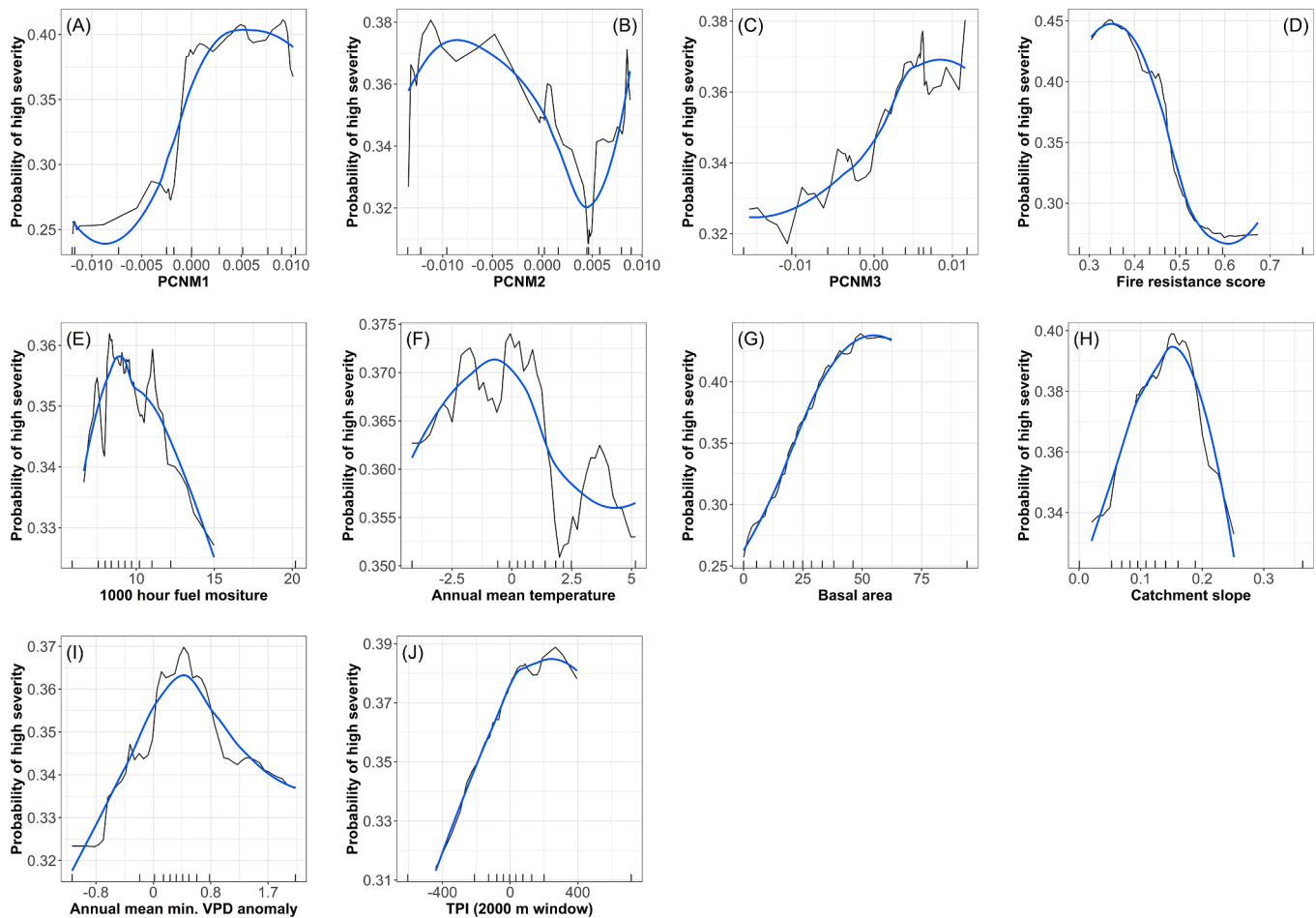


Fig. 3. Partial dependence plots for final random forest model for first-entry fires in long-unburned areas, in northeastern Washington State, occurring between 2001 and 2019. Plots depict the marginal effect of a predictor variable on predicted fire severity. PCNM (principal coordinates of neighborhood matrices) vectors measure spatial autocorrelation with lower-order vectors represent larger-scale spatial autocorrelation, and higher-order vectors represent local-scale spatial autocorrelation. VPD = annual vapor pressure deficit anomalies. TPI = topographical position index at 2000 m scale. Black lines show trends in high severity probability in response to predictors. Blue lines are loess (locally weighted scatterplot smoothing) of trends in high severity probability in response to predictors. Lines are plotted for the 2–98 percentiles, to remove extreme values. Tick marks on the insides of plots indicated distributions of values for each predictor, with a tick mark at every 10 percentile. Relationships between each predictor and the response, the probability of high severity as measured by the Relativized Burn Ratio (RBR), calculated as partial dependence plots where the values for each predictor are varied throughout their range while values for all other predictors are held to their mean values. As a result, partial dependence plots do not show interactions between predictors, and therefore the change in probabilities on the y-axis does not always correspond with variable importance (Fig. 3). Partial plots for refugia are in Appendix B. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

velutinus). We did not see any evidence that species composition, topography, or forest structure exerted stronger controls in reburns than in long-unburned areas, but that may indirectly reflect time since the last fire and previous burn severity because these can be good proxies for surface fuel abundance and vegetation successional development.

High burn severity was most likely to occur in reburns within stands that burned initially with lower severity and that had a low fire resistance score: high elevation subalpine forests where dominant trees species—Engelmann spruce, lodgepole pine, and subalpine fir—have thin bark, flammable foliage, low crown bases, resinous bark and foliage, and undergo little self-pruning of branches (Stevens et al., 2020). Initial fires may have burned with low-severity or skipped those areas entirely during due to discontinuous forest vegetation, high fuel moistures, wet weather during the burning season, or a combination thereof (Cansler et al., 2018; Cansler and McKenzie, 2014).

Our analysis of reburns does not identify places where previous fires stopped the spread of subsequent fires. The probability of high-severity fire was consistently lower in reburns than in long-unburned areas, and the probability of unburned areas was consistently higher, indicating that another stabilizing feedback that were not explicitly testing

for—self-limiting fire spread—may also be occurring. In northeastern Washington, fires in the cool-dry forest sometimes stop at the edge of young plantations (Lyons-Tinsley and Peterson, 2012), previous fires (Prichard and Kennedy, 2014), or discontinuous forest cover (Cansler et al., 2018). Self-limiting fire spread has also been documented in the Sierra Nevada, (van Wagtenonk et al., 2012) and the Rocky Mountain Region (Parks et al., 2018c, 2015a; Teske et al., 2012) and elsewhere around the globe (Prichard et al., 2017). Future research in the inland Pacific Northwest could explicitly include areas outside but adjacent to fire perimeters to better understand where and when self-limiting fire spread occurs in this region.

4.3. Scale and burn severity

Measures of spatial autocorrelation were the most important predictors in our models of predicting fire severity in long-unburned areas and reburns. Previous research that included spatial autocorrelation as a predictor variable in fire severity modeling interpreted the finding as revealing effects of contagious disturbance processes, e.g., pre-heating of fuels and improved effectiveness of flame lengths on steep slopes (e.

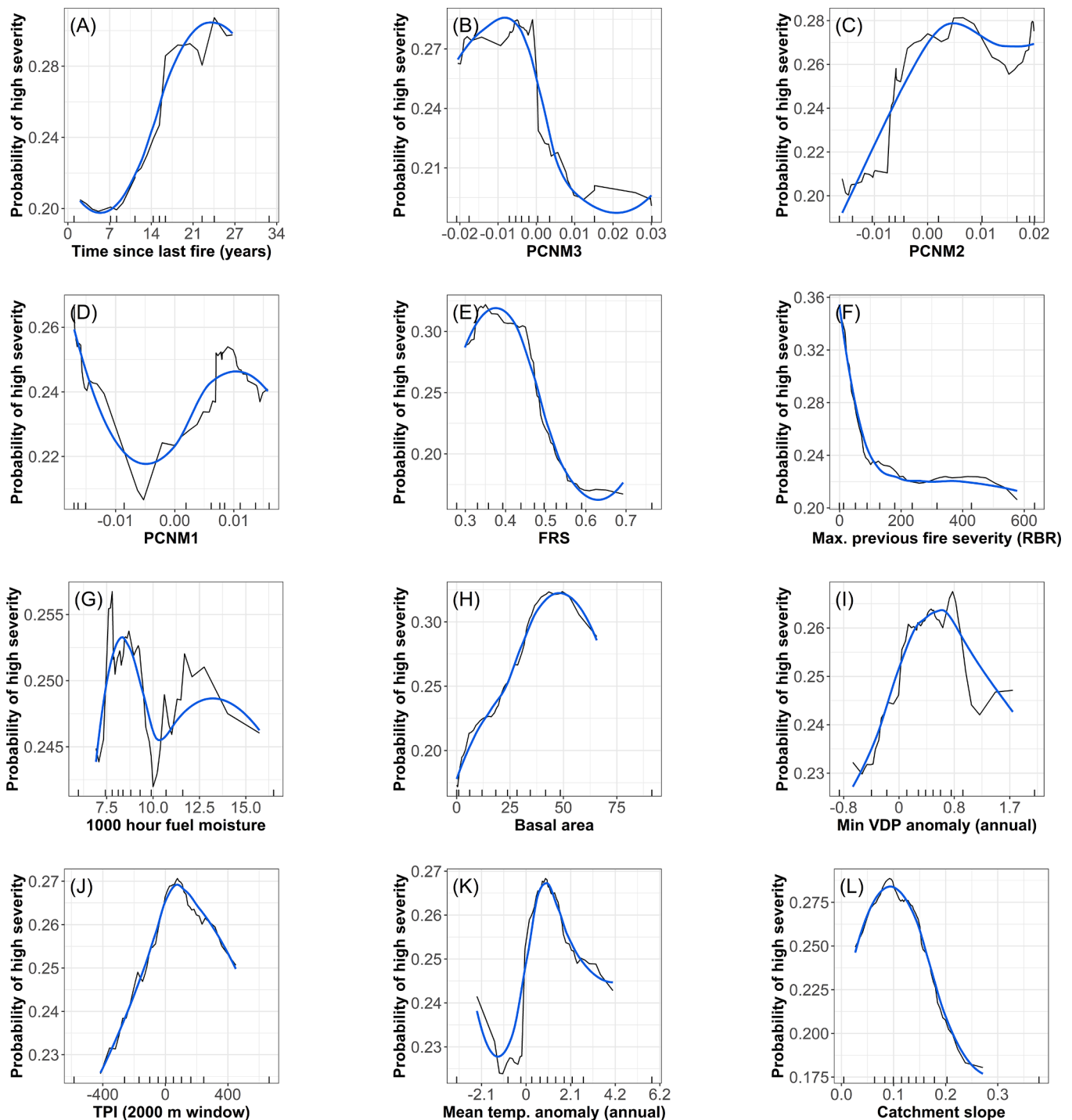


Fig. 4. Partial dependence plots for final random forest model for reburns, in northeastern Washington State, occurring between 2001 and 2019. Plots depict the marginal effect of a predictor variable on predicted fire severity. PCNM (principal coordinates of neighborhood matrices) vectors measure spatial autocorrelation with lower-order vectors represent larger-scale spatial autocorrelation, and higher-order vectors represent local-scale spatial autocorrelation. VPD = annual vapor pressure deficit anomalies. TPI = topographical position index at 2000 m scale. Black lines show trends in high severity probability in response to predictors. Blue lines are lowess (locally weighted scatterplot smoothing) smoothed trend lines of trends in high severity probability in response to predictors. Lines are plotted for the 2–98 percentiles, to remove extreme values. Tick marks on the insides of plots indicated distributions of values for each predictor, with a tick mark at every 10 percentile. Relationships between each predictor and the response, the probability of high severity as measured by the Relativized Burn Ratio (RBR), calculated as partial dependence plots where the values for each predictor are varied throughout their range while values for all other predictors are held to their mean values. As a result, partial dependence plots do not show interactions between predictors. Partial plots for refugia are in [Appendix B](#) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

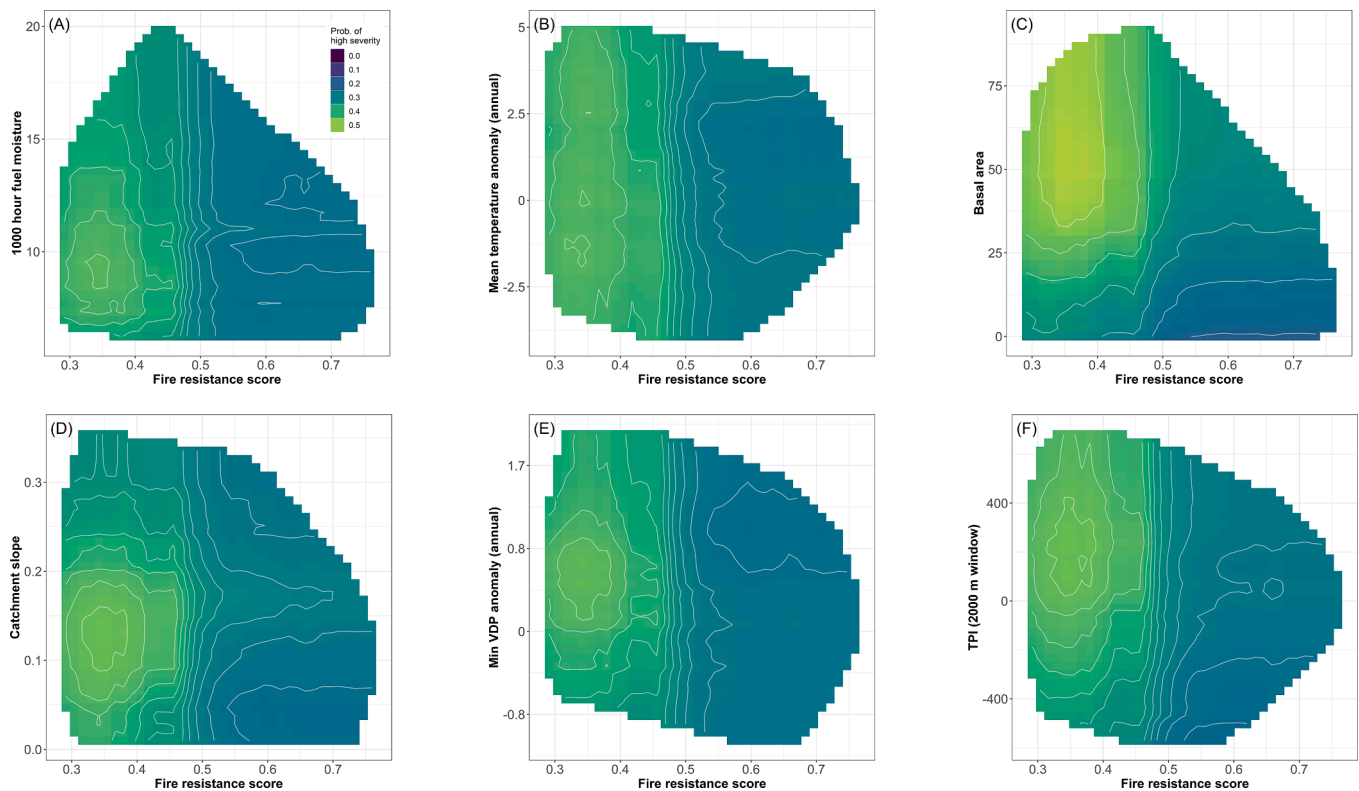


Fig. 5. Two-variable partial dependence surfaces showing probability of high severity fire, as measured by the Relativized Burn Ratio, in areas that were long-unburned before the fire. The most important predictor variables was the fire resistance score (FRS) captures community-scale tree species fire resistance traits (x-axis of each panels; Stevens et al., 2020). VPD = annual vapor pressure deficit anomalies. TPI = topographical position index at 2000 m scale. Fill color indicates a higher probability of high severity, and color ramps in Fig. 6 and Fig. 7 are the same, to aid comparisons. White contour lines are included to aid interpretation. White background with no data indicate there was not sufficient samples of the combination of variables for prediction.

g., Wimberly et al., 2009). In contrast, Povak et al. (2020a) found the variance explained by spatial autocorrelation is mostly duplicative of the variance explained by other environmental variables. Our results are consistent with Povak et al. (2020a) in that large-scale spatial autocorrelation was important in predicting burn severity, not small-scale spatial autocorrelation, which would be indicative of pre-heating of fuels near the flame front. In our models it likely represents large-scale environmental variation that is either unmeasured by the other variables we tested, or multiple environmental drivers operating jointly (Povak et al., 2020b).

We likewise suggest that there is an issue of scale and complexity associated with the extent of our analysis area, which influences which predictor variables have the highest importance in our models. This was a regional analysis, and thus falls between the extent of national fire severity modeling (Dillon et al., 2020) and individual fire modeling (Coen et al., 2018; Povak et al., 2020b). Similar analyses at this ecoregion scale (Dillon et al., 2020; Parks et al., 2018a) have not explored the importance of changing variable sign or interactions, thereby limiting our comparisons to variable importance, not the direction of covariate relations. For example, a machine-learning model developed by Parks et al. (2018a) based on fire severity data from large fires predicted high-severity fire within ecoregions of the US. They found that live fuel moisture and weather, which are combined in our weather variable category, together explained > 55% of the variance in the Okanagan Highlands province, which overlaps our study area, but that study did not show the direction of relationships. We suggest our results indicating complicated or unexpected relationships with annual climate variables, and the low variance explained by some fire weather and topographic metrics that we did not retain in the final models, may reflect analysis of a “middle number domain”, where factors operating at a variety of different scales lead to complicated and contingent observed

relationships (sensu McKenzie et al., 2011; O’Neill et al., 1986). Alternatively, there may be space and time mismatches, between the coarse spatial resolution daily fire data, coarse temporal resolution annual climate variables, and moderate resolution burn severity response data.

We expect that modeling at the scale of an individual burn period may better elucidate the complex relationships between fuels, weather, and local topography (e.g., Povak et al., 2020b), especially if finer-scale weather data were available. In contrast, modeling at ecoregion or larger scales (e.g., Dillon et al., 2020) may better elucidate relationships with large scale gradients, such as species distributions and relative abundance and associated energy and water limitations on vegetation structure and composition. Explicitly investigating how the importance of variables changes when modeling is conducted at different spatial domains could lead to better model interpretation and identification of the most relevant scales for prediction application.

4.4. Management implications

The contribution of this study is that it demonstrates the strong effects of previous wildfire and prescribed fire on subsequent fire severity across a large landscape and multiple forest types, many fire years, and wide ranges of climate and weather. We found that management treatments that include prescribed fire were most effective at decreasing the severity of subsequent fires. These results are consistent with previous research in our study area (Agee and Lolley, 2006; Lyons-Tinsley and Peterson, 2012; Prichard et al., 2020; Prichard and Kennedy, 2014), and elsewhere in western North America (Kalies and Yocom Kent, 2016; Schwilk et al., 2009; Stephens and Moghaddas, 2005), but our sampled area encompasses > 7,000 sampled 30-m areas in the entire reburned landscape (51,919 ha; Table 6), and all 3,086 ha within prescribed fire areas that were subsequently burned by a wildfire, instead of field plots

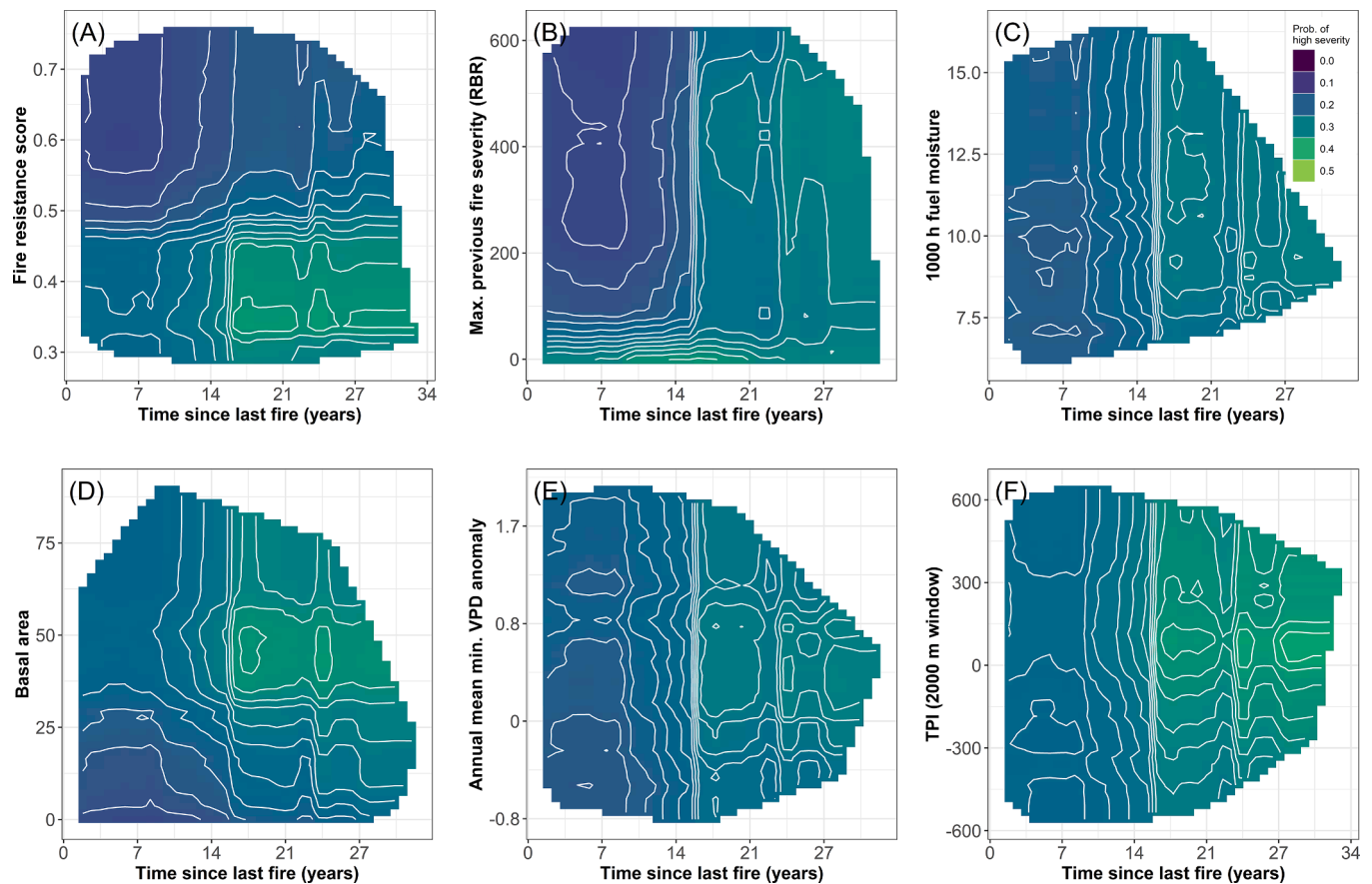


Fig. 6. Two-variable partial dependence surfaces showing probability of high severity fire, as measured by the Relativized Burn Ratio, in areas that were reburned. The most important predictor variables in reburns was the years since the last fire (x-axis). VPD = annual vapor pressure deficit anomalies. TPI = topographical position index at 2000 m scale. Fill color indicates a higher probability of high severity, and color ramps in Fig. 6 and Fig. 7 are the same, to aid comparisons. White areas with no data indicate there was not sufficient samples of the combination of variables to confidently predict the relationship.

Table 9

Niche overlap and two-sample Kolmogorov–Smirnov (K-S test) results for *treatment-fires* and postfire pre-reburn treatments. Wildfires occurred from 2001 to 2018, and treatments took place from 1982 to 2017. In reburns, first fires occurred from 1985 to 2014, and reburns occurred between 2001 and 2018. Sample sizes subsamples used in the statistical analysis are provided in Table 6.

Treatment	Niche overlap	D (test statistic)	P-value
<i>Treatment-fires</i>			
Thinning	0.810	0.170	<0.001
Thinning and harvest	0.536	0.476	<0.001
Harvest	0.794	0.211	<0.001
Harvest and planting	0.790	0.215	<0.001
Planting (old; ≥ 20 years before fire)	0.850	0.158	<0.001
Planting (recent; ≤ 10 years before fire)	0.842	0.148	<0.001
Prescribed fire	0.628	0.377	<0.001
Prescribed fire and harvest	0.520	0.489	<0.001
Prescribed fire, harvest, and planting	0.476	0.535	<0.001
<i>Treatment-fire-fire</i>			
Harvest and planting	0.734	0.272	<0.001
Planting	0.733	0.258	<0.001
<i>Fire-treatment-fire</i>			
Harvest	0.855	0.155	<0.001
Harvest and planting	0.823	0.092	<0.001
Planting	0.759	0.252	<0.001

sampling small portions of the landscape. Our prescribed fire treatments results are compelling not only because they caused a decrease in overall burn severity, but also almost completely prevented high-severity fire.

Thus, prescribed fire sets up a strong stabilizing feedback, increasing resilience to subsequent fires.

Most of the other treatments, including thinning, and harvest combined with planting also decreased the severity of fires occurring in long-unburned areas. These treatments likely decreased fire severity by decreasing horizontal and vertical fuel continuity. These results too are supported by previous research indicating that thinning alone can moderate fire behavior, in our study area (Prichard et al., 2020; Prichard and Kennedy, 2014). But across western North America, the combination of thinning and prescribed fire is most effective at moderating fire behavior and reducing fire severity (Fulé et al., 2012; Kalies and Yocom Kent, 2016; Martinson and Omi, 2013; Prichard et al. 2021, Schwilk et al., 2009). We also found that harvest treatments burned with higher severity than paired controls, which is consistent with previous research showing that harvest operations can increase surface fuel loads when tree limbs and tops are relocated to surface fuel beds, resulting in higher fire severity (Prichard and Kennedy, 2012; Stephens et al., 2009). Further insights may be gained from research at ecoregion scales to specifically identify the sets of conditions when thinning and prescribed fire are not effective at reducing fire severity.

When recent plantings burned, they often burned with higher severity, most likely due to the lack of fire resistant traits of young conifers: thin bark and low crow bases result in more severe fire injury in small conifers (Agee, 1996; Canisler et al., 2020; Hood et al., 2018). Previous research has found both positive (Zald and Dunn, 2018) and negative (Lyons-Tinsley and Peterson, 2012) associations between young stands and burn severity. Post-fire planting, along or in other combination with other management, is best implemented with on-the-

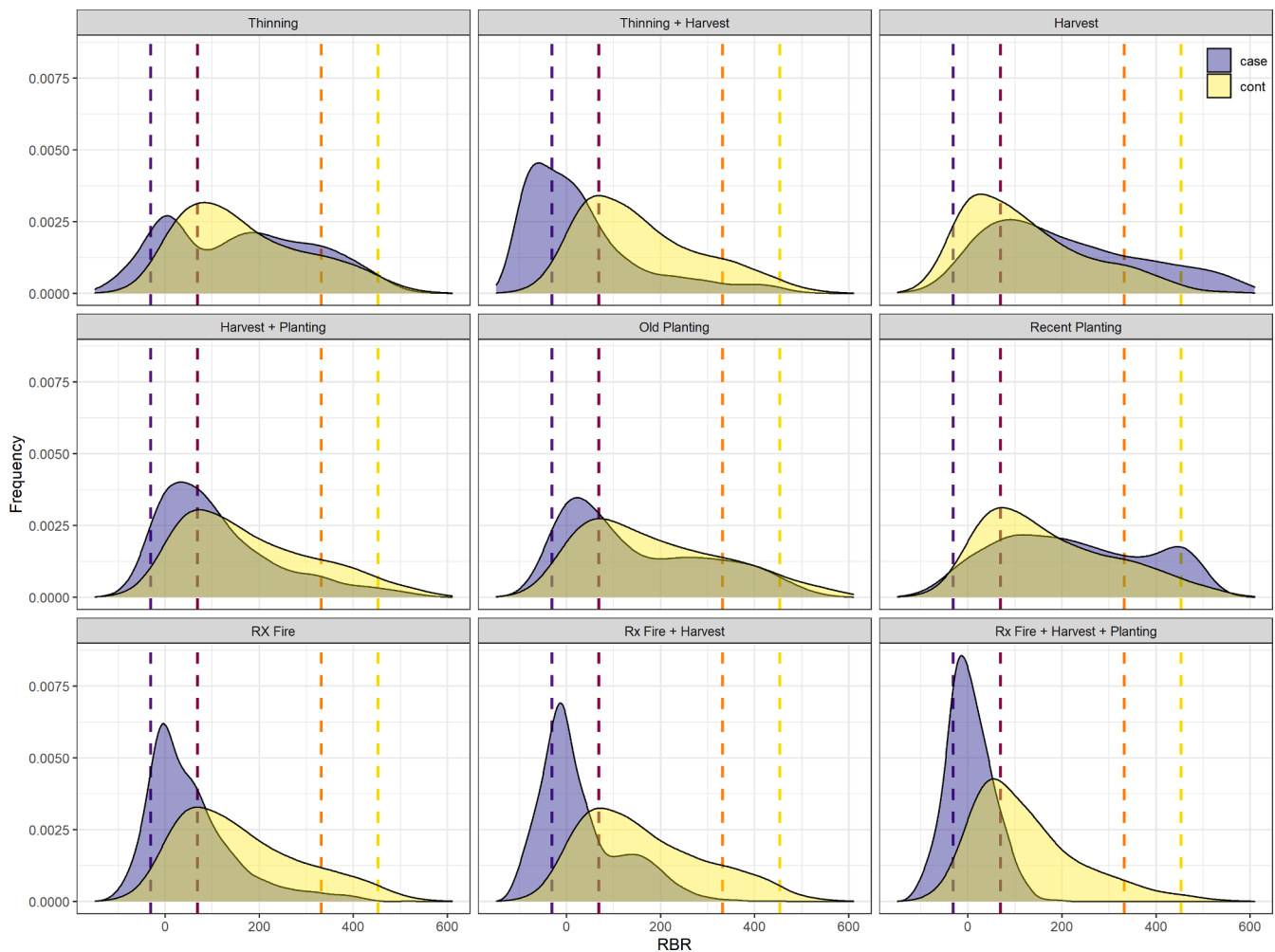


Fig. 7. Burn severity distributions for areas treated then burned (i.e., “treatment-fire”) and untreated burned controls. Density plots showing the frequency distribution of the Relativized Burn Ratio (RBR), a measurement of burn severity, for untreated areas (controls; yellow) and silvicultural or fuel treatment (cases; purple) in areas that were treated before a wildfire. Vertical dashed lines show the thresholds: <2% basal area loss (dark purple), unburned-low and moderate severity (magenta), low-moderate and high severity mixes (orange), and >98% basal area mortality (i.e., stand replacing severity; yellow). Data are from wildfires that occurred between 2001 and 2018 and treatments occurring from 1982 to 2017, within the northeastern Washington State, USA study area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ground practices that matched the natural regeneration dynamics of the forest community (Stevens et al., 2022), as well as in locations that account for larger-scale landscape priorities (Churchill et al., 2022), and expected future climate and fire regimes (Larson et al., 2022). We did not see evidence for increase burn severity in plantings that took place after an initial fire and then subsequently reburned (Fig. 7). Therefore, we reiterate the findings of Lyons-Tinsley and Peterson (2012): treatment of surface fuels before planting occurs provides an important dampening effects on subsequent burn severity in young plantations in northeastern Washington.

5. Conclusions

Species composition across large bioclimatic gradients had the strongest influence of fire severity in long-unburned areas in northeastern Washington, USA. Previous wildfires, prescribed fires, and management treatments functioned as stabilizing feedbacks, decreasing the severity of subsequent fires. If managers wish to decrease the severity of subsequent fires, then their best tools are (1) prescribed fire treatments and (2) allowing fires to burn under moderate weather conditions. Managers can also use thinning to decrease the severity of subsequent fires but thinning combined with prescribed fire is most

effective (cf. Johnston et al., 2021). Planting, in contrast, could either increase or decrease burn severity, depending on the timing of subsequent fires and whether post-harvest slash is properly burned. We did not find any evidence for amplifying feedbacks that have been observed in other regions (Halofsky et al., 2011; Harvey et al., 2016) between the severity of initial fires and subsequent fires. Here, high-severity was less likely in areas that previous burned with high-severity. Our results strongly support the moderating influences of previous wildfires, harvest, thinning, and especially prescribed burns on the severity of subsequent wildfires.

CRediT authorship contribution statement

C. Alina Cansler: Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Formal analysis, Visualization. **Van R. Kane:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration. **Paul F. Hessburg:** Conceptualization, Writing – original draft, Writing – review & editing, Project administration. **Jonathan T. Kane:** Methodology, Validation, Formal analysis, Data curation, Visualization. **Sean M.A. Jeronimo:** Methodology, Data curation, Writing – review & editing. **James A. Lutz:** Resources, Conceptualization, Writing – original draft,

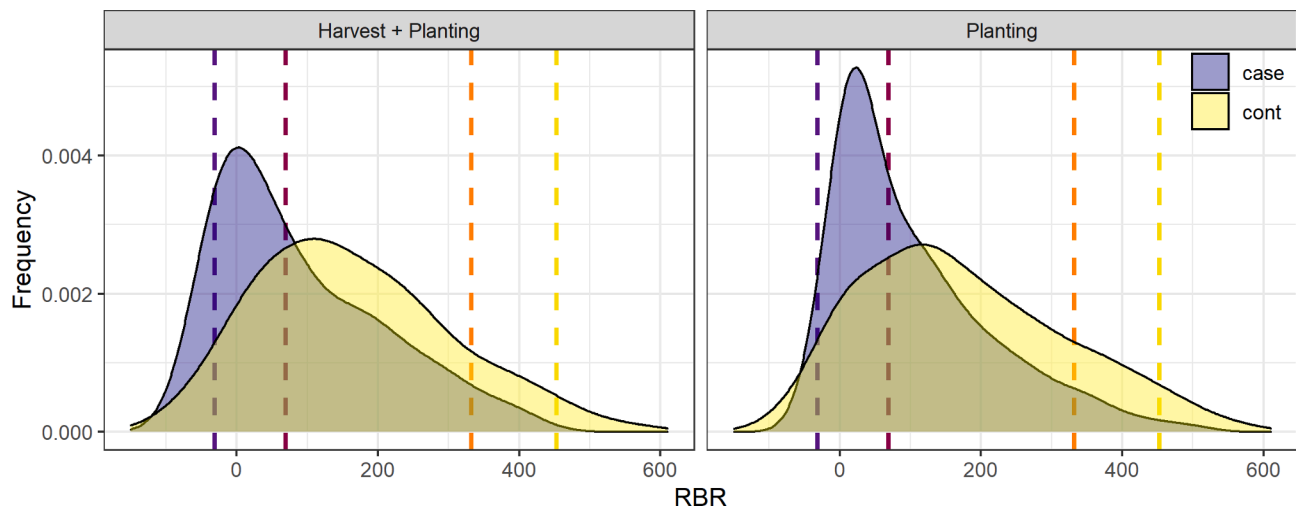


Fig. 8. Burn severity distributions from reburns in areas treated then burned by two fire (i.e., “*treatment-fire-fire*”) and untreated burned controls. Distributions show the severity of the second fire, Density plots showing the frequency distribution of the Relativized Burn Ratio (RBR), a measurement of burn severity, for untreated areas (controls; yellow) and each silviculture or fuel treatment (cases; purple), for equally-sized match subsamples in areas that were treated before fire. Vertical dashed lines correspond with the following thresholds: <2% basal area loss (dark purple), refugia-low and moderate severity (magenta), low-moderate and high severity (orange), and > 98% basal area mortality (i.e., stand replacing severity; yellow). Data are from wildfires that occurred between 2001 and 2018, and treatments occurring from 1982 to 2017, within initial fires occurring from 1985 to 2017. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

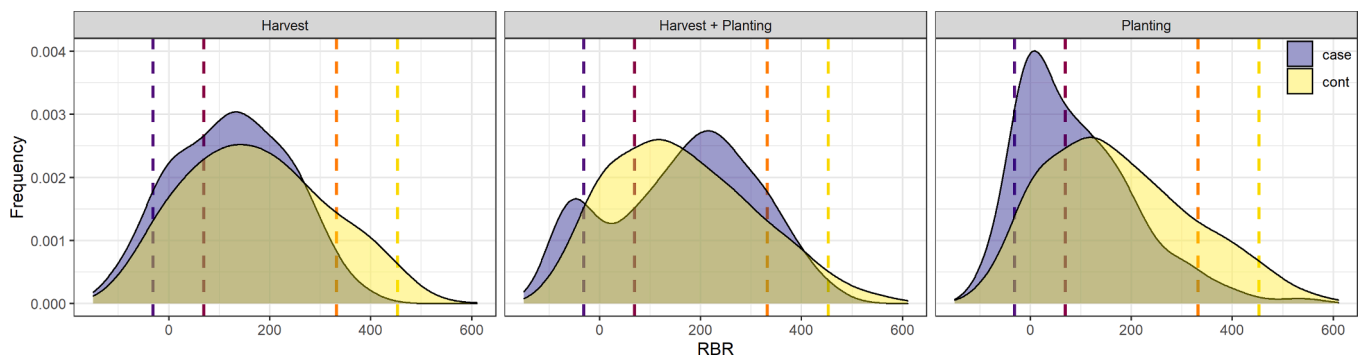


Fig. 9. Areas that were burned, treated, then reburned (i.e., *fire-treatment-fire*) and untreated controls burn severity distributions or the reburns. Density plots showing the frequency distribution of the Relativized Burn Ratio (RBR), a measurement of burn severity, for untreated areas (controls; yellow) and each silviculture or fuel treatment (cases; purple), for equally-sized match subsamples in areas that were treated before fire. Vertical dashed lines correspond with the following thresholds: <2% basal area loss (dark purple), refugia-low and moderate severity (magenta), low-moderate and high severity (orange), and >98% basal area mortality (i.e., stand replacing severity; yellow). Data are from wildfires that occurred between 2001 and 2018, and treatments occurring from 1982 to 2017, within initial fires occurring from 1985 to 2017. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Writing – review & editing. **Nicholas A. Povak:** Methodology, Conceptualization, Writing – review & editing. **Derek J. Churchill:** Conceptualization, Writing – review & editing. **Andrew J. Larson:** Supervision, Project administration, Funding acquisition, Conceptualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.foreco.2021.119764>.

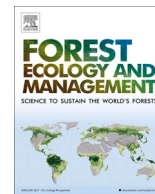
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Post-fire landscape evaluations in Eastern Washington, USA: Assessing the work of contemporary wildfires

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ABSTRACT

In the western US, wildfires are modifying the structure, composition, and patterns of forested landscapes at rates that far exceed mechanical thinning and prescribed fire treatments. There are conflicting narratives as to whether these wildfires are restoring landscape resilience to future climate and wildfires. To evaluate the landscape-level work of wildfires, we assessed four subwatersheds in eastern Washington, USA that experienced large wildfires in 2014, 2015, or 2017 after more than a century of fire exclusion and extensive timber harvest. We compared pre- and post-fire landscape conditions to an ecoregion-specific historical (HRV) and future range of variation (FRV) based on empirically established reference conditions derived from a large dataset of historical aerial photo imagery. These four wildfires proved to be a blunt restoration tool, moving some attributes towards more climate-adapted conditions and setting others back. Fires reduced canopy cover and decreased overall tree size and canopy complexity, which moved them into, or slightly outside, the FRV ranges. Moderate- and low-severity fire generally shifted closed-canopy forest structure to open-canopy classes. Patches of high-severity fire shifted patterns of forest, woodland, grassland, and shrubland towards or beyond the HRV ranges and within the FRV ranges by increasing the total area and size of non-forest patches. However, large patches of high-severity fire in dry and moist mixed-conifer forests homogenized landscape patterns beyond FRV ranges towards simplified conditions dominated by non-forest vegetation types. Fires realigned and reconnected landscape patterns with the topo-edaphic template in some cases, but pre-existing fragmentation and spatial mismatches were compounded in many others. Patches of large-tree, closed-canopy forest were reduced by high-severity fire, and the potential to restore more climate-adapted large-tree, open-canopy forest was lost. Re-establishing landscape patterns with desired patch sizes of forest, in particular patches with large trees, will take many decades to centuries and may not occur in drier locations or where seed trees are no longer present. While large wildfires burning during extreme fire weather conditions can move some attributes towards HRV and FRV ranges, intentionally planned mechanical and prescribed-fire treatments that are integrated with strategic wildfire response will better prepare and adapt landscapes for future wildfires and climate.

1. Introduction

The interaction of extensive forest densification and expansion over

the last century, increasing wildfire and insect activity, and warming climatic conditions is driving abrupt changes across many fire- and drought-prone landscapes in the interior western US (Hessburg et al.

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2019, Hagmann et al. 2021). The need for large-scale intentional management actions to increase the resilience of landscapes to changing disturbance regimes and climate has been clearly established (Prichard et al. 2021). Although the pace and scale of mechanical and prescribed fire treatments are increasing, wildfires are modifying landscapes at far greater and increasing rates (Reilly et al. 2017, Parks and Abatzoglou 2020, North et al. 2021). Currently, there are conflicting narratives as to whether wildfires are having beneficial or detrimental effects on landscapes that have been highly altered by fire exclusion and timber harvests (Stephens et al. 2016, Haugo et al. 2019, North et al. 2021). This conflict highlights the need for improved empirical understanding of the “work” that wildfires accomplish at landscape scales (North et al. 2012, Barros et al. 2018, North et al. 2021, Stephens et al. 2021a).

Contemporary wildfires are often perceived as human and ecological catastrophes (McWethy et al. 2019). Under current fire management policies that emphasize suppression, most wildfire spread occurs during extreme-fire weather when containment is very difficult (Stephens et al. 2016). Thus contemporary wildfires often result in large and uncharacteristic patches of high-severity fire in forests that historically experienced principally frequent, low- and moderate-severity fires (Cansler and McKenzie 2014, Reilly et al. 2017, Stevens et al. 2017, Parks et al. 2018). These large patches tend to homogenize structural conditions across landscapes (Cassell et al., 2019; Singleton et al., 2021), synchronizing them for future fires and insect outbreaks and increasing likelihood of climate-driven conversion to non-forest (Davis et al. 2019, Kemp et al. 2019, Spies et al. 2019, Coop et al. 2020). High- and some moderate-severity fire also reduce populations of remaining large fire-resistant trees and patches of closed-canopy, large-tree forest structure that sustain numerous wildlife species and store significant land sector carbon (Lutz et al. 2012, Spies et al. 2018, Jones et al. 2021). Re-establishing patches of large trees will take many decades to centuries and may not be possible in significant portions of landscapes. Finally, many wildfires cause significant damage to human communities and infrastructure, and prolonged smoke exposure negatively affects human health (Liu et al. 2015).

Alternatively, some wildfires, or portions of wildfires, can accomplish many goals related to restoration and climate adaptation (Collins and Stephens 2007, Schoennagel et al. 2017, Barros et al. 2018, Haugo et al. 2019, Stephens et al. 2021b). Moderate- and low-severity fire can enhance fire and drought resistance by consuming surface fuels, killing small trees, reducing canopy cover and crown bulk density, elevating crown base height, shifting composition towards fire- and drought-tolerant tree species, promoting fire-adapted understory plants, and restoring fine scale patterns of individual trees, tree clumps, and openings (Lydersen and North 2012, Larson et al. 2013, Kane et al. 2019, LeFevre et al. 2020, Furniss et al. 2021). High-severity patches that are consistent with historically characteristic patch sizes generate biologically important early seral habitat (Swanson et al. 2011), and contribute to restoring patchworks of forest, woodland, grassland, and shrubland that have been highly altered by forest encroachment (Hessburg et al. 2016, 2019, Stephens et al. 2021b). Wildfire response strategies that utilize informed risk analysis before and during fire events can allow fires to safely achieve these positive outcomes during moderate fire weather, while suppressing and containing fires in high-risk locations or during unfavorable weather periods (Thompson et al., 2018; Young et al., 2019; Dunn et al., 2020; North et al., 2021).

The extent to which contemporary large wildfires are restoring landscape-level pattern is especially uncertain. Realignment of the spatial arrangement and patch size distributions of vegetation composition and structure with the topo-edaphic conditions of a landscape is a key component of restoring the self-reinforcing and stabilizing resilience mechanisms of landscapes with active fire regimes (Moritz et al. 2011, Perry et al. 2011, Hessburg et al. 2015, 2019). Patterns of burn severity are influenced by existing vegetation, fuels, and topography (Halofsky et al. 2011, Kane et al. 2015), and are thus constrained by ecological memory that reinforces pre-fire patterns (Peterson 2002, Collins et al.

2009, Harris et al. 2020).

In landscapes where pre-fire landscape pattern was heavily fragmented by past harvesting and disconnected from the topo-edaphic template, wildfires can drive further fragmentation that can negatively affect wildlife habitat and future fire behavior (Vanbanchi et al. 2017, Zald and Dunn 2018). Conversely, extensive patches of dense forest created by fire exclusion set up dry and moist mixed-conifer forests for high-severity patches that exceed historical size distributions, especially when driven by extreme fire weather that can override local spatial controls on fire size and severity (Cansler and McKenzie 2014, Povak et al. 2020b, Prichard et al. 2020). In addition, the remaining closed-canopy forest may not be located in topo-edaphically favorable and climatically sustainable locations across the burned and unburned parts of a landscape.

Assessing the relative beneficial and detrimental “work” of wildfire necessitates the use of reference conditions that are clearly linked to similar environmental and disturbance regime settings and desired landscape-level functions. In the interior western US, active historical fire regime conditions are often used for this purpose as they represent conditions that are resilient to a wide range of disturbances and climatic fluctuations, while providing a wide range of ecological functions (Fule 2008, Keane et al. 2009, Wiens et al. 2012, Safford and Stevens 2017, Murphy et al. 2021). However, historical reference conditions (HRV) will become less useful as climate change becomes more pronounced (Littell et al. 2010, Halofsky et al. 2018). Thus, robust adaptation strategies for fire-prone ecosystems should utilize HRV conditions as a guidepost, but seek to set landscapes on a trajectory towards conditions adapted to future climates (i.e., future range of variation – FRV) (Stephens et al. 2010, Schoennagel et al. 2017, Hessburg et al. 2019).

Here, we evaluate how four recent large wildfires in eastern Washington -spanning a range of burn severity proportions and patch sizes- changed landscape-level vegetation patterns relative to HRV and FRV reference conditions within 3–22 months of each fire. We demonstrate an approach for assessing the landscape-level work of wildfires that can be used as a core component of post-fire landscape evaluations to guide post-fire management (Larson et al., 2022). Specifically, we evaluate the extent to which wildfires spanning a range of pre-fire conditions and burn severity patterns achieved four key landscape restoration and climate adaption goals (Hessburg et al. 2015). These four goals include:

1. Shift the amount and pattern of forest, woodland, and non-forest vegetation types to within the HRV and in the direction of the FRV.
2. Shift the amount and pattern of forest structure to within the HRV and in the direction of the FRV.
3. Sustain open- and closed-canopy patches with large and old trees.
4. Shift species composition towards more drought adapted, fire-tolerant species.

2. Methods

2.1. Study Area: Four fires in four subwatersheds

We conducted departure assessments at the subwatershed level (Hydrologic Unit Code 12, (Seaber et al. 1987)). Four subwatersheds were used in this study and represent four distinct landscapes that were each analyzed separately. The grain of the landscape analyses in each landscape are patches (polygons) of vegetation that are based on vegetation structure and topography with a 4 ha minimum size. The four subwatersheds were four separate analyses that together represent a range of landscape conditions and fire effects. They were not randomly selected and are not intended for pooled statistical analyses to draw global inferences. As this landscape assessment approach is conducted at the scale of subwatersheds, only the portions of each fire that fell within the selected subwatershed were included in this study. Thus, the results do not apply to the entire fire event, but to the subwatershed boundary. Each subwatershed also contains area that is outside of the fire perimeter

in varying amounts (Table 1). Evaluation of the entire landscape area is relevant to class and landscape metric comparisons of the post-fire landscape and the HRV and FRV reference conditions.

We selected four subwatersheds that burned in 2014, 2015, or 2017 (Table 1, Fig. 1). Initially, all subwatersheds in the study area (eastern Cascades and Okanogan Highlands areas of Washington) were identified that were more than 66% forested and had at least 33% of their area burned by 2014–2017 fires. Twenty five subwatersheds met these criteria. The four subwatersheds were then selected based on three factors. First, the subwatersheds were chosen to span a gradient of fire severities that ranged from predominantly large patches of high-severity fire (Benson Creek– 2014 Carlton Complex fire) to predominantly moderate- and low-severity fire (Scatter Creek – 2015 North Star fire) (Table 1, Fig. 2). Burn severity maps were based on satellite-measured relative differenced normalized burn ratio (RdNBR) (WA DNR 2021 following methods from Parks et al. 2018) with region-specific translation into proportional post-fire basal area (BA) loss (Saber 2019). Second, wildfires that burned across a broad range of dry, moist, and cold forests were emphasized. Finally, subwatersheds in which the US Forest Service and other landowners were interested in incorporating the results into management planning were prioritized.

The four selected subwatersheds are located in the eastern Cascades and Okanogan Highlands areas of Washington (Fig. 1). Broad-scale climatic patterns across this area are characterized by cold-wet winters, hot-dry summers, and warm-wet transitional seasons (Table 1). Precipitation and temperature gradients driven by elevation, disturbance history, and topo-edaphic complexity create landscapes with varying intermingled forest and non-forest types and fire regimes (Agee 2003).

Table 1

Fire severity, forest type, climate, and elevation information for the four subwatersheds and their associated wildfires used in this study.

Subwatershed	Benson Creek	West Fork Teanaway	South Fork Boulder	Scatter Creek
Fire name & year	Carlton Complex 2014	Jolly Mountain 2017	Stickpin & Renner 2015	North Star 2015
Total area (ha)	9,824	10,149	17,840	6,367
Area burned (ha)	8,386	5,065	5,857	3,560
High Severity (%)	55 ¹	47	37	16
Moderate Severity (%)	26 ¹	37	28	19
Low Severity/Unburned (%)	18 ¹	16	35	64
Dry forest (% of landscape)	64	38	37	26
Moist forest (% of landscape)	0	14	7	43
Cold forest (% of landscape)	0	45	54	29
Non-forest (% of landscape)	36	3	2	2
Elevation range (m)	439–1,452	682–1,964	582–2,174	655–1,562
Mean JAN temperature (°C) (sd)	−4.2 (0.4)	−2.5 (0.6)	−5.1 (0.6)	−4.9 (0.2)
Mean JULY temperature (°C) (sd)	18.1 (1.1)	15.9 (0.8)	16.6 (1.2)	17.2 (0.4)
Mean annual precipitation (mm) (sd)	424 (34)	1285 (228)	681 (49)	420 (11)

¹ The percentage area burned at different fire severities includes non-forest acres (e.g. herbland, shrubland, woodland areas). A significant portion of the Carlton Complex fire in the Benson Creek subwatershed burned through pre-fire herbland that maps out at moderate and low severity due to regrowth of grasses immediately after the fire. Across the subwatershed, the percentage of forested area that burned at high-, moderate- and low-severity was 67%, 18%, and 15%, respectively.

Lower elevation and south-facing slopes at mid-elevations contain shrub-steppe communities along with ponderosa pine and Douglas-fir woodlands. Low to mid elevations contain dry mixed-conifer forests (ponderosa mixed with Douglas-fir, as well as occasionally western larch or grand fir) that historically experienced low- and some mixed-severity burns at 5–25 year intervals (Everett et al. 2000, Agee 2003).

Moist mixed-conifer forests composed of western larch, Douglas-fir, grand fir, ponderosa pine, and western white pine are found at mid-elevations in valley bottoms, riparian areas, and on north-facing slopes. They experienced low- and moderate-severity burns as well, but with a greater proportion (20–25%) at high-severity, owing to occasionally longer (25–80 year) fire return intervals (Hessburg et al. 2007). Cold subalpine forests (subalpine fir, Engelmann spruce, lodgepole pine, and western larch) occupy upper elevations and typically experienced moderate- and high-severity burns at 75–150 year return intervals; however, fire-fire interactions and reburning occasionally reinforced low- or moderate-severity fire (Prichard et al. 2017). Combined with extensive aboriginal fires (Boyd 1999), the result was a multi-level patchwork of forest and non-forest vegetation conditions that conferred resistance and resilience to large-scale disturbances and climatic fluctuations (Peterson 2002, Parks et al. 2015, Hessburg et al. 2019).

Each selected subwatershed has its own unique pre-fire characteristics and fire effects that are noteworthy (Table 1). Benson Creek contains only dry mixed-conifer forest, shrub-steppe, and woodlands, with no moist or cold forest. The subwatershed is almost entirely within the Okanogan-Wenatchee National Forest (OWNF) and was extensively harvested by means of selection cutting and overstory removal treatments in the 1970s and 1980s. Extreme fire weather during the 2014 Carlton Complex fire led to a very large patch of high-severity fire that burned through most of this landscape (Fig. 2). Mechanical fuels reduction and prescribed treatments were conducted in the southeast portion of this landscape between 2008 and 2013. Most of this treated area did not burn in the Carlton Complex fire (Prichard et al. 2020).

The northern half of the West Fork Teanaway subwatershed that burned in the 2017 Jolly Mountain fire is almost entirely Inventoried Roadless Area (similar to Wilderness in management allocation) within the OOWNF and contains steep, complexly dissected terrain. Fire severity was predominantly high and moderate (Fig. 2, Table 1). In contrast, the largely unburned southern half of the landscape was formerly industrial forestland and experienced extensive harvesting over the last several decades.

The South Fork Boulder Creek subwatershed is located on the east-side of the Kettle Mountain Range and has some components of Northern Rocky Mountain mixed-conifer forests such as extensive western larch in moist and cold forests, and western red cedar in moist forests. Ownership is primarily Colville National Forest (CNF). This subwatershed experienced significant past timber harvesting, but not as extensively as the other three landscapes. The Renner and Stickpin fires burned 33% of this landscape in 2015 with a relatively balanced mixed of low, moderate, and high-severity patches (Table 1). Larger patches of high-severity fire dominated in upper elevation forests (Fig. 2).

Almost all of the Scatter Creek subwatershed was harvested in the 1960s–1990s with shelterwood and overstory removal treatments. This subwatershed resides primarily on the CNF and has more gentle topography than the other three. The North Star fire burned 56% of this landscape in 2015. Most of the fire (80%) burned at low-severity with small patches of moderate- and high-severity scattered throughout (Fig. 2).

2.2. Pre- and post-fire vegetation attributes

To collected pre- and post-fire vegetation attributes, we employed a well-established methodology that is currently in use for landscape-level restoration efforts in eastern Washington (Gärnter et al., 2008; Hessburg et al., 1999b, 2013; Hessburg et al., 1999a; USDA, 2012; WA DNR,

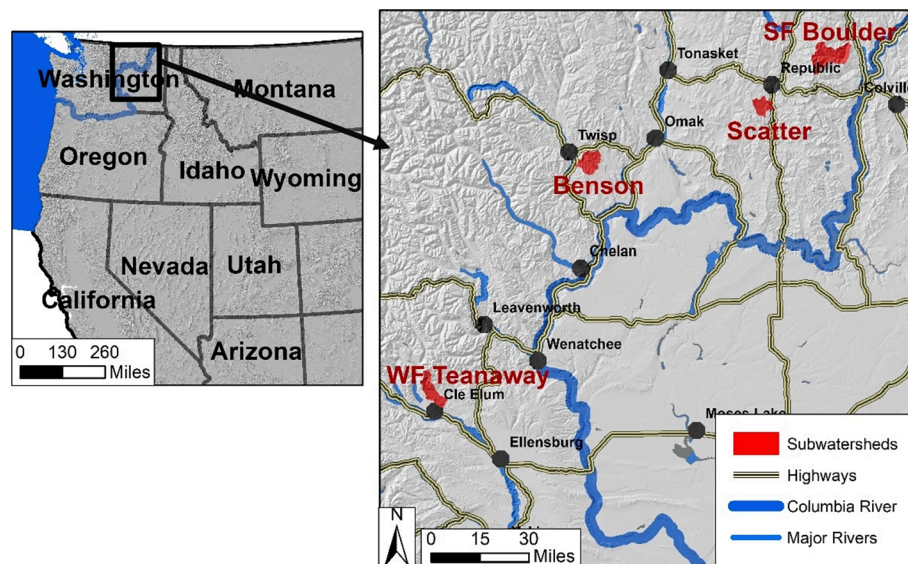


Fig. 1. Location of four subwatersheds selected for pre- and post-fire departure analysis.

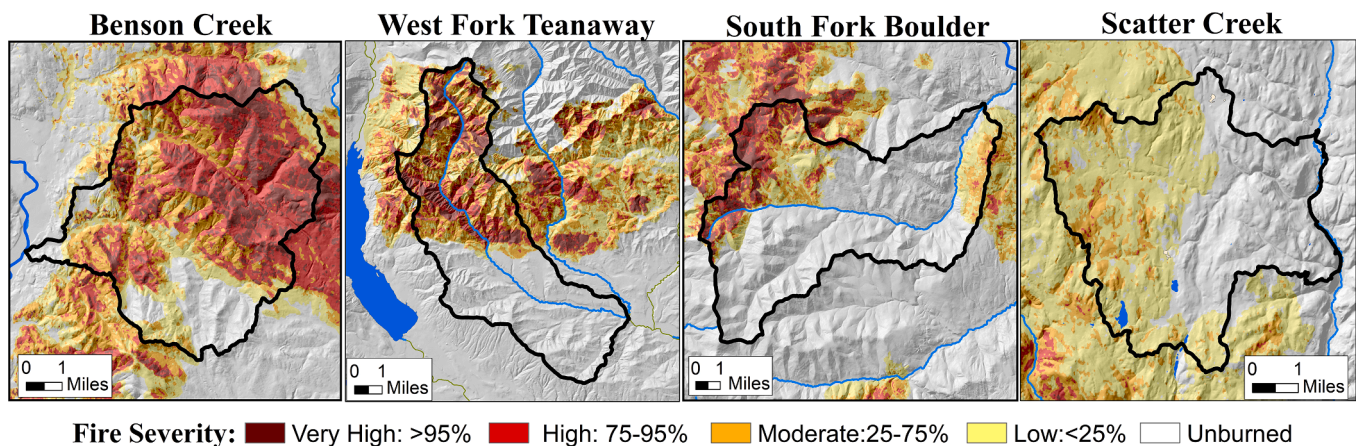


Fig. 2. Fire severity maps for four fires in the four study area subwatersheds (severity expressed as percentage of pre-fire basal area). Note the gradient from predominantly large patches of high-severity fire on the far-left panel to predominantly moderate- and low-severity fire with smaller patches of high-severity fire on the far-right panel. The large patch of high-severity fire in Benson Creek occurred in dry mixed-conifer forest, which is uncharacteristic for this forest type. Similarly, many of the large high-severity patches in the middle section of West Fork Teanaway were uncharacteristic for the moist and dry mixed-conifer types in which they occurred. Conversely, the large high-severity patches in South Fork Boulder were characteristic for the subalpine forest in which they occurred. The small to medium sized high- and moderate-severity patches in Scatter Creek were also characteristic of the predominantly dry and moist forest types in this subwatershed.

2020). This approach employs standard photo-interpretation (PI) techniques with a specific protocol that was originally developed for the Interior Columbia Basin Ecosystem Management Project (Hessburg et al. 1999a).

Pre-fire patches (polygons) were first manually delineated for each subwatershed based on vegetation structure and topography with a 4 ha minimum size. Photo-interpreted raw attributes - canopy cover, overstory and understory size class and tree species, number of canopy layers, and snag density - were then estimated for each polygon, along with other attributes (See Hessburg et al. 2013 for a complete list). Using imagery from the closest year after the fire, this PI process was repeated for the burned area of each subwatershed using the pre-fire polygons and raw attributes as a reference to minimize re-measurement error. Polygons were reconfigured as needed to capture post-fire conditions. Polygons in the unburned portion of the subwatershed were checked for any significant change in conditions. The acquisition dates of the pre-fire imagery for the four subwatersheds ranged from 1 to 14 months before fire, while post-fire imagery ranged from 3 to 22 months after fire.

Using these raw attributes, three derived attributes were calculated

for each patch (polygon): physiognomic type, structure class, and cover type. Classification criteria for the physiognomic type and structure class attributes are shown in Table 2. Cover types are based on overstory and understory tree species using the classification key described in Hessburg et al. (2013). A number of class and landscape metrics (McGarigal 2012) were then generated for each of the three derived attributes (See Hessburg et al. (2013) for a full list). Three class metrics - percent land (percentage of the landscape area- PL), area-weighted mean patch size (MPS), and cumulative patch size distributions- were selected to parsimoniously capture the primary changes from the fires in a parsimonious manner (Cushman et al. 2008).

Digital imagery for 2013, 2015, and 2017 was obtained from the Washington Department of Natural Resources for this project, which purchases a stereo, higher resolution (40 cm) version of NAIP (National Agricultural Imagery Program) from the vendor that produces NAIP imagery. Digital, "heads up" stereo digitizing software was used for PI (DAT/EM System International 2019).

Table 2

Classification criteria for physiognomic type and forest structure class. Canopy cover is total overhead tree crown cover, as estimated by the photo-interpreter for a polygon. Tree size is the estimated diameter at breast height of the dominant and co-dominant trees, derived from photo-interpreted overstory and understory size class and canopy cover attributes for a polygon. See [Hessburg et al. \(1999a\)](#) for additional information on photo-interpreted attributes and shrub and herb/forb cover types.

Attribute	Class	Definition
Physiognomic Type	Forest	≥25% canopy cover
	Woodland	5–24% canopy cover
	Shrubland	<5% canopy cover, shrub species dominant
	Herbland	<5% canopy cover, herb or forb species dominant
	Non-Vegetated	Post-fire bare ground, rock, water, developed, or other non-vegetated types
Forest Structure Class	Open	<5% canopy cover (includes non-forest and non-vegetated types); or 5–44% cover and overstory ≤ 25.4 cm
	Small-Closed	≥45% canopy cover and tree size < 25.4 cm
	Medium-Open	5–44% canopy cover and tree size 25.4–50.8 cm
	Medium-Closed	≥45% canopy cover and tree size 25.4–50.8 cm
	Large-Open	5–44% canopy cover and tree size > 50.8 cm
	Large-Closed	≥45% canopy cover and tree size > 50.8 cm

2.3. Departure analysis

We quantified departure by comparing the pre- and post-fire conditions of each subwatershed to an ecoregion-specific historical (HRV) and future range of variation (FRV). HRV is based on empirically established reference conditions derived from a large dataset of historical aerial stereo imagery that was generated as part of the Interior Columbia Basin Ecosystem Management Project ([Hessburg et al. 1999a](#)). Class and landscape metrics are quantified and analyzed at the subwatershed level. These metrics are derived from photo-interpreted raw attributes that are collected for polygons (minimum 4 ha size) within a subwatershed ([Hessburg et al. 1999a](#)). We utilized the same PI protocol for this study that was used for this historical dataset. Historical imagery has also been used to quantify landscape-level departure from reference conditions in other regions using similar methods ([Skinner 1995](#), [Scull et al. 2017](#), [Lydersen and Collins 2018](#), [Calbi et al. 2020](#)).

To establish HRV ranges for metrics for a specific subwatershed, historical data from 10 to 16 reference subwatersheds within the same ecological sub-region are used ([Hessburg et al. 2000](#)). The FRV is obtained by using the same historical dataset, but with a climate change analogue, “space for time substitution landscape sampling” approach ([Gärnter et al. 2008](#)). A second set of 10–16 reference subwatersheds from a warmer and drier ecological sub-region are selected to form the FRV. Climate projections from the RCP 4.5 greenhouse gas emissions scenario ([Stocker et al., 2014](#)) were used to select ecological sub-regions for the FRV for each target subwatershed (see [Hessburg et al. 2013](#) for a full description of this approach).

For each of the derived attributes (physiognomic type, structure class, and cover type), PL and MPS were graphically compared to the HRV and FRV ranges to assess which types were below, within, or above the reference ranges before and after the fire. The lower and upper values for the HRV and FRV reference ranges were based on the 20th and 80th percentile values for each metric from the 10–16 subwatersheds that formed the HRV and FRV ranges, respectively. Only percent land departures for cover types are presented here. Pre- and post-fire cumulative patch size distributions for forest structure class were also graphically compared to the HRV and FRV distributions.

In addition to analyzing changes in the three derived attributes, we used a principal components analysis (PCA) ordination to assess the

overall direction of changes caused by wildfire in relation to the reference ranges. We selected six raw attributes to define the PCA axes: total canopy cover, overstory canopy cover, number of canopy layers, overstory tree size, understory tree size, and snag density. The reporting units were individual forested polygons of HRV, FRV, pre-fire, and post-fire datasets, with contributions to the PCA weighted by polygon area. We visualized data in ordination space by plotting area-weighted centroids of HRV and FRV subwatersheds overlain with pre- and post-fire centroids for analysis subwatersheds. We also plotted the six structure classes ([Table 2](#)) for reference by using area weighted mean values of all the polygons from the historical and current subwatersheds for each structure class.

To assess how different wildfire severities affected the work of wildfire, we examined the pre- to post-fire transitions in forest structure class caused by low-, moderate-, and high-severity fire. The goal was to better understand how different burn severities across all four of the fires shifted forest structure classes. We combined burn severity maps ([Fig. 2](#)) with pre- and post-fire forest structure maps and then pooled the results across all four landscapes. We generated flow diagrams for low-, moderate-, and high-severity fire to report these results. Minor transitions (<2% of the area for each severity class) were not shown. All analyses for the entire study were conducted in R version 3.6.1 ([R Development Core Team 2020](#)).

3. Results

As the individual fires in each subwatershed were analyzed independently, results are presented for each subwatershed separately. Figures for two of the landscapes with contrasting results are included here, while figures for the other landscapes are provide in Appendix A. The last section reports combined results for structure class transitions from different burn severities.

3.1. Benson Creek

Driven by extreme fire weather, the 2014 Carlton Complex fire burned over 3,000 ha of forest at high-severity. This high-severity patch merged with adjacent pre-fire native herbland and shrubland areas to create a 6,822 ha herbland patch ([Fig. 3](#)), thereby flipping this landscape from forest to herbland dominated ([Figs. 3 & 4](#)). Post-fire, the percent land (PL) and area-weighted mean patch size (MPS) of herbland is well above the HRV and FRV reference ranges. The MPS of forest shifted from well above HRV and FRV to within the HRV and FRV reference ranges ([Fig. 4](#)). The fire also converted most of the woodland to herbland thereby pushing woodland area and patch sizes to the lower end of both HRV and FRV reference ranges.

The wildfire shifted the PL and MPS for most of the forest structural classes to the lower end of the HRV and FRV reference ranges ([Fig. 4](#)), especially the large-tree, closed-canopy and medium-tree, closed-canopy classes. The extreme weather driven runs of the fire converted almost of the large-tree, open-canopy patches to the open class, while moderate- and low-severity fire created new patches of large-open ([Figs. 3 & 4](#)). The net result was no change in the PL for this class and a slight increase in MPS. The fire reduced PL of ponderosa pine and Douglas-fir cover types and converted most of these sites to herbland ([Table 3](#)). No shifts from one forest cover type to another were detected.

Overall, the Carlton Complex fire shifted forest structure conditions from outside to within the HRV and FRV reference ranges, but right to the lower limit of forest cover ([Fig. 4E](#)). The large patch of high-severity fire that merged with adjacent pre-fire herbland patches now occupies 70% of the landscape ([Fig. 3](#)). This coarsened and homogenized the landscape pattern, reducing the once higher abundance of small- to medium-sized patches ([Fig. 4F](#)).

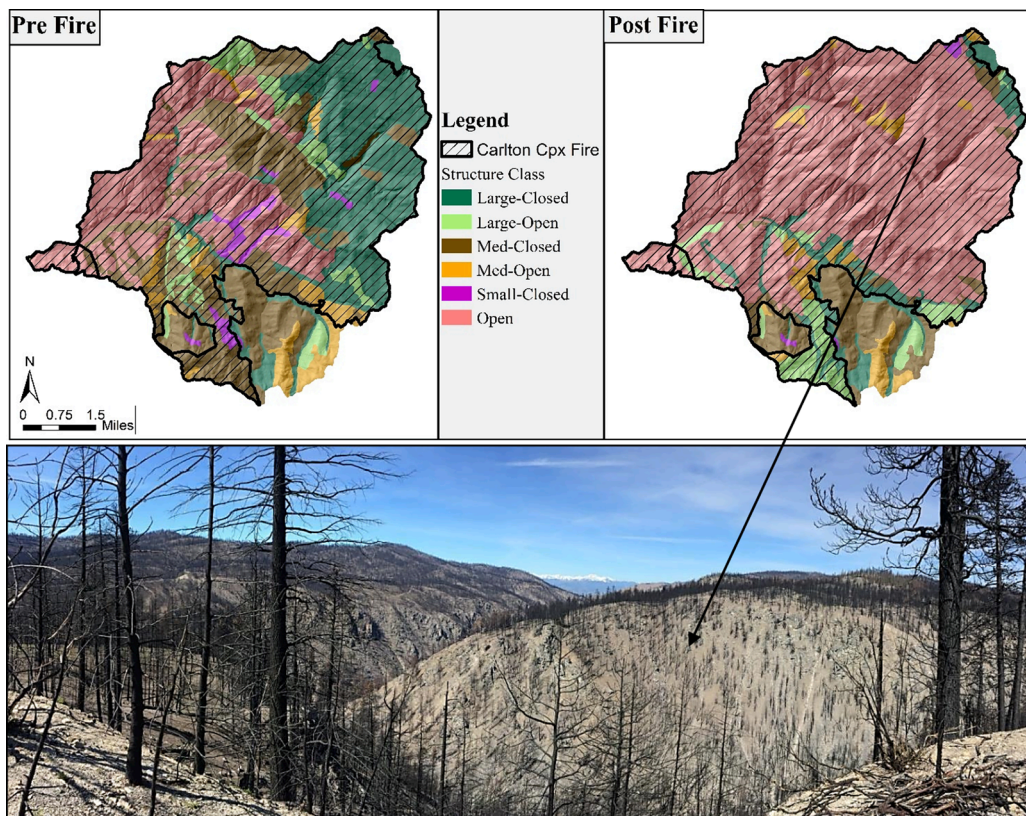


Fig. 3. Top panel: pre- (left) and post-fire (right) forest structure classes in Benson Creek. Lower panel: >3,000 ha patch of high-severity fire created by the Carlton Complex Fire in 2014 in Upper Finley Canyon within the Benson Creek subwatershed. Note that high-severity burn patches occurred in uncharacteristic dry forest biophysical settings after a long period of fire exclusion and selection cutting of the largest fire-tolerant trees. See Table 2 for structure class definitions. Photo: Susan Prichard.

3.2. South Fork Boulder Creek

Despite burning only 33-percent of this subwatershed, the 2015 Renner fire and 2015 Stickpin fire moved this landscape in the direction of the FRV reference ranges. High-severity fire in the western, upper elevation portion of the subwatershed significantly reduced the PL and MPS of forest by breaking up a very large patch of forest (Fig. A1, A2). Post-fire, non-vegetated PL and MPS were above both reference ranges, but many of these patches are forest that burned at high-severity and will quickly transition to shrubland, herbland, or young forest. The post-fire landscape remains predominantly forested (78% of the area), at the high end of FRV range. The MPS of forest is still well above both ranges (Fig. A2).

The fires converted the medium-closed and small-closed structure classes that were at the high end of FRV range to the open and medium-open classes (Fig. A2). The large-open and large-closed classes were minimally affected. The area of Douglas-fir, subalpine fir, and lodgepole pine cover types were all reduced from a pre-fire condition that was above or at the high end of the HRV reference range towards the FRV range and converted them to non-forest types (Table 3), while ponderosa pine and western larch cover increased slightly.

Overall, the fire shifted forest structure conditions from the HRV to the FRV reference ranges by reducing canopy cover and tree size/canopy complexity (Fig. A2E). In the pre-fire condition, the patch size distribution of forest patches was dominated by smaller patch sizes relative to most of both reference ranges (Fig. A2F). Post-fire, we observed that high- and moderate-severity fire patches had broken up some larger patches of forest, which further fragmented the landscape.

3.3. West Fork Teanaway

The 2017 Jolly Mountain fire burned at a range of severities and fire severity patch sizes (Table 1, Fig. 5). Moderate- and high-severity fire converted patches of forest to woodland and non-vegetated

physiognomic types (burned ground), shifting the PL of forest to the lower end of both reference ranges (Fig. 6). Many of the post-fire non-vegetated patches (burned ground) are likely to quickly transition to shrubland, herbland, or in some cases young forest.

The primary effect of the fire on structural classes was to convert the large-closed class to the open class and medium-open class (Figs. 5, 6). Interestingly, the MPS of the large-closed class increased, while the PL of declined from 46 to 31%. As only very small patches of large-closed are left within the fire perimeter, the remaining large patches in the unburned area increased the MPS. The subalpine fir cover type was significantly reduced and converted to non-forest (Table 3), while the Douglas-fir cover type increased modestly.

Overall canopy cover and forest structural conditions were outside of both reference ranges before and after the fire due to low canopy cover (Fig. 6E). The fire moved tree size/complexity from the upper edge to the middle of both reference ranges. Pre-fire, the patch size distribution was skewed towards smaller patches (left side of the envelope in Fig. 6F), relative to both reference ranges. The Jolly Mountain fire broke up the few existing larger patches of forest, further fragmenting the landscape to the point where the patch size distribution is now slightly outside of both reference ranges.

3.4. Scatter Creek

The predominantly low-severity 2015 North Star fire shifted some vegetation attributes in the direction of the FRV reference range while moving other attributes in the opposite direction. The PL of the forest physiognomic type was reduced to below the HRV reference range, but well within the FRV range (Fig. A4). Similarly, PL of herbland and woodland increased above the HRV range, but within the FRV range. The fire reduced the MPS of forest by breaking up large patches, but only slightly increased the MPS of herbland and woodland patches (Fig. A4).

The fire shifted medium-closed PL and MPS from the upper end of the HRV and FRV ranges to the middle of those range (Fig. A4), converting it

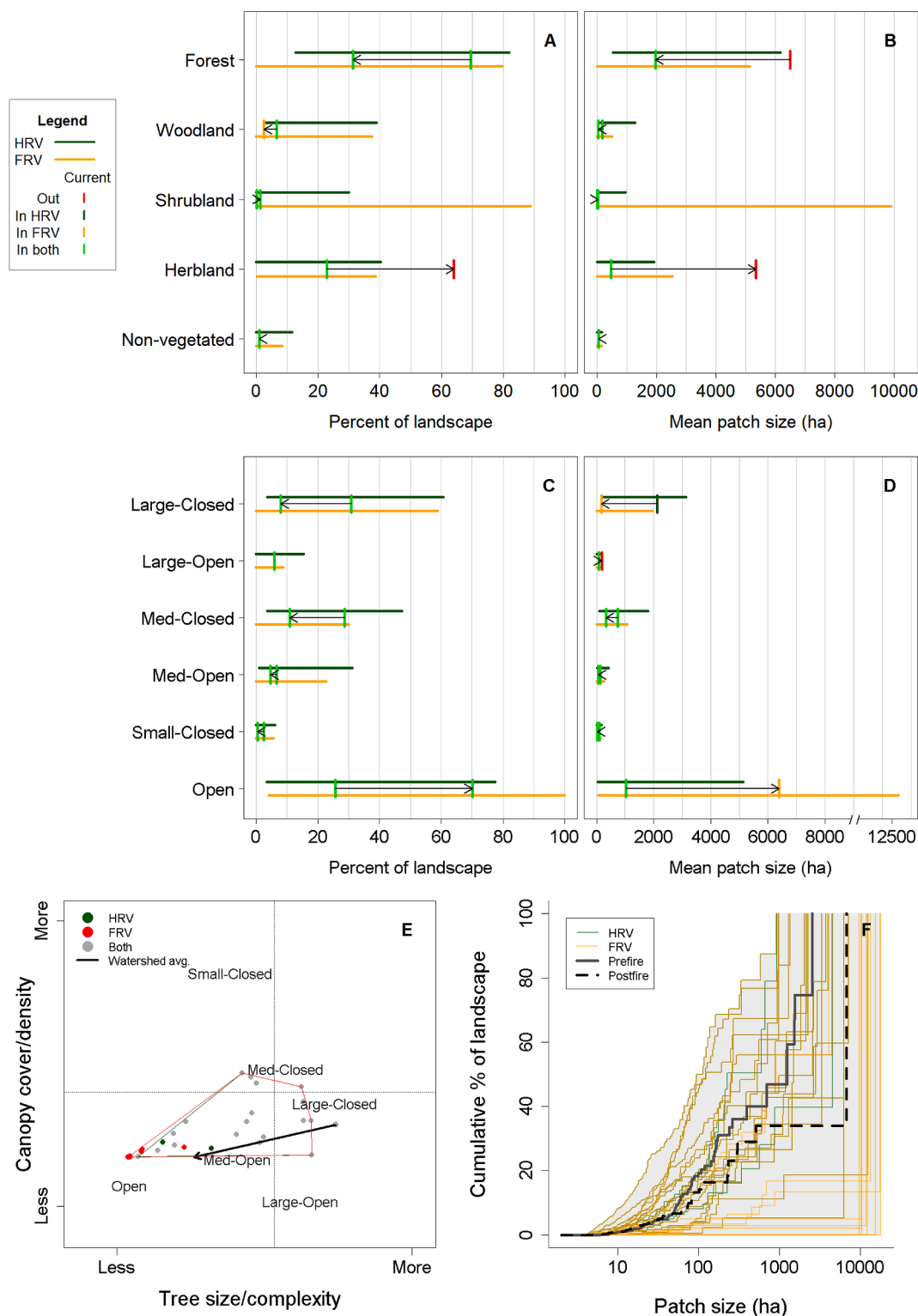


Fig. 4. Pre- and post-fire pattern metrics for the Benson Creek subwatershed. The upper and middle rows display the percentage of landscape area (left) and area weighted mean patch size (right) for physiognomic types (A,B) and forest structure classes (C,D) relative to the historical (HRV) and future (FRV) reference ranges. Arrows show the direction of change from pre to post-fire conditions. “Out” indicates that the current condition for the metric of interest is outside of both reference ranges. “In” indicated that the current condition for the metric of interest within one or more reference ranges. Panel E shows principal components analysis (PCA) of 6 forest structural attributes. Green and red dots show area-weighted centroids of the HRV and FRV sample subwatersheds of an ecological subregion. The arrow shows the fire-caused forest structural change in PCA space, with the arrow pointing from the pre-fire centroid to the post-fire centroid. Panel F displays cumulative patch size distributions of structure classes for pre- and post-fire patches. Each yellow (FRV) and green (HRV) line within panel F shows the cumulative patch size distribution for an individual reference subwatershed. See Table 2 for physiognomic type and forest structure class definitions.

Table 3

Pre- and post-fire cover type transitions caused by wildfire for four study subwatersheds in reference to the historical (HRV) and future ranges of variation (FRV). Values are percentage area of the forested landscape. The OTHER class includes post-high-severity fire conditions with bare ground. Post-high-severity fire areas in Boulder and Teanaway are shown as OTHER, while these areas were classified as HERB in Benson and Scatter due to the presence of herbaceous cover by the time of the postfire imagery. Note that the name of the cover type is the name of the dominant tree species, but other associated species may also be present. For more information on cover type classifications see [Hessburg et al. \(1999a, 2013\)](#).

Cover Type	Benson Creek			South Fork Boulder			West Fork Teanaway			Scatter Creek		
	Pre → Postfire	HRV	FRV	Pre → Postfire	HRV	FRV	Pre → Postfire	HRV	FRV	Pre → Postfire	HRV	FRV
PIPO	62 → 22	5–73	0–63	7 → 7	0–29	5–73	42 → 41	0–11	13–71	14 → 15	24–62	5–73
LAOC	–	–	–	3 → 4	5–71	0–5	–	–	–	1 → 2	0–19	0–5
PSME	12 → 9	2–43	0–39	51 → 44	13–62	2–43	35 → 38	5–54	9–46	57 → 52	8–49	2–43
PICO	–	–	–	15 → 12	0–12	0–7	0 → 0	0–6	0–7	–	–	–
ABLA	–	–	–	22 → 19	0–5	0–4	17 → 5	3–39	0–32	20 → 17	0–12	0–4
HERB	25 → 67	0–40	0–44	–	–	–	0 → 0	0–4	0–15	4 → 13	1–17	0–40
SHRUB	0 → 1	0–39	0–88	0 → 0	0–0	0–39	0 → 0	0–8	0–9	–	–	–
OTHER	1 → 1	0–10	0–2	1 → 14	0–8	0–10	5 → 13	1–63	0–32	3 → 1	0–6	0–4

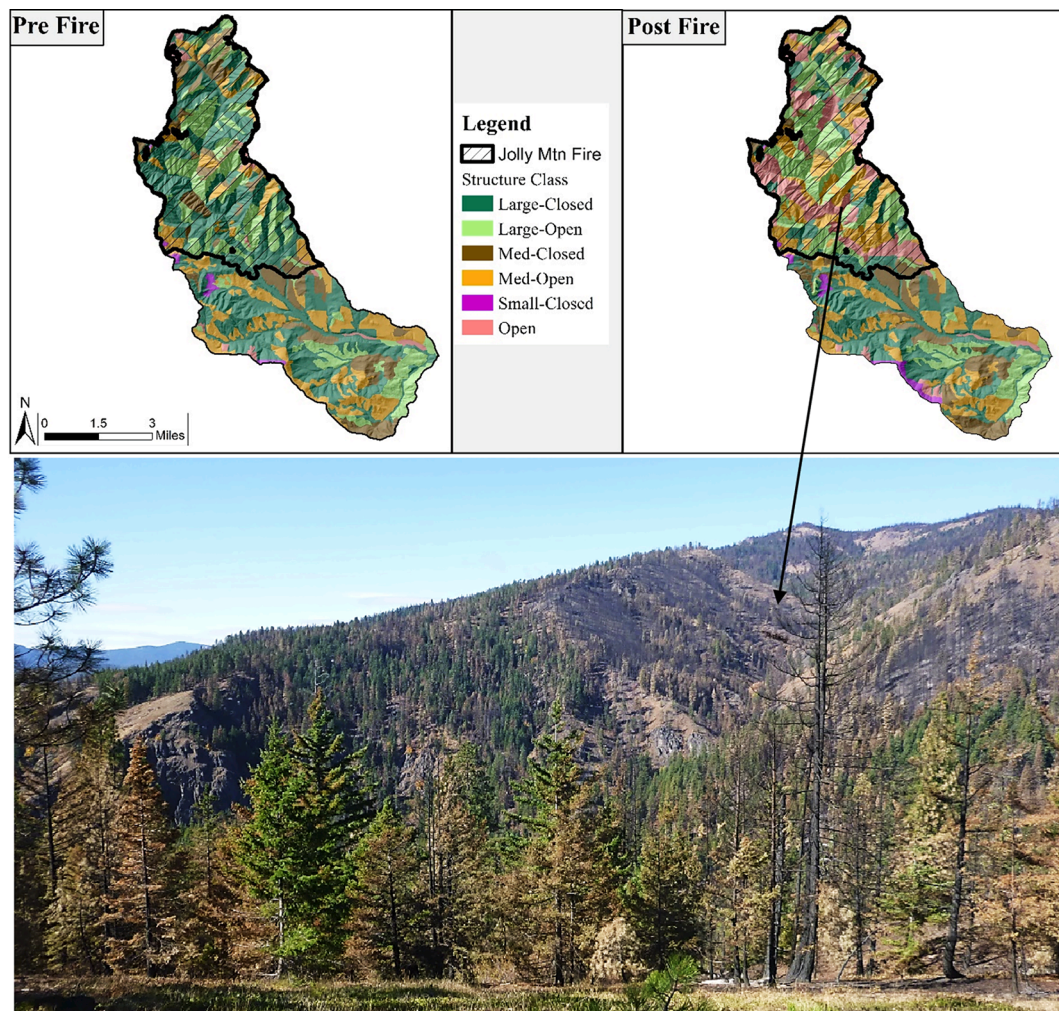


Fig. 5. Top panel: pre- (left) and post-fire (right) forest structure classes in the West Fork Teanaway subwatershed. The wildfire reinforced and further compounded the pre-fire fragmentation of this landscape relative to the HRV and FRV. Bottom panel shows photo of high-, moderate-, and low-severity patches created by the Jolly Mountain Fire in 2017 in the West Fork Teanaway subwatershed. See [Table 2](#) for structure class definitions. Photo: Scott Downes.

to the large-open, medium-open, and open classes. However, the large-open class is still relatively rare (5% PL), and the MPS is at the low end of the HRV and FRV ranges. While not affected much by the fire, the large-closed class occupies less than 10-percent of the landscape, which is below the HRV and at lower end of the FRV reference range. Likewise, the MPS of large-closed is lower than both reference ranges. Douglas-fir and subalpine fir cover types were reduced and mostly converted to

herbland ([Table 3](#)), but are still above both reference ranges. Ponderosa pine and western larch increased slightly.

Overall, the fire shifted forest conditions in the direction of lower canopy cover and reduced tree size and canopy complexity ([Fig. A4E](#)). Pre-fire, the landscape was already below the HRV range for tree size and canopy complexity, but at the upper end of both reference ranges for canopy cover. Medium and larger size patches of closed-canopy forest

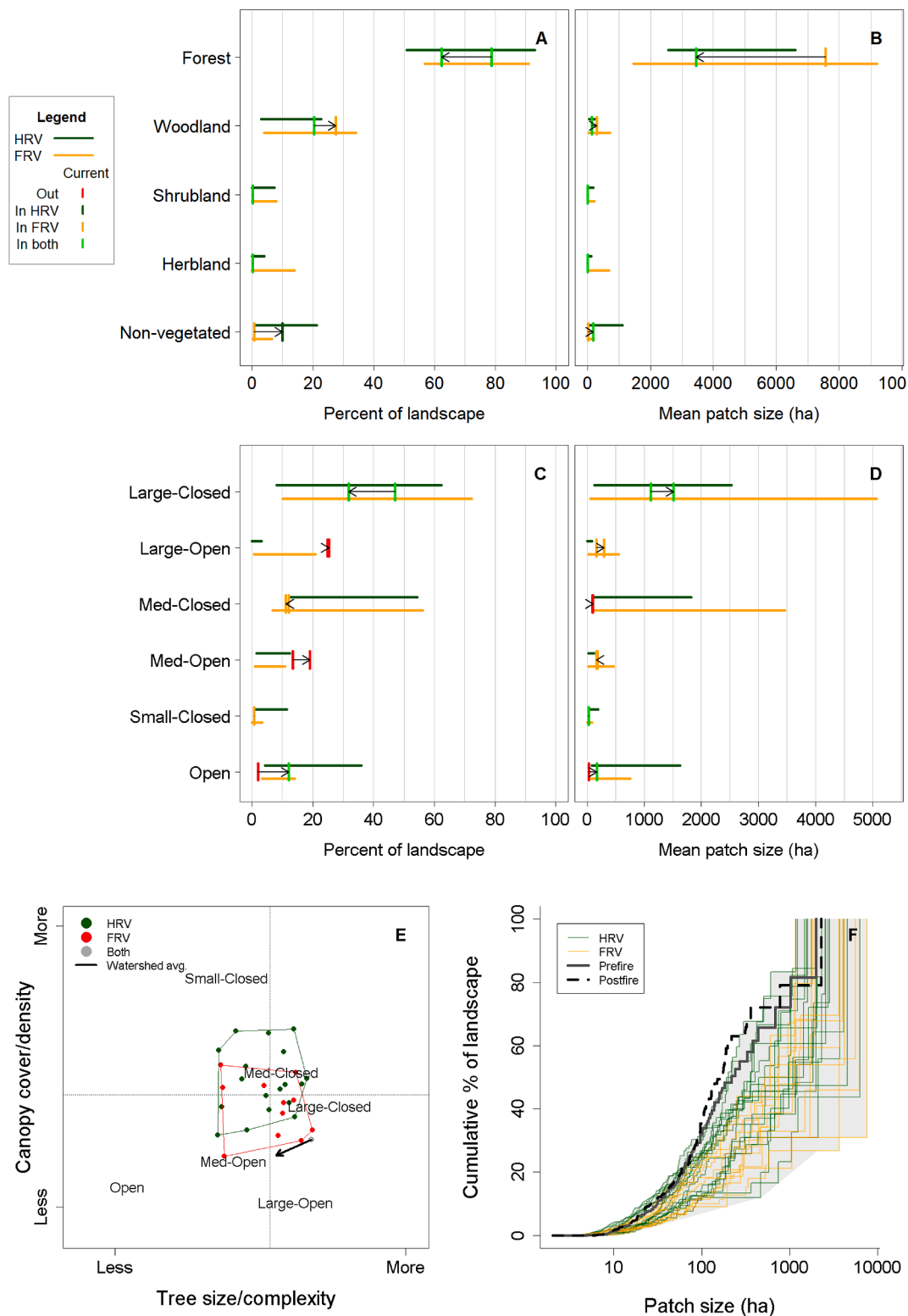


Fig. 6. Pre- and post-fire pattern metrics for the West Fork Teanaway subwatershed. The upper and middle rows display the percentage of landscape area (left) and area weighted mean patch size (right) for physiognomic types (A,B) and forest structure classes (C,D) relative to the historical (HRV) and future (FRV) reference ranges. Arrows show the direction of change from pre to post-fire conditions. “Out” indicates that the current condition for the metric of interest is outside of both reference ranges. “In” indicated that the current condition for the metric of interest within one or more reference ranges. Panel E shows principal components analysis (PCA) of 6 forest structural attributes. Green and red dots show area-weighted centroids of the HRV and FRV sample subwatersheds of an ecological subregion. The arrow shows the fire-caused forest structural change in PCA space, with the arrow pointing from the pre-fire centroid to the post-fire centroid. Panel F displays cumulative patch size distributions of structure classes for pre- and post-fire patches. Each yellow (FRV) and green (HRV) line within panel F shows the cumulative patch size distribution for an individual reference subwatershed. See Table 2 for physiognomic type and forest structure class definitions.

were broken apart by generally small patches of high- and moderate-severity fire (Fig. 2, Fig. A3). This further fragmented the landscape, which was already close to the fragmented side of the patch size distribution relative to both the HRV and FRV ranges prior to the fire (Fig. A4F).

3.5. Effect of burn severity on forest structure class transitions.

Wildfires burning at different severities drove predictable transitions in forest structural classes (Fig. 7). Most of the area that burned at low-severity across all four subwatersheds remained in the same structure class. However, low-severity fire did shift the medium-closed class to medium-open in some cases, and also caused transitions from medium- to large-size classes. Moderate-severity fire had a wide range of effects, including shifting dense, medium- and large-tree forest to medium-open and large-open classes. The medium- and large-tree open classes generally remained in the same class, but tree size was changed in some cases in both directions. The predominant effect of high-severity fire was to move the closed classes into the open class. The large-open classes that burned at high-severity often remained in the same class, although some patches were converted to open. Also, the large open was shifted to medium-open in some cases.

4. Discussion

Wildfire proved to be a blunt restoration tool. The mixed effects were

not surprising given that the wildfires we assessed burned during hot and dry conditions in landscapes that had experienced over a century of fire exclusion, extensive timber harvest, and minimal mechanical fuels reduction and prescribed fire treatments. The fires shifted some landscape-level attributes towards or within the bounds of the HRV and FRV reference ranges, while other fire effects reinforced or compounded prevailing departures or created new ones. The wide variation in fire effects we observed was expected, yet common themes emerged from our evaluations. By design, our analysis was conducted shortly after each fire. Some of the fire induced changes will be mediated by rapid vegetation re-growth, while others will persist for many decades or longer.

By comparing the effects of wildfires on landscapes with different topo-edaphic conditions, pre-fire vegetation, and fire weather conditions, we gained insight into the extent to which wildfires of different severities achieved four key landscape restoration principles (Hessburg et al., 2015; Larson et al., 2022). The following sections describe the work of each wildfire in light of these principles:

4.1. Progress towards shifting the amount and pattern of forest, woodland, and non-forest vegetation types to within the HRV and in the direction of the FRV.

Three of the four wildfires (in the Boulder, Teanaway, and Scatter subwatersheds) reversed, to varying degrees, the increase in forest and loss of woodland, grassland, and shrubland patches that were

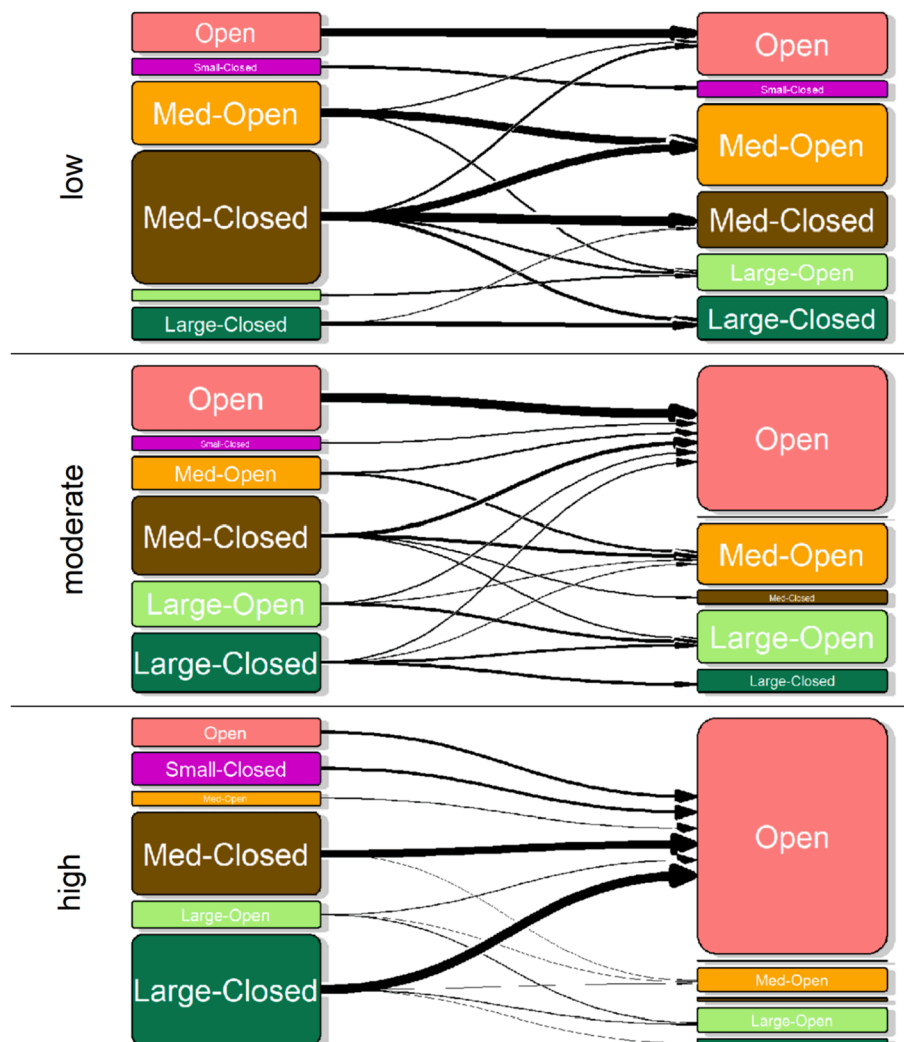


Fig. 7. Flow diagrams showing transitions in forest structural classes caused by three wildfire severities pooled across the four study subwatersheds. The lines with arrows show the transition pathways. The width of the lines are proportional to the amount of area that followed each pathway. The height of the boxes are proportional to the total area of each structure class in the pre- (left side) and post-fire (right side) pooled sub-watersheds for each fire severity class. Low severity is 0–25%, moderate severity is 25–75%, and high severity is 75–100% of pre-fire basal area consumed, respectively. Minor transitions (<2% of the area) are not shown in order to enhance the readability of the figure. See Table 2 for structure class definitions.

historically common in the Interior Columbia Basin and elsewhere in western North America (Dickinson 2014, Hessburg et al. 2019, Coop et al. 2020 p. 2016, Bielski et al. 2021, Hagmann et al. 2021). These fires generally shifted physiognomic patterns towards or beyond the HRV ranges and to within the FRV ranges. These fires burned with a relatively balanced range of high- and moderate-severity fire patch sizes. Sufficient forest area and patch sizes were maintained due to the substantial area that burned at low- to moderate-severity.

By reducing the dominance of large forest patches ($\geq 25\%$ tree cover) and increasing the number and size of other physiognomic patch types, these fires likely enhanced the hydrological and wildlife habitat functions associated with non-forest patches (Stephens et al. 2021b). In addition, the more varied patchworks of different vegetation types, forest structure, and fuel profiles will promote heterogeneous severity patterns in future fires (Collins et al. 2009, Coop et al. 2016, Stevens-Rumann et al. 2016). Depending on size and location, these non-forest patches will likely encourage a more climate adapted fire regime by facilitating spread of low-intensity, short flame length fire to surrounding forest patches, thereby inhibiting the spread of high-severity fire and insect outbreaks (Hessburg et al. 2019).

Post-fire, early-seral conditions are highly dynamic (Swanson et al. 2011), especially in moist and cold forests. Given that most of the high-severity patches are in moist and cold forest types in these three landscapes, we expect that many areas will transition back to forest or woodland within 10–20 years due to high regeneration rates in these forest types and the smaller sizes of some high-severity patches (Povak et al. 2020a). Yet some of these high-severity areas will likely become long-term shrublands, grasslands or broadleaf deciduous forest patches (Shinneman et al. 2013), depending on conifer seed rain availability from surviving trees, adjacency to forest patches, subsequent reburns, and future climatic conditions (Kemp et al. 2016, Stevens-Rumann and Morgan 2016, Cansler et al. 2018). Broadleaf deciduous forest patches, especially quaking aspen, were another key to forest landscape resilience under historically active fire regimes, owing to the moist site and fuel conditions associated with them (Hagmann et al. 2021).

In contrast, the extreme fire weather driven Carlton Complex fire in the dry forest dominated Benson Creek landscape moved physiognomic conditions away from more climate adapted conditions by homogenizing landscape pattern (Prichard et al. 2020). The 6,822 ha patch of herbland created by the fire pushed the area weighted mean patch size (MPS) and percent land (PL) of herbland well beyond the HRV and FRV reference ranges. Pre-fire patches of woodland were also consumed and eliminated from this large burn patch. While patches of high-severity fire provide important habitat elements for many species (Swanson et al. 2011), large ($\geq 10^3$ ha) high-severity burn patches in pine and dry mixed-conifer forest were very rare historically (Hagmann et al. 2021) and can lead to declines in wildlife diversity (Jones et al. 2021, Steel et al. 2021).

Much of the herbland patch will not likely return to a woodland or forest condition due to a lack of nearby conifer seed rain and the current and projected high moisture deficits for this area (see moisture deficit projections in (Larson et al., 2022)). Furthermore, surface fuel beds will quickly rebuild due to a combination of grass accumulation and woody fuels from fire-killed trees (Lutz et al. 2020). This will facilitate future reburns that will likely kill most small trees that are able to establish, further reducing the likelihood of forest recovery (Coppoletta et al. 2016, Stevens-Rumann and Morgan 2016, McIver and Ottmar 2018, Lydersen et al. 2019, Cansler et al. 2022). The snags and early-seral plant communities in this patch will provide habitat for post-fire specialists for one to two decades (Hutto 2006) until the dead wood decomposes or is consumed by future fires.

Options to facilitate a gradual transition to a more climate-adapted patchwork of forest, woodland, herbland, and shrubland in this landscape are now greatly limited. The US Forest Service did replant a significant portion of the high-severity burn areas several years after the fire. However, multiple years of dry spring and summer conditions after

replanting are likely to greatly lower survival (North et al. 2019). Future accumulation of fuels and reburns are likely to further impede forest recovery (McIver and Ottmar 2018). The homogenized landscape pattern is thus likely to persist and the functions associated with a more forested landscape will be absent. This combination of increasing moisture stress and large patches of high-severity wildfire are precipitating expansion of non-forest vegetation types across the western US (Chambers et al., 2016; Coop et al., 2020; Coppoletta et al., 2016; Davis et al., 2019; Kemp et al., 2019; Savage and Mast, 2005; Stevens et al., 2021). Monitoring of these high-severity patches is warranted to assess replanted areas, as well as natural tree regeneration and other plant communities that establish.

A potential post-fire management strategy for fire-converted patches is assisted migration of drought-adapted oak species that often increase in abundance after high-severity fires in other regions (Halofsky et al. 2011, Guiterman et al. 2018). While not locally present, populations of Gary oak (aka Oregon white oak; *Quercus garryana*) are present approximately 180 km to the south and west of this area (Pellatt and Gedalof 2014), and could be introduced if the projected future climate is deemed suitable (Case and Lawler 2016).

4.2. Progress towards shifting the pattern and amount of forest structural conditions to within the HRV and FRV.

Wildfires reduced overall forest canopy cover and tree size-canopy complexity in all four burned landscapes to within or slightly outside of the FRV ranges. High-severity fire drove the greatest degree of change by converting closed-canopy structure classes that were at the upper or middle end of both reference ranges to early-seral forest and non-forest vegetation types (open structure class). The open structure class was shifted from the lower end of both ranges to within the FRV ranges or upper end of the HRV ranges in most cases. Moderate- and low-severity fire also shifted some closed-canopy structural classes to more fire- and drought-tolerant medium- and large-tree, open-canopy structural classes, but patch sizes were not significantly increased. Overall, the PL of medium-closed or large-closed structure classes was shifted from the middle or upper end of both reference ranges to the middle or lower end. Patch sizes of closed-canopy classes were generally reduced, but the MPS of these classes remained within the middle to lower end of the HRV and FRV reference ranges.

The large HRV and FRV ranges for many of the structure classes represent a relatively wide array of possible conditions across a landscape. Different parts of the ranges provide different combinations of ecosystem functions that can be more or less resilient to future disturbances. While large high-severity patches in dry and moist mixed-conifer forests, such as occurred in Benson Creek, may abruptly move aggregate canopy cover and forest structure into the FRV, they can set landscapes on a self-reinforcing trajectory towards simplified conditions dominated by young forests and non-forest vegetation types that may lead beyond FRV ranges when future wildfires occur (Cassell et al., 2019; Coop et al., 2016; Rammer et al., 2021; Steel et al., 2021; Stevens et al., 2021). In contrast, wildfires that burn primary at moderate- and low-severity, such as occurred in Scatter Creek, can increase the area and patch size of large- and medium-tree, open-canopy forest while maintaining sufficient patches of closed-canopy forest. Small- and medium-sized high-severity patches can restore patchworks of forest and non-forest. Such fires result in more biologically diverse landscapes where future fires are more likely to act as stabilizing feedbacks and enhance landscape resilience (Kane et al. 2019, Murphy et al. 2021, Prichard et al. 2021, Taylor et al. 2021, Berkey et al. 2021, Cansler et al. 2022).

Restoring landscape pattern by realigning the spatial arrangement and patch size distributions of forest structure with the topo-edaphic template is another critical aspect of climate adaption (North et al. 2009, Hessburg et al. 2015). The four fires proved to be an imprecise tool in accomplishing this goal. In the Teanaway landscape, extensive timber

harvests in the unburned southern half of the landscape had already fragmented and reduced medium- and large-closed forest. Extensive high-severity fire within the Jolly Mountain fire greatly reduced and further fragmented the remaining closed forest in the northern half the landscape, pushing the cumulative patch size distributions to the very edge or just outside of both reference ranges. Many of the patches of large-closed forest that burned at high-severity were located on climatically favorable sites that are projected to have moisture deficit levels that will support dense, moist mixed-conifer forest in the future (WA DNR 2020). In contrast, most of the closed-canopy forest that remains is located on drier biophysical settings where future climate projections indicate high drought vulnerability and risk of high-severity fire.

This mismatch of forest structure and topo-edaphic conditions will make sustaining a sufficient area, as well as larger patches, of closed-canopy forest very challenging in the future (Spies et al. 2019). Mechanical or fire based treatments to lower fire risk and drought vulnerability in the remaining dense forest will further reduce and fragment closed-canopy forest and push the landscape beyond the FRV range for overall canopy cover. Re-growth of large-closed forest from medium-open or large-open classes will take several decades, if not longer, and future fires are likely to set this back. Similarly, Benson Creek is now vulnerable to a future wildfire moving forest landscape conditions beyond FRV range for canopy cover and structural conditions, particularly as the dense unburned portion of the landscape remains vulnerable to drought (Larson et al., 2022).

The 2015 North Star fire made some progress in reconnecting patterns of forest structure with the topo-edaphic template, but more work is needed. Past overstory removal treatments in the Scatter Creek landscape, combined with fire exclusion, greatly reduced and fragmented large-closed structure to the lower end of the FRV reference range and well below the HRV range, resulting in a pre-fire landscape dominated by medium-closed forest. Low and moderate-severity fire transitioned some medium-closed forest to medium- and large-open forest on south facing slopes and other drier sites, but fire also broke up the larger patches of dense forest in the most favorable topo-edaphic locations.

The Scatter Creek landscape still resides at the upper end of both ranges for canopy cover, however, with a relatively large amount of medium-closed and medium-open forest remaining. Options exist for mechanical and fire-based treatments to further align vegetation with the topo-edaphic template by building larger patches of medium- and large-open forest in drier topo-edaphic locations through treatment of adjacent medium-closed forest (Larson et al., 2022). To fully restore fuelbeds and fire resistance, these large patches can then be treated with prescribed fire or managed wildfire to reduce post-fire fuel accumulation and consume activity fuels from mechanical treatments.

The two wildfires in the Boulder subwatershed moved the amount of open-canopy forest towards the HRV and FRV ranges and helped to reconnect structural conditions with the topo-edaphic template. Low- and moderate-severity fire created somewhat larger patches of open-canopy forest at lower elevations and on south facing slopes, while high-severity fire restored missing early-seral forest at higher elevations. The fires only burned a third of this landscape, however, and more work is needed.

4.3. Progress with conserving closed- and open-canopy patches with large and old trees.

Large and old trees of fire resistant species are the structural backbone of fire-dependent forests and a critical component of forest ecosystem resilience (Franklin and Johnson 2012, Lutz et al. 2012, 2018, Hessburg et al. 2015). Populations of old trees contain high levels of resistance to wildfires (Cansler et al. 2020) and contain a broad base of genetic diversity (Hamrick et al. 1989, de la Mata et al. 2017) that can facilitate regeneration and establishment of climate-adapted tree

provenances, thus aiding forests to naturally adapt to a shifting climate after disturbances (Storfer et al. 2007, Luo and Chen 2013).

Congruent with many other studies, patches of open-canopy, large-tree forest proved to be relatively resistant to wildfire in each of the four landscapes (Stephens et al. 2008, Prichard et al. 2010, Safford et al. 2012, Pawlikowski et al. 2019). Even when this structural class experienced high-severity fire, enough large trees survived to avoid conversion to the open class in many cases. Some large-open patches were converted to non-forest by the extreme weather driven fire in Benson Creek, as well as on steep slopes in the Teanaway subwatershed. However, the overall abundance and MPS of the large-open class remained stable or increased in both subwatersheds due to fire driven transitions from medium- and large-closed to this class.

In contrast, the closed-canopy, large-tree structure class was prone to high- and moderate-severity fire owing to its high vulnerability to crown fire initiation and spread. In the Benson and Teanaway landscapes, fires shifted the PL and MPS of this structure class to the lower to middle end of both reference ranges. Loss of large-tree, closed-canopy forest has been a common feature of many other large wildfires (Taylor and Skinner 1998, Agee and Skinner 2005, Spies et al. 2006, 2018).

The option to treat a portion of the large-closed structure class that burned at high-severity and convert it into more fire- and drought-resistant large-tree, open-canopy forest has been lost (Restaino et al. 2019, Churchill 2021). Intentional, landscape-level restoration treatments prior to these wildfires could have realigned landscape pattern with the topo-edaphic template. Proactive thinning and prescribed burning treatments could have expanded the amount and patch sizes of the large-open class in the more fire- and drought-prone portions of the landscape (Hessburg et al., 2015; USDA, 2012), which would have reduced the likelihood of crown fire transmission to the remaining large-closed patches (Ager et al. 2007, Tubbesing et al. 2019). Furthermore, large-closed structure in the most favorable topo-edaphic and future climatic locations could have been selected for retention (Camp et al., 1997; Spies et al., 2019; Larson et al., 2022), promoting a higher future abundance of fire refugia (Meddens et al. 2018, Krawchuk et al. 2020, Meigs et al. 2020). Promotion of refugial patches on the landscape could potentially be a cost-effective solution to retain a variety of ecosystem services.

Not all of the large-closed structure class burned at high- to moderate-severity, however. The PL and MPS of large-closed forest remained stable in the Boulder and Scatter Creek landscapes. High-severity fire did convert this structural condition to non-forest in some places. This was offset in other locations, however, by low-severity fire shifting medium-closed to this class by thinning out smaller trees and increasing average tree size while maintaining adequate canopy cover ($\geq 50\%$ cover). Other large-closed patches experienced low-severity fire and did not change structural class. In Benson Creek, a number of closed-canopy patches in the southern portion of the subwatershed that had received thinning and prescribed fire treatments persisted through the wildfire (Prichard et al. 2020). These results suggest that large-tree, closed-canopy forest can be sustained in some locations in an active fire regime, and that probable burn severity is more important than burn probability in defining fire refugia (Krawchuk et al. 2020, Meigs et al. 2020).

4.4. Progress with shifting species composition towards drought-adapted, fire-tolerant species.

Wildfires offer an opportunity to transition composition in towards climate- and wildfire-adapted species and phenotypes. Drought- and fire-intolerant species were reduced by the four wildfires in our study, but this reduction was mostly driven by conversion to non-forest by high-severity fire. These early-seral patches offer an opportunity to shift to more drought and fire-tolerant species or phenotypes provided that seed sources are available (Povak et al. 2020a). Alternatively, planting can assist these transitions (Chmura et al. 2011, North et al. 2019) where

forest is likely to persist in the future and is desirable from a physiognomic pattern perspective (see Section 4.1, Larson et al., 2022).

Moderate- and low-severity fire slightly increased the amount of ponderosa pine and western larch cover types in several of the landscapes by reducing understory fire-intolerant species composition. This effect is likely underestimated by photo-interpretation (Lydersen and Collins 2018), as well as other remote sensing methods (Jeronimo et al. 2018, Furniss et al. 2020), because – when observing conditions from above – it is difficult to detect changes in understory structure and composition beneath an overhead canopy, or in the shadows of larger trees. Continued monitoring with field and remote sensing methods could provide longer-term information about regeneration and establishment of desired species after fire (Cansler et al. 2022).

4.5. Study limitations

Quantifying HRV or FRV reference ranges for evaluating landscape-level structural and compositional patterns is challenging in any landscape. While understanding of tree- to stand-level structure and pattern in historical and contemporary frequent-fire forests is well developed (Larson and Churchill 2012, Churchill et al. 2013, 2017, Pawlikowski et al. 2019, LeFevre et al. 2020, Murphy et al. 2021), landscape-level reference data do not exist for many vegetation types across the interior West (Johnstone et al. 2016). Historical imagery is an established empirical data source for establishing reference conditions over large areas, and for quantifying landscape changes (Skinner 1995, Scull et al. 2017, Lydersen and Collins 2018, Calbi et al. 2020). Other sources of reference data, such as simulation modeling (Hemstrom et al. 2014, Keane et al. 2018, McGarigal et al. 2018), early timber inventories (Hagmann et al. 2013, 2014, 2021, Stephens et al. 2018), and LiDAR data from contemporary landscapes with restored fire regimes (Jeronimo et al. 2019) all have advantages, but also their own set of limitations and uncertainties (Keane et al. 2009, Hagmann et al. 2018), particularly with regards to landscape pattern (Keane et al. 2002).

The imagery used to create the historical dataset used in this study is from the 1930 s-1950 s period (Hessburg et al. 1999a). A statistical imputation process was used to replace any harvested trees, as evidence of prior harvesting and type of harvest were photo-interpreted attributes (Hessburg et al. 2013). However, decreased fire frequency in the early part of the 20th century led to increases in forest cover by the 1930–1950 s in many locations in the interior western US (Hagmann et al. 2021). Thus, the HRV and FRV ranges used in this study likely over-represent forest cover, especially in the understory, relative to landscapes with active fire regimes (Hagmann et al. 2017, Lydersen and Collins 2018, Jeronimo et al. 2019). Interpretation of the results of this study should thus be mindful of this reality. We focused on the lower end of HRV and FRV ranges for closed-canopy conditions and the upper end for open-canopy classes to account for this issue. For future studies, both the HRV and FRV reference conditions could be adjusted down for amounts and patch sizes of the forest physiognomic type and closed-canopy structural classes and increased for woodland and open-canopy structural classes. Additional proxy records and simulation modeling discussed in the above paragraph could be used for this purpose.

4.5.1. Management implications and Conclusions

Wildfires in seasonally dry forests of the western US are an inevitable fact of the 21st century. The goal of adaptive forest treatments is to prepare them for climate change and increases in wildfire activity. In the context of wildfire prepared landscapes, most wildfires will function as maintenance treatments, reinforcing the good work of more characteristic wildfires and adaptive treatments. The four wildfires we assessed, however, burned under hot and dry conditions in landscapes that had experienced over a century of fire exclusion, extensive timber harvest, and minimal mechanical fuel reduction and prescribe fire treatments. The results from the work of these four fires provide five important

implications for restoration and climate adaptation efforts.

1. **Wildfire is a blunt tool in fire-excluded, untreated landscapes.** Wildfires that burn with a characteristic mix of severities and patch sizes can shift landscape towards more climate-adapted, resilient conditions. However, large, uncharacteristic high-severity patches can push landscapes towards simplified conditions outside of FRV ranges. Wildfires often reduce the number and size of large-tree patches and diminish options to restore large tree, open-canopy forest.
2. **Moderate- and low-severity fire can be a good first entry.** These fires tend to shift closed-canopy forest conditions to more fire resistant and resilient, open-canopy structural conditions and more fire-tolerant species. However, additional fire and/or mechanical treatments are typically needed within 10–20 years to reduce future fuel loads and achieve desired compositional and structural conditions (Prichard et al., 2021; Larson et al., 2022).
3. **High-severity fire can restore or homogenize patchworks of forest, woodland, grassland, and shrublands.** Large patches of high-severity fire in dry and moist mixed-conifer forests homogenize physiognomic patterns by converting large forest areas to grassland or shrubland (Stevens et al., 2017; Singleton et al., 2021), raising their vulnerability to short interval reburning and limiting future developmental trajectories. Small-, as well as some medium-sized, high-severity patches can restore self-reinforcing patchworks of forest and non-forest vegetation that build resistant to future large, high-severity fires.
4. **Wildfires can compound pre-existing departures in landscape patterns.** Wildfires burning during extreme fire weather conditions are unlikely to realign forest conditions that have been disconnected from the topo-edaphic template by past timber harvesting and fire exclusion. Instead, they can reinforce existing mismatches by compounding overly homogeneous or fragmented patterns (Zald and Dunn, 2018). Mechanical treatments that heavily reduce canopy cover over large areas and overly fragment landscape pattern – further mismatching conditions to the topography – may result in wildfires that reduce the amount and patch sizes of closed-canopy forest beyond FRV ranges. Alternatively, treatments that are heavily focused in one part of the landscape, while leaving large patches of closed-canopy forest in fire- and drought-prone locations, can set up landscapes for future high-severity disturbances.
5. **Integration of landscape-level restoration treatments with strategic wildfire response can best adapt landscapes to future climate.** Mechanical and prescribed fire treatments that intentionally prepare landscapes for fire by following landscape restoration principles (Hessburg et al., 2015; Stephens et al., 2021a) will likely result in more positive outcomes from coming wildfires, which can then be allowed to do further adaptive work (Hessburg et al. 2021, North et al. 2021). This is analogous to how a combination of mechanical thinning and prescribed fire are the most effective stand-level treatments (Hudak et al. 2011, Safford et al. 2012, Cansler et al. 2022). When wildfires occur in untreated or partially treated landscapes, wildfire response strategies based on informed risk analysis can allow fires to accomplish positive work during moderate fire weather, while suppressing and containing fires in high-risk locations or during unfavorable weather periods (Young et al., 2019; Dunn et al., 2020). Post-fire management can then further the good work of wildfires where necessary or ameliorate negative effects (Meyer et al., 2021; Stevens et al., 2021; Larson et al., 2022).

While the work ahead is daunting, time tested knowledge and tools exist to prepare landscapes for a warmer and drier future with more fire (WA DNR 2020, Prichard et al. 2021). Over time, these methods can help re-establish wildfire as a helpful ecosystem process that also maintains safer landscapes for people, instead of a catastrophe to be feared and suppressed.

CRediT authorship contribution statement

Derek J. Churchill: Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Formal analysis, Visualization, Data curation, Funding acquisition. **Sean M.A. Jeronimo:** Conceptualization, Methodology, Formal analysis, Visualization, Data curation, Writing – review & editing. **Paul F. Hessburg:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Project administration. **C. Alina Cansler:** Conceptualization, Writing – review & editing. **Nicholas A. Povak:** Conceptualization, Methodology, Writing – review & editing. **Van R. Kane:** Writing – review & editing, Project administration. **James A. Lutz:** Conceptualization, Writing – review & editing. **Andrew J. Larson:** Supervision, Project administration, Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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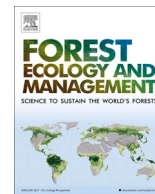
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Mechanical thinning without prescribed fire moderates wildfire behavior in an Eastern Oregon, USA ponderosa pine forest

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ABSTRACT

Reducing fuels to better manage risk of high severity wildfire in seasonally dry, fire-prone forests of the western U.S. is an important goal of forest managers, including private landowners, non-governmental organizations, tribal, state, and local governments, and federal agencies. Managing fire risk is a critical objective of the U.S. Forest Service, which emphasizes the use of thinning to reduce tree density and ladder fuels followed by prescribed fire to reduce surface fuel. But the area of Forest Service land treated with thinning and prescribed fire is lagging far behind the area treated only with mechanical thinning due to regulatory and logistical challenges in prescribed fire implementation. Determining if mechanical thinning alone (without prescribed fire) can achieve adequate fire risk reduction has important implications for addressing the fire and fuel management goals set by Congress and the Administration, as well as the management objectives set by non-federal actors. In this study, we report on the effects of mechanical thinning and standard post-thinning fuels management but without prescribed fire on modeled fire behavior and changes in fuel loading over time in a ponderosa pine forest in Eastern Oregon. Thinning without prescribed fire significantly reduced potential crown fire immediately following thinning and also moderated surface modeled fire behavior beginning 2–3 years following thinning. Although small (<7.6 cm diameter) woody surface fuel loading increased following thinning, other ground and surface fuels (i.e., litter and duff) declined substantially, which we attribute to surface disturbance from ground-based logging, decreased deposition of litter, and increased decomposition. These results suggest that fuel reduction and fire risk management objectives can be met with mechanical thinning alone for a number of years. Prescribed fire is likely necessary to extend the effectiveness of mechanical thinning after significant tree or shrub regeneration. Continued monitoring will allow managers to use prescribed fire most efficiently to achieve fire and fuel management objectives.

1. Introduction

The natural fire regime of seasonally dry forests across western North America was historically characterized by frequent, low intensity surface fire that maintained open stands of older trees (Hagmann et al., 2021; Heyerdahl et al., 2001). Beginning in the late 1800s, logging that removed old fire-resistant trees, unregulated grazing that removed herbaceous fuel, and organized fire suppression and exclusion have resulted in significantly increased tree density, fuel continuity, and surface fuel loading (Abella et al., 2007; Hessburg and Agee, 2003).

These changes to dry forests, along with a warming climate, have resulted in increasingly large, fast-moving fires with stand replacing fire effects that have significant negative impacts to old-growth habitat, water quality, and human infrastructure (e.g., Jones et al., 2019; Sankey et al., 2017; Williams, 2013). A variety of actors, including non-governmental organizations, tribal governments, state and local governments, and private landowners are adapting to climate change by reducing fuels across the seasonally dry forests that they manage (Charnley et al., 2017). The federal government is making significant investments in thinning to reduce fuels across lands managed by the U.S.

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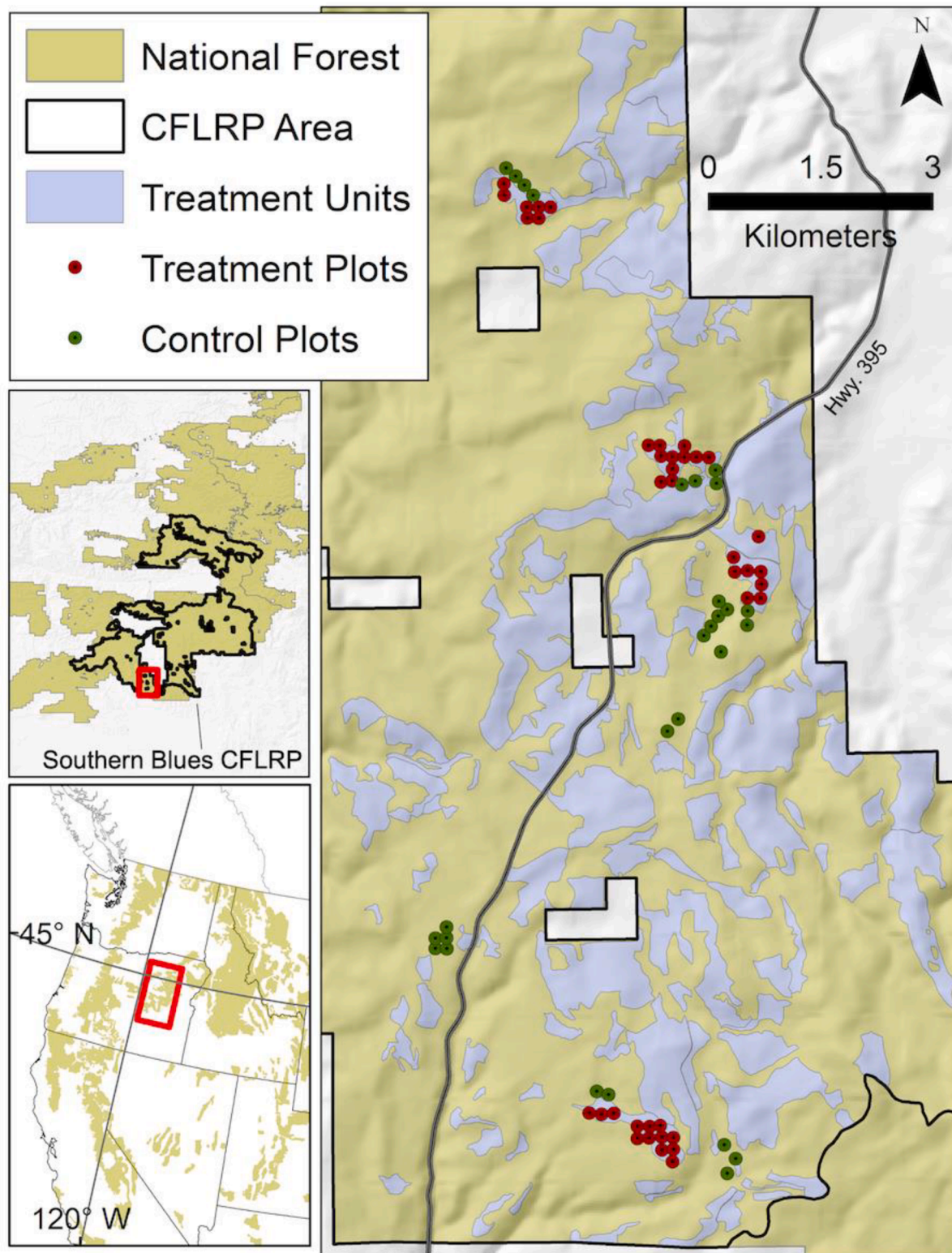


Fig. 1. The Marshall Devine planning area (right panel) in the southern Blue Mountains (middle left panel) in Eastern Oregon (bottom left panel). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Forest Service (USFS), which manages the majority of seasonally dry forests in the western U.S. (Chapin et al., 2021; Prichard et al., 2021; Stephens et al., 2020).

Evaluating the effectiveness of fuel reduction treatments is important for targeting future investments and designing treatments in an adaptive management framework (Stephens and Ruth, 2005). A large number of

studies have evaluated the influence of fuel reduction thinning on fire behavior in seasonally dry forests of the western U.S. Past research has drawn conclusions about the effects of thinning by statistical analyses of forest structural and compositional elements known to influence fire (e.g., Knapp et al., 2017), modeling of fire behavior in thinned stands (e.g., Parsons et al., 2018), or by evaluating effects of wildfire that burned

thinned stands (e.g., Lydersen et al., 2017). Results from individual studies, as well as metaanalyses and syntheses (e.g., Willms et al., 2017; Kalies and Yocom Kent, 2016; Martinson and Omi, 2013; Fulé et al., 2012; Stephens et al., 2009) demonstrate that mechanical thinning followed by prescribed fire is generally effective at moderating wildfire severity. A few studies (e.g., Cram et al., 2015) report little difference in fire effects across a variety of treatments including thinning only and thinning followed by prescribed fire. But the majority of published studies suggest thinning that is not followed by prescribed fire is less effective at moderating fire severity than thinning combined with prescribed fire (e.g., Prichard and Kennedy, 2012; Schwilk et al., 2009). Some studies suggest that thinning without prescribed fire can increase wildfire severity by adding fine fuels to the forest floor (e.g., Raymond and Peterson, 2005).

One of the most extensive studies of fuel management was the U.S. national Fire and Fire Surrogate study (FFS). The FFS involved a total of twelve treatment sites, seven located in western U.S. states and five located in eastern states. At each site, treatments were designed to thin stands so that 80% of the residual dominant and co-dominant trees would survive a wildfire under 80th-percentile fire weather conditions. Three different treatments—mechanical thinning only, prescribed fire only, and mechanical thinning plus prescribed fire—were replicated within at least three randomly assigned treatment units that measured at least 15 ha in size. The overarching goal of the FFS study was to evaluate the effectiveness and ecological consequences of commonly used fuel reduction treatments (McIver et al., 2013). Results across these twelve diverse study sites were somewhat mixed. One study that summarized results of treatments across sites found that the mechanical thinning plus fire treatment was best suited for the creation of stands with fewer and larger trees, reduced surface fuel mass, and greater herbaceous species richness, but that the mechanical thinning plus fire treatment sometimes resulted in invasion of sites by invasive species (Schwilk et al., 2009). Another comprehensive summary of FFS results suggested that all treatments were relatively effective at moderating modeled fire behavior (Stephens et al., 2009).

Congress has taken several steps to increase the pace and scale of fuel reduction thinning treatments on lands managed by the USFS across the western U.S. The Healthy Forest Restoration Act passed by Congress in 2003 streamlined planning processes (Pub. L. 108–148; Radmall, 2004). In 2009, Congress authorized the Collaborative Forest Landscape Restoration Program (CFLRP), which provides augmented funding for thinning to reduce fuels and restore forest resiliency to high priority national forest landscapes managed by the USFS (CFLRP; Pub. L. 111–11; Butler et al., 2015). Although the area of western U.S. national forest land treated by mechanical thinning has increased in recent decades, prescribed fire applied to national forests has remained flat over the last 20 years due to shortfalls in agency capacity, regulatory constraints on smoke production, and risk-averse agency culture (Kolden, 2019; Engebretson et al., 2016; Quinn-Davidson and Varner, 2012). If both thinning and prescribed fire are necessary to moderate future wildfire behavior, it may be difficult if not impossible for fuel treatments to influence fire behavior at the landscape scales envisioned by Congress (Vaillant and Reinhardt, 2017; North et al., 2015; North et al., 2012).

In this paper, we report results from long-term monitoring of a typical dry forest fuel reduction project on USFS lands in the southern Blue Mountains of Eastern Oregon. The southern Blue Mountains is one of 23 high-priority CFLRP areas that receives augmented funding from Congress to accelerate the pace and scale of forest restoration. Between 2012 and 2020, over \$17 million has been invested to mechanically thin ~87,000 ha across the 220,000 ha CFLRP area. Less than one-fifth of the area treated with mechanical thinning in the southern Blues has also been treated with prescribed fire. Treating mechanically thinned areas with prescribed fire has been significantly slowed by budget constraints, regulatory restrictions on smoke production, local opposition to fire use, and restrictions on burning imposed by COVID-19 response measures (Zhou et al., 2021; Engebretson et al., 2016; Quinn-Davidson and

Varner, 2012).

The objective of this study was to determine if mechanical thinning without a followup prescribed fire treatment moderated modeled wildfire behavior. Like most stands that have been thinned in the southern Blue Mountains, the thinned stands we studied had experienced post-thinning fuel treatments that are typical of forest restoration activities, including hand or machine piling of activity fuels and burning of piles. But follow-up prescribed fire that is planned to occur across treated stands had not yet been applied at the time of this writing. To determine if typical thinning treatments in the absence of prescribed fire were still effective at moderating fire, we used a well-tested fire behavior model to simulate wildfire effects in these stands under different weather and fuel moisture scenarios. Ground and surface fuel loadings play a critical role in wildfire behavior in ponderosa pine forests (Keane, 2013), and so we also created statistical models of changes in individual ground and surface fuel components (hereafter surface fuels for simplicity) in thinned stands in order to better understand drivers of modeled changes in fire behavior.

2. Methods

2.1. Study area

We collected and analyzed data from the Marshall Devine planning area, the first fuel reduction thinning project completed in the southern Blue Mountains using CFLRP funds (Fig. 1). The 13,841 ha Marshall Devine planning area is one of 28 different planning areas within the southern Blues CFLRP area where thinning activities are analyzed in environmental assessments or environmental impact statements prepared pursuant to the National Environmental Policy Act (NEPA). The Marshall Devine planning area is located on the northern edge of the Great Basin and climate is semi-arid continental. Thirty-year average precipitation was 612 mm, 80% of which fell between November and May, mostly as snow. December and January are the coldest months with an average temperature of -3.3°C . The hottest months are July and August, with an average temperature of 17.4°C (PRISM, 2020). Lightning ignitions associated with summer convective storms are common (Rorig and Ferguson, 1999). Before the adoption of fire exclusion policies in the late 1800s, mean fire return intervals within the Marshall Devine planning area were approximately 11 years (Johnston et al., 2017).

The Marshall Devine planning area is characterized by gently rolling hills. Elevations range from 1,433 to 2,012 m. The area is dominated by ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) with scattered western juniper (*Juniperus occidentalis* Hook.) in the understory. Common understory shrubs include mountain mahogany (*Cercocarpus ledifolius*), bitterbrush (*Purshia tridentata*), sagebrush (*Artemisia tridentata*), and snowberry (*Symphoricarpos albus*), along with dozens of species of native perennial grasses and forbs. The entire area was heavily logged as part of the Bear Valley Timber Sale, which removed $>2 \times 10^6 \text{ m}^3$ of old-growth ponderosa pine timber between 1928 and 1968 (Cox, 2010; Langston, 1995). USFS records indicate limited cutting occurred between 1983 and 1997 in many of the stands we studied (USDA, 2012).

As a result of fire exclusion and past logging that primarily targeted older trees, prior to thinning most forested stands in the Marshall Devine planning area were characterized by dense stands of 90- to 130-year-old ponderosa pine, with scattered older (>250 year old) trees. Before thinning, stand basal area ranged from 35 to 46 $\text{m}^2 \text{ ha}^{-1}$. Mechanical thinning treatments completed between late summer of 2014 and spring of 2015 removed 85,000 m^3 of sawlogs across 2,900 ha. In all stands we studied, trees up to 53 cm diameter at breast height (DBH) were removed until residual stand basal area was reduced to between 11.5 and 16 $\text{m}^2 \text{ ha}^{-1}$ (USDA, 2012). Thinning was accomplished using cut to length or whole tree yarding systems. Trees smaller than commercial size were removed by hand crews following commercial thinning. Some non-commercial material was removed and sold for fuel. As in the case

Table 1

Number of Forest Vegetation and Fuels (FVF) plots measured from 2014 to 2019 in ponderosa pine forests in the Marshall Devine planning area.

Stand ID	Treatment	2014	2015	2016	2017	2018	2019
MDE006	Thin	8	7	7	7	7	8
MDE018	Thin	11	11	11	11	11	11
MDE049	Thin	7	7	7	7	7	7
MDE094	Thin	13	–	13	–	13	13
MDE992	Control	–	–	–	–	4	–
MDE993	Control	–	–	–	–	2	–
MDE994	Control	–	–	–	–	3	–
MDE995	Control	5	–	–	–	5	–
MDE997	Control	3	–	–	–	2	2
MDE998	Control	15	–	–	–	9	5
MDE999	Control	–	–	–	–	4	4
	Total Thin	39	25	38	25	38	39
	Total Control	23	0	0	0	29	11
	Total	62	25	38	25	67	50

with almost all similar restoration projects, much of the remaining non-commercial material was hand or machine piled and the piles burned a year or two after thinning. Prescribed broadcast burning across the entire surface of treatments units was planned for all Marshall Devine treatments units, but as of this writing, no prescribed fire has been completed in the stands we studied.

2.2. Field data collection

Data were collected as part of the Southern Blues CFLRP Forest Vegetation and Fuels (FVF) multi-party monitoring program (Johnston et al., 2021). Between 2014 and 2018, the FVF program established 511 long-term monitoring plots throughout the Southern Blues CFLRP area. Monitoring plots were established by randomly selecting thinned stands within different NEPA planning areas. Circular plots 0.1 ha in size were systematically located approximately 150–250 m apart within thinned stands. Control plots were also located in untreated stands that are 1) within the same NEPA planning area as treated stands; 2) keyed to the same plant association as treated stands; 3) have similar stand density index (SDI) as treated stands before thinning (± 15 SDI); and 4) were of similar slope, elevation, and aspect. Plots in treated stands are measured once before thinning, and both treatment and control plots are remeasured following thinning as funding, monitoring priorities, and other exigencies (e.g., large wildfires) allow.

A total of 62 FVF plots—39 plots in thinned stands and 23 plots in control stands outside of thinned stands—were located in the Marshall Devine planning area in the summer of 2014 immediately before thinning began. Distance between plots in these treatment areas was 150 m apart, and resulted in a similar sampling intensity as the FFS sampling design. Most treatment plots were remeasured in the summer of 2015 after thinning was completed and in subsequent years until 2019. Most control plots were remeasured in 2018. A total of 7 control plots could not be relocated or were judged unsuitable for remeasurement in 2018 because of damage from off-highway vehicle use or grazing activities. To compensate for the loss of these control plots, we located an additional 13 control plots in nearby unthinned stands (Table 1). We were unable to establish more than 13 additional control plots to match the number of thinned plots because of a lack of extensive unthinned stands similar in characteristics to thinned stands. All plots were measured within 20 days of the time of the initial measurement in the summer so that time of year did not significantly influence fuel characteristics (for instance, the height of live herbaceous fuel).

Within each plot, FVF monitoring crews recorded the species of trees and took a number of measurements of trees within plots (e.g., diameter, height, and height to fine aerial fuels) as well as plot-scale overstory tree characteristics (e.g., plot canopy closure and stand structure). We tallied 1-, 10-, 100-, and 1,000-hour (<0.6 cm, 0.6 to 2.5 cm, 2.5 to 7.6 cm, >7.6 cm) woody fuel particles along two 18.3 m transects extending

from plot center (Brown, 1974). We measured the depth of litter and the depth of duff at three points along each transect. Litter consisted of all detached and dead leaves, cones and bark scales (the vast majority of litter was ponderosa pine needles). Duff consisted of partially decomposed litter found between the lower layer of litter and mineral soil. We estimated live understory vegetation fuels using the photoload sampling technique in two 1-m² microplots located along each transect (Keane and Dickinson, 2007). Finally, we recorded understory species composition and ground cover (bare dirt, litter, etc.) at 25 points along each transect (Herrick et al., 2005). Our surface fuel data collection along transects represents approximately half the transect length per area of treatment unit as the FFS (see Section 1). Test plots undertaken prior to field data collection indicated that doubling the length of transects did not significantly reduce confidence intervals for estimates of surface fuels, and also resulted in significant trampling of vegetation within plots that hampered collection of detailed understory vegetation, which was also of interest as part of the broader study.

Woody fuels were converted to surface fuel loading using the equations found in Brown (1974). Litter and duff measurements were converted to surface fuel loading using depth-to-weight coefficients for ponderosa pine litter from the Sierra Nevada found in van Wagtenonk et al. (1998). We confirmed these coefficients produced accurate depth-to-weight conversions for our study area by measuring the depths of litter and duff at 11 randomly selected sites outside of plots, removing that material from the field, kiln drying these samples to remove moisture, and weighing samples.

2.3. Fire behavior modeling

The timing and location of plot measurements permitted several different comparisons of modeled fire behavior over time in response to thinning. First, we compared modeled fire behavior between thinned stands and unthinned control stands in 2018, the year when all FVF thinning and control monitoring plots in the Marshall Devine planning area were measured. Second, we compared modeled fire behavior within thinned stands in 2014 before thinning occurred and in every subsequent year between 2015 and 2019 after thinning was completed. For the purposes of fire modeling, we averaged all plot measurements within each stand where we collected data, reasoning that fire spread, crown fire potential, and other modeled fire behavior outputs were most interpretable at a stand scale.

We modeled fire behavior using the Fuel Characteristic Classification System (FCCS) version 3.0, part of the Fuel and Fire Tools software application (FERA, 2020; Ottmar et al. 2007). At the time of our analysis, the FCCS modeling environment contained 216 fuelbeds representative of vegetation conditions across the U.S. We modified the ponderosa pine-high density (fuelbed #211) and ponderosa pine-post thin (fuelbed #212) with field-collected surface fuel loading and canopy and understory characteristics to create custom fuelbeds for each Marshall Devine treatment and control stand in each year plots within each stand were measured. To characterize potential differences in fuel moisture, we developed custom environmental moisture scenarios from historical weather data covering the length of the study period (2014–2019). We calculated 80th, 90th, 95th and 99th percentile historical fuel moisture characteristics for each fuel component. We also ran FCCS using sustained wind speed scenarios of 8, 16, and 24 kph, which wildland fire reports we examined suggested were moderate, high, and very high sustained wind speeds typically encountered in the course of recent (last 12 years) wildfire suppression operations in the southern Blue Mountains. For each combination of fuel moisture and wind speed, we calculated the following surface fire behavior outputs for each stand in each year: Fire rate of spread (m per minute), flame length (m), and reaction intensity (watts m²).

FCCS also output “crown fire initiation” and “crown-to-crown transmissivity,” which estimate the potential for torching of the canopy and fire spread through the forest canopy respectively. At the time of this

Table 2

Percent difference in FCCS fire behavior outputs between thinned stands and control stands in 2014 and in 2018.

	2014			2018		
	Thin	Control	Difference thin-control	Thin	Control	Difference thin-control
Rate of spread (m/min)	5.02	4.97	−1%	4.24	6.07	43%
Flame length (m)	1.39	1.46	5%	1.32	1.66	26%
Reaction intensity (W m ²)	9978	9249	−7%	8277	9423	14%

writing, FCCS does not support customization of environmental conditions (fuel moisture and windspeed) for crown fire potential outputs as it does for surface fire behavior. Both crown fire initiation and crown-to-crown transmissivity are reported as a relative index from 0 to 9, with 0 indicating no potential for crown fire and 9 indicating total consumption of overstory tree canopies.

Supplementary materials summarize total surface fuel loading data (S.1) provide detail about FCCS inputs and FCCS model runs (S.2), and development of moisture scenarios (S.3).

2.4. Statistical models of surface fuel loading

We created models to evaluate change in the surface fuel loading response over time in thinned stands using a linear mixed model with measurement year as a fixed effect, forest stand where plots were located as a random effect, and a first-order auto-correlation term to account for repeated measurements. While FCCS fire behavior modeling results were evaluated at the scale of forest stands (model inputs were averaged across plots), in statistical models we used individual 0.1 ha circular plots as sample units to increase power to detect change in individual fuel components. We modeled six different surface fuel responses: 1) Fine down wood, which included woody fuel particles from 0 to 7.6 cm in diameter (1-, 10-, and 100-hour fuels); 2) litter; 3) live surface fuels; 4) all fine surface fuels, which combined fine down wood, litter, and live surface fuels; 5) duff; and, 6) all surface fuels including woody fuel particles of any size, litter, live surface vegetation, and duff. Surface fuel

responses 1, 2, 3, and 4 represent changes in flashy fuel components with low heat residence times that combust rapidly and contribute to fire spread. Surface fuel responses 5 and 6 represent change both to flashy fuel components that contribute to fire spread and duff and large woody particles (>7.6 cm diameter) that release energy over time periods ranging from seconds to days (Prichard et al., 2017; Battaglia et al., 2008).

All models were implemented using the *nlme* package in R (Pinheiro et al., 2020; R Core Team, 2020). During preliminary analyses, we tested a variety of biophysical (e.g., elevation and heat load) and vegetation (e.g., plant association group) variables as potential predictor variables. However, none of these terms had any meaningful predictive power, probably because plots were quite similar with respect to vegetation (all ponderosa pine plant associations), elevation (min = 1,530 m, max = 1,678 m, mean = 1,599 m), slope (min = 0%, max = 15%, mean = 4%), and aspect (generally flat or situated on a gently sloping hill). We examined diagnostic plots and log transformed the woody fuel particle response to stabilize variance in model residuals.

The stakeholders and managers with whom we developed this research are interested in the magnitude of the effect of treatment vs. no treatment and/or time since treatment. To ensure the relevance of our results to end users (Keeler et al., 2017), we considered time since thinning to have a significant effect when 95% confidence intervals for the estimated mean surface fuel response between years did not overlap. This approach ensures that managers and stakeholders have confidence that there is large and meaningful change in fuel loading and not simply that there is weak evidence against a null hypothesis, although we also provide traditional measures of statistical significance (i.e., *p*-values) in model results (Wasserstein et al., 2019).

3. Results

3.1. Fire behavior modeling

There was little difference between modeled fire rate of spread, flame length, and reaction intensity in thinned stands and control stands in 2014 before thinning was completed. By 2018, four years after thinning was completed, rate of spread, flame length, and reaction intensity were 43%, 26%, and 14% greater respectively in unthinned controls than in thinned stands (Table 2). FCCS model runs of thinned stands under different fuel moisture and wind scenarios from 2014 to

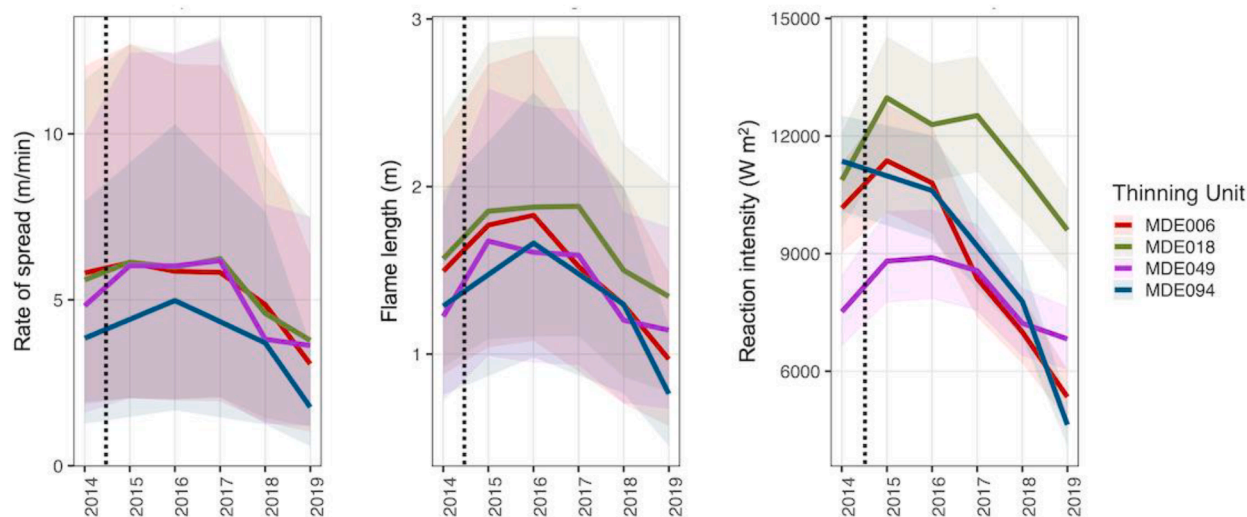


Fig. 2. Modeled fire behavior in thinned Marshall Devine stands in 2014 (prior to thinning) and for five years after thinning was completed (2015–2019; thinning is indicated by the dotted line). Solid lines indicate mean values for each thinned stand for each fire behavior metric over all modeled wind speeds (8–24 kph) and fuel moisture scenarios (80th to 99th percentile fuel conditions). Transparent ribbons indicate the full range of values for each metric for all wind speed and moisture scenarios.

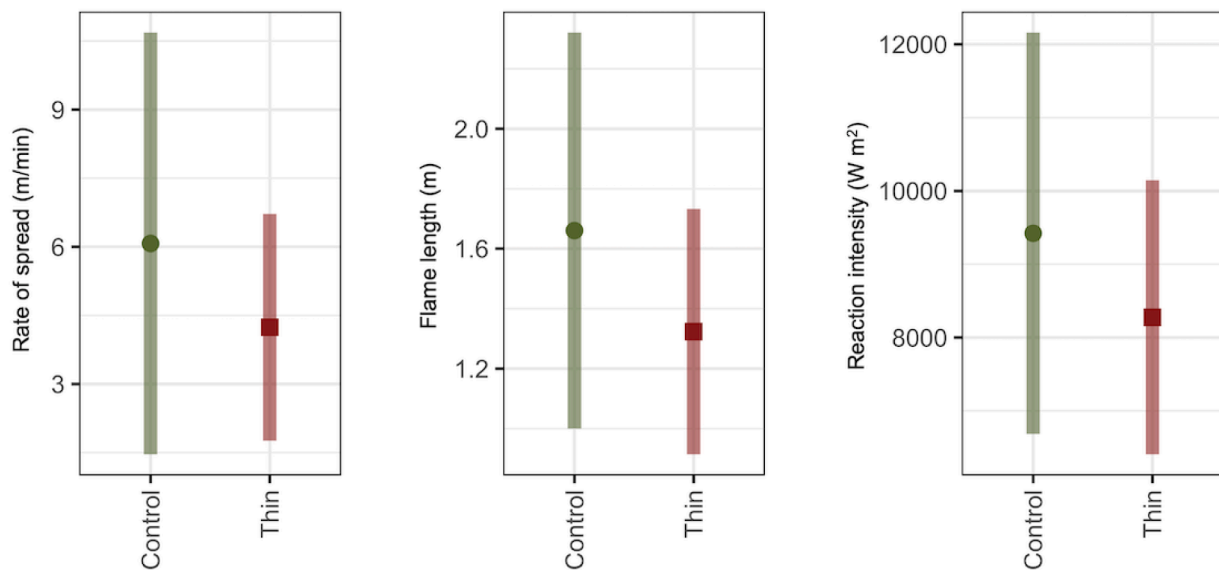


Fig. 3. Modeled fire behavior for control stands and thinned stands in 2018, the year where all plots were measured. Points indicate mean values over all wind speed and moisture scenarios. Lines indicate the full range of values for each metric for all wind speed and moisture scenarios.

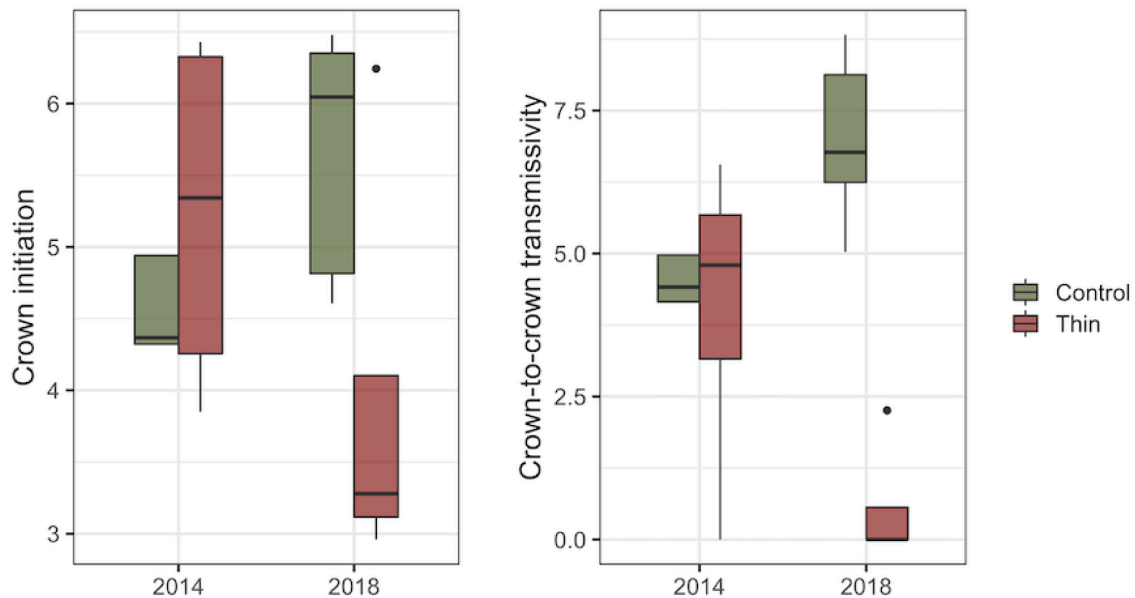


Fig. 4. Crown fire potential modeled in FCCS in thinned stands and unthinned controls in 2014 before thinning began and in 2018 four years after thinning had been completed. FCCS outputs crown fire potential (the y-axis) as a dimensionless index from 0 to 9.

2019 showed an increase in modeled fire behavior outputs for 2 to 3 years following thinning followed by sharp declines (Fig. 2). Mean surface fire rate of spread in thinned stands across wind/moisture scenarios increased by 23% immediately following thinning and did not decline to below the pre-thinning rate until 2018. By 2019, the mean rate of spread across moisture/wind scenarios was 39% lower than the pre-thinning rate. Mean flame length across thinned stands and wind/moisture scenarios increased by 27% immediately following thinning and did not decline to below pre-thinning flame length until 2018. By 2019, average flame length was 24% lower than the pre-thinning flame length. Mean reaction intensity across thinned stands and wind/moisture scenarios increased by 11% immediately following thinning but declined to below the pre-thinning rate by 2017 and was 34% lower than pre-thinning levels by 2019. In 2018, when all control and thinning plots were measured, mean rate of spread, flame length, and reaction intensity were all higher in control stands than in thinned stands (Fig. 3).

There was little difference between modeled crown fire potential indexes in thinned stands and unthinned controls in 2014 before thinning began. In 2015, immediately following thinning, crown initiation potential increased by 30%. By 2016, crown initiation potential was 16% less than before thinning began and remained 16–20% lower than pre-thinning crown initiation potential from 2017 to 2019. The crown-to-crown transmissivity index declined to nearly zero immediately following thinning and remained near zero over the time period analyzed. There was little difference in crown fire potential between thinned stands and unthinned stands before thinning began in 2014, but by 2018 there was far less potential for crown fire in thinned stands (Fig. 4).

3.2. Statistical models of surface fuel loading

Mean total fine surface fuel loading was estimated to be 10.3 Mg

Table 3

Results of statistical models of surface fuel loading over time.

Fine surface fuel loading					
Year	Fuel loading (Mg ha ⁻¹)	SE	Lower CI	Upper CI	p
2014	10.3	1.0	7.3	13.4	<0.01
2015	15.7	1.6	10.6	20.8	<0.01
2016	16.2	1.5	11.3	21.0	0.01
2017	13.3	1.4	9.0	17.7	<0.01
2018	11.4	1.1	8.0	14.9	<0.01
2019	9.8	0.9	6.9	12.8	<0.01

Total surface fuel loading					
Year	Fuel loading (Mg ha ⁻¹)	SE	Lower CI	Upper CI	p
2014	67.1	8.6	39.8	94.4	<0.01
2015	33.1	4.6	18.5	47.8	0.01
2016	40.2	5.2	23.7	56.7	<0.01
2017	32.7	4.6	18.2	47.3	0.01
2018	27.6	3.5	16.3	38.9	<0.01
2019	17.6	2.2	10.4	24.7	<0.01

ha⁻¹ in 2014 before thinning began and increased to a mean of 16.2 Mg ha⁻¹ in 2016 before declining to 9.8 Mg ha⁻¹ in 2019. The increase in the two years following thinning was marginally significant, although 95% confidence intervals for total fine surface loading estimates overlapped in other years and thus provide no evidence of a significant change in fine surface fuel loading between stands before they were thinned and in the last several years of our study. There was evidence of a significant decline in total surface fuel loading over time. Total mean surface fuel loading was estimated to be 67.1 Mg ha⁻¹ in 2014 before

thinning but had dropped to 17.6 Mg ha⁻¹ by 2019. This large decline was mostly attributable to significant declines in litter and duff fuel loading, which constituted a large proportion of total surface fuel loading. Fine surface fuels (small woody particles, litter, and live vegetation) increased immediately following thinning in 2015 due to an increase in fine woody particles from logging and declined to pre-thinning levels by 2019 as litter and duff fuel loading declined. Live surface vegetation was a minor component of total surface fuel loading that exhibited little change over time (Table 3 and Fig. 5).

4. Discussion

4.1. Fire and fuel loading dynamics following thinning

Significant declines in modeled surface fire behavior in thinned stands after 2–3 years following thinning provide strong evidence that mechanical thinning followed by typical post thinning fuel treatments including pile burning but without prescribed fire can moderate fire behavior. Modeled crown fire potential declined immediately following thinning, undoubtedly due to significant reductions of ladder fuels that carry fire into the crown and crown density that facilitates spread between crowns. Fig. 6 illustrates the dramatic reduction in amount and continuity of aerial fuels in our study area following thinning. Contrasts between thinned and unthinned controls also provide evidence that thinning in the absence of prescribed fire moderates modeled fire behavior. Thinned and unthinned stands were very similar with respect to modeled fire behavior in 2014 before thinning began. Four years after thinning, all modeled indexes of fire behavior had declined markedly in

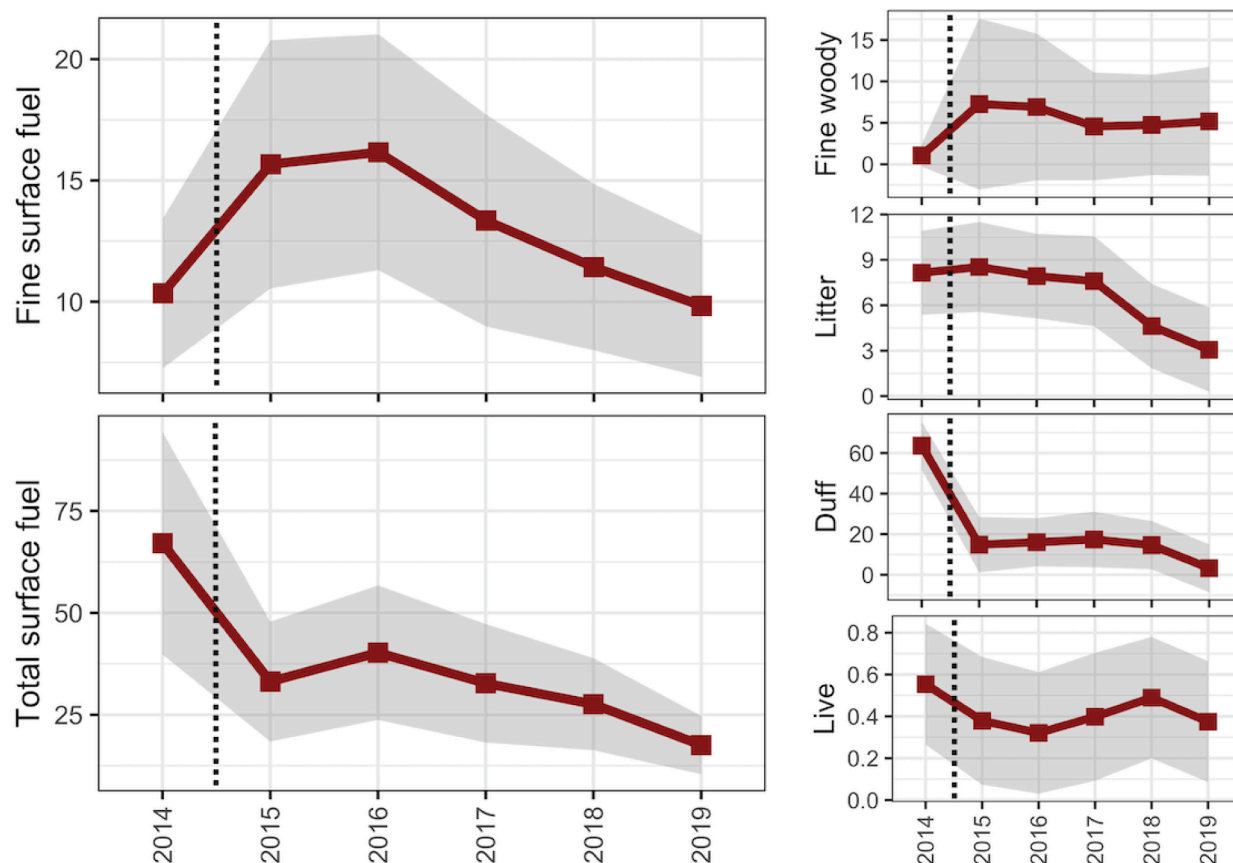


Fig. 5. Changes to surface fuel loading following thinning (indicated by dotted black line). Solid lines and points indicate estimates of mean surface fuel loading from statistical models. Transparent ribbons indicate confidence intervals ($\alpha = 0.05$) for estimates. Fine surface fuel = 1-, 10-, and 100-hour woody particles (0–7.6 cm diameter), litter, and live surface vegetation. Total surface fuel = 1-, 10-, 100-, and 1000-hour woody particles, litter, duff, and live surface vegetation. Fine woody = 1-, 10-, and 100-hour woody particles (0–7.6 cm diameter) (fine woody fuel loading is back-transformed from the log scale). Live = live rooted understory vegetation (shrubs, forbs and herbaceous plants). Unit of measurement for all panels = Mg ha⁻¹.



Fig. 6. Changes to overstory structure as a result of thinning. Marshall Devine thinning unit prior to thinning in 2014 (Panel A). The same view in 2019 five years after thinning (Panel B).

thinned stands but remained high in unthinned stands. In fact, modeled fire behavior was typically higher in unthinned controls in 2018 than in 2014. This may reflect inconsistency in measurements of control stands—we did not remeasure 7 plots in 2018 that were measured in 2014 and we established 13 new control plots that had not previously been measured. However, there was mortality of ponderosa pine from western pine beetle (*Dendroctonus brevicornis*) in many unthinned controls between 2014 and 2018 that often exceeded 25% and was sometimes in excess of 50%, which added fine fuels to the forest floor and left many trees that were alive in 2014 with red needles highly conducive to crown fire (Schoennagel et al., 2012). Although we did not explicitly test for the effects of pine beetle, we noted <5% mortality (mean < 1%) in all thinned stands. It is possible that increased tree vigor associated with thinning has the added benefit of moderating fire behavior relative to unthinned stands. Previous studies have shown that mechanical thinning is associated with increased radial growth, which in turn confers resistance to fire damage and insect attack (Tepley et al., 2020; Van Mantgem et al., 2020; Vernon et al., 2018).

Changes in individual surface fuel components in response to thinning varied among fuel components. As should be expected from felling trees, thinning operations increased the amount of woody fuel particles on the forest floor. Although confidence intervals for estimates of fine woody fuel particles mostly overlapped because of variability in fuel loading among plots, the four-fold increase in mean 1-, 10-, and 100-hour surface fuel loading that we measured likely had a meaningful effect on modeled and actual fire behavior. But this increase in surface fuel and modeled fire behavior was offset by a steady decline in litter and a dramatic decline in duff over time (Fig. 5). Litter fuel, composed almost entirely of ponderosa pine needles in our study area, is highly

flammable and a major contributor to fire spread, particularly in hot and dry conditions (Varner et al., 2015).

It is possible that observed declines in litter and duff are due to measurement error. Consistent and accurate estimates of litter and duff fuel loading are often difficult because of inconsistent delineation of litter and duff layers and imprecisions inherent in measurement of a shallow (0–60 cm) surface strata (Westfall and Woodall, 2007). However, we do not believe that observed declines in litter and duff are due to measurement error for three reasons: First, although we used different crews in different years, the same personnel applied the same training techniques for measuring litter and duff to each crew. Second, the same crews working in the same year observed significant differences in litter and duff fuel depths between thinned and unthinned stands consistent with our observations of a decline in litter and duff in thinned stands over time. Third, different crews working in different years in FVF plots outside of Marshall Devine stands, but in similar forest types, made observations of litter and duff fuel depths in thinned and unthinned stands that were consistent with our observations in Marshall Devine stands. Finally, we note that although our statistical models estimated changes in total litter and duff fuel loading, FCCS takes litter and duff inputs of depth and percent cover. While entering a total loading was optional, we chose to use the FCCS internal calculations in order to maintain consistency with other FCCS calculations. Although there may be error associated with measuring depth, our measurements of percent cover of litter along transects were straightforward and unlikely to be consistently biased.

We believe that the decline in duff fuel loading we observed following thinning is attributable to surface disturbance associated with ground-based logging which resulted in mixing of the duff layer with

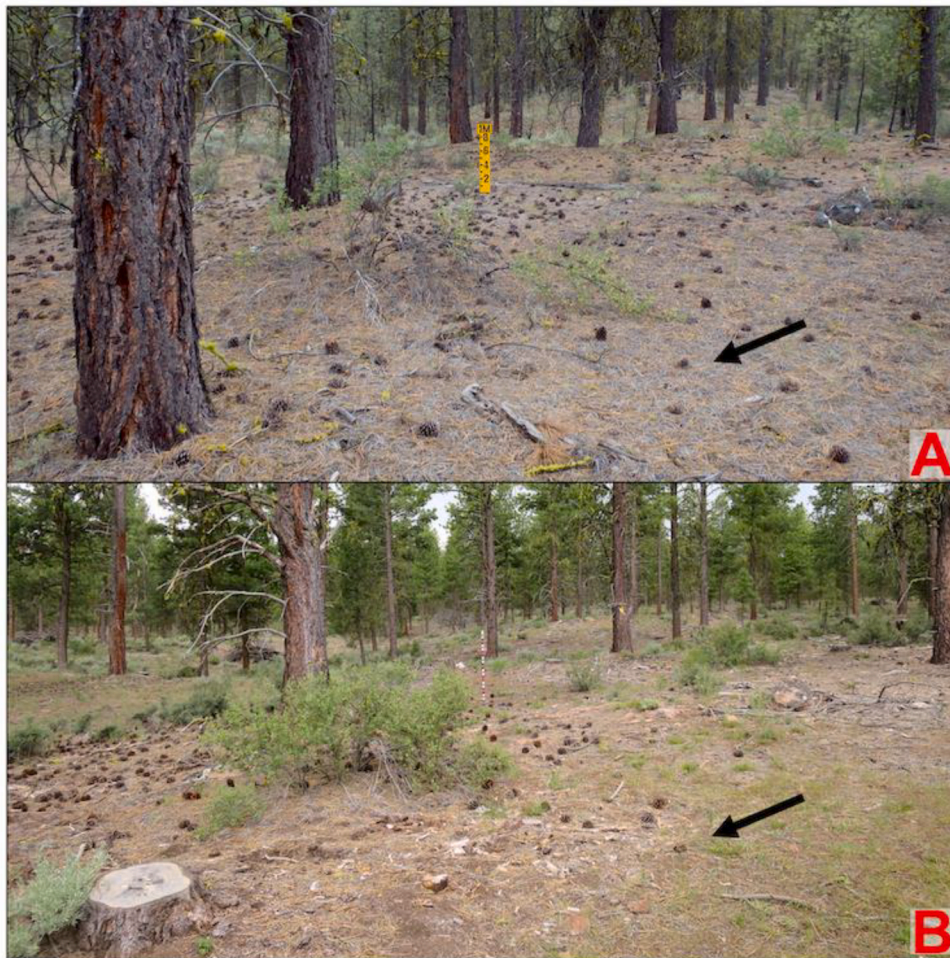


Fig. 7. Changes to litter and duff fuel loading following thinning. Marshall Devine thinning unit prior to thinning in 2014 (Panel A). The same view in 2019 five years after thinning (Panel B). Arrows point to examples of significant changes in litter and duff structure. Litter depth across Marshall Devine treatment units averaged 2.9 cm in 2014 and 1.6 cm in 2019. Duff depth across Marshall Devine treatment units averaged 4.7 cm in 2014 and 0.4 cm in 2019. Duff and litter layers were continuous across Marshall Devine treatment units prior to thinning, but patchy and less continuous following thinning.

mineral soil sufficient to make it less combustible. Our direct observations in the field also suggested that surface disturbance aerated duff and exposed it to increased solar radiation sufficient to accelerate decomposition (Zhang et al., 2010). We attribute the steady decline in litter over time to these same factors as well as decreased deposition of needles after overstory removal (Keane, 2008). These hypotheses are consistent with previous research that demonstrates that litter accumulation is correlated with canopy cover and sensitive to solar radiation and temperature (Nunes Biral et al., 2019; Hall et al., 2006). Examination of repeat photographs of plots lends support for our theory that significant reductions in litter cover were associated with canopy removal (Fig. 7).

4.2. Management implications

This study demonstrates that thinning in the absence of prescribed fire is effective at moderating modeled crown fire potential immediately following thinning and can moderate modeled surface fire behavior for a number of years after a relatively short period (1–3 years) of elevated surface fire behavior. We found no difference in modeled fire behavior or a difference in surface fuel loading between stands thinned using a cut to length logging system versus stands thinned using whole tree logging systems. Different logging systems have the potential to produce different quantities of woody fuels, but post-thinning fuel management treatments (piling and burning of slash) likely helped to reduce woody fuel loading across thinned stands within one to two years following thinning. We observed an increase in woody fuel loading following treatment followed by a slight decline in woody fuel within two years,

which is consistent with piling and burning of woody fuels (Fig. 8). But the majority of surface fuel loading decline that we observed following thinning was attributable to declines in litter and duff loading (Fig. 5).

It is likely that the observed trend of significantly declining surface fuel loading and significantly moderated modeled fire behavior will continue for a number of years as fine woody fuel particles decompose. Although we show that thinning in the absence of prescribed fire moderates modeled fire behavior for a number of years, prescribed fire is still an important tool for accomplishing fuel reduction and fire management objectives in ponderosa pine forests of the southern Blue Mountains and elsewhere (Mitchell et al., 2009). Prescribed fire is likely to be effective at extending the longevity of treatments in thinned stands at some point in the future when the trend towards decreasing surface fuel loading is reversed and surface fuel loading begins to exceed desired thresholds (Kalies and Yocom Kent, 2016).

Previous research suggests that conifer regeneration is a primary driver of increased fuel loading and fire hazard following thinning in ponderosa pine and Douglas-fir forests (Hood et al., 2020; Battaglia et al., 2008). We observed very little regeneration in Marshall Devine stands following thinning until 2019 (following a mast year in 2018) when we recorded an average of 8,700 seedlings ha^{-1} . In the course of previous studies in the area we observed significant seedling mortality following drought from 2012 to 2015 and it remains to be seen if trees established in 2019 thrive. Our observations of recent Marshall Devine regeneration patterns and past growth and establishment research in the area suggest that there will be irregularly distributed patches of ≥ 1 m tall ponderosa pine within thinned stands across the Marshall Devine area in approximately 12–20 years following thinning. It may be



Fig. 8. Post-thinning fuel treatment (piling and burning) resulted in reductions in woody fuels. Marshall Devine thinning unit prior to thinning in the summer of 2014 (Panel A). The same view after thinning with activity fuels piled in the summer of 2015 following thinning (Panel B). The same view in 2019 (Panel C). Piles were burned in winter or spring of 2015–2016.

difficult to reliably kill seedlings taller than this height with flame lengths typical of prescribed fire operations (Battaglia et al., 2008). This suggests that prescribed fire 10–18 years after thinning may be the most efficient way to accomplish fuel reduction objectives in our study area. This hypothesis should be validated by continued monitoring of thinning treatments and experimentation with different prescribed fire management regimes (Stephens et al., 2012).

We do not assume that mechanical thinning in the absence of prescribed fire will moderate fire behavior for many years following thinning across the southern Blue Mountains or at other sites across the western U.S. Our study area was a relatively low productivity site near the edge of the range of ponderosa pine with significant evapotranspirative demands on trees, particularly seedlings. As noted above, regeneration of conifers in the stands we studied lagged ground-based logging disturbance by many years and we anticipate that conifer regeneration will not be well established for at least another five years (Kolb et al., 2020). We observed little shrub response to overstory removal and logging disturbance in the stands we studied. In moister

and more productive sites we would anticipate significant regeneration of fast-growing grand fir in response to thinning. Other sites may see significant growth of shrubby species following thinning, which would contribute to live surface fuel loading in a relatively short amount of time following thinning. It is likely that the results we report here are applicable to other low productivity ponderosa pine sites across western North America, but are likely to be less applicable to more productive sites or sites with a significant shrub response to mechanical disturbance. We urge decisions about the timing of prescribed fire to be based on careful consideration of site conditions informed by ongoing monitoring.

5. Conclusion

Previous research (e.g., Raymond and Peterson, 2005; Waltz et al., 2003) indicates that reintroduction of fire following thinning is necessary to reduce fine surface fuel loading. But in dry ponderosa pine forests of the southern Blue Mountains of Eastern Oregon, we show that overstory tree removal followed by typical post-thinning fuel treatments without prescribed fire is associated with significant reductions in total surface fuel loading and moderates modeled surface fire behavior after an initial 1- to 3-year period of increased fire hazard. These findings provide important validation for investments in mechanical thinning by Congress through the CFLRP and other federal initiatives, and will also inform private and non-governmental landowners as well as tribal, state and local governments. Broad-scale evaluations of the effect of different fuel treatments (e.g., FFS) indicate that fire behavior outcomes may vary as function of site characteristics as well as specific treatment types, i.e., thinning vs. thinning and prescribed fire. The trends we observed over six years also suggests that treatment effects may vary significantly over time. We urge continued monitoring of our study area and other sites across western North America in order to adapt thinning treatments to lessons learned and optimize the restoration value of prescribed fire.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The Beartooth Highway: 2012-2013 Economic Impacts, Use, and Destination Image

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The Beartooth Highway: 2012 -2013 Economic Impacts, Use, and Destination Image



A compilation of three separate studies conducted along the Beartooth Highway with a summary and researcher observations in the introductory pages.

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The Beartooth Highway: 2012-2013 Economic Impacts, Use, and Destination Image

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The purpose of this study was to assess the economic impacts and visitor use of the Beartooth Highway. Until now, little was known about visitors to the Beartooth Highway Region. Data was collected from visitors during the 2012 summer and 2012-2013 winter seasons. In total, over 4,000 summer visitors and 1,600 winter visitors were intercepted during the study.

The Beartooth Highway is a nationally designated “All-American Road” situated in south-central Montana and north-central Wyoming. It spans 68-miles from Red Lodge, MT to the northeast entrance of Yellowstone National Park. Three gateway communities comprise the Beartooth Highway Region during the summer season: Red Lodge, MT, Cooke City/Silver Gate, MT and Cody, WY. During the winter season, Red Lodge, MT is not considered a gateway community because of road closures limiting access only to Cooke City/Colter Pass/Silver Gate, MT and Cody, WY (via the Chief Joseph Scenic Byway). Over 170,000 nonresident travel groups in the summer season and 16,000 nonresident travel groups in the winter season visited the Beartooth Highway Region.

This report is compilation of all reports generated from the study:

1. 2012 Summer economic impacts, use, and destination image report – This report details the summer data collection period and the respective results. Summer data collection began on May 31st and was completed in mid-September.
2. 2012-2013 Winter economic impacts, use, and destination image report – This report details the winter data collection period and respective results. Data collection for winter visitation was mid-December through mid-April.
3. 2013 Qualitative analysis of activity specialization of snowmobilers in Cooke City, MT – In-depth interviews were conducted with snowmobilers in Cooke City, MT during January, 2013. Themes and insights about snowmobiling in the Beartooth Region are compiled, outlined, and examined in this report.



Nonresident visitor expenditures contributed to over \$53 million in economic activity during 2012 summer and 2013 winter seasons. The economic impact for this region from nonresident travelers is substantial to local communities. Furthermore, results identified that nonresidents perceive the Beartooth Highway as a destination in itself, not simply a highway. Visitors came from all 50 states, a majority of Canadian provinces, and a large number of foreign countries including Germany, Australia, China, Chile, and New Zealand. For image attributes, nonresident travelers have a very positive perception of the Beartooth Highway. Scenic vistas, natural qualities, the relaxing feel, and abundance of activities are the most enjoyable aspects to visitors. Furthermore, the highway is perceived as more than a “road to Yellowstone National Park.” In fact, 32 percent of summer travelers visited the highway simply because of its designation as a national scenic byway. These results solidify the area as a destination in itself.

In terms of recreation, visitors participate in a wide range of activities from wildlife watching to snowmobiling to fly fishing throughout the year. Over half of the visitors to the region have previously visited, while first-time visitors comprise just under half of the sample. Interestingly, this suggests that there is not only a draw for visitors to return to the area, but unique aspects exist that continue to draw people back to the area.

Qualitative results indicated that snowmobilers appear to be very connected to the activity and the opportunities for satisfaction the activity provides. The amount and quality of snow in the region are the most driving factors influencing the travelers’ intention to visit. The Beartooth Region generally possesses the right conditions along with the amenities needed for this user group. However, there does not appear to be a strong sense of connection towards the place itself. For stakeholders, this indicates that promotion of the terrain and conditions of the region are critical. Furthermore, snowmobile users appear to enjoy the sense of “camaraderie” present in Cooke City, MT. However, winter visitors who were not snowmobilers felt a sense of exclusion while in Cooke City, MT. Because of this, there appears to be potential conflict between motorized and non-motorized users. It should be noted that non-motorized users still enjoyed their visit to the Beartooth Region.

Observations from the Researchers

Provided here are a variety of observations and recommendations from the researchers on some of the most relevant issues pertaining to the Beartooth Region. These observations are both data-driven and observational.



- The Beartooth Highway is a unique, but complex region in terms of management. During the study, it appeared to be difficult for visitors to navigate between areas that were managed by different stakeholders. An inclusive process of collaboration between all stakeholders may mitigate these issues observed. Thus, the Beartooth Highway should be looked at as a whole and not as separate parts.
- Yellowstone National Park and the Beartooth Highway share a connection that is unlike many other regions. This connection should be recognized and embraced by all stakeholders in order to provide the best experience for the visitor. It provides an opportunity for visitors to experience different landscapes and activities within the Greater Yellowstone Region.
- Summer visitation consisted of many visitors who were participating in passive activities (scenic driving, wildlife watching, and nature photography). Increasing awareness of the other types of activities available may encourage those visitors to lengthen their trip and participate in an activity outside of their norm.
- During winter, there appears to be a potential conflict between non-motorized and motorized users. Stakeholders in the Beartooth Region need to recognize this conflict and attempt to include all types of visitors into the region. For instance, although snowmobiling is widely popular during winter, the majority of visitors intercepted near Cooke City, MT were also participating in wildlife watching and activities in Yellowstone National Park in conjunction with other activities. Inclusion of these visitors may contribute to increased economic activity during the winter season as well as providing a more welcoming experience for non-motorized users.
- Visitors along the highway noted that signage is the primary need for improvement. A scenic byway is designed to be a “driving narrative” for those who travel. Thus, improvement of signage is a key concern for the visitor experience. As of now, a sign marking the summit of the highway does not exist, which many visitors commented on during intercepts. Improving signage and adding interpretive signs to pullouts would lead to a more fulfilling and informative experience. In our minds, one improper signage does exist: the 70 mph speed limit sign once the traveler entered Montana. For the visitor, this can be confusing and potentially dangerous.



- The economic stability of the Cooke City/Colter Pass/Silver Gate area and of Red Lodge, MT is tied directly to the Beartooth Highway. Cody, WY, on the other hand, needs the Beartooth to prosper economically since it receives the largest amount of summer economic activity, but has the luxury to survive due to the east entrance to Yellowstone. It is clear that the ability of travelers to use the Beartooth Highway is even more important than previously thought. If the highway does not open for a sustained period of time, local residents are losing out on critical expenditures that support their livelihoods. Stakeholders should be cognizant of this and strive to ensure that the highway is open for visitors as soon as possible.
- Winter season in Cooke City/Colter Pass/Silver Gate, MT is a unique situation. Because of limited accessibility to the region, Cooke City, MT transforms into a prime snowmobile destination. For this user group, there are few areas within their driving distance that possess these qualities. However, when snow is 'less than prime' snowmobilers will substitute their destination choice because of snow. Thus, ensuring a good visitor experience is even more important to Cooke City/Colter Pass/Silver Gate than realized. Finally, the touchy idea related to plowing the road from the east into Cooke City needs to consider all aspects. Currently, the 'plug' as locals call the unplowed area creates the uniqueness of the area and probably limits the amount of snowmobile use to what the area can handle. Any decision made about winter access will affect some users and needs to be clearly thought out.

Apart from these recommendations, the Beartooth Highway is an exciting, vibrant, and special place. Visitors to the region appear to be very interested in returning to the area and experiencing its hospitable, relaxing feeling and natural qualities. Preservation of these aspects of the Beartooth Region is of utmost importance. With the help of the stakeholders in gateway communities and other stakeholders, visitors will continue to have memorable experiences in the region.

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The Beartooth Highway: 2012 Summer Use and Image



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Research Report 2013-2

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Executive Summary

The Beartooth Highway is a 68-mile travel corridor that reaches nearly 11,000 feet in elevation with sweeping vistas of snow-covered ridges, high plateau views, lakes and trails. A 54-mile segment of the road is designated as the Beartooth All-American Road, one of only 31 All-American Roads highlighted as the most scenic byways in the United States. No visitor research had been conducted on the Beartooth Highway, therefore, the overall purpose of this report was to investigate traveler characteristics on the Beartooth highway including demographics, residency, activities, image, and travel patterns in the region with the gateway communities of Red Lodge and Cooke City, MT and Cody, WY.

Data was collected from May 31st through the end of September, 2012 at the three entry locations to the Beartooth Highway. A total of 4,267 nonresidents and 485 residents of the local counties were intercepted. Of the nonresidents given a follow-up survey, 1,473 mailbacks were returned (45% response rate).

- From May 31 – September 30th total traffic on the Beartooth highway was 178,904 vehicles. Nonresidents represented 91% of total traffic: 76,147 through YNP NE entrance; 57,727 from Red Lodge; 28,391 from WY highway 296.
- Visitors came from all 50 states (81% of visitors), 7 Canadian provinces (3% of visitors), and 30 foreign countries (5% of visitors with England and Germany the highest numbers).
- 32 percent of visitors primarily traveled the highway because it is a federally designated scenic byway, higher than any other reason for traveling the Beartooth. 54% of all visitors responded that the Beartooth Highway was a main destination.
- On average, nonresident visitors spent 2 nights in the Beartooth Region including Red Lodge, MT, Cooke City/Silver Gate, MT, Cody, WY and along the highway itself.
- 49 percent of the visitors also spent a night in Yellowstone; 27% spent a night in Billings; 25% spent a night in West Yellowstone and 25% spent a night in Jackson, WY.
- 44 percent of nonresidents were traveling the Beartooth Highway for their first time.
- Scenic driving (84%), nature photography (61%), and wildlife watching (58%) were the most common activities along the Beartooth Highway. Repeat visitors were more likely to be wildlife watching, day hiking, camping, birding, and fishing than first-time visitors.
- The most frequently reported visitor motivations for traveling the Beartooth Highway focused around the scenic beauty, natural surroundings, and open space.
- The physical attributes of the highway generally received high marks however visitors were least agreeable to the statement that there were good interpretive signage.
- Emotive responses to traveling the highway show that first-time visitors were more reserved, nervous, stressed, and afraid than repeat visitors.
- The Beartooth Highway gateway communities are perceived in a positive light with Cody, WY receiving the highest marks of the three communities for image and beliefs about the community.
- Resident travel made up 10 percent of the total intercepts. Residents stated that they travel the highway on average 17 times per year.

This study suggests that visitors perceive the Beartooth Region as more of a destination than a travel route to Yellowstone National Park. Continued and enhanced collaboration and funding between gateway communities, YNP, the forest service and the highway departments will ensure success of the highway as an economic contributor to the region and to help preserve the ecosystem for the future.

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Introduction

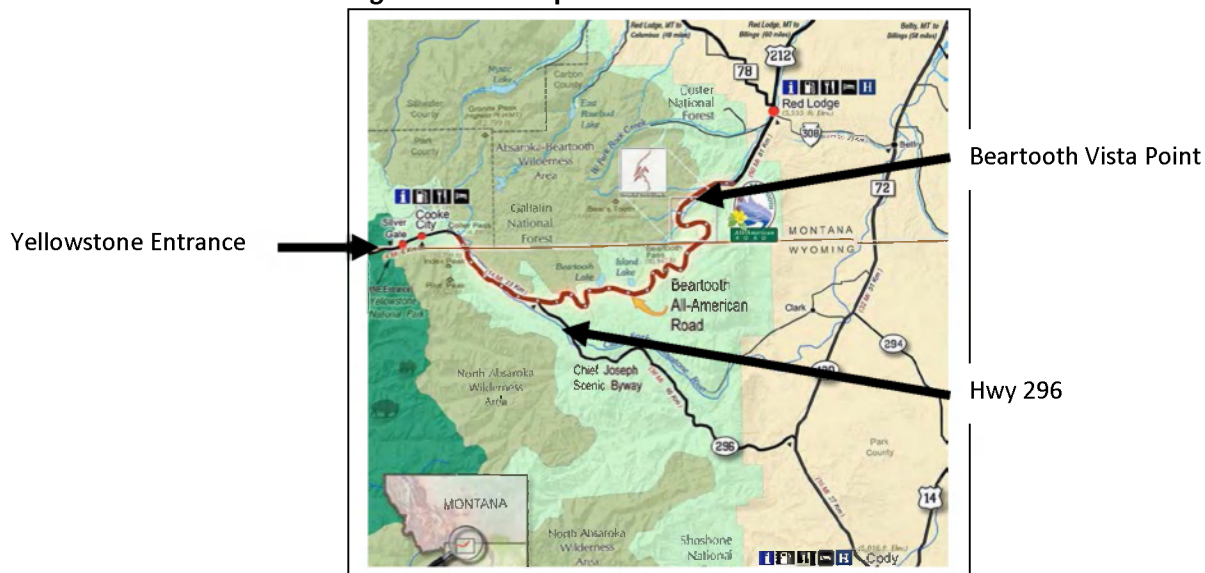
The purpose of this study was to assess the economic impact, traveler characteristic, and destination image of the Beartooth Highway and gateway communities of Red Lodge, MT, Cooke City, MT and Cody, WY. Data was collected from visitors along the Beartooth Highway during the sampling period of May 31st, 2012 to September 21st, 2012. Subsequent results are only from data collected during the summer season. A separate winter portion of the study will represent data from December 15th, 2012 through March 15, 2013.

Methods

This project employed a single method for data collection. Starting on May 31, 2012, visitors were intercepted along the Beartooth Highway (US 212) and asked to participate in a survey about their travel along the Beartooth Highway. Visitors were segmented based on their permanent residency and asked a short set of questions regarding their travels.

Visitors were surveyed at 3 locations along the Beartooth Highway: the northeast entrance of Yellowstone National Park, Rock Creek Vista Point (20 miles south of Red Lodge), and on the Chief Joseph Highway (3 miles south of WY 296 & US 212 junction) (Figure 1). Survey locations were chosen based on their classification as an exit of the Beartooth Highway. Sampling periods consisted of four day intervals every two weeks. Two week intervals were used to avoid intercepting visitors more than once.

Figure 1: Intercept sites



When intercepted, travelers were asked to state their permanent residency. Residents (travelers residing in Park County or Carbon County, MT or Park County, WY) were asked five questions and allowed to proceed on their way. The remaining travelers (nonresidents of the three counties) were asked seven questions and given a mail-back questionnaire with various questions regarding trip

expenditures, perceived destination image, recreation experience, and visitor characteristics. A total of 4,772 travelers were surveyed along the highway. Of the total travelers surveyed, 3,251 mail-back questionnaires were handed out to nonresident travelers and 1,473 completed and returned the questionnaire (45% response rate).

Results

The results are presented in two sections. The first section represents results of the five to seven intercept questions asked of the 4,772 travelers. The total visitation number along the Beartooth Highway is generated from these intercept questions, and the numbers generated from the Montana and Wyoming Departments of Transportation, as well as Yellowstone National Park northeast entrance counts. Responses from both residents of the area and nonresidents are included in this section.

The second section represents results of the longer and more detailed mail-back survey. This section includes an overview of the demographics, trip characteristics of respondents including activities and motivations for traveling the Beartooth, destination image results, gateway community image, and an analysis of the open-ended visitor comments. Throughout this section the results are given in three segments: 1) All travelers; 2) First time visitors to the Beartooth Highway (BTH); 3) Repeat visitors to the Beartooth.

SECTION 1: Intercept Survey Results

This section provides the results of the 5-7 questions answered by all intercepted travelers. It represents 485 residents of the three local counties (Carbon and Park Counties, Montana and Park County, Wyoming). Results represent 3,869 residents of the United States, 156 residents of Canada, and 258 other foreign visitors (Table 1).

To estimate the nonresident proportion of traffic along the Beartooth Highway, both highway counts and actual proportion counts were used. Traffic counters from the northeast Yellowstone entrance gate, the Montana DOT traffic counter at the Beartooth Pass, and a traffic counter set up near the junction of Wyoming 296 and US 12 were used for a full traffic count. Surveyors recorded the ratio of nonresidents to residents during the sampling days. This ratio was applied to the full traffic numbers to generate the nonresident portion of traffic on the Beartooth Highway (Table 1-3).

Table 1: Northeast Gate of Yellowstone National Park Traffic Counts and Nonresident Proportions

	June	July	August	September	All Months
Total Monthly Traffic	16,003	23,504	22,598	17,719	79,824
Average Daily Traffic	533	758	729	591	653
Northeast Gate Nonresident Total	14,899	22,658	21,739	16,851	76,147
Northeast Gate Nonresident Percentage of all traffic	93%	96%	96%	95%	95%

Table 2: WY 296 Traffic Counts and Nonresident Proportions

	June	July	August	September	All Months
Total Monthly Traffic	7,650	10,835	10,370	6,300	35,154
Average Daily Traffic	255	350	335	210	287
WY 296 Nonresident Proportion Total	6,189	8,288	8,389	5,525	28,391
WY 296 Nonresident proportion Percentage of all traffic	80%	77%	81%	88%	82%

Table 3: Red Lodge/Vista Point Traffic Count and Nonresident Proportion

	June	July	August	September	All Months
Total Monthly Traffic Count	12,915	21,359	18,492	11,160	63,926
Average Daily Traffic	431	689	597	372	522
Red Lodge Nonresident Proportion Total	10,849	19,010	17,345	10,524	57,727
Red Lodge Nonresident proportion Percentage of all traffic	84%	89%	94%	94%	90%

Table 4 shows the residence breakdown of visitors along the beartooth highway. Visitors came from all 50 states, 7 Canadian provinces, and 30 foreign countries.

Table 4: Residence of Visitors on the Beartooth Highway

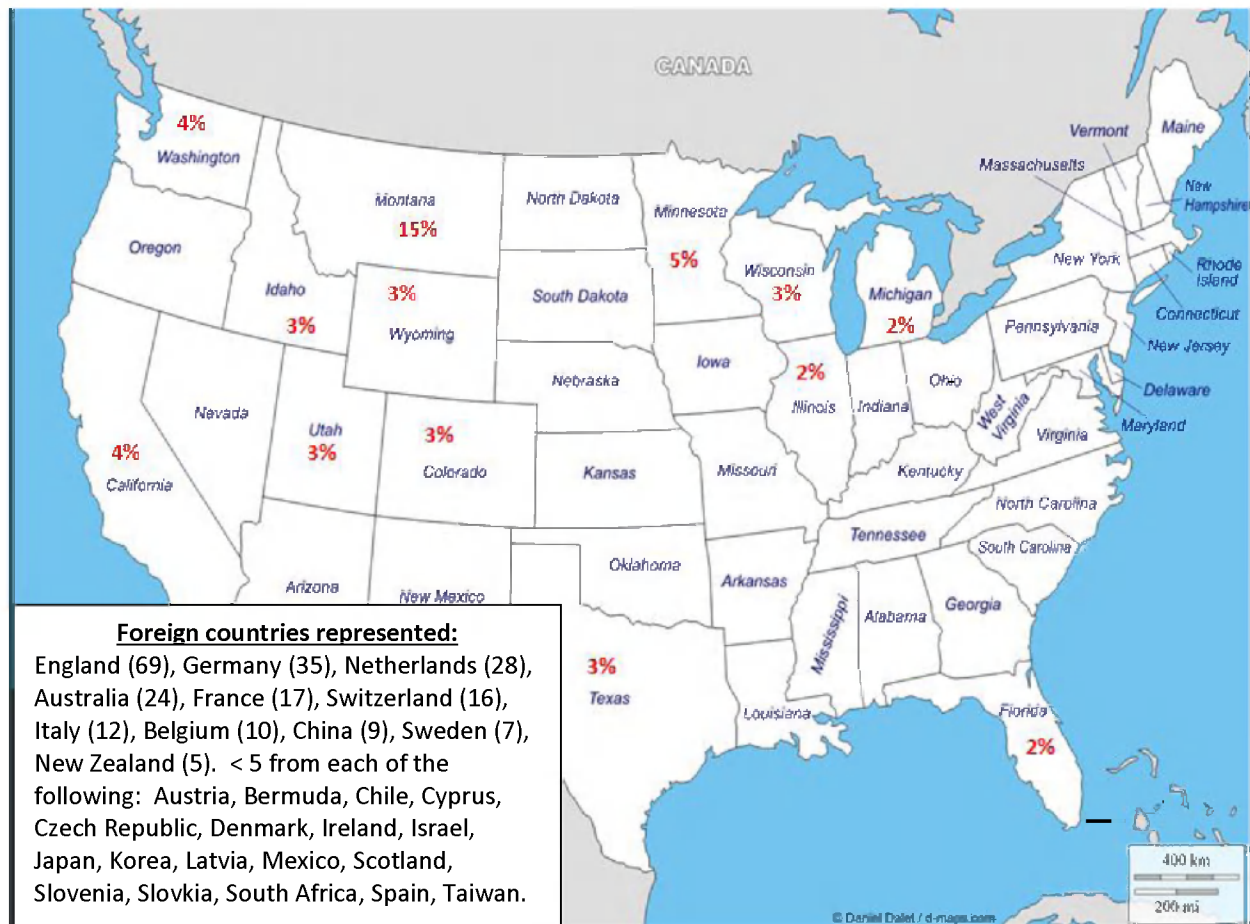
Visitor Residence – All Intercepted Traffic	#	%
Locals (Park County, WY; Park County, MT; Carbon County, MT)	485	10%
United States	3,869	81%
Foreign (other than Canada)	258	5%
Canada	156	3%

*Four cases were labeled as missing data.

Nonresident Visitors

Figure 1 shows where the largest group of visitors were from who traveled the highway. A full list of residences is provided in Appendix C.

Figure 1: Residence of Beartooth Highway Visitors (highest representation)



On average, nonresidents had 2.36 people in their group and spent almost two nights in the Beartooth Region (Table 5). They were more likely to enter the Beartooth Highway via Red Lodge or Yellowstone's northeast exit and travel by car, truck or motorcycle (Tables 6 & 7).

Table 5: Nonresident Group Size and Nights Spent in BTH Region

	Number of Travelers in Vehicle	Number of Nights Spent in Beartooth Region
Mean	2.36	1.83
Median	2	1

Table 6: Point of Entry to BTH

Nonresident Entry Point	#	%
Red Lodge (Vista Point)	1,869	44%
Silver Gate/YNP	1,699	40%
Chief Joseph Highway (WY 296)	700	16%

Table 7: Nonresident Vehicle Type

Vehicle Type	#	%
Car/Truck	3,501	82%
Motorcycle	595	14%
Car/Truck w/trailer	99	2%
RV	85	2%
Bicycle	7	<1%

Resident Visitors

Residents usually had two people in their group and were likely to travel the highway 6-17 times per year (Table 8). Residents were most likely to enter the Beartooth via Wyoming Highway 296 or through Red Lodge and were driving a car or truck (Tables 9 & 10).

Table 8: Resident Group Size and Yearly Usage of BTH

	Number of Travelers in Vehicle	Resident Yearly Usage of BTH
Mean	2.11	17 Times/year
Median	2	6 Times/year

*Yearly usage of BTH delimited to 99 times per year.

Table 9: Resident Point of Entry on BTH

Entry Point	#	%
Chief Joseph Highway (WY 296)	192	40%
Red Lodge (Vista Point)	182	38%
Silver Gate/YNP	<u>111</u>	<u>23%</u>
Total	485	

Table 10: Resident Vehicle Type

Vehicle Type	#	%
Car/Truck	407	84%
Car/Truck w/Trailer	42	9%
Motorcycle	30	6%
Bicycle	3	<1%
RV	2	<1%

Intercept Survey Summary

On-site intercept results show that nonresident travelers are staying, on average, 1.83 nights, and have an average of two travelers per vehicle. While close in numbers, Red Lodge (44%) was shown to be the most common entry point for nonresident travelers, followed by Silver Gate (40%) and the Chief Joseph

Highway (16%). Results show that the majority of nonresident travelers are using a car/truck (82%) to travel the BTH and motorcycles (14%) are shown to be the second most popular mode of travel.

Resident travelers tend to use the BTH an average of 17 times per year and have an average of 2 travelers per vehicle. The Chief Joseph Highway (40%) was the most common entry point for resident travelers, followed by Red Lodge (38%) and Silver Gate/YNP (23%). Again, car/truck (84%) was the most common mode of travel along the BTH for resident travelers. The northeast gate of Yellowstone National Park had the highest proportion of nonresident travelers (95%) and the Chief Joseph Highway had the lowest proportion of nonresident travelers on the highway (82%). A total of 178,904 vehicles were recognized by traffic counters for the 2012 summer season. Of those counted, 162,265 were estimated to be nonresidents (91%).

SECTION 2: Mailback Survey Results

Section 2 is segmented into various subsections. Each subsection is a part of the mailback questionnaire handed out to nonresident travelers on the BTH. As a reminder, these results are only nonresident travelers and do not include residents of the local area. Due to the large presence of first-time visitors, results are segmented into first-time, repeat and all visitors. Section 2 will be presented as such: demographics, overall trip characteristics, gateway communities, and visitor comments.

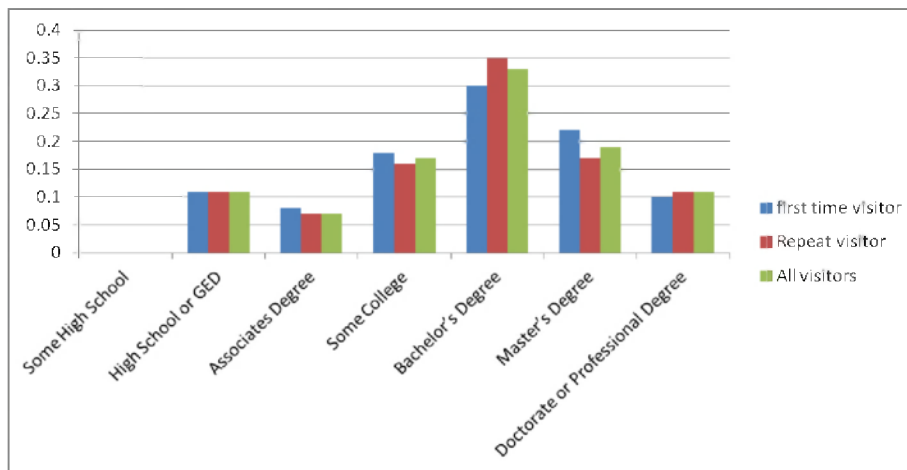
Demographics

The majority of Beartooth Highway visitors have a Bachelor's degree or higher (63%). There is very little difference in education level between first-time and repeat visitors (Table 11, Figure 2).

Table 11: Level of Education

Highest Level of Education	First-Time Visitors		Repeat Visitors		All Visitors	
	#	%	#	%	#	%
Some High School	4	<1%	6	<1%	10	<1%
High School or GED	71	11%	89	11%	160	11%
Associates Degree	53	8%	54	7%	107	7%
Some College	118	18%	127	16%	245	17%
Bachelor's Degree	196	30%	285	35%	481	33%
Master's Degree	145	22%	138	17%	283	19%
Doctorate or Professional Degree	64	10%	91	11%	155	11%

Figure 2: Level of Education by first-time, repeat, and all visitors



A fairly well shaped bell-curve describes the income levels of visitors to the Beartooth. The majority of visitors earn between \$50,000 and \$150,000 each year. The same pattern exists for both first-time and repeat visitors (Table 12, Figure 3). The average age of visitors was 56 years old. First-time visitors were slightly younger (54) than repeat visitors (57) (Table 13). Males were 10 percent more likely to respond to the survey than females (Table 14).

Table 12: Annual Household Income

Average Household Income	First-Time Visitors		Repeat Visitors		All Visitors	
	#	%	#	%	#	%
Less than \$25K	22	3%	29	4%	51	4%
\$25K to less than \$50K	62	9%	121	16%	183	12%
\$50K to less than \$75K	141	21%	181	22%	322	22%
\$75K to less than \$100K	129	19%	154	19%	283	19%
\$100K to less than \$150K	137	21%	135	18%	272	19%
\$150K to less than \$200K	64	10%	63	8%	127	9%
\$200K or greater.	60	9%	62	8%	122	8%

Figure 3: Household Income by First-Time, Repeat, and All Visitors

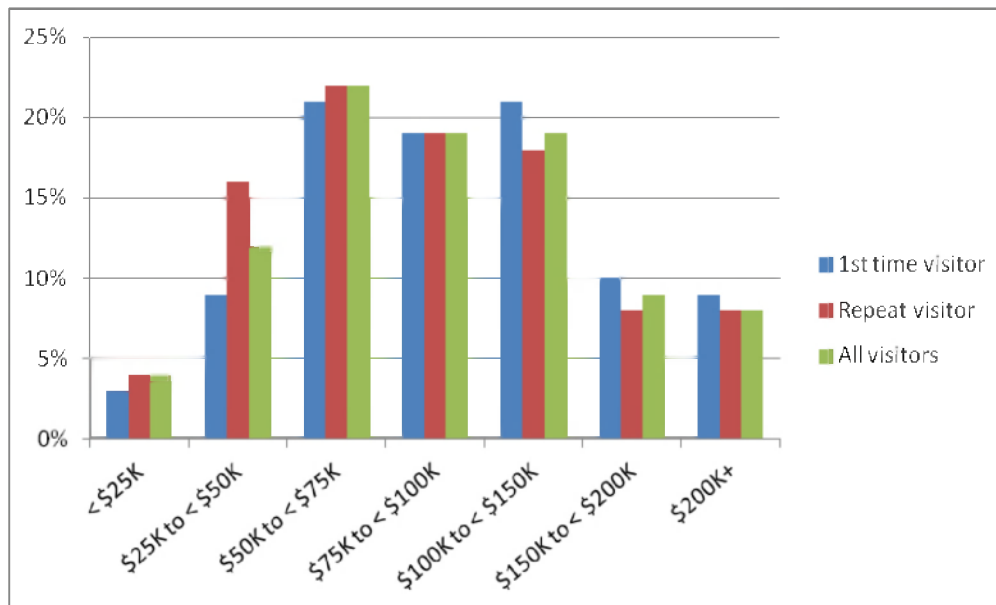


Table 13: Age of Travelers

Age of Travelers	First-Time Visitors	Repeat Visitors	All Visitors
Mean	54 Years	57 Years	56 Years
Minimum	18 Years	18 Years	18 Years
Maximum	86 Years	89 Years	89 Years

Table 14: Gender of Travelers

Gender	First-Time Visitors	Repeat Visitors	All Visitors
Male	330 (51%)	459 (57%)	789 (54%)
Female	316 (49%)	327 (41%)	643 (44%)

OVERALL Trip characteristics:

In this subsection, trip characteristics will be discussed in two parts: (1) visitor behavior, (2) highway experiences and reasons for traveling. Results will be displayed in similar format with first-time visitors, repeat visitors, and all visitors on the BTH. A summary will be provided at the conclusion of the overall trip characteristics.

Visitor Behavior

The average length of stay in the Beartooth by all visitors was 2.34 nights (Table 15). The average number of nights spent reported on the mailback survey is higher than on the on-site survey (1.83 nights vs 2.34 nights). This may be due to a number of reasons including: misinterpretation of study region boundaries, staying longer than originally intended, or those who did spend more time in the region were more likely to complete the mailback survey. Repeat visitors had a longer stay in the region (2.83 nights) than first-time visitors (1.73 nights).

Table 15: Visitors Average Length of Stay in the Beartooth Region

Location of Nights Spent	First-Time Visitors	Repeat Visitors	All Visitors
Cooke City, MT	.34 Nights	.92 Nights	.66 Nights
Red Lodge, MT	.36 Nights	.67 Nights	.53 Nights
Cody, WY	.75 Nights	.50 Nights	.62 Nights
Along the BTH	.19 Nights	.40 Nights	.31 Nights
Along Chief Joseph Hwy	.09 Nights	.34 Nights	.22 Nights
Total	1.73 Nights	2.83 Nights	2.34 Nights

*Nights spent were delimited to 30 nights per trip.

Removing the day-trippers to the region and only looking at nights spent by visitors who spent at least one night, Table 16 shows more nights in the region by all travelers. Sixty-three percent of all visitors spent at least one night in the region. Travelers who spent at least one night stayed an average of 3.73 nights, although repeat visitors (4.36 nights) stayed longer than first-time visitors (2.82 nights) on average.

Table 16: Average Nights Spent of Travelers Who Spent at Least 1 Night in the Beartooth Region

Location of Nights Spent	First-Time Visitors	Repeat Visitors	All Visitors*
Cooke City, MT	.56 Nights	1.4 Nights	1.05 Nights
Red Lodge, MT	.60 Nights	1.04 Nights	.85 Nights
Cody, WY	1.2 Nights	.78 Nights	.98 Nights
Along the BTH	.31 Nights	.62 Nights	.49 Nights
Along Chief Joseph Hwy	.15 Nights	.52 Nights	.36 Nights
Total	2.82 Nights	4.36 Nights	3.73 Nights

*63% of all visitors spent at least one night in the region.

In addition to time spent in the Beartooth region, nearly half of the visitors spent at least one night in Yellowstone National Park (Table 17) on their current trip. This was followed by at least one night spent in Billings (27%), West Yellowstone (25%), or Jackson, Wyoming (25%).

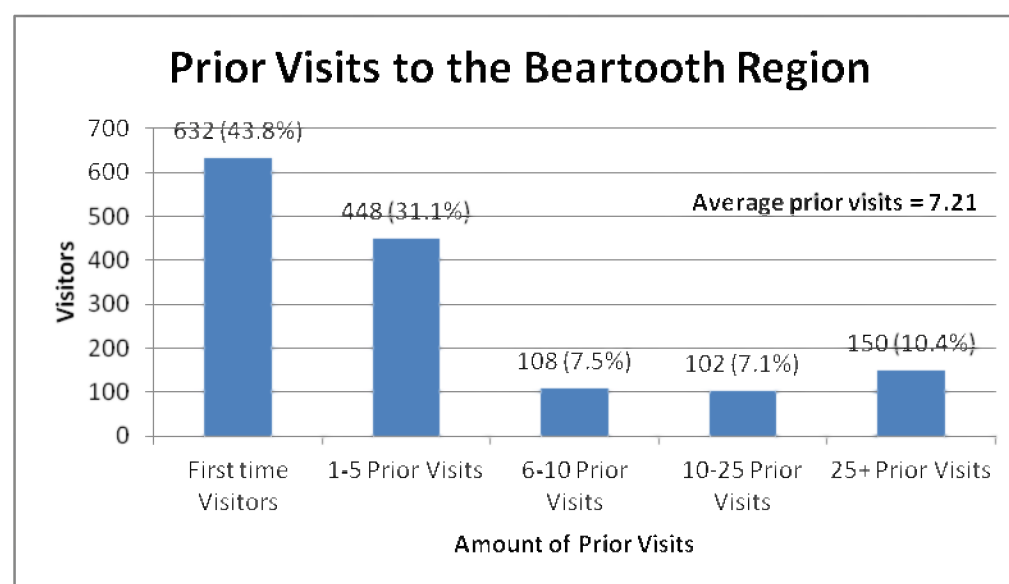
Table 17: Regional Locations where Nonresidents Spent at least one Night on Current Trip

Other Locations Visitor Spent a Night	First-Time Visitor		Repeat Visitor		All Visitors	
	#	%	#	%	#	%
Yellowstone NP	322	48%	246	40%	568	49%
In or near Billings, MT	154	23%	158	20%	312	27%
In or near West Yellowstone, MT	156	24%	134	17%	290	25%
In or near Jackson, WY	168	25%	116	14%	284	25%
Grand Teton NP	123	19%	91	11%	214	18%
In or near Gardiner, MT	81	12%	76	9%	157	14%
In or near Bozeman, MT	71	11%	73	9%	144	12%
In or near Livingston, MT	30	5%	41	5%	71	6%

*Percentages may fluctuate due to missing data.

Figure 4 displays the split between first-time visitors and repeat visitors to the region. Forty-four percent of travelers were visiting the region were first-time visitors. Thirty-one percent of visitors visited 1-5 times prior to their current trip. However, ten percent of visitors had been to the region 25+ times. These results show that there is a large diversity of travelers in the region including first-time visitors, visitors who have only been to the area five times or fewer, and a range of visitors who come back many times.

Figure 4: Prior Visits to the Beartooth Region by Nonresident Travelers



While this study represents travel along the Beartooth highway, it is interesting to note that about one quarter of the travelers did not actually go over the Beartooth Pass. Seventy-five percent of visitors did travel over the Beartooth Pass during their trip to the Beartooth Region (Table 18), and that percent did not change if the visitor had been here numerous times or were traveling for the first time on the highway.

Table 18: Travelers Who Went Over Beartooth Pass

Traveled over the Beartooth Pass	First-Time Visitor		Repeat Visitor		All Visitors	
	#	%	#	%	#	%
Yes	500	75%	606	75%	1106	75%
No	117	18%	191	24%	308	21%

Eighty percent of the travelers did a day-trip to/from Yellowstone National Park in a gateway community. Red Lodge and Cooke City had the highest percentage (31%) of respondent that day-tripped to or from YNP.

Table 19: Visitors that Day Tripped to/from YNP to a Gateway Community

Day Tripped to/from YNP from...	First-Time Visitor		Repeat Visitor		All Visitors	
	#	%	#	%	#	%
Cooke City, MT	188	28%	274	34%	462	31%
Red Lodge, MT	208	31%	245	30%	453	31%
Cody, WY	177	27%	167	21%	344	26%
N/A	135	20%	165	20%	300	20%

Activities in the Beartooth Region generally seem to be passive activities with scenic driving (84%) being the most common, followed by nature photography (61%) and wildlife watching (58%) (Table 20). Day hiking (21%) was the most common active activity. Other active activities in which visitors participated included: fishing/fly fishing (8%), motorcycle riding (5%), backpacking (3%), road/tour biking (3%), skiing/snowboarding (2%), canoeing/kayaking (2%), and mountain biking (1%). First-time visitors tended to not participate in as many active activities as repeat visitors.

Table 20: Activities along the Beartooth Highway

Activity	First-Time Visitors		Repeat Visitors		All Visitors	
	#	%	#	%	#	%
Scenic Driving	533	80%	621	77%	1154	84%
Nature Photography	390	59%	451	56%	841	61%
Wildlife Watching	326	49%	468	58%	794	58%
Historical Site	137	21%	165	20%	302	22%
Interpretive Site	132	20%	162	20%	294	21%
Day Hiking	93	14%	197	24%	290	21%
Camping	58	9%	103	13%	161	12%
Birding	41	6%	93	12%	134	10%
Fishing/Fly Fishing	22	3%	82	10%	104	8%
Motorcycle Riding	34	5%	40	5%	74	5%
Backpacking	10	2%	32	4%	42	3%
Road/Tour Biking	13	2%	23	3%	36	3%
Horseback Riding	6	1%	18	2%	24	2%
Festivals/Events	6	1%	16	2%	22	2%
Skiing/Snowboarding	6	1%	16	2%	22	2%
Canoeing/Kayaking	6	1%	14	2%	20	2%
Mountain Biking	6	1%	13	2%	19	1%
ATV/OHV	2	<1%	15	2%	17	1%
Sporting Event	1	<1%	6	<1%	7	<1%
Motor boating	0	0	3	<1%	3	<1%
Hunting	0	0	2	<1%	2	<1%
Snowshoeing	0	0	2	<1%	2	<1%
Snowmobiling	0	0	1	<1%	1	<1%
Cross Country Skiing	1	<1%	0	0	1	<1%
Sledding	0	0	1	<1%	1	<1%

Highway Experiences and Reasons for Traveling the Beartooth Highway

The following results will present results about reasons for traveling the highway, pre-trip planning, beliefs about the highway, experiential feelings while along the highway, and various other aspects about the trip experience.

Table 21 represents the reasons why visitors drove the Beartooth Highway. Interestingly, the statement “I drove the Beartooth Highway because it is a designated scenic road (69%)” was seen as being the most common response for all travelers. It was followed by “I heard it was a pretty drive (54%),” and “it is the road to Yellowstone National Park (37%).” For this question travelers could select as many responses as they felt fit their reasons. First-time visitors were significantly more likely to indicate that they heard it was a pretty drive and that it was recommended to them than repeat visitors. Repeat

visitors were significantly more likely to say it was their access to recreation along the road. It appears that once the road has been traveled, visitors see the opportunity for recreation and return to the Beartooth region.

Table 21: Travelers' Reasons for Traveling the BTH

Reasons for Traveling the BTH*	First-Time Visitors		Repeat Visitors		All Visitors	
	#	%	#	%	#	%
1. It is a designated scenic road.	447	67%	551	70%	998	69%
5. I heard it was a pretty drive.	423	64%	360	45%	783	54%
4. It is the road to Yellowstone National Park.	253	38%	280	35%	533	37%
6. It was recommended to me.	332	50%	199	25%	531	37%
2. It was the shortest route to my destination.	132	20%	209	26%	341	24%
3. It was my access to recreation along the road.	40	6%	161	20%	201	14%
7. An electronic map suggested the route (e.g. GPS, Google Maps, Garmin, etc.).	48	7%	19	2%	67	5%

*Visitors could select more than one reason.

Table 22 represents travelers' primary purpose out of all of the reasons they selected above. Again, "It is a designated scenic road" (32%) was shown to be the most common choice indicating that the Beartooth Region is perceived as more than a travel route, but a place to see and visit.

Table 22: Primary Reason for Traveling the BTH

Reasons for Traveling the BTH	First-Time Visitors		Repeat Visitors		All Visitors	
	#	%	#	%	#	%
1. It is a designated scenic road	153	23%	292	36%	445	32%
5. I heard it was a pretty drive	161	24%	161	20%	322	23%
6. It was recommended to me	145	22%	48	6%	193	14%
4. It is the road to Yellowstone National Park	102	15%	79	10%	181	13%
2. It was the shortest route to my destination	52	8%	92	11%	144	10%
3. It was my access to recreation along the road	10	2%	91	11%	101	7%
7. An electronic map suggested the route (e.g. GPS, Google maps, Garmin, etc.)	11	2%	2	<1%	13	1%

*Visitors selected only one response from the previous question to be their primary reason.

In Table 23, multiple statements regarding visitor beliefs about the Beartooth Highway were asked of respondents. For ease of display, the "strongly disagree" and "disagree" statements were combined to

be “disagree,” and the same was done with the two “agree” statements. The means, however, represent the 4-point scale data.

Statements about planning trips with scenic byways in mind (85%), traveling the Beartooth Highway in the future (93%), and recommending the BTH to others (96%) were all shown to have high agreeability by all travelers. The only statement about planning and re-visitation to the region that was not agreed upon by a very large majority was the statement “In planning my trip, the Beartooth Highway was a main destination (54% agree)”. However, repeat visitors were much more likely to agree to this statement (61%) compared to first time visitors (45%). This suggests that people who have traveled the Beartooth Highway in the past, now return to the road because it is a main destination.

Table 23: Statements about the Beartooth Highway

	First time		Repeat		All visitors	
Beartooth Highway Statements	N	%	N	%	N	%
“In planning this trip, the BTH was a main destination.”						
Disagree	353	51%	300	37%	653	44%
Agree	297	45%	495	61%	792	54%
Traveler Mean*	2.42		2.85		2.65	
“I plan my travel routes to include scenic byways, like BTH.”						
Disagree	106	16%	87	11%	193	13%
Agree	545	82%	706	89%	1251	85%
Traveler Mean*	3.09		3.24		3.17	
“I would travel the Beartooth Highway again in the future.”						
Disagree	48	7%	27	3%	75	5%
Agree	602	91%	769	95%	1371	93%
Traveler Mean*	3.34		3.63		3.50	
“I would recommend others to travel the BTH”						
Disagree	20	3%	13	2%	33	2%
Agree	631	95%	786	97%	1417	96%
Traveler Mean*	3.64		3.76		3.70	

*Scale: 1=strongly disagree to 4=strongly agree

Other questions asked the visitor to respond to the physical attributes of the road. Of these characteristics, the Beartooth being free of debris and litter (3.45) ranked the highest out of all attribute statements. The statement regarding the quality of interpretive signs saw the lowest agreeability (2.96) from travelers (Table 24). Comparing first-time to repeat visitors, very little difference exists in their responses to the physical attributes of the highway.

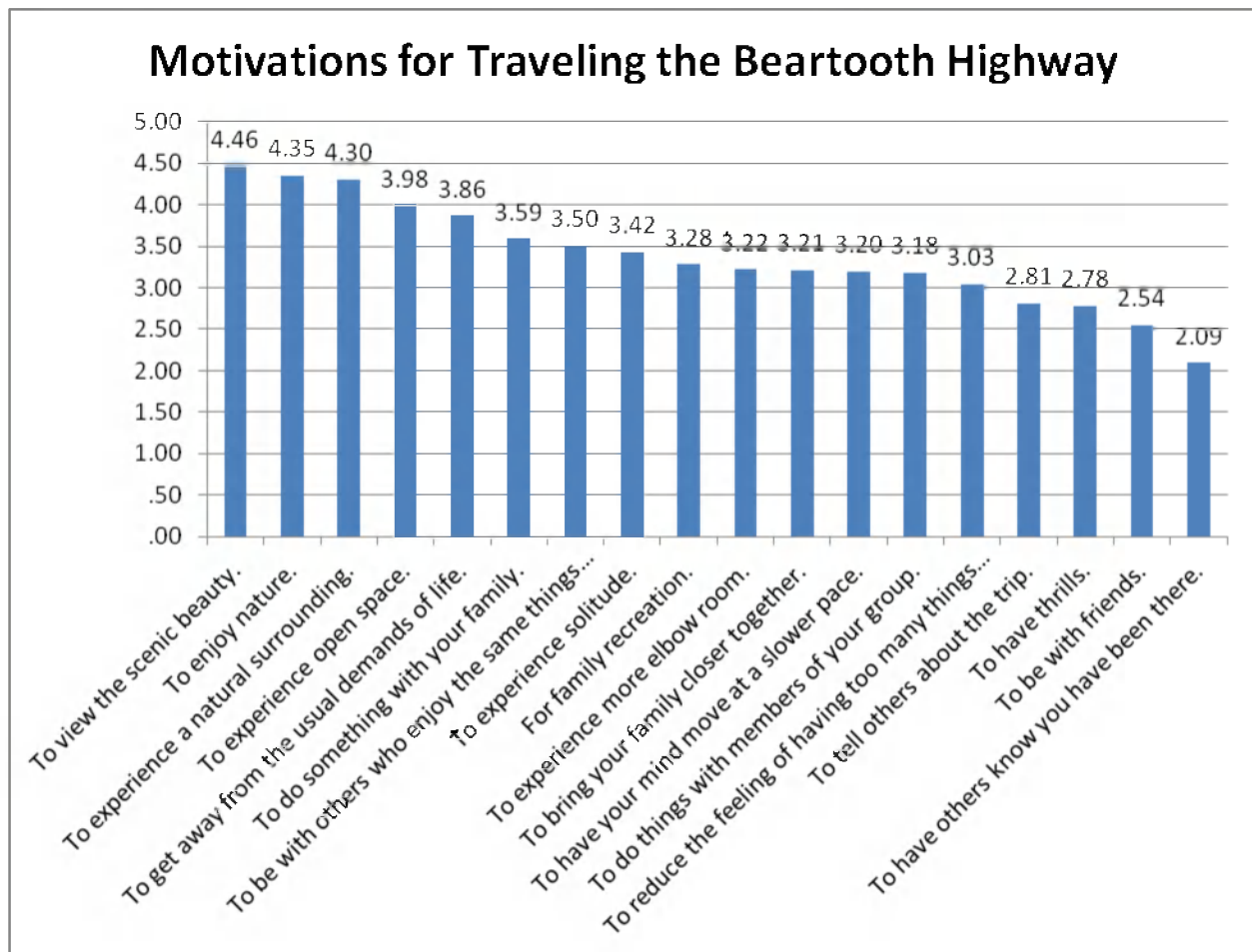
Table 24: Characteristics of the Beartooth Highway

	First-time Visitors	Repeat Visitors	All Visitors
The Beartooth Highway is/has...*	Mean	Mean	Mean
...free of debris and litter. (n=1448)	3.49	3.43	3.45
...of good physical quality (n=1442)	3.35	3.38	3.37
...easy to navigate. (n=1445)	3.22	3.29	3.26
...safe and secure to drive on. (n=1446)	3.19	3.26	3.23
...a variety of outdoor recreational opportunities. (n=1376)	3.03	3.14	3.09
...ample number of pullouts. (n=1442)	3.06	3.03	3.04
...good interpretive signs. (n=1426)	3.00	2.93	2.96
...too crowded. (n=1428)	1.83	1.96	1.90

*Scale: 1= strongly disagree to 4= strongly agree

Figure 5 displays the motivations of travelers on the highway. Visitors were asked to answer each statement on a 5-point scale from “not at all important” to “extremely important.” The higher the mean, the more important the motivation statement was to the visitor. Top ranking motivations were “to view the scenic beauty (4.46),” “to enjoy nature (4.35),” “to experience a natural surrounding (4.30),” and “to experience open space (3.98).” These motivations were listed highest out of a collection of motivations selected that pertained to the experience of traveling a highway. Interestingly, this indicates that visitors feel the naturalness of the Beartooth Region was an extremely important aspect of their trip.

Figure 5: Motivations of Travelers on the Beartooth Highway



*Scale = 1 = "not at all important" to 5 = "extremely important"

Experiences and Feelings While Traveling on the Beartooth Highway

Respondents were asked to rate, on a sliding scale, their feelings while traveling the Beartooth Highway. To understand the image of a destination, both the experiences/feelings and the beliefs need to be considered. The experiences/feelings section included 12 questions that the respondent answered based on their current trip to the Beartooth Highway region. Each question had a feeling variable on one side and its antonym on the other side for the respondent to answer. The questions were set up like the following example and respondents checked the degree to which they were 'happy or sad,' 'relaxed or stressed,' and so on at the time of traveling the Beartooth.

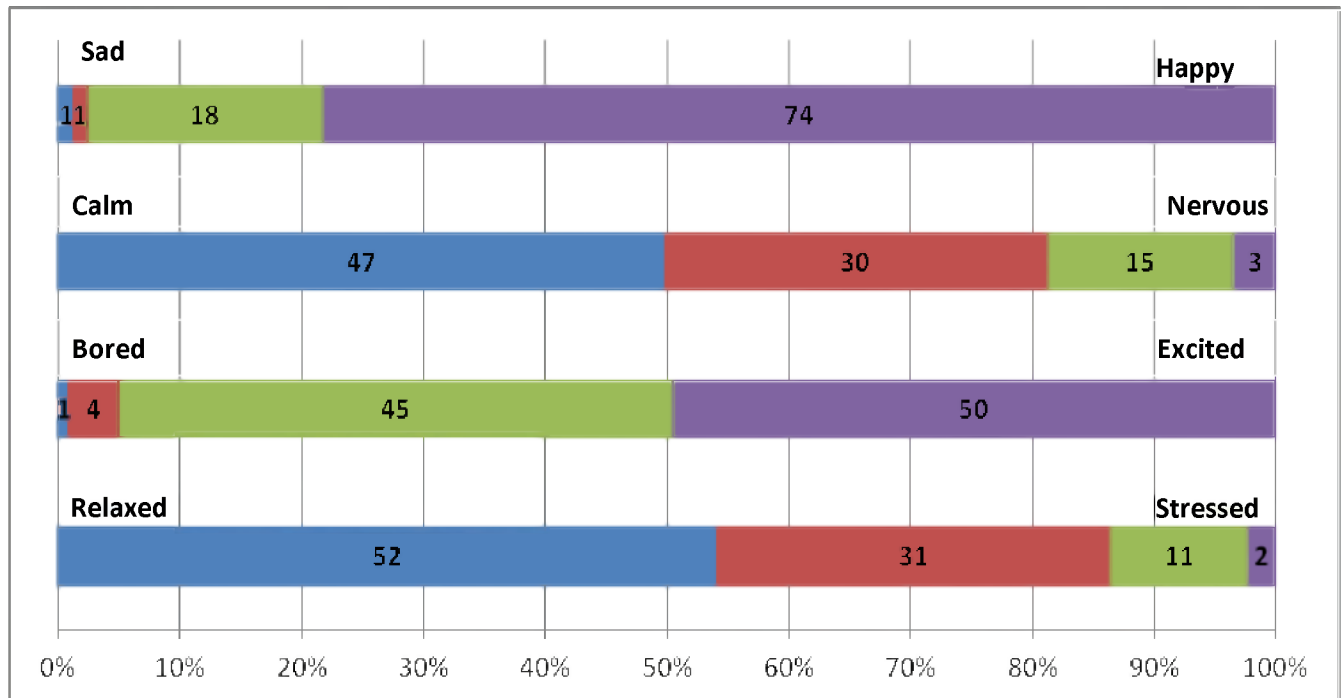
Sad	☐	☐	☐	☐	Happy
Relaxed	☐	☐	☐	☐	Stressed

The following graphs are displayed with the twelve questions about nonresident feelings while traveling the Beartooth Highway. Each bar graph has an emotion or feeling on the left and the right. Respondents rated each pair of emotions by checking 1, 2, 3, or 4. A one represents the strongest degree of feeling to

that emotion on the left and a four represents the strongest degree of feeling to the emotion on the right. Percentages are then displayed by color for each degree of emotion; “1” = blue, “2” = red, “3” = green, “4” = purple. The graphs are displayed by 4 questions per graph.

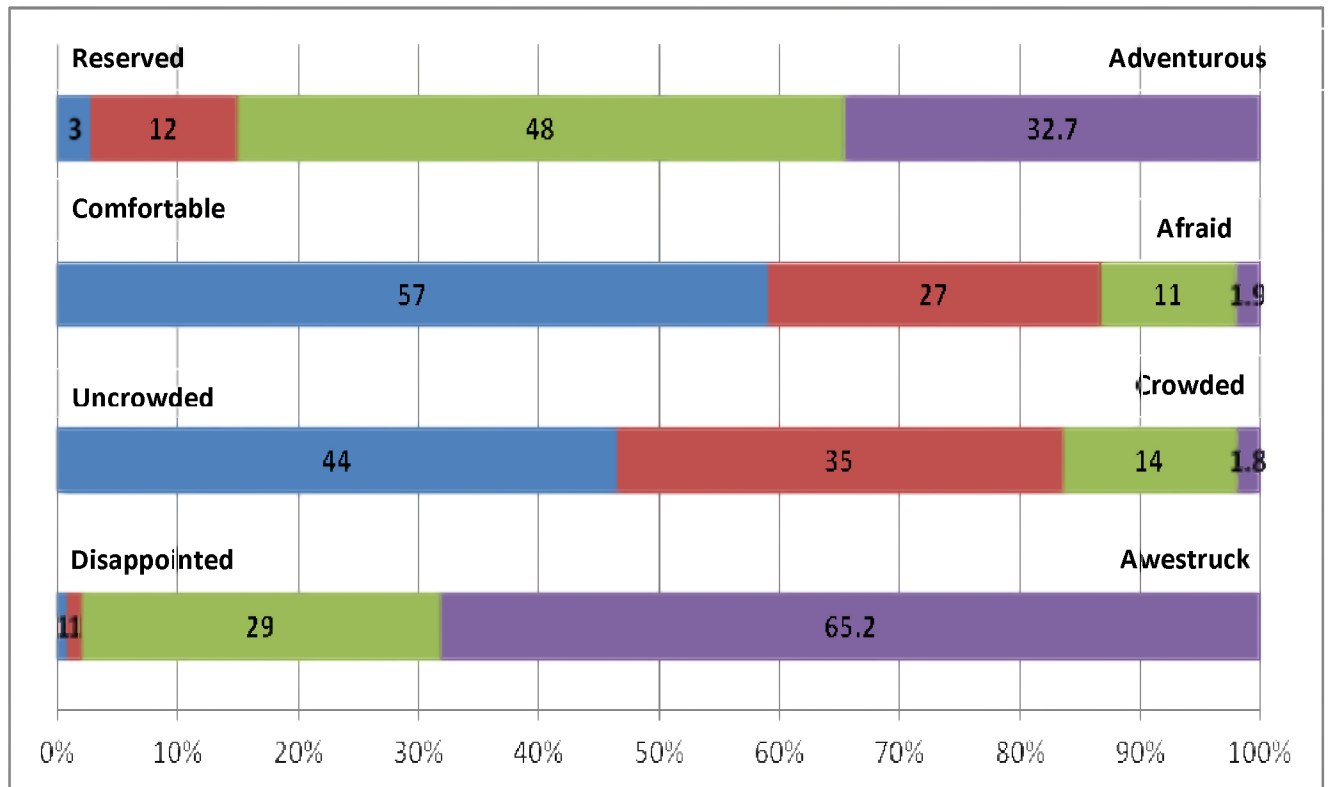
Looking at the Figure 6, results show that nonresidents feel relaxed (83.3%), excited (95%), calm (77%), and happy (92.6%) while traveling the Beartooth Highway. Some respondents (17.8%) felt that they were nervous while traveling, which could be attributed to multiple aspects of the experience including the nature of the winding highway.

Figure 6: Beartooth Highway Experiences (sad-happy; calm-nervous; bored-excited; relaxed-stressed)



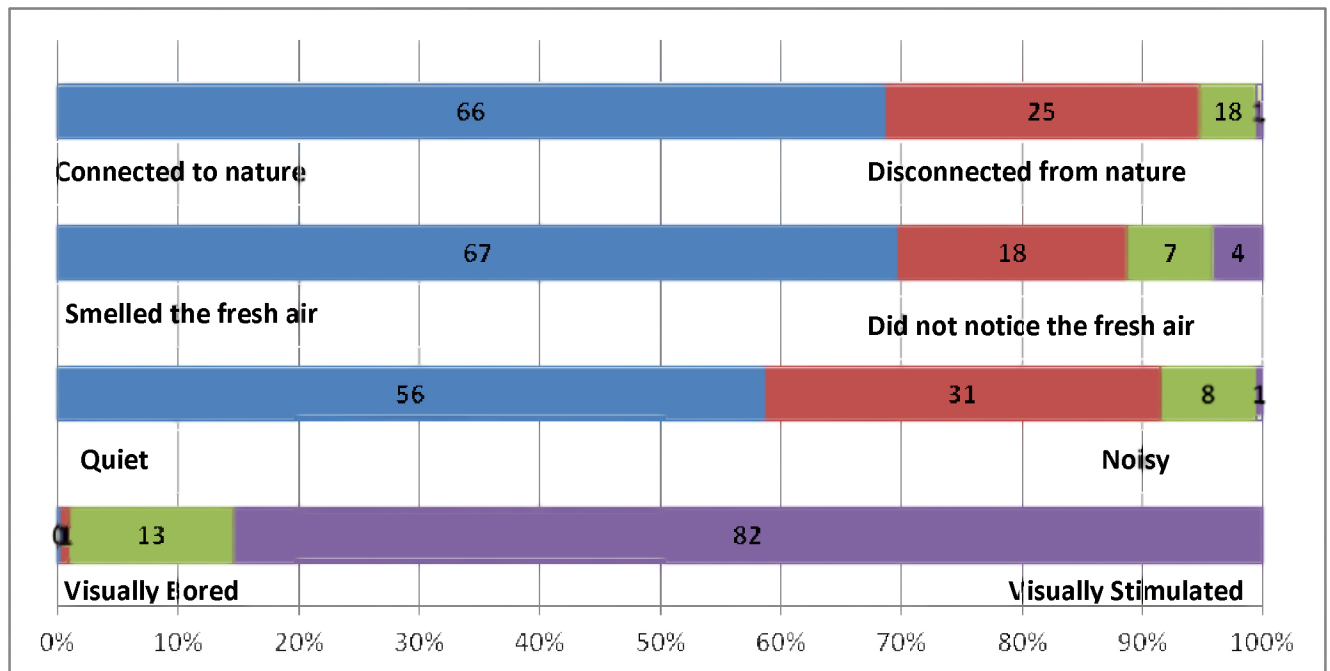
In Figure 7, respondents stated they felt adventurous (80.4%), comfortable (83.1%), uncrowded (79.1%), and awestruck (93.7%) during their travels on the Beartooth Highway. A similar pattern of responses was seen between the two questions regarding if the traveler felt calm/nervous and comfortable/afraid. Despite a large number of visitors in the region, most visitors felt uncrowded on the highway during their travels. This result suggests that the amount of people or traffic in the region is acceptable to a large majority (79%) of respondents.

Figure 7: Beartooth Highway Experiences (reserved-adventurous; comfortable-afraid; uncrowded-crowded; disappointed-awestruck)



Finally in Figure 8, visitors tended to feel connected to nature (91%), smelled the fresh air (84.6%), thought the Beartooth Highway was quiet (86.6%), and were visually stimulated (94.5%). Thus, results show that visitors feel a unique connection to the natural surroundings and are feeling enjoyable emotions. The idea of being “connected to nature” along a highway is interesting and a bit difficult to understand. While most visitors were participating in passive activities, visitors still felt a connection with the natural surroundings. It is very possible that simply getting out of the car at various pull-outs along the way gave them a natural experience.

Figure 8: Beartooth Highway Experiences (nature connection-disconnection; fresh air-no fresh air; quiet-noisy; visually bored-visually stimulated)



Another way to look at the emotive responses is through the means of each variable. To do this we recoded some of the data so that the negative emotion was given a 1 and the positive emotion was given a 4. The researchers used some subjectivity to determine what was a negative or positive emotion. The following emotive points were given the 'negative' responses: sad, nervous, bored, stressed, reserved, afraid, crowded, disappointed, disconnected from nature, did not notice the fresh air, noisy, and visually bored. Table 25 displays the means from highest to lowest visitors. Again, it is interesting to note that first-time visitors were more reserved, nervous, stressed, and afraid than repeat visitors.

Table 25: Affective Emotion while Traveling the Beartooth Highway

Negative = 1	First-time Visitors	Repeat Visitors	All Visitors	Positive = 4
Visually bored	3.84	3.85	3.84	Visually stimulated
Sad	3.73	3.76	3.75	Happy
Disappointed	3.68	3.63	3.65	Awestruck
Disconnected to nature	3.59	3.66	3.63	Connected to nature
Did not notice fresh air	3.47	3.60	3.54	Noticed the fresh air
Noisy	3.54	3.46	3.50	Quiet
Bored	3.44	3.44	3.44	Excited
Afraid	3.34	3.52	3.44	Comfortable
Stressed	3.27	3.47	3.38	Relaxed
Crowded	3.33	3.24	3.28	Uncrowded
Nervous	3.16	3.37	3.28	Calm
Reserved	3.08	3.24	3.17	Adventurous

Gateway Communities

If travelers visited one of the gateway communities of the Beartooth Region; Red Lodge, MT, Cooke City, MT, or Cody, WY they were asked to rate their feelings and beliefs about the community. Respondents were asked to only respond to questions about the gateway communities where they stayed for an hour or longer in the community on their current trip. This was done in hopes of limiting the perception of the community to only the most recent trip.

Red Lodge, MT

Red Lodge, MT is located on the north end of the Beartooth Highway and is considered a gateway community along the Beartooth Highway. The highway designation begins at the south end of Red Lodge and is used in many marketing and promotional initiatives by the town. Red Lodge represents the most visited gateway community on the Beartooth Highway. Forty-two percent (609) of respondents said they visited Red Lodge for at least one hour or longer on this trip.

Travelers felt that “Red Lodge provides a relaxing feeling (3.29)” and “a welcoming experience (3.24)” provided the highest emotional feeling from the community (Table 26). Travelers rated “Red Lodge provides opportunities to experience local cuisine (3.15) and places to purchase local arts/crafts (3.15)” as the next two agreeable aspects about Red Lodge.

Table 26: Red Lodge, Montana Image Statements

Red Lodge, MT provides...	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
...a relaxing feeling. (n=586)	11 (2%)	17 (3%)	350 (60%)	208 (36%)	3.29
...a welcoming experience. (n=576)	14 (2%)	19 (3%)	358 (62%)	185 (32%)	3.24
...opportunities to experience local cuisine. (n=547)	6 (1%)	47 (9%)	355 (65%)	139 (25%)	3.15
...places to purchase local arts/crafts. (n=542)	10 (2%)	35 (7%)	358 (66%)	139 (26%)	3.15
...unique and rich heritage. (n=543)	8 (2%)	36 (7%)	378 (70%)	121 (22%)	3.13
...authentic shopping opportunities. (n=555)	11 (2%)	43 (8%)	374 (67%)	127 (23%)	3.11
...opportunities to engage in local culture. (n=496)	11 (2%)	67 (14%)	339 (68%)	79 (16%)	2.98
...new and different activities. (n=474)	15 (3%)	142 (30%)	258 (54%)	59 (12%)	2.76
...exciting nightlife. (n=384)	27 (7%)	134 (35%)	193 (50%)	30 (8%)	2.59
...a crowded feeling. (n=562)	126 (22%)	326 (58%)	87 (16%)	23 (4%)	2.01

*Scale: 1 = “strongly disagree” to 4 = “strongly agree.”

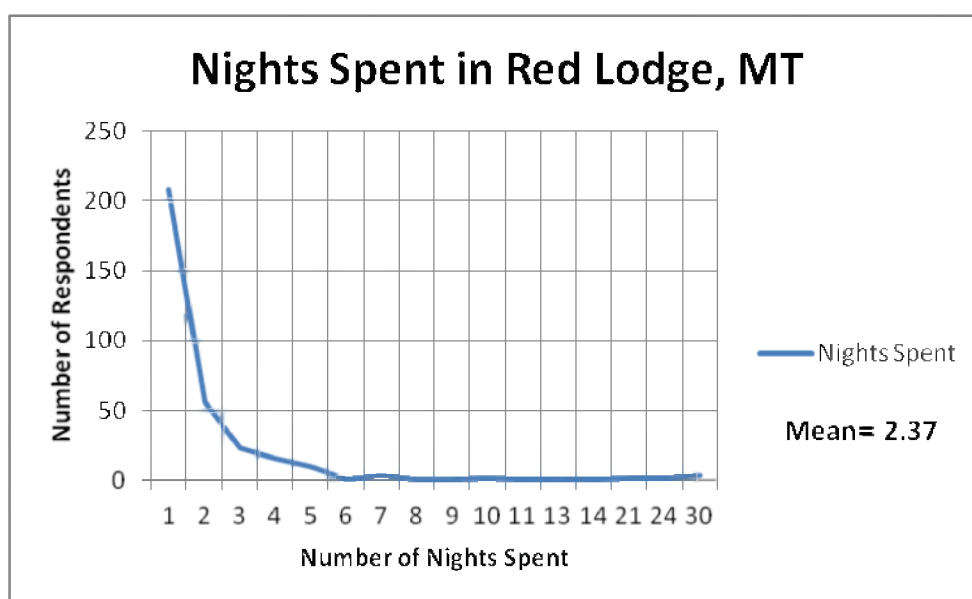
Table 27 results show that 44 percent of intercepts along the Beartooth Highway were at the Red Lodge entry point.

Table 27: Red Lodge, MT Total Nonresident Travelers for summer 2012

Entry Point of Beartooth Highway	Frequency	Percent
Red Lodge, MT (boundary south of Red Lodge)	71,396 Nonresident Travelers	44%

Figure 9 results are based on visitors who spent at least one night in Red Lodge, MT during the duration of their current trip. The majority of visitors spent between 1-7 nights with a mean of 2.37. This mean is similar to the overall amount of nights spent by travelers in all regions of the Beartooth Highway.

Figure 9: Nights Spent in Red Lodge, MT by Travelers Who Spent at Least 1 Night



*Mean represents only visitors who spent at least one night in Red Lodge, MT on their current trip.

Cooke City, MT

Cooke City, MT is located on the western end of the Beartooth Highway. Its close proximity to Yellowstone National Park makes for a popular location for many different types of visitors. Cooke City/Silver Gate, MT is 68 miles from Red Lodge, MT and roughly 90 miles from Cody, WY. Five hundred and twelve (35.3%) nonresident respondents stated that they visited Cooke City for at least one hour or longer on their current trip. Results are taken from only those 512 respondents who stayed in Cooke City, MT.

Travelers rated “Cooke City, MT provides a welcoming experience (3.1)” as the most agreeable statement about the community. In contrast, travelers rated the statement “Cooke City, MT provides opportunities to experience local cuisine (2.14)” as least agreeable (Table 28).

Table 28: Cooke City, MT Image Statements

Cooke City, MT provides...	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
...a welcoming experience. (n=492)	14 (3%)	45 (9%)	309 (63%)	124 (25%)	3.10
...a relaxing feeling. (n=503)	9 (2%)	37 (7%)	398 (59%)	159 (32%)	3.00
...unique and rich heritage. (n=470)	12 (3%)	68 (15%)	302 (64%)	88 (19%)	2.99
...exciting nightlife. (n=350)	73 (21%)	171 (49%)	90 (26%)	16 (5%)	2.97
...places to purchase local arts/crafts. (n=458)	18 (4%)	76 (17%)	304 (66%)	60 (13%)	2.89
...authentic shopping opportunities. (n=473)	26 (6%)	114 (24%)	281 (59%)	52 (11%)	2.76
...opportunities to engage in local culture. (n=424)	23 (5%)	129 (30%)	234 (55%)	38 (9%)	2.68
...new and different activities. (n=414)	31 (8%)	151 (37%)	199 (48%)	33 (8%)	2.57
...opportunities to experience local cuisine. (n=484)	18 (4%)	74 (15%)	297 (61%)	95 (20%)	2.14
...a crowded feeling. (n=481)	168 (35%)	230 (48%)	73 (15%)	10 (2%)	1.84

*Scale: 1 = “strongly disagree” to 4 = “strongly agree.”

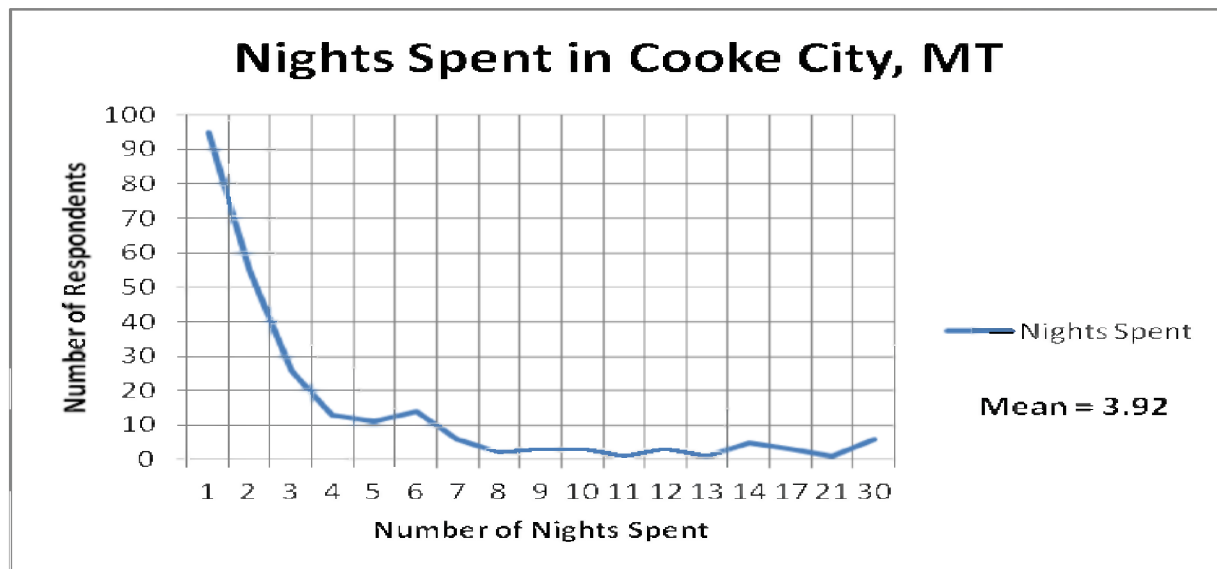
Cooke City/Silver Gate, MT had the second highest percentage (39.6%) of entries by visitors traveling the Beartooth Highway (Table 29). Travelers at this location would be coming through the northeast entrance of Yellowstone National Park, which is the start of the Beartooth Highway.

Table 29: Cooke City, MT Total Nonresident Travelers for Summer 2012

Entry Point of Beartooth Highway	Frequency	Percent
Cooke City/Silver Gate, MT	64,906 Nonresident Travelers	40%

Visitors who spent at least one night in Cooke City, MT had the highest mean of nights spent out of the three gateway communities. With a mean of 3.92, travelers are spending more nights on average (if they spent a night) in the Cooke City/Silver Gate region (Figure 7). Compared to the other gateway regions, Cooke City saw more travelers who spent greater than seven nights. There may be a few explanations, but most likely it is due to the close proximity to Yellowstone National Park.

Figure 10: Nights Spent in Cooke City, MT by Travelers Who Spent at Least 1 Night



*Mean represents only those visitors who spent at least one night in Cooke City, MT on their trip.

Cody, WY

Cody, WY is located 62 miles southeast of the Beartooth Highway. A visitor can leave the Beartooth Highway and travel the Chief Joseph Scenic Byway (WY296) which ultimately can lead to Cody. Yellowstone National Park can be accessed from Cody, WY through two entrances, but only one requires travel along the Beartooth Highway. Five hundred and ninety-one (40.5%) nonresident respondents stated they visited Cody, WY for one hour or longer on their current trip. Results are taken from only these 591 respondents. In Table 30, results showed that visitors rated “Cody, WY provides a unique and rich heritage (3.36)” as the most agreeable statement about the community. The least agreeable statement was seen to be “Cody, WY provides an exciting nightlife (2.72).”

Table 30: Cody, WY Image Statements

Cody, WY provides...	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
...unique and rich heritage. (n=553)	6 (2%)	37 (7%)	367 (67%)	133 (24%)	3.36
...a welcoming experience. (n=549)	4 (1%)	24 (4%)	336 (61%)	185 (34%)	3.28
...places to purchase local arts/crafts. (n=529)	7 (1%)	19 (4%)	343 (65%)	160 (30%)	3.24
...opportunities to engage in local culture. (n=515)	7 (1%)	31 (6%)	336 (65%)	141 (27%)	3.19
...a relaxing feeling. (n=562)	8 (1%)	43 (8%)	359 (64%)	152 (27%)	3.17
...authentic shopping opportunities. (n=534)	12 (2%)	35 (7%)	349 (65%)	138 (26%)	3.15
...opportunities to experience local cuisine. (n=545)	8 (2%)	37 (7%)	367 (67%)	133 (24%)	3.15
...new and different activities. (n=503)	9 (2%)	69 (14%)	289 (58%)	136 (27%)	3.10
...exciting nightlife. (n=410)	26 (6%)	121 (30%)	206 (50%)	57 (14%)	2.72
...a crowded feeling. (n=540)	75 (14%)	272 (50%)	151 (28%)	42 (8%)	2.30

*Scale: 1 = “strongly disagree” to 4 = “strongly agree.”

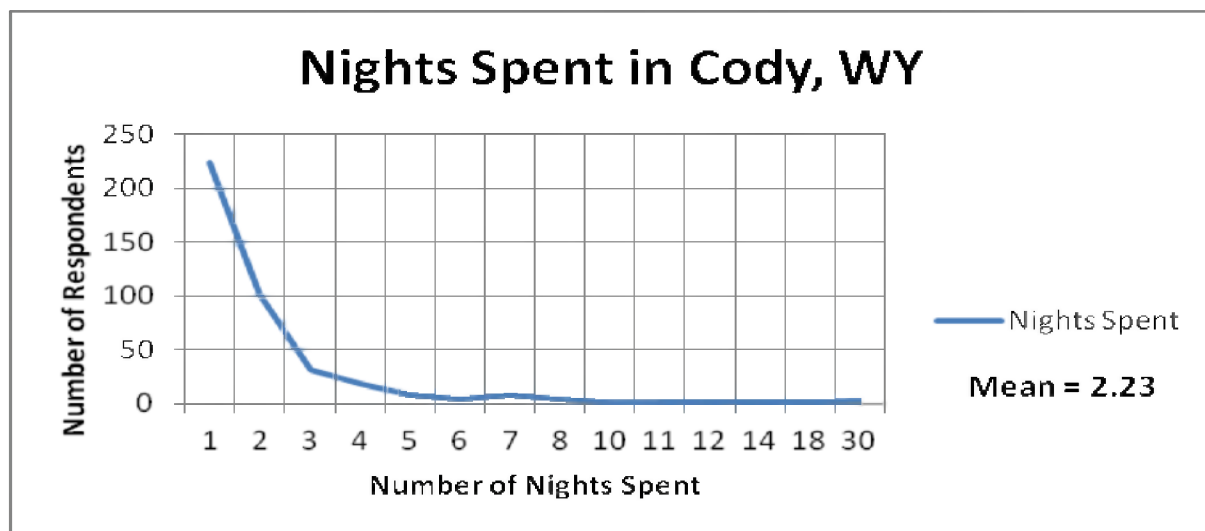
The Chief Joseph Highway was least used point of entry for the Beartooth Highway with only 17 percent of travelers entering at this location (Table 31). However, this entry point is the most difficult to reach and requires a more out-of-the-way approach than other locations in the region.

Table 31: Chief Joseph Highway Total Nonresident Travelers for Summer 2012

Entry Point	Frequency	Percent
Chief Joseph Highway	27,585 Nonresident Travelers	17%

Visitors who spent at least one night in Cody, WY had the lowest mean for nights spent in the community (2.23) (Figure 11). However, the difference is minimal compared to Red Lodge. Results for Cody travelers who spent at least one night look similar to Red Lodge in terms of travelers and the number of nights spent. Visitors to these communities may have different motivations or reasons to stay in these two communities than those who stay in Cooke City.

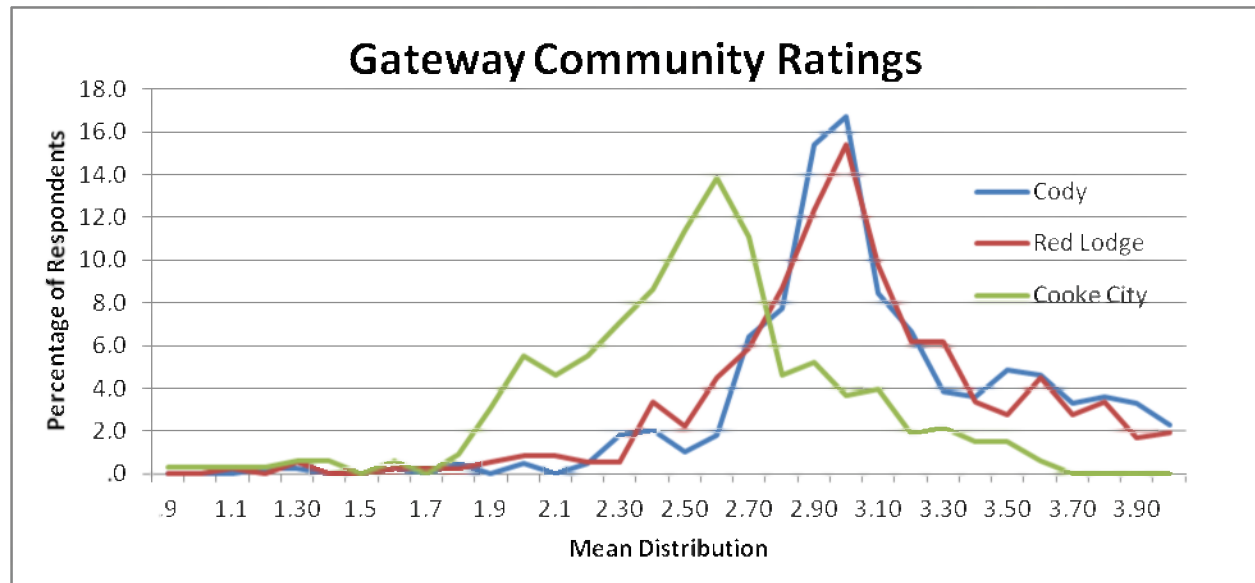
Figure 11: Nights Spent in Cody, WY by Travelers Who Spent at Least 1 Night



*Mean represents only visitors who spent at least one night in Cody, WY on current trip.

Figure 12 represents the mean ratings of each gateway community. As shown, Cody (3.09) and Red Lodge (3.02) have similar distribution of means, but Cooke City (2.53) has a lower distribution of total means. These results were formulated by taking the average of each respondent's ratings of the gateway communities and recoding the statement "...a crowded feeling" into a positive scale. Thus, if respondents selected "1" for that statement, the response was re-coded to a "4." This assumes that the feeling of crowdedness is a negative feeling to the visitor. While Cooke City has a lower mean distribution, the town is much smaller and more remote than any of the other locations. This may contribute to the lack of amenities and facilities available for visitors.

Figure 12: Mean Ratings of Community Attributes



Gateway Community Summary

In general, each gateway community is perceived in a positive light in both the beliefs and feelings from nonresidents. Cody, WY was rated the highest of the three communities and Cooke City was rated the lowest of the three. However, due to the remoteness of Cooke City/Silver Gate, MT, it is much more difficult for the community to provide the same amenities as Cody and Red Lodge. Cooke City also was seen to be perceived as the least crowded out of the three communities.

Visitor Comments

Upon completion of the mail-back questionnaire, nonresident visitors were asked to write any additional comments or questions they had regarding the Beartooth Highway. In total, 588 travelers wrote comments on their survey. To reduce the data into a manageable size, comments were categorized into 25 overall categories (Table 32). Visitors commented in more than one category. Therefore, the total number of comments is higher than the total number of visitors who made the comments. Following Table 32 is a discussion of the top five categories which received the most number of comments. All comments can be found in Appendix B.

The most likely comment to be written was a general comment about enjoying the Beartooth highway. There were 363 positive comments written by the visitors.

Table 32: Categories of Visitor Comments

Comment Categories	Frequency
General positive comments	363
Gateway communities	89
Scenic drive/beautiful drive	83
Yellowstone National Park	81
General negative comments	52
Family/Friends	48
Returning visitor / frequent visitor	48
Plan to return to region	39
Needs more signage/road improvements	37
MT/WY resident	27
Traveled Chief Joseph Highway	24
Visitor to MT/WY	20
Preservation of area / Keep it the way it is.	20
Retired	17
Smoky / Low visibility	15
Will recommend to others	14
Motorcycle riding	13
Thank you for the research	12
International traveler	11
Comments against motorcycles	6
Categories don't apply to this visitor	6
Bicycle trip/bicycled on BTH	4

*Comments could include multiple categories.

Themes

- 1) General Positive Comments** – General positive comments were seen to be the most popular type of comment category with 363 comments. This category is overwhelmingly larger than other categories listed, which is very encouraging. In contrast, there were only 52 negative comments mentioned by the visitors to the Beartooth.

Examples of general positive comments include:

"This area is awesome; I loved to drive on the Beartooth Highway and I will visit Yellowstone. Wild, impressive, to be respected."

"Enjoyed very much. Very happy we included this destination in our vacation route."

"A friend told me "this road will steal your soul!" He was right. The most gorgeous place I've ever been inside the US. Hands down!"

Thoughts – Seeing as this category saw such a large number of comments, it can be determined that many visitors thoroughly enjoyed their trip to the region. Branding this highway as a destination and not specifically a highway could increase awareness of the sights in the area. As a few visitors pointed out, they were unaware of the highway prior to their trip. This response was corroborated by the lower mean score for the Beartooth Highway as a pre-planned destination. Increasing the awareness for the region may provide a greater number of visitors (if desired).

- 2) **Gateway communities** – The category of gateway communities saw the second highest amount of comments by nonresident visitors. Comments that talked about Cooke City/Silver Gate, Red Lodge or Cody were included in this category. Eighty-nine respondents discussed one of these communities in their comment.

Example gateway community comments include:

“A group of us from college met in Red Lodge specifically to do the bike tour over the Beartooth. We had such a good time that we are planning on doing it again next year and will bring spouses and children too. Haven’t been in Red Lodge in years. Pleasantly surprised to see it all shined up and embracing tourism.”

“Came here again to visit Cooke City and for the fishing/hiking in the whole area. Beartooth Highway is a bonus!”

Thoughts – Not only do visitors come to drive/recreate on the Beartooth Highway, but they also enjoy visiting the surrounding communities that are the gateways to the region. It is important that the gateway communities embrace visitors coming to the region. The gateway communities should look for ways to collaborate to improve the visitor experience and promote the Beartooth Highway.

- 3) **Scenic / beautiful drive** – Nonresident visitors noted that they appreciate the scenic qualities and naturalness of the Beartooth Region. Eighty-three nonresident visitors commented about these scenic qualities of the Beartooth Highway. This category ranked as third highest in comments.

Example scenic/beautiful drive comments include:

“Best mountain scenery we have ever experienced. Please leave as is. We don’t need another 4 lane highway through scenic America. Slow down and take it all in.”

“Fantastic scenery, great animal watching opportunities, fascinating road construction.”

Thoughts – As expected, the Beartooth Region draws many visitors for the natural and scenic qualities it possesses. Ensuring the protection of these vistas and ecosystem should be a priority. Many visitors stressed the importance of keeping this area the way it is in order for enjoyment by future generations. If the area is marketed as a scenic region/byway, maintaining and preserving the natural quality is necessary for the visitor’s enjoyment.

- 4) **Yellowstone National Park** – Nonresident visitors frequently commented on how Yellowstone National Park was a part of their trip while along the Beartooth Highway. Eighty-three respondents commented about YNP in the mail-back questionnaire.

Example Yellowstone National Park comments include:

“Scenic highway was a high point of our trip thru Yellowstone and Grand Tetons! Only drove 3/4 of it and then turned back to go back to Yellowstone; ran out of time! Recommended sister-in-law to drive through it! Cooke City has a great visitor center! “

“Travel(ed) from Cody to Red Lodge on Chief Joseph and Beartooth Highway under blue skies and sunshine then returned a few hours later from Red Lodge to Cooke City and Yellowstone experiencing rain sleet and light snow. We had a great time. What a variety and great experience. Can’t wait to do it again.” -

Thoughts – The Beartooth Highway shares its border with one of America’s prized landmarks, Yellowstone National Park. This unique connection between the park and the highway is seen through the comments from visitors expressing a great experience between the two. Embracing this connection could facilitate and even more enjoyable experience for visitors who come to each destination. Increased awareness of the opportunity to drive this alpine highway so close to Yellowstone may enhance the visitors’ overall trip.

- 5) **General negative comments** – Even though the majority of visitors did have a pleasant experience while in the Beartooth Region, there are a number of comments regarding displeasure amongst nonresident visitors. Fifty-two nonresident travelers provided a negative comment about their trip in the region.

Example comments include:

“Needs more guardrails! Maybe another bathroom/rest area.”

“I would have liked more pullouts & unobtrusive interpretive signs (the types of vegetation, wildlife that live there, temperature extremes, history of construction, elevation, etc.) We had a map, but many may not have. A kiosk with maps would be helpful.”

Thoughts – Many of the negative comments that were written focused around improvements to signage or road safety. A better look at these issues may need to be considered. Interpretive signage had one of the lowest mean scores in terms of satisfaction in the quantitative portion of the questionnaire as well. These comments reinforce the idea that management should revisit the signage options along the road. For many the signage may be lacking and/or somewhat confusing. Scenic byways are meant to be a driving narrative for the visitor. The Beartooth Highway has a good deal of room to describe its rich heritage.

Discussion

The Beartooth Highway caters to a variety of users who may or may not have differing expectations of the region. The demographics of travelers in the region are diverse. Visitors old and young choose to travel over the nearly 11,000 ft. scenic byway. As 90 percent of travel on the highway consists of nonresidents of the three gateway counties, it is important to consider the opinions of those who are primarily using the highway. The large percentage of nonresidents using the highway indicates the importance of nonresident travel in the region. With that said, visitor experiences while on the highway tend to be positive and encouraging for those who support the highway.

In most cases highways are perceived as a travel route from one destination to another. This study, however, suggests that visitors perceive the Beartooth Region as more of a destination than a travel route to Yellowstone National Park. For many travelers, the Beartooth Highway is a destination that is part of a larger trip or is the primary destination in itself. Federal designation proved to be the most prevalent reason (31%) why travelers used the Beartooth Highway, which affirms the idea of being more than a travel route. The gateway communities of Red Lodge, Cooke City and Cody provide many amenities for travelers to make their trip a better experience. Yellowstone National Park plays a large role in the trip for many travelers as well. However, while half the Beartooth travelers also visit Yellowstone National Park, the park is not the main purpose for using the Beartooth Highway for the majority of visitors.

Travelers on the Beartooth Highway participate in a wide array of differing activities. While generally passive, the activities range in difficulty and in location in the region. An interesting discovery is that while many people are scenic driving, many feel as though they are connected to nature. The highest ranking motivation was “to view the scenic beauty (4.46)” which can be done with a car. However, the next highest ranking motivations related to the natural surroundings and to experience open spaces. As the experiences and feelings section area highlights, the fact that visitors are in a car does not affect whether or not they are connected with nature. The feelings that travelers experienced in the region and on the highway tend to be very positive and encouraging. Travelers have a sense of being happy, adventurous, awestruck, excited and comfortable while along the highway. Understanding these experiences helps put together the larger picture of the image of the Beartooth Region and allow to get a “feel” for the region.

Travelers’ beliefs about the Beartooth Highway and gateway communities were rated positively. The lowest ranking statement about the highway pertained to interpretive signage. While it was still at an “agree” level, there could be room for improvement in signage. A theme from visitor comments was focused on signage and may affirm that a more in-depth look should be considered. Visitors tend to see the Beartooth providing quality outdoor recreational opportunities, free of debris and litter, easy to navigate, and of good physical quality.

Cooke City saw the highest mean of nights spent for all visitors in the Beartooth Region, as well as for visitors who spent at least one night. This may be due to many reasons, but its proximity with Yellowstone NP is probably the main contributor. Red Lodge and Cody both had nonresident visitors spend nights in them that were visiting the Beartooth. Red Lodge and Cooke City saw more repeat visitors than first-time visitors. Cody tended to see more first-time visitors to the Beartooth than repeat visitors spending the night.

Due to the high level of agreeability, gateway communities of the Beartooth Highway should look towards promoting the unique and rich heritage of each location. Results showed this statement to either be the most agreed upon (Cooke City and Cody) or second most agreed upon (Red Lodge) out of all questions regarding the image of the gateway communities. Thus, preserving the authentic, traditional heritage and values may be important for visitors to the region. Visitors tended not to agree as much with image questions regarding new and different activities and nightlife in some of the gateway communities, but that may be expected considering the size and nature of the towns. In Cooke City, nonresidents are spending more nights in the town if they spent a night. The attributes of these towns may have an influence in the amount of nights spent in the town. However, due to the remoteness and small scale of the towns, certain attributes may be less feasible or impossible to meet the needs of most visitors.

Visitor comments represent important pieces of information that may not be included in the designed survey. Feedback from the visitors who choose to visit the region can give insight into strengths and weaknesses of the area. Travelers in the Beartooth Region had many positive comments to say about the area. The top four comment categories of general positive comments, gateway communities, beautiful/scenic drive, and Yellowstone National Park provide a glimpse into visitor's free-thought about the Beartooth Highway and surrounding region. These comments can be used by marketers, highway departments, forest managers, and gateway community leaders as ideas on how to make the Beartooth Highway a more enjoyable experience. However, negative comments were included in the top five as well, reminding everyone that there is always room for improvement. Addressing these negative comments could make for a better visitor experience.

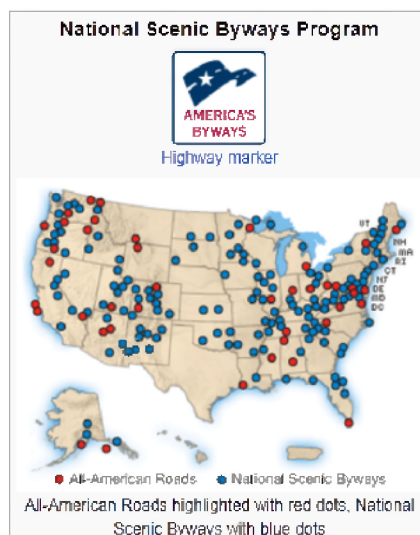
In the following section, recommendations for management will be discussed. These include observations and interpretations from data and how to improve the visitor experience.

Management Implications

- 1) Continued and enhanced collaboration between the gateway communities, the forest service, national park service, and highway departments is important. An organization such as the Friends of the Beartooth can be the agent for collaboration. Since this group represents the interest of the highway, it is easier to manage opportunities and challenges that may arise without a bias toward one or more interested party. One organization can be the communicator to all visitors about the highway conditions, closures, and opportunities for visitors. It is recommended that those communities and adjoining organizations solidify the need of an organization such as the Friends of the Beartooth by outlining goals and objectives for the highway to be carried out by the group. Joint funding by all interested parties will ensure the success of the highway.
- 2) The Beartooth Highway should not be thought of as only a travel route into Yellowstone National Park. Instead, it should be thought of and managed as a separate destination with the distinct pleasure of having a connection to a national park! Survey results showed that 32 percent of visitors were primarily traveling on the road because of its designation as a scenic road. This was the highest primary reason for being on the highway. Being designated as an All American Scenic Highway appears to be a draw. Promotion of this highway and region as a nationally designated road is paramount to continued and growing visitation levels which ultimately provide an economic boost to the gateway communities. This

study provides evidence that it is in the best interest of the gateway communities, forest service, park service, and transportation departments to support the continuation of national scenic byways.

- 3) Expansion or improvement of interpretive signage needs to be evaluated. As stated by federal designation, an “All-American Road” is to be a driving narrative for travelers on the road. An update of signage would give visitors more information regarding the construction of the highway, geology/ecology in the region, the history of the gateway communities and other various informative aspects. Through the education of visitors about the region, further support for highway and revisitation to the gateway communities may be possible.
- 4) From Fly-fishers to day hikers to scenic drivers to bikers, user groups are widespread and dynamic, but many of them have the similar motivations for recreating or traveling the highway. Each user group should be taken into account when management decisions are considered. All user groups should be encouraged to visit the area and management decisions about particular issues need to continue to take these user groups into account. Decision-making should be focused on improving the experience as a whole for all users.
- 5) As shown on the following map, there are no national scenic Byways (the blue dots on the map) in Montana and Wyoming and yet both states have some of the most scenic highways the country has to offer.



While the Beartooth All-American Road is the only designated road in these two states, this study supports the idea that designation is very important in the decision making by visitors of which routes to travel. It is recommended that both states re-evaluate their reasons for not being part of the national scenic byways program. The National Scenic Byways Program is part of the U.S. Department of Transportation, Federal Highway Administration. The program was established to help recognize, preserve and enhance selected roads throughout the United States. Since 1992, the National Scenic Byways Program has funded 3,174 projects for state and nationally designated byway routes in 50 states, Puerto Rico and the District of Columbia. While the byways program is always under the scrutiny of the U.S. Congress as a place to reduce costs, it has generally been able to defend itself as an economic

stimulator to many rural areas. Montana and Wyoming, very rural states, would gain economically from additional scenic highway designations.

- 6) In addition to point #5 above, foreigners traveled the Beartooth at a healthy rate (258 travelers or 5% of all travelers). Two things come to mind. First, foreigners are likely to note a scenic byway when making their route choice and it is well known that foreigners spend more than domestic travelers while in the states. Second, while it is a small percentage of visitors, information presented in alternative languages need to be considered in management of the area. Proper, international road signage should be considered for those travelers who may not speak English as a first language. Awareness of the issues that foreign travelers may have when traveling in the region is also important in anticipating and predicting conflict. Also, road signs need to be taken into context of the situation. Road signs that are applicable and relevant to the conditions of the highway should be a priority in a variety of languages.
- 7) Regional impact of the Beartooth Highway can be seen in towns outside of the gateway communities. Towns such as Billings, MT, West Yellowstone, MT, Jackson, WY and of course Yellowstone NP have many Beartooth travelers staying in their communities. Because these are important connector points to the Beartooth, the Friends of the Beartooth should strengthen these relationships and work collaboratively on marketing, signage, and preservation of the highway and surrounding ecosystems. All these areas can 'claim' the Beartooth thereby increasing awareness and use.

Appendix A: Survey Instruments

On-site Survey

Site ID _____ Date _____

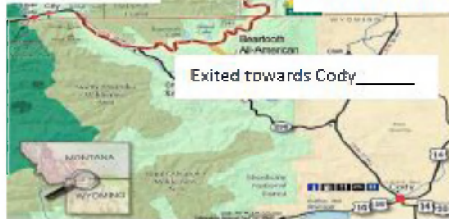
Residents of the Beartooth Hwy

1. Are you a resident of any of these counties: Carbon county, MT; Park county, MT; or Park county, WY?
___ Yes ___ No (Continue with #1A below)
a. If yes, which one? ___ Carbon, MT ___ Park, MT ___ Park, WY
2. Approximately how many times in a year do you travel on any segment of Hwy 212 between Red Lodge and the northeast entrance of YNP? _____
3. How many people are in this vehicle? _____
4. Where did you enter the Beartooth Highway? ___ Silver Gate ___ Chief Joseph ___ Red Lodge
5. Today while driving on the Beartooth Hwy, how many times will you have left highway at any of these three spots?



Exited towards YNP _____

Exited towards Red Lodge _____



Exited towards Cody _____

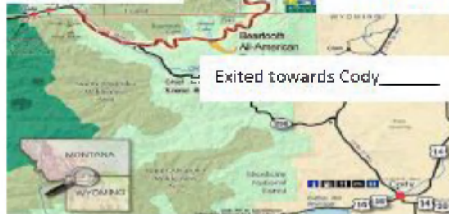
Nonresidents of the Beartooth Hwy

- 1A. If not, (from those three counties) what is your State/Province/Country of residence? _____
2. What is your zip/postal code? _____
3. How many people are in this vehicle? _____
4. On this trip, are you spending any nights in the Beartooth Hwy Region? ___ Yes ___ No
5. Where did you enter the Beartooth Highway? ___ Silver Gate ___ Chief Joseph ___ Red Lodge
6. While driving on the Beartooth Hwy today, how many times will you have left highway at any of these three spots?



Exited towards YNP _____

Exited towards Red Lodge _____



Exited towards Cody _____

Mailback Survey

Beartooth Highway Visitor Survey

The Beartooth Highway (Hwy 212) runs between Red Lodge, MT and Silver Gate, MT.

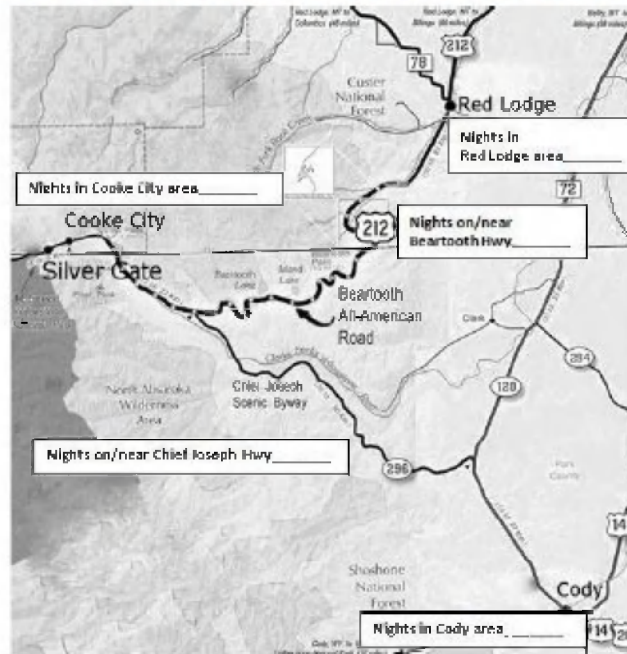
On this trip, what was your mode of travel along the Beartooth Highway?

- ☐ Car/Truck
 ☐ RV
 ☐ Motorcycle
☐ Car/Truck w/ trailer
 ☐ Bus
 ☐ Bicycle

During your travels along the Beartooth Highway, how often were you the driver of your mode of travel? (Please tick the box that best represents your answer)

- ☐ Not at all
 ☐ Infrequently
 ☐ About half
 ☐ Often
 ☐ All the time

Please indicate on the map the number of nights you spent in/near any of the three gateway communities as well as on/near the Beartooth Highway. Write in "0" if you did not spend a night in any of these five areas.



For this trip to the Beartooth area, please indicate the amount spent and where you spent those dollars.

	Along the highway	Red Lodge, MT	Cody, WY	Cooke City/Silver Gate
Camping	\$	\$	\$	\$
Hotel/motel	\$	\$	\$	\$
Ranch/B&B/rental cabin	\$	\$	\$	\$
Gasoline/oil	\$	\$	\$	\$
Restaurant/bar	\$	\$	\$	\$
Groceries/snacks	\$	\$	\$	\$
Retail/souvenirs	\$	\$	\$	\$
Outfitters/guides	\$	\$	\$	\$
Auto/RV repair	\$	\$	\$	\$
Auto/RV rental	\$	\$	\$	\$
Transportation fares	\$	\$	\$	\$
Entrance fees, admissions, licenses	\$	\$	\$	\$
Services (i.e. medical, hair cut, massage)	\$	\$	\$	\$
Other (describe below)	\$	\$	\$	\$
Description of other expenses:				

In which of the following locations did you spend at least one night away from home on this trip? (Please check all that apply)

- ☐ Yellowstone Natl Park ☐ In or near Jackson, WY ☐ In or near Bozeman, MT ☐ In or near Gardiner, MT
☐ Grand Teton Natl Park ☐ In or near West Yellowstone, MT ☐ In or near Livingston, MT ☐ In or near Billings, MT

I used the northeast entrance of Yellowstone National Park to/from the following communities... (Please "X" in the box if you drove from any of these cities)

- ☐ Cody, WY ☐ Red Lodge, MT ☐ Cooke City, MT ☐ N/A

I drove the Beartooth Highway because... (check all that apply)

- ☐ 1. It is a designated scenic road ☐ 5. I heard it was a pretty drive
☐ 2. It was the shortest route to my destination ☐ 6. It was recommended to me
☐ 3. It was my access to recreation along the road ☐ 7. An electronic map suggested the route (e.g. GPS, Google maps, Garmin, etc.)
☐ 4. It is the road to Yellowstone National Park

Of the reasons you checked above, which one was the PRIMARY reason? (Check only one box)

- 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

Prior to this trip, approximately how many times have you visited the Beartooth Highway Region including the gateway communities?

On this trip, did you travel over the Beartooth Pass?

- ☐ Yes ☐ No

While driving the Beartooth Highway on this trip, please describe the weather you experienced. (Please "X" the box that best represents your answer)

Amount of precipitation	None ☐	Little ☐	Some ☐	Frequent ☐	Heavy ☐
Outdoor Temperature	Cold ☐	Cool ☐	Moderate ☐	Warm ☐	Hot ☐
Amount of Wind	None ☐	Slight Breeze ☐	Some Wind ☐	Windy ☐	Very Windy ☐
Degree of Visibility	Could Not See Anything ☐	Low Visibility ☐	Moderate Visibility ☐	Good Visibility ☐	Crystal Clear ☐

How much time were you out of your vehicle or off your bike along the Beartooth Highway? (Please "X" the box that best represents your answer)

- ☐ Never ☐ Less Than 1 Hour ☐ 1 - 2 Hours ☐ 1/2 Day ☐ Full Day ☐ More than 1 Day

Indicate your agreement level on the following questions or statements. (Please "X" the box that best represents your answer)

	Strongly Disagree	Disagree	Agree	Strongly Agree
In planning this trip, the Beartooth Highway was a main destination.	☐	☐	☐	☐
I plan my travel routes to include scenic byways, like the Beartooth Highway.	☐	☐	☐	☐
I would travel the Beartooth Highway again in the future.	☐	☐	☐	☐
I would like to visit Red Lodge, MT in the future.	☐	☐	☐	☐
I would like to visit Cooke City, MT in the future.	☐	☐	☐	☐
I would like to visit Cody, WY in the future.	☐	☐	☐	☐
I would recommend others to travel the Beartooth Highway.	☐	☐	☐	☐

The Beartooth Highway is/has... (Please "X" the box that best represents your answer)

	Strongly Disagree	Disagree	Agree	Strongly Agree
...of good physical quality.	☐	☐	☐	☐
...safe and secure to drive on.	☐	☐	☐	☐
...easy to navigate.	☐	☐	☐	☐
...free of debris and litter.	☐	☐	☐	☐
...too crowded.	☐	☐	☐	☐
...ample number of pullouts.	☐	☐	☐	☐
...good interpretive signs.	☐	☐	☐	☐
...a variety of outdoor recreational opportunities.	☐	☐	☐	☐

Please describe the variation of your thoughts and feelings while traveling the Beartooth Highway on this trip.
(For each pair of descriptive words below, please "X" one box per line that best represents your answer)

01. Relaxed	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Stressed
02. Bored	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Excited
03. Calm	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Nervous
04. Sad	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Happy
05. Disappointed	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Awestruck
06. Unfounded	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Crowded
07. Comfortable	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Afraid
08. Reserved	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Adventurous
09. Visually Bored	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Visually Stimulated
010. Quiet	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Noisy
011. Smelled the fresh air	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Did not notice the fresh air
012. Connected to nature	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Disconnected from nature

Please indicate activities in which any member of your travel group participated while along the Beartooth Highway. ("X" at the top)

☐ Camping	☐ Wildlife Watching	☐ Canoeing/Kayaking	☐ Sledging/snowboarding
☐ Backpacking	☐ Mountain biking	☐ Fishing/fly fishing	☐ Cross Country skiing
☐ Day hiking	☐ Motorcycle riding	☐ Sporting event	☐ Snowmobiling
☐ Horseback riding	☐ Road tour biking	☐ Historical site	☐ Sledding
☐ Nature photography	☐ Scenic driving	☐ Interpretive site	
☐ Hunting	☐ ATV/CHV	☐ Festivals/events	
☐ Birding	☐ Motorcycling	☐ Snowmobiling	

On this trip, did you visit Red Lodge, MT for one hour or longer? ☐ Yes ☐ No (Skip questions about Red Lodge, MT)

Red Lodge, MT provides... (Please "X" one box per line)

...authentic shopping opportunities.	☐ Strongly Disagree	☐ Disagree	☐ Agree	☐ Strongly Agree
...unique and rich heritage.	☐	☐	☐	☐
...exciting nightlife.	☐	☐	☐	☐
...opportunities to experience local cuisine.	☐	☐	☐	☐
...opportunities to engage in local culture.	☐	☐	☐	☐
...places to purchase local arts/crafts.	☐	☐	☐	☐
...new and different activities.	☐	☐	☐	☐
...a welcoming experience.	☐	☐	☐	☐
...a relaxing feeling.	☐	☐	☐	☐
...a crowded feeling.	☐	☐	☐	☐

On this trip, did you visit Cooke City, MT for one hour or longer? ☐ Yes ☐ No (Skip questions about Cooke City, MT)

Cooke City, MT provides... (Please "X" one box per line)

...authentic shopping opportunities.	☐ Strongly Disagree	☐ Disagree	☐ Agree	☐ Strongly Agree
...unique and rich heritage.	☐	☐	☐	☐
...opportunities to experience local cuisine.	☐	☐	☐	☐
...exciting nightlife.	☐	☐	☐	☐
...opportunities to engage in local culture.	☐	☐	☐	☐
...places to purchase local arts/crafts.	☐	☐	☐	☐
...new and different activities.	☐	☐	☐	☐
...a welcoming experience.	☐	☐	☐	☐
...a relaxing feeling.	☐	☐	☐	☐
...a crowded feeling.	☐	☐	☐	☐

On this trip, did you visit Cody, WY for one hour or longer?

☐ Yes

☐ No (Skip questions about Cody, WY).

Cody, WY provides... (Please "X" one box per line)

	Strongly Disagree	Disagree	Agree	Strongly Agree
...authentic shopping opportunities.	☐	☐	☐	☐
...unique and rich heritage.	☐	☐	☐	☐
...opportunities to experience local cuisine.	☐	☐	☐	☐
...exciting nightlife.	☐	☐	☐	☐
...opportunities to engage in local culture.	☐	☐	☐	☐
...places to purchase local arts/crafts.	☐	☐	☐	☐
...new and different activities.	☐	☐	☐	☐
...a welcoming experience.	☐	☐	☐	☐
...a relaxing feeling.	☐	☐	☐	☐
...a crowded feeling.	☐	☐	☐	☐

What are your reasons for visiting and traveling the Beartooth Highway? (Please "X" one box per line)

	Not at all important	Somewhat important	Moderately important	Very important	Extremely important
To view the scenic beauty.	☐	☐	☐	☐	☐
For family recreation.	☐	☐	☐	☐	☐
To be with friends.	☐	☐	☐	☐	☐
To tell others about the trip.	☐	☐	☐	☐	☐
To get away from the usual demands of life.	☐	☐	☐	☐	☐
To experience solitude.	☐	☐	☐	☐	☐
To enjoy nature.	☐	☐	☐	☐	☐
To bring your family closer together.	☐	☐	☐	☐	☐
To do things with members of your group.	☐	☐	☐	☐	☐
To have others know you have been there.	☐	☐	☐	☐	☐
To have your mind move at a slower pace.	☐	☐	☐	☐	☐
To experience open space.	☐	☐	☐	☐	☐
To experience a natural surrounding.	☐	☐	☐	☐	☐
To do something with your family.	☐	☐	☐	☐	☐
To be with others who enjoy the same things you do.	☐	☐	☐	☐	☐
To have thrills.	☐	☐	☐	☐	☐
To reduce the feeling of having too many things to do.	☐	☐	☐	☐	☐
To experience more elbow room.	☐	☐	☐	☐	☐

What is your age?

What is your gender?

☐ Male

☐ Female

Are you a domestic or international traveler?

☐ Domestic

☐ International

What is your highest completed level of education? (Please "X" only one box)

☐ Some High School

☐ Some College

☐ Masters Degree

☐ High School Diploma or the equivalent (GED)

☐ Associates Degree

☐ Doctorate or Professional Degree

☐ Bachelors Degree

What best describes your household annual income in US dollars? (Please "X" only one box)

☐ Less than \$25K

☐ \$50K to less than \$75K

☐ \$100K to less than \$150K

☐ \$200K or greater.

☐ \$25K to less than \$50K

☐ \$75K to less than \$100K

☐ \$150K to less than \$200K

Please provide any additional comments:

Thank you!

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Appendix B: Open Ended Comments

A group of us from college met in Red Lodge specifically to do the bike tour over Beartooth. We had such a good time that we are planning on doing it again next year and will bring spouses and children too. Haven't been in Red Lodge in years. Pleasantly surprised to see it all shined up and embracing tourism
A lot of the questions would have been better answered with an N/A because we were just going to lunch within YNP.
An n/a box for some items would bring out more truth. Eg I did not care about night life or local crafts, but agree/disagree does not measure that.
Absolutely beautiful drive, we loved it and would highly recommend it. Only suggestion would be to provide more advance notice of some of the more scenic pullouts.
Also bicycled the road
Although we did not do the complete Beartooth Road this trip, we have drove it in the past several times. The views are breathtaking. The drive exhilarating, and walking just a short distance is relaxing and helps you connect to nature. Gives you a sense of solitude.
America the Beautiful!
An absolutely awesome highway; would return in a heartbeat if I didn't live to far away in CT.
An awesome vacation!
And thank you!
Annual income should not be apart of this survey. Had that been first I would not have completed this survey.
Answers for our reasons for traveling the Beartooth Highway seem to indicate that we did not enjoy it, however, we wanted to see the Chief Joseph and needed to go over B.H. to get back home. We do enjoy the B.H.!
As a divorced parent, in a dating-after-divorce relationship, my boyfriend and I saw this trip as a bit of a test of our relationship and how our two boys would do as brothers in the future. What an amazing positive experience! I think we passed the test!
As previously stated, we went over the Beartooth mostly because it was the shortest route to Red Lodge where our friends live 4 miles out of town. It was a beautiful drive. We are from CO and drive the mountain a lot.
Asked my sweetheart that I dated while I was in the air force in A62 to marry me at the wyoming creek. She said yes! I was raised 9 miles west of Red Lodge.
Awesome hwy and I plan to return.
Awesome place, love the effort you people put it and wish you success in your future endeavors.
Awesome Sites!
Awesome! Will be recommending it to friends!
Awestruck - alpine beauty!
Bathrooms at the top of the world were filthy, very surprised to see that. Also Red Lodge needs nicer hotels. Comfort Inn was unsatisfactory, musty odors, etc.
Beartooth highway and mountains is the great American experience.

Beartooth Highway has always amazed me. I have returned many times since my first visit in 1984. I hope it stays the same forever.
Beartooth highway is an awesome road. Love the scenic vistas and the beauty of the high country! Need to drive it more often.
Beartooth Highway is best route for Cody to Mammoth Hot Springs, least traffic, great scenery. Cody is used to restock the RV.
Beartooth Highway was beautiful but needs more signs (elevation, names, distance, maybe buried by snow?). Cooke City - Tense, unfriendly town. Felt like they just wanted to get you in, take your money, move you out. Food was over \$35. Gas 4.29 per gallon. 4.00 for a sticker. No incentive to stay in Cooke over Yellowstone. Inside the park much cheaper. Gas was 4.09. Meals were cheaper and the friendliest staff we have ever encountered. Still very beautiful. Good luck!
Beartooth mountains are awesome, beautiful.
Beartooth Pass drive was very pretty drive. Late summer so traffic was not much.
Beartooth Pass is awesome!
Beartooth Pass was a beautiful and exciting experience! Good luck w/ your thesis!
Beartooth was a beautiful drive. We would recommend to others.
Beautiful drive and one of the best experiences of the trip.
Beautiful drive! Cody is a nice town. Great steak at the chop house.
Beautiful drive, but just passing through en route to Yellowstone.
Beautiful drive. Parents had crossed Beartooth Pass 50 years ago. Spent 5 days visiting YNP.
Beautiful drive. Will be back to do some hikes in the future.
Beautiful from N.C. Would love to come again!
Beautiful Highway!
Beautiful Hwy also very beautiful chief Joseph Hwy and wonderful way to bring us to Cody.
Beautiful Montana/Wyoming Byway!
Beautiful ride, too bad the smoke caused a haze which lessened the impact of the view.
Beautiful scenery, wonderful experience. Spent 1 night in Billings and 2 nights in West Yellowstone.
Beautiful scenery.
Beautiful trip over Monster Mountain was scary for me. I'm scared of heights! God's handiwork is awesome!

Beautiful Trip!
Beautiful views! We enjoyed Red Lodge and wish that we could have spent more time there.
Beautiful way to drive to Yellowstone. Good luck on your thesis!
Beautiful way to exit Yellowstone!
Beautiful! Awesome! Good luck on your Masters.
Beautiful, exciting drive, but AAA trip time estimates are way off. Would be useful to let them know!
Being retired I plan all my trips after most peoples' vacation time. (Summer months)
Best mountain scenery we have ever experienced. Please leave as is. We don't need another 4 lane highway through scenic America. Slow down and take it all in.
Best of luck!
Best of success to you!
Best wishes for completion of your Master's thesis Jake.
Best wishes on your great work!
Best wishes on your survey and thank you for the opportunity to drive "the most beautiful" road I have ever traveled!
Best wishes with your statistical analysis!
Between Red Lodge & Yellowstone it would be nice to have road fully open.
Breathtaking drive. Please don't make it "safer"
Cabin owner in Cooke City.
Came from Michigan to Red Lodge. Came to race in the Sept. 8th Yellowstone alpine Klymb. A 141 mile bike race over Beartooth and Chief Joseph Pass.
Came here again to visit Cooke City and for the fishing/hiking in the whole area. Beartooth Highway is a bonus!
Camp sites and hotels are expensive.
Camped overnight at Keyser Brown Lake - Awesome!
Chief Joseph Hwy needs repair! The tar strips are extremely dangerous to motorcycles - someone is going to get hurt or killed if you don't repair it.
Conditions were smokey because of fires so visibility was not as good as usual.
Congrats on your thesis! Keep going!
Cooke City does not seem welcoming to visitors. It should be a destination for visitors to Yellowstone. Good luck with your master's degree.
Cooke City is the hidden gem of the Park area. Need to promote better. No one has heard of it!

Did a day trip from Billings. Up Chief Joseph to Cooke City then down to Red Lodge over the Beartooth Highway.
Did my best even though we only visited Cooke City for one night. Then returned down to Lamar Valley, so we didn't really fit the questionnaire really. Though visiting Cody we came from Canyon Lodge.
Did not see summit sign. Add geologic ages of rocks. We were traveling from Bozeman, MT to Ft. Collins, CO. Wanted to travel a scenic highway rather than the interstates.
Didn't check all of the boxes because some of them don't apply. I'm single so no family.
Difficulty in finding out when Beartooth Highway was open after snow clearance. Better communication required.
Disappointed in number of animals seen while on the Beartooth Hwy. Beautiful view from the top and along the way, both sides.
Do not care for grizzly bear threat when camping. Get rid of grizzly bears.
Don't ever change this road! I love the curves and turn just the way it is.
Don't let Montana kill wolves and Bison! Wildlife is the #1 reason I visit the areas.
Don't vote for Obama! I wish I had purchased souvenir t-shirts in Cooke City, as the prices, selection and quality were better than within Yellowstone Park.
Drive across the Beartooth was a conjunction with a visit to Yellowstone. We bought breakfast in Gardiner and gasoline in the park. Our stops on Beartooth were to recreate outside.
Drive was nice. Was just passing through and hope to spend more time in area in future.
Drove through on our way from Billings to Yellowstone.
Enjoy seeing the wildlife even when I'm not carrying a rifle.
Enjoyed Beartooth Highway. With snow on the mountains, it was very scenic (13 June, 2012).
Enjoyed photography at lakes.
Enjoyed the day trip - next we will be to Cody and the Western museum.
Enjoyed the sights and animals along the Beartooth Hwy. This road was an afterthought in our plans to see Yellowstone. It was a different way to head home.
Enjoyed very much. Very happy we included this destination in our vacation route.
Enjoyed visiting with the young guy conducting the survey!
Every chance I get, I take guests up the pass. I live in Billings so aware of the guest community questions are not relevant.
Fall is the best time of the year to enjoy the Beartooth Pass after Labor Day Weekend. A lot less traffic and cooler weather.

Fantastic scenery, great animal watching opportunities, fascinating road construction.
Finances were taken care of by 58 year old father who was riding with. 2 nights backpacking at East Rosebud.
Finding roads narrow for RV travel, driver cannot relax at all. Would love to travel the Beartooth Hwy and pass, but not in an RV! Signage in Western USA not helpful to overseas tourists.
First time area without travel trailer, wanted to travel new routes to daughter in Driggs, ID.
First time in the mountains. It was great! Did not plan to go this way. Glad we did.
Fishing trip with my 40 Yr. old son.
Friends from Fishtail, MT recommended. We are from NY State.
From Las Vegas, NV
From N.C. rented care especially for the ride due to traveling in a motor home.
From Virginia. This scenic byway was told to us by a close friend. Took him for his word in fact recommended we start at the Northeast gate. We did every entrance to park Beartooth twice and Beartooth scenic drive was more spectacular than Yellowstone. Will recommend to all who come West.
Give Jake a passing grade.
Glad to help with the survey. Good luck with the project.
Go Bobcats!
Go Grizzlies!
God and the engineers and builders did a good job.
Good luck - we appreciate this opportunity. Thanks for the great experience.
Good luck and hope you find what you're looking for.
Good luck for your master thesis from Germany! The Beartooth Hwy is described in our travel book!
Good luck from the UK! Jake Jorgenson it was a pleasure to meet!
Good luck Jake!
Good luck Jake!
Good luck on the survey and your thesis!
Good luck on your efforts to get your degree.
Good luck on your Master's degree!
Good luck on your Masters degree. This area was amazing, loved it, even though parts were scary.
Good luck on your masters program.
Good luck on your Master's thesis!
Good luck on your master's thesis!
Good luck on your Masters!
Good luck on your project!
Good luck on your research.
Good luck on your research.
Good luck on your thesis!

Good luck on your thesis!
Good luck on your thesis!
Good luck on your thesis!
Good luck on your thesis! Thanks for caring!
Good luck on your thesis! Will be checking the results!
Good luck on your thesis. Glad we could help!
Good luck using this info.
Good luck with paper.
Good luck with your Masters degree!
Good luck with your Masters degree!
Good luck with your masters.
Good luck with your project. I graduated from Utah state in 1986 with B.S. in Forestry.
Good luck with your research project. Hopefully this will help you out.
Good luck with your research!
Good luck with your studies!
Good luck with your survey and thesis! Say hi to Wayne and the gang.
Good luck with your survey. Go Griz!
Good luck with your thesis
Good luck with your thesis and your future!
Good luck with your thesis!
Good luck with your thesis!
Good luck with your thesis!
Good luck with your thesis!
Good luck with your thesis!
Good luck with your thesis!
Good luck with your thesis! An additional part of our experience on the Beartooth Hwy was spent geocaching, which wasn't on the form.
Good luck with your thesis! It's worth it!
Good luck!
Good Luck!
Good luck!
Good luck!
Good luck!
Good luck!
Good luck!
Good luck!
Good luck!
Good Luck!
Good luck!

Good luck!
Good luck! Enjoyed the drive.
Good luck, hope this helps!
Good luck, Jake and ITRR. Very professional when greeting and explaining! We'll be back.
Good luck, Jake!
Good luck.
Good survey - should perhaps add more "Don't Know" Or "does not apply" selections.
Good Trip!
Gorgeous drive! We were here in late September and everything was wonderful!
Great area for road trip.
Great drive. Some views were hazy due to smoke from wildfires.
Great Road! Put elevation signs up along the road.
Great scenic road didn't have enough time to visit towns and cities here.
Great survey. Good luck finishing your M.S.
Great trip for early September.
Great trip!
Great trip!
Great trip! Had a wonderful time! Beautiful country!
Great trip! Will return next year.
Great trip.
Grew up as a child going to YNP via Cooke City from Bridger, MT. Been to YNP 100's of times since a baby.
Grew up driving it!
Had a good ride on my motorcycle.
Had an awesome time. Will recommend to everyone. Good luck with your research.
Had my windshield broken in Yellowstone due to careless road repairs, construction of loose gravel over tar. Stones were flying everywhere. The Park could have prevented this by thinking in advance.
Happy we traveled Chief Joseph Scenic Byway, beautiful country even though we did not go up to Red Lodge.
Harley Davidson Motorcycles are pretty annoying. Riders can be nice, but they are loud and kind of scary.
Have been across 12 times on a motorcycle.
Have fun with you Master's project!
Have fun, stay safe. Say hi to your coworker, keep smiling, get a good job, pay s.s.
Have lived in general area all my life. 1st time on highway and will tell others about trip and will visit again for sure.

Have seen Beartooth Pass written up in magazines. Highly rated, should invite PBS or Nat Geo with direction to make a documentary of the building and use of the BTH - I find it interesting that the Swedish engineers designed the road. No where do you ask where the traveler is from, it might make a difference someone from CO might be half as impressed as someone from the East Coast.
Have tried to do the pass for 17 years and it's never been open for me. Was told in AM at Red Lodge. We bypassed via 298 a nice route, but still not open over the pass. Will try to make it before I die.
Have used the Beartooth for my whole life - own cabin up there.
Haze from fires detracted. Lack of animals also a disappointment.
Heck of a ride!!
Here on vacation from Ireland for 2 weeks, flew into Denver for fly/drive. Very enjoyable experience, Best of luck on your thesis.
Hope this helps but some of the questions seem irrelevant.
Hope this helps in your schooling.
Husband loved the drive. Our second time through. Although his fingers cramped holding the wheels. Daughter wanted to see Cody and agreed to drive to visit Red Lodge. Good luck on your paper.
I am a Billings resident. I motorcycle the BTH 5-6 times a year; alone or with other cyclists.
I am a resident of Silver Gate July through October each year. I have been since 2001.
I am an international traveler from China with my four friends. Beartooth Highway (212) is the most thrilling experience in our 7-day stay in Yellowstone and the nearby area.
I am Australian!
I am from Japan, I don't understand the expression "elbow room."
I am here working, doing wetland ecological condition assessments.
I did not expect such a mountainous drive, therefore I was a little stressed and nervous to get to Billings in time.
I do believe that Montana would benefit by promoting wildlife north of Yellowstone and maybe have an area they can attach to Yellowstone sightseeing.
I enjoyed the survey! Good luck!
I feel sorry for people who have not experienced the Beartooth Hwy grandeur.
I had an athletic student staying at my home and thought he needed to see the Beartooths before he went back to Iowa. Need port potties along the way.
I had just one suggestion; we missed the turn-off for Greenough Lake campground, no signage from highway.
I have been on the Beartooth Highway previously and have enjoyed all parts of the roads and cities. This particular trip happened to be a much shorter drive-through.

I have been traveling this area for close to 30 years, when Dead Indian Pass was rock and gravel. The key issue for me now is having nice bathrooms and a sign as to the next one might help.
I love driving Beartooth Pass on my motorcycle. I think it's one of the top 10 motorcycle rides in America. However, this was not a motorcycle trip.
I love going to Yellowstone Park and the Beartooth Highway is the most scenic. We have gone there at least 2 times a year since 1966.
I love the Beartooth Highway & when I die I tell my wife and kids to sprinkle at least some of my ashes along the pass.
I love the mountains! The rodeo was great in Red Lodge!
I produced a housing conference in Cody for 4 days and then met friends to do some camping and biking on the Beartooth and Chief Joseph Highways.
I ride my motorcycle on the Beartooth Highway for the scenery and to appreciate the amazing resources we have as Americans. I bring my family here to vacation, as they love the paces and wonderful views. As an aside: do not discount the power of internet forums to influence travelers' decision o travel on the Beartooth. (mctourer.com)
I saw the Beartooth Pass on the computer and felt it would make a good motorcycle ride from Minnesota. It did and I will be back!
I spent nothing in camping or hotels because I backcountry camped the whole time. It was the most awesome experience I have ever had.
I think that having motor vehicles and bicycles on Beartooth Hwy is extremely dangerous.
I thoroughly enjoyed the Beartooth Highway especially after the crowds in Yellowstone! It was breathtaking in beauty and so grand, quiet and peaceful. I will return! And would like to spend more time in Red Lodge and Cooke City. Do not advertise the Beartooth Highway!
I travel alone so it would be helpful for some of the questions about family to have n/a.
I traveled the CHJ to see the scenery. This was not so important on the western part of the Beartooth Highway because I had seen it before. At that point, the highway was merely a means to get from Point A to Point B. I did enjoy the scenery a second time, but that was secondary. I primarily wanted to see the scenery I hadn't seen before: Bighorn Canyon, Medicine Wheel, Chief Joseph Byway, Climb Mt. Washburne and hike to Union Falls.
I wanted to use the NE entrance to see sight and wildlife. It was closed the year before.
I was disappointed with the visibility because of the smoke from the fires. A ranger told us if we came at the end of May we would most likely not have the smoke to deal with. We hope to come again.
I was familiar with Chief Joseph as I am a historian. The highway was a highlight of our trip, and I will recommend this passage.
I was in Red Lodge for a meeting. Everyone recommended the BTH, so I took it, even though it took me several hours out of my way home to Kansas. I also loved the Big Horn pass
I was in the fun bicycle race on 9/8/12
I was moved to tears by the sensational vistas of the Rocky Mountains along the Beartooth Pass.

I was raised in Cody and now live in Billings. Was traveling by myself and have been on this highway and in Yellowstone numerous times.
I was really amused by the beauty and wonder of the Beartooth area.
I was thrilled to see and photograph a mountain goat up close.
I was traveling alone, but I think families would enjoy the road. I was surprised to find lodging in Cooke City. Would consider staying there in the future. Maybe should advertise more as an alternate to Jackson. Had a nice lunch at a small cafe in Cooke City. I enjoy the many non-chain options. Good luck with your thesis!
I went to the top of the pass to back country ski. Beautiful!
I will recommend this route to anyone traveling to the area. It was absolutely beautiful!
I will return to travel the Beartooth Highway I am sure.
I wish someone would do a survey on Yellowstone. Yellowstone is overrun with trash, stomped down grass, way too many people, and baby diapers. Find a way to keep the Beartooth area pristine and uncrowded!
I would have liked more pullouts & unobtrusive interpretive signs (the types of vegetation, wildlife that live there, temperature extremes, history of construction, elevation, ect.) We had a map, but many may not have. A kiosk with maps would be helpful.
I'd spend more time hiking if not for the grizzly bears.
If we did not have time constraints and young children we would have hiked more!
I'm a full-time RVer. I wander wherever something sounds interesting.
I'm afraid this isn't helpful because we used to live in the area so long. We love all this area has to offer and bemoan the number of people who "drive through" without appreciating the beauty.
I'm sure there are plenty of opportunities to do more than we did, just wasn't on our schedule. First time to Cooke City, enjoyed it. 2nd trip to Red Lodge and Cody. Like both places.
I'm traveling through the US in 3 months. Beartooth Highway has been one of the absolute highlights! It's great!
In general, US country is a very good example of respect, nature, wild environment, courtesy and friendly people approach. Thank you!
Income in combination of working at what we love and investment income. Day trip from Whitehall, MT through Yellowstone with family visitors.
Intro letter says random sample, assistant was attempting to wave everyone into survey, but only those stopping pulled off and once pulled off, only those willing to participate stopped to receive survey. 2 components of selection/participation bias. Good Luck!!
Investing in guardrails on the BTH would be helpful.

It is always exciting to see the skies, mountain goats. Just a beautiful drive.
It was a beautiful day trip. We try to do it every year since that we live in Columbus. Have brought many family members here from back East and Washington.
It was a beautiful drive - we are glad we took the time to do this.
It was a gorgeous surprise - loved it and loved the Beartooth Cafe.
It was a lovely trip in spite of heavy smoke from Idaho fires. The Buffalo Bill Museums are fantastic and the mountains are exceptional.
It was an enjoyable road while we were on it, but our primary reason was it was the most logical connection from NE entrance to Cody.
It was an unexpected adventure, did not know it would be like we saw. Our god is an awesome god!
It was beautiful - need more cabins at lower rates! (primitive would be fine).
It was beautiful, traveled from Gardiner and the Chief Joseph Hwy. Really loved it. Did not go over the Beartooth. Next time! Good luck Jake!
It was raining on the West entrance, foggy at Beartooth Pass. Clear on the east side. Visibility was low at the pass. Our travel was from Hardin, MT to Yellowstone.
It was very enjoyable to see the Beartooth mountains. Family took me up there while I was on vacation.
It was very smoky on the top of Beartooth, but enjoyed our trip.
It would be nice to see elevation levels or did I miss them? Beautiful ride, glad we did it.
It would make the drive more interesting if more signs giving elevation were in place (i.e. as in Yosemite and Death Valley and others). But wow! What an awesome drive, never forget the day we drove the Beartooth Highway!
It's a great highway. I always try to fit it in my schedule since parts have been rebuilt. It is so nice it's too bad you end up at Yellowstone though.
It's always an interesting ride.
It's simply a beautiful place to be and travel through.

I've been here before and was on a road trip with my brother and I wanted him to see it. He loved although he states that I didn't stop enough.
I've been on winding roads that had no guardrails. This highway made me feel safer and the road was in excellent condition.
Jake - Good luck with your thesis!
Jake good luck with your study! Nicely done!
Jake Jorgenson did a great job of representing the University of Montana. Thanks to him from an Alum - Class of '75.
Jake Jorgenson was a very personable young man, so happy to help him.
Jake, good luck!
Just a weekend ski trip from Bozeman so many questions didn't apply.
Just driving through on our way from NC to Alaska. Good luck dude!
Last time in Cooke City was 1974, while still a small town. It sure has gotten larger. Hoping to drive through again next year.
Leave Cooke City/Silver Gate alone! We go there because West Yell/Cody/Red Lodge/Jackson is just like any tourist trap.
Live in Billings; travel the Beartooth/Chief Joseph highway a couple of times each year, because of the scenery.
Live in northwest Indiana. Been to YNP 2 times and used the Beartooth Highway both times.
Looking forward to riding the Beartooth Highway on a motorcycle next year with other riders.
Lots of bikers and too loud engines. Kind of ruined some hiking/picnicking. Too many mosquitoes!!
Love Beartooth Highway and Yellowstone Park.
Love BTH! Motorcycles are quite loud though. Take away from experience, lots more could be done with interpretive signs. (I.e. geology, rock slides, plants, building of the road).
Love nature! I am a nature photographer. Loved your place!
Love the Beartooth Highway and the area! Good luck with your thesis!
Love the Beartooth Pass. Some like more pullouts and nice rest area near the top last time I was here.
Love the Beartooth Wilderness. Wish I had more time to go on a long hike, but the drive gets you a good view in limited time. Good luck on your master's thesis!

Love the drive, beautiful!
Love the nature!
Love the park!
Love to do it again - only next time from east to west.
Loved it!
Loved it! Stayed in Billings with son who moved there. Did visit Cody on another day. You have one of the most beautiful states ever! Keep it that way!
Loved motorcycling the Beartooth. Stayed in Red Lodge 2 Nights. Ate in Cooke City.
Loved that there was no graffiti or rubbish lying around.
Loved the Beartooth Highway!
Loved the scenic roadway, God's awesome creation!
Made decision to take Beartooth Hwy only day before based off recommendation by visitor center in Eastern MT. The route very much enhanced our road trip across country.
Masters candidate we met quite polite, knowledgeable. We had a great trip and will be back!
May God bless you and U.S.A. Beartooth Hwy is the great scenic byway, travelling in the USA is the great thing. We feel wonderful.
Montana is a beautiful state and I hope to return in the future.
Montana is a great place and just absolutely gorgeous.
More altitude markers.
More awesome than I remembered it.
More informed interpretive signs; natural history, pioneer/explorer/ highway construction, native American history, geology, signs prohibiting tractor/trailer traffic.
More scenic views with parking.
More signage needed describing natural resources and indicating hiking trails and scenic viewpoints.
More signs at summit. Elevation and mt. names.
Most beautiful drive anywhere! More signage needed to remind tourists not to stop on the roadway, more turn-outs needed! More informative signage needed as to formations and history!
Most beautiful highway to ride a motorcycle! We'll be back.
Most likely once in a lifetime visit.
Most of our journey was on the Chief Joseph Scenic Byway from Cody to enter Yellowstone at Northeast Entrance. So only short distance on Beartooth. Answers reflect the short distance.
Most terrifying drive ever. On the map it looked like a short drive to Billings, it didn't show all the switch backs.
Motorcycles are too loud! Way too loud!

My answers are based on the 11 days we have been at Hunter PK ranch. We will be here for a total of 21 days. We plan to visit Yellowstone park both this next week.
My answers may be a bit skewed - especially the part about expenditures. My parents live in Cooke City in the summer so I visit a lot but don't spend much often times.
My family and I have been driving the Beartooth Highway since 1941.
My family and I have traveled the pass in the past and camped overnight.
My family has owned cabins near the intersection of the BTH and Chief Joseph highway for 76 years. I vacation there almost yearly 1 week to a month in the summer time.
My family loves driving through the Beartooth Highway! We look forward to it every year!
My grandpa lives in Cody, WY and my uncle lives in Jackson. My mom grew up in MT and WY. I have lived in NC my whole life. I try to visit my family every 3-5 years.
My husband and I have always wanted to visit Yellowstone. We have had a fantastic time and Beartooth pass was an unexpected but very exciting bonus.
My husband and I were celebrating our 38th anniversary. It was wonderful!
My husband, daughter and I loved the visit. We live in Gillette Wyoming 39 years ago. We love the people and the wonderful views and wildlife. My husband has a Doctorate and gave a lecture at Redcreek Lodge. Thank you!
My husband's parents built a cabin on the Clark's Fork of the Yellowstone in 1949, so he has been coming to this country to fish since he was 11 years old.
My main reason for traveling the Beartooth Hwy is to reach the many trailheads for backpacking.
My second trip and my wife were along. My first trip was in 2011 and by motorcycle and alone. Both trips were great.
My sister-in-law has a cabin in Silver Gate. We come up fairly often to spend time with her and her husband is a good friend. I came alone this time to spend time with the husband.
My wife and I are Billings residents. We travel the Beartooth Highway several times yearly to visually enjoy and photograph the area.

My wife and I drove from Billings, MT. We stayed at Mammoth Hot Springs in Yellowstone. Then we drove to Red Lodge and stayed for 3 days. Then drove back to Billings for our plane back to N.J.
My wife will not ride in a car over "the Beartooth." I suggested "roller skates." This is a real problem.
Need ATV trail - controlled and marked - off the top to see and explore the top of Beartooth Plateau. Some sort of fee (\$10) to help control and maintain. Huge group to tap into.
Need better and cleaner pit toilets like the ones provided in YNP.
Need better spots to pull off road and take pictures.
Need signs at pass!
Needs more guardrails! Maybe another bathroom/rest area.
Nice country and not too crowded yet!
Nice place but being loved to death.
Nice place to visit...thinking about moving to the area.
No services along the Joseph Highway.
No sign marking the top of the Beartooth Pass. Well kept up highway.
No summit sign, which everyone wants to, have in their picture at the top of the Beartooth Highway.
Not applicable should be a rating! Nice to see you doing thesis work!
Noticed some wash out on the road on a couple of places. Otherwise did not think twice about safety. Beautiful and awesome. Will be back!
On June 28th, we leave to go to Glacier Nat'l Park area for 2 months.
On this trip we were traveling from Dead Indian Campground on the Chief Joseph HWY to the Lamar Buffalo Ranch to attend a weekend field seminar. I have tried to answer the questions based on that trip and not our many other trips to the Beartooth Highway which we find spectacular! We are campground hosts at Dead Indian Campground since 2009.
One of my favorite places in the World!
One of the best, most scenic, well constructed road I've been on. Thanks Wyoming.
One of the most scenic drives I have done.
Only 2 in vehicle, wonderful scenic drive. Good luck!
Our 3 families camp at Cooke City every Labor Day Weekend, four wheeling and great times. We just go for a drive over the Beartooth Hwy for the beautiful drive at least 2 to 3 times a year. What more could a person ask for!!!

Our car GPS kept trying to steer us away from the Beartooth toward Billings. Glad we didn't. More guard rails and interpretive signs. High on the list of most beautiful places we have ever been.
Our celebration from Ohio to Alaska for our retirement.
Our experience on the Beartooth (1st time today) was relaxing and beautiful. We loved it.
Our honeymoon!
Our primary purpose was to visit Yellowstone, 2 nights at the Yellowstone Inn.
Our primary reason for visiting was to attend a wedding along the Chief Joseph Hwy.
Our visit to MT centered around Glacier and billings and back. Beartooth and top loop in Yellowstone was a last day stop, but it was a highlight!
Ours was a weeklong backpacking trip. To get to the trailhead we needed to use the Beartooth Highway
Partly a work trip: TV crew doing nature shots w/ owls, mtn goats and bears.
Please do not encourage cell phone towers in this area. Most drivers are already oblivious to everything but themselves. I can only imagine the mayhem if a tourist saw a deer and were on their cell phone at the same time. I've been a regular visitor for 25 years and a part time resident in Cooke City for 10 years. I love the area and plan to retire here. Please help keep this area authentic! All the best and good luck with your study.
Please let the highway department know we do not want the highway widened west of Beartooth Lake. The highway should be managed for scenic beauty, not higher speed transportation. It should be managed like highways in Yellowstone.
Please more geologic history at the turnouts. My husband has attempted to travel this road a number of times without success, snow or closed/rock slides. So fulfillment of trip of lifetime for him. I'm still cleaning out my shorts.
Please pave the gravel pull-outs on Beartooth Pass to insure safety of motorcyclists and vehicles
Porta potty restroom in Cooke City was more than disgusting. When informed, Exxon station employee said it would be emptied in 2 days. Uck!!
Pretty drive - would recommend it. Great breakfast in Cooke City!
Primary purpose of this trip was a summit climb of Granite Peak in the Beartooth-Absaroka Wilderness, and I traveled alone. This was my second traverse of the Beartooth Hwy between Cooke City and Red Lodge.
Primary reason for traveling Beartooth - it was a different route between Cody and the interstate on the way to Yellowstone.

Proposals have been made to straighten and substantially widen the Beartooth Hwy. I am NOT in favor of doing so because the values, experiences, ect. would be substantially degraded and it would just be another road from "point A" to "point B"
Protect your Natural Parks and wildernesses.
Protecting and preserving the wilderness qualities of the Beartooth-Absaroka Wilderness and YP are infinitely more important than tourism in the "gateway communities".
Purpose of this trip was wildlife watching in Lamar Valley. We came from W. Yellowstone and stayed the night in Cooke City.
Recently moved to Montana for the recreation opportunities.
Recently retired.
Red Lodge is a great town. Would love to see it and ski it in the winter. Loved the hike and the creek lodge. Some motels and businesses could help with internet advertising and PR.
Red Lodge is very expensive, spendy hotels and shops, not super friendly. If it wasn't for the Beartooth Highway we wouldn't travel there.
Red Lodge seems to me to be extremely commercialized since we visited 15 years ago. Cody, very much more friendly interested in people, not money.
Retired
Retired widower traveling alone and working the summer in Grand Tetons.
Retired, but working in YNP. Yay!!!
Retired, doing what we want. Original destination is Glacier and going to the sun road. Yellowstone home via the Beartooth.
Retired.
Retired.
Retired/from the U.K.
Retirement income.
Route to Glacier NP via Helena for us.
Scenery is magnificent, Great buffalo experiences.
Scenic highway was a high point of our trip thru Yellowstone and Grand Tetons! Only drove 3/4 of it and then turned back to go back to Yellowstone, ran out of time! Recommended sister-in-law to drive thru it! Cooke City has great visitor center! Good luck on your thesis!
See the photo collage!
Shocked at how many folks (with kids) get out of their cars against rules when a bear is seen, but a totally glorious drive plus magnificent Teton Park
Silver Gate is a well kept and less trashed up town.

Silver Gate was neat, but the cleanliness of the rooms, for the amount we paid, was very poor.
Smoke from forest fires diminished the experience and the length of stay in area.
Snow stopped us this trip (early June) - but won't when we visit again!
So excited we took family advice to take this route after Yellowstone! Will highly recommend to others! Good luck on your thesis!
Some of these categories need N/A or "didn't do" answers.
Sorry I am French and do not understand some of the words such as "more elbow room", "crowded/uncrowded" or "pullouts". Shops are closed till 10 on the morning. I would buy more if they were open at 8:30 or 9 am.
Sorry in the delay in returning this, but I hope it helps.
Sorry it's late, just got back home.
Sorry this is so late!
Sorry, but I think this is a poorly designed survey which contains a lot of redundancy. Looks like a typical government exercise.
Speed limit is ridiculously high! Too fast!
Spent 2 nights wilderness camping in Sunlight Basin off the Chief Joseph Scenic Byway. Will return there again.
Spent night in Yellowstone, then headed to Colorado. So Beartooth and Cody were our chosen path-often viewing wildlife in Lamar Valley.
Spent time in Yellowstone. Day trip to Red Lodge for photo ops. Left Yellowstone via Cody, went to Buffalo Bill Museum
Stayed in Silver Gate one night.
Stop commercializing the area. It is fine the way it is. I.e. trophy homes and tourist traps.
Survey wasn't printed on the inside pages (JAKE)
Take into consideration it was a gray, wet day and we still loved the ride! Although we didn't have them with us (me and my husband and dog in car) we were on our way to a mini-family reunion at Tetons, Yellowstone and Glacier. This ride was a means to that end. Thank you for keeping it open! Sorry to take so long filling this out, it got buried with maps and stuff. Our trip was great.
Thank you for keeping the MT Roads information online updated. That is where we looked for the Beartooth Pass! Thanks!
Thank you!
Thank you! I loved it! Probably the most beautiful drive in America!

Thanks for doing research, good luck and hopefully you research will encourage continued funding of the highway!
The amount and availability of hike able/car aided backcountry/side country skiing is fantastic great spring skiing! I will be back yearly!
The Beartooth Highway is an awesome scenic highway. It was my second time on the highway. My husband and I waited to share the experience with our sister in law who had never traveled it before. She was amazed!
The Beartooth Highway is worth going out of one's way to experience.
The Beartooth Highway needs to be widened. Some of the turns are too tight for larger vehicles. Another bathroom area would be nice.
The Beartooth Highway was awesome! Thoroughly enjoyed the drive and will recommend to others! Drove from West Yellowstone on our way to Wisconsin.
The Beartooth Parkway and this region of Wyoming and Montana make me proud to be an American citizen. It is a national treasure. Keep up the good work you do, especially for our future generations.
The Beartooth Pass is the most beautiful we have seen in Europe and USA. Keep it that way.
The Beartooth Pass was fabulous.
The best in using the information to complete your Master's thesis! The Beartooth Highway is great!
The day we traveled the Beartooth Highway, I was designated driver for my parents. We only traveled a very short distance on that highway before we were stopped and given this survey. My parents plan their trips and my sister and I drove for them. Sorry if I wasn't much help.
The Harley Davidson motorcycles should be banned from Yellowstone National Park. Cody is overrun with them.
The highway needs more reuse containers. We have traveled this area for 20 years. In the past, there were reuse containers, now there are none.
The main reason for traveling along the Beartooth Highway was to see the towns of Cooke City and Silver Gate and to see how the forest recovered after the 1988 fires.
The maintenance of the Beartooth Highway is amazingly good! I can't imagine how much work it demands.
The more people you meet the better you understand their likes and dislikes. You need to design and setup 5 question surveys that can be done orally. Then you can watch facial expression with answers. Agree answer may not be what the facial expression says. Reward them with a beartooth patch or symbol.

The one thing that caught my attention was the questions about interpretive signs. I would like to see geological info and ecological info available for public education.
The purpose of my excursion on the Beartooth Hwy was to complete my visit to the 3-4 Yellowstone Park Entrances. I stayed overnight at each of the others (West Yellowstone and Gardiner) but if I had known more about the park and distances I would have stayed 1 night in Cooke.
The road from Cody to Cody was easy to navigate and in extremely good condition. No stress, a very good trip.
The RVs and trucks often were too wide and extended left of center. This was dangerous and might be a reason I would skip the Beartooth Hwy in the future.
The survey students were friendly! I hope the thesis goes well!
There should be more notice of pullouts and mileage signs on the highway.
This area is awesome; I loved to drive on the Beartooth Hwy and I will visit Yellowstone. Wild, impressive, to be respected :)
This entrance to the park was recommended for wildlife viewing and was convenient to our travel plans. While the pass is breathtakingly beautiful, my discomfort with heights made me feel uncomfortable.
This highway and cities (Cooke and Red Lodge) have been the best time of my 2 week trip. Keep it somewhat secret! It would be very disappointing if it got too crowded or too organized like a park.
This highway is a national treasure and should be preserved for generations to come. Thank you.
This is my 52nd year coming to the Beartooth area. My extended family has been coming here since the 1950's.
This is something everyone should experience in their life. Roads need shoulders!
This is the best scenic highway of my trip.
This part was included in a trip on West American during the month.
This really doesn't apply to us.
This was a day trip. I am from Billings as was my friend.
This was a side-trip from Yellowstone, did not drive the entire highway due to smoke. Ate in Cooke City.
This was a spectacular drive! Only disappointment was the lack of signage. Any signs would have been helpful, mile markers, mileage to Cooke City, elevation, identification of passes, as well as interpretive signs. A simple map showing the various turnouts, rest areas, picnic areas. It would also have been a nice addition.

This was a wonderful experience. We are from the East Coast and enjoyed your beautiful area!
This was both husband and wife's input.
This was one of the coolest trips I have ever been on. Absolutely beautiful and relaxing!
This was one of the most beautiful drives I have done across country. Good luck on your thesis!
This was our 3rd trip in Yellowstone. We stayed in one of your campgrounds last year and at the west entrance in ID 2 years ago. We love it.
This was our first time to Beartooth Pass and enjoyed it more than Glacier National Park. We will definitely tell friends and when possible, visit this area again! Unfortunately it's a long way from Texas!
Too much construction delays.
Too smoky due to fires to answer many questions accurately.
Took a day trip from Gardiner to Cooke City to see the park and have lunch. Have enjoyed the areas covered by the survey many times.
Tourism of local folks should be encouraged more. It amazes me how few people that are locals actually tour the park when lots of folks from all over the world come to see it. I know a lot of people from home that never go there. What a shame!
Trails along the BTH could be better indicated. Put signs along the highway with information about elevation when you're at the summit.
Travel from Cody to Red Lodge on Chief Joseph and Beartooth Highway under blue skies and sunshine then returned a few hours later from Red Lodge to Cooke City and Yellowstone experiencing rain sleet and light snow. We had a great time. What a variety and great experience. Can't wait to do it again.
Traveled Beartooth many times. Stayed in Red Lodge and Cody numerous trips. Usually stop in Cooke City, but got a late start this time. Have recommended to many friends over the years.
Traveled cross country from San Francisco, CA to Richmond, VA and back via car for pleasure, enjoyment and to see the historical sites.
Traveled the Beartooth on motorcycles in heavy rain turning to snow.
Traveling through stumbled upon this road - has been a highlight of our trip.
Unprecedented beauty. Red Lodge = very nice, welcoming and friendly. Cooke City = not so much. A little too rural/remote.
Very beautiful!!!
Very enjoyable trip, beautiful country, relaxing.
Very enjoyable, would do it again in a heartbeat!
Very nice trip!
Visibility around Beartooth Highway was low due to smoke.

Visiting family in Roscoe, MT.
Visiting the Beartooths is a near religious experience to me.
Vista point needs more interpretive signs that show names of the mountain peaks from there.
Want to return when air is crisp and clear.
Wanted to re-visit Red Lodge because my husband grew up there. We also drove the Chief Joseph - Great road! We love the Beartooth Hwy/plateau/surrounding area and will be back from California again.
Was a surprising experience, first time on that road. Will be back someday for a longer visit.
Was awesome!
Was not on Beartooth Highway very far. Rode to Cooke City with brother and sister-in-law just to see what it looked like. Someone my brother worked with was really impressed.
Was taking a family from Dubai, India on a tour of the parks.
Wasn't expecting the climb up but can't wait to experience it all over again!
We (my friend) traveled this route because we knew it was a #1 scenic route. We would like to encourage better signage, both altitude and top of the pass.
We actually went on the Chief Joseph Road first before getting to Beartooth Hwy. It was extremely picturesque so not on hwy for very long! Sorry! Maybe next time!
We also drove to Powell, Wy and spent \$22.30 between 2 different retail stores outside of Cody. We could have stayed longer and then we would have time to go to the museum in Cody, WY.
We appreciated that campgrounds were open on the Beartooth in late September. We looked for wildlife, but all we saw were cows. Saw wildlife in Yellowstone.
We are both retired and have been coming to this area for over 20 years. Love it! Stay in cabin with friends above Cooke City.
We are from Missoula. We drove to RL over the Beartooth camped at PCCG (after stopping in CC) Drove over the CJSB to Cody, spent the night, went to the rodeo, then came through the east entrance at YNP, out to Mammoth, spent the night at Bozeman and back to Missoula.
We are Montana residents who drive the Beartooth once a year, usually in conjunction with touring Yellowstone N.P. We avoid Cooke City because it's a sh*thole.
We are retired and income reflects current income and retirement

We are retired as the "decompress" type questions really don't apply.
We are retired so don't need to "get away." Good luck with your study!
We are staying in an RV near West Yellowstone and this was a day trip to the BTH. We will visit the area again and stay on the east side of Yellowstone.
We are traveling from Ottawa, Canada to Seattle, WA mainly visiting National Parks.
We brought our elderly neighbor who had never been on the Hwy. She says it was "one of my best days."
We came from Billings and stayed in West. The Beartooth Highway was a deliberate travel route, because of its beauty rather than going through Gardiner.
We came on our trip from Yellowstone to Cody was a very nice road. Because the guy was so friendly we fill this form!
We camped at Fantan Lake 3 nights. Fly fished Fantan, Crystal, Sawtooth, Cliff and Chain lakes. Wonderful experience.
We come from Bozeman every year to camp and ski. We love it at Red Lodge!
We could definitely see a difference in signage and railings, good or excellent in Montana, not well in Wyoming. There were some areas in Wyoming that I did not feel safe due to lack of railings.
We decided to stay in Red Lodge and Cody to help us explore different parts of the Yellowstone National Park. In the process of travelling from the park to Red Lodge, we drove on the Beartooth Hwy and really enjoyed the experience. Red Lodge was also very nice. We didn't get a chance to really experience Cody.
We did not appreciate basically being "forced" to pull off the road and take the in-person survey. We had 2 small children with us and every minute counts! Let it be known who is conducting the survey and that it is optional.
We did not go through Cody on the way to Yellowstone. Exited Yellowstone through Cody. We live east of YNP. Entered park through Cooke City.
We did see very little wildlife or wildlife signs in the backcountry of the Beartooth Plateau. Birding was good though.
We discovered more things than we expected. More history on the Chief Joseph Highway. Greatly enjoyed the whole area and looking forward to a return trip and follow the entire Beartooth Hwy.
We drove from West Yellowstone to Red Lodge, then home to Casper, WY. We spend a lot of time in these areas.

We enjoyed our visit to this area. We've been before and hope to return many times.
We enjoyed the experience a lot!
We enjoyed this part of our vacation immensely. The beauty of this area is inspiring and relaxing.
We frequently drive the pass. Sometimes ski, sometimes sled. Always take visitors over the pass.
We go to our cabin this way if it is the sunlight basin and this is the shortest way. The traffic doesn't know to pull over when there are a lot of cars following if when it is slow.
We had an awesome time! Beautiful highway!
We had car trouble in Yellowstone and we drove this hwy to get our car fixed in Cody. We didn't know about this Hwy before.
We had hoped to take a day trip to Cody from Gardiner, but we didn't start early enough. Still, it was a beautiful drive.
We have a second home in Red Lodge where we spend about 4 months a year. We travel the Beartooth 4 or 5 times during this time. We always take our visitors over the Beartooth into Cooke City. This trip we were disappointed because it started to rain so we turned around at the Wy border and came back.
We have a son, daughter-in-law and 3 grand-children in Red Lodge as well as a get-away family cabin. We visit 3-4 times a year. We also have had family reunions with over 4 children and their children. We have also taken a number of our friends with us to share the Red Lodge/Yellowstone experience.
We have been coming to this area for 20 years. Camping for the first 10, and then buying a cabin in Silver Gate for the last 10.
We have been coming to this area on vacation for over 30 years. When we were younger we hiked, fished and camped in many of these areas. So, now we just enjoy the views and experiences along the way.
We have been married for 46 years. We go to black hills and Yellowstone. We went about 10 times before we heard of Beartooth Pass. Red Lodge needs to advertise more. Beartooth pass is great needs more advertisement. The young student Jake was very polite. A great place!
We have been over the Beartooth many times. The most beautiful road I have seen. Was disappointed due to being smoky. Reduced long range visibility.
We have lived in the area for most of our life. We are retired and are now able to spend longer time out here. Beartooth Highway coming from Red Lodge is fine; at the summit hwy border to top of the world store is too narrow.
We have spent many years away from MT. overseas and on the East Coast. We have retired to MT and BTH is sort of a home base for us.

We have traveled up and down the Beartooth Highway since 1974. We try to do it at least once a year just to enjoy the trip and enjoy the scenery.
We have visited other mountainous areas of the US, i.e. CO and the signs stating what elevation we were at. Saw while we were at in the higher elevations where snow was present and it would have been interesting to know the elevation.
We like to explore the opens paces of the West since we are from the East Coast.
We live in Billings, MT and are Montana Natives (MSU graduate) - have been traveling into Yellowstone Nat'l Park (thru all entrances hundreds of times. It is one of our favorite places on earth and the excitement level has never diminished, not once! We love the outdoors, wildlife & nature.
We live in Billings; visit the highway as often as possible. Access to lakes, trails and YNP has taken us to the highway many times in the 18 months we've lived in Billings. Very lucky to live near it!
We live in Bozeman so travel the Beartooth frequently - to Cooke City/Silver Gate at least monthly. Cooke City to pass/top of the world several times a summer, to Cody a few times a summer, from Bozeman to Red Lodge to Cooke City 1-2 times a year.
We live near Billings and like to make this trip at least once a year to stay connected to the mountains.
We love and value our time in Montana and Wyoming.
We love driving the Beartooth always!
We love Yellowstone!
We loved all of Yellowstone and cannot wait to return again!
We moved to Billings, MT from Oklahoma 2 years ago and we find Montana to be magnificent. We have hiked; fly fished, biked and skied near Red Lodge numerous times. We love Red Lodge, Yellowstone, Glacier NP, Bozeman area.
We only drove over the Beartooth because it was between us and Yellowstone. It was too scary to cross for any other reason. Our GPS made us. Husband/driver loved it.
We picnicked in Red Lodge side campgrounds and toured camp areas.
We predominately spend time at Pebble Creek in YNP. We also have friends who own cabins in Silver Gate and spend time with them.
We really enjoyed the drive. Parts of it reminded us of New Zealand. It was really scenic.
We spend summers at the RV park near Emigrant and enjoy making several day trips to the Beartooth area every summer.
We stayed 5 nights in West Yellowstone, traveled to each park entrance. Wanted to see Cody and Chief Joseph Scenic Byway reentered park at Silver Gate.
We stayed at friend's cabin in Silver Gate so most of our time was spent between Lily Lake and Trout Lake in Yellowstone. We didn't travel over the pass but have in the past. We returned home via Gardiner.

We stayed in the Cody valley rather than Cody. My answers reflect the ranch where we stayed.
We take this trip 2-3 times a year and love this route home.
We took a trip a few years ago and used the Chief Joseph Hwy, Decided to drive Beartooth the next time we were here. Moon Handbook Montana gives a great recommendation and description of the Highway.
We took an extra amount of time crossing over the Beartooth Pass because of all the spots to pull over to view the awesome scenery!
We took Chief Joseph to Cody instead of Pass to Red Lodge due to anxiety over narrow shoulders and drop-offs.
We travel the Beartooth because it is a lovely drive and goes right to Red Lodge, our destination of this trip. We did stay 2 nights in Gardiner too.
We travel this area often and enjoy the surrounding areas. We travel to Red Lodge many times a year and often eat there.
We travel this area on our motorcycle often and always enjoy. We think everyone goes way above to provide a great experience. Only good to report. Thank you.
We traveled Chief Joseph and some Beartooth Pass.
We traveled from Cooke City to Cody instead of Red Lodge because our trip had been cut short unexpectedly by one day. Very much wanted to do Beartooth Pass. Two years ago while on motorcycle could not pass due to snow in late June.
We traveled over Beartooth Pass 26 years ago with our sons and enjoyed it then. We included it in this trip and enjoyed the ride again.
We used the Crazy Creek campground as a base for visiting the Lamar Valley. We left the park via the East entrance to Cody. In previous trips we drove the Beartooth from Red Lodge to the park. Both were wonderful drives.
We visit Red Lodge annually and are from Nebraska. We travel the Beartooth Highway about every other year! Good Luck and God bless!
We visit Yellowstone every year or so. Visited Cody 2 weeks ago and we visited Red Lodge last weekend. We have been here since July 14th and we will leave Billings September 20th.
We went for our anniversary get away. We will be back! One day was not enough. Signs announcing waterfall hikes/trails would be nice.
We went to a wedding at the Lake Lodge in Yellowstone.
We were disappointed Red Lodge businesses closed so early 5-6 pm on a Friday night. No time to look around.
We were given this route by AAA without knowing what to expect. Since I am terrified of heights, I did not enjoy this route. My husband enjoyed it, but did admit the driving was very intense for him.
We were on our way back to Tetons as our 3 week trip was complete. The NE entrance of Yellowstone was the last area of Yellowstone that we wanted our grandson to see.
We were only on Beartooth Highway for a short amount of time, just to get to Chief Joseph Scenic Byway on the way to Sheridan, WY.; ultimately Mt. Rushmore, SD.

We were only on it for a short stretch, turning onto 296 and heading to Cody.
We were sorry that there was a smoke haze. It reduced visibility, but did not hamper the grandeur. Loved it!
We were staying in Yellowstone and decided to drive east to explore. We stopped in Silver Gate to get some coffee and then were recommended this ride. It was great!
We were traveling east on Highway 90 and came into Yellowstone on Highway 89. Departed the park at the Northeast entrance on the same day.
We weren't aware the Beartooth Hwy existed. We wanted to get to Yellowstone ASAP. Good luck with your thesis.
We will be back with others! Definitely will take those who visit in the summer!
We will be spending 3 days in Silver Gate next May. Road is usually closed when we are here in Spring. If open, I would love to go over to Red Lodge.
We wished we would have had the chance to spend more time in Red Lodge. It looked very appealing to us!
Went looking for moose.
We're from MI, flew to Billings, rented a car and headed to Yellowstone. We didn't do enough research ahead of time to learn of the Beartooth Highway, so it was a wonderful surprise. Absolutely beautiful! and my husband loves to drive, he was in heaven!
We've rented a small 1 room cabin in Red Lodge for the last 3 summers.
What a fine time! Divine!
What is the elevation on the top of Beartooth Pass?
When I stay for 1-2 weeks in Yellowstone I try to get up to the Beartooth Pass at least one day.
When we drove the highway it was very hazy from the fires. I would like to come back when it is clearer as the views would be more impressive. This trip our major destination was Yellowstone, but I would like to come back and spend more time in the Beartooths.
When we get out of state visitors we always go to Yellowstone over the pass.
When we visit National parks, I try to avoid crowds. One way to do this is to skip staying inside the parks and skip staying in the first city outside of the parks. I try to stay one town further down the road. It's cheaper and less crowded.
Will definitely return to the area - this was our first time to the area. We do travel extensively just not here until now. We will be back!
Wolf watcher spends growth in and around park.
Wonderful 1st trip to Montana! We will be back!
Wonderful experience! Can't wait to visit again.
Wonderful!
Wrong time of year to visit Yellowstone. Way too crowded! Next I'll go in May/June or Sept/Oct.

You should reduce your list significantly! It discourages us to send! Success!

Your survey at the lookout point was well organized without being intrusive or interrupting our enjoyment. Thank you! Good luck with your project.

Appendix C – Place of Residency (State and Canada/Foreign Country)

State	Frequency	Percent
Montana	730	15.3
Minnesota	228	4.8
California	199	4.2
Washington	180	3.8
Wyoming	151	3.2
Colorado	149	3.1
Texas	139	2.9
Wisconsin	136	2.8
Utah	118	2.5
Idaho	117	2.5
Florida	109	2.3
Michigan	105	2.2
Illinois	99	2.1
Pennsylvania	93	1.9
Ohio	87	1.8
Iowa	82	1.7
Missouri	81	1.7
North Dakota	76	1.6
Tennessee	62	1.3
North Carolina	61	1.3
Indiana	57	1.2
Arizona	54	1.1
Oregon	54	1.1
Georgia	52	1.1
New York	51	1.1
South Dakota	48	1.0
Virginia	48	1.0
Nebraska	47	1.0
Massachusetts	40	.8
New Jersey	39	.8
Kentucky	37	.8
Oklahoma	33	.7
Nevada	31	.6
Louisiana	29	.6
Arkansas	28	.6
Kansas	27	.6

Maryland	27	.6
Alabama	24	.5
Connecticut	23	.5
Maine	17	.4
South Carolina	17	.4
New Mexico	14	.3
New Hampshire	11	.2
West Virginia	11	.2
Vermont	10	.2
Alaska	9	.2
D.C.	9	.2
Mississippi	6	.1
Delaware	3	.1
Hawaii	3	.1

Country	Frequency	Percentage
Canada	159	3.4
England	54	1.1
Germany	35	.7
Netherlands	25	.5
Australia	24	.5
France	17	.4
Switzerland	16	.3
Belgium	10	.2
China	9	.2
Sweden	7	.1
New Zealand	5	.1
Ireland	4	.1
Spain	4	.1
Austria	3	.1
Holland	3	.1
Scotland	3	.1
Denmark	2	.0
Japan	2	.0
Taiwan	2	.0
Bermuda	1	.0
Chile	1	.0
Cyprus	1	.0
Czech Republic	1	.0

Israel	1	.0
Korea	1	.0
Latvia	1	.0
Mexico	1	.0
Slovenia	1	.0
Slovakia	1	.0
South Africa	1	.0

Provinces	Frequency	Percentage
Alberta	51	1.1
British Columbia	28	.6
Manitoba	16	.3
Prince Edward Island	1	.0
Quebec	16	.3
Saskatchewan	17	.4

Economic Contribution of Summer Season Travel in The Beartooth Region - Nonresident Expenditures

Summer Season 2012 Contribution of Nonresident Visitor Spending to the Local Economies*

- Nonresidents of the Beartooth Region are defined as residing outside of Park or Carbon County, MT or Park County, WY.
- During summer, 2012, nonresident travelers spent \$44.96 million while traveling in the Beartooth Region.
- Nonresident travelers spent \$12.8 million in Red Lodge, MT, \$20.1 million in Cody, WY and \$12.1 million in Cooke City/Silver Gate, MT.
- This \$44.96 million in nonresident spending supports \$50.24 million in economic activity and supports 616 total jobs due to spending in the Beartooth Region.

Table 1 - 2012 Carbon County, MT Economic Impact (Spending in Red Lodge, MT area)

\$12.8 million in nonresident spending contributes:	Direct	Indirect	Induced	Combined
Industry Output	\$9,687,000	\$2,506,000	\$1,470,000	\$13,663,000
Employment (# of jobs)	134	28	14	176
Employee Compensation	\$2,418,000	\$455,000	\$247,000	\$3,120,000
Proprietor Income	\$465,000	\$191,000	\$88,000	\$745,000
Labor Income	\$2,884,000	\$646,000	\$335,000	\$3,864,000
Value Added	\$4,816,000	\$1,251,000	\$833,000	\$6,900,000

Table 2 - 2012 Park County, WY Economic Impact (Spending in Cody, WY area)

\$20.1 million in nonresident spending contributes:	Direct	Indirect	Induced	Combined
Industry Output	\$15,389,000	\$4,737,000	\$2,922,000	\$23,049,000
Employment (# of jobs)	192	44	27	263
Employee Compensation	\$4,184,000	\$970,000	\$663,000	\$5,817,000
Proprietor Income	\$797,000	\$511,000	\$212,000	\$1,520,000
Labor Income	\$4,981,000	\$1,481,000	\$875,000	\$7,337,000
Value Added	\$8,271,000	\$2,550,000	\$1,754,000	\$12,575,000

Table 3 - 2012 Park County, MT Economic Impact (Spending in Cooke City/Silver Gate, MT area)

\$12.1 million in nonresident spending contributes:	Direct	Indirect	Induced	Combined
Industry Output	\$9,537,000	\$2,215,000	\$1,777,000	\$13,529,000
Employment (# of jobs)	134	26	18	177
Employee Compensation	\$2,740,000	\$476,000	\$383,000	\$3,599,000
Proprietor Income	\$291,000	\$173,000	\$86,000	\$550,000
Labor Income	\$3,031,000	\$649,000	\$468,000	\$4,149,000
Value Added	\$4,905,000	\$1,096,000	\$984,000	\$6,985,000

Beartooth Region nonresident travel spending data was collected June 1, 2012 - September 21, 2012

* IMPLAN economic input-output model software was used in these analyses.

Table 4 - 2012 Red Lodge, MT Nonresident Traveler Expenditures

Expenditure Category	Total Expenditures	Allocation by Category
Hotels and Motels	\$3,609,000	28%
Restaurant and Bar	\$2,964,000	23%
Gasoline and Oil	\$2,359,000	18%
Retail	\$1,231,000	10%
Groceries and Snacks	\$1,090,000	8%
Rental Cabin/B&B/Resorts	\$915,000	7%
Campgrounds	\$308,000	2%
Licenses/Fees/Admissions	\$113,000	1%
Auto Rental	\$85,000	1%
Misc. Purchases	\$162,000	1%
Total	\$12,836,000	

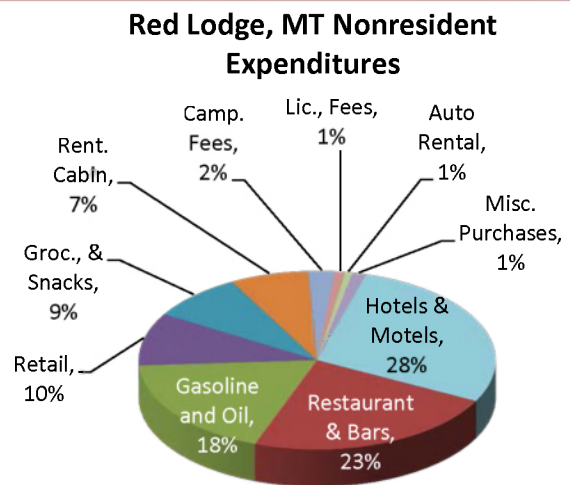


Table 5 - 2012 Cody, WY Nonresident Traveler Expenditures

Expenditure Category	Total Expenditures	Allocation by Category
Hotels and Motels	\$6,818,000	34%
Gasoline and Oil	\$3,624,000	18%
Restaurants & Bars	\$3,509,000	18%
Retail	\$1,827,000	9%
Groceries and Snacks	\$1,739,000	9%
Licenses/Fees/Admissions	\$811,000	4%
Rental Cabin/B&B/Resort	\$650,000	3%
Campgrounds	\$518,000	3%
Auto Repair	\$195,000	1%
Auto Rental	\$147,000	1%
Guides/Outfitters	\$110,000	1%
Misc. Purchases	\$102,000	1%
Total	\$20,050,000	

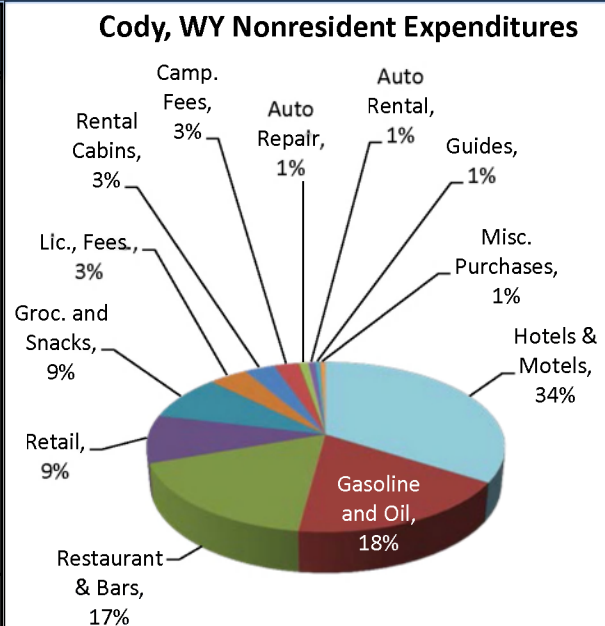
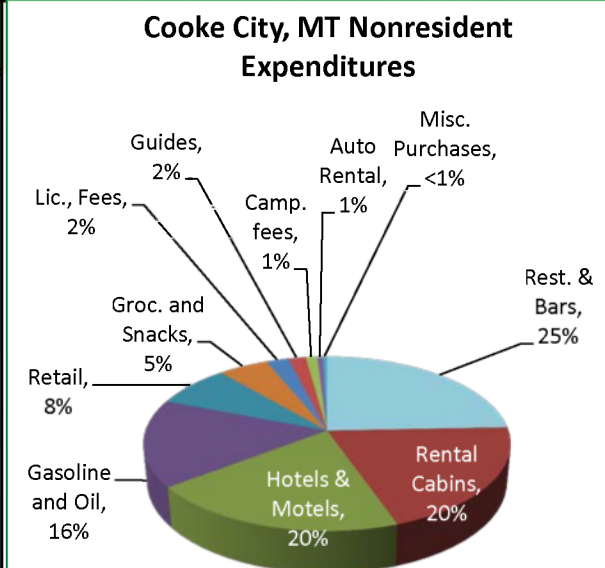


Table 6 - 2012 Cooke City/Silver Gate, MT Nonresident Traveler Expenditures

Expenditure Category	Total Expenditures	Allocation by Category
Restaurants & Bars	\$2,942,000	24%
Rental Cabin/B&B/Resort	\$2,445,000	20%
Hotels and Motels	\$2,418,000	20%
Gasoline and Oil	\$1,961,000	16%
Retail	\$944,000	8%
Groceries and Snacks	\$613,000	5%
Licenses/Fees/Admissions	\$276,000	2%
Guides/Outfitters	\$215,000	2%
Campgrounds	\$140,000	1%
Auto Rental	\$74,000	1%
Misc. Purchases	\$48,000	<1%
Total	\$12,076,000	



Summer 2012 Visitor Spending on the Beartooth Highway - Traveler Characteristics, Main Purpose, and Activity Type

Total Trip Expenditures by Taveler Characteristics and Trip Purpose[^]

	Traveler Characteristics					Main Purpose of Trip ¹	
	All Travelers	First-Time	Repeat	Day-Trip	Overnight	"Because it is a Scenic Byway"	"Road to Yellowstone"
Sample size	1,473	665	808	546	927	445	181
Total Nonres. Travelers ²	162,265	73,019	89,246	60,038	102,226	51,600	20,932
Length of Stay (nights)	2.34	1.74	2.84	-	3.72	2.16	2.62
% of All Travelers	100%	45%	55%	37%	63%	32%	13%
Campgrounds	\$5.95	\$6.37	\$5.61	\$0.00	\$8.87	\$4.75	\$5.05
Hotels and Motels	\$79.16	\$86.68	\$72.98	\$0.00	\$116.48	\$95.43	\$72.06
Rental Cabins/B & B	\$24.71	\$21.70	\$27.19	\$0.00	\$57.92	\$27.08	\$27.88
Gasoline and Oil	\$48.96	\$47.41	\$50.25	\$25.52	\$42.42	\$49.90	\$39.16
Restaurants and Bars	\$58.02	\$55.82	\$59.84	\$23.15	\$78.57	\$66.22	\$60.70
Groceries and Snacks	\$21.22	\$17.59	\$24.20	\$7.71	\$29.16	\$20.51	\$20.57
Retail Purchases	\$24.66	\$23.17	\$25.86	\$11.41	\$32.45	\$29.53	\$21.18
Guides/Outfitters	\$2.31	\$1.90	\$2.66	\$0.36	\$3.46	\$1.42	\$2.93
Auto Rental	\$1.88	\$2.30	\$1.55	\$0.28	\$2.83	\$1.83	\$2.04
Auto Repair	\$1.72	\$1.68	\$1.73	\$0.87	\$2.20	\$1.16	\$2.94
Transportation Fares	\$0.17	\$0.16	\$0.18	\$0.10	\$0.21	\$0.21	\$0.23
License/Fees	\$7.39	\$7.51	\$7.30	\$3.40	\$9.74	\$7.11	\$8.07
Services	\$0.92	\$0.45	\$1.32	\$0.23	\$1.32	\$0.45	\$0.61
Total Trip Expenditures	\$277.07	\$272.74	\$280.67	\$73.03	\$385.63	\$305.60	\$263.42

Total Trip Expenditures by Activity Type^{^^}

Expenditure Category	Road Tourers	Active Outdoors	Knowledge Seekers	Passive Viewers
% of Sample	8%	32%	19%	41%
Average Nights Spent	3.03	3.75	2.12	1.35
Campgrounds	\$7.57	\$10.40	\$3.07	\$4.05
Hotels and Motels	\$97.68	\$61.39	\$113.31	\$79.36
Rental Cabins/B & B	\$20.39	\$37.04	\$23.64	\$19.45
Gasoline and Oil	\$48.35	\$59.40	\$58.49	\$40.88
Restaurants and Bars	\$66.25	\$64.18	\$66.72	\$50.68
Groceries and Snacks	\$21.23	\$33.40	\$18.62	\$14.16
Retail Purchases	\$28.43	\$25.35	\$30.76	\$22.71
Guides/Outfitters	\$3.78	\$4.30	\$1.58	\$0.93
Auto Rental	\$0.38	\$3.17	\$2.08	\$1.38
Auto Repair	\$4.19	\$1.82	\$2.66	\$0.78
Transportation Fares	\$0.00	\$0.24	\$0.25	\$0.13
License/Fees	\$7.20	\$8.29	\$9.70	\$6.10
Services	\$1.09	\$2.04	\$0.62	\$0.21
Total Trip Expenditures	\$306.54	\$311.01	\$331.51	\$240.82

¹ These were two of the main purposes for traveling the Beartooth Highway and represent 45% of all travelers.

[^] Expenditures may appear lower than typical costs in these categories because they are averaged across all visitor groups.

^{^^} Respondents were clustered into 4 distinct groups based on activity participation. Activities in each group are as follows:

"Road Tourers" = motorcycle riding and road biking.

"Active Outdoors" = day hiking, backpacking, camping, canoeing/kayaking, fishing, birding, mountain biking, and horseback riding.

"Knowledge Seekers" = visiting a historical site and visiting interpretive site.

"Passive Viewers" = scenic driving, wildlife watching, and nature photography.

² Nonresidents of the Beartooth Region are defined as residing outside of Park or Carbon County, MT or Park County, WY.

The Beartooth Highway: 2012-2013 Winter Economic Impacts, Use, & Image



*Note: Picture courtesy of <http://www.beartoothpowder.com>

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This report was funded by Friends of the Beartooth All-American Road, the Wyoming Department of Transportation, Wyoming Office of Tourism, Park County Travel Council, Yellowstone Park Foundation, Yellowstone Country Montana, and the Montana Lodging Facility Use Tax.

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Executive Summary

The purpose of this study was to assess the economic impact, use, and destination image held by visitors of the Beartooth Highway and gateway communities of Cooke City/Colter Pass/Silver Gate, MT and Cody, WY during the winter season. Data was collected in the winter of 2012-2013, from December 15th until April 12th, at exits of the Beartooth Highway. On-site surveys were collected by surveyors at these two exit locations along the highway: the Northeast gate of Yellowstone National Park, and the junction of WY 296 and WY 120. Sample periods were randomly chosen days with an equal number of weekend/weekdays. A total of 1,645 visitors were intercepted along the highway, 1,106 nonresident and 539 residents to the local counties of Park County, MT and Park County, WY. Of those 1,106 nonresidents intercepted, 290 mailback surveys were completed and returned for a response rate of 26%.

- Forty-six percent of nonresident travelers were first-time visitors to the region. Eleven percent of repeat visitors had been to the region at least 25 times prior to their current trip.). Forty-four percent of nonresidents were overnight travelers while 56 percent were on a day trip to the Beartooth Region.
- 62 percent of mailback respondents traveled to the region because of the proximity of wildlife in Yellowstone National Park.
- Of the 34,241 travel groups recorded over the sample period, a total of 16,379 total nonresident traveler groups (48%) were estimated during the winter season.
- Nonresident visitors in the on-site survey spent, on average, 1.47 nights in the Beartooth Region. Visitors who spent at least one night averaged 3.11 nights in Cooke City/Colter Pass/Silver Gate, MT and .47 nights in Cody, WY per trip. Forty-four percent of nonresident visitors were overnight travelers while 56 percent were day-trippers.
- Visitors stated wildlife watching (21%), scenic driving (20%), nature photography (19%), and snowmobiling (18%) are the most frequently participated in activities in the Beartooth Region. When visitors were asked to state their primary activity, snowmobiling is identified as top activity.
- Visitors were segmented into three activity groups based on primary activities: “snowmobilers,” “active users” (XC skiers, day hikers, snowshoers, backcountry skiers), and “passive users” (wildlife watchers, nature photographers, scenic driving, eating at a restaurant/getting fuel only).
- The Beartooth Highway during the winter season is rated very positively by nonresident visitors. Visitors noted that the road is well maintained, free of snow, provides a wide range of outdoor recreational opportunities, and a high quality winter recreational experience.
- Significant differences are present between activity groups in perceptions of recreational aspects and Cooke City/Colter Pass/Silver Gate, MT.
- There is potential conflict between active/passive users and snowmobilers in the Beartooth Region. Open-ended comment analysis identified multiple changes user groups would like to see including improved trail maintenance, more available services, and expanded recreation area.

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Introduction

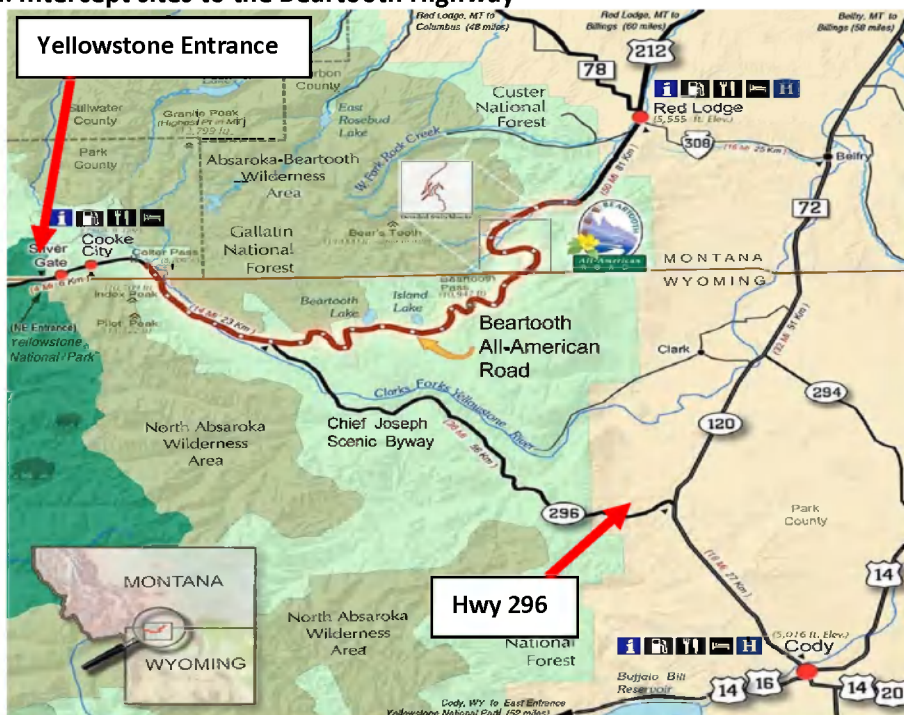
The purpose of this study was to assess the economic impact, use, and destination image held by visitors of the Beartooth Highway and gateway communities of Cooke City/Colter Pass/Silver Gate, MT and Cody, WY during the winter season. Data was collected from visitors along the Beartooth Highway during the winter sampling period of December 17th, 2012 to April 12th, 2013. In this report, results are provided for the winter use, economic impacts, and perceived image of the Beartooth Highway. A 2012 summer economic impact and destination image study was previously conducted on the Beartooth Highway and can be found at

<http://www.itrr.umt.edu/Research2013/BTHSummerReport.pdf>.

Methods

To collect traveler data, one methodology was used. During the sampling period, visitors were intercepted in their vehicles at the two exit points of the Beartooth Highway: the northeast entrance of Yellowstone National Park and on WY 296 (Chief Joseph Scenic Byway), 1 mile from WY 120. Intercept locations were chosen due to the unique nature of the Beartooth Highway during the winter season. From mid-October through May, the highway is closed east of Cooke City/Colter Pass/Silver Gate, MT for 8 miles (access to Cooke City/Colter Pass/Silver Gate, MT from this direction is by snowmobile only) and east of the Junction of WY 296 and the Beartooth Highway (over Beartooth Pass) because of large amounts of snow along the corridor. Thus, these intercept locations are the only entrances and/or exits to access recreation and the towns of Cooke City/Colter Pass/Silver Gate, MT. Traffic data from counters supplied by Yellowstone National Park (YNP) and Wyoming Department of Transportation (WYDOT) was used to obtain an estimate of the total population of vehicles along the highway during the winter season.

Figure 1: Intercept sites to the Beartooth Highway



When travelers were intercepted, they were first asked to state their permanent residency. Residents (travelers residing in Park County, MT or Park County, WY) were given an abbreviated version of the on-site survey and allowed to continue on their way. Unlike the summer season, residents of Carbon County, MT were not considered local because of winter road closures preventing access. The remaining travelers (nonresidents) were given a more in-depth on-site survey and a mailback questionnaire with various questions regarding trip expenditures, perceived destination image, recreation experience, and visitor characteristics. In total, 1,645 vehicles were intercepted along the highway. Of those intercepted, 539 were local residents and 1,106 were nonresidents. Two-hundred and eighty-nine mailback responses were received, resulting in a 26 percent response rate, which is low when compared to the summer use study (45%). Many factors may have contributed to this lower response rate such as visitor characteristics, weather present during interception, length of trip, and purpose of trip. However, mailback results still are considered a good sampling of winter visitors.

In regards to the economic impact model used, IMPLAN (Impact analysis for planning) is an economic software modeling program designed for measuring impacts based on visitor spending. A county-based economic model for each county (Park County, MT and Park County, WY) was constructed to best estimate impacts. Full-trip expenditure data is inserted into IMPLAN and then analyzed to determine the effect of visitor spending in each county economy.

Results

Results are presented in three sections throughout this report. The first section displays results of the on-site intercept questions. Overall population metrics are calculated by using the traffic data previously explained. The proportion of nonresident visitors, estimated through analysis of the on-site survey data, is then applied to the overall population to attain a total number of nonresident visitors during the winter season. In addition, nights spent, overall activities participated in, and residency figures are displayed.

The second section presents the economic impact assessment for the winter season. Economic results are displayed using visitor spending impacts by nonresidents who returned the mailback survey. Special considerations are made pertaining to some industry sectors including the exclusion of some industry sectors because of a limited sample size. Exclusions are detailed prior to reported impacts.

The third section presents results of the in-depth, nonresident mailback survey. This section includes various subsections including demographics, trip characteristics, activities, destination image, gateway community image perception, and an analysis of open-ended visitor questions and comments. Following the results section, discussion and stakeholder implications are presented.

SECTION 1: Intercept Survey Results

This section provides the results of the eight intercept questions asked on-site of visitors on the Beartooth Highway. Four of the eight questions pertained to residents of the region. Results in Section 1 represent 1,022 residents of the United States, 32 residents of Canada, and 47 other foreign visitors (Table 1). For questions pertaining to permanent residency (Tables 1 and 2), activities (Table 6), and awareness of road closures (Table 4), local residents' responses are included.

Intercept Survey Summary

Visitors primarily came from the United States, with Canadian and foreign visitors comprising only five percent of the sample (Table 1). Among visitors to the Beartooth Highway, 45 states, 4 Canadian provinces, and 18 foreign countries are represented. Montana represents the highest percentage of residency by nonresident visitors to the BTH region (43%), followed by Minnesota (6%), North Dakota (6%), Wyoming (5%), and Washington (4%) (Figure 2).

Table 1: Visitor residency

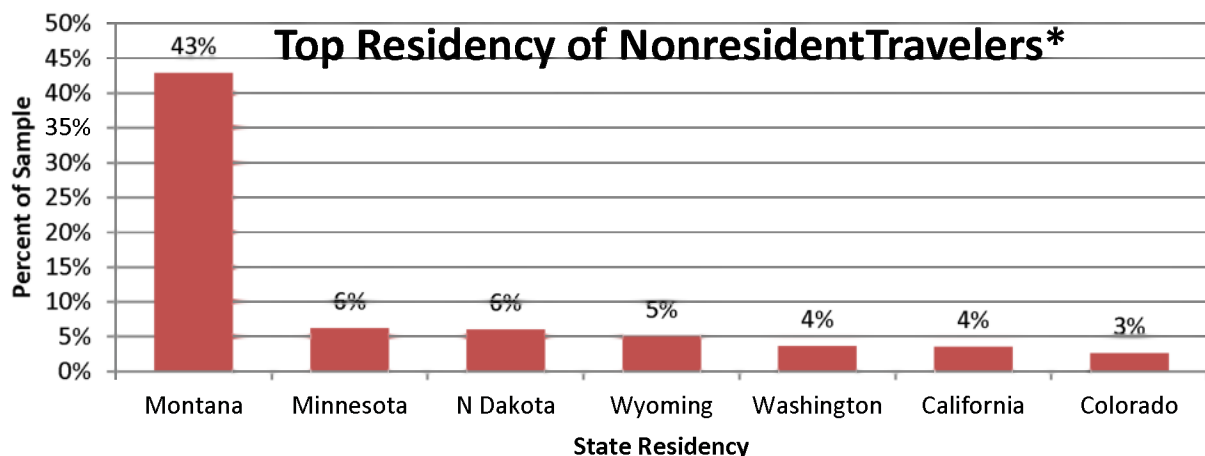
Visitor Residence – All Intercepted Traffic	#	%
Locals (Park County, WY; Park County, MT)	539	33%
Nonresidents	<u>1,101</u>	<u>67%</u>
	<u>1,640</u>	<u>100%</u>
Residency of Nonresidents		
United States	1,022	62%
Foreign (other than Canada)	47	3%
Canada	32	2%

Percentage of resident use of the Beartooth Highway is much higher in the winter than in the summer. In the summer, the residents were 10 percent of the Beartooth region use compared to 33 percent in the winter. Of residents who were intercepted in the winter, 74 percent reside in Park County, WY, while 26 percent reside in Park County, MT (Table 2).

Table 2: County residency by local travelers

County	#	%
Park County, WY	396	74%
Park County, MT	143	26%
Total	539	100%

Figure 2: Residency of travelers



*Percentage totals are of the entire nonresident sample's residency.

Fifty-three percent of nonresidents arrived to the Beartooth Region via I-90 traveling east from Idaho, followed by I-90 traveling west from SD (17%) and I-94 traveling west from ND (16%) (Table 3). Ninety-two percent of visitors (both locals and nonresidents) who were traveling on WY 296 (Chief Joseph Scenic Byway) were aware of the road closures on the Beartooth Highway prior to their arrival, with five percent unaware of the closure (3% did not answer the question) (Table 4). Forty-four percent of nonresidents were overnight travelers while 56 percent were only on a day trip. Upon arriving in the Beartooth Region, on-site intercept results show that nonresident travelers are staying an average of 1.47 nights and have an average of 2.56 travelers per vehicle (Table 5). The majority of nights are spent in Cooke City/Colter Pass/Silver Gate, MT (1.25 nights) while nights spent in Cody, WY appear to be much lower (0.22 nights) (Table 5). Furthermore, nonresident visitors spent 1.84 nights in MT towns other than Cooke City/Colter Pass/Silver Gate and 0.46 nights in WY outside of Cody, WY (Table 5).

Table 3: Travel route choice

Travel Route	#	%
I90-traveling east from Idaho	560	53%
I90-traveling west from WY & SD	192	17%
I94-traveling west from ND	179	16%
I-15 traveling south from Alberta	44	4%
I25-traveling north from WY	43	4%
Jackson, WY to Cody, WY	35	3%
I90-traveling west from Billings to WY 296	14	1%

Table 4: Awareness of road closure

Aware of Road Closures*	#	%
Aware of closure	563	92%
Not aware of closure	33	5%

*Asked to both residents and nonresidents who were traveling on WY296

Table 5: Length of stay on Beartooth Highway and region

	Proportion of Day Trip /Overnight	Nights spent in Cooke City/Colter Pass/Silver Gate	Nights spent in Cody, WY	Nights spent in MT	Nights spent in WY	Travelers in Vehicle
Mean	-	1.25	0.22	1.84	0.46	2.56
Median	-	0	0	0	0	2.00
# of Overnight	483 (44%)	-	-	-	-	-
# of Day Trippers	620 (56%)	-	-	-	-	-

While visiting, travelers (resident and nonresident) participated in many activities in the Beartooth Region. Eating at a restaurant or stopping for fuel was participated in by 46 percent of travelers. Scenic driving (32%), snowmobiling (25%), wildlife watching (22%), and nature photography (18%) are indicated as other popular activities.

Table 6: All visitor activities in BTH Region

All visitor's activities*	Frequency	Percentage
Eat at a restaurant or get fuel	747	46%
Scenic driving	524	32%
Snowmobile	414	25%
Wildlife watching	354	22%
Nature photography	301	18%
Backcountry skiing	75	5%
Cross-country skiing	74	5%
Snowshoeing	57	4%
Day hiking	44	3%
Hunting or Trapping	14	1%

*Both residents and nonresidents were allowed to select multiple activities.

Finally, total traffic numbers at both locations were recorded and analyzed. The proportion of residents to nonresidents, as observed during the on-site surveying, was applied to the traffic counts to arrive at estimates of resident and nonresident traffic in the Beartooth Region. WY 296 (Chief Joseph Scenic Byway) was used by 25,026 total vehicles during the sample period. Of these vehicles, 9,063 were nonresident travelers (36%) and 15,963 were resident travelers (64%) (Table 7). The northeast entrance of Yellowstone National Park catered to 9,215 total vehicles, 8,051 nonresidents (87%) and 1,164 residents (13%) (Table 8). In total, 16,379 nonresident vehicles visited the Beartooth Highway Region during the winter season of 2012-2013. When combined with residents, 34,241 vehicles proceeded past the sample sites during the winter season (Table 9).

Table 7: WY 296 - Traffic count and nonresident proportion*

	All	Nonresident	Resident
Total Traffic (December 17th – April 12th)	25,026	8,328	15,963
Average Daily Traffic	168	60	107
WY 296 Nonresident Proportion Total	36% nonresident / 64% resident		

*Data obtained from traffic counter on WY 296 provided by Wyoming Department of Transportation.

Table 8: NE Entrance of YNP - Traffic count and nonresident proportion*

	All	Nonresident	Resident
Total Traffic (December 17th – April 12th)	9,215	8,051	1,164
Average Daily Traffic	52	45	7
Northeast Gate Nonresident Total	87% nonresident / 13% resident		

*Data obtained from traffic counter at the NE entrance of Yellowstone National Park.

Table 9: Total traffic count and nonresident proportion

	All	Nonresident	Resident
Total Traffic (December 17th-April 12th)	34,241	16,379	17,862
Average Daily Traffic	110	57	53
WY 296 Nonresident Proportion Total	48 % nonresident / 52% resident		

SECTION 2: Economic Impact Assessment

Economic impact assessments are conducted in order to best estimate the effect of visitor spending in the local economies. In the summer of 2012, visitor spending contributed to over \$50 million in economic activity to Carbon County, MT, Park County, MT, and Park County, WY. Before presenting the winter season economic impact assessment, a few key aspects should be noted regarding the nature of the impacts.

The economic impact assessment is split into two countywide impacts; Park County, MT and Park County, WY. Because of the winter road closure, Carbon County, MT, which includes Red Lodge, MT, is not included in winter season economic impacts. Furthermore, Cody, WY had a very small sample size compared to Cooke City/Colter Pass/Silver Gate. Thus, many of the expenditure categories that were included on the mailback survey are not included in the Park County, WY impact assessment.

These industry sectors include: campgrounds, B&B's, guest ranches, rental cabins, guides & outfitters, snowmobile/auto repair, snowmobile/auto rental, Yellowstone NP fees, other admissions, entrance fees, and licenses, and services. In Cooke City/Colter Pass/Silver Gate, campgrounds, guides & outfitters, and services are not included in the economic impact assessment due to a small sample size. While it is recognized that spending may, or in some cases did, occur in these sectors during the winter season, the sample is not large enough to generalize to the total population of travelers. Thus, economic impact numbers may appear to be smaller than what is expected by those in certain sectors. Furthermore, spending on admissions/licenses in Cooke City/Colter Pass/Silver Gate, MT was split evenly to represent Montana and Wyoming snowmobile permit sales. Due to this split, \$23,670 of licensing fees in Cody, WY is not allocated to Park County, WY in the impact. However, it is acknowledged that permitting fees are relevant to the winter impact of both states. The following page contains the economic impact analysis for Park County, MT and Park County, WY.



Economic Contribution of Winter Season Travel in The Beartooth Region - Nonresident Expenditures

2012-2013 Winter Season Contribution of Nonresident Visitor Spending to the Local Economies*

- During winter, 2012-2013, nonresident (visitors living outside of Park County, WY or Park County, MT) travelers spent \$2.53 million in the BTH Region.
- Nonresident travelers spent \$2.35 million in Cooke City/Colter Pass/Silver Gate, MT and \$186,000 in Cody, WY.
- This \$2.53 million in nonresident spending supports \$3.01 million in economic activity and supports 38 total jobs due to spending in the Beartooth Region.

Table 1 - 2012-2013 Park County, MT Economic Impact (Spending in Cooke City/Colter Pass/Silver Gate, MT area)

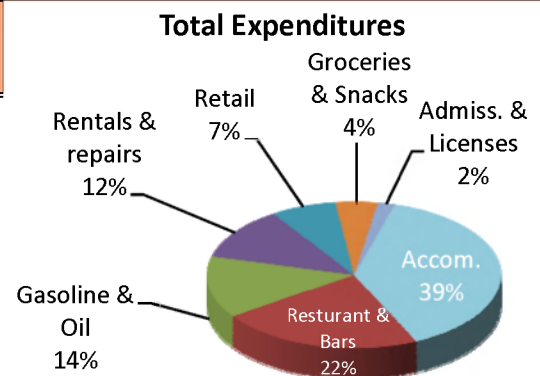
\$2.35 million in nonresident spending contributes:	Direct	Indirect	Induced	Combined
Industry Output	\$1,923,000	\$496,000	\$375,000	\$2,794,000
Employment (# of jobs)	26	6	4	36
Employee Compensation	\$544,000	\$102,000	\$80,000	\$727,000
Proprietor Income	\$88,000	\$35,000	\$18,000	\$141,000
Other Property Type Income	\$182,000	\$87,000	\$87,000	\$355,000
State & Local Taxes	-	-	-	\$184,000

Table 2 - 2012-2013 Park County, WY Economic Impact (Spending in Cody, WY area)

\$186,000 in nonresident spending contributes:	Direct	Indirect	Induced	Combined
Industry Output	\$143,000	\$45,000	\$27,000	\$214,000
Employment (# of jobs)	2	<1	<1	2
Employee Compensation	\$38,000	\$9,000	\$6,000	\$54,000
Proprietor Income	\$7,000	\$5,000	\$3,000	\$13,000
Other Property Type Income	\$18,000	\$8,000	\$6,000	\$32,000
State & Local Taxes	-	-	-	\$16,000

Table 3 - 2012-2013 All Nonresident Traveler Expenditures

Expenditure Category	Total Expenditures	Allocation by Category
Accommodations	\$979,000	39%
Restaurants	\$565,000	22%
Gasoline & Oil	\$347,000	14%
Rentals & repairs	\$295,000	11%
Retail	\$183,000	7%
Groceries & Snacks	\$117,000	5%
Admissions/Licenses	\$47,000	2%



Beartooth Region nonresident travel spending data was collected December 17th, 2012 – April 12th, 2013.

* IMPLAN economic input-output modeling software was used in for these analyses.

Economic Impacts Summary

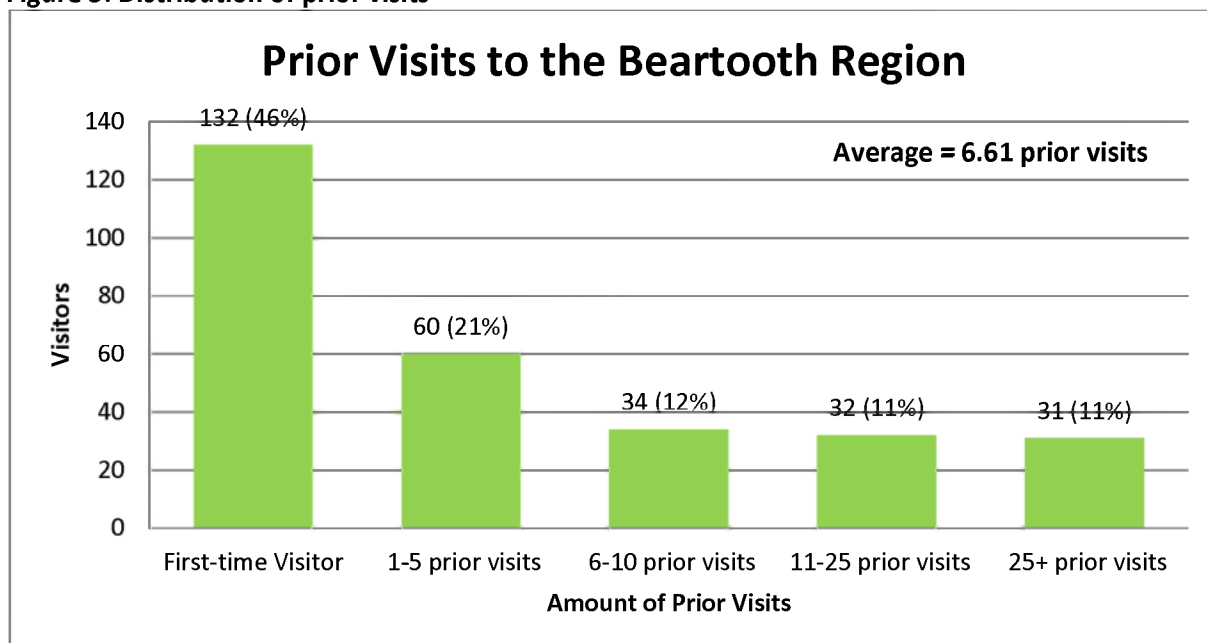
As the above assessment indicates, it is clear that Cooke City/Colter Pass/Silver Gate, MT is primarily where nonresident visitor spending occurs. Cooke City/Colter Pass/Silver Gate, MT accrues over \$2 million more in visitor spending during the season than Cody, WY. Cody, WY appears to be less prevalent for spending by BTH visitors in the winter season. In the summer season, Park County, WY (Spending in Cody, WY) had the highest amount of impact with over \$23 million in impacts. In total, winter visitors account for over \$3 million in economic impact to the Beartooth Region, supporting 38 jobs.

In terms of industry sectors, accommodations are indicated as having the highest share of total expenditures with \$979,000 (39%). Accommodations include hotels/motels, ranches, bed & breakfasts, and rental cabins. Restaurants (22%), gasoline & oil (14%), and rentals/repairs (11%) follow in terms of percentage of nonresident spending.

SECTION 3: Mailback Survey Results

Section 3 is segmented into various subsections. Each subsection is a part of the mailback questionnaire handed out to nonresident travelers on the BTH. As a reminder, these results only include nonresident travelers. Interestingly, the distribution of “first-time visitors” and “repeat visitors” is very similar to the summer distribution. Slightly over half (54%) of the visitors to the BTH Region during winter are repeat visitors, and 46 percent are classified as first-time visitors (Table 10). Because of this split, comparative statistics of the two visitor types are displayed throughout much of the data. One subsection also categorizes visitors based on their primary activity group

Figure 3: Distribution of prior visits



*Responses delimited to 25+ prior visits.

Demographics

In this subsection, respondent demographics of winter travelers are presented. Comparative analyses of first-time, repeat, and all visitors are included. Although demographics are fairly simplistic, they provide an important first look at the visitors of the destination. Furthermore, comparing and contrasting demographics between visitor types provides insight into the destination's visitor make-up.

Demographically, there is not high variability amongst Beartooth Highway first-time and repeat visitors. The majority of visitors who were in the Beartooth Region during winter were repeat visitors (54%), but first-time visitors (46%) were almost as prevalent (Table 10). Visitors tend to be well-educated (Table 11), a variable amount of income (Table 12), and a mean age of 51 years old (Table 13). Fifty-nine percent of all visitors were male and 39 percent female (Table 14). Repeat visitors have a slightly wider discrepancy in gender with 62 percent male and only 35 percent female.

Table 10: Prior visits to the BTH Region

First-time or Repeat Visitor*	All Visitors
Repeat	157 (54%)
First-time	132 (46%)

*Visitors were asked to state number of prior visits to that Beartooth Region during winter season only.

Table 11: Highest level of education completed

<u>Highest Level of Education</u>	First-Time Visitors		Repeat Visitors		All Visitors	
	#	%	#	%	#	%
Bachelor's Degree	40	31%	49	32%	89	31%
Master's Degree	32	24%	30	20%	62	22%
Some College	16	12%	26	17%	42	15%
High School Diploma or the equivalent (GED)	12	9%	21	14%	33	12%
Doctorate or Professional Degree	15	11%	19	12%	34	12%
Associates Degree	12	9%	7	5%	19	7%
Some High School	2	2%	2	1%	4	1%
Total					283	98%

Table 12: Average household income

	First-Time Visitors		Repeat Visitors			All Visitors	
Average Household Income	#	%	#	%		#	%
Less than \$25K	8	7%	3	2%		11	4%
\$25K to less than \$50K	19	14%	12	8%		31	12%
\$50K to less than \$75K	25	19%	26	18%		51	19%
\$75K to less than \$100K	22	17%	31	21%		53	20%
\$100K to less than \$150K	24	18%	43	30%		67	25%
\$150K to less than \$200K	14	11%	12	8%		26	10%
\$200K or greater	12	9%	19	13%		31	12%
Total						270	93%

Table 13: Mean age and distribution

Age of Travelers	First-Time Visitors	Repeat Visitors		All Visitors
Mean	52 Years	50 Years		51 Years
Minimum	18 Years	22 Years		18 Years
Maximum	77 Years	88 Years		88 Years

Table 14: Gender distribution

Gender	First-Time Visitors	Repeat Visitors		All Visitors
Male	72 (55%)	97 (62%)		169 (59%)
Female	57 (43%)	55 (35%)		112 (39%)

Overall Trip Characteristics

In this subsection, characteristics of the visitors' current trip in the region are analyzed. Trip characteristics are discussed in three parts: (1) visitor behavior, (2) visitor activities with first-time visitors, repeat visitors, and all visitors on the BTH, and (3) travel routes.

Visitor Behavior

Visitors who stayed at least 1 night in the region spent the majority of their nights in Cooke City/Colter Pass/Silver Gate, MT (3.11 nights) and only .47 nights in Cody, WY. Repeat visitors in Cody, WY tend to spend roughly .5 nights more than first-time visitors. On average, repeat visitors in total spend .7 nights more in the Beartooth Region per trip than first-time visitors, if they spent at least 1 night in the BTH region (Table 15). Gardiner, MT (25%) was identified as the most frequent location to spend at least one night outside of Cooke City/Colter Pass/Silver Gate, MT or Cody, WY, followed by Yellowstone NP (11%), Bozeman, MT (10%), and Billings, MT (8%) (Table 16).

Table 15: Nights spent by those visitors who stayed at least 1 night in BTH Region

Location of Nights Spent*	First-Time Visitors	Repeat Visitors	All Visitors
Cooke City/Colter Pass/Silver Gate, MT	2.97	3.18	3.11
Cody, WY	.13	.62	.47
Total	3.10 nights	3.80 nights	3.58 nights

*Only nonresidents who spent at least 1 night included.

Table 16: Distribution of nights spent outside of BTH Region*

	First-Time Visitor		Repeat Visitor		All Visitors	
<u>Other Locations Visitor Spent a Night</u>	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>
In or near Gardiner, MT	35	27%	37	24%	72	25%
Yellowstone NP	19	14%	12	8%	31	11%
In or near Bozeman, MT	17	13%	11	7%	28	10%
In or near Billings, MT	6	5%	17	11%	23	8%
In or near Livingston, MT	8	6%	6	4%	14	5%
In or near West Yellowstone, MT	6	5%	3	2%	9	3%
In or near Jackson, WY	6	5%	2	1%	8	3%
In or near Sheridan, WY	2	2%	2	1%	4	1%

*Percentage totals per column may vary due to missing data. If visitors spent a night in more than one town, they were able to select multiple responses.

In Table 17, respondents indicated all the possible reasons they visited the BTH region followed by primary reason in Table 18. Overwhelmingly, visitors selected the purpose because “it is close to wildlife viewing in Yellowstone” (84% for all purposes; 62% for primary purpose). Looking at primary purpose, twenty percent stated because “it has the best snow for my outdoor recreation.” Responses were designed with outdoor recreation in mind because much of the activity in the area during the winter is for that purpose. Repeat visitors are more likely to visit the area primarily because of the snow quality than first-time visitors (27% and 12%, respectively). However, first-time visitors (72%) are more likely to visit because of wildlife in YNP than repeat visitors (54%) (Table 18).

Table 17: All Purposes for visiting BTH Region

	First-Time Visitor		Repeat Visitor		All Visitors	
<u>Purpose for visiting*</u>	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>	<u>#</u>	<u>%</u>
It is close to wildlife viewing in Yellowstone.	83	89%	81	80%	165	84%
It has great terrain for my outdoor recreation.	15	16%	32	31%	47	24%
It has the best snow for my outdoor recreation.	10	11%	31	30%	41	21%
It has convenient access to winter trails.	12	13%	20	19%	32	16%
It has good trails for my outdoor recreation.	9	10%	20	19%	29	15%

*Respondent could select as many purposes as they desired.

Table 18: Primary purpose for visiting BTH Region

Primary purpose for visiting*	First-Time Visitor		Repeat Visitor		All Visitors	
	#	%	#	%	#	%
It is close to wildlife viewing in Yellowstone.	91	72%	83	54%	174	62%
It has the best snow for my outdoor recreation.	15	12%	41	27%	56	20%
It has great terrain for my outdoor recreation.	11	9%	22	14%	33	12%
It has good trails for my outdoor recreation.	4	3%	5	3%	9	3%
It has convenient access to winter trails.	6	5%	2	1%	8	3%

*Respondent was instructed to select only one primary purpose.

Visitor Activities

The following tables and figures display information pertaining to activities participated in by residents and nonresidents within the Yellowstone National Park area and in the Beartooth Highway Region (outside of YNP boundaries). There is a heavy focus on outdoor recreation in the region during the winter season. This section offers a more specific look at what winter activities visitors are participating in.

Tables 19 and 20 represent frequency of participation by visitors (both local and nonresident) in various winter activities. As stated previously, the winter season in the Beartooth Region is primarily focused around some form of outdoor recreation. During winter, limited opportunities for more passive touristic opportunities besides wildlife watching, photography, and scenic driving exist. Thus, an abbreviated listing of activities was used when compared to the 2012 summer study. In tables 19 & 20, visitors were asked to select all of the activities in which they participated from the list provided. These questions were asked to gauge the range of participation in the listed activities, as well as to note the activities participated in most frequently. Among all visitors in the BTH Region, wildlife watching (21%) is indicated as the top activity, followed by with scenic driving (20%), nature photography (19%), and snowmobiling (18%) (Table 19). In Yellowstone NP, wildlife watching (27%) is the top activity for all visitors, again followed by scenic driving (24%) and nature photography (22%) (Table 20). While all activities are important to consider, the primary activity in which visitors participated in the region is more telling. Thus, visitors were asked to state which activity from the list provided was the primary activity on their current trip (Figures 4 & 5).

Table 19: Activity participation in BTH Region

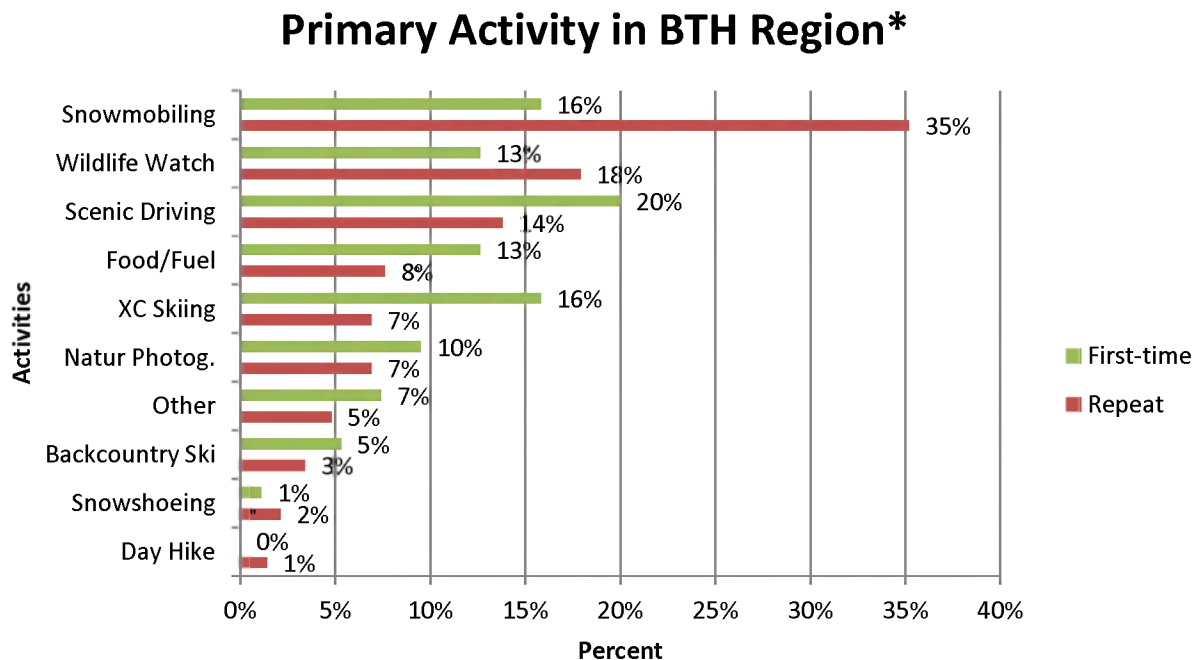
BTH Activity	First-Time Visitors		Repeat Visitors		All Visitors	
	#	%	#	%	#	%
Wildlife Watching	25	19%	36	23%	61	21%
Scenic driving	25	19%	32	20%	57	20%
Nature photography	28	21%	27	17%	55	19%
Snowmobiling	11	8%	41	26%	52	18%
Stopped for food/fuel only	14	11%	12	8%	26	9%
Cross-Country skiing	6	5%	9	6%	15	5%
Day hiking	5	4%	9	10%	14	5%
Snowshoeing	3	2%	9	6%	12	4%
Backcountry skiing	2	2%	6	4%	8	8%

Table 20: Activity participation in YNP

YNP Activity	First-Time Visitors		Repeat Visitors		All Visitors	
	#	%	#	%	#	%
Wildlife Watching	37	28%	41	26%	78	27%
Scenic driving	32	24%	38	24%	70	24%
Nature photography	33	25%	31	20%	64	22%
Wolf Watching	25	19%	22	14%	47	16%
Day hiking	9	7%	15	10%	24	8%
Snowshoeing	9	7%	10	6%	19	7%
Cross-Country skiing	6	5%	11	7%	17	6%
Snowmobiling	4	3%	6	4%	10	4%
Backcountry skiing	2	2%	4	3%	6	2%

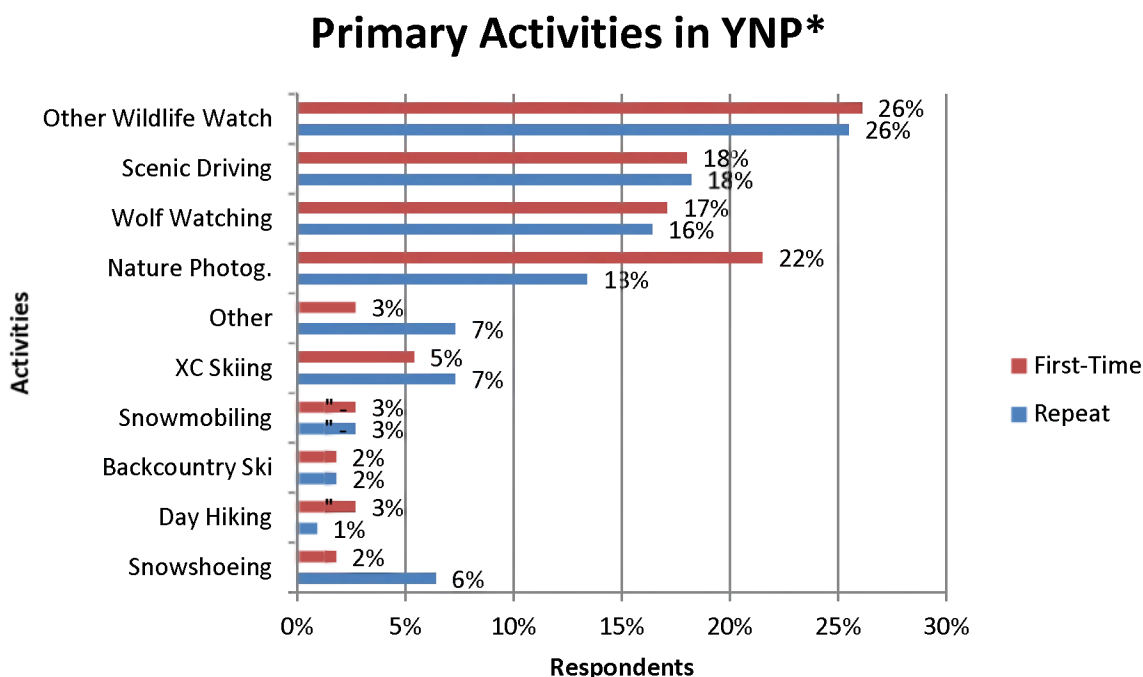
As for primary activities in the BTH region, repeat visitors (35%) indicated snowmobiling as a much more prevalent primary activity than first-time visitors (16%) (Figure 4). In fact, every activity besides nature photography is shown to have been more frequently selected by repeat visitors as their primary activity in the BTH Region. In the YNP region, wildlife watching was the most frequently identified primary activity by both first-time (26%) and repeat visitors (26%) (Figure 5). Visitors more often chose passive activities, such as scenic driving, as their primary activity in the YNP Region. First-time visitors, while still participating in BTH activities, are more focused on activities inside of YNP. Further discussion and results are presented based on primary activities in a following subsection entitled “Activity Segments.”

Figure 4: Primary activity in BTH Region



*"First-time" respondents (n = 95). "Repeat" respondents (n = 144).

Figure 5: Primary activity in Yellowstone National Park



* "First-Time" respondents (n = 111). "Repeat" respondents (n = 109).

Travel Routes

This sub-section provides results regarding the route nonresident travelers used to access the region. In the mailback survey, visitors were given a map and asked to trace their route, indicating which towns they passed through, where they entered the region, and where they exited the region. Figure 6 is the map that visitors used to trace their route. The region outlined east of Yellowstone NP is the Beartooth Region's winter area. Percentages of those who drove through each town are displayed next to the town name. Table 21, following the map, represents the entry and exit points visitors indicated on the survey. Respondents were instructed to place an "E" next to the town/highway where they entered the region and an "X" next to the location they exited.

As Table 21 indicates, the highest percentage of visitors entered the highway at the western end of I-90 or Bozeman, MT. Forty-nine percent of visitors stated that they passed through Livingston, MT and 55 percent passed through Gardiner, MT. On the eastern side of the BTH region, 29 percent of visitors passed through Cody, WY at some point of their trip to the Beartooth Region. However, one does not have to pass through Cody, WY if arriving from the north or the east. There appears to be a smaller percentage of those who stated they used the Wyoming routes for accessing the highway (Figure 6).

Results indicate that places such as Billings, MT, Bozeman, MT, and Cody, WY are areas that receive a large number of visitors passing through their towns to reach the BTH Region. Due to the high number of responses, towns with high pass-through frequencies would be appropriate locations to incorporate information regarding the Beartooth Region for use prior to the visitor's arrival.

Figure 6: Towns passed through in Greater Yellowstone Area

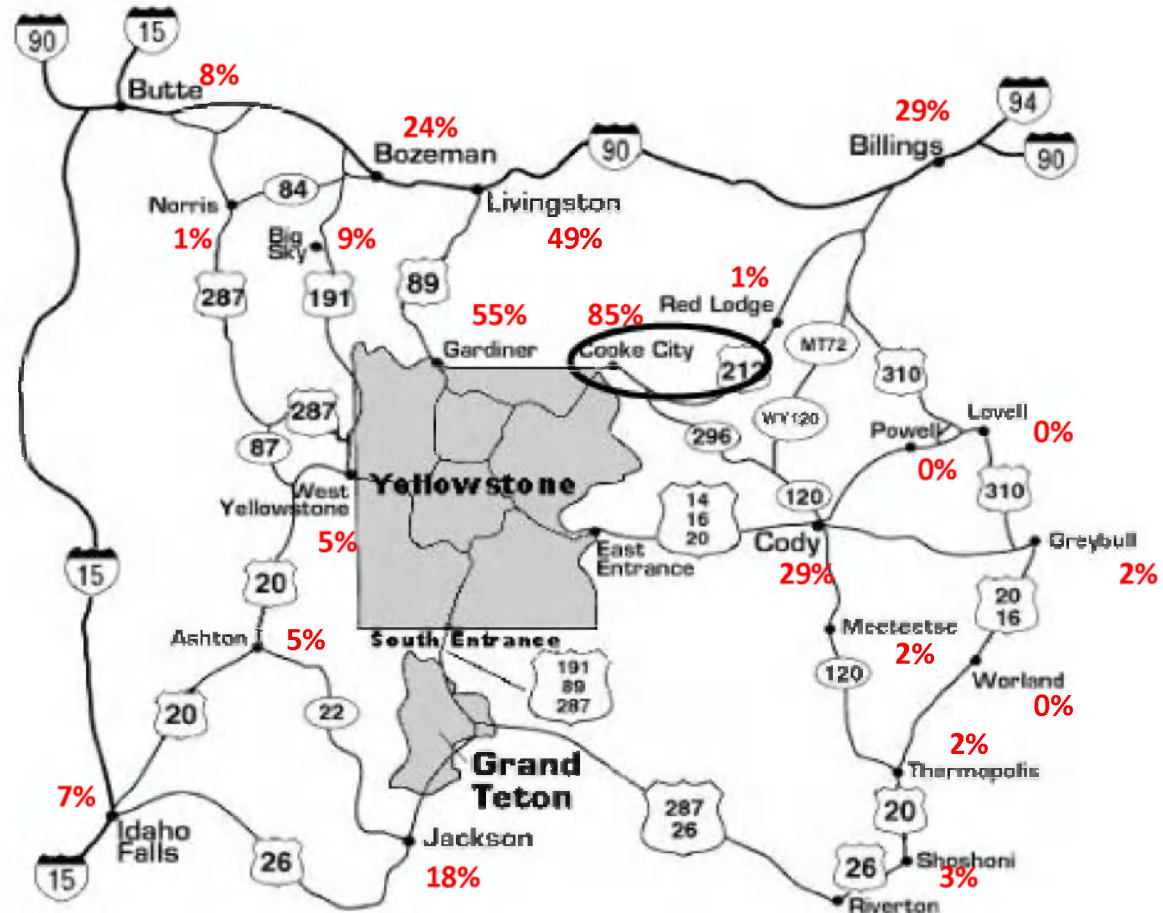


Table 21: Entry and exit points to Greater Yellowstone Area

Entry/exit Point	Enter Frequency	Percent	Exit Frequency	Percent
I-90 from West	25	24%	22	22%
Bozeman	25	24%	24	24%
I-90 from East	22	21%	24	24%
I-94 from East	10	10%	7	7%
Livingston	10	9%	10	10%
I-15 from South	7	7%	8	8%
I-15 from North	2	2%	8	8%
Jackson	2	2%	3	3%
Riverton	1	1%	0	0%
Shoshone	1	1%	1	1%
Greybull	1	1%	0	0%
Thermopolis	0	0%	0	0%
Worland	0	0%	1	1%
Lovell	0	0%	0	0%

*Because of a large number of missing data, percentage totals are based only on those who responded to the question, thus, inflating percentages.

Image of the Beartooth Highway during Winter Season

Destination image can be defined simply as “the sum of beliefs, ideas, and impressions that a person has of a destination (Crompton, 1979a).” Visitors in the summer of 2012 perceived the Beartooth Highway Region as well-kept, wild, and providing a sense of relaxation. The winter season is extremely different in nature. The following results provide a look into how winter visitors perceive road conditions, recreation qualities, and access during the winter in the Beartooth Highway Region. Quantitative statistics are presented first, followed by an analysis of open-ended questions pertaining to these subjects. A summary of image related questions is included in the discussion section of this report.

Table 22 displays mean responses and distribution of ratings for road conditions of the Beartooth Highway during the winter season. All results are, generally, very positive for first-time, repeat, and all visitors. The highest scoring statement relates to the maintenance and plowing of the Beartooth Highway. Independent t-tests were conducted to determine if significant differences exist in mean scores between first-time and repeat visitors. First-time visitors perceived the safety and security of the Beartooth Highway significantly higher than repeat visitors, which was the only significant difference between groups amongst all responses.

Table 22: Road conditions statement ratings and independent t-tests

Beartooth Highway Statements	First-Time		Repeat		All visitors	
	N	%	N	%	N	%
“During winter, the parts of the Beartooth Highway that are plowed are well maintained and free of snow.”						
Disagree	7	8%	14	12%	21	10%
Agree	78	92%	106	88%	184	90%
Mean	3.27		3.13		3.20	
“The Beartooth Highway provides good winter recreation access and parking.”						
Disagree	10	13%	12	10%	22	12%
Agree	63	87%	105	90%	168	88%
Mean	3.08		3.21		3.16	
“It is easy to find road reports for the Beartooth Highway Region.”						
Disagree	11	19%	24	26%	35	23%
Agree	47	81%	70	74%	117	77%
Mean	3.01		2.88		2.93	
“The Beartooth Highway is safe and secure to drive on in the winter.”*						
Disagree	12	15%	29	25%	41	21%
Agree	69	85%	88	75%	157	79%
Mean	2.97		2.88		2.92	

Scale – 1 = “strongly disagree” to 4 = “strongly agree”

*Significant differences between first time and repeat visitor groups at the .05 level.

The recreation statements were overall positive for first-time, repeat, and all visitors (Table 23). The highest rated statement is "The Beartooth Highway provides a wide range of outdoor winter recreation opportunities" with a mean of 3.34 out of 4. Independent t-tests were conducted to determine if differences were present between repeat and first-time visitors. Four statements had significant differences: "higher quality winter rec. experience," "rather recreate in this Beartooth Region than anywhere else," "I will return to this Beartooth Region," and "I will recommend to others to visit." Repeat visitors had significantly higher ratings in these questions than first-time visitors. Thus, this shows that first-time and repeat visitors may perceive winter recreation differently.

Table 23: Recreational image perception and independent t-tests

		First-Time		Repeat		All visitors	
Beartooth Highway Statements		N	%	N	%	N	%
“The Beartooth Highway provides a wide range of outdoor winter recreation opportunities.”		Mean	3.29		3.81		3.34
	Disagree	6	6%	4	3%	10	4%
	Agree	96	94%	139	97%	235	96%
“I will recommend to others to visit this Beartooth Region during the winter season.” *		Mean	3.20		3.42		3.33
	Disagree	13	13%	5	4%	18	7%
	Agree	87	87%	139	96%	226	93%
“I will return to this Beartooth Region for my winter recreation.” *		Mean	3.13		3.44		3.31
	Disagree	13	14%	3	2%	16	7%
	Agree	79	86%	140	98%	219	93%
“This Beartooth Region met my expectations for my winter recreation.”		Mean	3.21		3.34		3.29
	Disagree	5	6%	1	1%	6	2%
	Agree	87	94%	140	99%	227	98%
“The Beartooth Region has a higher quality winter rec. experience than other places I have visited.” *		Mean	2.83		3.06		2.98
	Disagree	34	41%	28	21%	62	29%
	Agree	50	59%	103	79%	153	71%
“I would rather recreate in this Beartooth Region than anywhere else.” *		Mean	2.48		2.80		2.68
	Disagree	51	59%	52	39%	103	47%
	Agree	35	41%	83	61%	118	53%
“This Beartooth Region is too crowded to enjoy my winter recreation.”		Mean	1.87		1.93		1.90
	Disagree	82	90%	123	88%	205	89%
	Agree	9	10%	17	12%	26	11%

Scale - 1 = "strongly disagree" to 4 = "strongly agree"

*Significant differences at the .05 level.

Activity Segments

In this subsection, responses are compared and contrasted based on primary activities in the Beartooth Highway Region. This form of analysis allows stakeholders to better understand the visitors' perceptions, beliefs, and feelings based on activity groups.

A-priori segmentation was used to separate respondents into three activity groups in the Beartooth Region: snowmobilers, active users, and passive users. These three groups were determined to best represent the sample of visitors participating in activities while along the BTH. In previous travel studies, a-priori segmentation has been identified as a reliable method of separating respondents into groups. "Active users" consist of those who indicated their primary activity as cross-country skiing, snowshoeing, backcountry skiing, or day hiking. Snowmobiling is a very engaging and active sport, but because of being motorized, it is separated into its own category for comparative purposes. "Passive users" consist of those who indicated their primary activity as wildlife watching, scenic driving, eating at a restaurant/getting fuel, or nature photography. Based on these three segments, demographics, image perception, and significant differences in responses to several questions are presented below.

Demographics

Table 24: Activity segment demographics

	Snowmobilers (n=66)	Active (n=35)	Passive (n=125)
Age	43.4	53.76	53.31
Prior Visits	12.7	7.2	4.92
Nights spent	2.32 Cooke City/Colter Pass/Silver Gate .18 Cody, WY	2.83 Cooke City/Colter Pass/Silver Gate .09 Cody, WY	.42 Cooke City/Colter Pass/Silver Gate .28 Cody, WY
Primary reason for visiting	59% "Best snow for my winter rec."	40% "Best snow for my winter rec."	95% "Close to wildlife viewing in YNP"
Gender	89% Male, 11% Female	62% Male, 38% Female	47% Male, 53% Female

Figure 7 indicates the mean ratings of recreation image by activity segment groups. The graph indicates a tendency of a progression of higher mean scores from snowmobilers to active users to passive users. Thus, there appears to be a relationship between type of activity segment and ratings of recreational image between activity segments.

Table 25 displays differences present between activity groups on their perception and rankings of the questions related to recreation along the BTH. A One-Way ANOVA test was conducted to indicate if differences exist. Out of seven questions, five questions are indicated as having significant differences between groups. Snowmobilers rated questions 2, 3, 6, and 7 significantly **higher** than the passive users group. This indicates that snowmobilers perceive the quality of recreation, likelihood to return, and intent to recommend more positively than passive activity respondents. Active users had significantly higher ratings than passive users in questions 1 and 6. Thus, active users perceive the Beartooth Highway to have a wider range of outdoor recreation opportunities and are more likely to return to the region than passive viewers. There were no significant differences between groups on level of crowding and whether their expectations were met. These significant differences are discussed in the "Stakeholder Implications" section of this report.

Figure 7: Perception of recreation by nonresident activity groups

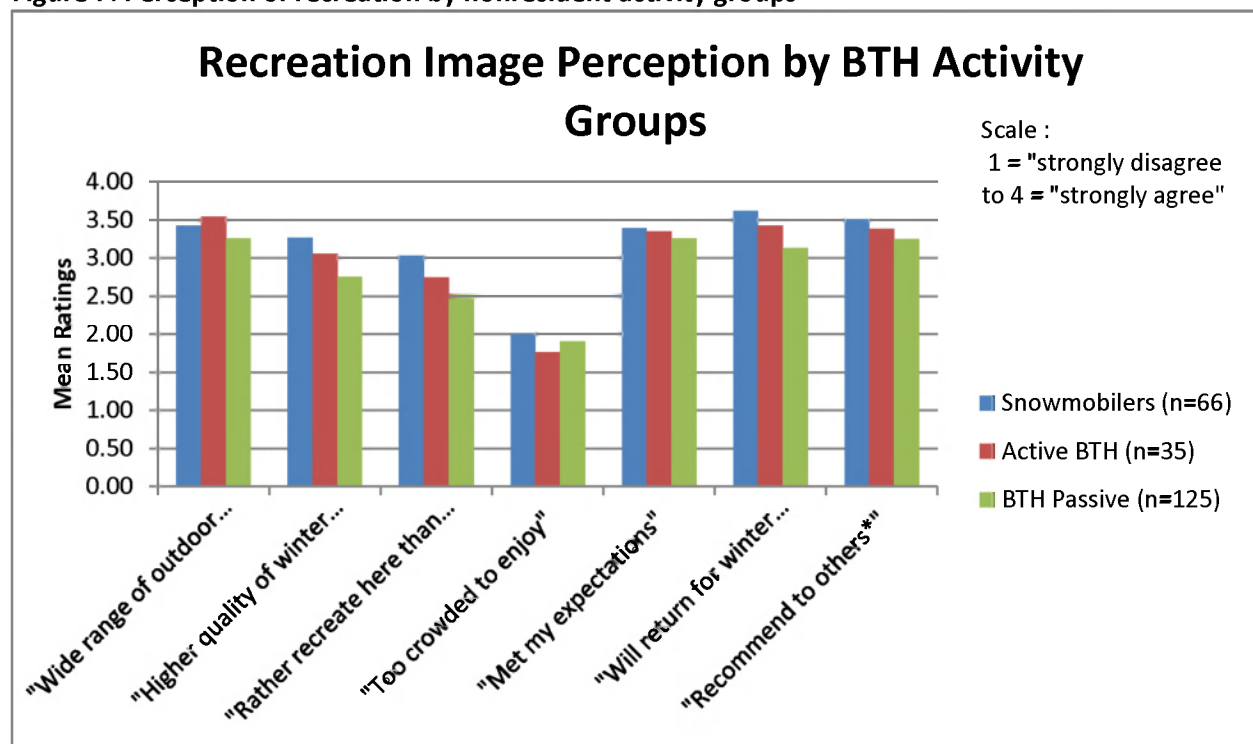


Table 25: Significant differences in activity segment recreation image ratings (ANOVA test)

Significant differences between groups?*	
1. "...wide range of outdoor rec."	Yes (active/passive)
2. "...higher quality recreation than other places."	Yes (snowmobilers/passive)
3. "...rather recreate in BTH than any other place."	Yes (snowmobilers/passive)
4. "...too crowded to enjoy."	No
5. "...met my expectations."	No
6. "...will return to region."	Yes (snowmobilers/passive) (active/passive)
7. "...recommend to others."	Yes (snowmobilers/passive)

*Significance at the .05 level.

As shown in Table 26, the rating of road conditions and access on the Beartooth Highway is not as variant as questions pertaining to recreation between groups. The only significant difference identified through the ANOVA test was between "snowmobilers" and "active users" on safety and security of the road. Snowmobilers rated the highway as significantly safer and more secure to drive on than active users. Passive users are identified having the highest rating of this statement.

Table 26: Road condition statement ratings by activity segment (ANOVA test)

Road Conditions	Snowmobiling	Active	Passive
"...safe and secure to drive on."	2.92*	2.35*	3.06
"...well maintained and free of snow."	3.13	3.1	3.26
"...easy to find road reports."	2.9	2.82	2.94
"...good winter recreation access and parking."	3.31	2.94	3.18

Scale – 1 = "strongly disagree" to 4 = "strongly agree"

*Significant differences at the .05 level

The final section on activity segments relates to visitors' awareness of limited winter access to the Beartooth Highway (Table 27). As previously stated, accessing the Beartooth Highway is difficult due to an 8-mile road closure east of Cooke City/Colter Pass/Silver Gate to Pilot Creek. This section is left unplowed because Colter Pass receives large amounts of snow, and provides snowmobiler access to the trail systems in the surrounding national forests.

Table 27 indicates that almost all visitors were aware of this closure prior to visiting the region. However, a few respondents in each activity group were unaware. Furthermore, visitors were asked if access were to improve, would it make them more inclined to visit during winter. Both snowmobilers and active users leaned more towards "no," while passive users had a very close split that slightly favored being more inclined to visit if winter access were expanded. These results will be further analyzed in the discussion section and in the open-ended comments.

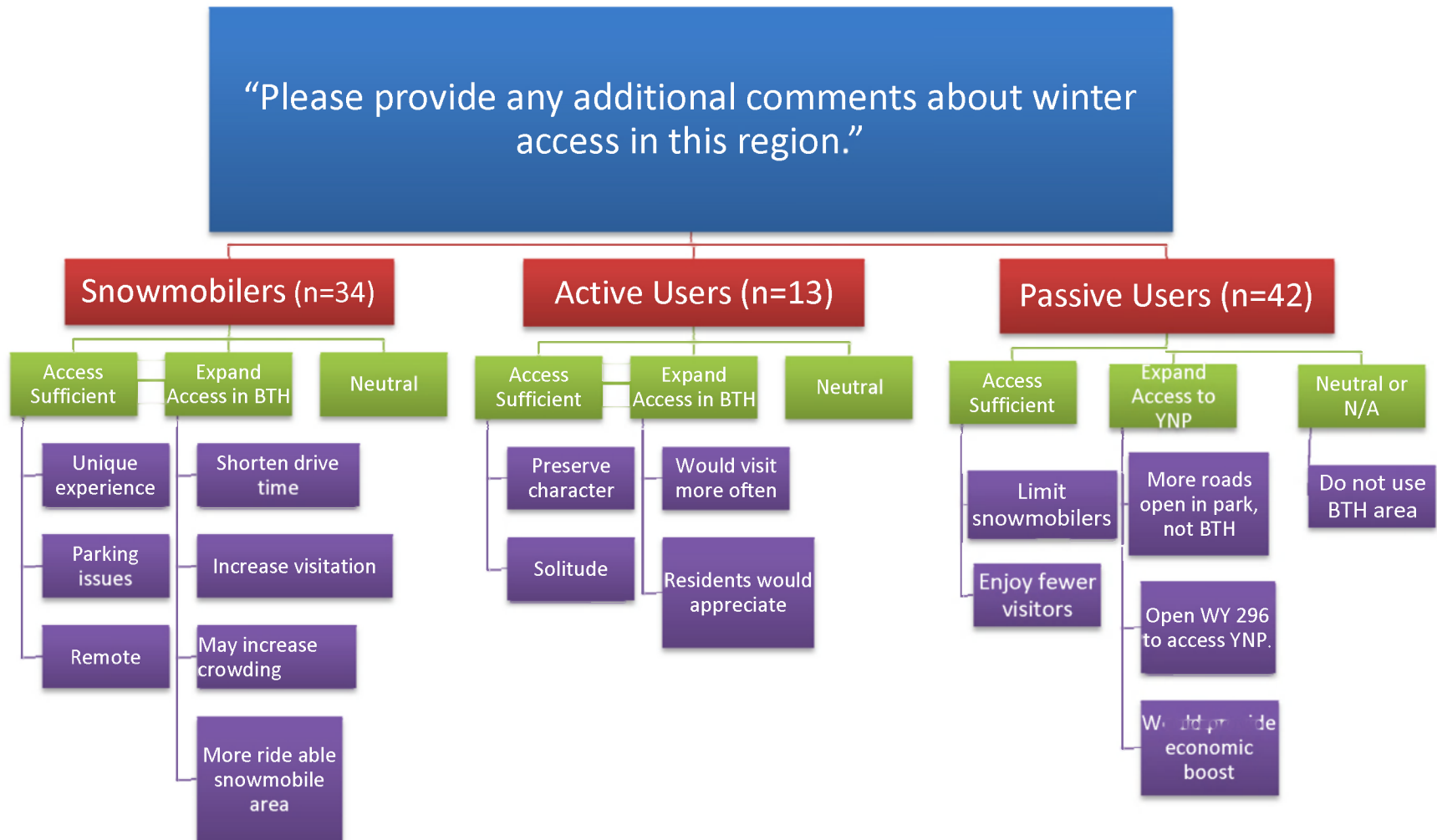
Table 27: Winter access by activity segment

Winter access questions	Snowmobilers	Active	Passive
Prior to visiting, were you aware of limited access due to winter road conditions?	95% Yes 5% No	94% Yes 6% No	92 % Yes 8% No
Would expanded access make you more inclined to visit during winter?	42 % Yes 58 % No	23.5% Yes 76.5% No	51% Yes 49% No

Open-Ended Question Analysis

On the mailback portion of the nonresident survey, four open-ended questions were asked of visitors about their concerns on issues of access, recreation, and potential changes. This provides the visitors a chance to explain concerns and opinions through their own words. The following results are a discussion of open-ended questions based on the three activity groups. A diagram displaying common themes that arose during analysis is provided for each question. Following the diagram, a synopsis of each activity group's comments is presented with sample quotes pertaining to the topic.

Figure 8: Open-Ended Comment Analysis - Winter access



“Please provide any additional comments about winter access in the region.” (Figure 8)

Snowmobilers (34 snowmobilers): The conversation on access in the Beartooth Region for snowmobilers tends to focus on a few different themes that arose during the analysis; maintaining current access, extending access through to Wyoming and a neutral stance on the issue. Snowmobilers’ opinions on access slightly favor the option of maintaining current access by a small margin. However, a number of users prefer improved access to the region. In some responses, expanding access referred to the area that snowmobilers could use, rather than expanded road access. This progressed into opinions on wilderness management around the region. Some neutral stance users note that extended access may be preferred, but parking would be a critical issue in Cooke City/Colter Pass/Silver Gate, MT, which may not be able to practically accommodate the large number of visitors.

Quotes from this activity group include:

“Cooke City is a unique experience with the road closed at the end of town and only allowing snowmobile access to the east.”

“Plow the road the last 9 miles from Pilot Creek parking lot to Cooke City! I would travel twice as much to Cooke City if it was plowed. It is a pain to drive around to Livingston if you're driving from the east and want to have your truck in town!”

“We would come no matter what.”

Active Users (13 users): Similar to snowmobilers, active users generally side towards maintaining the current level of access. Comments referring to current access keeping the area “less crowded” and protecting “Cooke City and its character” are two common reasons for not expanding access. However, one respondent mentions that “In one way, it would be easier for residents (and tourists) if there was another entry via car.” Only a few respondents note that they wish for expanding access. Equal amounts have a neutral stance on the issue.

Quotes from this activity group include:

“The Beartooth Hwy closure is essential to Cooke City and its character. Keep it exactly how it is!”

“Would love the road to be open all winter. We would come at least 2 more times. It would save us 2.5 hours.”

Passive Users (42 users): Passive users, in general, tend to have a neutral stance on the issue or mention issues related to Yellowstone National Park access, not Beartooth access. Despite this neutral trend, 12 passive users note that they would like to see WY 296 opened into Cooke City/Colter Pass/Silver Gate, MT. However, nine passive users note that they enjoy access the way it currently exists due to lack of crowding and a “feeling of remoteness.” Thus, no consensus among passive users regarding access can be identified.

To summarize comments about winter access, it is clear that there is no opinion that is outweighed by another. In all three user groups, there are respondents who are on both sides of the issue. Neutrality is also present throughout the conversation.

Figure 9: Open-Ended Comment Analysis - Aspects visitors enjoyed the most

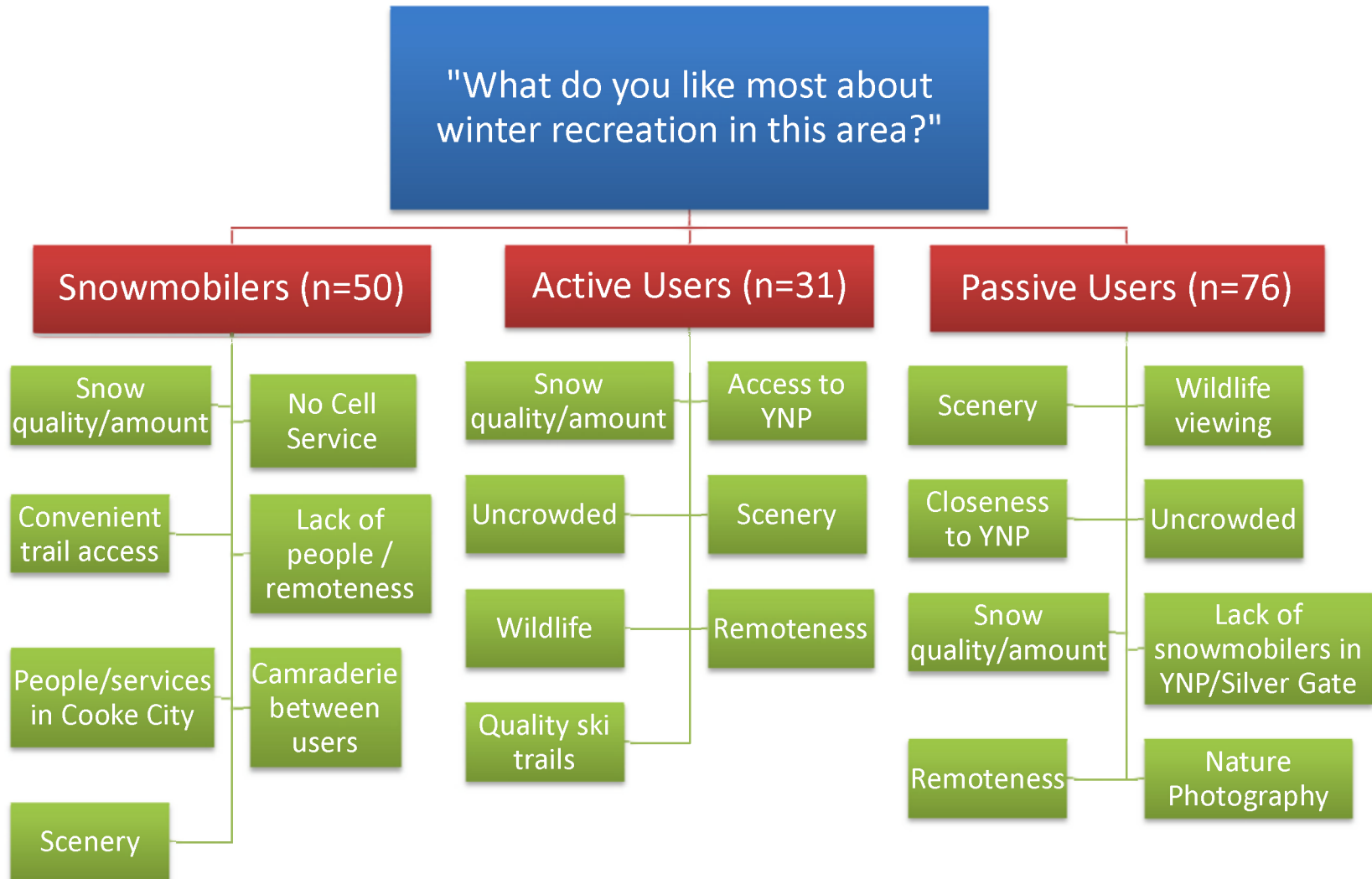
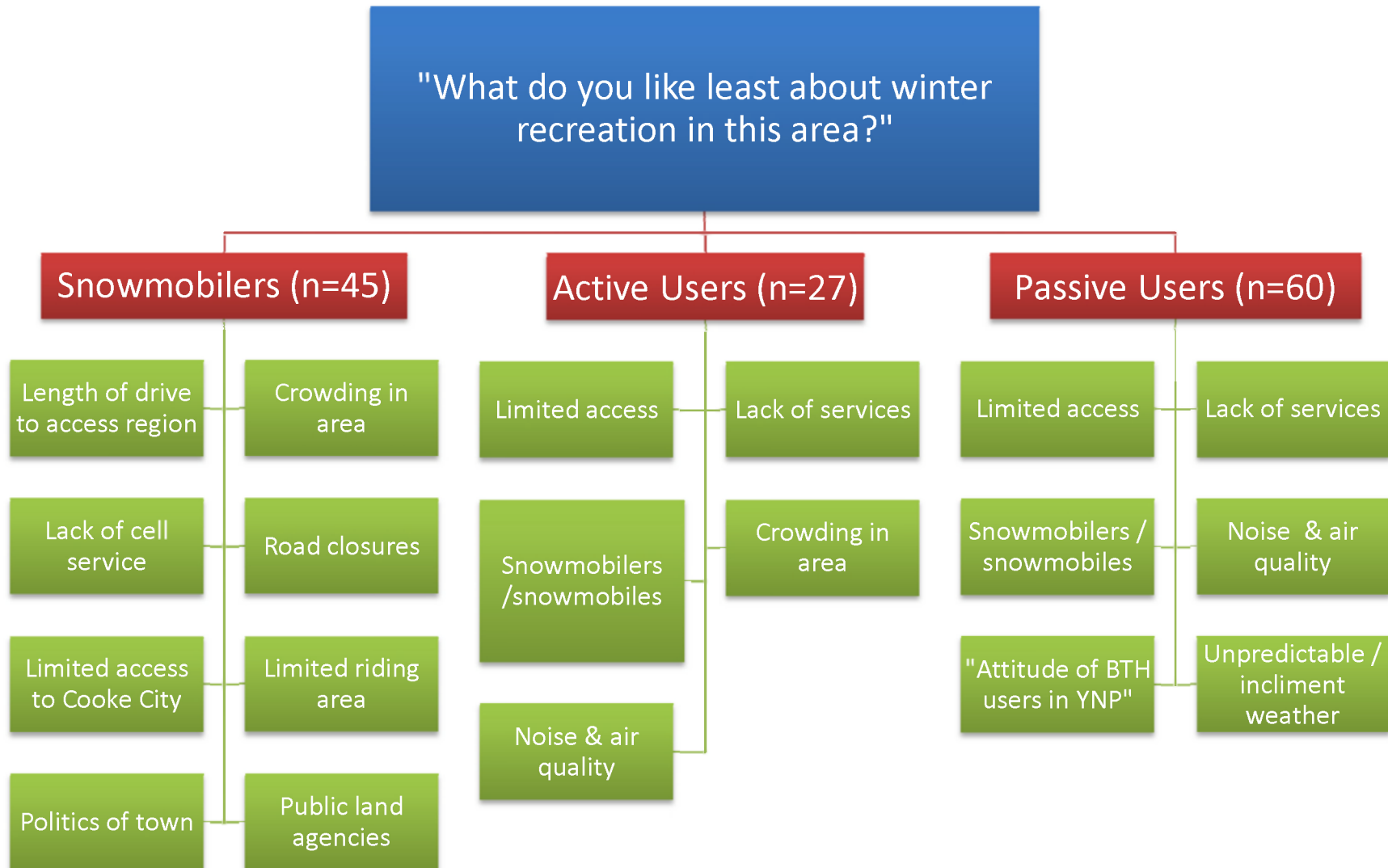


Figure 10: Open-Ended Comment Analysis - Aspects visitors enjoyed the least



“What do you like most / like least about winter recreation in this area (Figures 9 & 10)?”

Snowmobilers (45 users): Unlike active and passive users, snowmobilers are generally focused on their recreation, especially snow quality/amount. Thus, their likes and dislikes are aimed at their recreational preferences. There is a noted lack of comments concerning Yellowstone National Park, unlike other users. Aspects of enjoyment are: snow quality/amount, lack of cell service, convenient trail access, local people in Cooke City/Colter Pass/Silver Gate, MT, feeling of camaraderie between users, and remoteness. Disliked aspects include: length of drive to region, lack of cell service, limited riding area, politics of town, public land managers, crowding in area/trails, and limited access to Cooke City/Colter Pass/Silver Gate, MT.

Quotes from this activity group include:

“Excellent snow conditions, most extreme riding area. Got to know a lot of locals, easy to create friendships.”

“It is a relatively small area and with so many snowmobilers all the time it is crowded and not much powder to play in unless just after new snow.”

“It is very difficult to plan a trip here short notice. Plans must be made in advance and if you just so happen to miss fresh snow or rental availability, area can get tracked up in very short weekend with limited areas to ride.”

Active Users (27 users): Active users enjoy some of the same aspects as snowmobilers, such as snow quality, scenery, and remoteness, but tend to be more holistic in their opinions. Other aspects they enjoy are: wildlife in the area, lack of other people, remoteness, access to YNP, and the high quality ski trails. This group is focused on a combination of the overall experience as well as recreation. Their dislikes of the area seem to be much different than snowmobilers, perhaps even aimed at that user segment. Dislikes include: snowmobiles and snowmobilers in general, noise and air pollution, crowding in towns/area, lack of adequate services, and limited access to the region. Thus, this shows there is a potential for conflict in the region between recreation groups.

Quotes related to this section include:

“Few people are there so not crowded. Small town atmosphere is nice. It’s really beautiful.”

“Silver Gate is for x-c skiers. Prefer to not deal with good-old-boy snowmobiles.”

“The road closure between Cooke City and WY. We would explore that way, but only snowmobiles have that access. Why is that?”

Passive Users (60 users): Passive users’ state likeable aspects that are generally not focused on any type of recreation. Their likes focus on the scenery, environment, and feelings of the area. Aspects that they enjoy include: wildlife, scenery, peacefulness, remoteness, proximity to YNP, lack of snowmobilers in YNP/Silver Gate, amount of snow, and lack of people. Aspects disliked include:

snowmobilers and snowmobiles, noise and air pollution, lack of services, the attitude of BTH users inside of YNP, limited access, and unpredictable or inclement weather.

Quotes from this activity group include:

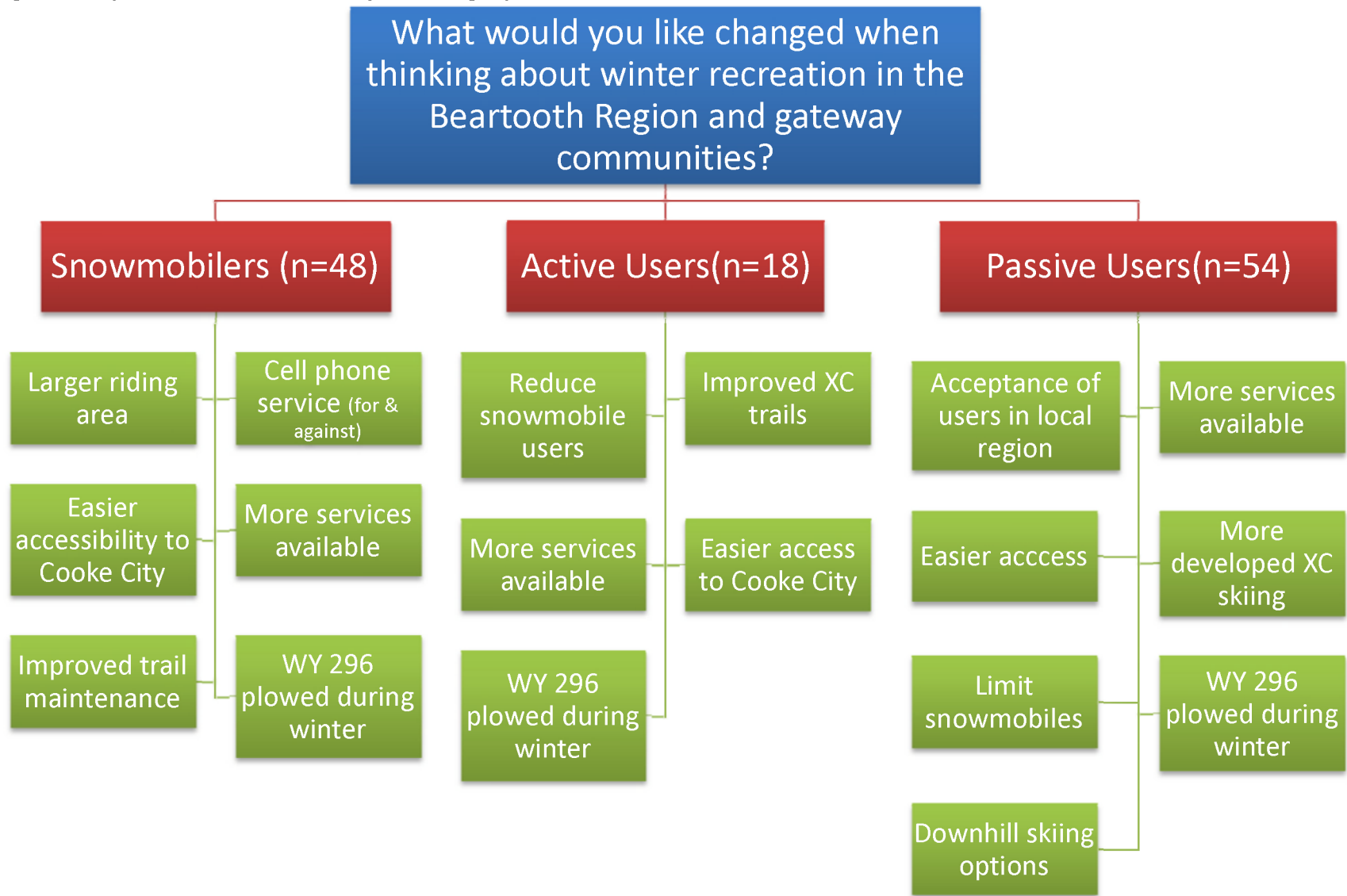
"It's quiet and has access to wilderness/wildlife. Great service and questions answered at visitor center in Cooke City."

"Loved the atmosphere! Enjoyed our meal at Soda Butte Lodge!"

"Heavy motor-head vibe around snowmobiles in Cooke City. I'm fine with giving snowmobiles a place; I don't like the blue-collar culture."

In summary, results indicate a general consensus that amount and quality of snow is a definite draw for the area, as well as remoteness, scenery, and lack of people. Snowmobilers tend to enjoy aspects related to their recreation, while active and passive users are focused on a holistic experience. Also, it appears active and passive users do not have a high tolerance of snowmobiles and snowmobile culture. This may create conflict in some areas where a variety of users are attempting to fulfill their recreational goals.

Figure 11: Open-Ended Comment Analysis - Changes preferred for winter recreation



“What would you like changed when thinking of your winter recreation in the Beartooth Region and the gateway communities (Figure 11)?”

Snowmobilers (48 users): Snowmobilers indicate six changes preferred regarding winter recreation in the Beartooth Region: larger riding area, cell phone reception, improved accessibility to Cooke City/Colter Pass/Silver Gate, MT and trails, WY 296 plowed, expanded services, and improved trail maintenance. Again, many of the comments listed by snowmobilers are related directly to their recreation. One aspect that is not mentioned is any sort of evidence of conflict with other users. In terms of conflict in the region, some respondents in this user group indicated issues with wilderness areas and restrictions enforced by public land agencies. It should be noted that while a number of visitors mention a desire for cell phone service, a large number of visitors state that the lack of cell phone service was preferred.

Quotes from this activity segment include:

“Be nice if some of the other shops were open when weather keeps you off the mountains.”

“I want it kept open for riding snowmobiles. I have been riding there for 20 years and my family enjoys the riding and scenery as well. I would like more area opened.”

Active Users (18 users): Active users have only five suggested changes: reduction of snowmobile use, improved ski trails, more services available, easier access into Cooke City/Colter Pass/Silver Gate, MT/WY 296 plowed. Interestingly, active users' changes are focused on access to the region, trails, and the number of people in towns. It appears that active users do not seem to spend as much time in the town and may not require lavish amenities. Their experience is more focused on accessing areas for recreational experiences. Providing expanded options for dining and lodging as well as increasing the amount of usable area outside of YNP may be beneficial for this segment.

Quotes from this activity segment include:

“Better separation of motorized and non-motorized trails.”

“Silver Gate is our 1st choice. Only one real business is open and their cabin and store is perfect. Cooke City is too rude, smoky and loud. The snowmobiles ruin the area and the riders are rebels on and off the road. Someone needs to plow 212 and open all those opportunities, to and from Billings and Cody.”

Passive Users (54 users): Passive users, while having the largest sample size, indicate the highest number of preferred changes including: more services available, improved XC ski trails, easier access/WY 296 plowed, downhill ski options, limit on snowmobiles, and a more generous attitude towards nonmotorized users. Suggested changes provide insights into how passive users perceive the area. It appears as though they may not feel as welcome in the Beartooth Region as other users. However, image analysis still indicates high levels of enjoyment at the location. Furthermore, passive users indicate that better developed and promoted recreational opportunities may entice them to stay longer and visit more frequently.

Quotes from this activity segment include:

“Any more open roads would only mean more fun to have and reasons to stay longer in the region.”

“More information on cross country skiing and snowshoeing trails in the area available in lodging or online.”

To summarize the various changes that users would prefer, increased services and more usable recreation areas are desired. It appears that passive and active users prefer lesser numbers of snowmobilers. While all groups indicated that they would like to see better access to the area, passive and active users indicated a desire to limit the amount of snowmobiling. Furthermore, snowmobilers prefer an expanded riding area because of a rising number of users for the resource.

Additional Comments: Upon completion of the mailback survey, visitors were provided a space in order to write down any additional comments about their experiences. Because of the wide variety of comment themes, a diagram is not presented for these comments. A synopsis of each activity group’s additional comments follows instead.

Snowmobilers (20 users): As previously stated, the themes that were present in the additional comments were varied. A number of snowmobilers, however, reiterated the fact that they would wish for the road to be kept the way it currently exists. Conversely, a few restated their wishes to open the highway during the winter season. Comments also focus on expanding the riding area once again. In general, the comments were positive and indicate their aspiration for changes not to impact their recreational opportunities.

Quotes related to this section include:

“I hope the state of Montana doesn’t start plowing 212 from Cooke City/Colter Pass/Silver Gate, MT to Pilot Creek all winter long. PS we come from west central MN.”

“I would not like to see the road into town plowed because it will just make the town over-run and too crowded. It’s a perfect community just the way it is.”

“Plow the road to Wyoming!”

Active Users (7 users): This user group did not provide many additional comments. However, their comments are overall very positive and discuss their well-wishes on how unique and special the area is to them. Comment themes ranged from their preference of visiting in winter, desire to have ski equipment rentals, and issues on wolf management.

Quotes from this section include:

“Thank you so much for plowing the roads. Your maintenance in the park is outstanding & we are so grateful for these opportunities.”

“Very unique and special area. Please support rentals of backcountry ski equipment, snowshoes and road bikes. How or where? Let’s make it happen!”

“The biggest disappointment of the trip was learning of the number of wolf shootings this past year. We may join the tourism boycott if MT does not modernize and reform its wolf management practices.”

Passive Users (33 users): In a continued theme, the passive users’ additional comments were generally focused on YNP issues. Many users state their love of the area and how special it is, but also their dislike of some aspects of Cooke City/Colter Pass/Silver Gate, MT. Silver Gate is seen as a more preferential spot for users participating in wildlife viewing, nature photography, and scenic driving, because of the potential conflicts in opinions and values. Issues of accessing the region, wolf management/hunting, and the importance of tourism in the region are prevalent in the additional comments.

Quotes from these comments include:

“Hopefully more people will realize the importance of tourism to the economy of the region and use taxpayer dollars to help access the area.”

“Please stop the wolf hunting. If a list of businesses who advocate and support wolf hunting is available I would use it to boycott those establishments. Create a buffer around the park.”

“We drive from Bozeman to Cooke City about 3-4 times each winter to view the scenery, have lunch in Cooke City, then tour around and head back. We’ve been doing this for 15 yrs. The road between the N entrance to Cooke City is greatly improved and appreciated”

Open-Ended Comments Summary

Evaluating the comments from the open-ended portion of the survey provided by all three user groups provides a better understanding of the wants, needs, and desires for the area held by the users. In general, most users tend to enjoy similar aspects such as remoteness, amount of snow, beautiful scenery and the lack of people in the area. However, results indicate a potential conflict between motorized and non-motorized users, which could be a future issue. A number of prior studies have been conducted regarding recreation conflict, specifically between skiers and snowmobilers (Jacob & Schreyer, 1980; Ruddell & Gramann, 1994; Vitterso, Chipeniuk, Skar, & Vistad, 2004). Furthermore, it appears passive users are more concerned with issues in Yellowstone National Park, while the BTH Region is more of a secondary attraction. Utilizing new methods to engage these visitors may be beneficial to the BTH Region.

Based on comments, visitors would prefer expanded services in the region, especially dining and lodging. Unfortunately, Cooke City/Colter Pass/Silver Gate, MT can be a difficult location for residents in the winter season. Limited access, inclement weather, and a tourism-based lifestyle make living in the region full-time increasingly complicated. Expanded services and opportunities may entice visitors to lengthen their stay or visit more frequently. The issue of access into the region is relatively split between users. A number of users prefer the current access; however, others would prefer to see the road plowed. Visitors also expressed opinions stating that it should be left up to the residents of the area. While accessing Yellowstone NP from this side is preferred by some users, others feel it may degrade the experience. A full list of comments by users is provided in the appendix.

Gateway Communities

Travelers were asked to rate their feelings and beliefs regarding the gateway communities. Prior to answering any questions about the gateway community, respondents were asked if they visited the gateway community on their current trip for any amount of time. Respondents were asked to disregard community-specific questions if they did not visit the town on their current trip. This was done in hopes of limiting the perception of the community to only the most recent trip. Those who did answer were instructed to indicate their level of agreement with statements regarding their perception of the community. Results are presented for each community in Tables 28-32, below.

Cooke City/Colter Pass/Silver Gate, MT

Cooke City/Colter Pass/Silver Gate, MT is located on the western end of the Beartooth Highway, five miles from Yellowstone National Park. This adjacent location to America's 1st National Park makes for a popular destination for a variety of visitors. During the winter season, Cooke City/Colter Pass/Silver Gate, MT caters to a large amount of winter recreationists. Two-hundred-thirty (83%) nonresident respondents stated on the mailback questionnaire that they visited Cooke City/Colter Pass/Silver Gate, MT for at least one hour or longer on their current trip. Table 28 represents the proportion of intercepts during the winter season at the Cooke City/Colter Pass/Silver Gate, MT sample site. Sixty-three percent of all respondents stopped were entering from the NE entrance of Yellowstone National Park.

Table 28: Number of intercepts at Cooke City/Colter Pass/Silver Gate, MT site

	Frequency	Percent
Cooke City/Colter/ Pass/Silver Gate, MT	1029 Intercepts	63%

*Results from on-site survey (n=1642)

Table 29: Cooke City/Colter Pass/Silver Gate, MT image perception

Cooke City/Colter Pass/Silver Gate, MT provides...	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
A relaxing feeling.	5 (2%)	12 (6%)	111 (53%)	81 (39%)	3.28
A welcoming feeling.	5 (2%)	15 (7%)	124 (59%)	68 (32%)	3.20
A unique and rich heritage.	6 (4%)	15 (9%)	102 (60%)	46 (27%)	3.11
Ample # of lodging options.	4 (3%)	25 (16%)	98 (63%)	28 (18%)	2.97
Quality lodging options.	5 (3%)	30 (21%)	82 (56%)	29 (20%)	2.92
Quality dining options.	9 (5%)	52 (28%)	102 (54%)	26 (14%)	2.77
Authentic shopping opportunities.	10 (7%)	42 (30%)	70 (51%)	16 (12%)	2.67
Ample # of dining options.	13 (7%)	57 (30%)	106 (55%)	16 (8%)	2.65
Exciting nightlife.	20 (17%)	39 (34%)	44 (38%)	12 (10%)	2.42
A crowded feeling.	66 (33%)	101 (50%)	20 (10%)	15 (7%)	1.92

*Scale: 1 = "strongly disagree" to 4 = "strongly agree."

To better understand the perceptions of Cooke City/Colter Pass/Silver Gate, MT (the main staging area for Beartooth Region recreation), an ANOVA test was conducted to determine if activity groups significantly differed on their image ratings. The means of each question by group and whether they were significantly different are displayed below.

Table 30: One-Way ANOVA test: Cooke City/Colter Pass/Silver Gate, MT image perception by activity segment

Cooke City/Colter Pass/Silver Gate, MT provides...*	Snowmobiling**	Active**	Passive**
Authentic shopping opportunities.	2.81	2.70	2.52
A unique and rich heritage.	3.30	2.96	3.05
Exciting nightlife.	2.98¹	2.12¹	1.79¹
Ample # of lodging options.	3.21¹	3.05	2.80¹
Quality lodging options.	3.17¹	3.14²	2.63^{1,2}
Ample # of dining options.	2.98¹	2.44¹	2.52¹
Quality dining options.	2.98¹	2.67	2.60¹
A welcoming feeling.	3.30	3.21	3.11
A relaxing feeling.	3.42	3.38	3.17
A crowded feeling.	2.24¹	1.70¹	1.79¹

* Scale – 1 = “strongly disagree” to 4 = “strongly agree.”

**Superscript numbers indicate significant differences at the .05 threshold between groups with like numbers.

Table 30 indicates 6 of the 10 questions asked about Cooke City/Colter Pass/Silver Gate, MT had significant differences between activity groupings. Snowmobilers have significantly higher mean responses than both active and passive users pertaining to the nightlife, number of dining options, and perception of a higher level of crowding. Furthermore, snowmobilers’ perception of the number of lodging options and quality dining options is significantly different from passive users, with snowmobiler’s level of agreement with those two statements being higher than those of passive users. Active users and passive users had significantly different means on one question; quality of lodging options in Cooke City/Colter Pass/Silver Gate, MT.

Results show that snowmobilers tend to perceive Cooke City/Colter Pass/Silver Gate, MT in a better light than the other activity groups, especially passive users. Passive users rated Cooke City/Colter Pass/Silver Gate, MT’s image questions lowest on seven of the 10 questions asked. This difference is discussed further in the following section of the report.

Cody, WY

Cody, WY is located 62 miles southeast of the Beartooth Highway. The Chief Joseph Scenic Byway (WY296) joins the Beartooth Highway and leads to Cody, WY. Cody, WY has two entrances to Yellowstone NP in close proximity, but neither is open during the winter season. The Chief Joseph Highway is open and cleared during the winter but not cleared the remaining eight miles into Cooke City/Colter Pass/Silver Gate, MT. Thus, visitors have to park and use a snowmobile or skis to continue, or leave the same way they entered. Very few respondents visited Cody, WY during their winter trip to the Beartooth Highway. Table 31 displays the number of intercepts that occurred on the Chief Joseph Scenic Byway exit point. In total, 37 percent of all intercepts transpired on WY 296. Because of low visitation by respondents, the sample is not sufficient to compare means among activity groups. The results

presented below are from a much smaller sample (25 respondents) than the Cooke City/Colter Pass/Silver Gate, MT (230 respondents).

Table 31: Intercepts at Cody, WY site

Entry Point	Frequency	Percent
Chief Joseph Highway	613	37%

*Results from on-site survey (n=1642)

Table 32: Cody, WY image perception

Cody, WY provides...	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
A unique and rich heritage.	0	1 (6%)	5 (28%)	12 (67%)	3.61
Quality lodging options.	0	1 (5%)	6 (32%)	12 (63%)	3.58
Ample # of lodging options.	0	0	8 (44%)	10 (56%)	3.56
A relaxing feeling.	1 (5%)	0	7 (35%)	12 (60%)	3.50
Ample # of dining options.	0	1 (6%)	7 (41%)	9 (53%)	3.47
A welcoming feeling.	1 (5%)	0	9 (45%)	10 (50%)	3.40
Quality dining options.	0	1 (5%)	10 (53%)	8 (42%)	3.37
Authentic shopping opportunities.	1 (5%)	0	11 (58%)	7 (37%)	3.26
Exciting nightlife.	0	3 (33%)	4 (44%)	2 (22%)	2.89
A crowded feeling.	3 (15%)	11 (55%)	3 (15%)	3 (15%)	2.30

*Scale: 1 = "strongly disagree" to 4 = "strongly agree."

Despite Cody, WY's small sample size, results identified Cody, WY's image to be very positive from those who did spend time in the community. Cody, WY's unique and rich heritage, which it is known for, ranked highest among all attributes by visitors to the town. Interestingly, many of the amenity services were ranked very high as well. The only attribute associated with Cody, WY that was ranked lower than a 3.0 pertains to the nightlife of Cody, WY. It is noted that that this sample size is not representative of all visitors, but should be taken into consideration for comparative purposes.

To summarize gateway community image, results indicate that both communities are perceived in a generally positive light by visitors. Cooke City/Colter Pass/Silver Gate, MT appears to be a vibrant area for winter recreation, but perhaps lacks some amenities that several visitors may desire. Cody, WY's unique and rich heritage is a common aspect enjoyed by many; however, the town is sparsely visited by winter travelers.

Cody, WY may be able to capitalize on the amount of drive-through traffic that was visiting from the east side of the Beartooth Mountains. As traffic analysis indicates, a large number of nonresident visitors are using WY 296 to access the Beartooth Highway. Using this information to their advantage, promotional entities in Cody, WY could attempt to encourage visitors to lengthen their stay in their town or to provide opportunities for revisitation in the future.

Discussion

On-site Survey

The Beartooth Highway during the winter season appears to be a vibrant, active, and special place for many of the users who frequent the region. While intercept results indicate a smaller population of visitors using the region (16,379 nonresidents), those who do are dedicated and enjoy many of the aspects. On-site surveys provided a glimpse into the visitors of this destination.

Visitors are generally arriving from states that are within a shorter drive time than those during the summer season. Montana, Minnesota, and North Dakota are three of the most frequently represented states for visitors in the winter season. Furthermore, it appears that visitors are generally using I-90 or I-94 to access the Beartooth Region. This may be because of the fact that 92 percent of visitors indicated they were aware of the road closure between Cooke City/Colter Pass/Silver Gate, MT and Pilot Creek. While all activities listed were noted as having some level of participation, five activities outnumbered others. Eating at a restaurant/getting fuel, scenic driving, snowmobiling, wildlife watching, and nature photography were noted as the top five activities participated in by all users intercepted. Although, a large spread of activities are represented by a proportion of visitors during the winter season. This first section of the report is used to gauge the total population of visitors, which seems to very much enjoy the area.

Economic impacts

Economic impact analysis reveals a telling picture about visitor spending during the winter season. Cooke City/Colter Pass/Silver Gate, MT accrues a large amount of spending from winter visitors, compared to elsewhere. Cody, WY, while receiving some contribution, does not have much economic activity from the Beartooth's winter visitors. However, this isn't to say that visitors are not passing through Cody, WY during their travels. Twenty-nine percent of visitors did indicate that they passed through Cody, WY on their way to the Beartooth Highway, but many did not spend money. There may be opportunities to encourage visitors to spend more money or lengthen their trip by staying in Cody, WY to increase visitor spending.

Cooke City/Colter Pass/Silver Gate, MT, on the other hand, does quite well for itself during the winter season. During the winter season, an estimated \$2.3 million was spent by visitors. For the small population of wintering residents in Cooke City/Colter Pass/Silver Gate, MT (less than 75 permanent residents), this spending is crucial to the viability of the community. Because of 56 percent of visitors indicated as day-trippers, there appears to be a relationship between the Beartooth Region and Yellowstone National Park. Many visitors are stopping in the Beartooth Region, but may not be spending the majority of their time in the area. Even though accommodations have the highest spending total, large amounts of spending occurs at restaurants and bars, in gasoline stations, and on retail purchases, as well as on rentals and repairs. Cooke City/Colter Pass/Silver Gate, MT's limited service providers can view this as a positive indication of visitor spending. Those who travel to Cooke City/Colter Pass/Silver Gate, MT are spending money in multiple sectors of the economy, not only focusing on accommodations. While the spending is much lower than in summer season, it provides opportunities for those who wish to spend their winter in the area.

Mailback results

The mailback survey is where the bulk of the information about the Beartooth Region was gathered. Nonresident winter visitors are from a smaller regional and demographic area compared to summer season, but the statistics still provide useful insights. Repeat visitors outnumber first-time visitors 54 percent to 46 percent, respectively. Like the summer season, there appears to be a definite draw for a first-time visitor, but there is more to the area that keep others coming back. For many, repeat visitation leads to increased recreation. For example, with snowmobiling in the Beartooth Region, snowmobiling is a much more frequent activity for repeat visitors than first-time visitors. Providing a welcoming, positive experience to first-time visitors has a high likelihood to encourage re-visitation to the area.

Visitor demographics reveal that winter travelers tend to be well-educated, roughly 51 years of age, and 59 percent male. The winter season of the Beartooth Region tends to be frequented by more males than females, especially when activity segments are compared. A comparison of winter demographics is related to a parallel study of winter recreationists who were interviewed.

Qualitative interviews were conducted in winter 2013 of recreation users in Cooke City, MT. According to many of the interviews of winter recreationists, many users who are snowmobiling in the area for the first time are intimidated by the level of skill needed to use the area. Thus, it may discourage those who do not feel comfortable with their skills from visiting. Some interviews noted that women do not enjoy the area as much because of the risks involved with the activity and make-up of the destination. This isn't to say that women are not riding because of a lack of skills, but other factors may contribute to this discrepancy. According to survey results, women still do frequent the area, but may not have the same type of activity participation.

In regards to visitor behavior, Cooke City/Colter Pass/Silver Gate, MT is shown as having the majority share of nights spent when compared to Cody, WY. Again, it appears Cody, WY is not as popular a destination during winter season. Interestingly, Cody, WY is visited by repeat visitors longer than first-time visitor. It may be that once a visitor experiences Cody, WY, they wish to spend more time on a future visit. Planners and promoters may be able to take advantage of this statistic to increase first-time visitation to Cody, WY so they will likely return in the future.

The distribution of activities is focused on wildlife watching, scenic driving, snowmobiling, and nature photography. Coinciding with primary purpose, it appears a large number of those interested in wildlife watching are frequenting both YNP and the BTH during winter. Although Cooke City/Colter Pass/Silver Gate, MT is seen as a premier snowmobiling destination, there are a large proportion of other visitors in the region. Thus, it would be worthwhile holistically, and especially economically, to integrate these visitors into the destination. However, caution should be taken when integrating these two recreation groups.

For overall image perception, the Beartooth Region is perceived very positively, similar to summer season. Both road conditions and recreational aspects are perceived highly, with some aspects lower than others. If improvements were to be made, the ability to find road reports and ensuring safety of conditions may be of interest in improving image ratings. Furthermore, some respondents do not perceive as high a "sense of place" with the Beartooth as others. For instance, the mean rating for recreating in the Beartooth "rather than any other place" is somewhat lower than other aspects (2.68). This may be due to some visitors not participating in many of the primary activities in the Beartooth Region.

Finally, the gateway communities' image results identify Cooke City/Colter Pass/Silver Gate, MT as being heavily visited, but rated lower than Cody, WY. Conversely, Cody, WY is well liked, but sparsely visited. Cooke City/Colter Pass/Silver Gate, MT may be lacking in some amenities that visitors would prefer. For instance, the number of dining options is rated lower than many other aspects of the town. While Cooke City/Colter Pass/Silver Gate, MT may not have the ability to expand services, it may be an area to consider. Cody, WY is perceived very positively, but has a very low frequency of visitation. Capitalizing on those who may not know, or may choose not to stay in Cody, WY may provide an exceptional experience to visitors.

Activity segments

Because of the diversity of activities, visitors were segmented by an a-priori segmentation into three activity groups for comparison purposes: snowmobilers, active users (XC skiers, backcountry skiers, snowshoers, and day hikers), and passive users (wildlife watchers, nature photographers, scenic drivers, and only eating at a restaurant/getting gas). Demographically, snowmobilers appear to be 10 years younger in age, have at least 5 more prior visits, and have a much larger split in gender (89% male/11% female) than both active and passive users. This, in itself, shows that there are demographic differences in the user groups. However, it may not be possible to say that these results represent all users in the Beartooth Region as a large percentage did not mail their surveys back to the researcher.

While overall demographics are not extremely diverse, when separated by activities, visitors tend to be much more variable. Women tend to participate in passive activities more frequently than men. Active users and snowmobilers visit due to the quality of snow, while passive users are drawn because of the proximity to wildlife in YNP. Furthermore as the visitor shifts from a passive user to active user to snowmobiler, the number of prior visits increases. Thus, it appears that snowmobilers are most frequent visitors, while passive users have not visited as often prior to their current trip.

Moreover, image perception appears to be heavily influenced by which type of activity segment one is placed. Snowmobilers tend to perceive most aspects of the Beartooth Region significantly more positive than passive users, especially in recreational categories. However, all groups perceive crowding and the ability for their expectations to be met similarly. Passive users are noted as having a lessened interest in many of the recreational activities in the Beartooth Region, which may contribute to their lower rating of these aspects. Road conditions only significantly differed in safety/security between snowmobilers and active users, indicating little difference in perceptions. Thus, it may be said that as the recreation becomes more specialized and motorized (passive → active → snowmobiling), there is a more positive perception of recreation in the Beartooth Region.

Open-Ended Comments

The final section pertaining to activity segments included open-ended questions about access, recreation, and changes. As stated previously, winter access to the region is limited due to the annual closing of the Beartooth Highway east of Cooke City/Colter Pass/Silver Gate, MT for eight miles. Furthermore, this topic has historically been very contentious. Local stakeholders and residents have maintained access in its current state, but discussion has been ongoing. In this question, all three user groups identified as having three classifications of answers: access sufficient, desire to expand access, and neutral or N/A. Each user group had multiple people who fit into these classifications.

The main consideration that should be taken away from the open-ended question about winter access is that visitors have varying opinions on the topic. All three user groups voiced concerns of losing

the sense of remoteness, concern for crowding potential, and limited area for visitors. Users did note that, for many, the drive times would be shortened dramatically. For stakeholders, the decision appears to lie between two areas of consideration: potential increased visitation and potential loss of the sense of place. The opinions of both the visitors who support the local economy as well as the residents who live in the region should be considered in future discussions.

Visitors in the region tend to have very diverse thoughts on what they enjoy about the region. Aspects such as remoteness, snow quality, scenery, lack of people, a sense of camaraderie, and proximity to YNP were all identified as positive aspects of the region. For snowmobilers, the aspects they enjoyed focused primarily on their specific form of recreation. Active and passive users enjoyed more holistic aspects and the feelings the place gave them. However, some passive users did comment on recreation even if they didn't participate in that recreation activity.

Inherently, there are some aspects of any region that visitors desire to be better. When asked about dislikes in the BTH region, visitors had some of the same opinions such as difficulty in accessing the area. Non-motorized users appear to have a dislike for motorized users, but the feelings are not reciprocal. Thus, there may be areas of potential conflicts similar to regions discussed in previous studies (Jacob & Schreyer, 1980; Ruddell & Gramann, 1994; Vitterso et al., 2004). Mitigating these conflicts could be done by local stakeholders. In order for this to succeed, all parties must be willing to accept the others' issues. Historical context and value judgments may be difficult to minimize impacts.

The final open-ended question pertained to desired changes in the area. Changes correlated to the dislikes stated previously. Two changes that were recommended by some members of all groups pertained to the availability of services and access issues during the winter season. A need for increased services is a popular topic of change mentioned by all visitors. For snowmobilers, a frequent suggestion was expanding the riding area, because of an increase in use. This may not be feasible because much of the land outside of YNP is designated wilderness area. Active and passive users indicated that limiting the amount of snowmobiles as their primary concern. Furthermore, some users in this group indicated a lack of welcoming to the area because of their choice of recreation. Thus, this may be an area to further investigate.

Stakeholder Implications

In this section, recommendations and implications that arose from the results are presented. These recommendations are suggestions for improving the experience of all visitors.

1. **Winter Beartooth visitation and spending is primarily focused on the Cooke City/Colter Pass/Silver Gate, MT region** – Unlike the summer season, where visitors split much of their time in the region, winter visitation is much more concentrated in the Cooke City/Colter Pass/Silver Gate, MT region of the Beartooth Highway. This could be because of the proximity to recreation areas and length of driving from Cody, WY. Furthermore, the majority of visitors are only spending a short amount of time in the region as highlighted through the proportion of day-trippers and overnight travelers. However, it should be noted that there is potential for Cody, WY to attract visitors to their town and possibly lengthen their stay.
2. **Visitors have an overall positive perception of the Beartooth Highway Region during the winter season** – The results identify, similar to summer season, that visitors tend to enjoy almost all aspects of the Beartooth Highway in the winter season. The lack of people, sense of

solitude, great snow quality and amount, closeness to Yellowstone NP, wildlife, and recreational opportunities are some of the aspects that visitors enjoy. In general, it appears as though many visitors to the region during the winter are more focused on the activities in which they are participating. This is somewhat different than summer season, because visitors were more likely to participate in rather passive activities.

3. **A wide variety of visitor types are present during winter season** – When most people think of the Beartooth Region during winter, snowmobiling is the main activity that comes to mind. However, results have indicated that other types of users are visiting the region. In fact, the proximity to wildlife in Yellowstone NP is noted as the primary reason 62 percent of mailback respondents visited the Beartooth Region. For stakeholders, understanding the needs and wants of these other visitors can improve the overall experience. For instance, active users hope for improved trails and trail maintenance for cross-country skiing in the region. Improving some of the desires of change that users have may be beneficial. Furthermore, encouraging users who may not be participating in the most popular activities in the Beartooth Region to engage in other activities may provide an economic boost to the region.
4. **Even during winter, a unique connection between the Beartooth Region and Yellowstone NP exists** – The Beartooth Region and Yellowstone National Park are noted as continuing their unique connection outside of summer. Because of the fact that many visitors use Yellowstone NP to access the Beartooth Region, unexpected experiences may occur to those visitors. For instance, snowmobilers who are focused on Beartooth Region recreation may participate in wildlife watching while passing through Yellowstone. This is important to recognize; both regions should embrace the unique visitor experiences that happen in their area, which may be absent in other popular winter recreation destinations.
5. **Significant differences exist between activity groups and their perceptions of the Beartooth Region** – Understanding visitor perceptions and using them to facilitate memorable experiences is an important goal for destinations. Results indicate that user groups perceive aspects of the Beartooth Region quite differently. Those who participate in snowmobiling tend to see recreational aspects and Cooke City/Colter Pass/Silver Gate, MT's image in a more positive light than passive users. Enhancing the image of the region to all users could be of interest of stakeholders. Cooke City/Colter Pass/Silver Gate, MT has a unique area that caters to many people with varying interests. Attempting to include visitors who may perceive less positively into the community may bring about lengthened trips and increased economic benefits. Consequently, this implication closely ties into the following.
6. **Consider all viewpoints before making decisions in the area** – It has become clear that there are multiple viewpoints on most issues. It cannot be said that the views held within one activity group or visitor type align. For instance, access to Cooke City/Colter Pass/Silver Gate, MT has historically been a contentious topic. As results show, there is no consensus between visitors on what they would like to see in regards to access. In this case, all potential consequences must be taken into account, both for residents and nonresidents. Many of the decisions that could be made may negatively affect other users, which could lessen the experience. Mitigating these impacts could be a goal to strive for when decision-making.
7. **There is a potential for conflict between user groups in the region** – As noted previously, studies have found conflicts between recreation groups based on many factors. In this region, some active and passive users voiced their dislike of snowmobiling and attitudes towards

nomotorized users. Snowmobilers, however, do not indicate any issues with other users in the area. There may be opportunities for the local communities to welcome non-snowmobilers into the region and provide a memorable experience. Respondents in the active/passive user groups very much enjoy the Beartooth Region, but some may not visit due to these feelings regarding snowmobilers. If feasible, it is recommended that more services be developed in Silver Gate so as to provide non-motorized recreation visitors a place differentiated from Cooke City. This may reduce the dissatisfaction that some active and passive recreationists have with snowmobilers.

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Appendix A: Survey Instruments

On-site Survey

BEARTOOTH FRONT END QUESTIONS

1. What is your permanent residence? _____
2. IF FROM MT OR WY: Are you a resident of Park County, MT/Mammoth or Park County WY? YES NO
3. How many people are in this vehicle? _____
4. What activities did/will you do on this trip in the Beartooth Region (NOT YNP) (CIRCLE AS MANY AS STATED)

Eat at a restaurant and/or got fuel
Snowmobiling
XC Skiing
Backcountry skiing
Scenic driving
Snowshoeing
Wildlife watching
Day hiking
Nature photography
5. **NONRESIDENT ONLY:** On this trip, how many nights are you spending in Cooke City/Silver Gate?

6. On this trip how many nights are you spending in the Cody, WY area? _____
7. On this trip how many total nights away from your permanent residence are you spending in WY (other than Cody)? _____
8. On this trip how many total nights away from your permanent residence are you spending in MT (other than Cooke City/Silver Gate)? _____
9. On this map (SHOW MAP) what route did you take to get to the Beartooth Region? _____
10. NEWT AND JANIE ONLY: Were you aware that you can't get to Cooke City or YNP in your vehicle from this direction?

YES NO

ID NUMBER _____

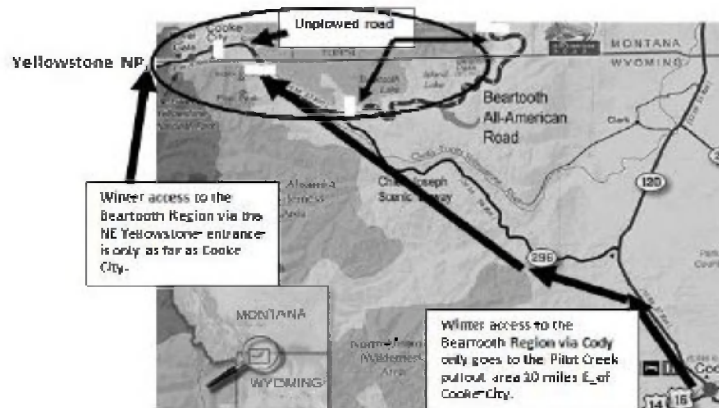
DATE _____

SITE CODE _____

Mailback Survey

Beartooth Region Winter Visitor Survey

This is a study of winter visitors to the Beartooth Region. The circle shows the general area of interest for this project. Road access to this area is through the NE entrance of Yellowstone National Park or highway 296 in Wyoming.



Please indicate how many nights you spent in the gateway communities on this trip. Write in "0" if you did not spend a night in these two areas.

Cooke City/Silver Gate, MT

Cody, WY

In which of the following locations did you spend at least one night away from home on this trip? (Please "X" all that apply)

- ☐ Yellowstone Nat'l Park ☐ In or near Billings, MT ☐ In or near Bozeman, MT ☐ In or near Sheridan, WY
☐ In or near Gardiner, MT ☐ In or near West Yellowstone, MT ☐ In or near Livingston, MT ☐ In or near Jackson, WY

For THIS trip to the Beartooth Region, please indicate the amount of money spent in the gateway communities by filling in the appropriate column(s) below.

	Cody, WY	Cooke City/Silver Gate
Camping	\$	\$
Hotel/motel	\$	\$
Ranch/B&B/rental cabin	\$	\$
Gasoline/oil	\$	\$
Restaurant/bar	\$	\$
Groceries/snacks	\$	\$
Retail/souvenirs	\$	\$
Outfitters/guides	\$	\$
Snowmobile/Auto repair	\$	\$
Snowmobile/Auto rental	\$	\$
Yellowstone National Park Fee	\$	\$
Other entrance fees, admissions, licenses	\$	\$
Services (i.e. medical, kennel, massage)	\$	\$
Other (describe below)	\$	\$
Description of other expenses:		

I visited the Beartooth Region because... (Please "X" all that apply.)

1. It has the best snow for my outdoor recreation ☐ 4. It is close to wildlife viewing in Yellowstone. ☐
 2. It has great terrain for my outdoor recreation ☐ 5. It has convenient access to winter trails ☐
 3. It has good trails for my outdoor recreation ☐

Of the reasons picked above, what is your MAIN reason for visiting the Beartooth Region on this trip? (Please "X" only one box that corresponds to one of your selections in the question above.)

1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐

Prior to this trip, how many times have you visited the portion of the Beartooth Region circled on the map in the **WINTER**?

On this trip, please indicate activities you participated in for the two areas listed below. ("X" all that apply)

In the Beartooth Region

1. Snowmobiling..... ☐
2. XC skiing..... ☐
3. Scenic driving..... ☐
4. Backcountry skiing..... ☐
5. Snowshoeing..... ☐
6. Wildlife watching..... ☐
7. Day hiking..... ☐
8. Nature photography..... ☐
9. Stopped for food/fuel only..... ☐
10. Other (please specify).....

In Yellowstone National Park

1. Snowmobiling..... ☐
2. XC skiing..... ☐
3. Scenic driving..... ☐
4. Backcountry skiing..... ☐
5. Snowshoeing..... ☐
6. Wolf watching..... ☐
7. Other wildlife watching..... ☐
8. Day hiking..... ☐
9. Nature photography..... ☐
10. Other (please specify).....

Of the activities you checked above (left column), which activity was your **PRIMARY** activity in the **Beartooth Region**? (Please put the activity # (1-10) in the box to the right. If you did not participate in an activity in the Beartooth Region, write "N/A").

Of the activities checked above (right column), which activity was your **PRIMARY** activity in **Yellowstone National Park**? (Please put the activity # (1-10) in the box to the right. If you did not participate in an activity in Yellowstone NP, write "N/A").

On this trip, did you stop in Cooke City/Silver Gate, MT at all? ☐ Yes ☐ No (Skip questions about Cooke City, MT)

Cooke City/Silver Gate, MT provides... (Please "X" one box per line)

	Strongly Disagree	Disagree	Agree	Strongly Agree	N/A
...authentic shopping opportunities.	☐	☐	☐	☐	☐
...a unique and rich heritage.	☐	☐	☐	☐	☐
...exciting nightlife.	☐	☐	☐	☐	☐
...ample # of lodging options.	☐	☐	☐	☐	☐
...quality lodging options.	☐	☐	☐	☐	☐
...ample # of dining options.	☐	☐	☐	☐	☐
...quality dining options.	☐	☐	☐	☐	☐
...a welcoming feeling.	☐	☐	☐	☐	☐
...a relaxing feeling.	☐	☐	☐	☐	☐
...a crowded feeling.	☐	☐	☐	☐	☐

On this trip, did you stop in Cody, WY at all? ☐ Yes ☐ No (Skip questions about Cody, WY)

Cody, WY provides... (Please "X" one box per line)

	Strongly Disagree	Disagree	Agree	Strongly Agree	N/A
...authentic shopping opportunities.	☐	☐	☐	☐	☐
...a unique and rich heritage.	☐	☐	☐	☐	☐
...exciting nightlife.	☐	☐	☐	☐	☐
...ample # of lodging options.	☐	☐	☐	☐	☐
...quality lodging options.	☐	☐	☐	☐	☐
...ample # of dining options.	☐	☐	☐	☐	☐
...quality dining options.	☐	☐	☐	☐	☐
...a welcoming feeling.	☐	☐	☐	☐	☐
...a relaxing feeling.	☐	☐	☐	☐	☐
...a crowded feeling.	☐	☐	☐	☐	☐

Please indicate your level agreement with these statements about road conditions on the Beartooth Highway.
(*X* one box per line.)

	Strongly Disagree	Disagree	Agree	Strongly Agree	N/A
The Beartooth Highway is safe and secure to drive on in the winter.	☐	☐	☐	☐	☐
During winter, the parts of the Beartooth Highway that are plowed are well maintained and free of snow.	☐	☐	☐	☐	☐
It is easy to find road reports for the Beartooth Highway Region.	☐	☐	☐	☐	☐
The Beartooth Highway provides good winter recreation access and parking.	☐	☐	☐	☐	☐

Prior to visiting, were you aware that there was limited highway access to this region due to winter road closures? Yes ☐ No ☐

Would expanded or better access to the region make you more inclined to visit in the winter? Yes ☐ No ☐

Please provide any additional comments about winter access in this region:

Please indicate your level of agreement with these statements about recreation in this Beartooth Region. (*X* one box per line.)

	Strongly Disagree	Disagree	Agree	Strongly Agree	N/A
This Beartooth Region provides a wide range of outdoor winter recreation opportunities.	☐	☐	☐	☐	☐
This Beartooth Region has a higher quality winter recreational experience than other places that I have visited.	☐	☐	☐	☐	☐
I would rather recreate in this Beartooth Region than anywhere else.	☐	☐	☐	☐	☐
This Beartooth Region is too crowded to enjoy my winter recreation.	☐	☐	☐	☐	☐
This Beartooth Region met my expectations for my winter recreation.	☐	☐	☐	☐	☐
I will return to this Beartooth Region for my winter recreation.	☐	☐	☐	☐	☐
I will recommend to others to visit this Beartooth Region during the winter season.	☐	☐	☐	☐	☐

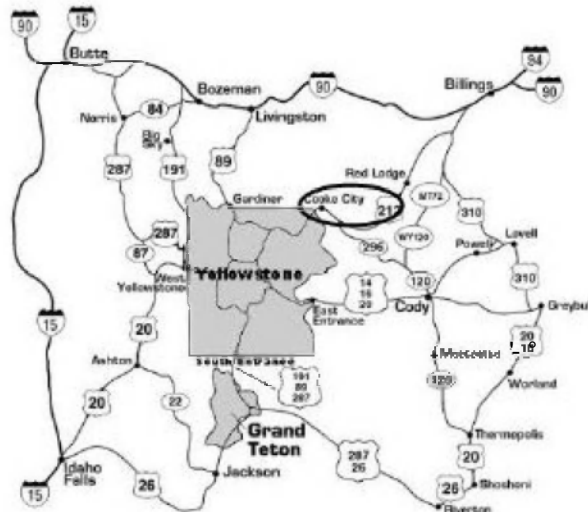
What do you like most about winter recreation in this area?

What do you like least about winter recreation in this area?

What would you like changed when thinking of your winter recreation in the Beartooth Region and the gateway communities (i.e. Cooke City/Silver Gate, and Cody)?

Below is a map of the Greater Yellowstone Area. Please indicate the route you took to access the Beartooth Region. The purpose of this is to understand which routes people are using in order to reach the Beartooth Region. Remember, the Beartooth Region for this study is circled on the map.

1. Place an "E" where you entered the area (to get to the Beartooth Region).
2. Trace the complete route you used to access the Beartooth Region (the circled region) on the map.
3. Place an "X" where you exited the area. (The "E" and "X" may be in the same spot).



What is your age?

What is your gender? ☐ Male ☐ Female

Please check where you permanently reside:

☐ United States ☐ Canada ☐ Central/South America ☐ Overseas (Europe, Asia, Etc.)

What is your highest completed level of education? (Please "X" only one box.)

☐ Some High School ☐ Some College ☐ Master's Degree
☐ High School Diploma or the equivalent (GED) ☐ Associates Degree ☐ Doctorate or Professional Degree
☐ Bachelor's Degree

What best describes your annual household income in US dollars? (Please "X" only one box.)

☐ Less than \$25K ☐ \$25K to less than \$50K ☐ \$50K to less than \$75K ☐ \$75K to less than \$100K ☐ \$100K to less than \$150K ☐ \$150K to less than \$200K ☐ \$200K or greater

Please provide any additional comments:

Thank you!

Institute for Tourism and Recreation Research 32-Campus Drive #1234, Missoula, MT 59812 (406)245-5595 itr@ctr.umt.edu

ID:

Appendix B: Open Ended Comments

1. Winter Access:

Snowmobilers –

"2 ways to get into town/work would be nice if business had tow sleds available."

Access in the winter from Pilot Peak with snowmobiles is perfect. During Peak times- if the road were plowed. There is not enough parking in Cooke or Silver Gate for all the snowmobiles- you would have way too many people.

Access is generally good- Chief Joseph Hwy is generally well maintained.

Better expanded access would ruin the recreation in Cooke City due to the town is so small that the town would get overwhelmed with snowmobile trailers the town could not handle that. The parking lot is the best thing.

Better winter access would lessen the appeal of this area.

Cooke City is a unique experience with the road closed at the end of town and only allowing snowmobile access to the East.

Cooke City provides the best snow & terrain for our sport. It is very limited as far as areas allowed to ride. However, I have created lasting memories with friends & family (wife and children) from this area. I will continue to come here until I am no longer physically able.

Do not plow the roads that are currently unplowed

Don't plow the road to town!

Grooming switchbacks on Red Lodge side would make snowmobiling and skiing more accessible from that side.

I enjoy the Beartooth very much but there are so much of them that are inaccessible to the public which is very unfortunate.

I enjoy y time every year here

I feel that the current arrangement is a good compromise. Access via snowmobile from the east make Cooke City a special snowmobile destination and those interested in driving to Cooke also have a well maintained access from the west.

I love the remote qualities of Cooke because of the harder access to the area. It makes the experience a lot better to get to town.

I wish the road from West Yellowstone to Cooke was kept open for the winter.

I wish the road was open into Cooke City with a parking lot in town or on the edge of town. I hate buying a \$25 permit for Wyoming and only use it to drive 4 miles from the parking lot to the Montana border. And then back to our vehicle.

If all trailers went into Cooke City there would need to be a lot more parking in Cooke City.

If Bear Tooth pass was plowed we would be more likely to come here more often.

Keep road open from Pilot Creek to Cooke City

Open road to Cooke City would be nice.

Please plow the highway so access from Wyoming is better.

Plow Pilot Creek to Cooke City!

Plow road from Cooke to Pilot Creek

Plow the road the last 9 miles from Pilot Creek parking lot to Cooke City! I would travel twice as much to Cooke City if it was plowed. It is a pain to drive around to Livingston if you're driving from the east and want to your truck in town!

Provide a route from Red Lodge.

The current access to Cooke City in the winter is sufficient. No need to plow from Pilot to Cooke City.

The worst stretch of road is where 296 meets 212 through to pilot creek parking area! It would be nice to have that plowed better.

There should be a better sign to let you know you need to turn left to go to Cooke City when you are in Mammoth Springs

Visitor survey of road survey.

We have been coming for years. It would be nice to drive to Cooke without going through Park but where do you park all the trucks and trailers in Cooke City?

We usually visit once every winter and once every summer. Would visit more if had even more snowmobiling trails to utilize%2C or if we didn't require guide in park.

We would come no matter what.

Will require parking access to Cooke City.

You have to realize and accept what MT weather is capable of producing. Deal with it or stay home.

Active Users-

Access is adequate from the west, the direction I come from.

Accessibility as it is makes our experience enjoyable as less crowded.

Cooke City is the location of my cabin so access doesn't matter to me. I'll use whatever is available.

Didn't go up the Highway due to Snowmobiles.

Keep it as it currently exists.

Road from NE park entrance to Silver Gate was safe, secure, well maintained and free of snow. The Beartooth Hwy closure is essential to Cooke City and its character. Keep it exactly how it is!

The current status is the safest. We left Silver Gate in October 2011 after visiting our cabin- we were going over the Beartooth pass to catch our flight home in Billings. The road was fine when we started in Silver Gate. However there was rain by Chief Joseph and then ice at the top of the pass. We almost went off the highway. Super scary!

The limited access keeps out some riffraff

This has been a battle for years. Was told \$30 million was spent to improve 212 and they still won't plow outside of Cooke City! What a waste!

We lived in Cooke City for 3 years. In one way it would be easier for residents (and tourists) if there was another entry via car. In one way it makes Cooke City so unique in its location because it is so remote. If the road out to East of Cooke City was opened in winter, there might be a need for more parking for trucks, snowmobile trailers in town.

What part of Beartooth Hwy is plowed?

Would love the road to be open all winter. We would come at least 2 more times. It would save us 2.5 hours.

Passive Users:

212 out of Red Lodge need to be open further up switchbacks-(vista pt.) At least to 1st switchback.

Access-visiting Red Lodge from Yellowstone might be nice.

Answers refer to N-East entrance- Cooke

As a Californian, I suggest opening the road from Cody to Cooke City. Snowplow it if feasible. It would bring an economic link to this corner of the park.

Calling Yellowstone National Park yields plowing between Gardiner MT to Cooke City MT is not available but does not explain about closures in Beartooth Region or east of Cooke City MT.

Come multiple times per year for scenery and wildlife viewing. Driving summer up Beartooth Highway. Not interested in snowmobiling or skiing.

From Cheyenne we had to go to Billings- Livingston- Gardiner- Silver Gate (in Feb). I may come more often in winter if the road from Cody was open.

I imagine the people that live here would benefit from an open road in the winter-for visitors I believe it provides a limited wilderness experience.

I like that it's remote and few people go. We go to this region in winter b/c it's quiet w/ better wildlife viewing opps than other times of year (kind of). We like skiing, we don't like snowmobiling.

I would like to see ski shuttles that can drop you off so you can ski to your car or the towns of Silver Gate & Cooke City.

I'm glad the road is open to Cooke City, provides another opportunity for food/fuel when visiting the park.

If the roads were open all winter or earlier in the spring, we would visit much more often.

I'm a semi- pro wildlife photographer. I drive a 4x4 RAM truck with snow tires- if more areas were open I would travel those areas.

It takes us 6 hrs to drive from Wapiti, WY to Cooke City in the winter and 1.5 hours in the summer. We spend a good deal of time and money in Cooke City in the summer and have only visited twice in the last 5 years in the winter.

It would be nice to find an additional way to access Old Faithful.

It would be nice to see further areas of the park in the winter if possible.

Its closed%2Flimited access is what makes it attractive, less people, less crowded.

Just drove across Lamar Valley and came to Cooke City for lunch one day!

Leave it alone. Maybe less snowmobilers.

More access... more people not good.

Open road from Red Lodge to Cooke City

Open the road from West Yellowstone to Mammoth within the park.

Opening the road between Cody and Chief Joseph would improve access from Billings

Roads were great.

Safe but limited by conditions

Spring/ summer we stay @ Silver Gate- would enjoy winter stay in cabins @ Silver Gate- find some snowmobiles too noisy!

Thanks for all the work done to keep the road open.

The remote location of Cooke City and Silver Gate is a draw in the winter. However, I can see residents may want easier access. Access for recreation may change the flavor of activity. We access via Bozeman due to air travel so access from Cody is not required.

They should just plow the 1 mile stretch between the WY & MT sides

To improve access and safety the road from Chief Joseph to Cooke City should be open all year.

We are retired and live near Columbus, MT. When you have house guests as we often do, a trip to Yellowstone Park is almost a requirement!

We believe leaving the highway open from Cody to Cooke City all winter is important. It will improve the area and shorten our travel time by 3 hours.

We came across I-90 across Montana to get to Gardiner because we knew the road is not open.

We came primarily to visit YNP- our visit to the Beartooth was only for food. However it was easy to get to from the park.

We drove from MN to Yellowstone. We wished we could have come in via Cody to Cooke City instead of going up through Montana via Billings.

We felt like we missed a lot. I thought a winter place would be open in winter. Disappointed.

We like it being isolated and rather uncrowded.

We live in Livingston, so we are pleased with access as is- makes for a nice early spring day trip.

We planned to have something to eat in Cooke City but nothing was open at 4.30pm.

We went to visit Yellowstone and only left to go to Cooke City to get something to eat and to turn around.

Wish there were more plowed roads!

Would be nice to get to Pilot-Index outlook

2. Like Most about Winter Recreation: Snowmobilers:

Always has snow. Not overcrowded!

Ample amounts of snow

Ample snow for snowmobiling.

Beautiful area great people exceptional country perfect snow.

Being able to snowplow through area.

Being in the mountains

Cell phones don't work. The business owners welcome us. The scenery is absolutely beautiful. The snowfall for riding sleds is epic. Get to see friends made here from all over the country. You can ride from town.

Deep snow and one of the only towns in the U.S. where the road ends in the winter. Very unique.

Deep snow conditions.

Easy trail access- I hope they never plow 212 east of Cooke City- we'd stop going there.

Everyone shares the trails and resources, area.

Excellent snow conditions; most extreme riding area. Got to know a lot of locals; easy to create friendships.

Good snow and friendly people.

Good snow and services.

Good snow fall, snow base.

Heavy snowfall.

I have brought my family to Cooke City 2-3 times every winter for the last 18 yrs. I love the snowmobiling, but we downhill ski and sled. For a fan of snowmobiling, the consistent fresh snowfall, varied terrain and regularly groomed trails cannot be surpassed.

I know the area very well. Family lives there.

I like that Cooke City is on the edge of the mountains. It only takes a few minutes to leave town and you are on top of the mountains.

I like the area as well as the people.

It's great to snowmobile in Cooke City because of the distance from town to rec. areas. Have been to West Yellowstone and Bighorn, but prefer Cooke as the place to go; been coming 20 yrs.

Lack of people- no cell service! Yay!!

Limited access

Lots of good snow!!

Quality and amount of snow, proximity to Billings.

Quality of snowmobiling.

Scenery and snowmobiling Friendly atmosphere.

Scenic and good snow.

Snow condition.

Snow level.

Snow quality and scenery.

Snow quantity and quality, terrain, snow covered terrain.

Snowmobiles.

Snowmobiling.

Snowmobiling with family.

Snowmobiling, x-country skiing, nature photography, snowshoeing, scenic driving.

The ability to drive my snowmobile right up to my hotel and snowmobile right from there.

The deep snow for snowmobiling. The way the city caters to snowmobilers.

The quantity and quality of the snow.

The remote area we enjoy the relaxing atmosphere of Cooke City.

The snow.

The snow and the terrain. The quiet small town feel.

The snow quality and steep terrain.

The snowmobiling conditions.

The steep and deep.

The terrain and easy snowmobile access to the mountains.

The trails are groomed well and the service @ Exxon is great!

The variety of terrain and snow depth for snowmobiling.

We have snowmobiled in this area since 1968. We know the area well and comfortable riding it.

Wide open area, not crowded.

Active Users:

Abundant snow.

Access to high mountain area for back country skiing.

Access to Yellowstone Park.

Beautiful scenery. Great sunshiny days. Great snowshoeing, skiing and hiking.

Close access to Yellowstone touring, viewing of animals

Few people are there so not crowded. Small town atmosphere is nice. It's really beautiful.

Good snow, not crowded, quaint for skiing.

Great snow.

Great snow conditions for skiing.

How uncrowded it was. I like that the main road closes.

Lots of snow!

Nice XC ski trails

Peacefulness (Silver Gate and YNP). Great snow conditions- amazing athletic opportunities.

Quality of snow, isolation of Silver Gate, bird feeders at Hartman's in Silver Gate.

Scenery, snow, Cooke City

Scenery, snow, lack of other people.

Scenery, X-country ski trails, wildlife

Silver Gate is for x-c skiers. Prefer to not deal with good- ol- boy snowmobiles.

Snow.

Snow and beauty. Great skiing and wildlife in Yellowstone is awesome. Want to see more wolves but the hunting ruined that this year.

Snow trails for skiing, beautiful scenery, fun atmosphere.

Snow, Solitude.

Snowmobiling.

Solitude and space.

The abundance of trails, open space for the winter sports, the beauty of the area, the quality of snow.

The peace and quiet. The minimal tourists. The beauty and the grooved ski cross country trails.

The pristine beauty of the XCountry ski trails and back country skiing. The quiet cabins that was open in Silver Gate.

The terrain - both amount of it and the quality. Also great snow pack each year. It's getting more and more crowded but still good.

Uncrowded- wild terrain- great snow.

We came in Spring and town was very quiet. No great dinner options, just limited menu.

Wildlife viewing.

Passive Users:

Access and quiet.

Access to Lamar Valley for wildlife viewing.

Access to Yellowstone.

All the snow.

Animals outnumber tourists.

Aren't many people here yet still good atmosphere.

As a wildlife photographer I really enjoy the lack of summertime crowds.

Beautiful and not too many people.

Beautiful scenery and wildlife viewing for photography.

Cross country skiing! On this trip, we just decided to do a day trip from Bozeman (where we live) through the park to eat lunch in Cooke City. In the past, we've stayed in Silver Gate at Pine Creek Cabins and cross country skied.

Excellent snow and wildlife viewing.

Few people. Beautiful scenery. Lots of animals in and around Yellowstone National Park.

Fewer people.

Good road access to wildlife viewing, pullouts, restrooms and quality management

Great landscape and wildlife.

I don't think it's so much as the area outside the park. I am interested in the park, as the park and its wildlife. I don't want to be around snowmobiles and other land vehicles.

I enjoy the quiet.

I only visited for wolf, wildlife viewing and photography. Staying in Cooke City gave me easier access to YNP.

I wanted to snowmobile everything closed after 12:00pm wanted tour.

It always is snowing.

It is very scenic.

It's quiet and has access to wilderness, wildlife. Great service and questions answered at visitor center in Cooke City.

Lack of snowmobilers in Silver Gate.

Lack of snowmobiles in Yellowstone. Variety and number of ski trails.

Loved the atmosphere! Enjoyed our meal at Soda Butte Lodge!

Moose sightings.

Not crowded the two weekends we went!

Not sure I want to be back in Cooke City/Silvergate in winter- too many snow machines.

Not well informed about activities other than snowmobiling which we do not do. (choose not to)

Portions of YNP are open during winter, spring months.

Predictable snow condition- good coffee!

Primarily wolf watching. Although the hunters have killed so many wolves it is not as enjoyable as it once was. Other activities are hiking and snowshoeing. The quality and quantity of the snow make it great fun snowshoeing. And it is beautiful.

Proximity to Yellowstone NP.

Quaint town!

Quiet and relaxing winter recreation with adequate services.

Really only went for wildlife watching and spent most of our time in the park.

Remote and quiet.

Remote location.

Remoteness.

Scenery.

Scenic drive.

Scenic drives- wildlife viewing.

See and photographing wildlife.

Sports.

Spotting moose.

The abundant wildlife- photographic opportunities- not crowded- breathtaking scenery- the peacefulness- Silvergate.

The amount of snow.

The availability of viewing wildlife.

The Beartooth are is great, we have lots of great terrain in our area though.

The beauty.

The beauty of the mountains.

The roads into Yellowstone are plowed and allow exploration at one's own pace and choosing.

The scenery and wildlife are fantastic. It is crowded due to the closure of many businesses during winter.

The wildlife!

There are plenty of elk and we come for elk hunting every year.

There is plenty of snow! Many people do it so trails are groomed well.

There's going to be snow. You drive thru Yellowstone and see animals. The locals appreciate you showing up and spending money. We stay in cabins at Silvergate. Next year we'll probably cook in the cabin because food/restaurants are not open late but that isn't a big deal.

Uncrowded

We are all about wildlife.

We are not snowmobilers. We go to Yellowstone and the surrounding areas in winter for a unique winter experience.

We didn't really recreate in the region, only in YNP. However I liked how uncrowded the park was so I would say this would also be a positive of the Beartooth region.

We were on a driving tour and did not stop in Silver Gate or Cooke City. It was the end of the road and we turned around and went back to Yellowstone.

Well taken care of.

Wildlife.

Wildlife in the snow – beautiful.

Wildlife viewing.

Wildlife viewing and photography.

Wildlife viewing, remote location quality of snow, beautiful scenery viewing opportunities.

Wildlife viewing, watching, photographing.

Wildlife watching.

Wildlife watching, Skiing, snowshoeing.

Wildlife, quality of activities, the wilderness, also the clean efficient snowmobiles in Yellowstone.

Wildlife.

XC skiing, snow shoeing, scenic driving.

XC skiing, wildlife viewing.

3. Like Least about Winter Recreation?

A lot of people from Midwest.

4 1/2 hour drive from Helena.

Avalanches.

Cell service.

Closed areas to snowmobiling.

Clouds! and nothing you can do about that.

Crowded, too many people, area is too small- should be expanded.

Distance from my home.

Driving around to get vehicle access to Cooke City.

From Billings and having to drive out and around almost to Cody then up Chief Joseph Highway.

Hi-way 212 road closure coming from the east.

Holidays- we stay away- it is the only crowded times.

How popular Cooke City has become compared to prior years.

I can't drive to town from the east.

I wish I lived closer.

I wish the trails in Montana were groomed better or more often. I would like cell phone service in town. It is a relatively small area and with so many snowmobilers all the time it is crowded and not much powder to play in unless just after new snow.

It is very difficult to plan a trip here short notice. Plans must be made in advance and if you just so happen to miss fresh snow or rental availability. Area can get tracked up in very short weekend with limited areas to ride.

Lack of cell phone service.

Leaving and going home. The short drive on 212 after 296 to Pilot Creek isn't good.

Leaving pickup and trailer 10 miles away from Cooke City.

Limited access to Cooke City.

Need more area's open up for snowmobiles. Do away with the wilderness areas.

No cell phone access; just because I had work to do.

No snow.

Not being able to drive in Cooke City.

Not enough area to ride. Too much wilderness.

Not enough groomed snowmobile trails- can see most everything in 1-2 days (but it's very beautiful and worth the trip still) cabins, hotels are run down (when affordable take pets).

Not enough money to spend whole winter.

Nothing.

Nothing its perfect leave it alone.

Park Rangers.

Politics of town. Lack of parking.

Restriction on where I can ride.

Snowmobile riding area could be bigger.

Snowmobile trails and areas could be better marked or labeled.

The drive around to get to Cooke City.

The lack of snowmobiling are open. Too much wilderness!

The management @ Arctic Cat store Exxon station were both rude when entering shop area for services, got door slammed in my face at both stores!!

The ride in and out of parking lot.

The road to Wyoming is not plowed.

The waste from state and federal governments.

Too crowded, more area needs to be opened to snowmobiles.

Town can get crowded when they receive a lot of snow.

Wolf watchers blocking the highway. All the game wardens and forest service people it takes to stand at the entrance and check stickers. There was at least 10 of them last time I was there. I think 2 would be enough.

Active Users:

Access to multiple areas (e.g. Cooke City and West Yellowstone) is difficult.

Air quality in Cooke City.

All the idiot sled heads who are dangerous and slash our ski lines.

Distance from our home town.

Hard to drive in some areas.

Isolated!

Need more open restaurants for dinner

Not much is open!

Number of snowmobile tractors going through Yellowstone Park.

Remote and hard to get to.

Road closure from Chief Joseph.

Skiing.

Smelly, noisy snowmobiles and drunks in Cooke City.

Snowmobile.

Snowmobile noise.

Snowmobile noise and exhaust.

Snowmobile noise up by Cooke City- however we understand the desire & need for this activity.

Snowmobilers, noise, smell, mentality.

Snowmobiles.

Snowmobiles, though they are less smelly and noisy these days & I know they're vital in a place as remote as this area in winter, so I can live with them.

Snowmobiles, but there were none where we were.

Snowpack was lower than expected.

The lack of pull- outs in the refrigerative canyon area.

The number of snow machines operating out of Cooke City.

The road closure between Cooke City and WY. We would explore that way, but only snowmobiles have that access. Why is that?

Too many snowmobiles.

When Cooke is busy- it's very, very busy. We chose to come when it's quiet.

Passive Users:

Access and lack of down hill skiing.

All the trucks pulling big trailers with snow machines riding your bumper as you're trying to photograph and view wildlife from Mammoth to Lamar Valley.

Cloudy skies.

Cold- limited access to YNP.

Cooke City to Cody closure.

Crazy snowmobilers.

Crowded with snow machines

Difficult access.

Dining options.

Don't care for noisy snowmobiles.

Ease of access is poor in the winter. We must travel 3 hours longer in the winter time.

Food options.

Heavy Motorhead vibe around snowmobiles in Cooke City. I'm fine with giving snowmobiles a place.. but I don't like the blue- collar culture.

It always is snowing.

Lack of food and gas.

Lack of restaurants open.

Lack of road to Cody.

Limited access.

Limited winter camping sites.

Long distance to gain access to park.

Loud snowmobiles in town.

Loud, obnoxious, Californians.

Most of Yellowstone is closed.

Noisy and rowdy with snowmobiles - Cooke City.

None.

Not a fan of the snowmobiling culture in Cooke City.

Not very many people.

Nothing.

Poor access, very few businesses open.

Roads not accessible year round.

Smelly snowmobiles and their noise.

Snow machines.

Snowmobile culture of Cooke City

Snowmobile activity.

Snowmobile exhaust and noise.

Snowmobiles- noise and smell.

Snowmobiles.

Snowmobiles. We prefer winter @ Mammoth where snowmobiles are not allowed- the quiet goes with winter serenity.

Snowmobiles that are too noisy.

So far there has been nothing we are dissatisfied with.

So hard to get to.

Sometimes it feels like the snowmobilers don't mix with the tourists visiting. I'd like to see it more skier friendly.

That the road ends at Cooke City.

That the road to Cody is closed.

The 2-stroke very noisy & polluting snowmobiles outside Yellowstone. It was hard to breathe in Cooke City, but we loved the town.

The attitude of snowmobilers when driving on YNP roads. Many of them drive over the speed limit, crowd over the center line or go over the center line. Many speed by pullouts that are full of cars, people with cars and people cornering and going and they create a dangerous situation because of the speed they go by with their trailers.

The cold weather!

The snowmobiles.

This is not winter related- more and better turn off for motorcycle parking in Yellowstone park and Beartooth Highway.

Too many businesses closed! Would have bought gifts!

Too many snowmobiles.

Too many trucks pulling snowmobile trailers and driving too fast.

Uncertainty of driving conditions.

Unplowed roads after March 15th.

We have no opinion because we make day trips from Big Sky. We truly enjoy these trips.

Winter is cold.

Would like more areas to be opened up.

You can see animals in Lamar Valley.

4. Changes the visitor would like to see:

Snowmobilers:

Able to snowmobile on main street. Better shopping.

Access from east (Billings/Red Lodge).

Allow snowmobiles in wilderness.

Area is too small for the # of snowmobiles.

As I said before the ride over Wyoming pass is a joke for only driving 4 miles. More shopping in town, cell phone towers in town and the road opened up with parking in town or on the edge of town. More dining options also.

Be nice if some of the other shops were open when weather keeps you off the mountains.

Better access for me and my children.

Better trail maintenance, more riding area.

Bigger snowmobile riding area.

Cell phone service in Cooke City.

Cellular reception.

Continue to improve and accommodate.

Cooke Cit cell tower.

Drive my 4wd to Cooke City I would pay a fee to drive into Cooke City and stay there.

Every motel adding phones to their rooms.

Expanded areas to ride, more lodging options, and expanded rental units.

Groom snowmobile trails more often.

I want it kept open for riding snowmobiles. I have been riding there for 20 years and my family enjoys the riding and scenery as well. I would like more area opened.

I would visit the Yellowstone National Park during winter months if snowmobilers were not forced to utilize a guide.

Keep road open.

Less restrictions on snowmobile areas.

Less wilderness closed to snowmobiles- open all up!

More area to ride.

More hot tubs and massage parlor, other than that its excellent.

More instructions re trails by outfitter.

More snow.

More travel options through Yellowstone during winter for regular vehicles , ability to travel on snowmobiles without a guide when in the park.

Motorized wilderness access

No change, don't build any fancy shops and try to make the area different. We enjoy it because it is!

None.

Nothing.

Nothing- maybe cell coverage.

Nothing, would like to see that the area is kept open to snowmobilers.

Nothing!

Open road to Cooke City.

Open the road.

Open up more area for snowmobiling.

Open up the wilderness areas to snowmobiles.

Phone coverage.

Plow road all the way to Cooke. Allow grooming Beartooth Hwy.

Plow the highway all way through.

Plow the road from Pilot Creek parking lot to Cooke City!

Plowing Beartooth Pass--willing to pay to drive through!!

Reduce the size of the wilderness to increase the snowmobiling area.

Roads to the east of Cooke City could be could be plowed so we don't need to snowmobile into town.

To be able to drive into Cooke City from Pilot Creek.

We used to have no groomed access just the Beartooth Highway.

We would like to drive to town from east. It's too far to go around from MN, but knowing what we know about Cooke, we cannot see how they could handle all those trucks, trailers that are out at the parking area.

Active Users:

Better dining options

As the winter season winds down, there are ample opportunities for cycling in YNP (leaving from Cooke or Silver Gate)- as the Cooke/Gardiner road isn't too busy yet. Anyways to strengthen that.

Better parking for snowmobile users.

Better plowed areas.

Better separation of motorized and non-motorized trails.

Better XC ski trails outside the park.

Cut back on the number of snowmobilers in the area.

It's too bad that you can't stay in the Ranger cabins nearest to the Lamar valley. Better trail location for the upper and lower Barriett ski trails. It's a bit confusing to find the trail head.

More bird feeders visible. More cross country ski trails.

More x-country ski trails.

No change would be fine with me.

Not sure.

Nothing it's perfect untouched like it is.

Offer half pay or hourly snowmobile rentals for a lower price.

Road opened from Chief Joseph Hwy.

Silver Gate is our 1st choice. Only one real business is open, stop the car trading post, and their cabin and store is perfect. Cooke City is too rude, smoky and loud. The snowmobiles ruin the area and the riders are rebels on and off the road. Someone needs to plow 212 and open all those opportunities, to and from Billings and Cody.

Passive Users:

A more generous attitude towards non hunting and non snowmobiling folks.

Access to a general store for supplies.

Access year round, down hill skiing, more basic winter camping locations

Access. Without the much needed access, Cody residents don't frequent Cooke City/Silver Gate and consider the park somewhere they can't go until the East Gate opens in May.

Any more open roads would only mean more fun to have and reasons to stay longer in the region.

At least one official RV camp site.

Better hotels in Cooke City.

Buffer zone for wolves. Wolves in this area not a threat to livestock.

Chair lift!

Cleaner snowmobiles, quieter snowmobiles, otherwise we are quite delighted and loved our visit. Cody is too far away to be a gateway community. Should close Sylvan pass.

Cooke City could be a bit quainter of a town and not so junky. More groomed XCOUNTRY trails

Did not come specifically to recreate. Relax!

Elevate the level of lodging and dining, provide downhill skiing and X country lodge, beautiful area; low class facilities.

Encourage through grants more guided trips for snowshoers- expand through local business.

For everything not to close early.

I did not find a gift shop open on a Saturday afternoon in Cooke City (for my visitors).

I would like to see cross country skiing developed more- and promoted.

I would limit the snowmobiles%2C but I also realize this is what keeps Cooke City's economy going. I would like to see more XC trails that snowmobiles are not allowed on.

I'd like to be 50 years younger and rent a snow machine.

If more roads were open in the park that would be nice.

If the road was open we would have gone home through Cody. We love Cody and when we go to Yellowstone in the summer we stop in Cody. (from Denver)

Increased vehicle access to remote locations.

Keep the US212 to WY296 connection open year round

Leave as it currently is.

Limit snowmobiles more than now in Yellowstone

More alternatives to dining out.

More amenities for day visitors.

More cross country ski rentals in Cooke City. More trails.

More information on cross country skiing and snowshoeing trails in the area available in lodging or online.

More open accommodations during the day time

More places (restaurants/shops) open.

More Specific printed, internet info on what is open and when (days, hours, etc) seasonally.

No snow machines in town.

Nothing.

Nothing at all.

Nothing-great.

Open gift shops.

Open highway from Cody to Cooke City year round. It will improve travel time and improve the quality of retailers in the region. It would also benefit Cory and improve year round traffic there. We like Cody but avoid it in winter.

Open road to Cody during winter.

Open the road at Cooke City so we can get to Cody.

Open the road to Cody.

Plow 212 between Cody/Chief Joseph.

Plow the roads open earlier in the spring %26 later into the fall.

Plow the roads.

Small lodges for meals

Some nicer, more upscale dining /accommodations in Cooke City.

Some place to eat without snowmobiles.

There is nothing we would like to change. We love these areas.

Want it accessible.

Wish more stores had been open in Cooke City.

Won't change anything except maybe a better "open" motel in Silver gate.

Additional Comments:

Don't close the Pilot Parking Lot. 2nd generation family participant, soon approaching 3.

Glad to help anyway, please keep snowmobiling going in this region!

Good luck opening the area up. Unfortunately there are more people that want it shut down than opened up. You have a uphill battle on your hands.

Griz suck!

I got this survey at the east entrance to the park, was someone handing them out at the Pilot Creek parking lot too? I would guess there is a lot more traffic coming into Cooke from that direction.

I hope the state of Montana doesn't start plowing 212 from Cooke City to Pilot Creek all winter long. PS we come from west central MN.

I rode snowmobile with my 2 sons who had been there before. Great trip and made new friends! and met great people!

I think if you plow that road you will ruin it for us snowmobilers. It's only 9 miles to trail ride to town. Makes it fun. I know I wouldn't go anymore. Would be way too packed- already is.

I think the wolves need to be removed from the park or at least kept at a manageable number. They have decimated the elk, moose, and deer herds. No more wilderness.

I would like any information on how to keep the land we snowmobile on open.

I would not like to see the road into town plowed because it will just make the town over-run and too crowded. It's a perfect community just the way it is.

If you need more input please contact me we come along every winter with group of 8-12 and also come in summer.

Make dog population in Cooke City 10- open up more land to snowmobiles- the good stuff.

Need to keep open the snowmobile trails. Grooming is very important. Open up the wilderness areas to snowmobiles.

Please keep Cooke City open. Been riding here for 20 yrs and wouldn't change a thing.

Plow the road to Wyoming!

Stopped coming to this area as often in the past few years as it is becoming too crowded for the size of the town and area open to snowmobiles.

We love all of the Beartooths- summer, winter, spring, and fall. Not too many other places with such splendid wild lands that are accessible.

Would like to see more roads open in Yellowstone during winter to regular vehicles and would like to see Beartooth Hwy open/plowed sooner in spring.

Active Users:

First went to Cooke City in the late 1950's. Stayed there with the boy scouts in the mid 60's.

I prefer winter in this area. I do come here at least once in early or late summer. Love Cody and the Chief Joseph Hwy. I would love to see it in the winter. Would cut about 5 hours of drive time, too.

Thank you so much for plowing the roads. Your maintenance in the park is outstanding & we are so grateful for these opportunities.

The biggest disappointment of the trip was learning of the number of wolf shootings this past year. We may join the tourism boycott if MT does not modernize and reform its wolf management practices.

Very unique and special area. Please support rentals of backcountry ski equipment, snowshoes and road bikes. How or where? Let's make it happen!

We have a cabin in Cooke City and would like to go more often because of time can only go when have several days off.

We were 6 people on a college spring break trip.

Passive Users:

Beautiful Region!

Butte to Livingston, to Gardiner to Cooke City then back via the same route. We do this trip every year and always enjoy it.

Come every year. This year twice.

Glad to help out.

Go Bobcats!

Good luck on your degree!

Good luck with the survey. I was saddened to hear of the slaughter of the wolves in the area surrounding YNP.

Good luck!

Good Luck!

Hope the grad student does well.

Hopefully more people will realize the importance of tourism to the economy of the region and use taxpayer dollars to help access the area.

I (rather we, the whole family were along) are appalled that the states are shooting wolves. It's the main draw for us to hear the molly pack alpha as it were shot by a pair of hunters is the most discouraging and off putting. No wildlife, no visitors.

I had a passenger with me- doesn't seem to account for this.

I would never lodge in Cooke/Silver Gate in the winter season. For one, everything smells like snowmobile oil at night, but most importantly, unless you bring your own food and supplies, you might starve to death or die from boredom over eating such a poor selection of food. Gardiner isn't too much better, but it is better. Meals in Cooke is just way too much a risky proposition.

Love the area, but Cooke City is/seems "shady". I really felt I had to watch my vehicle closely. The characters hanging out at the Soda Butte Lodge where we stopped for lunch were questionable. In addition, conversation clearly led to anti wolf tones. I am pro wolf!

My first winter experience here and I loved it and will return.

Please stop the wolf hunting. If a list of businesses who advocate and support wolf hunting is available I would use it to boycott those establish. Create a buffer around the park.

Road closed should never be removed, possibly replace with access gate like along off-ramps or 90 freeway. Yellowstone NP should provide information to not enter into the park coming from Cooke City, MT as the plow info is misleading and could potentially trap tourists or visitors.

Some questions make little sense. Beartooth Highway is closed!

Stop shooting wolves near the park boundary. Main reason I come here... photograph wolves! Need buffer zone.

Thank you for doing this study.

The main reason we came to Yellowstone/Cooke City was to see the wildlife, especially the wolves. It was beautiful but I was disappointed we didn't see more wolves.

This is a useful project. Thanks for your effort.

We are 6 adults who traveled to Montana for a short winter getaway! But we did enjoy our lunch and short visit to Cooke City. Two of us traveled the Beartooth Highway between Cooke City and Red Lodge during the summer of 2012. What an awe-inspiring drive!!

We are residents of W. Yellowstone, MT from June through October and usually visit the NE part of Yellowstone 2-3 times, staying in Cooke City or Silver gate for 3-4 nights. We visit the area in the winter when we can.

We drive from Bozeman to Cooke City about 3-4 times each winter to view the scenery, have lunch in Cooke City, then tour around and head back. We've been doing this for 15 yrs. The road between the N entrance to Cooke City is greatly improved and appreciated.

We go to Yellowstone every spring and fall. This is the first time we stayed in Silver gate. We will stay there again. Please open the road to Cody so we can come every winter too.

We love the area in the spring summer and fall. have visited several times. This was our first winter visit.

We met a nice person from Silver Gate who spoke to us about wolves and wolf management. Also discussed politics in Cooke City. Enjoyed the people! Will visit again, next year in the winter. We did spend quite a bit at outdoor stores and restaurants in Bozeman due to that being our entry area. We flew into/out of Bozeman (only regional airport with frequent flight connections).

We really enjoy that the road is open to cars in the winter. It is a special treat to drive it.

White, college student, Minnesota.

With better year round access and more lodging and dining, there would be a lot of local traffic out of Wyoming. WY and MT people seek solitude that Beartooth provides. (It's not Big Sky)

2013

Activity Specialization: Interviews of Snow Machine Users in Cooke City, MT



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Activity Specialization: Interviews of Snow Machine Users in Cooke City, MT

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Research Report 2013-10

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Executive Summary

The purpose of this study was to explore snow machine (snowmobile and snowcat) recreationist's reasons for choosing the Beartooth region and to identify whether these visitors have attachment or dependence on place for their recreation. This study was an exploratory qualitative research project using in-depth interviews as the methodological approach. Eighteen interviews of snow machine riders (snowmobile and snowcat) were conducted over a 5-day period in Cooke City. Interviews were conducted at bars & restaurants during morning, afternoon, and evening hours. Interviews, ranging from 10 minutes to 25 minutes, were taped and transcribed verbatim then entered into the NVivo qualitative software package for analysis.

Interviewees were groups or individuals riding in the Beartooth region. The majority of travel groups were from mid-western states such as North Dakota, Minnesota, as well as eastern Montana and Wyoming. While snowmobiling was the main activity for most groups some visitors engaged in other activities such as ice climbing, snowshoeing, nature photography, and Yellowstone National Park activities. Six main themes emerged from the analysis.

1. **Visitor Characteristics:** Snow machine users were typically part of travel group of three or more people.
2. **Activities & Activity Participation:** In general, the level of specialization present in the snow machine recreationists is high. Visitors tended to take multiple trips a season to many places in order to recreate.
3. **Destination Choice:** Beartooth snowmobilers typically chose the Beartooth region because of the usual amount of snow, steep terrain, and convenience from home. Other places that are frequented by these visitors are the Big Horn Mountains, Island Park, West Yellowstone, Colorado, and California.
4. **Place Characteristics:** The top four positive characteristics of the Beartooth region are: the town of Cooke City and snow conditions, solitude, convenience, and challenge. The top four negative characteristics are: size of riding area, poor snow quality (currently), trail markings, and expensive prices.
5. **Concepts of "place":** Four concepts of place were identified through analysis: activity specialization, place dependence, recreation importance, and social bonding. The Beartooth region was identified as being substitutable to visitors only if snow quality was better in other locations. However, visitors did not appear to be deeply tied to the region in general.
6. **Recommended Changes & Road Access:** Visitors suggested that the riding area be expanded and trail markings be improved to enhance the visitor experience. The vast majority of interviewees did not wish for the highway to be plowed for normal vehicle use. Their concern was focused on traffic issues foreseen along the road, parking congestion in Cooke City, and loss of quality in the experience due to the possible change in number and type of snowmobilers.

Activity Specialization: Interviews of Snow Machine Users in Cooke City, MT

Introduction

The Beartooth Highway is a 68-mile travel corridor that begins in Red Lodge, MT and finishes at the northeast entrance of Yellowstone National Park. During the summer, the Beartooth Highway caters to hundreds of thousands of nonresident visitors drawn to the area by its natural and scenic qualities. The towns of Cooke City, MT, Red Lodge, MT and Cody, WY comprise the summer gateway towns of the Beartooth Highway.

During the summer of 2012, a study was conducted to assess the economic impacts and image of the Beartooth Highway. That study was a quantitative look into how tourism functions along a scenic byway. The summer study found that the Beartooth Highway provides economic contributions of over \$50 million in a 3-county region. Furthermore, the study provided an understanding as to why visitors travel the Beartooth and their perception of the highway. An additional study was needed to understand the winter portion of the Beartooth Highway.

In winter, the Beartooth Highway transforms into a very different place. The highway is unplowed in two places: 1) East of Cooke City for 8 miles and; 2) From the junction of WY 296 over the Beartooth Pass to Red Lodge. These unplowed road segments are used for winter recreation. Snowmobiling, backcountry skiing/snowboarding, cross-country skiing, wildlife watching, and Yellowstone Park activities are the main winter activities in the region. The Cooke City area (Colter Pass/Cooke City/Silver Gate), however, is known for winter motorized activities, primarily snowmobiling. Annual snowfall is usually abundant and consistent. The community of Cooke City provides a hub for users who wish to recreate in the national forest land outside of the town. Who are these snow machine users and why are they choosing the Beartooth region for their activity? Is there a special connection to the place itself or is it another aspect? Research on connection to place may help explain the traveler's reason for visiting, but the concepts of "place" and "place attachment" are diverse, rich, and complex. To explore if these complexities exist in this region, two methods of data collection were conducted: quantitative mailback surveys and qualitative in-depth interviews. Qualitative research can provide deeper meanings and intricacies of the visitor experience while quantitative data provide the visitor numbers of how many, who, why, and where. This report provides results from the qualitative portion of the study.

Purpose

The purpose of this study was to explore snow machine recreationist's reasons for choosing the Beartooth region and to identify any connection to the place. Understanding these connections can provide insights into the attachments and dependencies visitors hold for a particular place. For marketing purposes, indicating how visitors perceive the Beartooth Highway during the winter season provides information to better position and to promote their destination. The objectives of this research included:

- To explore the concept of place in the Beartooth region as felt by snow machine recreationists.
- To understand whether snow machine users have a sense of place dependence on the Beartooth region for winter recreation purposes.
- To understand the snow machine recreationist and identify other types of activities in which these visitors participate during the winter season.
- To better identify visitor characteristics of snow machine recreationists in the Beartooth region.

Methodology

During the winter of 2013, interviews were conducted with nonresident visitors to Cooke City, MT who were recreating on snowmobiles or snowcats (over-snow vehicles that can haul a small group of people, usually 5 or fewer). To qualify for the interview, respondents had to live outside of Park County, MT or Park County, WY. Winter recreationists were interviewed at restaurants and bars in Cooke City and asked a number of questions regarding their experiences in the Beartooth region. If the visitor was approached and was currently with another individual, the interview was conducted as a group interview. Generally, most interviews were conducted with at least 2 people in the group. A few groups were larger (5+) people along with a small number of single individuals were interviewed.

Interviews lasted between 10 and 20 minutes. Interviewees were told that their participation was voluntary and that their identity would be confidential. Semi-structured interviews were used and adapted to fit the nature of the topic. All interviews were recorded on a digital recording device. The interview guide for the study is included in the appendix of this report.

Eighteen interviews were conducted over a 5-day period. The majority of interviewees were participating in only snowmobiling, but a few indicated additional activities. The intent

behind in-depth interviews is to understand the topic of interest until a saturation point has been obtained. When no new information was found, data collection was seized as it became unnecessary. Thus due to the responses provided by the 18 interviews, this topic was thought to be exhausted.

In the analysis process, names and any identifying information were either changed or removed to ensure confidentiality of the respondents.

Analysis

Interviews were tape recorded and professionally transcribed verbatim. Final transcriptions were then used for analysis purposes. Transcriptions were imported into NVivo qualitative analysis software for analyzing the data.

Analysis of the interviews consisted of exploring and recording emerging themes between groups. While there are always individual differences, in-depth interviews provided a way for individuals to express themselves such that similarities between groups could be found. These similarities were grouped into categories and subcategories for comparative purposes. The emerging themes in this study have been identified as follows:

- Visitor characteristics
- Activities and activity participation
- Destination choice
- Concepts of “place”
- Place characteristics
- Recommendations for change
- Road access

These categories and subcategories were then further analyzed to understand meanings, compare differences, identify themes, and explore visitor characteristics. To provide a background on how and why this type of research is used, a brief review of the pertinent literature on place and recreation is provided in the following section.

Literature Review

The concept of “place” has become a focus in many areas of tourism literature. “Place” developed in tourism through geographical literature in the early 1960’s, and today place and tourism have evolved into a specific focus of the literature. Lew’s (1999) editorial piece on introducing the quarterly journal *Tourism Geographies* highlights the apparent need for tourism research to focus on the idea of place and tourism interweaving with one another. The geographical concepts of space and place can be utilized in a tourism framework to help understand meaning given to a destination. Humanistic geographers and scholars have attempted to understand the innate feeling that people associate with certain places. Part of this concept is referred to as “sense of place” (Relph, 1976; Tuan 1974, 1975). Tuan (1974) discussed the study of space, in humanistic terms, as “thus the study of people’s spatial feelings and ideas in the stream of experience (p.388).” Transforming a “space” into a “place” is a concept that humanistic geographers have been discussing for decades. Tuan (1975, p.152) defines place as “a center of meaning constructed by experience.” Moreover, it is through human beings and interactions that space is turned into place.

Agnew (1987) described three fundamental aspects for a place to be ‘meaningful’: (1) location, (2) locale, and (3) sense of place. Cresswell (2004) further discussed the meaning behind Agnew’s fundamental aspects of place through broader terms. First, place, and space, is a fixed location on the Earth’s surface that has objective co-ordinates. Each place has a location that is unique to itself. Second, locale refers to the “material setting for social relations (p.7).” Thus, this refers to the shape of place where people conduct their everyday lives, social exchanges and where events occur. Agnew (2011) also states that “places are not bounded, isolated entities as conventional regional studies have tended to regard them... They are best thought of relationally (p.24).” The mobility of place is a key factor into how conceptualizations of place form. Finally, the ‘sense’ of place is related to the human element of place. Russell & Ward (1982) defined sense of place as “the psychological or perceived unity of the geographical environment (p. 654).” The interactions of locals and tourists can create this sense of place and may lead to place attachment. Places are said to have “spirit or personality,” but only human beings can have a sense of place (Tuan, 1975, p.410).” This reaffirms that place is dependent on people. However as shown, the conceptualization of place and sense of place can vary between people.

Throughout time, place literature has identified multiple dimensions within the concept. Two of these dimensions are *place attachment* and *place dependence*. *Place dependence* is defined as “when the occupants of a setting perceive that it supports their behavioral goals better than an alternative (Stokols & Shumaker, 1981).” In recreation or tourism, this could be seen as a destination or setting that is best for what the visitor expects, wants, or needs and has little room for substitution of place. Furthermore, place dependence is typically tied in with recreational

levels of specialization. These higher levels of specialization in an activity (e.g. beginner skiers vs. expert skiers) can create conflict over dependence on a certain place (Jacob & Shreyer, 1980). For example, expert skiers may feel that they have more of a “claim” on a location that suits their needs better than beginner skiers. The visitor ultimately feels such a strong attachment to the place that their needs are dependent on the specific setting of that place. Meaning is applied to the place through the dependence of the settings.

Place attachment is defined as being “an affective bond or link between people and specific places (Hidalgo & Hernandez, 2001, p. 274).” Thus, place attachment is the feelings associated with a place or setting that a person may have. In a tourism context, understanding attachment provides researchers the ability to better relate with the feelings their visitors possess. As Kaltenborn & Williams (2002) discussed, place attachment can occur for insiders (locals) and outsiders (tourists) in different ways and at varying degrees of attachment. This indicates that while place attachment is thought of as an affective bond to a place, that bond is subjective in nature and should be treated as such.

This study was conducted to determine if place attachment or place dependence would help explain why snow machine winter recreationists visited Cooke City, Montana.

Results

Interview results are presented for each emerging theme followed by a brief discussion. Quotes from the interviews are provided that correspond to each topic. Some quotes were categorized in multiple categories and may be repeated in the discussion.

1. Visitor Characteristics

Visitor and trip characteristics were indicators throughout the interviews. Many of the interviewees were similar in their characteristics, but some differences did exist. These similarities and differences are shared throughout the analysis. For some sections, direct quotes are not presented, but data from interview analysis is summarized instead.

Residence

To begin each interview, the interviewees were asked for their permanent residence. Most visitors tended to be from mid-western states such as North Dakota, Minnesota, Montana, Wyoming and Iowa. However, one visitor group came from California and has returned multiple years in a row. In many cases, visitors traveled upwards of 10+ hours to recreate in the region.

Travel Groups

Observation of the number of people in the visitor group was noted at the beginning of the interview. Furthermore, a question about their travel party was asked of the interviewee. Nine out of the 18 interviews were conducted with a group of two people. Seven of the remaining 9 interviews were conducted with groups of three or more visitors. Two interviews were conducted with a single individual. However, it is to be noted that many visitors were part of larger travel groups (many smaller groups within the larger group). In general, it appears that nonresidents further away from home traveled in a group larger than three people. Visitors from shorter distances appeared to travel in smaller groups, but were generally not traveling alone.

Examples of direct quotes about travel groups when asked who they primarily travel with to this area:

Snowmobile couple from Williston, ND: “This trip we came alone. Some of his cousins are coming in the next couple of days and going to ride with us.”

2 Bozeman women: “Well, this is our niece, so some family and then we have close friends that we usually snowmobile with all the time.”

The make-up of travel groups is discussed further in the section regarding place and social bonding.

2. *Activities & Activity Participation*

Snow machine winter visitors in the Beartooth region during the winter season appear to be visiting to take part in a specific recreation activity or activities. Due to the limited access and the road closures in Yellowstone NP, no pass-through traffic exists. In total, three areas of activities appeared in the analysis of the data: 1) outdoor recreation, 2) social, and 3) Yellowstone National Park. By far, outdoor recreation had the highest participation and was the most important reason for being in the area for snow machine users.

Outdoor recreation included six activities: 1) snowmobiling, 2) snowshoeing, 3) nature photography, 4) ice climbing, 5) backcountry skiing/snowboarding, and 6) snowcatting. Sixteen of the 18 groups interviewed stated they were participating in snowmobiling. The two other groups were using a snowcat for access to ice climbing or backcountry snowboarding. Each of the other activities was only mentioned by one group and therefore, snowshoeing, nature photography, ice climbing and skiing/snowboarding were not common activities by snowmobilers.

2 WY snowmobilers: “We just heard it’s really good snowmobiling so we thought we’d come and try it. We have some friends that I work with that come here, they’re meeting us here.”

2 Bozeman women: “We went snowmobiling here two weeks ago. Eat breakfast a lot. And mostly just—Snowshoeing. We have been snowshoeing. We’re going to do that today too.”

Snow machine recreationists spend the majority of their time on their snow machines and most do not engage in other outdoor recreation in the Beartooth region.

Social activities were indicated as the second highest activity in which snow machine users participated while visiting the Beartooth region during the winter season. For this study, social activities are defined as dining with friends, playing card games, or conversing with friends and family in a local bar. Eight of the 18 travel groups mentioned that the social aspect of their trip was important, but still secondary to snowmobiling while in the Cooke City area. For many, these social activities were engaged in during evening hours after participating in snowmobiling or other outdoor activities.

2 Bozeman women: “They have entertainment [in Cooke City]. A band, their local band is really good so that's fun to listen to.”

3 ND snowmobilers: [When asked if they are participating in any other activities] “Beer drinking.”

2 WY snowmobilers: “[other activities...] Boozing, poker, eating. That's it.”

Social activities seem to be more of an amenity or way to replace down-time for winter recreationists. However, the social activities may be a medium for recreationists to share experiences and discuss the day’s activity.

The third activity category, related to **Yellowstone National Park**. While this category did not have many specific activities attributed to it, four travel groups indicated that they were in Yellowstone National Park during their trip. Activities such as nature photography and visiting the Boiling River were two of the specific activities that were identified by the snow machine winter visitors of the Beartooth region. While Yellowstone National Park is not the main destination of snow machine visitors, there is some level of participation inside the park with certain activities. This could be credited to the fact that one of the two points of access to Cooke City requires the visitor to drive through the northern section of YNP.

In summary, it is apparent that outdoor recreation is the main activity of snow machine users to the Beartooth region during winter. However, two other activity types (social and YNP) were identified in the data.

3. Destination Choice

Traveling to the Beartooth Highway in the winter is a lofty goal for users who are not spending a substantial amount of time in the region. Understanding why travelers choose to visit

this destination instead of other areas more accessible should be of key importance to local stakeholders and marketers. Indicating the reasons why people come to the Beartooth region for winter recreation may provide insights into how to attract others to the region to experience the unique area. In this section, factors for choosing the Beartooth region and their other stated recreation places are discussed.

Factors in Choosing the Beartooth Region

The Beartooth Highway is a destination that draws many tourists throughout the summer and winter seasons. However, why do they choose to visit in the winter for their winter recreation? What other places do they visit during their travels? Is there something about the Beartooth Highway area that entices them to visit the region? What influences their decision to visit?

Snow conditions: The most influential factor towards choosing the Beartooth region for their snowmobiling/snowcat recreation was snow quality and snow conditions. The aspect of snow was mentioned 41 times by the 18 interviewees when discussing why they were in the Beartooth region for their trip. For many, the amount of new snow was the most important element considered before visiting the region. Comments for why they chose this area for their recreation include:

Eastern MT Group: “Got more snow than anybody else.” [Asked if that determines their destination choice] “Oh, yeah.”

Iowa Snowmobilers: “Snow. They said they had the best snow probably for where we like to go for now. Last year we came because a friend of mine had another friend that had been coming here for years and said, hey, this is a good place to check out.” [Asked if snow makes a difference in their destination choice] “Yeah. If there was better snow somewhere else, we'd probably go there. If Steamboat would have just got a big storm and a bunch of snow, we'd have gone there.”

Snowmobile couple from Williston, ND: “Snow conditions. Well, they usually get better snow here than the Big Horns.” [Asked if it factors into the place they choose] “Uh-huh.”

The quality and amount of new snow appears to be a large determinant in why visitors chose the Beartooth region over others. As the “Iowa Snowmobilers” stated, they would have gone to Colorado if they “just got a big storm and a bunch of snow.” Snow amount or quality are rather unpredictable and cannot be actively managed. However, it is important to note that snow is the major player in why these visitors choose this destination. In later sections, the dependence on snow and snow quality will be discussed even further.

Other factors of destination choice included: 2nd home ownership, amount of amenities, length of intended stay, prior experience, recommended, and ability to try something new. These

factors in total were referenced 10 times in the interviews. While these reasons are not as high as snow conditions in terms of importance, they are necessary to understanding the complete picture of the Beartooth Highway snow machine user.

Quotes that discussed these other reasons for being in the Beartooth:

3 ND Snowmobilers: “Been here before and always had a good time.” [Stated it was a spot they pick every year.] “It seems like they always have more snow here than anywhere else around here. Big Horns is always kind of iffy if they got snow or not.”

5 ND Snowmobilers: “(We) go here probably 3 or 4 weekends a year and then (snowmobile) a thousand miles at home, maybe.”

2 Bozeman women: “Because we knew that you had a place to eat breakfast or lunch and have nice flushing potties. We, just on the spur of the moment, decided to go snowmobiling. We didn't actually come to go snowmobiling.”

2 WY snowmobilers: “[Friends] came sledding and they say, you should come to Cooke City, so we said all right. So planned the trip and here we are.”

While some factors that influenced destination choice were prevalent apart from snow, it was difficult to find a group of recreationists who did not mention snow as one of the main factors into why they chose this destination for their trip. Recommendation and prior experience seemed to be common among a number of groups as well. If they had not previously been to the region, it was recommended to them by friends, acquaintances, or family that suggested this area for their snowmobiling.

Other Recreation Places

In order to better understand the user groups in the region, interviewees were asked to state if they recreated in other places. A number of other popular destinations were mentioned. Seventeen sources indicated other places they went for recreation or travel as well. These places included: Big Horn Range, Island Park, MT, West Yellowstone, Togwiti Pass, Lolo Pass, Truckee, CA and Steamboat, CO. While this list is limited in the possible locations for recreation, it provides a baseline for where other potentially substitutable areas visitors frequent.

For instance:

2 Williston, ND snowmobilers: [When asked about amount of times snowmobiling in a season] “Half a dozen. We split between the Big Horns and Cooke.”

3 Bismarck, ND Snowmobilers: [About which other areas they recreate in] “I went to the Big Horns a lot and then Yellowstone, West Yellowstone.”

3 ND Snowmobilers: [About other recreation places] “Went to the Big Horns. Yellowstone. South Dakota, Deadwood.”

5 Devils Lake, ND Snowmobilers: [When asked if they mainly recreate in the BTH or other places] “Yeah, here and Big Horns, Togwiti. Where else have we been? West Yellowstone, and then when we're going to do Revelstoke in February, British Columbia.”

As results indicate, other recreation places were mentioned a number of times by interviewees. Even though they were on vacation in the Beartooth region, these visitors tend to have interest in other regions during their winter season snowmobiling as well. However, some of the visitors had traveled to the Beartooth region already during the season or were planning on coming back more times after this current trip. Finding out about the other recreation places that Beartooth users frequent gives perspective on what the visitor is looking for in a location. The visitors from North Dakota & Minnesota tended to visit the Big Horn Mountains quite frequently. Island Park and West Yellowstone were also two other areas that were commonly mentioned.

4. Place Characteristics

Before moving on to the dimensions and concepts of place, the characteristics of the Beartooth region are discussed. Describing the characteristics, features, feelings, and amenities about the place, a better picture of what the place means to people and their attachment to the place can be explored. The “place characteristics” are divided up into positive and negative responses.

In this section, 23 positive characteristics were identified through these snow machine winter recreationists’ responses. The list of positive characteristics are: sense of adventure, amenities & pricing, behavior of people, sense of challenge, convenience, crowding levels, first ascents of climbing, intimidating, lack of law enforcement, local people, number of activities, novelty, relaxation, riding area, scenery, settings & conditions, small town feel, snow conditions & quality, solitude, trails, and wildlife.

Twelve negative characteristics were identified such as: cell service & communications, prices, fumes, lack of access into YNP, lack of amenities, emergency services, noise, poor snow quality, size of riding area, trail markings, and lack of wildlife.

It should be noted that the number of positive characteristics greatly outweighed the negative characteristics of the place. Furthermore, the number of negative characteristics came from a much lower number of sources (only four groups mentioned any negative characteristics). It is apparent that the Beartooth region is considered to be a positive place for winter recreation in general.

Positive Characteristics

The most frequent responses for positive characteristics were settings & conditions (snow) (30 references), solitude (24 references), convenience (18 references), and challenge (16 references). Settings & conditions refer to both snow quality and the settings of the place. One example of the settings is the steepness of the terrain. Solitude was mentioned a number of times and generally related to the remoteness of Cooke City. Convenience meant either the ease of access and use of trails or the access to accommodations in the Beartooth region. Examples of these responses are as follows:

Settings & Conditions

2 Williston, ND snowmobilers: [When asked about place differences] “Steeper.” [Does it make it more fun?] “It is for us. More challenging too.”

Snowmobile couple from ND: [When asked about place differences] “The terrain is better. It's steeper. Wide open.” [If risk is associated and wanted] “I don't like riding trails. I'd just as soon beat my helmet on the handlebars than ride trails.” Yeah [If hill climbing is preferred].

Iowa snowmobilers: [When asked how this region differs] “It's a little more extreme, I'd say. I don't know. Big hills. Big hill climbs. A lot of places don't have big hill climbs. They have meadows to play in but not the big climbs. This kind of has it all.”

WY snowcat ice climbers: [Why they chose this location] “Because the snow is here.” [Whether it's all about snow conditions] “Yeah.” [If anything else attracted them] “No. Just — not really. Just to experience, you know, because everybody talks about it.”

MN snowmobilers: [About how this area is different than others] “The snow here is just powdery. The Big Horns is all windblown and hard.”

Solitude

Billings Snowmobiler: [In terms of remoteness] “Just shut the phone off —yeah. Otherwise you're getting bugged about other things and it's just —it's nice when you can get up here with a bunch of guys and phones are off. You've got to use a pay phone to dial out and call once a day and tell someone you're okay, but other than that, do what you want.”

[When asked if there was anything I missed] “No. Just, it's a good place to come. Like I said, half the girls like it, half the girls don't. Once they realize there's no cell phones and stuff, they kind of freak out. But then once they get over that fact, they understand the element of doing your own thing and not having to worry about phones and stuff. It's great.”

Iowa Snowmobilers: [When asked about differences from other places] “Oh, yeah. This is pretty small. I mean, Steamboat is huge. It's a ski town, a little more —there's the Wal-Marts and all the fancy, ritzy steakhouses and stuff like that. This is unique. I like the whole atmosphere of —there's not a through road. You kind of got to go clear out of your way to get here.”

WY snowcat ice climbers: “I guess I thought that it would be more —a little bit more resortie. A little bit more developed. I wasn't prepared for this —It's overwhelming to me but its cool, that's what it's about.”

Convenience

2 Williston, ND snowmobilers: [When asked about the Beartooth region apart from others they visit] “Yeah, and the other thing too is here, you just barely got out of town here, right in the thick of it, where in the Big Horns you tend to ride a lot longer distances to get to the riding areas.”

2 ND female snowmobilers: [About the convenient distance compared to other regions] “Island Park is 12 hours from us —so two more hours. You just shoot straight from Bozeman about two hours.”

[When asked why they choose this region] “Good people. The people are really nice. And we started renting a cabin here. It's just easier to leave our stuff here and come here all the time, rather than hauling our sleds all over.”

3 ND Snowmobilers: [When asked about why they choose the Beartooth over West Yellowstone] “Just convenient. It's a little closer too.”

Challenge

3 ND Snowmobilers: [When asked if they prefer this type of riding] “Yeah, 'cuz a lot of women aren't going to go here. It's too much straight up and down —Yeah, the risk factor is way higher. The challenge is here. Trail riding is for the wife and the kids and then —it's a lot harder riding here than anywhere else.”

5 ND Snowmobilers: [When asked about how this area is different than others] “It's more vertical out here. A lot more extreme. Not as many tree areas. Like West and like Togwiti, I'd say there there's more meadows and stuff but here you get more tree and (inaudible) stuff. Bigger climbs.”

[When asked about a memorable time in the BT] “Yeah. Every time I come out here you get lost. We always carry our GPS's because we know what's going to happen. That's kind of where

you find the snow is if you basically get off, get a little scared, and then you just pull out your GPS and you're not that far from where the trails are so it's not a big deal.”

As the responses indicate, the Beartooth Area has some unique features and characteristics about it that separate it from other destinations. Steepness and difficulty of terrain appear to be rather high in this area compared to others. Visitors tend to enjoy the fact that the area is remote and not like a “resort.” The most frequent comment was about the fact that the snow conditions in the region are typically better than many other areas. However, if snow was not abundant, the conditions did not seem to be as great. This may be because the steepness of the slopes and trails require a substantial amount of snow to make it safe and ride-able.

Negative Characteristics

While the Beartooth region had an overwhelming amount of positive characteristics associated with it by interviewees, some negative aspects were mentioned as well. The most mentioned negative features were: Riding area too small (6 references), poor snow quality (6 references), prices of goods/services (4 references), and trail markings (3 references). Taking a look into these characteristics gives stakeholders an idea of where to start improving the experience and possibly creating more of a bond/connection between the visitor and the place.

Riding area too small

2 Williston, ND snowmobilers: “I think if they had more riding areas in this vicinity, the trails and stuff wouldn't get so beat up that would help disperse the population better. Where in the Big Horns there's a lot larger riding area and you don't, we don't run into such, poor conditions there.”

2 Bismarck, ND snowmobilers: [When asked if there are changes they would like to see] “Yeah, move the boundaries back” [When asked about the riding area] “Oh, it's tiny. A small area. You can ride it all in one day.”

3 ND Snowmobilers: [When asked how West Yellowstone differs] “Well, it's a lot better, more accommodation lodging. I mean —much bigger. It's bigger. And the riding area, I mean, you've got probably 3,000 square miles of riding area and here you have like 36 square miles of riding area.”

Poor Snow Quality

2 Williston, ND snowmobilers: “Everybody we've talked to today got beat up out there because the snow is so tracked up. It makes the experience so, so much more enjoyable if you got new, fresh snow that isn't all tracked up, so I would guess that's going to be the number one factor for almost everybody.”

[When asked about travel group members condition due to snow] “Uh, yeah, he's hurt. He's sore. And it's brutal out there right now —They, I don't know if that's part of your study or anything, but —They've got to get the groomer out there. We got the crap beat out of us on the trails today.”

[When asked if there would be a point they would stop returning here] “Well, if it got to the point where we had these riding conditions all the time, I mean, I'm sure we'd be just going to the Big Horns, because, at least in the Big Horns, it's so spread out that you can still discover pretty untouched areas to ride in. Where, what we experienced today, there was just no area that was left untouched, and so that would definitely factor in. Like I said, this is our second time so we haven't been here enough to form, really good opinions based on how beat up it is, but when the other people we've talked to that have ridden here do prefer this over the Big Horns and it was on their recommendation that we came and we were, happy, but —“

Snowmobile couple from ND: [When asked about issues on snow conditions] “It gets tracked up. If it doesn't snow, you know, if you go a couple of weeks without snow, everything is packed down and tracked up and it's not really as much fun. Yeah, you get that deep powder, it's like you're riding a jet ski basically versus sitting on the hard pack.”

Trail Markings

2 Williston, ND snowmobilers: “We wish that the trails were marked better. That's one thing that we struggle with cause, it's only our second time and both times we've been here, we've gotten turned around, just because, for instance, you know, Lulu, you get to the end of that and then there's ride-able area for miles and miles and miles —“

“But there's absolutely nothing marked. And then there are so many riders here, there's tracks everywhere, so you can't necessarily know...GPS's and things like that help, but if they could expand their trail system, make it longer, and have it more clearly marked, that would definitely help. Even if it wasn't part of the trail, if they just had periodic things posted, like, here's where you're at, you know. In the Big Horns, every so often, there's like a wooden board and inside a Plexiglas case is a copy of the map, and it shows, you're here and shows you where some of the other stuff is. Of course we haven't explored all of it here but, we haven't seen anything like that.”

3 ND Snowmobilers: [When asked about changes they would like to see] “More grooming on the trails. Better grooming —It's all done locally, donations and stuff. But it's supposed to go towards your ticket when you pay for your licensing, you know. Game and fish is here. Who pays for them to be here? Taxpayer. Our ticket money, and every time you buy a license in North Dakota or Montana or Wyoming, that goes to the state to their game and fish, and that's for their monitoring of the trails. That's why we pay \$30 for these passes to drive these snowmobile

trails. That's what they're supposed to do. See, the trails are pretty beat to shit right now.”

[Asked even though they don't use them, if it would be nice to improve them?] “Just to get there. Yeah, you drive 3 or 4 miles on it, and it's every 3 feet there's a whoopdee-do, just because of that. One thing about marking the trails in Cooke City is not very good. We talked about that — The marking of the trails is really poor.”

[Asked how they currently mark trails] “Just a little orange diamond. Most places have a laminated paper and they say "you're here," and they have green trails, red trails, blue trails, so you know which trail you're going to be on next. You can get a map and they're all labeled. South Dakota does a great job. West Yellowstone does a good job.”

[Asked if they believe it is because of the level of specialization of riders] “Probably. But even under the conditions if it started snowing and blizzarding, you wouldn't be able to find —no matter how good you are. You need to know which trail you're on. And the trails aren't marked very well here.”

“Well, this is what you've got to look at for a trail. They all look the same. Kind of all looks the same. They could change it into different colors. And then this distance here to here (indicating), have a blue marker, blue triangles, and when you got on a different one, maybe go green and then red and then yellow. [Reaffirm the type of trail markings] Yeah, it's all orange diamond. It's like driving down the interstate and going to Minneapolis and now you're on Exit orange, you know.”

Expensive Prices

2 Bozeman Women: “But, as I said, the motels were more than twice as expensive here for the same hotel, I could get it for \$43 in Gardiner and \$100 here. So I was not tempted to spend \$100.”

[When asked about changes they have seen] “Not really. No. I mean, everything here is a lot more expensive any other place around. I mean, West Yellowstone is cheaper. It would have been nice to stay over here if it hadn't been so expensive. And I don't know if that price is here year round or not.”

As the results indicate, there are some negative characteristics associated with the Beartooth Area. A few of the characteristics mentioned can be improved, while others, such as snow condition cannot be managed. However, grooming and trail marking may allow for poor snow quality to be mitigated. Trail marking seems to be the most feasible area of improvement in which to focus. Designating specific colors/numbers for trails appears to be a need and an improvement that could be made easily by stakeholders. For many, it appears as though trail

markings are currently confusing and may lead to safety issues with bad weather. If visitors are in the region for their first time, it may make them feel more comfortable to have well marked trails better. Results indicate that even experienced riders prefer to have better marked trails that lead them to the areas they wish to recreate.

In summary, the Beartooth region is an overall positive place for snow machine winter recreationists. The steep terrain, generally good snow conditions, remoteness of the town, and convenience of access to accommodations are the top characteristics of the place. Recreationists prefer to have quality snow in these settings due to the challenge and opportunity for satisfaction. Improving trail markings is recommended. A systematic approach towards better designation of particular trails and improved signage along trail corridors may provide an overall better experience for riders. Furthermore, it may be beneficial to riders who find themselves in less than adequate conditions.

5. Concepts of “Place”

As discussed in the brief literature review, place is an important topic in geographic and recreation literature. Developing a feeling of a “sense of place” may entice visitors to return to the destination many years in a row. In order to uncover the dimensions of place, four areas of importance were identified as being part of the experience of snow machine recreationists in the Beartooth area. These areas are: activity specialization, place dependence, recreation’s importance to everyday life, and social bonding. A discussion and example quotations from each of these areas follows.

Activity Specialization

Interviewees were asked how many times they participate in their current activity in a given season. The purpose was to assess if they are a frequent participator or if it is only a “once-in-a-season/year/lifetime” event. Indicating frequency of participation and level of expertise can help understand the level of specialization of the user.

Some visitors did not recreate very often during a season:

3 ND Snowmobilers: [When asked how often they snowmobile in a season] “Maybe once or twice a season.”

[If asked if they try to plan one large trip during a season] “Try to. I try to. Every year, one or two times.”

6 ND Snowmobilers: “Some guys [in our group] come out once, some guys come out six times, seven times.”

Minnesota Backcountry Snowboarder: “I usually go on like two trips a year —well, three trips a year, I guess.”

Other groups participated very frequently in their activity:

9 California & Wyoming Snowmobilers: “Like times? Everywhere? You mean how many trips? 7-10. 1,000 miles, maybe. [Asked where else they visit] California. 2 trips here. These guys are going to be on their third trip in February. Truckee, California. They go to some places in Wyoming.”

6 Snowmobilers: [When asked how many times they visit Cooke City for winter recreation] “Try to at least 4 times a season.”

Snowmobile couple from ND: [When asked if they visit this area many times a season] “Oh, yeah. I don't know, at least 8. Probably the Big Horns once in a while but, I like Cooke.”

Visitors to the Beartooth region tend to have diversity in degree of participation in their activity. However, it appears as though many of the groups in the region tend to be more frequent participants. This correlates with the perception of more experienced riders in the region. Generally, the majority of riders had previously been to the area before. A few members of groups and a few complete groups had not been to the Beartooth region before their current trip.

Place Dependence

Place dependence is a concept that relates to the degree of substitutability a place has to its visitors. This was one of the main focuses of the study. If visitors feel a degree of dependence towards the Beartooth Area it may give stakeholders insights into how to market and manage the area. The analysis is split into those who said it was substitutable and those who thought it was not substitutable.

Eleven groups stated that their experience in the Beartooth region was substitutable to some degree. Six groups stated that their experience in the Beartooth region could not be fully met elsewhere and would prefer to recreate in this place. While 11 groups did think they would fill their recreation needs in other places, it is to be noted that they do enjoy their time in the Beartooth area. However, snow conditions seem to be more important than the location itself.

Substitutable

2 Williston, ND snowmobilers: “If Cooke did not exist; we’d be riding in the Big Horns. But, as long as Cooke's here, we will, just see whoever has the most snow and that's the place where we'll probably go. If they had equal snow, I'd probably pick Cooke over the Big Horns.”

2 ND female snowmobilers: [When asked if they could find this experience elsewhere] “Probably. I think so. Yeah, you could probably get to know the people in Island Park or —I mean, we would just take one-time trips there so you didn't really get to know the locals.”

3 ND Snowmobilers: [When asked if anywhere else would fill their recreation needs if the Beartooth Area was not there] “Probably go to West. [When asked if it is the same experience] It is, yeah. A little bit more to do in the evenings. A little more variety. Yeah, you got a little more nightlife.”

6 Snowmobilers: [When asked if they could find the same experience elsewhere] “Yeah. Island Park. [Asked about differences in the area] More open. You know, once you get into the mountain terrain, you know, (inaudible) a lot of trees to get there. Once you're there, it's pretty similar.”

Snowmobile couple from Williston, ND: [When asked if they could find the same experience elsewhere] “If this wasn't here, we'd go to Big Horns, Jackson Hole.” [When asked if these locations would provide the same feeling] “Yeah.”

Not Substitutable

9 Californian & Wyoming Snowmobilers: “This is the ultimate place for us. There's only maybe one place in California that compares to this. This place is the ultimate for us. The snow is really good and just so many —you can drive all day and not see the same thing. It's different than California.”

[When asked if any other place would provide same experience] “No. There wouldn't be any other place you guys would go that would be like this, would there? No. (Other places are) a lot more commercialized. This town is more rustic and real.”

Snowmobile couple from ND: “You'd have to go to Canada probably to get these types of wide open hills.” [Reaffirming that they said no other place would provide the same experience] “Not here, no.”

5 Iowa Snowmobilers: [When asked if they could have the same experience elsewhere] “Oh, it wouldn't be the same, because you've still got to trailer your sleds and —This is more and more convenient, except for driving 14 hours compared to 9 hours to Centennial. About 5 hours longer drive.”

MN snowmobilers: [When asked if another place would provide the same experience] “For us, it's the location. It's close to home. Closest, you know. Because it wasn't here or, say, the Big Horns, we'd have to drive another 7 1/2 hours south just to go to Snowy Range.”

The conversations pertaining to whether other recreation places would provide the same experience were insightful. Prior to data collection, the terrain of the Beartooth region alluded to anecdotal thoughts about dependence. There are few places that have such steep mountains and receive such large amounts of snow. Visitors during the summer stated that the Beartooth Mountains are superb for winter recreation. However, the data shows that many of the recreation groups think that other places would provide the same experience for their activity. A smaller number of groups have some level of dependence based on snow conditions and distance from home. Only two groups, one YNP travel group and one loyal Beartooth recreation group, stated that the location itself is what drew them to the region. Snow conditions, convenience, and terrain appeared to be more of a factor in drawing visitors to the region. This finding will be discussed further in relation to marketing and management implications.

Recreation Importance to Everyday Life

The importance of the activity to visitors is an important concept to understand because it tells us what type of connection people have to their recreational activities. If it is observed that recreational activities are extremely important to the individual, it can be said that they may be more inclined to form strong bonds to an area that facilitates these activities. For those who do not see their activity as a high priority in their life, it may be more difficult to develop a sense of loyalty to the place. Nine interview groups mentioned the importance of recreation in their everyday lives.

2 Williston, ND snowmobilers: [When asked about the importance of their activity to their everyday life] “We really enjoy it so we plan it and, I mean we have obviously a lot of stuff going on in our other lives, so when we have free weekends, we make it a goal to try to make it, five, six times a year or so. It's pretty important and- We've definitely got to plan it, because we're busy at work and we both have families —With young kids. You know, they play hockey, they swim, they've got stuff going on, so we've got limited opportunities.”

2 ND female snowmobilers: [When asked about their activity's importance in their everyday life] “My husband, definitely more so than I, but he can take more time off of work than I can.” [Is it a major part of your winter trip planning?] “Oh, yeah.”

3 Bismarck Snowmobilers: [When asked if recreation is a large part of their winter trip planning] “When I was younger I did, yeah. Now I'm married and I've got bills to pay. But, yeah, if I could, I'd come every weekend.”

5 Iowa Snowmobilers: [When asked if snowmobiling is a major part of their everyday lives] “For me, it is, because I farm —Yeah, it seems like I've got more time in the winter to do this kind of stuff. We've already got the pickups and the trailers, and stuff like that. It's easy for us to haul them.”

WY snowcat ice climbers: [When asked if ice climbing's importance in their everyday lives] "Pretty much just daydream about it. Getting to an age of not. But I like to move through the snow or (inaudible) move efficiently through the snow. I don't know. I've done a lot of things in my life to where you plan --I used to do a lot of deep mixed (inaudible) and plan everything out, plan, plan, plan, and all the what-ifs, what if this happens, what if that happens, what do you need to have with you, what do you need to do, and stuff and it becomes such a chore sometimes just to go out and do something that --it's not worth it. You get a lot of anxiety over everything that you go and do, you know, and with the snowcat, if this breaks, we've got to have that, and if that happens, we've got to have this and these tools, and then survivability gear, got tent, clothing, food, you know, so you can stay out a couple of nights or something in the wilderness or whatever happens. It's just kind of a chore."

Of the response on recreation's importance in their everyday lives, it appears that many of the groups see their winter recreation as somewhat important to very important. This shows that these visitors are quite dedicated to ensuring that their participation in these activities stay high. While some constraints exist (family, work, money), it appears that they have strong intentions to at least plan one trip to many trips a year strictly for this type of recreation.

For some, it is something that is on their mind often. Some are experienced in many forms of outdoor recreation and appear to be more ready for a relaxing experience in their recreation. Others appear to be comfortable with planning large trips and traveling long distances for their recreation. Groups that live in states without large mountains seem to be more willing to take more involved trips to meet their needs.

Social Bonding

One of the concepts of place that is not related to the place characteristics or the environment is social bonding. Social bonding is about the interactions with people who recreationists travel with and spend time with during their trip. At these locations, many people develop a bond due to the memories and experiences they have with friends, family, or people who enjoy the same things they do.

9 California & Wyoming Snowmobilers: [When asked what drew them to the region] "These guys." [Are the people you travel with the main part of the experience?] "Exactly."

Snowmobile couple from Williston, ND: [When asked if snowmobiling is important in their live] "Yeah. And a lot of it is our boys do it too. So we usually come out as a family. We all ride." [When asked who they traveled with this trip] "This trip we came alone. Some of his cousins are coming in the next couple of days and going to ride with us." [When asked if they normally travel with this group] "Usually the boys are with us, and maybe a couple of nephews."

3 ND Snowmobilers: [When asked how they know who they traveled with] “They're my buddies from Williston. There was what, 5 of us that came up.” [When asked how they knew the rest of their group] “Grew up together.” [When asked if they normally travel with these people] “Yeah. It makes it more fun if you go with your friends, I guess.”

5 Iowa Snowmobilers: [When asked who they typically travel with to the region] “Whoever wants to go and can go!”

Social bonding is an interesting concept that was somewhat important to the snow machine recreationists in the Beartooth region. A number of groups were traveling with friends or extended family while others were on a trip with people who just enjoyed the same activity or were acquaintances. It appears that while people enjoy being able to spend time with others, it is not a major role in the overall experience for many. Some people seem to travel to the region with whoever chooses to come at that current time.

In summary, place and place dependence are complex topics in the Beartooth region. While many concepts of place were described through the analysis, the ties or connection to the place seems low. A few groups appeared to have more of a “sense of place” than others, but in general, place seems to be less important to these recreation groups. If the snow conditions are above average, it appears that people then start to notice the amenities and nuances of the experience. However if snow conditions are less than ideal, it appears that the experience lacks somewhat. Many groups discussed that they “wished for more snow,” or that they were “getting tired of the beat up trails.” These statements seemed to supersede and trump the idea that they are loyal to the Beartooth area for snowmobiling.

6. Recommendations for Change & Road Access

The final section analyzes statements made by respondents about their recommendations for changes in the region and their opinion on access to the destination. First, the visitor's recommendations on changes/no changes are presented, followed by road access statements.

Recommendations for Change/No Change

In total, 10 visitor groups discussed changes they would like to see while nine visitor groups discussed the fact that no changes should be made. It is to be noted that some groups said that they would welcome some specific changes, but not to change other areas. This section presents and discusses these statements about visitors' preferences to leave the area as it is or to implement changes in the region.

Desired Changes

2 Williston, ND snowmobilers: “My recommendation would be to expand the riding area. But I'm guessing, practically speaking, most of the other ride-able area is federal forest service land which, is inaccessible and, but unless the state somehow were able to secure those lands. [When asked if there would be any point they would stop returning] Well, if it got to the point where we had these riding conditions all the time, I mean, I'm sure we'd be just going to the Big Horns, because, at least in the Big Horns, it's so spread out that you can still discover pretty untouched areas to ride in. Where, what we experienced today, there was just no area that was left untouched, and so that would definitely factor in.”

Group of 6 Snowmobilers: “Just open it up (riding area). Yeah. There's getting to be a lot of — there's a lot of traffic —I don't know the reasoning —a bigger area would help, in my opinion. [Does it get crowded on the trails?] Crowded as in sleds, if it doesn't snow for a week but lots of sleds, it gets tracked up. In a confined area, probably would bring more sleds in. For all of us to ride in fresh snow.”

Billings Snowmobiler: “Maybe a few more —not going to say restaurants —but more like — everything here is more like home-style food and stuff, so the food up here, especially across the street and stuff, everything is home cooked. It's just that element that, I mean, you wouldn't want a Taco Bell or anything up here by any means but – [When asked about variety] Yeah. My biggest complaint is stuff isn't opened late enough. Everyone wants to stay up and party till 2 and then —everything shuts down at like 9:00 for food.”

MN snowmobilers: “More snow. Everything I read said it was awesome, and we get here and it's all tracked up and hard.”

No Changes

2 ND female snowmobilers: [When asked if they would like to see changes] “Really, I don't have any problems.”

MN Backcountry Snowboarder: [When asked about desired changes] “Not really, I guess. No. Everything's been fine.”

Snowmobile couple from ND: “We've been coming here for 16 years. Yeah, I don't —not a lot of huge changes, which is a good thing.”

WY snowcat ice climbers: “No. I think that should be left to the people that live here. I tend not to get involved in other people's business.”

Responses about changes were diverse. The people who suggested changes typically had one area they wanted to focus their discussion around. Respondents who did not want change

had little to say about the issue. Two of the main issues that came out about changes were the riding area and variety of places to stay/eat. Due to the Beartooth Wilderness boundary, the snowmobile riding area tends to be confined to a smaller area than other snowmobile areas. With the increase in people over the past number of years, it appears that it can be congested in the main riding area or simply too tracked. While pushing the Wilderness boundaries back is not feasible, managing the number of users in a single period might be one avenue to protect the visitor experience. This, however, is a controversial idea and not likely to sit well with snowmobilers.

Road Access

Road access during the winter season is a hot topic in the region. For 8 miles east of Cooke City, the Beartooth Highway remains unplowed during the winter season. Snowmobilers and other recreation users use this section of the highway in order to access the trail system for the region. Visitors can either access Cooke City by traveling through Yellowstone National Park or by parking at the Pilot Creek parking lot at the MT/WY border (8 miles east of Cooke City). Whether or not to open the road to through-traffic has been debated for years. While this data does not suggest whether or not to open the road, it gives an idea of what the visitors who frequent the area believe should happen.

The majority of users (15 out of 18) stated that the road should be left the way it is currently. Many of the responses cited the number of vehicles that would be left without a place to park in the town of Cooke City if the road were opened. Furthermore, some visitors were enticed by the fact that Cooke City is a very remote location with “one-way-in, one-way-out” accessibility. As results have shown, remoteness & solitude are a major positive characteristic of the Beartooth region for many groups in this sample. It is to be noted that the vast majority of travel groups preferred to not have the road opened during the winter season.

Below are examples of responses to leave the road in its current state:

3 Bismarck Snowmobilers: “I think it's kind of cool that they shut that down. You get to ride on the highway. [Asked if it enhances their experience] “Yeah, I guess. I don't know, I guess that's never been a challenge. Just did it. [When asked if they would travel to the destination more if it was opened] No. It's just snow —we'd probably come around, that way is shorter for us. So, I guess, yeah, we'd probably take that way more often. It wouldn't change the amount of time we came out here, no. If you're going to drive 700 miles.”

3 ND Snowmobilers: “You'd have to remember what —how many dollars it's going to cost to keep that trail/road open. And where are all those trailers going to park? Yeah, there's just not enough room for all the parking space around here. That doesn't bother me doing that.”

Group of 6 Snowmobilers: “I thought it was really fun the first time coming in, because I didn't know what to expect, but —It's a little more like an adventure. Yeah. Whatever you put in your backpack, there's nothing more. You don't have your truck —Snowmobile gear, towel — everybody's gear is the same. It's a neat town.”

[When asked if they want it opened for more access] “It's really up to the locals. Personally, I don't know if it would make it better for the locals. It's up to them. It doesn't matter to me. It's fine the way it is. I come here because —if they opened it, I don't know if it would be busier or not. Obviously, the locals know whether they want it or not. I was just curious if you had heard anything different.”

9 California & Wyoming Snowmobilers: “When they start plowing the road – [When asked if that would change their travel] It would. If they plow that road, the party would be over. Be too many people in here. All these guys right here — You can only fit so many people in town. You know this area well? They all ride in from the parking lot. That's one of the experiences riding in, taking all your stuff —How cool is that, you're riding with all your gear – If they plowed the road, they're going to have a disaster.”

Backcountry Snowboarder: “I would leave it how it is. For a lot of reasons. I mean, first of all, it's kind of ridiculous to try to plow it all winter. And, I mean, unless you have money growing on a tree, whatever. That's one aspect of it. Otherwise, you know, I mean you can snowmobile on it and stuff, right, I think that would be a super cool experience. And if it was open for traffic that, obviously, wouldn't exist.”

Billings Snowmobiler: [When asked about road access] “It's ideal. Yeah. Just knowing that you can only get in from one way. I don't know, for the rest of us who come in from the Wyoming side, if you don't —a lot of people just frown, yeah, we'll go somewhere else, do something else. But then, again, you're getting further east, Billings —Bozeman a lot snowmobiling, west side of the state a lot of snowmobiling but once you hit Bozeman —or Billings, it's a lot of people but the drive is so drastic that they'll make the loop all the way around just to pull a four place enclosed in so that the kids or whatever can come too.”

Below are examples of those who would rather have it plowed during the winter:

2 Williston, ND snowmobilers: “If the groomer would be out, it'd be better. Either plow the road or groom it, one or the two.”

5 Iowa Snowmobilers: “That sure would be nice. I mean, just to be able to —Well, it's nice — But then you would ride on unless you have trail on the side of the road, which if they had that, then that would be all right. Then we could drive all the way in here. You might get the people in here that you wouldn't want, though, then. This time year, would you get everybody here? It would have been nice for us if we drove our trailers straight in here. You might get more people

here which would be less appealing because you want the fresher snow. You don't want it to be all tracked. If that were the case, they would have more parking here to park all the trailers.”

Snowmobile couple from Williston, ND: “It would make it easier for us and everybody else if it was plowed. A lot of the guys do drive around just because all their tools are in their trailers and shit. For 8 years, 10 years, we've been (parking at) Pilot Creek and riding in. This is the first time we've driven. For us it would definitely be easier. Yeah, if they plowed the snow, that would be a plus. That would be a major plus. It would cut off an hour and a half, two hours.”

In summary, it appears as if most visitors would like the road to stay how it is, unplowed. A number of groups cited the problem of the amount of traffic and trailers that would be in Cooke City and the lack of space to store them. While others stated that it would be nice, there were reservations as to how it would ultimately change the area. In general, keeping the road unplowed is preferable for almost all group of respondents in this study.

Conclusions & Implications

Conducting this study in the Beartooth region provided interesting and useful insights into how snow machine visitors connect with the place, changes they would recommend, and issues on road access. The winter Beartooth Highway caters to snowmobilers and snowmobiler recreation groups.

The level of specialization in the Beartooth region among those who are participating in snowmobiling activity seems to be very high. Due to the settings and conditions of the place, especially steep terrain, experience is a necessity. Avalanche dangers are high and the mountains are extremely steep. Some groups had inexperienced riders in their group. Only one group classified themselves as novice snowmobilers.

Contrarily as results indicate, the snow machine recreationists in the Beartooth region generally did not have a high level of connection with the place itself. Most were connected to the current snow conditions more than the place. With that said, the place became more important to them and provided more satisfaction if the snow conditions were above average. Convenience, snow conditions, and distance from home appeared to be more important than the more tangible characteristics of place.

This is an interesting insight into what drives a recreationist to visit a destination in the winter season. Many groups stated that they “chase the snow” and visit destinations that recently have had large snowstorms. During these interviews, the Beartooth region hadn’t had as much snow as originally thought, so many groups talked about the poor conditions of the trails.

Because snow appears to be the driving factor for destination choice, managing for and marketing to visitors is difficult. Snow conditions are extremely variable and unpredictable in nature. Providing a satisfying experience to the visitor appears to be complex if the conditions for their activity are not met. However, visitors did enjoy that there were a variety of social activities to participate in during the evening if conditions were not ideal.

As for recommendations for change, the Beartooth Area is already providing a satisfying experience to most visitors. To further enhance this experience, trail markings and size of riding area were two areas of focus that could be looked at in-depth. Because of the Wilderness boundaries, expanding the riding area is unlikely to occur. Managing for larger numbers of users may have to be part of planning discussions in the future. Trail markings appear to be complicated to understand and rather vague. Visitors stated that a more efficient method of marking trails that distinguishes one experience level from another would enhance their riding experience. Even though the more experienced riders do not tend to ride on trails very often, route finding and accessing the desired riding areas could be improved by marking trails with a classification system and route maps.

Finally, road access appeared to be a non-issue for most visitors. In fact, the vast majority of visitors preferred that the road be left closed due to traffic, parking, and experiential issues. Parking in Cooke City is already limited and many visitors stated that if the road was opened, there would be nowhere to park the large number of trailers currently parked at Pilot Creek. On any day, over 50 trucks plus trailers can be parked at the Pilot Creek parking area. A few groups indicated that traffic along the road would be less than ideal for riding to the trailheads if the road were plowed. Also, the solitude and remoteness of Cooke City is a key characteristic of the region and the experience.

In summary, the Beartooth region appears to be a destination that is preferred due to its vast amount of snow, steep terrain, and remote location. Visitors enjoy the “rustic and real” feel of the town and do not wish to see many changes to the region. The changes they do wish to see would be an expanded riding area and better trail markings. Road access does not appear to be an issue and the large majority of visitors prefer it to be left the way it is during the winter season. Snow machine winter recreationists do not appear to have an intense connection with the place, but do have a connection with their specific activity - snowmobiling.

Implications

1. Snow machine winter recreationists do not have a deep connection with the place itself. Their connection is with the quality and quantity of the snow. Those who promote and advertise snowmobiling in and around the Cooke City area would be wise to be honest about the snow conditions when asked by snowmobilers. This provides for a more satisfied visitor who will return because they know they are getting the truth. Perhaps

Cooke City could devise a snow condition scale from 1 to 10 based on pre-set variables. Each day, the chamber of commerce could adjust the number based on input variables and post it to a website. Along with the snow condition scale, Cook City can promote their terrain and remoteness of the Beartooth Mountains. This information would best suit the visitors who frequent the area and potential new visitors.

2. Trail markings and increasing the size of the riding area appear to be the most desired improvements in the Beartooth region.
3. Most visitors would prefer that the highway not be opened during the winter season because of traffic issues, parking and congestion that would result in the community of Cooke City. It would also call to question the quality of the experience in the region. Some may not return because the experience would change too much for their liking.
4. Since the Beartooth region is considered “substitutable” for many of the snow machine riders, promoting the snow quality, terrain, and location of the Beartooth Mountains is even more important than previously thought. If it doesn’t already occur, establishing an email list of snowmobilers and sending out ‘new snow’ announcements to the list could encourage riders to come to the Cooke City area over other areas.
5. Snow machine users from the mid-western states were well represented throughout the Beartooth region. If the Cooke City area would like to have more outdoor recreation participation, marketing to the Midwest is likely to encourage more visitors. These are folks who enjoy winter and cold temperatures. They do not have mountains in their backyard, so a place like Cooke City would be intriguing to them. Marketing to regions that are not well represented (Pacific Northwest, Southwest) may be a more difficult task. These people have mountains nearby and the cold temperatures experienced in the Beartooth region may deter some from finding Cooke City a desirable destination. It is imperative to describe the unique atmosphere of the Cooke City area to potential visitors west of the divide.

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Appendix A: Interview Guide

Hello, my name is Jake Jorgenson and I am from the University of Montana. I am a graduate student and I am interviewing people recreating in the winter season about their time spent here. Would you be willing to take time to give thoughts and feelings about winter recreation in this area? The interview will take only 20-30 minutes and your answers will be kept anonymous. If it is alright with you, I will be using a tape recorder for this interview to be able to go over my thoughts once I return home. Thank you for your time!

Purposes:

- 1) Assess the idea of “sense of place” among winter recreationists in the Beartooth region.**
Understand the ideas of place dependence, place attachment, social bonding, and place identity.
- 2) Uncover whether changes in region would affect the feeling and/or ability to recreate in the Beartooth region.**
- 3) Understand the choice of recreating in the Beartooth between first-time visitors and return-visitors.**
- 4) Understand Yellowstone’s connection to the Beartooth during the winter season.**

Starting questions:

What did you do today in the Beartooth region? What activities?

How often do you participate in the activity you did today? **Probe:** How often do you visit the Beartooth region for your winter recreation? Do you ever visit the region outside of the winter season? What other activities did you participate in on this particular trip?

Are you participating in any activities inside of Yellowstone National Park during your trip? **Probe:** Why/Why not? Are you visiting any other destinations on your trip?

Research questions: Place Dependence/Attachment/Identity/Social Bonding

1. Why did you choose to the Beartooth region for your trip? **Probe:** Anything else?
2. If there was one reason why you would choose to visit this region, what would it be? Why?
3. How is the Beartooth region different from other areas you recreate in? **Probe:** How is it the same?
4. Why did you choose to come to and stay in Cooke City during your trip? **Probe:** Is it different than other towns you would stay in for recreation? Why? How?
5. How would you describe the importance of recreating here to your personal life? **Probe IF RECREATE in other areas:** What about the other areas you recreate in?

6. Who did you travel with to the Beartooth region **Probe:** Do you normally recreate with these people? Why?

7. Think of a time and place in the Beartooth region that is memorable, special or meaningful to you. Think of the sights, sounds, and smells associated with that time or place. Why is it memorable, special, or meaningful? **Probe:** Can you explain in more detail?

8. Some people say that Cooke City is a relaxing feeling during the winter and others say it is a hectic and crowded feeling. What are your opinions on how the Beartooth region makes you feel when you visit?

9. If the Beartooth region was not here, how would your recreation needs be filled? **Probe:** Would another place allow you to have the same experience?

10. In your opinion, are there any changes you would like to see in the Beartooth region? If those changes occurred, how likely would they influence your travel plans or how often you visit the region? If they didn't occur?

If first time visitor: Has the Beartooth region met your expectations you had before you visited? Are they positive or negative? What were your expectations? How would changes in the region affect your choice to return to here for winter recreation?

If repeat visitor: Have you noticed any changes in the Beartooth region over the years you have visited here? Are they positive or negative changes? Have these changes affected your experience?

Thank you for your time! That's all the questions I have today. Your answers will remain anonymous and confidential. This research will go towards making the best experience for visitors in the Beartooth region.

PERSPECTIVE

Protect large trees for climate mitigation, biodiversity, and forest resilience

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Abstract

Protecting the climate system requires urgently reducing carbon emissions to the atmosphere and increasing cumulative carbon stocks in natural systems. Recent studies confirm that large trees accumulate and store a disproportionate share of aboveground forest carbon. In the temperate forests of the western United States, a century of intensive logging drastically reduced large-trees and older forest, but some large trees remain. However, recent changes to large tree management policy on National Forest lands east of the Cascade Mountains crest in Oregon and southeastern Washington allows increased harvesting of large-diameter trees (≥ 53 cm or 21 inches) that account for just 3% of all stems, but hold 42% of total aboveground carbon. In this article, we describe synergies with protecting large trees for climate mitigation, biodiversity, and forest resilience goals to shift species composition, reduce fuel loads and stem density, and adapt to climatically driven increases in fire activity in eastern Oregon.

KEYWORDS

aboveground forest carbon, biodiversity, climate change, eastern Oregon, large trees

1 | INTRODUCTION

Society has a narrow window of opportunity left to avert catastrophic consequences from the intertwined climate and biodiversity crises (IPCC, 2022), and forests offer major solutions at the intersection of these urgent imperatives. Forests account for 92% of all terrestrial biomass globally (Pan et al., 2013), store about 45% of the total organic carbon on land in their biomass and soils (Bonan, 2008), and removed the equivalent of about 30% of fossil fuel emissions annually from 2009 to 2018, of which 44% was by temperate forests (Friedlingstein et al., 2019). Moreover, forests provide critical habitats to

more than half of all known plant and animal species on Earth (Gibson et al., 2011; Vié et al., 2009). As climate change increases and accelerates amplifying feedbacks, preserving species- and carbon-rich forests becomes ever more important, alongside a rapid transition to net-zero fossil fuel CO₂ emissions (Matthews et al., 2022).

Forests of the western US contain large stocks of carbon and remove significant quantities of CO₂ from the atmosphere to help protect climate, biodiversity, and water security (Buotte et al., 2020; Law et al., 2021). But how we manage these forests will play a large role in determining future outcomes (Fargione et al., 2018; Hudiburg et al., 2009; Law et al., 2018). Oregon stands

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out with the most forested area in the western USA, yet the lowest proportion of its forests protected (Law et al., 2021), and significant opportunities to create strategic forest reserves (Law, Berner, et al., 2022). About 80% of tree mortality in Oregon and Washington is attributed to harvest (Berner et al., 2017). In this article we provide insights from a recent study that quantified large tree carbon stocks in diverse forests of eastern Oregon (Mildrexler et al., 2020), and describe synergies with protecting disproportionately valuable large trees for biodiversity and climate mitigation, and forest resilience goals.

2 | LARGE TREES DOMINATE ABOVEGROUND CARBON STORAGE

Trees capture and store massive amounts of carbon, thus forests are an essential component of limiting global warming to 1.5–2°C (IPCC, 2018). However, trees are not all equal in their capacity to slow climate change in the coming critical decades. Large trees play an inordinately large role in removing carbon from the atmosphere and storing it in long-lived tissues (Figure 1; Lutz et al., 2012; Leverett et al., 2021). Globally, studies have found that about half the aboveground carbon is concentrated in a small proportion of large trees (1%–5% of total stems) (Lutz et al., 2018; McNicol et al., 2018). Because most global forests are well below their potential carbon stocks due to past and current land management practices, they could store twice the carbon than now (Erb et al., 2018). As large trees grow larger, small increases in diameter add a relatively large amount of volume and biomass (Mildrexler et al., 2020; Stephenson et al., 2014). Protecting existing forests with large trees and letting more forests mature and develop additional large trees is crucial for preventing carbon emissions and for continued

accumulation of carbon from the atmosphere in the coming decades (Birdsey et al., 2023; Law, Moomaw, et al., 2022; Moomaw et al., 2019).

2.1 | The 21-inch rule and carbon stocks

Forests in eastern Oregon and southeastern Washington are recovering from a century of intensive logging that eliminated much of the region's large trees by selective harvest of the largest, most robust trees including clear-cutting older forests. Nevertheless, the United States Forest Service (USFS) recently weakened protection for trees 21 inches diameter at breast height (DBH) and larger ("21-inch rule") across six national forests in this region. The 21-inch rule specifically applied to large-diameter trees on millions of acres of federal public lands. To assess the consequences of the loss of these trees it is essential to quantify large tree carbon stocks prior to changes in management actions. Mildrexler et al. (2020) evaluated carbon storage in large-diameter trees across the six national forests located east of the Cascade Crest in Oregon and Washington ("eastside forests") (Figure 2). Specifically, we quantified the relative contribution of large trees (≥ 21 inches DBH) to aboveground carbon (AGC) storage based on analysis of 636,520 trees on 3335 USFS Forest Inventory & Analysis (FIA) plots, and also assessed the carbon implications of relaxing the 21-inch rule. In these forests, large trees compose a small fraction of total stems (2.0% to 3.7% of all stems among five dominant tree species) yet hold 33% to 46% of total AGC stored by each species (Figure 3). The very largest trees, >30 inches DBH, held an even greater proportion of carbon (16.6%) relative to their small numbers (0.6%) demonstrating the importance of letting large trees grow larger and accumulate more carbon. Our research contributes to growing recognition that forests with large trees play a



FIGURE 1 Large-diameter grand fir (*Abies grandis*) in a mesic, mixed-conifer forest of northeast Oregon. These carbon-rich forests have a large cooling effect on maximum temperatures, provide thermal refugia for biodiversity including sensitive species, and are a high priority for protection. Large grand fir form the best hollow trees for wildlife (Rose et al., 2001).

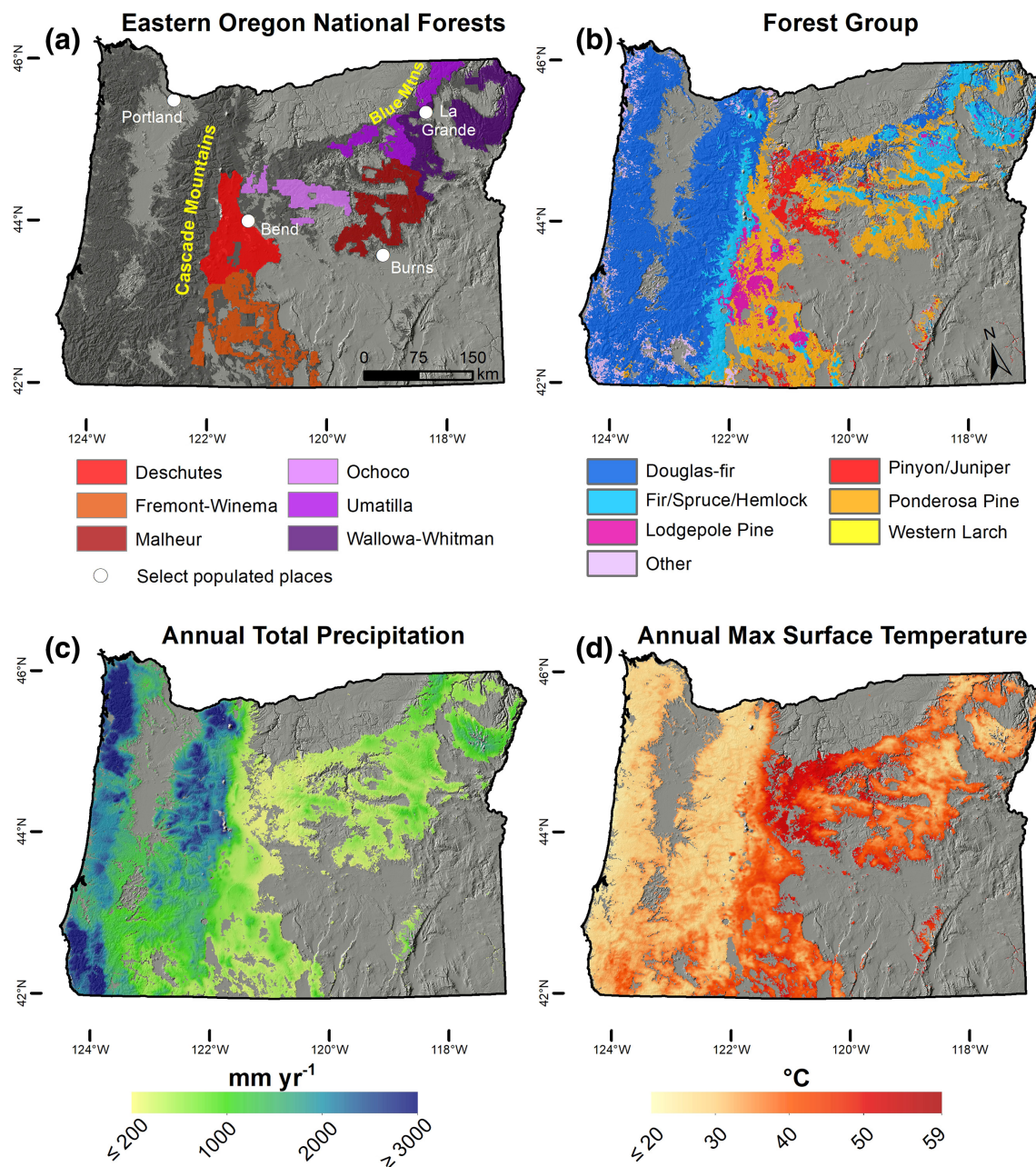


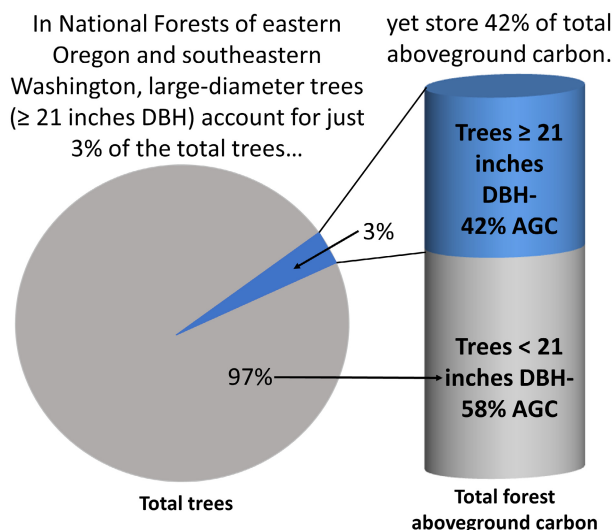
FIGURE 2 Forest and climatic diversity across the state of Oregon. (a) Extent of National Forests in Eastern Oregon. (Note a small portion of southeastern Washington included in our original study is not shown in this figure). (b) Distribution of forest groups. (c) Mean annual total precipitation from 1981 to 2010. (d) Mean annual maximum land surface temperature [LSTmax] from 2003 to 2020. Data sources include forest groups from Ruefenacht et al. (2008), precipitation climatology from Daly et al. (2008), and annual LSTmax derived using MODIS Aqua satellite data from Wan (2014).

very important role in climate mitigation now and in the near future (Lutz et al., 2018; Stephenson et al., 2014).

2.2 | A wildlife protection measure with a crucial carbon co-benefit

The 21-inch rule was implemented in the early 1990s as a habitat and species protection measure to recover large

tree structure and to protect remaining late successional and old-growth forest and associated species (e.g., American Marten, Northern Goshawk) (Bull et al., 2005; Bull & Hohmann, 1994; Henjum et al., 1994), similar to the Northwest Forest Plan (NWFP) that was implemented to ensure persistence of old-growth forest species and their habitat in the western portion of the region (FEMAT, 1993). The NWFP resulted in a strong carbon benefit for climate mitigation, in addition to protecting sensitive species and riparian



Species common name	% of total species trees ≥ 21 inches	% of total species AGC in trees ≥ 21 inches
Douglas-fir	3.7	37.5
Engelmann spruce	2.4	34.7
Grand fir	2.0	38.4
Ponderosa pine	3.7	45.8
Western larch	2.8	33.3
Overall	3.1	42.2

FIGURE 3 Percentage of all tree stems above and below the 21-inch DBH threshold and their total aboveground carbon (AGC) stores overall, and for five dominant tree species, evaluated based on measurements from USFS inventory plots located in the six eastside national forests.

systems (Turner et al., 2011). Mildrexler et al. (2020) showed that carbon storage associated with the 21-inch rule on the six eastside national forests is a significant co-benefit of this protective measure (Pörtner et al., 2021).

Detailed analysis of stand structure and carbon impacts is essential for science-based decision-making about large-tree forest management policies because such policies affect many different values and services provided by forests (Davis et al., 2019; Teich et al., 2022), including consequences on greenhouse gas emissions and for increasing atmospheric carbon removal and accumulation in forests (Fargione et al., 2018; Griscom et al., 2017). Moreover, large live trees eventually create large-diameter snags and downed wood that continue to store carbon for decades and contribute directly to biodiversity by providing unique specialized habitats such as hollow trees and logs, and micro-environments (Lutz et al., 2021; Rose et al., 2001). However, the USFS General Technical Report on the 21-inch rule did not assess large tree carbon stocks (Hessburg et al., 2020), even though storage and accumulation of carbon in forests is an increasing priority in National Forests (Depro et al., 2008; Dilling et al., 2013; Dugan et al., 2017). Consequently, quantitative assessments of management effects on both forest carbon and biodiversity are important, including assessment of the effects of long-standing rules before they are eliminated or weakened (Mildrexler et al., 2020).

The 21-inch rule has since been amended. Grand fir (DBH ≥ 53 cm and < 150 years) has lost protections in stands not designated as Late and Old Structure, and protections for all tree species have been significantly weakened from a standard to a guideline (USDA, 2021). This represents a major shift in management of large trees across the region, highlighting escalating tradeoffs between goals for carbon sequestration to mitigate climate change, and efforts to increase the pace, scale, and intensity of cutting across national forest lands. The potential impacts of removal of large grand fir on wildfire

are unclear, although a trait-based approach to assess fire resistance found that the grand fir forest type had the second highest fire resistance score, and one of the lowest fire severity values among forest types of the Inland Northwest USA (Moris et al., 2022).

3 | ARE LARGE GRAND FIR OUTCOMPETING LARGE PONDEROSA PINE AND LARCH?

The key rationale for amending the 21-inch rule is that increased cutting of large-diameter fir trees (≥ 53 cm DBH and < 150 years) is needed to facilitate the conservation and recruitment of early-seral, shade-intolerant old ponderosa pine (*Pinus ponderosa*) and western larch (*Larix occidentalis*) by reducing competition from shade-tolerant large grand fir (*Abies grandis*) (USDA, 2021). Previous studies have looked at tree age-size relationships (Merschel et al., 2019; Perry et al., 2004), large tree numbers, and changes in basal area (Hessburg et al., 2022), but there has been no spatial analysis of close-range comingling of large-diameter tree species across the six national forests covered by the 21-inch rule. This is an important consideration because the competitive interaction among large-diameter trees, and their protection under the 21-inch rule, should not be conflated with small tree dynamics and common dry forest restoration strategies to reduce small tree density and favor retention of early-seral species.

We therefore examined how often large trees (≥ 53 cm DBH) of these species co-mingle on USFS FIA plots (~ 1 acre) across the same six eastside national forests where we previously examined carbon storage by large trees (Mildrexler et al., 2020). Drawing on the same USFS FIA measurements as our prior study, we found that large ponderosa pine, grand fir, and western larch were present

TABLE 1 Coverage, mean annual precipitation from 1981 to 2010, and mean annual maximum land surface temperature from 2003 to 2020 for the major FTG's within the six national forests, standard deviations in parenthesis (excludes lands in Washington and Idaho).

Forest type group	Area (km ²)	Mean annual precipitation		Mean annual maximum LST	
		mm	in	°C	°F
Douglas-fir	2372	679.9 (187.3)	26.8 (7.4)	37.8 (3.5)	100.1 (6.3)
Fir/Spruce/Hemlock	12,224	974.3 (369.5)	38.4 (14.5)	33.2 (2.8)	91.8 (5.0)
Lodgepole pine	3573	822.0 (274.6)	32.4 (10.8)	37.2 (3.8)	99.0 (6.8)
Pinyon/Juniper	634	329.5 (96.0)	13.0 (3.8)	50.4 (3.7)	122.7 (6.6)
Ponderosa pine	18,514	548.3 (139.2)	21.6 (5.5)	39.8 (3.5)	103.6 (6.3)
Western larch	47	746.9 (78.9)	29.4 (3.1)	31.5 (2.4)	88.7 (4.3)

on 56%, 18%, and 7% of all plots ($n = 3335$). Large ponderosa pine co-mingle with large grand fir about 14% of the time (259 plots), leaving 86% of plots with large ponderosa pine without large grand fir (1616 plots). Similarly, large western larch co-mingle with large grand fir about 56% of the time. Large ponderosa pine and grand fir are found together on only 8% of all plots in the region, while large larch and grand fir are found together on only 4% of all plots in the region. In other words, large ponderosa pine are by far the most common tree species found in these six National Forests and infrequently co-mingle with large grand fir at the FIA plot scale, whereas large western larch are far less common and co-mingle with large grand fir about half the time, which is expected since these species occupy similar environmental settings that receive more moisture (Table 1, Johnson & Clausnitzer, 1992).

The relative prevalence of large ponderosa pine in eastside forests is good for climate resilience given that large-diameter pines are exceptionally drought and fire-resistant trees (Irvine et al., 2004; Irvine et al., 2007). In the drought-prone region of central Oregon, mature and old ponderosa pine forests had 60% to 85% higher seasonal gross photosynthesis than a young forest (Irvine et al., 2004). Large ponderosa pine trees experienced only 34% mortality in moderate severity fire, and accounted for 91% of post-fire stemwood production, while small trees experienced 82% mortality (Irvine et al., 2007).

Across the entirety of all six national forests large grand fir represent 2% of the total species population, a proportion slightly lower, but roughly on par with other dominant species (Figure 3, Mildrexler et al., 2020). It is not uncommon for grand fir to reach 250 to 300 years of age (Howard & Aleksoff, 2000). Thus, large grand fir ≥ 53 cm DBH and <150 years of age can continue growing and play an important role in storing and accumulating carbon from the atmosphere to help abate the climate crisis.

Synergy: Enhancing forest resilience does not necessitate widespread cutting of any large-diameter tree species. Favoring early-seral species can be achieved with a

focus on smaller trees and restoring surface fire, while retaining the existing large tree population.

4 | LARGE TREES, VULNERABILITY, STAND DYNAMICS, AND THE CARBON COST OF THINNING

As eastside forests recover from a century of intensive logging, it is important to distinguish between the shift of AGC stocks into small-diameter, fire-sensitive trees and the retention of a small fraction of the largest more fire-resistant trees that store disproportionately massive amounts of carbon. Small tree carbon stores are relatively unstable and at risk of loss to fire and drought, whereas large tree carbon stores are relatively stable and resistant (Hurteau et al., 2019). Physiological-based studies in ponderosa pine forests of Oregon have found that small trees are most vulnerable during drought relative to mature trees that have reached full root, bark and canopy development and respond to climate variability better than smaller trees (Domec et al., 2004; Irvine et al., 2004; Vickers et al., 2012). Buotte et al. (2019, 2020) identified forests in the western U.S. with high potential carbon accumulation and low vulnerability to future drought and fire using the Community Land Model and two climate models with high CO₂ emissions (RCP8.5), and species-specific traits capturing sensitivity of different species to water limitations and to drought and fire. The Eastern Cascades and Blue Mountains contain substantial area with opportunity to enhance forest carbon in large trees (Buotte et al., 2020; Law et al., 2018).

In dry forests historically maintained by a frequent, low-severity fire regime, the priority ought to be restoring the process of periodic surface fire. Prescribed fires create landscape heterogeneity, reduce surface and ladder fuels, lower stand density, and confer drought resistance to surviving trees (Knapp & Keeley, 2006; van Mantgem et al., 2016). In

these forests prescribed fire can modulate future fire activity (Schoennagel et al., 2017), and favor early-seral species such as ponderosa pine, western larch and Douglas-fir. Large trees of these species and grand fir are resilient to prescribed fire because they have attained the thick bark that provides resistance to low- and moderate-severity fire (Howard & Aleksoff, 2000; Pellegrini et al., 2017).

Thinning also has an inherent carbon cost that increases as larger trees are harvested, thereby putting thinning of larger trees in conflict with carbon goals because it takes so long to replace the harvested biomass (James et al., 2018; Law & Harmon, 2011). The underlying principle for these losses is the negative relationship between harvest intensity and forest carbon stocks whereby as harvest intensity increases, forest carbon stocks decrease and emissions increase (Hudiburg et al., 2009; Mitchell et al., 2009; Simard et al., 2020). Claims that carbon stores will be “stabilized” by increasing harvest of large-diameter trees that store and accumulate the most carbon (Johnston et al., 2021) are inconsistent with basic science on thinning (Zhou et al., 2013) and the carbon cycle (Campbell et al., 2012; Law et al., 2018). These claims ignore the large amounts of CO₂ rapidly released to the atmosphere following harvest (Hudiburg et al., 2019), and that large trees cannot be replaced in short timeframes. It can take centuries to reaccumulate forest carbon stocks reduced by harvest of large trees (Birdsey et al., 2006).

Even thinning smaller trees involves substantial carbon tradeoffs in the short term, a 30%–40% reduction in live tree carbon stores in some forests (Krofcheck et al., 2017; North et al., 2009). To minimize reductions in carbon stocks and emissions, focus on removing smaller-sized trees, restoring surface fire, and managed wildfire in favorable weather conditions (Mitchell et al., 2009; Stenzel et al., 2021).

Synergy: Small trees are more relevant to drought and fire vulnerability and store less carbon, whereas large trees are more resilient to fire and drought and are the highest priority for keeping carbon in the forest.

5 | DIVERSE CLIMATE REGIMES AND FOREST TYPES REDUCE CLIMATIC EXTREMES

It is critical to accurately represent the diversity of climatic regimes and forest types in decisions affecting large tree management because large trees play unique roles in ecosystem water and energy cycles, and these biophysical effects can promote local climate stability by reducing extreme temperatures in all seasons and times of day (Lawrence et al., 2022). Forest modulation of summer maximum temperature is especially powerful (Mildrexler et al., 2018) and can partly offset the projected increases in temperature due

to anthropogenic climate change (de Frenne et al., 2019). With heatwave frequency and severity projected to increase, the capacity of forests to buffer against temperature extremes and provide refugia is increasingly recognized as important to sustaining biodiversity in a warming world (Davis et al., 2019; de Frenne et al., 2019).

The six eastside national forests affected by the 21-inch rule cover a region of pronounced geographic and climatic variation and associated forest types (Figure 2; Johnson & Clausnitzer, 1992; Wyatt, 2017). Mean annual precipitation varied from 484 to 571 mm per year on the Ochoco and Malheur National Forests, to ~800 mm per year on the Deschutes, Umatilla and Wallowa Whitman National Forests (Mildrexler et al., 2020). We further examined the climatic regimes of the major forest types across the six national forests using satellite-based annual maximum land surface temperature (LST_{max}) and mean annual precipitation datasets (Figure 2D, Table 1). Our analysis shows that ponderosa pine and fir/spruce/hemlock types cover the largest area on the six national forests. The fir/spruce/hemlock type received the most total precipitation (~974 mm yr⁻¹) and had the second lowest annual LST_{max} (33.2°C). Average LST_{max} for the fir/spruce/hemlock type was 6.6°C (~12 °F) cooler than ponderosa pine (39.8°C), and 4.6°C (~8 °F) cooler than Douglas-fir (37.8°C). The pinyon juniper type had the lowest total precipitation (329 mm yr⁻¹) and highest annual LST_{max} (50.4°C) due to low canopy cover and heating of the dry surface during summer. These results show the region's pronounced variability in hydrologic and forest thermal regimes and highlight the thermal offsetting capacity of closed-canopied mesic forest systems. These valuable ecosystem services can be severely degraded by industrial logging (Lindenmayer et al., 2009).

Synergy: Mature and old mesic forests are a high priority for protection, provide crucial biophysical benefits on climate, including a large cooling effect on maximum temperatures regulating climate extremes and protecting biodiversity. Large grand fir is essential to this ecology.

6 | CONCLUSIONS

The 21-inch rule is an excellent example of a policy initiated for wildlife and habitat protection that has also provided significant climate mitigation values across extensive forests of the PNW Region. The rule resulted in a valuable resource of large-diameter trees in a landscape that remains below historical levels for large live trees and large snags due to historical logging (Bell et al., 2021). We have described synergies between protecting these disproportionately valuable large trees and forest resilience goals, providing common potential solutions for these urgent challenges.

Inland PNW forests can make a significant contribution to climate mitigation goals by protecting and enhancing carbon stores in large trees that accumulate and store the most carbon and are much more resistant to fire and drought than small trees, even when the current status of ecosystems has changed from historical baselines. Climate science makes clear that we do not have time to wait for regrowth after logging to accomplish these important ecosystem services (IPCC, 2022).

AUTHOR CONTRIBUTIONS

David J. Mildrexler led the writing. David J. Mildrexler and Logan T. Berner performed data analysis, investigation, and visualization. All authors commented on drafts, and assisted with writing, review and editing. All authors gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

This study relied on data from prior studies that are publicly available: Forest Inventory Data from the United States Forest Service (<https://apps.fs.usda.gov/fia/datamart/datamart.html>), MODIS Land Surface Temperature data from the Land Processes Distributed Active Archive Center accessed through Google Earth Engine, and gridded precipitation climatologies from Oregon State University PRISM Climate Group (<https://prism.oregonstate.edu/normals/>).

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Searching for a needle in a haystack: evaluating survey methods for non-indigenous plant species

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Abstract

The control and management of non-indigenous plant species (NIS) can be conceptually divided into three phases: inventory/survey, monitoring and management. Here we focus on phase one, determining which species are present and where they are located within the environment. Sampling for NIS is inherently time-consuming and thus costly. Many management areas are large and therefore can only be surveyed (partial observation of the total area by sampling) and not inventoried (total observation of area). Survey data should reflect the spatial distribution of the target species populations over the landscape. Such data can then be used in combination with environmental data, to create probability maps of target species occurrence for the entire area of interest. We used a GIS model to evaluate seven different survey methods for consistency and reliability of intersecting NIS species' patches and producing samples which reflect the spatial distribution of the population, and which can be performed in a cost and time-efficient manner. The GIS model was developed to create NIS populations which were then sampled using the different survey methods, and the results recorded. To improve the applicability of the model, four patch sizes and levels of occurrence were used, along with random and weighted distribution patterns in relation to patch proximity to roads and trails. Grid and random points, and targeted (stratified continuous) transects (starting on a road or trail (rights of way (RoW)) and finishing 2 km from any RoW) methods provided the most consistent samples of the population. Logistically, point methods required an unrealistic distance and time commitment in comparison with transect methods. The importance of collecting information on the size of NIS patches was demonstrated as more small patches were intersected than larger ones when the area infested was held constant. Thus, if frequency of patches is used to explain the results of a survey then comparisons between species and methods are difficult to interpret thus leading to erroneous conclusions. However, use of percentage of area infested estimates provides for easier comparison between species and sample methods. The targeted transect method provided the most reliable, efficient and consistent sample with the expected spatial distribution.

Abbreviations: NIS – non-indigenous plant species; perp.RoW – perpendicular to rights of way transect survey method; RoW – rights of way e.g. roads and trails; SaD – Seek and destroy survey method; YNP – Yellowstone National Park

Introduction

Invasion of natural communities by non-indigenous plant species is a threat to native biodiversity and is currently rated as one of the most important global-scale environmental problems (Vitousek et al. 1996). Significant effort is expended to manage or eliminate non-indigenous plant populations in natural and semi-natural areas.

In the USA, the National Park Service is required by law to inventory the 34 million ha of Parks classified as 'natural areas' under their jurisdiction and to maintain these in a state as 'unaltered by human activities as possible' (US National Park Service 1996). Stohlgren et al. (1995) completed a report on the status of the inventory lists for flora and fauna of National Parks; they found that less than 80% of inventories were complete in taxonomic, geographical and ecological coverage. The sampling procedures varied between Parks and often provided just a list of species present in that Park. More recently there have been advances to ensure that data attributes of different studies are comparable (Cooksey and Sheley 1997; NAWMA 2002; Stohlgren et al. 2003).

There has been little work addressing the advantages and disadvantages of different sampling methods for large natural areas. Stohlgren et al. (1995) stated that there is "no off the shelf sampling design and technique for optimizing geographical, ecological and taxonomic completeness in biotic inventories. Trade-offs are inevitable." In this paper we evaluate seven sampling/survey methods for their relative ability to detect non-indigenous species (NIS). Much of the terminology surrounding NIS has emotive connotations and is loosely defined and confusing (Rejmánek et al. 2002). Terms such as 'invasive', 'weed', and 'exotic' are often used interchangeably; we use the term 'non-indigenous species' to represent all of these terms (see Maxwell et al. 2003 for definitions). Non-indigenous species are those that are not originally from the area of interest, they could be from a different continent or a different area of the same continent.

Management of NIS should be regarded as a three phase process: inventory/survey, monitoring and management. Although all three phases can

be performed simultaneously, considering them as different phases is important for conceptual, theoretical, methodological, logistical and practical reasons. The first phase, inventory/survey, determines which species are present and their distribution within the environment. The second phase, monitoring, provides information on how patches are changing with time, their impact on the ecosystem and the impact of management on the patch. Monitoring objectives define and constrain the objectives and methods for inventory/survey because they require locating sample populations across the widest possible set of environments which define the habitat for a species. The final phase, management, is important for control of non-indigenous patches and populations, by reducing their distribution and impact. This paper focuses on phase one, inventory/survey of NIS.

An inventory/survey is required to provide baseline information regarding which species are present and where, within an area. The 'where' should include information on both NIS presence and absence. For many natural areas it will not be possible to inventory the entire area. Therefore, a survey that obtains a representative sample of the population is required so that the frequency of the species in the area of interest can be determined. In addition, the survey protocol should collect information on environmental variables associated with both presence and absence of NIS, plus an approximation of patch size. Environmental data help to improve our understanding of factors affecting NIS occurrence (Stohlgren et al. 2003). Correlations between the environmental variables and NIS occurrence data can then be used to produce probability of occurrence maps of target species (Franklin 1995; Guisan and Zimmerman 2000; Rew et al. 2005).

The design of a sampling method for a survey depends on the objectives of the study. For example, if the objective is to 'seek and destroy' NIS, an approach that is biased towards areas perceived to have higher occurrences of such species would generally be chosen. If the objective is to evaluate the frequency and distribution of a species in the landscape, an unbiased approach should be used. In addition, if there is prior knowledge about a species distribution, or how the distribution is associated with particular

variables that are known across the study area, a stratified approach can be used (e.g. Fortin et al. 1989; Thompson 2002). If the intention is to use the survey data to develop probability of occurrence maps for the entire area of interest a stratified approach linked to empirical modelling can be employed (see Guisan and Zimmermann 2000, for review). However, even when NIS are widespread and occur locally at high abundance, they frequently are scarce when considering a whole landscape. In this case, when NIS have very low frequency in the environment, an adaptive cluster sampling method may be appropriate (Thompson 2002). In this paper we consider the question of sampling for NIS in a natural ecosystem; the same approach could be used for agricultural and rangeland situations or, for native plants that occur at low frequencies or with low density distributions.

Specifically, we evaluate sample methods for use when the study/management area is large and cannot be inventoried. To achieve this, a sampling methodology is required that is based on an understanding of plant distribution. The appropriate theories to guide sample design are drawn from an understanding of the geographical structure and ecological organization of plant communities. There are two general categories of theory. The more prevalent category is based on the view that plant communities are groups of interacting species whose presence, absence, or even relative abundance can be deduced from “assembly rules” which are based on the functional roles of each species (inherently defined ecological niches) (Levins 1970; MacArthur 1972; Diamond 1975; Weiher and Keddy 1999). According to this theory, species coexist in interactive equilibrium with the other species in the community. The stability of the community and its resistance to invasion are derived from the adaptive equilibrium of member species, each of which has evolved to be the best competitor in its own ecological niche (i.e. niche separation). The theory assumes that the species which co-occur within a community are determined by interspecific competition for limited resources and other biotic interactions. That is, species distributions follow Gaussian curves but the curves overlap in environmental space. The other general theory that has emerged to explain community structure is based on an assumption that

communities are open, non-equilibrium assemblages of species largely thrown together by chance, history including genetic drift, and random dispersal (Hubbell 2001). Thus, this theory assumes that species come and go, their presence or absence is dictated by random dispersal and stochastic local establishment and extinction in environmental space. Hubbell (2001) called this the “Unified Neutral Theory” and contrasted it with the most prevalent theory described above, which he called the “Niche-Assembly Theory”.

If one considers the unified neutral theory as a null hypothesis then a first order determinant of NIS would be associated with dispersal. The second order determinant of NIS would be environmental variables, i.e. niche assembly theory. Both first and second order determinants would be subject to random factors. The mix of theories associated with plant distribution could be used to establish stratification of sampling.

Disturbance is often suggested as a key factor in enhancing the probability of non-indigenous plant establishment in plant communities (Grime 1979). The role of anthropogenic disturbances such as cultivation, trampling, domestic ungulates (Young et al. 1972; Mack and Thompson 1982; Tyser and Key 1988) and roads/trails (Tyser and Worley 1992; Parendes and Jones 2000; Trombulak and Frisell 2000; Gelbard and Belnap 2003; Watkins et al. 2003; Pauchard and Alaback 2004) and fire management practices (Godwin et al. 2002) are often seen as more influential than natural disturbances. Natural disturbances include soil disturbance by fauna, weather-related events including floods, wind damage and fires, and geological events such as landslides, mudflows and floods. Both anthropogenic and natural disturbance, depending on the intensity and extent, can destabilize the community equilibrium. Or, put another way they add noise to the metrics used to measure community stability such as relative abundance and frequency.

There is sufficient evidence to suggest that anthropogenic disturbances, particularly rights of way (RoW) (e.g. roads and trails) affect the distribution of NIS (Tyser and Worley 1992; Spellerberg 1998; Parendes and Jones 2000; Gelbard and Belnap 2003; Watkins et al. 2003; Pauchard and Alaback 2004). Therefore, in this study, we assume that the distribution of NIS

patches is weighted towards roads or trails, such that the abundance of patches increases as proximity to RoW increases. The weighted distributions were compared with random distributions. And, under both scenarios spatial dependence will be displayed at some spatial scale because of the geographic pattern of environmental factors or other spatial processes such as plant dispersal.

We evaluate one new design and six established survey methods for detecting NIS in natural ecosystems. The established methods are currently employed by land managers and scientific researchers. The methods were evaluated to determine the accuracy of the different approaches in terms of intersecting (detecting) target patches, how representative these data were of the population and, to compare the distance and time required to complete sampling in the field.

Materials and methods

A model was developed to evaluate seven different sampling methodologies using standard and adaptive sampling designs, on random and weighted distributions of four virtual NIS. The model has a simulation component and a sampling component. The simulation component creates distribution and abundance of the NIS. The sampling component implements the seven methods with standard and adaptive designs, to survey the NIS distribution and abundance. Evaluating these survey methods as they would be applied in the field is termed the standard sampling approach. The adaptive cluster sampling design was 'added-on' to the standard sampling approach. For clarity we will refer to the seven different sampling methods as survey methods; population will only be used in reference to the simulated 'true' population; a sample (of the population) will be used to refer to data produced

by an iteration of the simulation model using one of the survey methods; and a patch will be used to refer to a circular group of plants.

The simulation model was developed in ArcView (Version 3.2, ESRI, Inc). The area modelled was restricted to a randomly selected 10,000 ha area (10 km by 10 km) for computational speed. The area selected for the simulation was in the northern range of Yellowstone National Park (YNP), Wyoming, USA, since the most effective and efficient sampling method was to be used for an operational survey of this area. Environmental data, including the distribution of RoW, were available as data layers within the geographical information system (GIS) database in ArcView. RoW in the study area included about 12 km of primary road and 39 km of trails. No adjustment or allowance was made for elevation in the generation of the sampling points and transects.

Non-indigenous species abundance and spatial distribution

The four NIS distributions simulated provided a range of distribution and abundance patterns with regard to proximity to RoW, frequency in the study area and mean size of patch where present. To ensure that the simulated populations were representative of 'real' situations their parameters were obtained from field data collected in YNP during 2001 and 2002 (Rew, unpublished). The four species chosen to provide parameters for the virtual species simulations represent different NIS types and will be referred to as species A, B, C and D.

Parameters used in the model included patch extent (mean area), percentage infestation (calculated as area covered by patches/the total area surveyed) (Table 1) and a distribution weighting. The distribution weighting was created by fitting

Table 1. Number of patches and patch radii used in the model for species A–D, and the patch area, percentage area infested and circumference this achieved over the 10,000 ha simulation area.

Species	Total number of patches	Patch radius (m)	Area of one patch (m ²)	Area of all patches (ha)	Area infested (%)	Circumference of all patches (km)
A	15055	5.2	85.0	127.9	1.3	491.9
B	5033	10.2	326.9	164.5	1.6	322.6
C	1739	15.3	735.4	127.9	1.3	167.2
D	1220	41.1	5306.8	647.4	6.5	315.1

the patch-occurrence probability along a distribution curve relative to distance from RoW. The parameters used to generate the distribution curve were estimated from field data describing the distribution of NIS patches relative to RoW. The resultant simulated distributions are more densely populated in the areas proximal to RoW, and more sparsely populated in areas distant from RoW (Figure 1). This is consistent with using the dispersal vector as a first order process assumption (unified null hypothesis). The simulation model was run 100 times for each species, generating 50 random and 50 weighted population distributions.

Survey methods

Seven survey methods were used; one biased and six unbiased (Figure 2). The biased survey method reflects a method used by many land managers who use their knowledge of NIS distributions to develop a search pattern along RoW, particularly roads. We term this the 'seek and destroy' (SaD) approach. In the model this approach is performed along RoW, using transects. Of the six unbiased methods, one was systematic, two were totally random and the remaining three were random stratified on RoW or an environmental feature (Figure 2). The systematic method used a rectangular grid, and sampling was performed at the grid intersections. The five random, unsystematic methods included two totally random methods; random points and random walk. No limitations were placed on the pattern that the random walk transect could take, other than those required to keep the walking path within the study area. The three random stratified methods included two transect methods which were stratified on RoW. That is, transects started on a RoW, but the selection of the transect start points on the RoW was random. For the first of these methods the transect travelled perpendicular to the randomly located start position. This survey method was termed 'perp. RoW'. The start points for the second random-stratified method were established in the same way but it was ensured that transects ended 2 km from any RoW and the start location; these are termed 'targeted' transects. The third random-stratified method used transects stratified on

elevation contours, a technique used by some groups to reduce loss and gain of elevation when completing transects (S. Dewey, pers. comm.), and these were termed "contour" transects.

The total area surveyed within the simulation boundary was held constant at 20 ha for all methods. This represents 0.2% of the total area. The simulation employed a search radius of 5 m at grid intersections and for the random point method. A total of 2546 sample points were required to survey 20 ha. All of the other survey methods used transects which were 10 m wide and 2000 m long. For transects along rights of way (SaD) and elevation contours (contour) minor changes in the length of individual transects had to be permitted due to insufficient length of RoW or contours in some situations. The total area sampled was maintained at 20 ha for all transect methods. Overlap in the area surveyed was not permitted for point methods. No overlap was permitted for a distance of more than 10 m for transect methods. The 10 m overlap was permitted as some transect methods, particularly the random walk, were allowed to cross over previous survey lines. The positions of survey points for the grid method, contour and SaD had to be held constant between iterations as the small study area limited the number of configurations possible. The location of sample points/lines was random and changed for each iteration for all other methods.

The adaptive cluster design (Thompson 2002) was added to the standard survey methods, with the intent of evaluating the increased number of patches intersected when using such an approach. Assuming that presence of NIS patches is spatially autocorrelated, this strategy will gather more data at locations of NIS presence by expanding the search parameters in these areas. The adaptive procedure in the model applies an increased search radius of 50 m (in consecutive 10 m wide circles) around each NIS patch detected by the standard survey methods (Figure 3). The application of a 50 m search radius is iteratively applied to any subsequently detected NIS patches until no further patches are intersected within the search radius. The results of using the adaptive cluster design, in addition to the standard sampling design, were recorded as an independent dataset for each of the seven

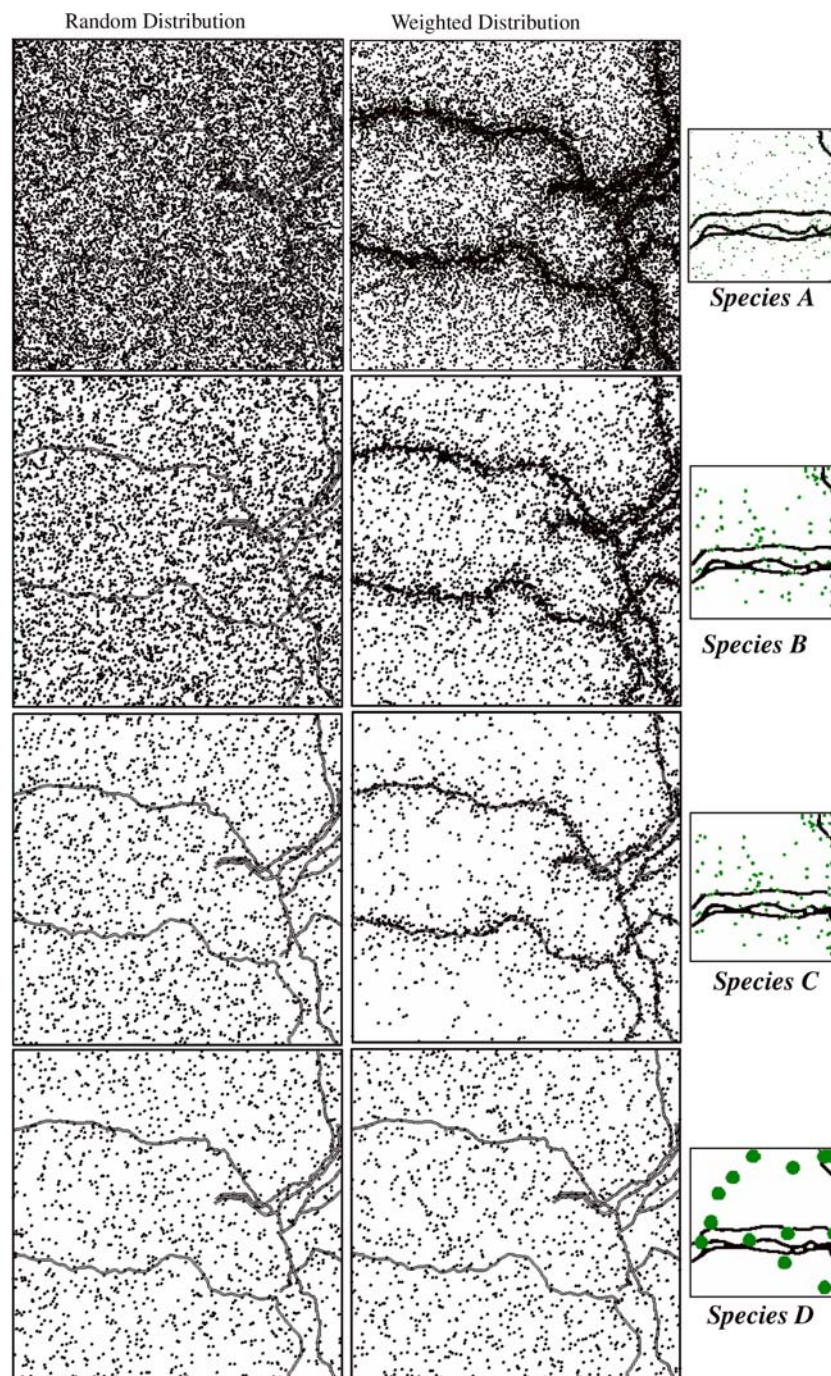


Figure 1. Example of the random and weighted distributions of species A–D used in the geographical information system model. Weighted distributions reflect species correlation with proximity to rights of way (shown by double solid lines). Thumbnails to the right hand side of the graphic depict the relative size of the different species' patches/populations and the different occurrence levels.

survey methods. The results of the standard and adaptive sampling design were evaluated independently.

Additional simulations were performed to demonstrate the effect of the four different patch radii on the number of patches intersected, when

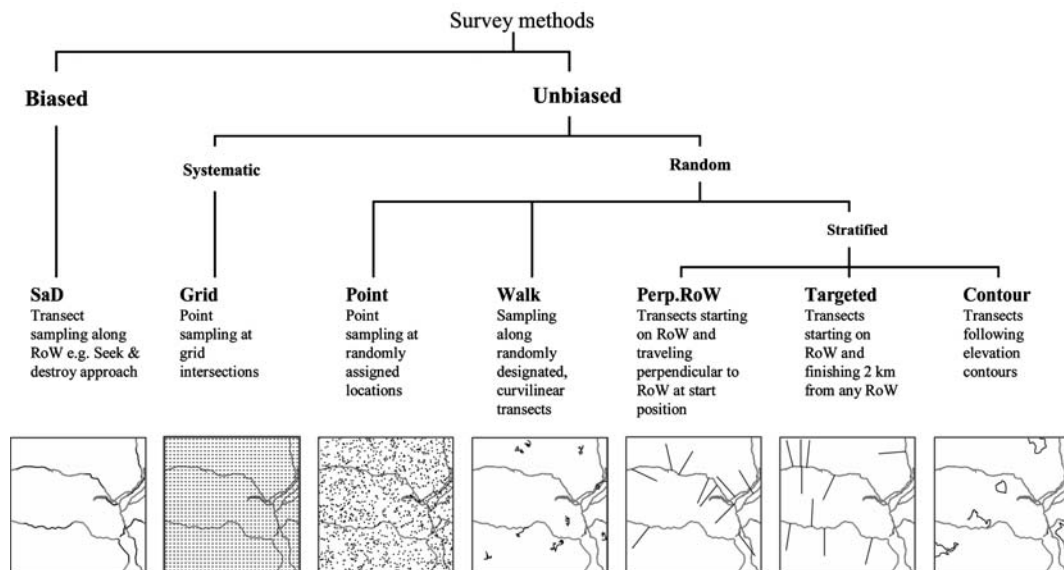


Figure 2. Hierarchical classification tree and diagrams of the seven survey methods evaluated for detection of non-indigenous species' patches using a geographical information system model. Titles given at the fifth level are the abbreviations used for the survey methods throughout the text. A 10 km × 10 km (10,000 ha) area was used in the model and rights of way (RoW) are represented by the light grey double solid lines. Dots represent the point sample locations; black lines the transects.

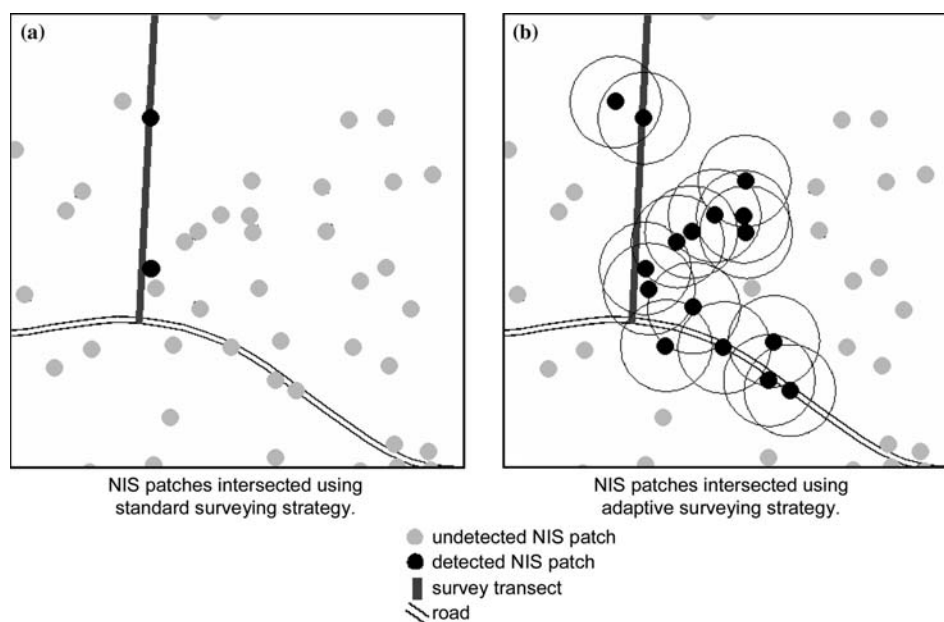


Figure 3. Example of the standard and adaptive sampling design employed in the simulation model for transect survey methods. The same approach was used for point survey methods (not shown). Non-indigenous species (NIS) are drawn to a significantly larger scale for visual clarity. The open circles represent 50 m radius adaptive search area.

the overall area covered by the four species' populations was held stable. The populations were then sampled using grid and targeted transect

survey methods. These additional simulations were only performed on random distributions and 50 iterations were run for each species.

Model output and analysis

The simulation model and all sampling methods were developed as a module (SampleMod) in ArcView 3.2 using the Avenue programming language. For each model iteration, SampleMod generated a new random and weighted NIS population distribution, as well as new sampling locations for each of the survey methods where possible.

For every iteration of the model each of the seven survey methods was applied and the number of target patches intersected by each method recorded. We could have designed the model only to count patches where all or the majority of the patch was within the sampled area (transect or sampling point). However, this is not how people sample in the field. Thus, patches were tallied in the results if any part of them was intersected by the survey transect or point. The simulated population mean (μ) and standard deviation (σ) of distance to RoW were calculated for each iteration, as well as the mean ($\bar{x}$) and standard deviation (s) of the patches intersected by each survey method. These statistics were recorded in separate tables for weighted and random NIS distributions using standard and adaptive designs, with separate records for each iteration of the model. Thus, survey methods which produced a $\bar{x}$ close to μ , and an s close to σ were considered superior to methods which obtained samples with greater differences between the population and sample statistics.

With each iteration of the model, the number of patches intersected, the mean and standard deviation of patch distance from RoW was recorded for each survey method. Distance to RoW was chosen as the characteristic measure for these comparisons, primarily because RoW was the principal disturbance factor upon which we were basing the distributions of our populations, and would thus yield the most reliable information about the similarity of the populations and samples.

Results from sampling with the different survey methods were evaluated in several ways. The number of patches intersected by each survey method was used to calculate a percentage frequency (using the number of sample points in grid and random point surveys); the percentage

of the sample area infested by the different number of patches was calculated using an average value for the proportion of each patch being intersected (this was derived using geometry). The distribution of the sample means with proximity to RoW was depicted graphically with box and whisker plots. A paired *t*-test was used to determine if the distribution of patches in proximity to RoW intersected with the targeted method, differed from samples generated using the other methods. Plus, the minimum distance to be travelled to reach all the survey sites for each method was measured using the survey locations depicted in Figure 2.

The least-cost paths to sample each of the survey points or transects was calculated for each of the survey methods. The least-cost/minimum distance path to connect all 2546 points/10 transects was calculated by creating polylines to connect each of the points/transects in ArcView GIS. The time taken to cover the least-cost paths was calculated assuming a walking speed of 1 km/h when sampling and 3 km/h when walking between sampling locations. All least-cost path estimates assume completing the entire survey in one period, rather than taking into account end-of-day return trips; and zero-gradient terrain, rather than taking topography and land cover into account. Thus, time and distance estimates are accepted to be underestimates of the true costs of applying these methods in the field, but apply equally to each method.

Analysis and display of data generated in SampleMod were performed in Arcview 3.2, S-Plus 2000 (Mathsoft Inc.), SigmaPlot 2001 (SPSS, Inc.) and Excel 2002 (Microsoft®).

Results

The point survey methods detected considerably more patches than the transect methods. As expected adding the adaptive sampling design to the standard sampling generally increased the number of patches intersected for all survey methods (Table 2). Additionally, when a species distribution is correlated more definitively with RoW (i.e. weighted distribution) the adaptive design combined with the SaD method would

be expected to show a dramatic increase in the number of patches intersected. This was true for the species A–C when using the SaD method, resulting in more patch intersections for those species compared with other transect or point methods. Similarly more interactions were made when using the SaD method plus adaptive sampling for Species B and C. Species D patches showed less correlation with RoW (Figure 1) and, as expected, the proportion of patches intersected did not show much, if any, increase when sampled with the SaD method or any method plus the adaptive design (Table 2).

Distribution of the samples

Sample data collected in a survey should reflect the distribution of the population, which in this model scenario is measured as proximity to RoW. When choosing a survey method one needs to know how well and how consistently sample data reflect the population distribution. In the simulation environment we know μ and σ of the population and the $\bar{x}$ and s of each sample. There were 50 samples (i.e. model iterations) for each survey method, and box and whisker plots were used to graphically depict these data and aid comparison between sample and population statistics (Figure 4).

Grid and point methods provided samples with similar mean and median patch proximity to RoW (i.e. narrow boxes and whiskers) as populations, for all species and both standard and weighted distributions (Figure 4). Samples generated using the targeted method also produced narrow boxes (representing 50% of the data) and whiskers (10th and 90th percentiles), and the outliers (all remaining data) were generally not spread far on the y -axis (proximity to RoW) (Figure 4). Samples from the random walk method provided a mean and median value similar to that of the population for all 50 iterations/samples but the length of the whiskers and position of the outliers demonstrate the variation between the samples for that method (Figure 4). This shows that although the random walk method can provide some samples with similar mean distance to RoW distributions as the population there is a lot of variability. This makes intuitive

sense, some random walks will traverse close to RoW, others will be in the backcountry, while many will traverse the full extent. Samples from the contour methods obtained mean and median values further from RoW than those of the population, and there was high sample variation. In contrast, samples collected using the perp.RoW transects systematically underestimated the median distance to RoW. The SaD method samples provided the narrowest box and whiskers of any method but the distribution of samples in relation to proximity to RoW did not reflect the population for any of the species. Thus, samples generated with the grid, point and targeted methods provided the least sample variation of all methods, with means and medians most similar to those of the populations of each of the virtual NIS.

Distance and time taken to complete surveys

The results above have shown that point and grid methods intersected more patches than transect methods, and that point, grid and targeted methods provided samples that most consistently represented the distribution of the population relative to RoW. However, there could be some logistical advantages of particular methods. Twenty hectares were sampled by each of the survey methods. The additional distance to be traversed to link all the sample points or transects together was calculated assuming that each method was walked in one period and that the most efficient (minimum distance) route was taken. The distances were calculated for the sample locations shown in Figure 2. Approximately 480 km would have to be walked to reach all grid intersections and random points; in comparison, 34–48 km would have to be traversed to reach all transects (Table 3). A speed of 3 km/h was assumed when traversing between sampling areas and 1 km/h when sampling and recording data. The time taken to complete the transect survey methods was between 31.3 and 36 h (Table 3). The grid and point methods were estimated to take 180 and approximately 178 h, respectively. Therefore, for logistical purposes of time and distance traversed in the field, the transect survey methods proved to be most cost-effective.

Table 2. Mean and standard deviation of number of patches intersected using the seven different survey methods, the percentage frequency given the number of observations ($n = 2546$), and percentage of the area infested given the number and proportion of patches intersected, for species A–D.

	Standard sampling				Adaptive sampling			
	Mean number of patches intersected	Standard deviation of mean	% frequency of species	% of area infested	Mean number of patches intersected	Standard deviation	% frequency of species	% of area infested
<i>Species A (population = 15,055, area infested = 1.3%)</i>								
<i>RANDOM</i>								
Grid	155	13.1	6.1	1.0	659	60.2	25.9	4.5
Point	159	10.7	6.3	1.1	641	60.4	25.2	4.3
Walk	52	7.4	2.0	1.0	132	25.0	5.2	2.7
Perp.RoW	64	9.3	2.5	1.3	191	36.7	7.5	3.8
Targeted	62	6.4	2.5	1.3	200	32.5	7.9	4.0
SaD	63	6.3	2.5	1.3	197	27.6	7.7	4.0
Contour	64	7.5	2.5	1.3	189	22.3	7.4	3.8
<i>WEIGHTED</i>								
Grid	157	15.5	6.2	1.1	5394	215.7	211.9	36.4
Point	160	9.1	6.3	1.1	5291	248.7	207.8	35.8
Walk	48	19.9	1.9	1.0	1313	1000.4	51.6	26.4
Perp.RoW	85	9.3	3.4	1.7	3291	451.8	129.3	66.2
Targeted	52	9.8	2.0	1.0	1143	407.5	44.9	23.0
SaD	487	96.8	19.1	9.8	4731	203.4	185.8	95.2
Contour	40	7.1	1.6	0.8	444	326.0	17.4	8.9
<i>Species B (population = 5033, area infested = 1.6%)</i>								
<i>RANDOM</i>								
Grid	116	12.0	4.6	1.8	183	21.1	7.2	2.9
Point	118	11.1	4.6	1.9	184	18.6	7.2	2.9
Walk	25	6.0	1.0	2.0	31	4.8	1.2	2.5
Perp.RoW	32	5.6	1.3	2.6	44	9.7	1.7	3.5
Targeted	31	5.3	1.2	2.5	44	11.5	1.7	3.5
SaD	31	5.5	1.2	2.5	45	9.0	1.8	3.6
Contour	32	5.9	1.2	2.5	43	8.7	1.7	3.5
<i>WEIGHTED</i>								
Grid	116	9.7	4.6	1.8	390	65.4	15.3	6.1
Point	114	9.8	4.5	1.8	391	59.7	15.3	6.1
Walk	24	8.4	1.0	1.9	47	19.6	1.9	3.8
Perp.RoW	45	8.5	1.8	3.6	120	37.3	4.7	9.6
Targeted	27	5.7	1.1	2.2	59	20.5	2.3	4.7
SaD	236	17.4	9.3	18.9	621	44.3	24.4	49.9
Contour	20	3.3	0.8	1.6	26	5.1	1.0	2.1
<i>Species C (population = 1739, area infested = 1.3%)</i>								
<i>RANDOM</i>								
Grid	74	8.0	2.9	1.3	84	9.6	3.3	1.4
Point	74	8.5	2.9	1.3	81	9.5	3.2	1.4
Walk	12	3.6	0.5	1.5	11	3.8	0.4	1.4
Perp.RoW	14	3.4	0.6	1.8	16	5.0	0.6	2.0
Targeted	13	4.0	0.5	1.7	15	4.3	0.6	1.9
SaD	15	3.9	0.6	1.9	15	4.4	0.6	2.0
Contour	14	3.4	0.5	1.8	15	4.1	0.6	2.0
<i>WEIGHTED</i>								
Grid	71	8.0	2.8	1.2	112	14.1	4.4	1.9
Point	71	8.2	2.8	1.2	115	15.4	4.5	2.0
Walk	14	5.6	0.5	1.8	11	6.8	0.4	1.4
Perp.RoW	27	6.8	1.1	3.4	33	10.3	1.3	4.2
Targeted	15	3.6	0.6	1.9	16	4.5	0.6	2.1

Table 2. (Continued).

	Standard sampling				Adaptive sampling			
	Mean number of patches intersected	Standard deviation of mean	% frequency of species	% of area infested	Mean number of patches intersected	Standard deviation	% frequency of species	% of area infested
SaD	155	11.3	6.1	19.8	193	17.7	7.6	24.7
Contour	9	3.8	0.4	1.1	8	3.9	0.3	1.0
<i>Species D (population = 1220, area infested = 6.5%)</i>								
<i>RANDOM</i>								
Grid	248	16.1	9.7	7.7	275	18.4	10.8	8.6
Point	254	13.7	10.0	7.9	277	16.1	10.9	8.6
Walk	14	3.3	0.5	4.8	15	4.6	0.6	5.3
Perp.RoW	23	5.1	0.9	8.1	23	4.9	0.9	8.2
Targeted	22	4.4	0.9	7.8	23	5.3	0.9	8.0
SaD	23	4.9	0.9	8.0	24	5.2	1.0	8.6
Contour	23	4.4	0.9	8.1	24	4.8	0.9	8.5
<i>WEIGHTED</i>								
Grid	265	13.9	10.4	8.2	281	15.3	11.0	8.8
Point	265	11.8	10.4	8.3	274	16.6	10.8	8.5
Walk	15	3.9	0.6	5.3	15	4.5	0.6	5.5
Perp.RoW	24	5.5	0.9	8.4	25	5.6	1.0	8.7
Targeted	23	4.9	0.9	8.0	24	4.4	0.9	8.4
SaD	23	4.9	0.9	8.0	24	5.1	0.9	8.3
Contour	22	5.2	0.9	7.8	23	5.3	0.9	8.1

Results are provided for both random and weighted distributions using both the standard and adaptive sampling designs. See Figure 2 for explanation of survey methods and Figure 3 for explanation of adaptive design.

Comparison between survey methods

From the above evaluations of the model output we can determine that transect methods provide the most effective logistical and financial approach. Targeted transects provided the second shortest and quickest method to implement in the field, and the most representative and consistent sample of a population. Therefore, the targeted method was used as the benchmark against which the other six survey methods were compared. Paired *t*-tests were performed between each of the methods and the targeted approach using proximity to RoW sample data. The proportion of pairs for which the method of interest showed no significant difference from the targeted method are provided in Table 4. Grid, point, walk and contour samples were not significantly different from the target approach samples for the majority of pairs. Agreement of less than 0.7 was more frequent when using the adaptive design, particularly for species A and B. As expected, perp.RoW samples generally (two exceptions) showed poor agreement with mean

proximity to RoW samples of the targeted methods. No samples generated using the SaD methods had spatial distributions similar to samples generated using the targeted method.

Effect of patch size

The initial model simulation demonstrated that point sampling methods, both grid and random point, intersected many more patches than the transect methods for both the random and weighted NIS distributions. This result was not intuitive as the area sampled equalled 20 ha (200,000 m²) for both point and transect methods. The perimeter of the transects equalled 40,200 m but the circumference of all the survey points totalled 79,985 m, which is almost twice that of the transects. This partially explains why more patches were intersected using the point rather than transect approach. In addition, the total circumference provided by the different patch sizes was positively related to the chance of a patch being intersected (data not shown).

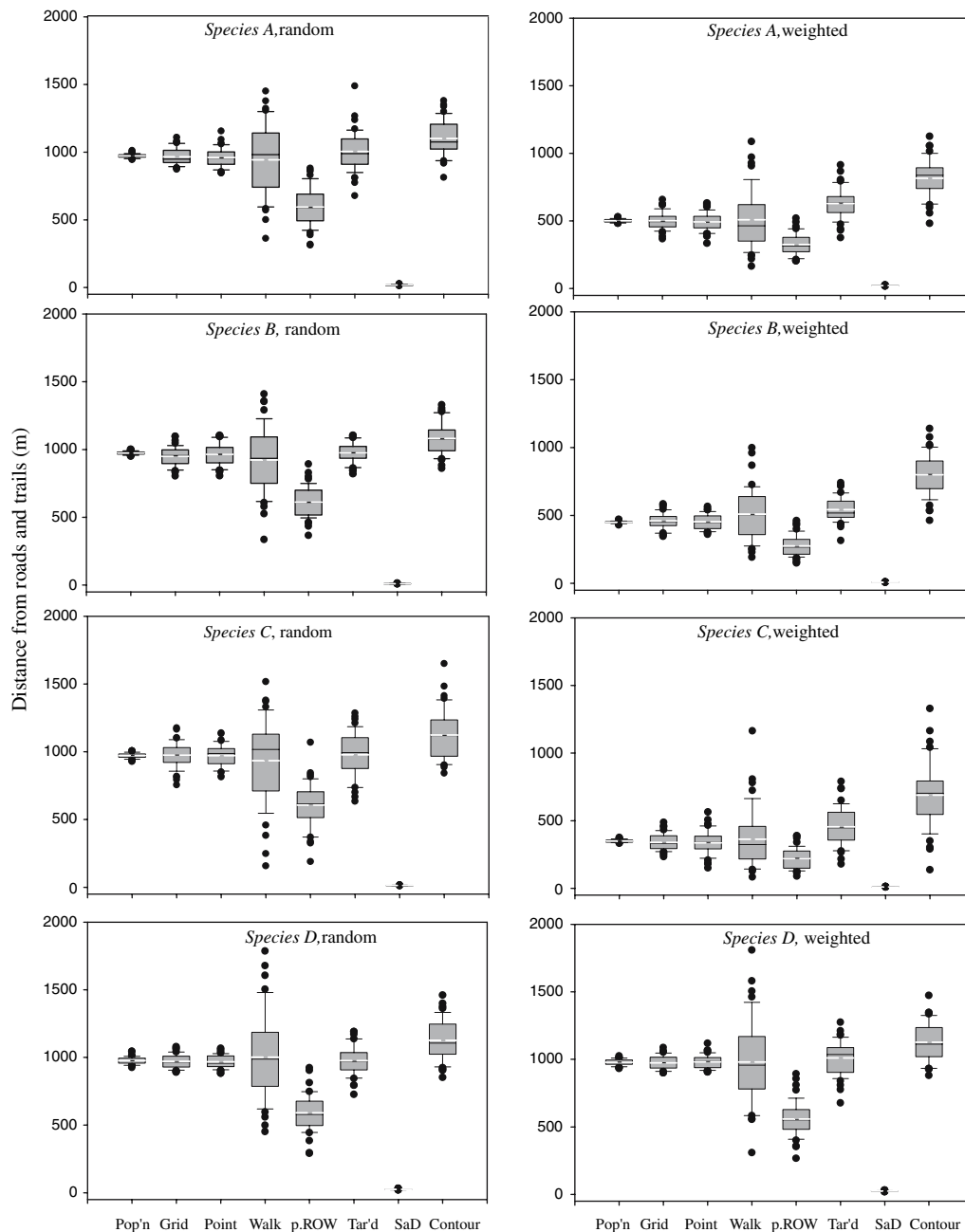


Figure 4. Box and whisker plots showing variation around the median distance from roads and trails for the populations and samples of the population using seven different survey methods. Fifty populations were simulated for both random and weighted distributions of *Species A–D*. Solid black line within grey box represents the median; dashed white line the mean; grey box represents 50% of the data; whiskers represent the 10th and 90th percentiles; and dots represent outliers. For explanation of different survey methods see Figure 2. Abbreviations include: Pop'n = population p.ROW = perp.ROW, Tar'd = targeted transects.

To investigate this issue in more detail we re-ran the model, retaining the four different patch radii (species A < species B < species

C < species D) but ensured that each of the virtual species covered the same area (1.3% of the total area, 1,278,884 m²). This was only per-

Table 3. Distance and time travelled between survey areas and total time necessary to complete the seven different survey methods, using the point or transect locations depicted in Figure 2. A speed of 3 km/h was assumed when travelling between sample areas and 1 km/h when sampling.

Survey method	Distance travelled (km) to reach survey areas	Time (h) to travel between survey areas	Total time (h) to complete survey
Grid	480.0	160.0	180.0
Point	475.0 (± 8)	≈ 158.3	≈ 178.3
Walk	48.0	16.0	36.0
Perp.RoW	33.8	11.3	31.3
Targeted	34.5	11.5	31.5
SaD	37.0	12.3	32.3
Contour	45.5	15.2	35.2

formed with random distributions, and grid and targeted survey methods. The area surveyed was the same (20 ha) and the results were recorded as before.

When the area covered by the four species was held constant more small radii patches (species A) were intersected than larger patches (consecutively species B, C, D) for each of the survey methods (Table 5). As before, more patches were intersected with the grid than the targeted method. The different patch numbers intersected by the two survey methods has important implications for estimates of species frequency (number of patches/number of observation points). The per-

centage frequency, sometimes referred to as occurrence, of the smaller radii species is higher. This would lead to incorrect estimates of NIS frequency in the environment. Using information on patch size, the percentage or proportion of the survey area infested can be calculated. The actual area of each patch intersected was recorded with an additional extension to the model. However, this type of information is generally not recorded in the field so we also calculated the percentage of area infested using an average value for the proportion of a patch intersected by each transect or grid method. The resulting infestation estimates are reasonably accurate and would provide a more accurate reflection of the importance of the different species than frequency calculations (Table 5).

The percentage frequency and percentage of the area infested were also calculated for the original data set (Table 2). As expected, the percentage frequency values provide little useful information when used to compare across survey methods. Point methods for the same species and distribution provided similar frequency estimates. Transect methods generally provided similar results for the same species with random distributions, but showed less agreement between methods for the weighted distributions (Table 2). This suggests that comparing percentage frequency values between methods or studies would

Table 4. Proportion of paired *t*-tests which showed no significance difference between samples from the targeted method and those from each of the other survey methods using both random and weighted distributions of species A–D and (a) standard and (b) adaptive sampling designs. Comparisons based on mean distance of patches to rights-of-way. 95% significance value was used.

	Species A		Species B		Species C		Species D	
	Random	Weighted	Random	Weighted	Random	Weighted	Random	Weighted
(a) <i>Standard</i>								
Grid	0.90	0.85	0.98	0.94	0.96	0.94	1.00	0.96
Point	0.94	0.83	0.96	0.96	0.96	0.92	0.98	0.94
Walk	0.81	0.71	0.81	0.81	0.83	0.83	0.83	0.75
Perp.RoW	0.33	0.40	0.17	0.17	0.54	0.71	0.54	0.21
SaD	0	0	0	0	0	0.04	0	0
Contour	0.77	0.69	0.88	0.88	0.92	0.81	0.90	0.88
(b) <i>Adaptive</i>								
Grid	0.98	0.60	0.85	0.56	0.92	0.75	0.94	0.96
Point	0.96	0.69	0.94	0.58	0.96	0.88	0.98	0.94
Walk	0.87	0.76	0.56	0.67	0.88	0.83	0.77	0.75
Perp.RoW	0.13	0.36	0.06	0.31	0.44	0.73	0.23	0.29
SaD	0	0	0	0	0	0.04	0	0
Contour	0.87	0.56	0.81	0.40	0.92	0.71	0.90	0.90

Table 5. Number of species A–D patches intersected when holding the area covered by each non-indigenous species (NIS) constant and sampling with a grid or targeted survey method. Percentage frequency, actual (from the model) and estimated (using geometric calculations) of area infested.

Survey method	Area covered by NIS held constant (1,278,887 m ² ; 1.3%)							
	Mean number of patches intersected		% frequency (n = 2546)		% area infested (actual)		% area infested (estimated)	
	Grid	Targeted	Grid	Targeted	Grid	Targeted	Grid	Targeted
Species A	120	61	4.7	2.4	1.2	1.3	1.2	1.2
Species B	71	24	2.8	0.9	1.3	1.3	1.3	1.9
Species C	55	14	2.2	0.6	1.2	1.3	1.2	1.8
Species D	40	5	1.6	0.2	1.2	1.4	1.2	1.7

not provide valuable or accurate insight into the data. Relative species frequencies were not calculated for this study.

Calculations of the percentage of the area infested are easier to interpret than frequency estimates. To estimate the percentage of the area infested one has to determine the mean proportion of each patch intersected, which can be achieved through probability and geometry. Percentage area infested calculations demonstrated that the point and target transects methods intersected the appropriate number of patches given the infestation level in the total area. The other transect methods over- or under-sampled the population. Percentage area infested values provided an additional approach for comparing between methods and species occurrence rate in the environment.

Discussion

Prior to developing the model, we hypothesized that several of the survey methods would produce samples which would accurately reflect the population infestation extent and spatial distribution in the landscape. Grid and random point sampling methods intersected significantly more patches than the transect methods for both the random and weighted distributions, with the same sampled area. These results have important implications for comparison between studies where different survey methods were employed. If only percentage frequency calculations are performed, surveys conducted using point methods will be seen to have higher populations of NIS than surveys conducted using transect methods

(SaD excepted) in the same area. In addition, patch size plays an important role. Populations with small patch size, here Species A, will be estimated to have a higher frequency than species with larger patches, here Species D. Limitations of frequency estimates are well known (e.g. Barbour et al. 1980; Crawley 1997; Thompson 2002) due to size and shape of plots and plants, and different environmental gradients etc. However, they are still used regularly in reports and are thus included in our evaluation. Calculating the percentage of the area infested provides for more reliable comparison between survey methods when the objectives are to estimate species occurrence as well as spatial distribution.

Trombulak and Frissel (2000) reviewed the ecological effects of roads and generally supported the view that roads are associated with negative biological impacts. Several studies have demonstrated that the abundance of NIS increases in closer proximity to RoW though there are differences in systems (Tyser and Worley 1992; Marcus et al. 1998; Parendes and Jones 2000; Gelbard and Belnap 2003; Maxwell et al. 2003; Watkins et al. 2003; Pauchard and Alaback 2004). Road density is high throughout continental USA (Forman 2000). For example, in the continental USA 20% of land is within 127 m of a road, 83% is within 1061 m and only 3% of land was more than 5176 m from a road (Riitters and Wickham 2003). Thus, RoW may provide an effective dispersal vector for species (e.g. Pauchard et al. 2003; Pauchard and Alaback 2004) aiding their dispersal into new environments. Consequently we chose proximity to RoW as an important factor which influences NIS distributions, thus allowing us to compare a biologically

relevant distribution with a random distribution. The results show that the grid, point and targeted survey methods provided samples similar to the population for both random and weighted (proximity to RoW) distributions of NIS.

Most NIS data will be collected as presence/absence data but rarely are other potentially correlated variables recorded to aid prediction of the target species occurrence. Evaluating sampling methods for predictive purposes has recently received more attention. Hirzel and Guisan (2002) evaluated four different sampling methods to predict habitat types. They evaluated random, regular, proportionally-stratified and equal-stratification methods in different habitat types at four sample sizes. They found that the most important factor was the number of samples taken, though systematic sampling provided better results than random and, including environmental information in the sampling design also improved the subsequent predictive models. They concluded that choosing the right sampling method can improve the results by a few percent and reduce the risk of making poor predictions; this was particularly apparent for presence/absence predictions. In their model, stratified sampling did not improve the predictive models greatly. However, in our model stratifying on RoW (e.g. targeted) proved to be preferable to grid and random point due to practicalities of time in the field.

The Gradsect design is a variation of a random stratified design, which samples along environmental gradients. It represents a compromise between randomized sampling of stratified multiple variables in order to minimize travel and cost (Austin and Heylingers 1989). Maggini et al. (2002) used a random stratified sampling approach to collect data for predicting ant distribution. They used an equal number of replicates per variable (e.g. vegetation, slope, aspect, etc.). To use random stratified methods for multiple variables it is necessary to have access to information on the effect of each of the different variables on the distribution of the response variable. Maggini et al. (2002) stated that stratifying on a number of variables becomes more complex as the number of target species increases, because each species may have a different response to individual and multiple variables. Hirzel and

Guisan (2002) suggest that unless such correlations are well known, sampling equally, not proportionally, within the multiple variables would probably be most effective, but this needs to be evaluated further. As relationships between NIS occurrence and environmental variables are poorly understood, and the knowledge we do have suggests species respond differently, we stratified on the one variable which is known to be important, proximity to RoW. We do not intend to suggest that environmental variables do not influence species distribution, neither that the effects of such variables could not be greater than RoW nor, that when such information is available it should not be used to help stratify the sampling method. Our objective here is to evaluate different sampling methods when the number of NIS is not necessarily known, their relation with environmental variables is different or unknown, and when the sampling area is large. Because these are the situations that many land managers face when make sampling decisions. Under these situations it may only be practical to stratify on one variable – RoW.

Many survey studies only collect data on presence/absence of a species and make no record of patch size. Sampling populations which cover the same overall area but have different patch sizes demonstrated clearly that patch size should be included as part of the surveying protocol. That is patches have unequal probability of being sampled and the importance of considering this is explained by Thompson (2002). More smaller patches were intersected than larger ones when the area of NIS was held constant. Evaluating these data purely on numbers of presence/absence and not including data on the estimated area infested will lead to erroneous conclusions of species frequency and consequently their management. When data on the size of individual patches is not recorded as part of a survey protocol, the mean size can be determined from a subsample of patches of an individual species, and an estimate of the percentage or proportion of the area infested can be calculated as demonstrated in Tables 2 and 5. Calculations of infested area and frequency will also be easier if transect data are collected continuously.

The four species modelled had different distributions relative to RoW, which was highlighted

as more patches of three of the species (species A–C) were intersected using the SaD method with weighted distributions than random. The SaD method was incorporated into the model as some managers assume that sampling along the main vectors of NIS spread will result in a large proportion of the patches being intersected for the same unit of time/effort. There is however, no evidence that this is correct since areas away from RoW are not searched. The simulation model demonstrated that while this method does result in a higher number of patches being intersected than the other transect methods, patches away from RoW are missed, even when using the adaptive design in conjunction with SaD sampling. It is often perceived that it is best to stratify management on new infestations and these may be ones at greater distances from RoW and thus those that would not be detected by the SaD method. Furthermore, the SaD method is essentially a Phase three operation, where the goal is not inventory/survey, but management. Data provided by this method of sampling can be misleading and lead to incorrect conclusions about the distribution and abundance of NIS. Additionally, since the data collected by SaD sampling are biased, they are also not suited to predicting and monitoring NIS distributions although these are important components of phases 1 and 2 of NIS management.

Our evaluation of the different survey methods suggests that none of the methods provide a perfect representation of the population but the targeted method is the most reliable and time efficient. Given these limitations, and if it is not possible to sample an area entirely, then it is prudent to collect additional information regarding environments and conditions where a species is *and* is not located. Such information can be used to increase our understanding of NIS distributions and can be updated periodically to sample unrepresented areas or as a result of geological, weather or anthropological disturbance. Pauchard et al. (2003) studied the occurrence of *Linaria vulgaris* at three different scales around West Yellowstone, Wyoming, USA, and the results provided a better understanding of the pattern of *L. vulgaris* invasion and helped to prioritize management of this species. The targeted survey method provides information over an extensive area and at a range

of scales, depending on how the data are collected in the field. This type of data collection provides information on rare NIS and new populations which should be targeted for management. The data can be used to develop predictive models (see Rew et al. 2005) of target species occurrence at appropriate scales (10–30 m) to help managers target their time managing NIS most effectively. Considering how well the survey method represents the population, and time in the field we feel that the targeted approach is most reliable.

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The 2024 state of the climate report: Perilous times on planet Earth

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We are on the brink of an irreversible climate disaster. This is a global emergency beyond any doubt. Much of the very fabric of life on Earth is imperiled. We are stepping into a critical and unpredictable new phase of the climate crisis. For many years, scientists, including a group of more than 15,000, have sounded the alarm about the impending dangers of climate change driven by increasing greenhouse gas emissions and ecosystem change (Ripple et al. 2020). For half a century, global warming has been correctly predicted even before it was observed—and not only by independent academic scientists but also by fossil fuel companies (Supran et al. 2023). Despite these warnings, we are still moving in the wrong direction; fossil fuel emissions have increased to an all-time high, the 3 hottest days ever occurred in July of 2024 (Guterres 2024), and current policies have us on track for approximately 2.7 degrees Celsius (°C) peak warming by 2100 (UNEP 2023). Tragically, we are failing to avoid serious impacts, and we can now only hope to limit the extent of the damage. We are witnessing the grim reality of the forecasts as climate impacts escalate, bringing forth scenes of unprecedented disasters around the world and human and nonhuman suffering. We find ourselves amid an abrupt climate upheaval, a dire situation never before encountered in the annals of human existence. We have now brought the planet into climatic conditions never witnessed by us or our prehistoric relatives within our genus, *Homo* (supplemental figure S1; CenCO2PIP Consortium et al. 2023).

Last year, we witnessed record-breaking sea surface temperatures (Cheng et al. 2024), the hottest Northern Hemisphere extratropical summer in 2000 years (Esper et al. 2024), and the breaking of many other climate records (Ripple et al. 2023a). Moreover, we will see much more extreme weather in the coming years (Masson-Delmotte et al. 2021). Human-caused carbon dioxide emissions and other greenhouse gases are the primary drivers of climate change. As of 2022, global fossil fuel combustion and industrial processes account for approximately 90% of these

emissions, whereas land-use change, primarily deforestation, accounts for approximately 10% (supplemental figure S2).

Our aim in the present article is to communicate directly to researchers, policymakers, and the public. As scientists and academics, we feel it is our moral duty and that of our institutions to alert humanity to the growing threats that we face as clearly as possible and to show leadership in addressing them. In this report, we analyze the latest trends in a wide array of planetary vital signs. We also review notable recent climate-related disasters, spotlight important climate-related topics, and discuss needed policy interventions. This report is part of our series of concise annual updates on the state of the climate.

Recent trends in planetary vital signs

In 2023, various historical temperature and ice extent records were broken by enormous margins (figure 1; Ripple et al. 2023a). Both global and North Atlantic sea surface temperatures were far above their 1991–2024 averages for much of the year—a pattern that has continued well into 2024 (figure 1a, 1b). Although Antarctic and global sea ice extent have now come into range of previous years, they remain well below their 1993–2024 averages (figure 1c, 1d). Global daily mean temperatures were at record levels for nearly half of 2023 and much of 2024 (figure 1e). On our current emissions trajectory, we may regularly surpass current temperature records in future years (Matthews and Wynes 2022).

Of the 35 planetary vital signs we track annually (figures 2 and 3), 25 are at record levels (supplemental table S1). The global failure to support a rapid and socially just fossil fuel phasedown has led to rapidly escalating climate-related impacts (table 1). Below, we focus on variables that have either changed greatly or are at record extremes.

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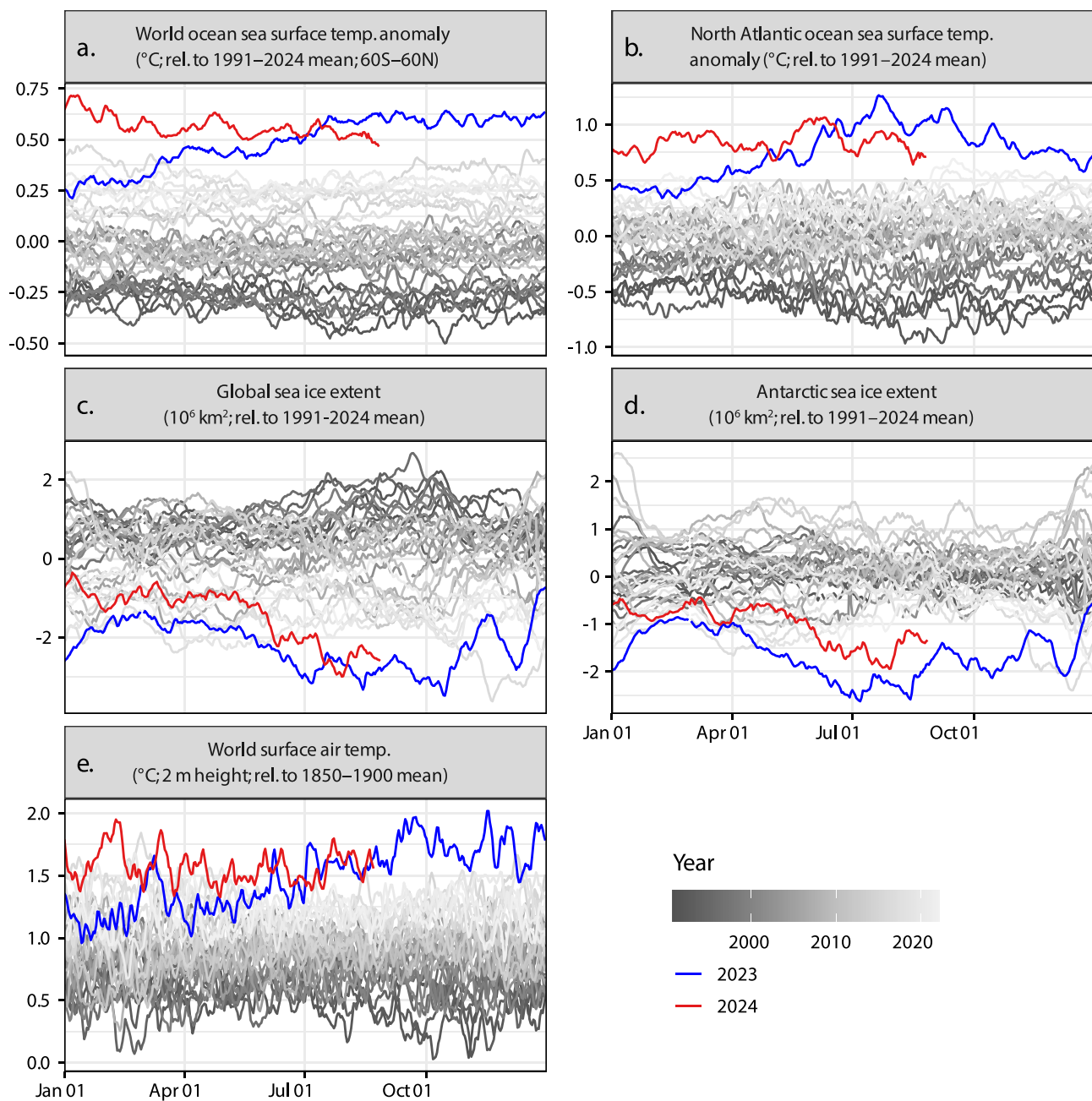


Figure 1. Unusual climate anomalies in 2023 and 2024. Ocean temperatures (a, b) are presently far outside their historical ranges. These anomalies reflect the combined effect of long-term climate change and short-term variability. Sources and additional details about each variable are provided in supplemental file S1. Each line corresponds to a different year, with darker gray representing later years. All of the variables shown are daily estimates.

The human enterprise

Our graphical account illustrates how humanity's collective size and consumption patterns continued to accelerate on multiple fronts. Although fertility rates were down slightly to a record low in 2023, other variables set all-time record highs, including human population, ruminant livestock population, per capita meat production, and gross domestic product (GDP; figure 2a–2e). Human population and ruminant livestock population have been increasing at approximately 200,000 and 170,000 per day respectively. Decoupling the growth in all of these variables with greenhouse gas emissions may be difficult (Ripple et al. 2024).

Energy

Fossil fuel consumption rose by 1.5% in 2023 relative to 2022 (figure 2h), mostly because of substantial increases in coal consumption (1.6%) and oil consumption (2.5%; figure 2h). Renewable energy use also grew in 2023, with solar and wind consumption together rising 15% relative to 2022 (figure 2h). Much of this growth can be attributed to the fact that renewable energy is often cheaper than comparable new fossil fuel alternatives (Roser 2020). However, fossil fuel consumption remains roughly 14 times greater than solar and wind energy consumption (figure 2h) and recent growth in the renewable share of electricity generation

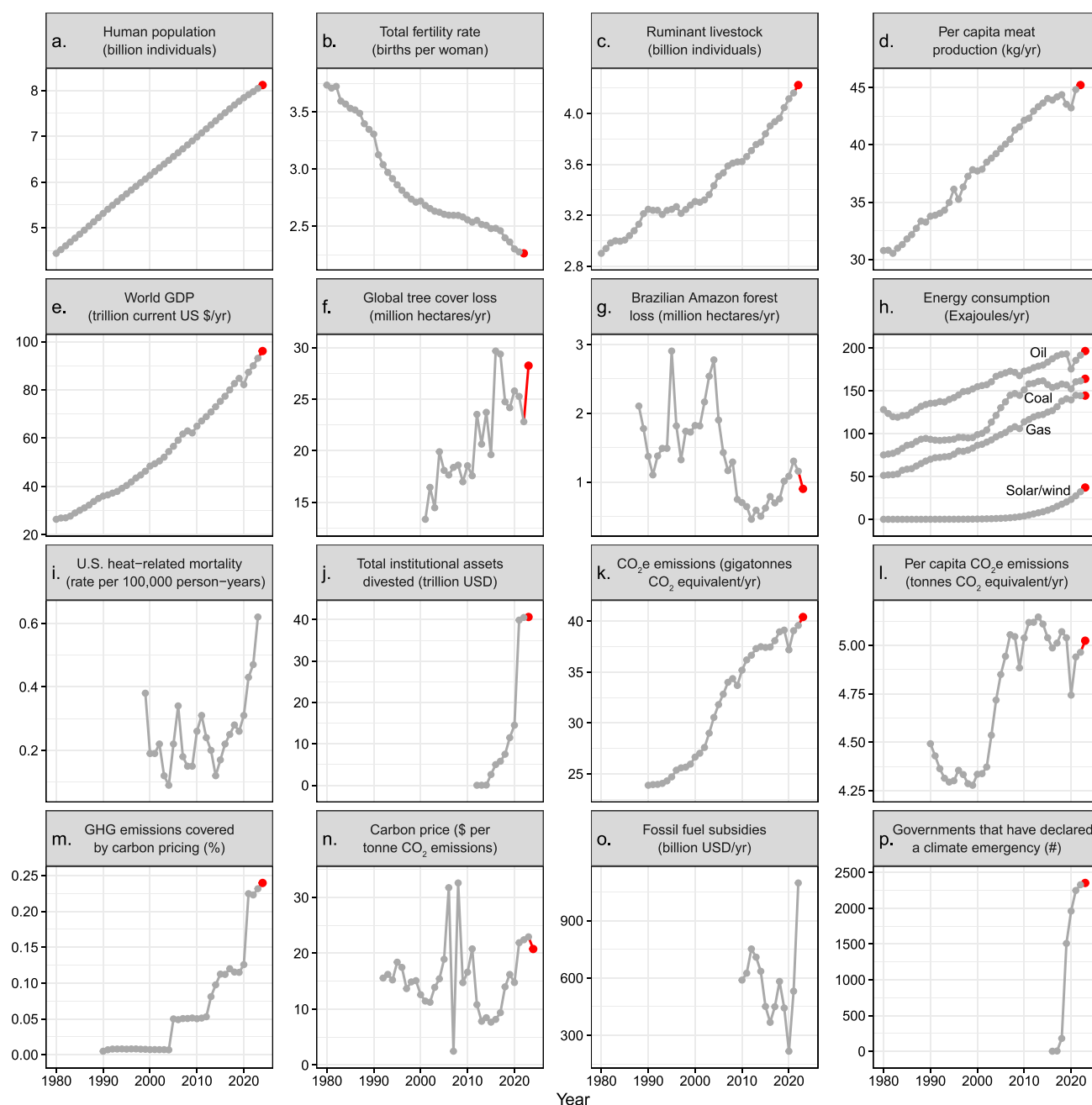


Figure 2. Timeseries of climate-related human activities. The data obtained since the publication of Ripple and colleagues (2023a) are shown in red (dark gray in black and white). In panel (f), tree cover loss does not account for forest gain and includes loss due to any cause. For panel (h), hydroelectricity and nuclear energy are shown in supplemental figure S3. Sources and additional details about each variable are provided in supplemental file S1.

mostly covered increased demand, instead of replacing fossil fuels (REN21 2024).

Forests

Global tree cover loss rose from 22.8 megahectares (Mha) per year in 2022 to 28.3 Mha per year in 2023, reaching its third-highest level (figure 2f); this was at least partly because of wildfires, which caused tree cover loss to reach a record high of 11.9 Mha (figure 3n). High rates of tree cover loss can drive a set of related feedback loops, wherein the loss of forest carbon sequestration leads to additional warming, which can drive further losses in carbon sequestration and so on (Ripple et al. 2023b, Goldman and

Carter 2024). This type of climate carbon feedback process could limit the success of some natural climate solutions. In 2023, there was also a dramatic decline in the land carbon sink according to Ke and colleagues (<https://doi.org/10.48550/arXiv.2407.12447> [preprint: not peer reviewed]). On a more positive note, the deforestation rate in the Brazilian Amazon continued to decline, dropping from 1.16 Mha in 2022 to 0.90 Mha in 2023 (figure 2g). This decrease may be partly because of the shifting policies of Brazil's government (Vilani et al. 2023) and comes at a critical time given that the Amazon may be nearing a tipping point where a loss of resilience and positive feedback loops contribute to large-scale forest dieback (Boulton et al. 2022, Flores et al. 2024).

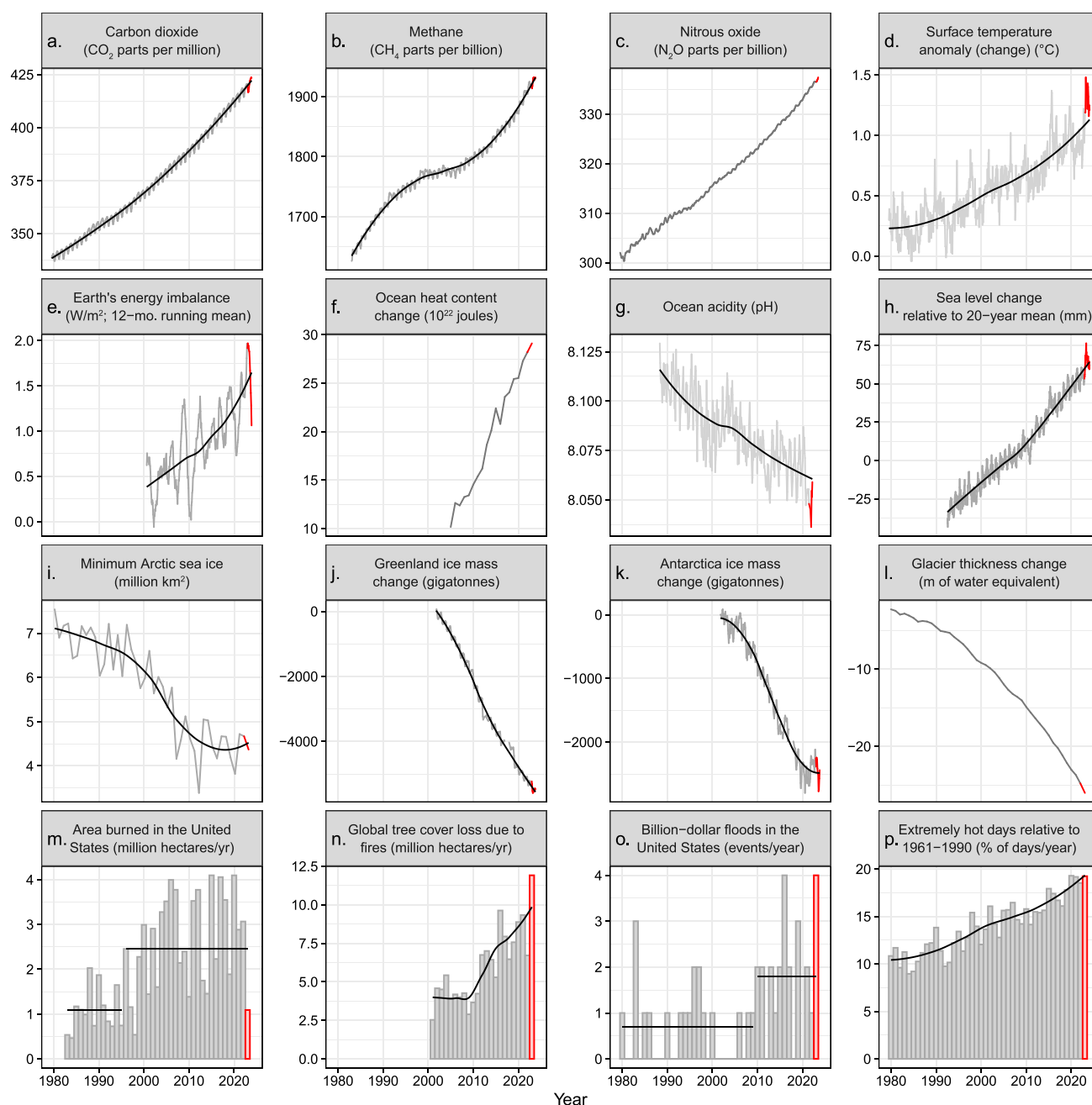


Figure 3. Timeseries of climate-related responses. The data obtained before and after the publication of Ripple and colleagues (2023a) are shown in gray and red (dark gray in black and white), respectively. For area burned (m) and billion-dollar flood frequency (o) in the United States, the black horizontal lines show changepoint model estimates, which allow for abrupt shifts (see the supplement). For other variables with relatively high variability, local regression trendlines are shown in black. The variables were measured at various frequencies (e.g., annual, monthly, weekly). The labels on the x-axis correspond to midpoints of years. Billion-dollar flood frequency (o) is influenced by exposure and vulnerability in addition to climate change. Sources and additional details about each variable are provided in supplemental file S1.

Global greenhouse gases and temperature

Annual energy-related emissions increased 2.1% in 2023, and are now above 40 gigatons of carbon-dioxide-equivalent for the first time (figure 2k). The top three emitting countries are China, the United States, and India, which, together, account for over half of global emissions (supplemental table S2). Anthropogenic emissions of aerosol pollutants are declining; because these aerosols have a net cooling effect, this reduction may be causing the rate of global warming to accelerate (Hansen et al. 2023). On the basis of global year-to-date averages, the concentrations of carbon

dioxide and methane are at record highs (figure 3a, 3b). Carbon dioxide levels were recently observed to be surging (NOAA 2024). Furthermore, the growth rate of methane emissions has been accelerating, which is very troubling (Shindell et al. 2024). Nitrous oxide is also at a record high (figure 3c); annual anthropogenic emissions of this potent long-lived greenhouse gas have increased by roughly 40% from 1980 to 2020 (Tian et al. 2024).

Surface temperature is at a record high, and 2024 is expected to be one of the hottest years ever recorded (figure 3d). Each 0.1°C of global warming places an extra 100 million people (or more)

Table 1. Recent climate disasters in November 2023 or later.

Timeframe	Climate disaster
November 2023	Storm Bettina over Black Sea brought heavy snowfall and rainfall to several countries along the Black Sea, affecting more than 2.5 million people and causing 23 fatalities. The burning of fossil fuels was responsible for an approximately twofold increase in the likelihood of this level of precipitation (Zachariah et al. 2024a).
February 2024	Wildfires in Chile killed at least 131 people and destroyed more than 14,000 homes. Climate change may have contributed to these fires by increasing the frequency and intensity of droughts and heatwaves, although other factors may have been involved, including El Niño and the loss of natural forests.
March–April 2024	Extreme heat affected a large portion of North Africa and the Sahel, potentially killing hundreds or thousands of people. Heat waves of this magnitude likely could not have occurred in the absence of climate change (Barnes et al. 2024a).
April 2024	Heavy rain led to flash floods in the Persian Gulf region, killing at least 33 people. Climate change probably exacerbated this rainfall.
March–May 2024	Heavy rainfall in East Africa caused severe flooding that killed hundreds and affected more than 700,000 people. This region has seen an increase in observed rainfall over the past 15 years that is at least partly attributable to climate change (Kimutai et al. 2024).
April–May 2024	Many regions of Asia experienced devastating heatwaves, with approximately 1,500 heat stroke fatalities in Myanmar alone (Pearce and Ware 2024). As part of the longest heat wave ever recorded in India, temperatures reached 50°C in some areas and heat-related illnesses resulted in at least 60 deaths. Climate change is making such heat waves more frequent and extreme in some parts of Asia (Zachariah et al. 2024b).
April–May 2024	Extensive flooding in southern Brazil devastated 478 cities, killed 173 people, and left 38 people missing, 806 injured, and 423,486 displaced. The estimated cost of the cleanup is US\$3.7 billion (Malabarba et al. 2024). It was estimated that climate change roughly doubled the likelihood of the extreme rainfall that caused these floods (Clarke et al. 2024).
May 2024	A wind storm in Texas, United States killed 5 people and left more than 600,000 people without power. Climate change may be making straight-line wind storms such as this one more frequent and intense.
May 2024	Severe Cyclonic Storm Remal killed at least 84 people in India and Bangladesh. Climate change has led to an increase in the frequency and intensity of such severe storms.
May–June 2024	Mexico and nearby areas faced extreme heat; at least 125 people have died in Mexico because of heat-related illnesses this year. Climate change is increasing the frequency of such extreme heat waves (Pinto et al. 2024).
June 2024	At least 1,170 pilgrims died in Saudi Arabia during an intense heat wave with temperatures reaching over 50 C. Climate change is contributing to heat waves such as this one.
June 2024	Heavy rainfall in Bangladesh caused landslides that killed at least nine people and floods that left nearly 2 million people stranded. Climate change has increased the intensity of floods in this region.
June 2024	Devastating wildfires burned roughly 440,000 hectares in the Brazilian Pantanal wetlands, threatening economic activities and killing many wild animals. Climate change is estimated to have caused a 40% increase in the intensity of the weather conditions that drove these wildfires (Barnes et al. 2024b).
July 2024	Hurricane Beryl was an exceptionally strong Atlantic hurricane that affected parts of the Caribbean, United States, and Yucatán Peninsula; it killed 64 people and caused more than US\$5 billion in damages. Climate change may have contributed to Beryl rapidly intensifying and reaching Category 5 status despite occurring relatively early in the hurricane season.
July 2024	A deadly heatwave in the Mediterranean resulted in at least 23 fatalities. It is highly likely that climate change contributed to the extreme temperatures that were observed.
August 2024	Hurricane Debby was a slow-moving hurricane that caused extensive flooding in the Southeastern United States and killed at least 10 people. Climate change has been linked to increasing hurricane rainfall and intensification rates and may be involved in the slowing of U.S. hurricanes.

Note: We list numerous recent disasters that may be at least partly related to climate change. This list is not intended to be exhaustive. Because of the recent nature of these events, our sources often include news media articles. For each event, we generally provide references indicating that the likelihood or strength of such an event may have increased because of anthropogenic climate change. References to scientific articles are given directly in the table, and links to news articles are provided in supplemental file S1. Some of these climate disasters may be at least partly related to changes in jet streams (Stendel et al. 2021, Rousi et al. 2022).

into unprecedented hot average temperatures (Lenton et al. 2023). On our current trajectory, future years will almost certainly be even hotter, because our climate continues to shift away from conditions associated with human thriving for much of Earth’s population (Vecellio et al. 2023). Even in the most optimistic scenarios, large-scale climate adaptation efforts will be needed, particularly for the most vulnerable populations (Ripple et al. 2022).

Oceans and ice

Ocean acidity and ocean heat content are both at record extremes (figure 3f, 3g), which has led to various ocean-related climate impacts. For example, heat waves in 2021 and 2023 caused marine animal mass mortality events (White et al. 2023, Goreau and Hayes 2024). In addition, the average global sea level is presently at a record high, mostly because of both overall warming and a strong El Niño in 2023 and part of 2024 (figure 3h; Lee 2024).

Continued sea level rise has the potential to displace hundreds of millions of people over the course of the century (Kulp and Strauss 2019). Melting continental ice contributes about half to sea level rise (Horwath et al. 2021), and the latest data indicate that Greenland's ice mass, Antarctica's ice mass, and the average glacier thickness are all at record lows (figure 3j–3l).

Climate impacts and extreme weather

Climate-related extreme weather and disasters are contributing greatly to human suffering (figure 4). Increasing heat and rainfall extremes are now far outside the historical climate (Robinson et al. 2021). The rapid increase in average global temperatures (figure 1e) has led to a massive rise in the incidence of heat extremes (figure 3p). This is linked to many adverse human outcomes, including direct mortality, increased healthcare costs, mental health issues, and deaths from cardiorespiratory diseases (Ebi et al. 2021). Climate change has already contributed to billions of people facing extreme heat (Arrighi et al. 2024). Heat-related mortality is rising rapidly in the United States (Figure 2i); the number of heat-related deaths increased by 117% from 1999 to 2023 (Howard et al. 2024). Last year, there were four billion-dollar floods in the United States (a tie for the record; figures 3o and S4). Since the publication of our last report (Ripple et al. 2023a), numerous other major climate-related disasters have occurred, including a series of heat waves across Asia that killed more than a thousand people and led to temperatures reaching 50°C in some parts of India (table 1). Because the Earth system is strongly nonlinear, extreme weather and disaster rates can increase dramatically in response to global warming, including impacts on plant and animal life (figure 3m, 3o and supplemental figures S4 and S5; Calvin 2019, Robinson et al. 2021).

Climate spotlight

In the present section, we spotlight recent developments in various different climate-related areas: coral bleaching, toxic orange rivers, solar radiation modification (SRM) research, climate scientists' opinion on global temperatures, climate change as a social justice issue, climate feedback loops and tipping points, and the risk of societal collapse.

Coral bleaching

Coral reefs benefit millions of people by providing a wide range of ecosystem services, including coastal protection, improved water quality, fisheries, and tourism opportunities; they also provide habitat for many species (Woodhead et al. 2019). Climate change is a particularly serious threat to coral reefs (Hoegh-Guldberg et al. 2017). Warm-water coral death is sometimes preceded by bleaching—the loss of a symbiotic relationship with microalgae (figure 5a; Hoegh-Guldberg et al. 2017). When a sharp spike in sea temperature unfolds well above the long-term average summer maximum, many corals die quickly within a week or two without having time to bleach. Others bleach and either die more slowly over a period of a few months or regain their color and survive (Hughes et al. 2018). As of 2024, extraordinarily warm ocean temperatures (figure 1a) are driving the fourth global-scale coral bleaching event ever recorded (previous events: 1998, 2010, 2014–2017; Thiern 2024).

Toxic orange rivers

Climate change in the Arctic is altering watershed hydrology and water biogeochemistry. Recently, researchers have observed an

emergent threat in Arctic streams that turned orange because of increased iron and toxic metals (figure 5b). This discoloration began in the last decade, coinciding with rapid global warming and permafrost thaw (O'Donnell et al. 2024). Compared with clear streams, orange streams are more acidic, have higher turbidity, and have elevated sulfate, iron, and trace metals. This discoloration correlates with declines in macroinvertebrate diversity and fish abundance, affecting drinking water and subsistence fisheries in rural Alaska (O'Donnell et al. 2024).

Solar radiation modification research

SRM research, also known as *solar geoengineering research*, has been dramatically increasing in recent years (figure 5c). It involves potentially risky techniques to reflect sunlight away from Earth to mitigate climate change effects. General categories of SRM include atmospheric, terrestrial, and space-based applications (Keith 2020). Specific methods, for example, include injecting aerosols into the stratosphere or brightening marine clouds. The Intergovernmental Panel on Climate Change (IPCC) has concluded that stratospheric aerosol injection is the most-researched SRM method, but there are a number of environmental concerns (IPCC 2018, Vioni et al. 2020). SRMs are also controversial because of potential unintended consequences and ethical concerns. Critics argue that it is misguided and may disrupt weather patterns and deter emissions reduction efforts (Whyte 2018). However, research continues to explore its feasibility and risks. SRM is often seen as a temporary, potentially important solution to both reduce warming and corresponding damages including for the highly important and fast-warming subpolar regions (Smith et al. 2022). Research into solar geoengineering needs to focus on understanding the potential environmental, social, and geopolitical impacts, as well as assessing effectiveness and safety on both regional and global scales (Sovacool et al. 2022). In addition, interdisciplinary research is required to explore ethical, legal, and governance frameworks, along with public perception and acceptance, while emphasizing the critical importance of drastically reducing greenhouse gas emissions. There is a consensus study available as a roadmap for solar geoengineering research and research governance (National Academies of Sciences, Engineering, and Medicine 2021).

Climate scientists' opinion on global temperatures

A 2024 opinion poll has unveiled the predictions of hundreds of prominent climate scientists of the IPCC, senior authors, and review editors (380 respondents). From a personal perspective, nearly 80% of these scientists anticipate global temperatures increasing by at least 2.5°C above preindustrial levels by the end of the century (Carrington 2024). Nearly half of them foresee a rise of at least 3°C. A mere 6% believe that the internationally agreed-on limit of 1.5°C will be achieved (figure 5d). This parallels an earlier survey of IPCC scientists, which showed that approximately 60% expected warming of at least 3°C (Tollefson 2021). These projections paint a bleak picture of the future, with many scientists envisioning widespread famines, conflicts, mass migration, and increasing extreme weather that will surpass anything witnessed thus far, posing catastrophic consequences for both humanity and the biosphere (Carrington 2024). It is important to keep in mind, however, that such characterizations can suffer from conflation of matters of science (i.e., how much warming are we committed to for a given emissions pathway) and matters of policy (what pathways are still possible and what the obstacles are).

Untold Human Suffering in Pictures



Figure 4. Photograph series depicting the impacts of climate-related disasters. First row (left to right): Rescue of people stranded by floods in the city of Canoas, Rio Grande do Sul (Brazil, 2024; Duda Fortes, Agência RBS), “Drought in Ethiopia due to rains unrealised” (Ethiopia, 2011; Oxfam East Africa; CC BY 2.0). Second row: Firefighters contain a bushfire burning around the town of Aberdare (Australia, 2013; Quarrie Photography, Jeff Walsh, Cass Hodge; CC BY-NC-ND 2.0), The aftermath of Hurricane Matthew (Haiti, 2016; UN Photo/Logan Abassi; CC BY-NC-ND 2.0). Third row: Inspection of a storm-damaged roadway in California (United States, 2023; Andrew Avitt/USDA Forest Service), Remnants of a house on Leyte island that was destroyed by Typhoon Haiyan (The Philippines, 2013; Trocaire/Wikimedia; CC BY 2.0). All quotes are from the Climate Visuals project (<https://climatevisuals.org>). See supplemental file S1 for details and more pictures.

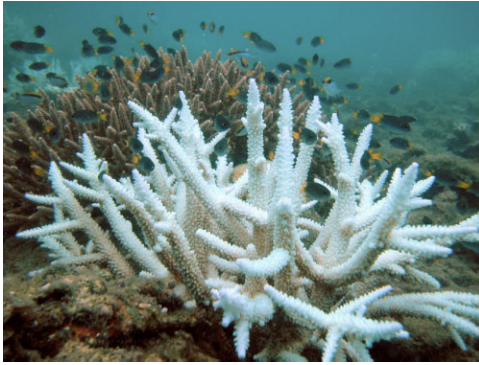
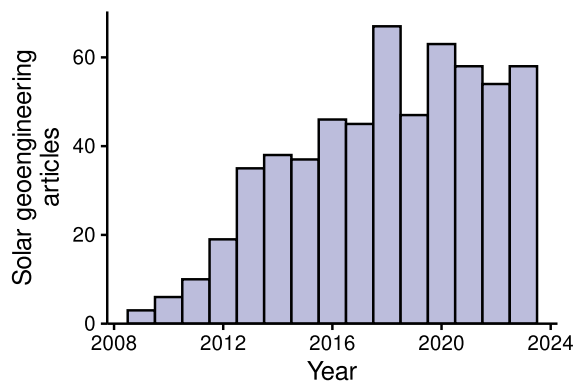
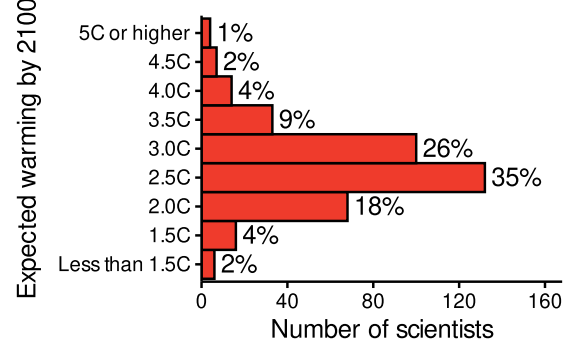
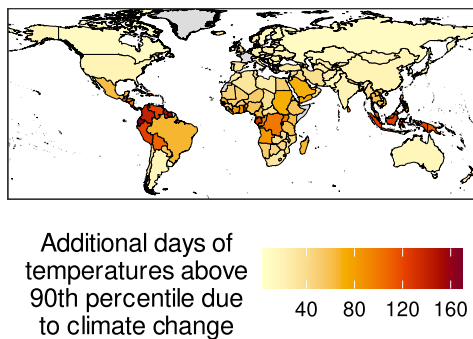
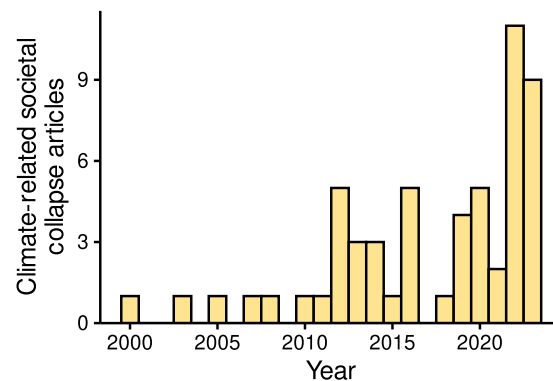
a. Coral bleaching**b. Toxic orange rivers****c. Solar Radiation Modification****d. Climate scientists' opinion on global temperatures****e. Climate change as a social justice issue****f. Risk of societal collapse**

Figure 5. Climate change spotlight topics. Already, many serious climate impacts are occurring, including coral bleaching (a) and permafrost thaw contributing to orange rivers with reduced fish abundance and drinking water quality (b). Recent years have seen a dramatic increase in the number of scientific publications related to solar radiation modification (c). A survey of hundreds of IPCC senior authors and review editors indicates that the majority expect catastrophic warming of at least 2.5 degrees Celsius this century (d). Extreme heat is expected to disproportionately affect people in less wealthy countries that have lower emissions (e). Climate change could eventually contribute to societal collapse—a possibility that is increasingly being considered by researchers (f). See supplemental file S1 for data sources and details. Photographs: (a) Acropora/Wikimedia Commons, (b) Ken Hill/National Park Service.

There is no way to know, for example, whether the polled IPCC physical scientists based their assessments on the science or simply on their views of the political prospects for action (Mann and Hayhoe 2024).

One of the numerous challenges for scientists is how to communicate about climate change (Guenther 2024). Some have argued that attitudes of pessimism and resignation can be obstructive to climate action. Moreover, some say those who oppose action have resorted to alternative strategies including the propagation of pessimism, because embracing a sense of helplessness

can undermine the motivation for action (Mann and Hayhoe 2024). Conversely, it has also been suggested that optimism gives rise to inaction, if people think things are fine and therefore action is not needed (Wilson 2021). In any case, the importance of tone may be overstated in this context, and more research is needed to better identify motivating factors for climate action (Bamberg et al. 2018).

With the increasingly undeniable effects of climate change, a dire assessment is an honest assessment. Denying the existential threat posed by climate change is becoming increasingly less

Table 2a. Summary of amplifying physical feedback loops.

Feedback	Effect of climate change	Effect on climate change
Water vapor [†]	↑ Increasing water vapor content	↑ Greenhouse effect
Sea ice albedo ^{*†}	↑ Sea ice melting or not forming	↓ Albedo
Ice sheets ^{*†‡}	↑ Glacier and ice sheet melting/instability	↓ Albedo
Sea level rise [‡]	↑ Sea levels	↓ Albedo (↑ coastal submergence)
Snow cover [†]	↓ Snow cover	↓ Albedo
Clouds [†]	Δ Cloud distribution and optical properties	Δ Cloud albedo and greenhouse effect
Ocean stratification	↑ Ocean stratification	↓ Carbon uptake by ocean
Solubility pump [†]	↑ Atmos. CO ₂ levels	↓ CO ₂ absorption by ocean
CH ₄ hydrates ^{*†}	↑ CH ₄ hydrate dissociation rates	↑ Release of CH ₄ into atmos.
Ice–elevation [‡]	↓ Ice sheet or glacier elevation	↑ Glacier and ice sheet melting, ↓ albedo
Antarctic rainfall [‡]	↓ Ice sheet extent, ↑ precipitation	↓ Albedo, ↑ deep ocean warming

Note: Feedback loops that may involve tipping elements are flagged with asterisks (*). As an approximate indicator of feedback loops that are most likely to be partly included in certain climate models, feedback loops that are referenced in figure TS.17 (feedback loops overview) or figure 5.29 (biogeochemical feedback loops) of IPCC (2021) are flagged with daggers (†). Many of these feedback loops will likely have major effects on Earth's climate, but others may be more speculative. Feedback impacts operate on a range of time scales; feedback loops we believe to be particularly slow are flagged with double daggers (‡). Symbols indicate decreasing (↓), increasing (↑), and changing (Δ). Abbreviations: atmospheric, atmos.; CH₄, methane; CO₂, carbon dioxide. See Ripple and colleagues (2023b) for full loop descriptions, grouping information, limitations, and selected references. The table and caption are adapted from Ripple and colleagues (2023b).

plausible. The fact is that avoiding every tenth of a degree of warming is critically important. Rather than presenting a climate change prognosis pessimistically or optimistically, we just want to act truthfully and tell it like it is. We must emphasize both urgency and agency when it comes to our characterizations of the needed action on climate (Mann 2023).

Climate change as a social justice issue

Climate change is a matter of diversity, equity, and inclusion (DEI), because the wealthy people that emit the most greenhouse gases are generally less vulnerable to climate impacts (figure 5e). Although the ramifications of emissions are global, they are particularly severe in the Global South (Ngcamu 2023). Vulnerability to climate change is shaped by a complex interplay of social, economic, and political factors, leaving historically diverse, underserved, and marginalized communities disproportionately affected (Levy and Patz 2015). DEI principles underscore the urgency to address these disparities. Embedding climate change within the framework of organizational DEI activities may help to foster comprehensive and meaningful progress toward equity and sustainability. By recognizing the disproportionate impacts of climate change on marginalized communities, organizations can work toward rectifying historical injustices by funding countries in the Global South to maintain decarbonization while addressing urgent climate change concerns. In addition, DEI considerations are relevant to international climate policy; for example, they can help guide efforts to rapidly and equitably phase out fossil fuel extractions (Muttitt and Kartha 2020).

The ethical dimensions of climate change have led many faith leaders to speak out on the issue (e.g., Nhat Hanh 2015, Pope Francis 2023). This represents an opportunity for diverse communities to build alliances around the issue.

Climate feedback loops and tipping points

Awareness and research need to increase on climate feedback loops. Feedback loops are processes that can either amplify or reduce the effects of greenhouse gas emissions. Many significant feedback loops enhance warming. At least 28 amplifying feedback loops have been identified (tables 2a, 2b). A particularly concerning feedback loop is the permafrost feedback loop, which involves rising temperatures causing permafrost thawing. This process releases more carbon dioxide and methane, leading to further

warming. Areas of active climate feedback loop research include permafrost–cloud interactions (de Vrese et al. 2024), glacier melt-water (Pelle et al. 2023), and biodiversity (Weiskopf et al. 2024). Because feedback loops are not yet fully integrated into climate models, current emissions reduction plans might fall short in adequately limiting future warming.

Some climate feedback loops are linked to tipping points, potentially triggering major and irreversible changes in the Earth system without further pushing by human activities. Tipping elements are biophysical systems on Earth with tipping point behavior that contribute to regulating the climate system (Lenton et al. 2008). They have recently been assessed for their tipping sensitivity. Five of sixteen climate tipping elements are likely to cross their tipping points at 1.5°C: the Greenland ice sheet, the West Antarctic ice sheet, boreal permafrost, low-latitude coral reefs, and the Barents Sea Ice (Armstrong McKay et al. 2022). Several climate tipping elements are connected, and if one tips, others may tip, triggering a tipping point cascade (Wunderling et al. 2024). Overall, this points to a complex situation where climate controlling feedback loops and tipping point systems are interconnected in a way that could trigger self-perpetuating processes that amplify warming beyond human control. Therefore, we recommend the IPCC publish a special report on feedback loops and tipping points.

Risk of societal collapse

The climate emergency is not an isolated issue. Global heating, although it is catastrophic, is merely one aspect of a profound poly-crisis that includes environmental degradation, rising economic inequality, and biodiversity loss (Hoyer et al. 2023). Climate change is a glaring symptom of a deeper systemic issue: ecological overshoot, where human consumption outpaces the Earth's ability to regenerate (Rees 2023, Ripple et al. 2024). Overshoot is an inherently unstable state that cannot persist indefinitely. As pressures increase and the risk of Earth's climate system switching to a catastrophic state rises (Steffen et al. 2018), more and more scientists have begun to research the possibility of societal collapse (Brozović 2023). Even in the absence of global collapse, climate change could cause many millions of additional deaths by 2050 (WHO 2023).

Along with the broader danger of overshoot, climate change could contribute to a collapse by increasing the likelihood of

Table 2b. Summary of amplifying biological feedback loops.

Feedback	Effect of climate change	Effect on climate change
Peatlands [†]	↑ Drying and fire, ↓ Soil carbon	↑ Release of CO ₂ into atmos.
Wetlands [†]	↑ Wetlands area (↑ precipitation)	↑ CO ₂ seq., ↑ CH ₄ emissions
Freshwater	↑ Aquatic plant growth rates	↑ CH ₄ emissions
Forest dieback*	↑ Amazon and other forest dieback	↓ CO ₂ seq., Δ albedo
Northern greening	↑ Boreal forest area, Arctic vegetation	↑ CO ₂ seq., ↓ albedo
Insects	Δ Insect ranges and abundances	↓ CO ₂ seq., Δ albedo
Wildfire [†]	↑ Fire activity in some regions	↑ CO ₂ emissions, Δ albedo
Soil carbon (other)	↑ Loss of soil carbon	↑ CO ₂ emissions
Soil nitrous oxide [†]	Δ Soil microbial activity	↑ Nitrous oxide emissions
Permafrost emissions*	↑ Permafrost thawing	↑ CO ₂ and CH ₄ emissions
Permafrost–cloud	↑ Permafrost thawing, landscape drying	↓ Summer cloudiness, ↓ albedo
Soil and plant ET	↑ ET from soils and plants	↓ Latent heat flux
Microbes (other)	↑ Microbial respiration rates	↑ CO ₂ and CH ₄ emissions
Plant stress	↑ Thermal stress, ↑ droughts	↑ Plant mortality, ↓ CO ₂ seq.
Desertification	↑ Desert area	↓ CO ₂ seq., Δ albedo
Coastal productivity	↑ Coastal ecosystem degradation	↓ Coastal ecosystem carbon seq.
Metabolic rates	↑ Phytoplankton respiration rates	↑ CO ₂ released into atmos.

Note: Feedback loops that may involve tipping elements are flagged with asterisks (*). As an approximate indicator of feedback loops that are most likely to be partly included in certain climate models, feedback loops that are referenced in figure TS.17 (feedback loops overview) or figure 5.29 (biogeochemical feedback loops) of IPCC (2021) are flagged with daggers (†). Many of these feedback loops will likely have major effects on Earth's climate, but others may be more speculative. Feedback impacts operate on a range of time scales. Symbols indicate decreasing (↓), increasing (↑), and changing (Δ). Abbreviations: atmospheric, atmos.; CH₄, methane; CO₂, carbon dioxide; evapotranspiration, ET; sequestration, seq. See Ripple and colleagues (2023b) for full loop descriptions, grouping information, limitations, and selected references. The table and caption are adapted from Ripple and colleagues (2023b) with the addition of the permafrost–cloud feedback (de Vrese et al. 2024).

catastrophic risks such as international conflict or by causing multiple stresses, resulting in system-wide synchronous failures (Kemp et al. 2022). The number of published articles using *climate change* and *societal collapse* language has been dramatically increasing (figure 5f; supplemental methods). Climate change has already displaced millions of people, and has the potential to displace hundreds of millions or even billions more, leading to greater geopolitical instability (Table S3). By the end of the century, roughly one-third of people worldwide could be outside the human climate niche, facing increased risk of illness and early death, famine, and a host of other adverse outcomes (Lenton et al. 2023).

Conclusions

Despite six IPCC reports, 28 COP meetings, hundreds of other reports, and tens of thousands of scientific papers, the world has made only very minor headway on climate change, in part because of stiff resistance from those benefiting financially from the current fossil-fuel based system. We are currently going in the wrong direction, and our increasing fossil fuel consumption and rising greenhouse gas emissions are driving us toward a climate catastrophe. We fear the danger of climate breakdown. The evidence we observe is both alarming and undeniable, but it is this very shock that drives us to action. We recognize the profound urgency of addressing this global challenge, especially the horrific outlook for the world's poor. We feel the courage and determination to seek transformative science-based solutions across all aspects of society (table S4). Our goal is to provide clear, evidence-based insights that inspire informed and bold responses from citizens to researchers and world leaders.

Rapidly phasing down fossil fuel use should be a top priority. This might be accomplished partly through a sufficiently high global carbon price that could restrain emissions by the wealthy while potentially providing funding for much-needed climate mitigation and adaptation programs. In addition, pricing and reducing methane emissions is critical for effectively mitigating climate change. Methane is a potent greenhouse gas, and unlike carbon

dioxide, which persists in the atmosphere for centuries, methane has a relatively short atmospheric lifetime, making reductions impactful in the short term (Shindell et al. 2024). Drastically cutting methane emissions can slow the near-term rate of global warming, helping to avoid tipping points and extreme climate impacts.

In a world with finite resources, unlimited growth is a perilous illusion. We need bold, transformative change: drastically reducing overconsumption and waste, especially by the affluent, stabilizing and gradually reducing the human population through empowering education and rights for girls and women, reforming food production systems to support more plant-based eating, and adopting an ecological and post-growth economics framework that ensures social justice (Table S4). Climate change instruction should be integrated into secondary and higher education core curriculums worldwide to raise awareness, improve climate literacy, and empower learners to take action. We also need more immediate efforts to protect, restore, or rewild ecosystems.

The surge in yearly climate disasters shows we are in a major crisis with worse to come if we continue with business as usual. Today, more than ever, our actions matter for the stable climate system that has supported us for thousands of years. Humanity's future depends on our creativity, moral fiber, and perseverance. We must urgently reduce ecological overshoot and pursue immediate large-scale climate change mitigation and adaptation to limit near-term damage. Only through decisive action can we safeguard the natural world, avert profound human suffering, and ensure that future generations inherit the livable world they deserve. The future of humanity hangs in the balance.

Supplemental material

Supplemental data are available at BIOSCI online.

The methods and details of planetary vital sign variables used in this report along with other discussion appear in supplemental file S1 of this article. A list of the scientist signatories for Ripple and colleagues (2020) as of 29 March 2023 appears in supplemental file S2 of this article. Note that these signatures are not for the current article.

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The World Scientists' Warning of a Climate Emergency paper (Ripple et al. 2020) now has more than 15,600 signatories from 165 countries, and we continue to collect signatures from scientists. To sign or learn more, visit the Alliance of World Scientists website at <https://scientistswarning.forestry.oregonstate.edu>. To view A Scientist's Warning, a recent documentary film on scientists speaking out, visit <https://www.youtube.com/watch?v=byXGCPo-80w>.

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Article

Effect of Topography on Persistent Fire Refugia of the Canadian Rocky Mountains

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Abstract: Persistent fire refugia, which are forest stands that have survived multiple fires, play an important ecological role in the resilience of mountainous forest ecosystems following disturbances. The loss of numerous refugia patches to large, high-severity fires in recent years is prompting the need to better understand drivers of fire refugia endurance. We investigate the role of topographic features on fire refugia survivorship based on pre-1950 fire regime conditions. Mapped refugia patches ($n = 557$) covering 28% of the forested landscape were used to develop three predictive models based on patch size (all sizes, <30 ha, <10 ha), as a function of explanatory variables describing several components of topography. Five topographic variables consistently favoured persistent fire refugia occurrence, though the ranking of explanatory variable importance varied among patch-size models. For the all-refugia model, elevation (23.7%), proportion of non-fuel at a 5000-m scale (20.3%), solar radiation (14.6%), Topographic Position Index at a 2000-m scale (10.1%), and distance from rivers (10.1%) were the top variables. The models' predictive abilities were high, but decreased with larger patch sizes. We conclude that many suitable areas are currently unoccupied by fire refugia; that random elements affect their survivorship; and that additional environmental factors not considered in this study may contribute to their persistence. With changing climate and fire-regime conditions, careful fire and forest management considerations will be needed to limit future losses of persistent fire refugia forests.

Keywords: Alberta; boosted regression trees; Canadian Rockies; fire refugia; mountains; subalpine; topography; wildfire

1. Introduction

The simple definition of a forest fire refugium is a forested area, big or small, that has escaped burning. However, various studies define the state of what qualifies as refugia, or fire refugia, differently. Franklin et al. [1] define refugia as areas persisting through a disturbance that contain biological legacies, such as organisms, organic materials, and organically generated patterns, which can be incorporated into the recovering ecosystem. Generally speaking, fire refugia are the result of site characteristics and spatial locations favouring lower fire susceptibilities [2,3]. Some consider residual island remnants within a recent fire to be refugia [4,5], whereas others are more concerned with persistences in which some patches of forests can survive multiple fires [2,3]. In the context of this study, persistent fire refugia are examined. Persistent fire refugia patches are common in the Canadian Rocky Mountains of Alberta (hereafter 'Alberta Rockies'), which is remarkable considering how active fire has been on the landscape during the last millennium [6–8].

In this fire-prone environment, fire refugia are forest stands that have escaped wildfires for centuries. They represent old-age forest patches embedded in or on the periphery of a historically active fire mosaic. Embedded patches tend to be the outcome of remnant patches having survived lower-intensity fires from short fire intervals and having built resistance over time through fuel development characteristics. In contrast, peripheral fire refugia patches do not tend to show evidence of surviving multiple fires, because fires do not repeatedly spread along the same footprint. In the context of this study, we defined and identified persistent fire refugia based on the guideline that stand ages had to be three times greater than the median fire return interval (“FRI”) [9]. In this case, fire refugia correspond to forests older than approximately 300 years given the historical fire regime of the Subalpine Natural Subregion of southern Alberta is regulated by a median FRI of 90 years [8].

The role of fire refugia in overall ecosystem functions and health is significant [10]. Refugias’ biological legacies contribute to faster ecosystem recovery following large and intense fire disturbances, as they form small ecological pools from which seeds can propagate [11]. This ecological function is particularly important for mesic sites in high-elevation terrain where common pioneer species, such as lodgepole pine (*Pinus contorta* subsp. *latifolia* Loudon) and aspen (*Populus tremuloides* Michx.), are outside of their ecological range and cannot effectively contribute to forest recolonisation following fire [12]. Fire refugia add to the overall biodiversity of a watershed by offering a diversified age-class mosaic [13,14] and by providing ecological niches specific to life organisms living in old-growth forests. In addition, forests older than 250 years are superior carbon sinks, due to increased carbon storage capacity through large wood volume, large coarse woody debris, and soil and ground organic matter [15]. The well-developed moss and shrub layers of old forests also contribute to stream bank stability [16] and stream water quality through sediment retention, water filtering and cooling [17]. The destruction of these stands by wildfire negatively impacts water quality for several years, due to the profuse release of sediments [18], nutrients [19,20], and heavy metals [21,22] that have accumulated over centuries.

Topography, being one of the components of the fire environment controlling fire behaviour [23,24], can greatly influence the pattern of fire spread in mountain landscapes [25]. Many wildland fire studies have examined the relationship between topographic elements and fire occurrence. In rugged terrain in the northern hemisphere, aspect, which influences the amount of solar radiation on slopes, is consistently associated with shorter FRIs on warmer slopes (S and W facing), whereas cooler aspects (N, and E facing) host older-aged forests due to longer FRIs [9,11,26–30]. Other variables commonly tested include elevation [9,28], convergent and divergent landforms [11,26,30,31], slope [9,27,28], and fuel continuity or fire barriers [27,29,32].

Few studies have focused specifically on factors explaining the survivorship of fire residual patches, either ephemeral or persistent [2,4,5,33]. The most recent studies examined numerous terrain metrics, including slope and aspect, and characteristics of the catchment basin, as well as topographic indices of wetness, convergence and wind shelter, along with climate and fire weather. They found that catchment slope, catchment aspect and topographic wetness index were the most significant model components for predicting fire residual patches density in northern New Mexico, USA [5]. In contrast, flat and moderate topographic complexity within a rugged mountain environment produced a greater proportion of unburned area under benign and moderate fire weather condition scenarios [4]. We expect that certain combinations of topographic elements can greatly increase the probabilities of survival and development of fire refugia zones in the Alberta Rockies, notably fire barriers. Patches of forests adjacent to features that do not support burning, or that reduce fire spread significantly, such as rocky outcrops, water bodies, or a vegetation type with low flammability, have better chances of escaping fire [9,32,34,35] (Figure A1).

In this study, we seek to identify topographic components favouring the persistence of fire refugia in the Alberta Rockies. Specific objectives consisted of: (1) assessing the contribution of topographic variables to fire refugia occurrence; (2) evaluating the functional form of the response between refugia occurrence and top explanatory variables; and (3) predicting and mapping the likelihood of refugia. Models were produced for different size thresholds to determine if controls of fire refugia occurrence vary

by refugia patch size. A large mountain landscape in the Alberta Rockies was chosen for its available fire refugia data set, which was produced from aerial photographs taken ca. 1950, capturing historical burning patterns before climate change and significant improvement to the effectiveness of fire suppression.

2. Materials and Methods

2.1. Study Area

The study area forms a total land base of 911,951 ha, 47% of which is forested (425,011 ha), and represents a collection of adjacent land jurisdictions located in the Alberta Rockies. It includes: Banff National Park (BNP), the Whitegoat and Siffleur Wilderness Areas (WSWA) including the North Saskatchewan Valley from BNP east boundary to the middle of Abraham Lake, the Spray Lake Recreation Area (SLRA), and the Elbow watershed (Figure 1). The majority of the area is in the Subalpine Natural Subregion, with the exception of main drainage valley bottoms (i.e., Bow and North Saskatchewan valleys) between 1400 and 1600 m, which are part of the Montane Natural Subregion. Nearly 50% of the subalpine is composed of rock and ice, heavily dissecting the forest cover. The treeline is found at around 2200 m. Serotinous lodgepole pine is the main fire-adapted species colonizing the Montane, the lower Subalpine and it can also be found in the upper Subalpine on warm aspects [36]. Engelmann spruce (*Picea engelmannii* Parry ex Engelm)—subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forest communities favour mesic conditions and are found in wetter areas of the Montane, and on cool facing slopes and high elevations of the Subalpine [36]. Alpine larch (*Larix lyalii* Parl.) are found along the treeline of the Subalpine, while pockets of aspen trees tend to be restricted to the Montane or the lowest elevations of the Subalpine.

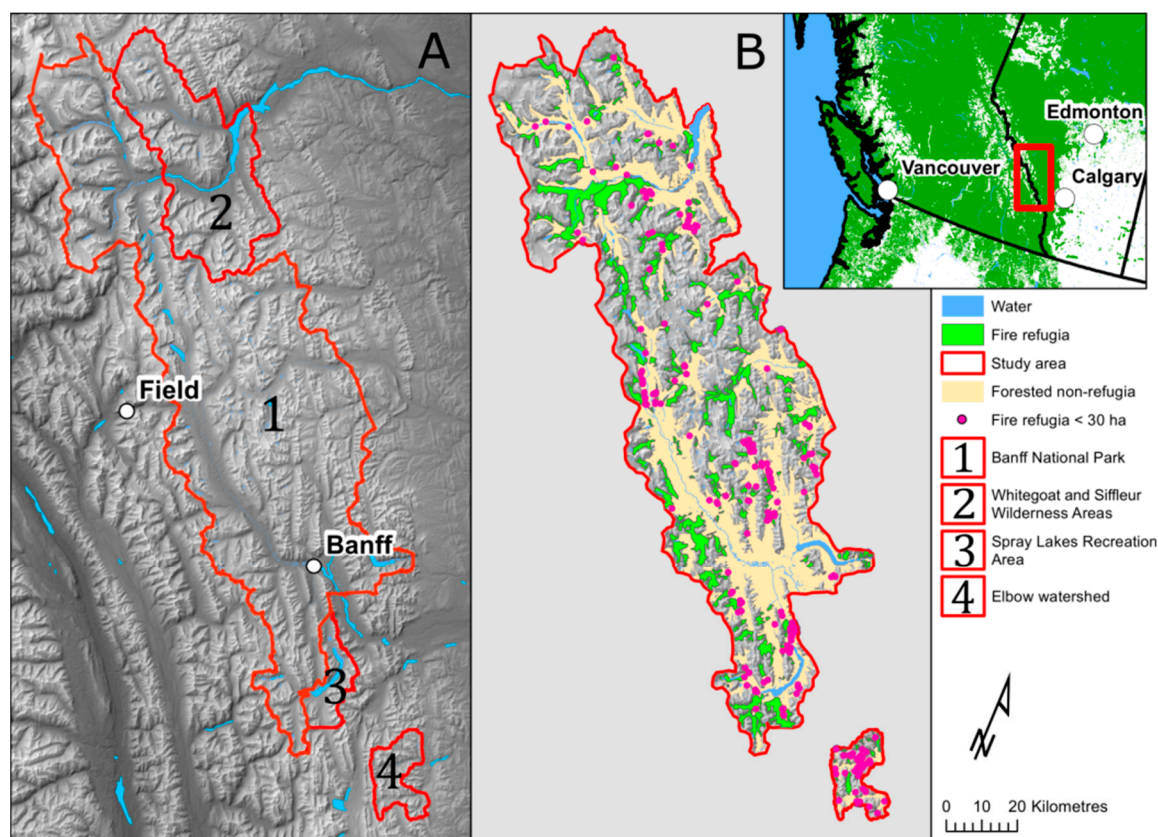


Figure 1. (A) Study area located in the Canadian Rocky Mountains of Alberta, Canada, composed of four jurisdictions; (B) Distribution of fire refugia patches (green), within the forested zone (beige). Refugia smaller than 30 ha are highlighted using pink dots.

As a result of ecological succession, persistent fire refugia patches are largely composed of Engelmann spruce—subalpine fir [36]. Lodgepole pine trees, which have a shorter life expectancy than the long fire-free intervals associated with fire refugia, tend to be sparse. However, they can still be an important component of refugia stands located on warm aspects and at lower elevations. Refugia represent decadent old-growth forests renewing themselves through small gap dynamics as a result of individual tree or tree cluster mortality [37–39]. Stands are made up of scattered large-diameter trees, standing live and dead, with in-filling of multi-size trees forming a layered canopy [13,14,40]. Large-diameter down woody debris in various degrees of decomposition and with various states of moss cover are scattered throughout [40]. The stands often include open pockets that can be vegetated by a shrub layer and small trees, as well as dense pockets of in-filling subalpine fir trees [41].

The study area is located on the east side of the Continental Divide and is subject to a lightning strike shadow resulting in a considerably lower risk of lightning fires (Figure A2) [42]. The Montane fire regime is almost exclusively driven by anthropogenic fires [8,43]. In spite of being lightning-ignition limited, there is abundant evidence of historical fires having contributed to shaping the forest mosaic of subalpine landscapes for thousands of years [6]. Fire frequency is significantly greater in the Montane, with a median FRI of about 30 years [8]. In the Subalpine, the median FRI is 90 years [8], but important spatial variations in FRIs based on topographic locations have been recorded [9,44].

2.2. Fire Refugia Data Set

All jurisdictions had existing field-based fire history data, from which either complete-stand-origin maps or fire-refugia-only maps were produced [45–49]. Fire history sampling methods followed those developed for stand-replacing fires [50,51]. While the sampling design at the time was not meant to study fire refugia, the large number of sample plots (1879) and tree cross-sections collected (6101) ensured all age cohorts present on the landscape were well sampled. Sampling plots were positioned on the edge of stand boundaries and four cross-sections on average were collected from dominant trees on each side of stand ecotones. The majority of fire refugia patches were identified from stand-origin dates, as few fire scars, if any, remained for dating old-growth forests in this stand-replacing fire regime environment. Not all fire refugia patches were visited due to difficulty of access on mountain flanks. Aerial photo interpretation using photography from ca. 1950, in combination with age data from nearby similar-looking stands, were used to assign stand-origin dates. Due to the distinctive photo tone and texture associated with old forests within a fire-generated forest mosaic, we are confident that fire refugia stands were correctly identified.

By using the rule of thumb of three times the length of the median FRI, forest stand-origin pre-dating 1700 were used to form the fire refugia data set. The mapping resolution ranged from 2 to 9 ha due to the variable map scales used. The pre-2000 stand-origin mapping was done at a coarser scale of 100 m, whereas fire refugia patches for the Elbow watershed were digitised on-screen from 2007, 0.5 m resolution, ortho-rectified imagery using 1949 aerial photography and fire history plots to guide fire refugia mapping. In total, 557 fire refugia polygons were identified within the study area. Collectively, they amount to 117,515 ha, representing 27.7% of the forested land base (425,011 ha). Fifty percent of patches were less than 30 ha in size, while 37% were less than 10 ha. In spite of the important number of small-sized refugia patches, they amount to only 1.8% and 0.7% of the total fire refugia area, respectively. Due to the large number of small-sized refugia patches available, we used these two patch size thresholds to verify whether small size refugia responded differently to topographic features than those of greater size. The spatial distribution of fire refugia is strongly associated with the Subalpine Natural Subregion, as few patches were recorded at valley bottom in the Montane. A visual assessment of the data showed a fairly even distribution of refugia patches throughout most of the subalpine watersheds within the study area.

Forest species composition is often a controlling element of fire regime characteristics [52,53], and fire refugia could potentially respond differently to topographic features based on vegetation. In our study, we decided not to address this component, as our refugia patches showed an

overwhelming dominance of spruce fir stands, which would make a topographic species response analysis difficult to interpret. We were also mindful that in rugged mountains, both aspect and elevation govern the micro-climate and ensuing species assemblage. In that regard, high correlations of FRI response between spruce and high elevation and cool aspects have been identified in the Alberta Rockies [9].

2.3. Topographic Variables Data Set

We considered topographic variables that could ecologically explain consistent changes in fire behaviour and fire spread patterns to the benefit of long-term forest survival during wildfire events. Following a literature review of studies having examined topographic elements in relation to fire residual patches [2,4,5,32], we shortlisted ten topographic variables believed to strongly influence persistent fire refugia: elevation, slope, solar radiation as a surrogate for aspect, topographic position index (TPI) [54], maximum rate of slope curvature change (maxcurv), which detects convergent and divergent terrain, proportion of non-fuel (NF), and distance from rivers (Strahler stream order ≥ 5) as a mean to capture headwaters of side drainages. Total annual solar radiation (Mwh/m^2) was calculated using the Area Solar Radiation tool from the Spatial Analyst Extension [55] in ArcGIS. The proportion of non-fuel (rocks and water) was calculated from the Ecological Land Classification Map for Banff National Park [56], from the Alberta Ground Cover Classification Mosaic [57,58] for the Elbow Watershed, and from 1:50,000 National Topographic Survey maps for the rest of the landscape. The remainder of the topographic variables were derived from a 30-m digital elevation model (DEM) produced from Canadian Digital Elevation Data at a scale of 1:250,000 [59].

Many area-based environmental variables are scale dependent [60]. Consequently, we assessed various scales as circular windows for TPI, NF, and maxcurv. TPI was tested at a scale of 300 m, 500 m, 1000 m, 2000 m, and 4000 m; NF was tested at a scale of 300 m, 500 m, 1000 m, 2000 m, and 5000 m; whereas maxcurv was tested at a scale of 300 m, 500 m, 1000 m, and 2000 m. This brought the total number of variables examined to 17. All topographic variables were mapped at 100-m resolution using Idrisi TerreSet [55,61,62].

The following variables are commonly assessed in topographic analysis studies, but we chose to exclude them. Topographic ruggedness index (TRI) had a strong association with rocky terrain above treeline, whereas less rugged values largely corresponded to the forested area, making it a poor indicator of refugia on the landscape. Similarly, topographic wetness index (TWI) had low scores across all angled terrain and only showed high scores for valley bottoms of main rivers. We also opted against any catchment metric variables aiming to capture cool-air-pool (CAP) drainages [63]. The Canadian Rockies do not have canyon-type ecosystems, and the few narrow canyons existing do not contain much treed vegetation that could become climate refugia. Hanging catchments in the upper Subalpine do not tend to be cold-air sinks during fire spread events associated with hot days. During the day, heated air rises along slopes, an effect that is exacerbated on warm aspects. Thus, the likelihood of a catchment metric being associated with persistent fire refugia is unlikely.

2.4. Topographic Variable Selection

The exploratory variable selection was performed through a series of steps to minimise the number of variables used in the prediction model. The Spearman rank correlation test served to eliminate highly correlated variables with a $|r| \geq 0.7$. In order to select the best variable from each correlated group of variables, we built single-variable generalised additive models (GAMs) predicting refugia presence for each independent variable. The variable with the higher deviance explained in each correlated group was retained. This resulted in the retention of nine independent variables to be considered for analysis (Table 1).

Table 1. Description of lead topographic variables considered. Value minimums, maximums, means and standard deviations are presented.

Variable Name	Description	Min.	Max.	Mean	STD
Elev	Elevation (m)	1291	3543	2163	383
maxcurv-1000 m	Maximum rate of slope curvature change in a 1000-m window	−0.0014	0.0181	0.0004	0.0005
maxcurv-300 m	Maximum rate of slope curvature change in a 300-m window	−0.0068	0.0977	0.0011	0.0019
Nonfuel-1000 m	Proportion of non-fuel in a 1000-m window (%)	0	100.00	57.61	42.40
Nonfuel-5000 m	Proportion of non-fuel in a 5000-m window (%)	0	100.00	58.44	30.13
Distance	Distance from rivers (m)	0	32,931	4963	6356
solar	Solar radiation (kWh/m ² /year)	153	1609	1078	204
TPI-2000 m	Topographic Position Index or relative position (m) in a 2000-m window	−564.77	1405.91	0.10	172.38
TPI-300 m	Topographic Position Index or relative position (m) in a 300-m window	−1373.27	661.53	0.01	14.54

2.5. Model Building and Analysis

We constructed boosted regression tree models (BRTs) of refugia presence-absence for three refugia size classes: <10 ha, <30 ha, and all refugia. BRT is a machine-learning modelling approach that fits multiple regression trees to attain high predictive performance that can account for nonlinear relationships [64]. BRTs do not require any a priori model specification or test of hypothesis [65], and can account for complex interactions among variables. The technique builds regression trees through “boosting”, using a stage-wise model-fitting process to selectively build each subsequent regression tree to minimise the residuals of the previous tree. At each individual tree, the training data is split by a ratio (i.e., the bag fraction), which defines the proportion of the training data to use to build a tree.

To ensure that each refugia size class model was generated in an unbiased fashion, all three models used the same nine variables. BRT model-building methods followed [66]. We used a stratified random sampling approach to extract 10,000 sample points for each of the three refugia size classes, and 10,000 absence (i.e., non-refugia) points in other forested areas. Each refugia size model was built from a random subset of 400 points from the presence pool of points and 400 points from the absence pool of points. We repeated this process 100 times and averaged the resulting 100 BRT models to create an ensemble model for each size class. This approach allowed for selecting different sample points between each individual sub-model in order to capture variation in fine-scale topographic variables and to limit the stochasticity in model outcomes.

All models were fitted using R gbm package [67]. We assumed a Bernoulli squared error loss function, given that our response variable was binomial. We built the models using 3-fold cross validation, a bag fraction of 0.5, and a tree complexity of 5. Tree complexity refers to the number of nodes in a tree, and we deemed a 5-node tree to be sufficiently deep to capture moderately complex interactions between topographic variables. We used a learning rate of 0.02, 0.015, and 0.005 for the <10 ha, <30 ha, and all-refugia models, respectively. We adjusted this learning rate for the three models such that each fire refugia class model built between 500 and 1500 regression trees for each submodel of the ensemble. The number of trees in each submodel corresponded to the point at which adding more trees would reduce cross-validated model performance. We performed model validation using *k*-fold cross-validation, which randomly divides the sample into *k* subsamples, of which a single subsample is retained for model validation, and the remaining folds are used for model training. Model performance was assessed using cross-validated area under the receiver operating characteristic curve (AUC), a measure of how well the model can distinguish between refugia and non-refugia. All test subsets are considered and the results from all *k* folds are then averaged.

Variable importance was assessed for each variable of the three refugia-size models. As computed from the gbm package [67], variable importance consists of the number of times the variable was selected as a tree node and the improvement resulting from including those nodes. We plotted the relative contribution for each variable as a percentage of the total deviance explained.

As a complement to the variable importance, we evaluated the relationships of likelihood of fire refugia to the top explanatory variables for each refugia-size model. The top five variables of the all-refugia model were retained for this analysis. These relationships were visualised by plotting the partial dependence to each explanatory variable of interest. Partial dependence plots represent the marginal effect of a given variable by holding the values of all other variables of the model constant at their mean value, thereby statistically controlling for the effect of these variables. The variable importance and partial dependence plots can be interpreted together to provide both the relative importance and the relationship of each explanatory variable to fire-refugia presence.

Finally, model predictions were mapped for each refugia-size model using the raster package in R [68]. The modelled likelihood of fire refugia was also mapped for each observed refugia patch, in order to assess model predictions on a per-patch basis.

3. Results

Mean model cross-validated AUC were 0.71, 0.77, and 0.84 for the all-refugia, <30 ha, and <10 ha models, respectively. BRTs consistently identified the same four topographic variables, in different orders of relative influence, as significant drivers of small, medium and all sizes of persistent fire refugia patches: elevation, the proportion of non-fuel in a 5000-m moving window, solar radiation (i.e., aspect) and distance from rivers (Figure 2). They represent a combined relative influence of 69%, 58% and 64% for the all-refugia, <30 ha, and <10 ha models, respectively. The other lead topographic variables, ranking fifth and sixth, according to the order of their relative influence among the three models, included TPI in a 2000-m moving window, the maximum rate of slope curvature change in a 1000-m moving window and proportion of non-fuel in a 1000-m moving window. While distance from rivers had less than 10% influence in the all-refugia model, its influence was 20% and 15% in the <10 ha and <30 ha models, respectively. Solar radiation had a consistent influence of 12 to 15% across all models, whereas some of the highest divergence in influence was proportion of non-fuel in a 1000-m window. At 12% influence, it ranked fifth for the <30 ha model, while it received the lowest influential score in the other models.

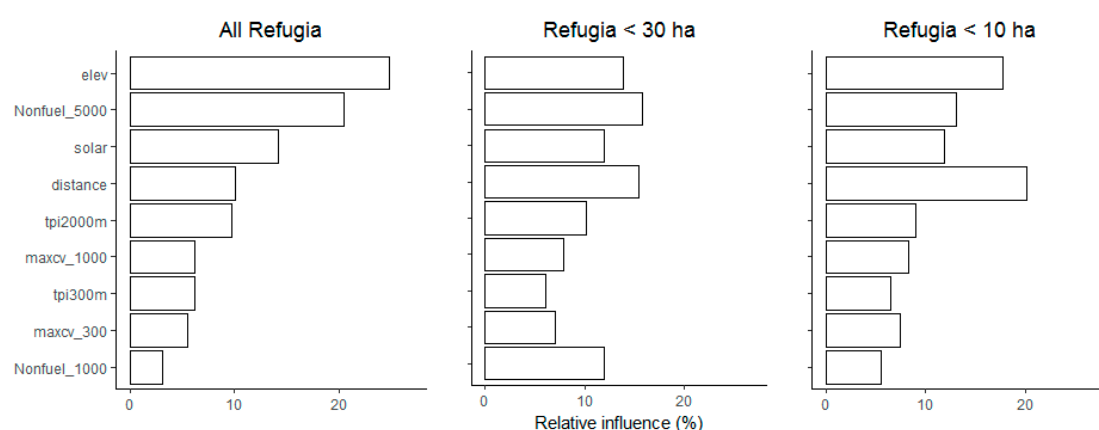


Figure 2. Relative importance of explanatory variables for each refugia size class, as percent of total deviance explained.

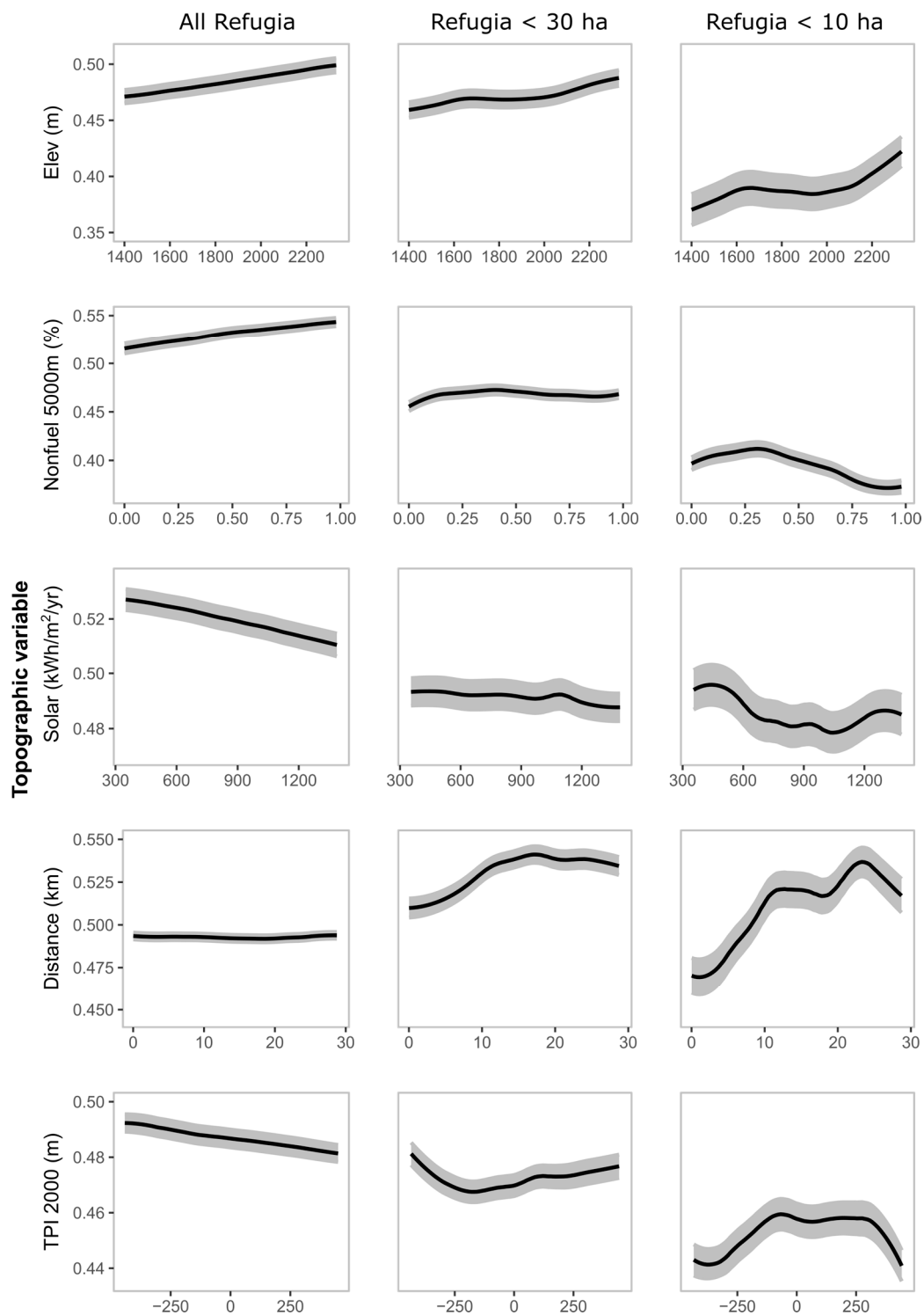


Figure 3. Partial dependence plots of fire refugia probability (y-axis) on five selected exploratory variables shown for the three fire refugia size-class models. The variables represent the five most important, as determined by the all-refugia model. Error bands represent 95% confidence intervals.

The relationships, expressed as partial dependence plots, of the likelihood of fire refugia to individual explanatory variables differed substantially among variable and among refugia-size models (Figure 3). For the all-refugia model, which is largely weighted towards patches larger than 1 km², trends tend to be linear, whereas patterns depicted in small-sized refugia models fluctuate more as

patch size decreases. Generally, there are more refugia as elevation increases, and with an increasing proportion of rocks in a 5000-m window. As solar radiation increases from cool to warm aspects, the presence of refugia diminishes. Fire refugia response to distance from rivers is relatively constant in the all-refugia model whereas the tendency is for increased number of small refugia away from main river valleys, towards headwaters. Refugia response to TPI in a 2000-m window is substantially variable, based on patch size. The all-refugia model suggests there are more refugia on towering landforms, whereas the <30 ha model indicates that refugia can be higher than the surrounding areas, as well as lower in depressed landforms. The <10 ha model points to a prevalence of refugia associated with uniform terrain and slightly lower than the surrounding land.

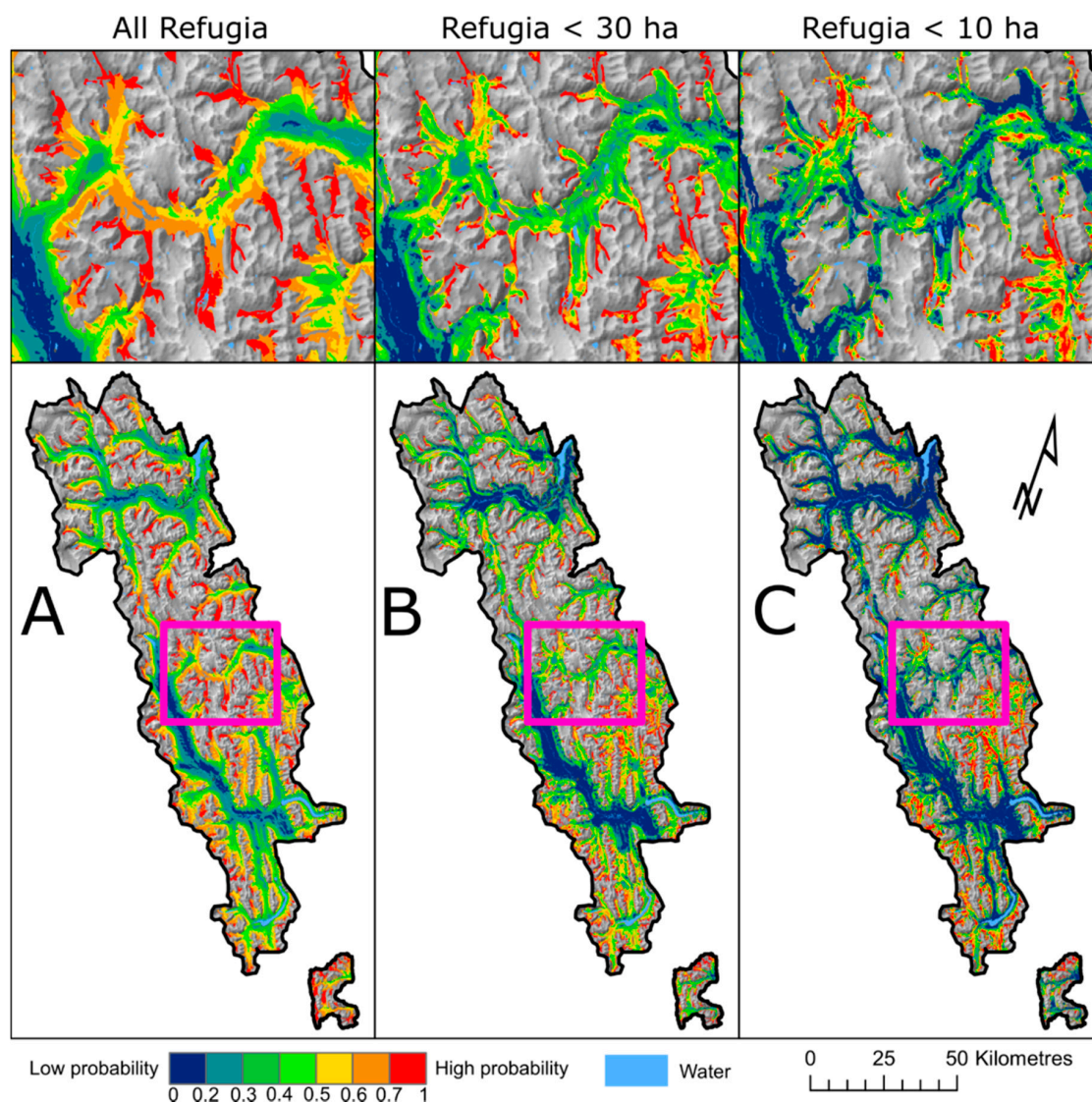


Figure 4. Model predictions of fire refugia probability. Predictions are shown for all-refugia (A); refugia <30 ha (B); and refugia <10 ha (C). Predictions were constrained to forested areas.

The spatial prediction maps of fire refugia probability show an area reduction of high probabilities (>0.7) with decreasing patch size (Figure 4). A calculation of the proportion of forested landscape falling in refugia probabilities >70% amounted to about 10% across all models, whereas the proportion of landscape showing 50% likelihood of refugia occurrence varied from 46, to 33 and 26% for the all-refugia, <30 ha and <10 ha models, respectively. When we assessed how well the models performed against the actual position of fire refugia patches in the study area, refugia falling in the >0.7 probability

zone amounted to 23, 38 and 57%, for the all-refugia, <30 ha and <10 ha models, respectively. However, the same assessment using probability zones >0.5, which is a positive likelihood of refugia occurrence, showed the models performed much better, with 71, 74 and 84% of refugia observations being well classified (Table A1, Figure A3).

4. Discussion

Given the unique perspective stemming from a rich data set covering a large-sized territory, our study provides a valuable contribution to understanding persistent fire refugia in the Canadian Rockies. The study design made it possible to define and validate spatial predictions, as well as having the flexibility to assess the role of topography on different sizes of refugia patches. The robust and meaningful model results not only identified the topographic variables that had the strongest response on persistent fire refugia, but also captured the response trends when lead variables were combined together. The validation of all three spatial prediction models of refugia size probabilities on the landscape allowed us to better understand and capture where fire refugia patches are most likely to persist. When we compared observed refugia patches against the probability of refugia occurrence map, understanding that the prediction map was built from those same refugia patches, we readily discerned which patches may truly be persistent as a result of their topographic location, versus those which may have remained more by chance (green and blue zones), given that they do not have a particular topographic setting that limits fire ignition and spread.

Elevation, solar radiation (i.e., aspect), proportion of non-fuel in a 5000-m window, and distance from rivers were consistently the most influential topographic variables across all models, but responses varied based on fire refugia size. The all-refugia model, which is heavily weighted towards large-sized patches, showed gentle linear response trends for all lead variables. This is explained by the large extent of some refugia patches, which can fill entire side drainages, and thus individual patches can cover a wide range of topographic variations. In contrast, patches <30 ha showed more sensitivity to topographic elements—notably, elevation and distance to rivers—but the best model response was obtained from refugia patches <10 ha. The small-sized model points to a strong positive linear relationship with elevation, but the other variables tested showed fluctuating (i.e., non-linear) refugia responses, which are common with environmental variables [69]. The environmental conditions in which fires burn can be highly variable due to important changes in the weather, vegetation types, and terrain, or from subtle changes in the relative humidity, temperature, wind direction and fuel moisture content, which ultimately dictate the rate of fire spread and the direction of movement of the fire. In this context, it is important to acknowledge that an element of randomness exists in the survivorship of forest stands to fire, even for persisting fire refugia [4].

As expected, elevation was a significant driver of persistent refugia in the Alberta Rockies, given that the longest FRIs are found at higher elevations [9,70,71]. This is explained by the cooler air, higher relative humidity conditions, greater precipitation amounts and prolonged snow cover that are associated with high elevations (>1800 m). It has been determined that for every metre of increased elevation, there is a 0.33% chance of decreased probability of burning [9]; thus, stand ages can easily exceed three hundred years nearing treeline and in proximity to headwaters.

Cooler facing slopes were found to be more likely to host fire refugia, but this was not a steadfast rule, notably for the smallest refugia patches. Receiving less solar radiation, especially during the early spring and late autumn, means that fuels from north- and east-facing slopes retain more moisture and require a greater number of warm and rain-free days to be available for burning [72]. Similar to high elevations, cool aspects have a longer lasting snow cover and hold a higher relative humidity than warm-facing slopes [73]. In the Alberta Rockies, high elevations combined with cool aspects produce the longest FRIs and allow for the development of old-growth forests [9]. Thus, it is logical that this synergy would also favour the persistence of fire refugia.

Similar to studies in other fire-prone areas, forest patch isolation as a result of rocky ridges, lakes or wetlands is a strong determinant of old forests [32,35,74]. The proportion of land without

vegetation (non-fuel) in a 5000-m moving window captured the high proportion of rocks associated with small valleys bound by rocky ridges on three sides. This represents the most rugged regions of the mountains, where rocky ridges above treeline heavily dissect the forest cover and inhibit fire spread from one drainage to the other. After elevation, proportion of nonfuel was the most influential driver for the persistence of refugia patches in the all-refugia model, as many of the largest fire refugia patches (>100 ha) are located in narrow valleys surrounded by rocky ridges.

Distance from rivers was an important driver in all refugia-size models, but more so for the <30 ha and <10 ha patches. While the response is not linear, there is generally an increase in fire refugia occurrence as a function of the distance from rivers. In our study area, a first wave of refugia tends to occur in river valleys at distances less than 5 km and includes small patches along the treeline, as well as larger patches along the river banks of north-facing slopes. The second upsurge in refugia probability represents patches located in secondary and tertiary drainages (Strahler stream orders 1, 2, 3), which are furthest from the main valleys and where fire is unlikely to spread deeply into these small side drainages. The influence of distance from rivers largely resides in the probabilities of ignition, which are the greatest at valley bottom of important drainages where human travel corridors are found (roads, trails).

Historically, anthropogenic fires had a tendency to originate from main valleys in the Montane [43] and propagate into smaller drainages, provided that burning conditions were favourable and winds shifted in such a manner that flames could be pushed into small drainages [8]. In combination with favourable topographic features, areas with low probability of ignitions, from both anthropogenic and lightning sources, are the likely explanations for the persistence of the largest patches of fire refugia. We presume that smaller-sized patches are the result of a greater exposure to fire over centuries, where larger refugia stands were dissected by one or several fires, or where fire residuals within fire perimeters built resistance to burning over time.

When we compare our results to those of similar studies, we corroborate elevation [2], aspect [4,5,75,76], fuel breaks [32], relative topographic position [4,5], convergence [4,5] and headwaters [2] as also being important topographic drivers of fire refugia occurrence. However, due to the different landscapes, vegetation and fire regimes, slope did not make the top nine variables in our study, although it ranked highly in others [4,5]. This outcome may also be due to the use of different variables, as interactions between some covariates can mask the true effect of weaker variables, as well as using different spatial scales of analysis [60]. Another reason for differences between studies could be from the type of fire refugia assessed. Our refugia were largely part of the overall forest fabric where patches tend to be in periphery of fires rather than residuals within recent burns. These discrepancies in results among studies may suggest that topographic drivers are somewhat different between ephemeral and persistent refugia (Figure 5).

The assessment of land cover from the spatial predicted maps of fire refugia revealed interesting facts. Only about 10% of the forested landscape offers ideal topographic conditions in which the probabilities of refugia occurrence are estimated to be greater than 70%. This value was similar across all three refugia-size models. It highlights how vulnerable fire refugia may become in a warming climate if only 10% of the forested Subalpine offers the best sheltering topographic conditions from burning. However, given that the current cover of refugia patches already amount to 28% of the forested area, and that the majority of refugia patches were classified in zones with predicted probabilities of fire refugia greater than 50%, we deduce there could be up to 46% of the forested landscape capable of hosting large-sized persistent refugia. This number diminishes to 25% of the forested landscape for small-sized refugia patches. When we compare the current refugia cover to that from the predicted probabilities, it is clear that forests growing on topographic features amenable to the formation of fire refugia are not necessarily protected from burning. Keeping in mind that our data set reflects pre-1950 fire regime conditions, when there were more fires burning and before the current climate warming, this outcome puts forward additional questions with regard to other driving factors that may influence the sustainability of persistent fire refugia.

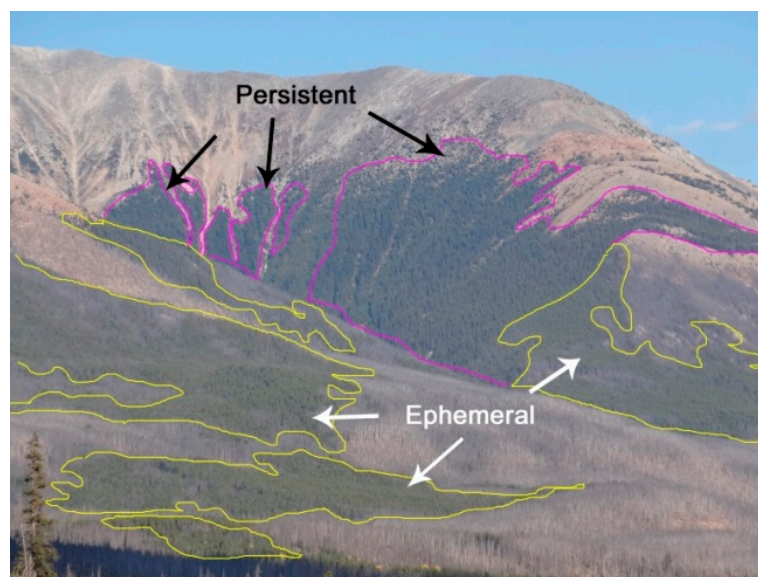


Figure 5. This photograph shows ephemeral fire refugia patches at lower elevations (in the foreground outlined in yellow) that survived the most recent fire. Ephemeral patches had burned during the previous two fires and are maintaining lodgepole pine stand communities, whereas the persistent fire refugia patches (pink outline) tucked at the headwall of a side drainage have avoided multiple fires and largely consist of spruce trees.

Given that the extent of the area with favourable topographic features is 39% greater than the current fire refugia cover, we conclude that other factors must be at play. First, there is an element of randomness to the distribution of fire refugia and their length of persistence (Figure A4), and additionally, topography itself may play a smaller role in the overall fire environment than anticipated, notably during large fire events [77]; second, other factors in combination with topography likely assist the ability of refugia to persist for centuries. Such factors could include the age of a fire refugium and its associated stage of fuel development. In subalpine old-growth forests, moist fuel conditions normally arise from a deep moss layer, large-diameter tree boles and a thick understory cover [40]. Such fuel characteristics have been found to be an important contributing factor of fire resistance of boreal forest fire refugia [78]. The amount and large diameter of snags and coarse woody debris associated with decadent forests require a drying time lag of 52 days following rain or snowmelt [72], making these stands more difficult to ignite unless there have been prolonged drought conditions.

The presence of recent burns and stands aged less than 50 years have been shown to limit the size of subsequent fires and influence future fire spread patterns [35,79–81]. The historical fire regime, which was largely anthropogenic on the east slopes of the Canadian Rocky Mountains, documented shorter pre-1950 FRIs at the valley bottom of primary drainages, which produced mixed-severity fire effects (i.e., fire intensities were variable, and fires were not entirely lethal) [8,43,72]. The stand age-resistance factor to fire ignition and spread was thus an additional contributing element enabling the development and persistence of fire refugia, notably when mean forest ages were younger within a watershed, or immediately adjacent to existing fire refugia. Coupled with key topographic conditions conducive to maintaining moister conditions such as high elevation and cool aspects [9], or being protected by fuel breaks [32], some forest stands were able to escape fire over decades and centuries during the historical fire regime. These older stands essentially built resistance against moderate-intensity fires, and even against the intensities produced from young lodgepole pine stands crowing; a typical fire behaviour associated with stands less than 60 to 70 years old, due to their high tree densities and low branches [82,83].

In this contemporary era of very large fires following decades of fire exclusion policies and a warming climate [84], we are questioning whether combinations of factors that promoted fire refugia in the past may no longer effectively do so in the future. In recent years, we have observed burning conditions in the Canadian Rockies that are conducive to producing large, high-severity fires with few island remnants, where fires burn at higher elevations, and frequently up to the treeline. Similar observations have been made in the Sierra Nevada [85] and the Northern Rockies [86]. Fuel development in tandem with sustained droughts and erratic wind events during burning are now making it exceptionally difficult for established fire refugia to survive [33,35,87]. These severe burning conditions are believed to be the results of combined factors directly affecting the fire environment once a fire has ignited. First, the warming climate trend is extending the fire season globally, both at the start and end [88]; second, long-lasting blocking ridges of high pressure have been leading to sustained drought conditions allowing for large-diameter standing fuels to dry out and burn more easily [89]; and third, the combination of fire exclusion and effective fire suppression over the last several decades has made the landscape forest mosaic more uniform from maturing forest conditions (e.g., densification, development of ladder fuels), which lead to higher intensity fires [85,90].

Following a fire hiatus of 80 years in many subalpine valleys of the Canadian Rockies, a homogeneous cover of dense mature lodgepole pine forests has developed [90] and offers little difference in canopy height or stand structure with nearby old forests or fire refugia stands. Under such fuel conditions, we believe fire suppression will have little effect, notably during extreme fire weather events. As a result, we have observed the decimation of very large old-growth patches from recent wildfires in the mountain national parks (e.g., Waterton Lake Kenow 2017 fire, Banff Spreading Creek 2015 fire). A troublesome post-fire outcome of these extreme-severity fires is the consumption of all soil organic materials, including coniferous seed banks (pers. obs. Spreading Creek Fire, Banff National Park). Under such circumstances, ecosystem resilience may be compromised considering ephemeral or persistent fire refugia are almost absent and vast expanses of area burned are far from seed sources, such as a refugium or the unburned forest mosaic.

5. Conclusions

Fire refugia are increasingly facing adverse external pressure that could eradicate these biological legacies. There is an even greater cause for concern, as results show topographic components, while having significant influence on the persistence of fire refugia, may not be as effective or as relevant as first thought under a warming climate and current fuel conditions. We are likely seeing the cascading effect of unintended consequences from decades of fire exclusion at lower elevations, exacerbated by severe droughts, and which are predicted to become more frequent in this climate warming trend. It will be necessary to further document the location and relative age of recently burned fire refugia patches to determine if randomness or a changing fire regime was the likely cause of destruction. If lost refugia are estimated to be more than 400 to 500 years old, there is a greater need for concern due to sensitive and very unique habitats being lost. With evolving climate and fuel conditions, contemporary burning regimes are changing, and the sustainability of persistent fire refugia over the next century will be challenged. The outcome of this research, derived from historical fire regime conditions, offers a benchmark from which to compare future trends. We advocate a careful management of landscapes containing persistent fire refugia (i.e., old-growth forests) moving forward.

Author Contributions: M.-A.P. and M.-P.R. conceived and designed the study; M.-P.R. and Q.E.B. prepared the data sets; Q.E.B. and M.-A.P. performed the statistical analyses; M.-P.R. interpreted the results; M.-P.R. wrote the paper with contributions from Q.E.B. and M.-A.P.

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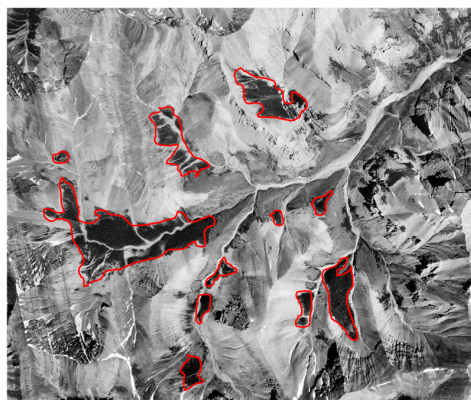
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1 and Figures A1–A3 contain supporting information on the lighting strike shadow, spatial predictions of fire refugia distribution and an illustration of what could be a persistent, random fire refugia.

Table A1. Percent area of forested land and percent area of refugia observations by fire refugia probability classes for the three fire refugia prediction models produced.

Refugia Probability	All-Refugia Model		30 ha Model		10 ha Model	
	Forested	Refugia obs.	Forested	Refugia obs.	Forested	Refugia obs.
0–10	0.00	0.00	5.23	0.27	21.63	1.27
10–20	5.03	0.74	12.57	0.58	18.72	0.89
20–30	14.91	3.91	14.64	3.28	13.80	2.66
30–40	16.64	8.53	17.02	7.10	10.95	3.80
40–50	17.78	16.35	17.42	14.93	9.14	7.47
50–60	18.16	21.49	13.91	17.81	8.64	11.39
60–70	16.58	25.95	8.96	17.72	7.29	15.06
70–80	10.63	22.32	5.65	14.43	5.71	21.01
80–90	0.27	0.70	4.20	19.96	3.35	23.16
90–100	0.00	0.00	0.40	3.91	0.76	13.29
>50%	45.63	70.46	33.12	73.83	25.76	83.92
>70%	10.90	23.02	10.25	38.31	9.83	57.47



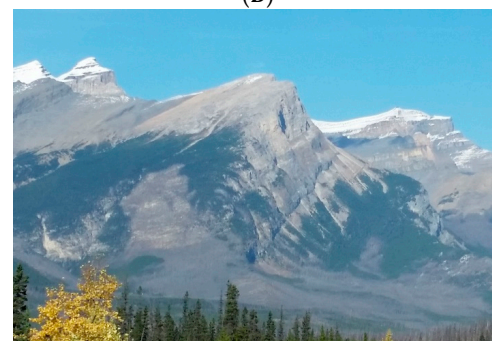
(A)



(B)



(C)



(D)

Figure A1. Examples of subalpine environment in which fire refugia patches are found: headwaters, near treeline, against fuel breaks. (A) 1949 aerial photo showing persistent fire refugia patches outlined in red following a 1910 fire that burned most of the valley; (B) Fuel breaks such as rock slides and treeline inhibit fire spread and enhances survivorship to fire; (C) Small side valley surrounded with rocks is completely composed of fire refugia forest; (D) Persistent fire refugia at high elevations avoided a prescribed burn.

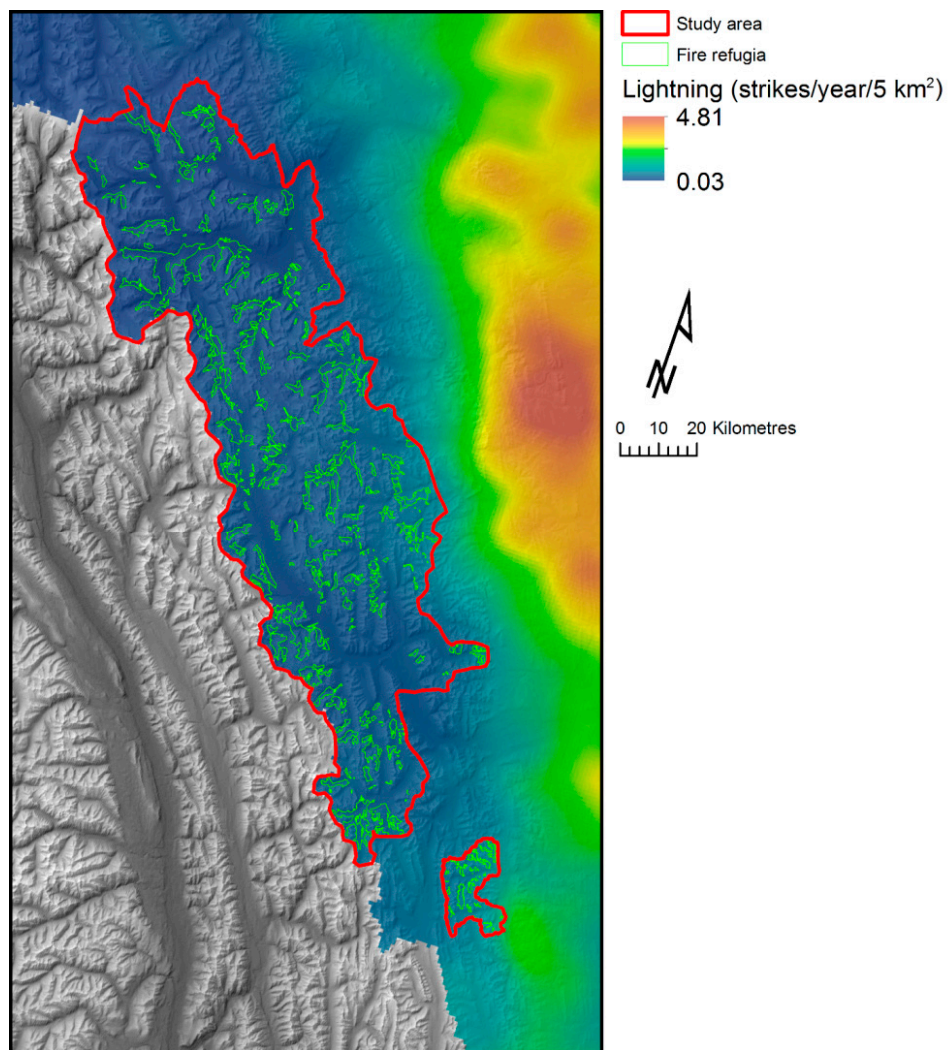


Figure A2. Average annual lightning strike density recorded over $5\text{ km} \times 5\text{ km}$ grid cells. The lightning strike shadow corresponds to the zone with less than approximately 10 strikes/year. Fire refugia patches are shown as white outlines. Lightning data source: Government of Alberta, 2006 to 2015.

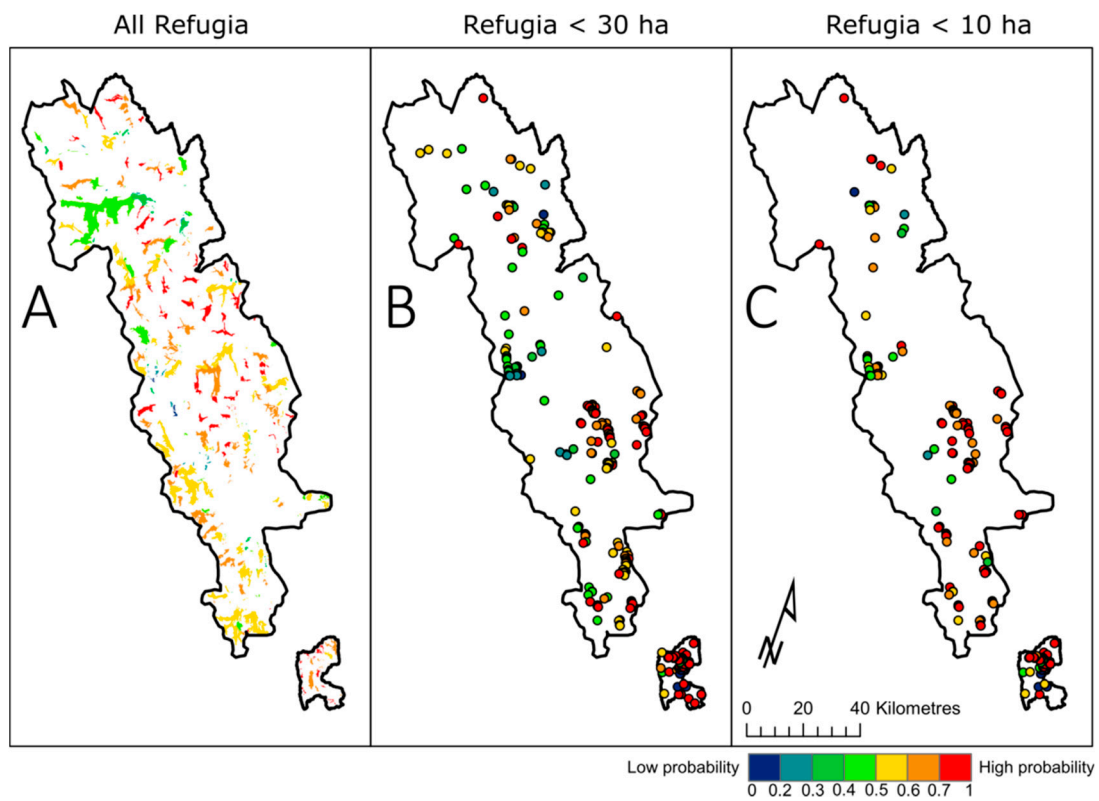


Figure A3. Model spatial prediction weighted means summarised by individual refugia for the all-refugia model (A); refugia <30 ha model (B); and refugia <10 ha model (C); refugia smaller than 30 ha are represented as points.

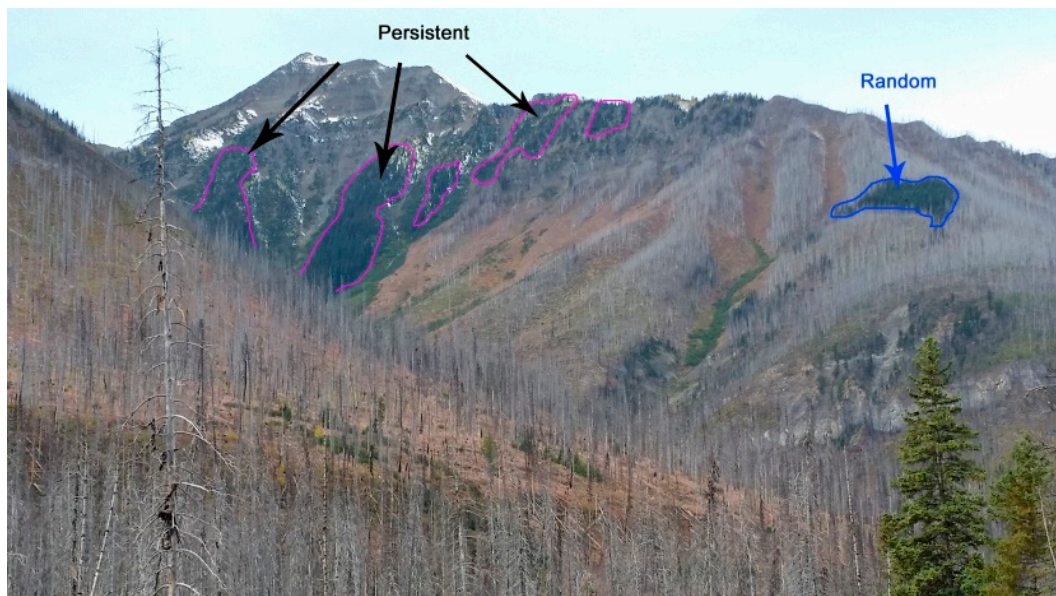


Figure A4. Persistent fire refugia patches (pink outline) are near treeline and at the headwaters of the side drainage. Whereas a refugium located mid-slope (blue outline) that was surrounded by forest may also be persistent, but owes its survival to random effects or factors other than topography.

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