Outliving the outbreak: how the landscape architecture profession can address bark beetle impacts in the Rocky Mountain region

by

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A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF LANDSCAPE ARCHITECTURE

Department of Landscape Architecture and Regional & Community Planning
College of Architecture, Planning and Design

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Abstract

Bark beetles have played a fundamental role in coniferous ecosystems for thousands of years but have recently reached unprecedented levels of reproduction and infestation within the Rocky Mountain region (Oatman 2015, Bentz 2009). In Colorado alone, mountain pine beetles and spruce beetles have killed 21% of Colorado's forests since 1996 (Romeo 2019). Concurrent outbreaks, extended north and east range, and longer lifespans of bark beetles have contributed to more significant infestations that are primarily a result of increasing temperatures and less regional precipitation (Bentz 2009). Mountain-based industries such as skiing, tourism, and recreation are threatened by loss of tree stands and potential fire danger (Prestemon et al. 2013; Frost 2009; Wells 2005). With the increasing visual and physical impacts of bark beetles on mountain ecosystems, landscape architects will need to understand how to respond to these impacts within the natural and built environments. Management applications on infected stands will impact the aesthetic value of coniferous forests, which can have negative influences on visitor perceptions (Arnberger et al. 2018). This report documents the projected extent and significance of existing bark beetle outbreaks relative to historical trends/events and the degree to which landscapes are impacted by the loss of scenic value following bark beetle outbreaks.

This report uses previous outbreaks to evaluate future scenarios of bark beetle impacts to address the potential threats to mountain ecosystems and implications on human experiences. Guidelines were then generated based on landscape management techniques of bark beetle, such as promoting biodiversity and reducing even-aged tree stands, as well as applying principles of landscape aesthetics (Bentz 2009). The goal of this report is to encourage discussions within the landscape architecture community to ensure a balance between the sustainable environmental treatment of bark beetle infestations and preservation of both visual and cultural value of infested forests.

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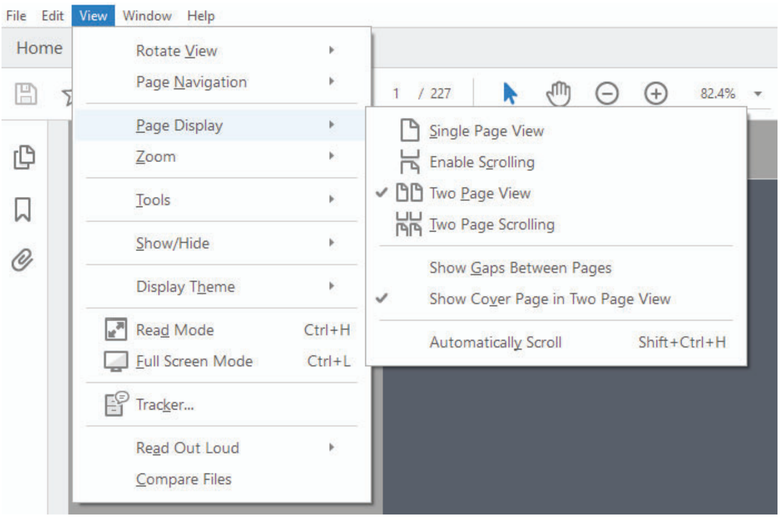

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A report submitted in partial fulfillment of the requirements for the degree:
Master of Landscape Architecture

Department of Landscape Architecture and Regional & Community Planning
College of Architecture, Planning and Design
Kansas State University

Master's Project Committee:
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Bark beetles have played a fundamental role in coniferous ecosystems for thousands of years but have recently reached unprecedented levels of reproduction and infestation within the Rocky Mountain region (Oatman 2015, Bentz 2009). In Colorado alone, mountain pine beetles and spruce beetles have killed 21% of Colorado's forests since 1996 (Romeo 2019). Concurrent outbreaks, extended north and east range, and longer lifespans of bark beetles have contributed to more significant infestations that are primarily a result of increasing temperatures and less regional precipitation (Bentz 2009). Mountain-based industries such as skiing, tourism, and recreation are threatened by loss of tree stands and potential fire danger (Prestemon et al. 2013; Frost 2009; Wells 2005). With the increasing visual and physical impacts of bark beetles on mountain ecosystems, landscape architects will need to understand how to respond to these impacts within the natural and built environments. Management applications on infected stands will impact the aesthetic value of coniferous forests, which can have negative influences on visitor perceptions (Arnberger et al. 2018). This report documents the projected extent and significance of existing bark beetle outbreaks relative to historical trends/events and the degree to which landscapes are impacted by the loss of scenic value following bark beetle outbreaks. This report uses previous outbreaks to evaluate future scenarios of bark beetle impacts to address the potential threats to mountain ecosystems and implications on human experiences. Guidelines were then generated based on landscape management techniques of bark beetle, such as promoting biodiversity and reducing even-aged tree stands, as well as applying principles of landscape aesthetics (Bentz 2009). The goal of this report is to encourage discussions within the landscape architecture community to ensure a balance between the sustainable environmental treatment of bark beetle infestations and preservation of both visual and cultural value of infested forests.

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My family. Thank you for your unconditional and relentless support throughout every moment of my life. Thank you for the hundreds of hours spent driving back and forth from home to help me. Mom, thank you for staying on the phone with me for hours at a time to help me figure out your recipes. Dad, thank you for talking me through entire Rapids games in real time and spending one of your Saturdays trying to tell me how to change my bike tires. It was one of my proudest moments. Halle, thank you for coming up that weekend of my first year and walking around so much you got blisters on your feet, you have no idea how much I needed you there. Bryce, I know you always talk about how much you hate Kansas, but thank you for the hugs that you give me when I come home.

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Nymph Lake in Rocky Mountain National Park.
(Russell 2014)

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INTRODUCTION

1. INTRODUCTION

SUMMARY

Bark beetle infestations have occurred throughout history and are a natural part of the coniferous ecosystems. However, impacts of climate change have led to thriving bark beetle conditions that have resulted in unprecedented outbreaks and high tree mortality rates. The loss of conifers throughout the Rocky Mountain region are impacting the visual state of some of America's most beloved landscapes, such as Rocky Mountain, Yellowstone, Grand Teton, and Glacier National Parks, in addition to other recreational and residential properties in the region.

This report analyzes the historical patterns and future predictions of two types of bark beetles, mountain pine beetle and spruce beetle, to understand the impacts posed by recent and projected future outbreaks to the landscape architecture profession. This report utilizes precedent studies and content analysis to detail the current and potential impacts to the field of landscape architecture, as well as the use and perceptions of the forestry techniques used to address outbreaks. Literature explored in this report focuses on historical outbreaks, current impacts regarding socio-economic and aesthetic effects, and future implications of a changing climate and unprecedented bark beetle outbreaks. Through further investigation of perceptions of forest beauty and public responses to bark beetle treatments, management guidelines are created to preserve scenic beauty in projects impacted by bark beetle outbreaks. This report seeks to start a dialogue among landscape architects so the profession can accurately understand the severity of bark beetle impacts, as well as the need to incorporate suitable landscape management techniques into projects in the Rocky Mountain region and beyond. Through this, we will be able to "outlive" the outbreak by fully enjoying life, instead of letting it dictate the visual landscape.

Figure 1.2
Old mountain pine beetle kill in Colorado.
(Ciesla 2015)

PROBLEM STATEMENT

Between 2000 and 2012, bark beetles killed 46 million acres of trees, an area slightly smaller than the state of Colorado, with mountain pine beetles responsible for half of the mortality (Funk et al. 2014). In Colorado alone, mountain pine beetle and spruce beetle have combined to kill trees in 21 percent of Colorado's forested land since 1996 (Romeo 2019). The impacts of bark beetles are becoming more widespread for pine and spruce trees across the United States, and the landscape architecture profession has not begun to assess this threat. Because the treatments to address bark beetle outbreaks are varied and can influence perceptions of scenic beauty in affected forests, its implications to landscape architecture need to be explored (Barker, 2003).

The aesthetic and physical impacts of bark beetle outbreaks can adversely affect community perceptions and forest value, which will negatively influence economic revenue and developments. With the wide breadth of landscape architecture projects and a growing number of projects within the wildland-urban interface, landscape architects need to understand the severity of the issue in order to address it properly. To get a more in-depth sense of impacts to the built environment, the landscape architecture profession needs to better understand bark beetle outbreaks and assess the potential effects that the rest of the Rocky Mountain region will face. This report utilizes GIS data and climate information from Colorado to gain a more in-depth analysis of impacts to the landscape architecture profession. Precedent studies and analysis of forest treatment methods were also used to gain a better understanding of the relationship between the management of bark beetle outbreaks and public perceptions of the affected landscape.

IMPORTANCE

Present outbreaks of bark beetles differ from previously recorded infestations because of their intensity, range, and synchronicity of attacks (Bentz 2009). Predicted impacts of climate change will create more stressful conditions for forests across North America from rising temperatures, increasing drought conditions, and loss of snowpack. These environmental conditions are creating habitats where bark beetles increase their frequency of attacks, in addition to generating more suitable environments for bark beetles in forests that have yet to be impacted (Bentz et al. 2010). Though current outbreaks of bark beetle have recently begun to decrease, predictions of the next several decades expand the range of mountain pine beetle and spruce beetle outbreaks and severity. This expansion will undoubtedly affect more communities across the United States, and thus influence more work being conducted by landscape architects within impacted mountain communities for the built and natural environment.

PERSONAL RELATIONSHIP

Growing up in Colorado, the impacts of bark beetles have been hard to ignore and disheartening to face. The excessive losses of pine and spruce trees from the mid-2000s are now a stark reminder of the impacts of massive bark beetle outbreaks. I have always been interested in addressing this issue in my future career, and I am grateful to have the opportunity to bring more attention of the topic to the landscape architecture profession.

GOALS

The goals of this report are to:

- Start a dialogue and provide communication regarding the future impacts of bark beetles in the public and private sectors of life that landscape architects primarily interact within the mountain landscapes of the West.
- Stress the effects of bark beetle impacts in common areas of landscape architectural influence/work, such as national/state parks, tourism, residential developments, and community planning.
- Create management guidelines that increase the scenic quality of affected forests, while also considering ecological and sustainable forest management.
- Create an informative document that alerts landscape architects of future threats that bark beetles impose on the profession to promote more research and attention within the industry.

RESEARCH QUESTIONS

Central question:

How can landscape architects address the aesthetic and visual impacts of bark beetle infestations in the Rocky Mountain region?

Secondary questions:

- What do climate change predictions reveal about the potential for bark beetle expansion and outbreaks?
- How do predictions of bark beetle expansion relate to important project fields within the landscape architecture profession?
- How does the public perceive typical treatment methods?
- Which fields of landscape architecture will be most impacted by bark beetles in the Rocky Mountain region?
- How can landscape architects mitigate losses in scenic beauty?
- How can landscape architects improve responses to bark beetle infestations in the Rocky Mountains through considerations of forest management techniques and landscape aesthetics?

Figure 2.1
Rocky Mountain National Park in winter
(Weber 2017)

2 BACKGROUND

2. BACKGROUND

2.1 BARK BEETLES

Bark beetles are tiny insects with hard, cylindrical bodies that reproduce under the bark of trees (USDA Forest Service 2019). Bark beetles have naturally occurred in the forests of North America for thousands of years and have been dated back to the Holocene era, approximately 12,000 years ago (U.S. National Park Service 2018, Bentz 2009). They have acted as beneficial and essential components of the coniferous ecosystem, attacking larger and older trees and helping to renew forests with younger, more productive trees that promote natural forest regeneration (Bentz 2009).

Bark beetles spread when females, or pioneer beetles, locate a “frail tree” and emit a chemical signal (a pheromone plume) to alert others to swarm the tree (Oatman 2015). They chew through the bark until they reach the phloem, which carries sugar and nutrients through the tree (Oatman 2015). Female beetles lay up to 200 eggs, and between one to three weeks later, larvae hatch and begin to develop inside the tree. As the larvae grow, they tunnel and feed around the circumference of the tree which impedes the flow of water and nutrients (Bentz 2009). Adult bark beetles can also carry fungi with them (commonly the blue stain fungus) that attack trees by disrupting the vascular system and preventing the flow of nutrients throughout the tree (U.S. National Park Service 2005, 3). By obstructing the movement of water, mountain pine beetles are able to attack and colonize a tree within 48 hours, and as a result of both organisms, the tree is killed within one year (Graham et al. 2016). After the beetle matures, it flies from the host to find a new tree and continue the life cycle. Healthy trees within ¼ of a mile from the beetle-infested tree are at risk for a new attack (U.S. National Park Service 2005, 3).

Figure 2.2
Mountain pine beetle galleries.
Galleries are the tunnels created within the tree's bark as the beetles eat and lay their eggs.

(Tunnock 1995)

TYPES OF BARK BEETLES

While there are over 600 different types and species of bark beetles throughout the world. Two of the most aggressive types in the Rocky Mountain region are mountain pine beetles (Dendroctonus ponderosae Hopkins) and spruce beetles (Dendroctonus rufipennis Kirby) (USDA Forest Service 2019). Under stressful conditions, these aggressive bark beetle species can defeat host tree resistance which allows the beetles to reproduce rapidly (Jenkins et al. 2012). Mountain pine beetles (see Figure 2.3) attack and kill live trees species such as lodgepole pine, ponderosa pine, bristlecone pine, whitebark pine, western white pine, sugar pine, limber pine and more (USDA Forest Service 2019, Bentz 2009). Spruce beetle (see Figure 2.4) has not been as destructive as mountain pine beetle (in terms of acreage affected, see Figure 2.17), but has attacked approximately 40 percent of spruce-fir forests in the state of Colorado since 2000, including Rocky Mountain National Park, the San Juan Mountains, the West Elk Mountain, and the Sawatch Range (Lill 2019). Hosts of spruce beetle are typically limited to Englemann spruce, White spruce, Lutz spruce, Sitka spruce, and Colorado blue spruce (Bentz 2009).

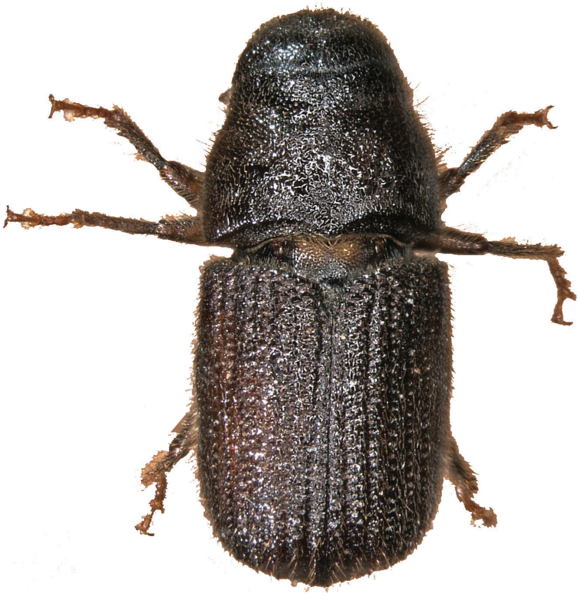


Figure 2.3
Adult mountain pine beetle.
Actual size is 1/8 to 1/3 inch.
(Mercado 2012)

Figure 2.4
Adult spruce beetle.
(O'Donnell and Cline 2012)

Figure 2.5
Actual adult mountain pine beetle size compared to a penny.
(Hodgson 2020)

STAGES OF OUTBREAKS

There are different stages of a bark beetle infestation that represent varying levels of mortality. Susceptibility begins when a stand can support an outbreak which becomes endemic when one to several trees are attacked per hectare (Jenkins et al. 2012). Epidemics coincide with periods of short-term stress and drought and is characterized when 80 percent or more of susceptible trees are killed. During epidemic periods, "canopy openings result in significant increase in live shrub and herbaceous cover," and the epidemic phase typically lasts between 5 and 10 years, ending when "most large-diameter trees have been killed and the bark beetle population returns to endemic levels" (Jenkins et al. 2012).

Once a substantial number of attacking adult beetles have burrowed into the tree and laid eggs, the tree has little chance of survival and will be doomed long before any of the indicative signs of infestation are visible (Bentz 2009). With mountain pine beetles, needles of the pines will turn from yellowish-red to a rusty red color nine to ten months after infestation, before dropping from the branches the second summer after the tree has been infested (see Figure 2.6) (Colorado State Forest Service 2019a and U.S National Park Service 2005). Following the successful infestation of spruce beetles, the needles will turn to a pale yellowish-green color and typically drop from the tree following the second summer after the tree has been infested (see Figure 2.6) (Colorado State Forest Service 2019b).

Bark beetle outbreaks and mortality will have both short- and long-term impacts to local ecosystems. Typically, large stands of even-aged trees will be most impacted during outbreaks, which allows younger trees to quickly grow after competition is reduced for light, nutrients, and water (Bentz 2009). Mountain pine beetles accelerate the natural succession of forests by killing the dominant canopy trees, thereby opening space for under-story trees (Romme et al. 1983). Infestation and mortality lead to tree decomposition; however, it occurs very slowly in drier climates like those in the Rocky Mountains, where a killed lodgepole pine will fall to the ground within five to ten years (Bentz 2009). Mountain pine beetles impact foundational species of white pines such as whitebark pine, bristlecone pine, and limber pine, which are longer-lived and are vital to the survival of other local species.

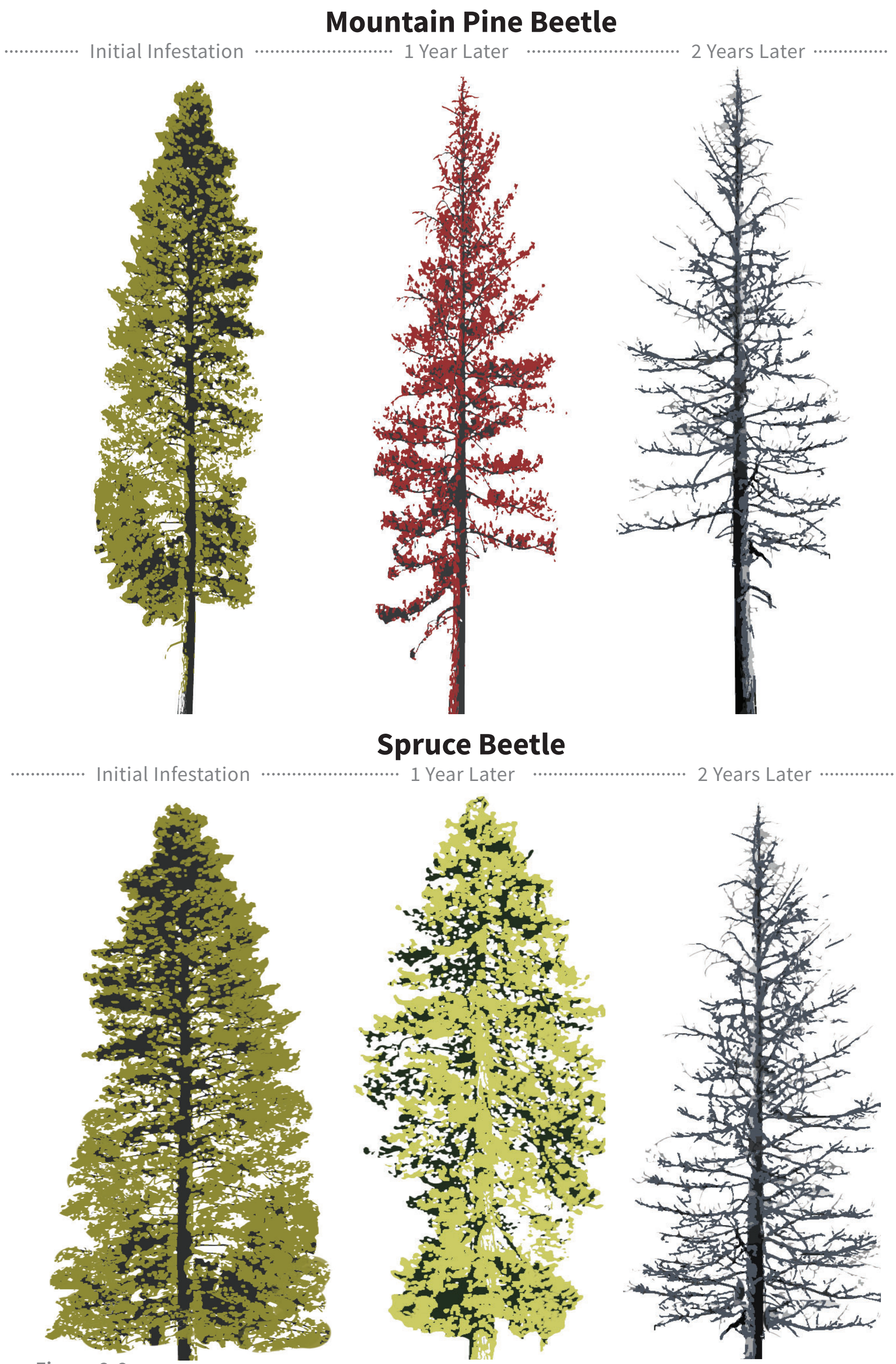


Figure 2.6
Tree progression following bark beetle infestation.
(Hodgson 2020)

Figure 2.7
Preparing lodgepole pine infested with mountain pine beetle for treatment in Crater Lake National Park.

(Unknown 1924)

Figure 2.8
Large sugar pine tree attacked and killed by mountain pine beetle in Yosemite National Park.

(Miller 1916)

HISTORICAL OUTBREAKS

In 1898, the head of the Forestry Division, and later the first Chief of the Forest Service, Gifford Pinchot heard reports of bark beetles from throughout the country. At that time, the Division had no experts in entomology and hired Andrew D. Hopkins in 1901 to conduct special investigations (Graham et al. 2016). Hopkins grew to be an expert on bark beetles from studying the southern bark beetle and would grow to shape the future of American forest entomology (Graham et al. 2016). The Black Hills beetle, Dendroctonus ponderosae (at the time of discovery), was studied and coined by Hopkins, and was attacking and killing ponderosa pine in Wyoming, Utah, Colorado, Arizona, New Mexico, and northern Mexico (Graham et al. 2016). Mountain pine beetle was first mentioned by Hopkins in 1905 and further described in 1909, attacking pines in "Idaho, Montana, northwestern Wyoming, Oregon, Washington, and California and in the Canadian Province of British Columbia" (Graham et al. 2016, 9)

Early European and American entomologists like A.D. Hopkins were instrumental in bringing the bark beetle epidemic to the public's attention and promote greater management. Fear of potential impacts to the timber industry spurred initial concerns of bark beetle impacts, but before 1915, "Americans paid little attention to forest insects because the perceived abundance of timber provided little incentive to study the role of insects in forests", and many foresters believed that insects could not be controlled effectively (Barker 2003). When the threats were eventually seriously considered, foresters were determined to manage the insects by removing older and defective trees and emphasized a connection between healthy forests and efficient timber production.

2.2 CURRENT IMPACTS

TOURISM – NATIONAL PARKS

Within the Rocky Mountain region are several of the nation's most cherished and enjoyed national parks, forests, and monuments. Seventy-two percent of the forested land in the six states of the Rocky Mountains (New Mexico, Colorado, Wyoming, Utah, Montana, and Idaho) is federally owned (Funk et al. 2014). This land includes the nation's most cherished landscapes such as Yellowstone, Grand Teton, Glacier, and Rocky Mountain National Parks, which generate over $1 billion in visitor spending and attract 11 million visitors a year (Funk et al. 2014). Sixty million people visited the 37 national forests that also reside in this region, including White River National Forest in Colorado, the most visited national forest for recreation, with 9 million visits a year (Funk et al. 2014).

One of the most impacted and visible locations of bark beetle infestations in the United States is Rocky Mountain National Park. The park resides in north-central Colorado and encompasses 265,780 acres, with nearly 60 percent of that land being forested and dominated by lodgepole pine and spruce/fir trees (U.S. National Park Service 2005, 1). Aided by its accessibility to the Denver metropolitan area about 65 miles away, it is a very popular attraction and received 4,590,462 visitors in 2018, the highest annual visitation ever recorded for the park (U.S. National Park Service 2019). Bark beetles threaten several aspects of the parks that necessitate management, though the park's enabling legislation explicitly states the preservation of "natural conditions," which includes the presence of bark beetles (U.S. National Park Service 2005, 3). These problems include the danger of dead trees that threaten people and property within the park, compromised integrity of the historic landscape, and decreased private property values within and surrounding the park (U.S. National Park Service 2005, 3).

Figure 2.9
Campground closed during removal activites related to Mountain pine beetle.
(Cranshaw 2013)

Figure 2.10
Older mortality in Williams Fork Basin, Colorado.
(Ciesla 2015)

RESIDENTIAL AND BUSINESS IMPACTS

Residential areas that are most susceptible to bark beetle attacks reside within the wildland-urban interface. This area is characterized by development where housing mixes with undeveloped vegetation and wilderness (Radeloff et al. 2005). The wildland-urban interface makes up nine percent of the land area of the United States and contains 39 percent of all housing units in the nation (Radeloff et al. 2005). Bark beetle infestations cause physical, visual, and psychological impacts to communities that reside nearby and within the wildland-urban interface. The visual and aesthetic value provided by the tree canopy are highly significant and essential contributions to properties within the wildland-urban interface. Concerns about fire have contributed to fire suppression practices that have altered forest ecosystems and made trees more susceptible to bark beetle outbreaks (Price et al. 2010). Infestations and management techniques are both impactful for scenic amenities and safety of developments, which hamper economic value through negative associations.

Continuing perceptions of danger and aesthetic loss of bark beetle infestations have significant impacts on affected communities. Surveys conducted between six communities in the Kenai Peninsula revealed that the most common perceived impacts of spruce beetle outbreaks were falling trees, logging, increased availability of firewood, and increased fire hazard (Flint 2006, 214). In addition to the fear of falling trees and increased fire hazards, other negative impacts cited by over 75 percent of respondents were visual/aesthetic decrease, loss of privacy, and changes in wildlife and fish habitat. However, other positive impacts cited by over 75 percent of the respondents were increased ecological awareness, expanded timber industry, new views, and creation of jobs (Flint 2006, 214). The impacts, both biophysical and social, were mostly felt by communities that were experiencing the most recent and most extensive spruce beetle infestation. However, communities that were not experiencing notable and current spruce beetle infestation still have negative perceptions of bark beetles from falling trees, increased fire hazards, and aesthetic loss (Flint 2006, 217).

ECOLOGY – WILDLIFE AND AIR POLLUTION

Bark beetles are a natural part of coniferous ecosystems and have always had varied relationships with different species of native animal species. Many species respond positively to bark beetle outbreaks, such as ungulates (elk, deer, moose, etc.), as a result of the boom of vegetation left on the forest floor and increase of cover (Ivan et al. 2018). Woodpeckers and other bird species also thrive in beetle-infested areas, as insectivorous predators have greater food availability, and often become indicators of outbreaks from their increased activity (Morrisey et al. 2008, Colorado State Forest Service 2019b) However, red squirrels, golden-mantled ground squirrels, chipmunks, and coyotes showed a negative association with beetle activity and decreased activity in impacted regions (Ivan et al. 2018). Another unexpected positive association with bark beetle infestation is an increased habitat for bees. As the canopy of forests is lost, it opens the forest floor with light that promotes more flowering plants to grow and creates more livable conditions for the bees (Lill 2019).

However, the loss of trees also result in large-scale ecosystem impacts that extend beyond flora and fauna. High rates of tree mortality caused by bark beetle infestations impact the natural carbon cycle through increased carbon dioxide released from the dead trees. In places like British Columbia, the beetle-killed trees release 990 million tons of $CO2$ into the atmosphere, an amount almost five times the standard emissions released by transportation in Canada (Kurz et al. 2008). This loss is altering affected forests from carbon sinks to carbon sources, and thus positively contributing to climate change factors (Kurz et al. 2008).

Figure 2.11
Photograph of a woodpecker feeding on beetles in and under bark.
(Dewey 1995)

WILDFIRE

There is a complex relationship between the effects of fire on beetle-impacted forests. Fire is a major agent in the beginning and end of forest succession and has substantial influences on the productivity, diversity, and stability of the ecosystem (U.S. National Park Service 2005). Between 1984 and 2011, there was a 73 percent increase in the annual number of massive wildfires in the Rocky Mountain region, and research has indicated that these wildfires are lasting longer (two and a half months longer) and burning more area (seven times as much total area) (Funk et al. 2014). Studies conducted throughout the 20th century to understand the correlation between fire and bark beetles yielded different findings: in the short term, fires could introduce insect epidemics by weakening trees (Barker 2003). Studies that looked at the long term, like the South Ice Cave study, demonstrated that fires could lessen the risk of bark beetle damage by removing competing under-story vegetation and promoting tree growth (Barker 2003). The severity of fire and damage to trees ultimately have the most significant impact on bark beetle production, which is highly variable (Barker 2003).

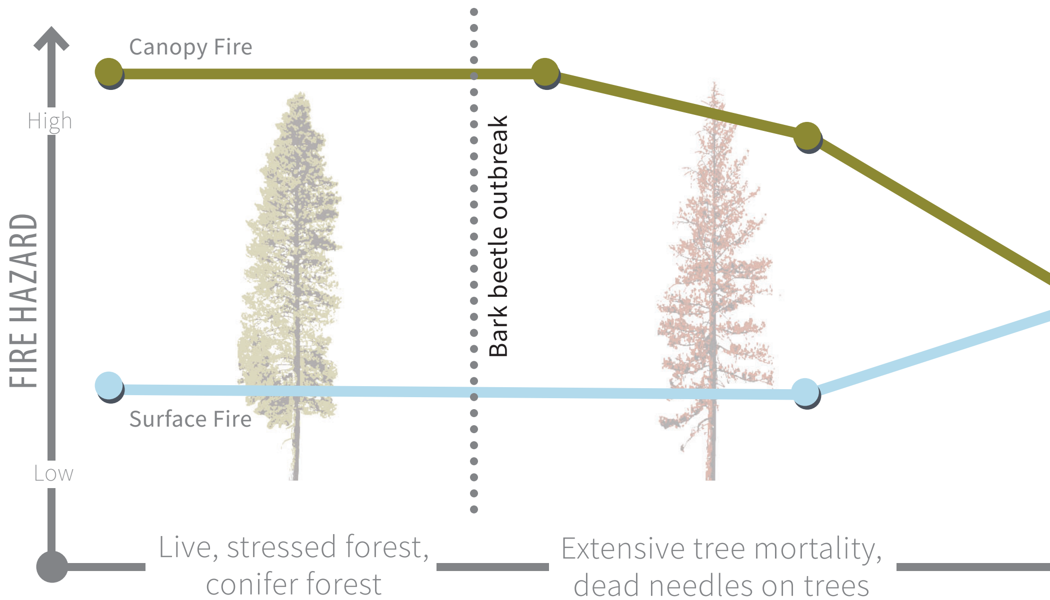
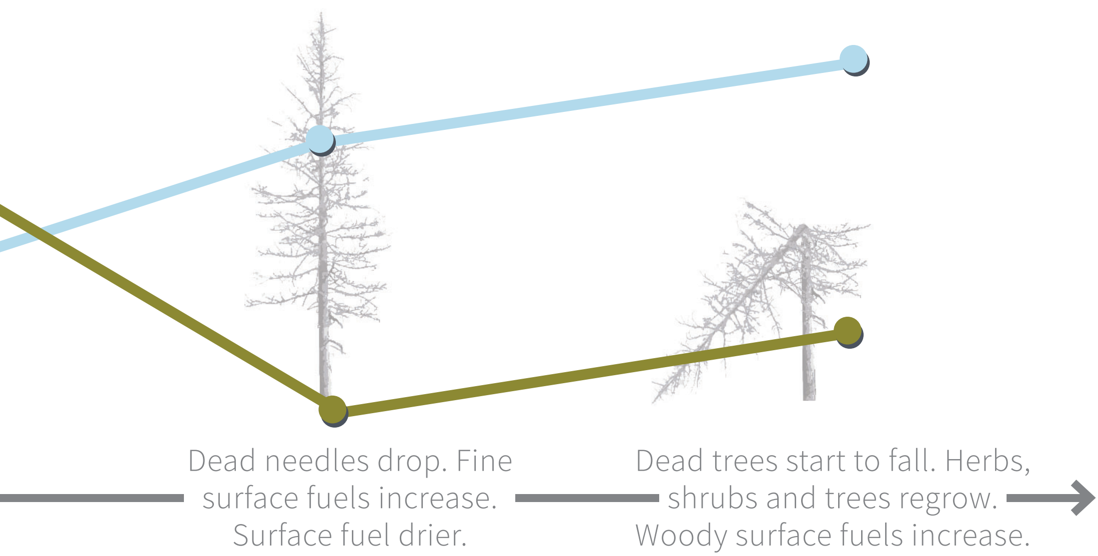


Figure 2.12
Fire hazard associated with bark beetle infestation over time.
(Hodgson 2020)

There has also been much investigation into the correlation between bark beetle outbreaks and increased fire hazards and fire potential. While there is a large perception that dead trees created by bark beetle outbreaks increase fire susceptibility and spread in affected forests, several studies have indicated that there is a varied correlation between the two despite the number of large fires rising dramatically across the western United States over the past 25 years (Jenkins et al. 2012). Some forest researchers hypothesize that the highest fire hazard exists immediately after bark beetle infestations when the needles are still on the tree, and then drops significantly once the needles fall from the tree (Hicke et al. 2012). Hart et al. (2015) reported through their research of mountain pine beetle infestations that there was not a difference in burned area in red-stage or gray-stage stands during three peak years of wildfire activity. As such, the widespread perception among the public that recent bark beetle outbreaks have led to more extensive wildfires is counter to what is currently known about the major drivers of wildfires in western U.S. forests (Hart et al. 2015). Fire behavior is still largely dependent on factors such as climate, slope, vegetation structure/species, so it is difficult to determine a definitive relationship with bark beetle infestations. Still, a large consensus among the public sphere associates high fire danger with beetle killed-trees, which in turn impacts perceptions of safety in residential and recreational settings.



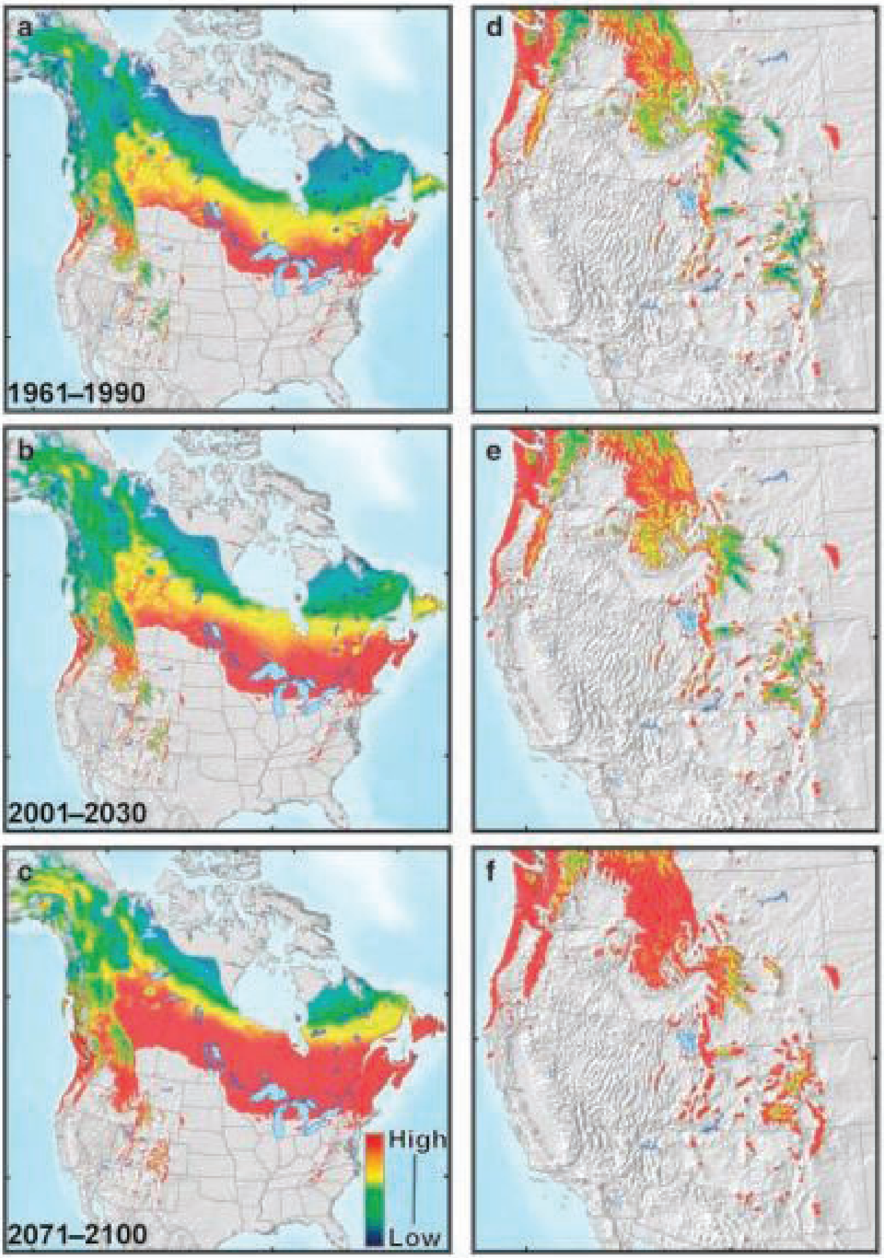
2.3 MANAGEMENT TECHNIQUES

Much of the trouble that arises from bark beetle outbreaks is the difficulty in treating trees once they have been infected. Bark beetles live underneath the bark in a protected layer, which makes them difficult to control with insecticides. Currently, there no registered insecticides that can prevent tree mortality following infestation (University of California IPM 2008)

Landscape maintenance techniques are another form of preventative treatment to lessen the impacts of bark beetle outbreaks. The health of trees in both residential and forest settings is promoted by thinning trees or removing selected trees before bark beetles attack, which reduces competition for moisture, sunlight, space, and nutrients (Donaldson and Seybold 1998). Pruning and disposing of bark-beetle infested limbs help reduce overcrowding and is part of the management process called sanitation (Donaldson and Seybold 1998, Bentz 2009). Sanitation and thinning use mechanical methods of Integrated Pest Management, such as solarizing, burning, chipping, stripping, and hauling (National Park Service 2005).

Figure 2.13
Logging beetle-infested trees.
(Billings 2005)

Figure 2.14
Maps showing predicted probability of spruce beetle offspring developing in a single year in spruce forests.
The probability is shown during three climate normal periods: 1961-1990, 2001-2030, and 2071-2100.
(Bentz et al. 2010)



2.4 FUTURE IMPLICATIONS

UNPRECEDENTED NATURE

While bark beetles have always been a natural part of the coniferous ecosystem, the last 30 years have been indicative of a heightened level of activity and an unprecedented outbreak of mountain pine and spruce beetles. Large outbreaks have happened historically, but evidence suggests that there have never been so many concurrent outbreaks at such a broad scale that involve different species and locations at the same time (Bentz 2009). Spruce beetles can survive in all places where spruce trees exist, but mountain pine beetles were previously limited by extreme climates. However, mountain pine beetles have now extended past its historical range more northwards (lodgepole pines) and southwards (ponderosa and other pines) (Bentz 2009). Mountain pine beetles are also beginning to attack new tree species such as jack pine and lodgepole pine hybrids that have never acted as historical hosts, in addition to attacking and reproducing in spruce trees in British Columbia and Colorado. This marks the first evidence of multiple generations of mountain pine beetles in a non-pine species (Bentz 2009).

CLIMATE CHANGE

Since 1900, the global average surface temperature has increased by about 1.4°F, with 1°F of change occurring since 1979 (Walthall et al. 2013). CO_2 concentrations have also increased, passing 400 parts per million (ppm), which is higher than any level measured in the last 800,000 years. This change will result in further increases in average temperature, as the United States is predicted to warm between 1.8 and 3.6°F throughout much of the country over the next 30 years. A low emissions scenario (CO2 concentrations increase to 550 ppm) projects that temperature would increase 5.4-7.4°F within the Interior West by 2080, while a high emissions scenario (CO2 concentrations increase to 800 ppm) would increase temperatures between 9 and 10.8 °F in the Interior West (Walthall et al. 2013). Much of the United States will see hotter nights and fewer frost days, with the Intermountain West projected to decrease 40-50 frost days a year (Walthall et al. 2013).

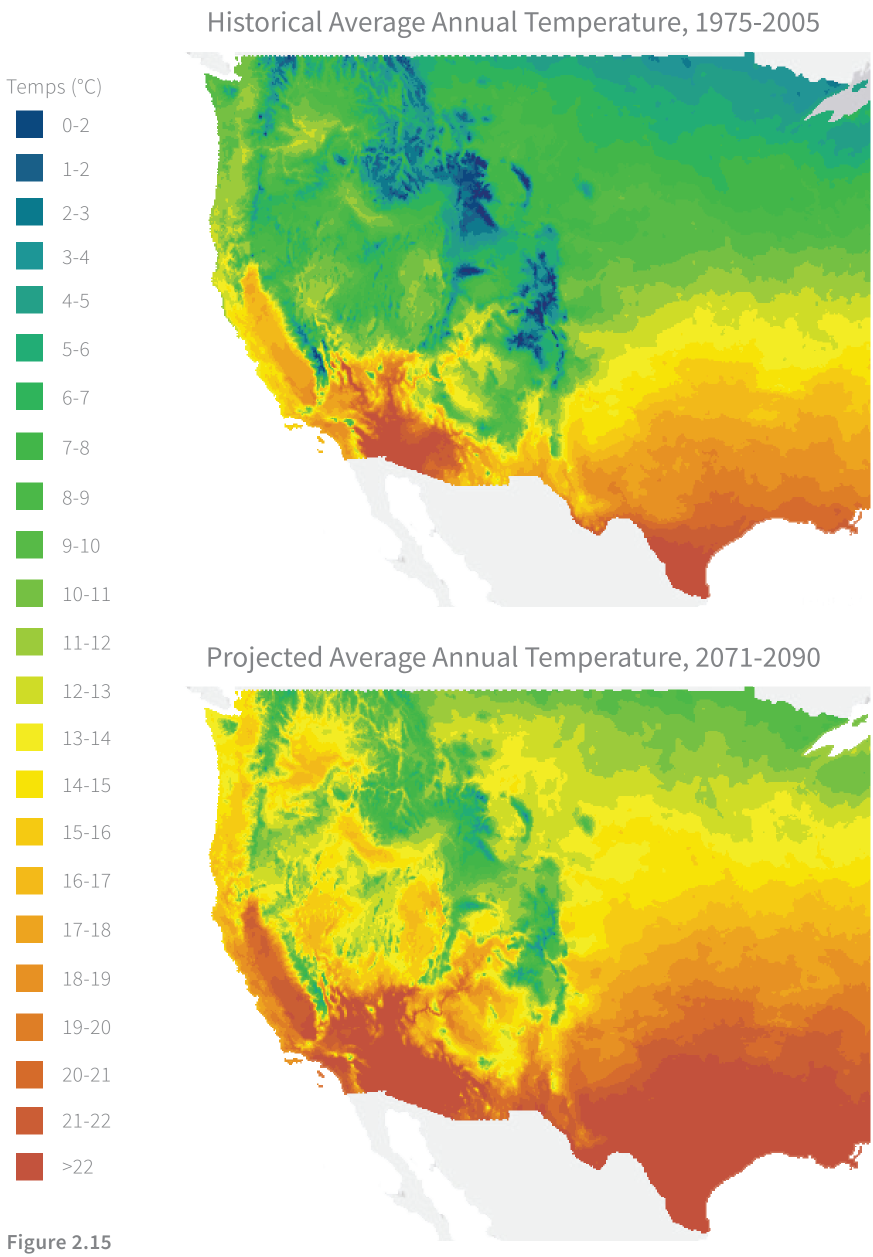


Figure 2.15
Historical and projected average temperatures in the western United States.
(Hodgson 2020)

D0 - Abnormally Dry

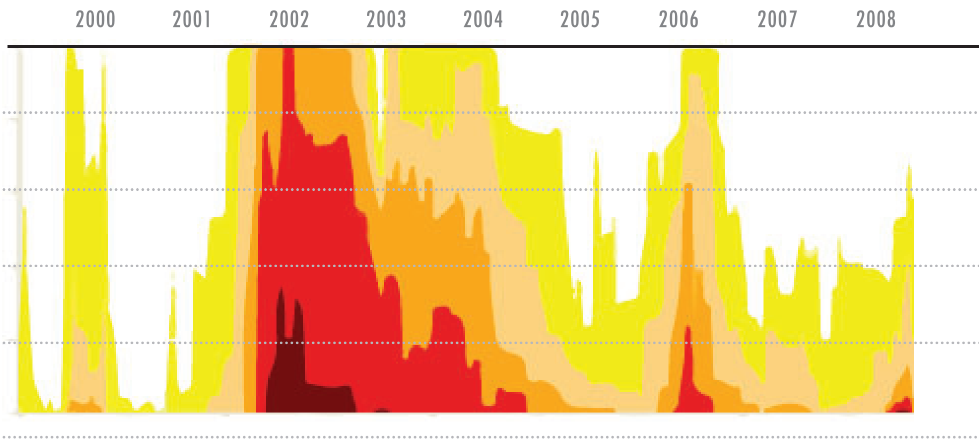
D1 - Moderate Drought

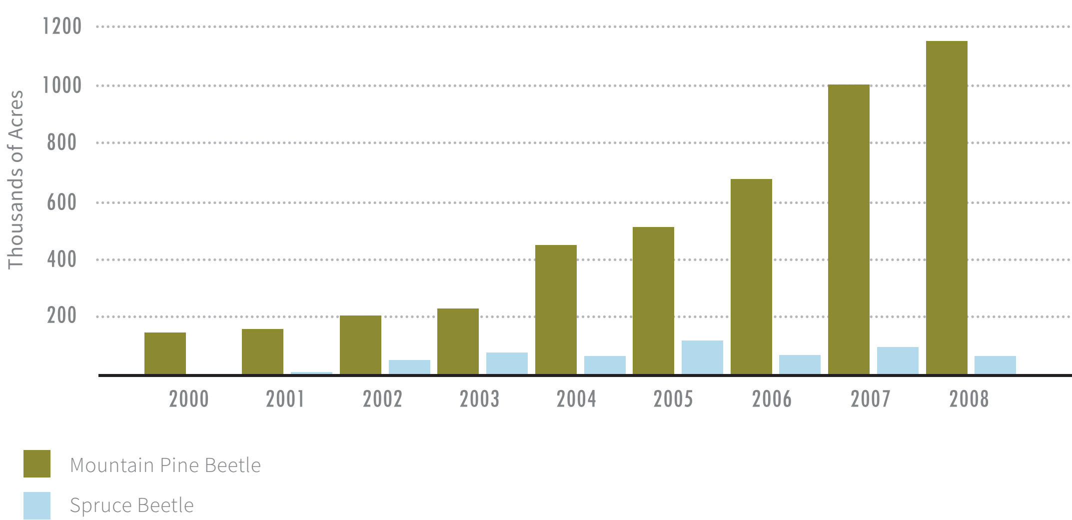
D2 - Severe Drought

D3 - Extreme Drought

D4 - Exceptional Drought

Figure 2.16
Drought percentages in Colorado.
(National Drought Mitigation Center 2020)





Within the Rocky Mountains, the region has seen impacts from climate change that are impacting fire risk and bark beetle outbreaks. Between 1999 and 2003, the region recorded the driest year since 1895, the fourth-lowest five-year precipitation total ever recorded (22 percent below average) and second hottest five-year interval since 1895, which triggered many forest impacts that we see today (Funk et al. 2014). Current climate trends further alter the climate to be hotter and drier than the 1999 to 2003 period (see Figure 2.16), with changes in precipitation leading to higher frequency and duration of droughts and longer dry seasons (Bentz et al. 2010 and Funk et al. 2014).

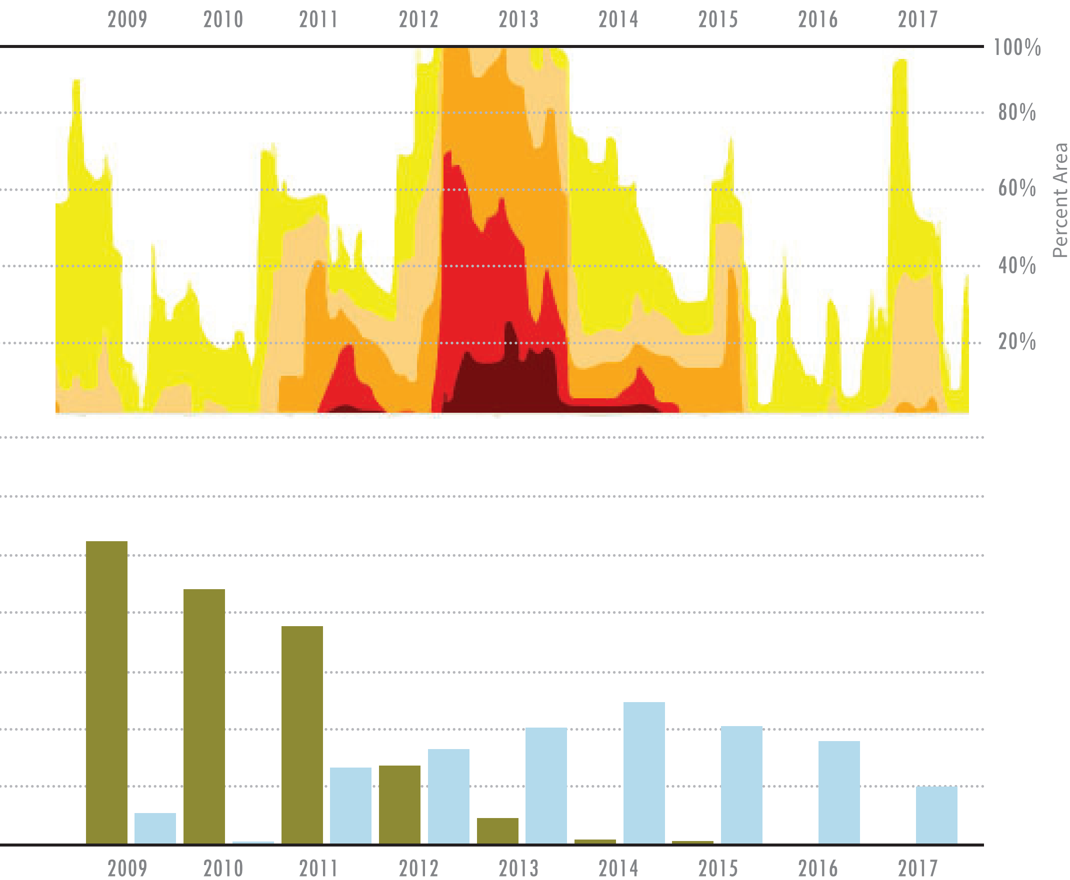


Figure 2.17
Area infested by mountain pine beetle and spruce beetle in Colorado.
(Hodgson 2020)

CLIMATE EFFECTS ON BARK BEETLES

Bark beetles are ectotherms, meaning that their survival is thermally-dependent and their population success is highly sensitive to climatic changes (Bentz 2019). Temperature impacts the rate of development, and in species like mountain pine beetle, it indicates when to move onto the next life stage when they have accumulated enough thermal energy. These temperature thresholds help the beetles survive cold-induced mortality and ensure synchronized emergence during the summer months for adults (Bentz 2009, 11). Spruce beetles are unique and can enter "diapause," a resting state where they can resume their development after detecting cues such as temperature changes and long periods of solar radiation of the tree bark (Bentz 2009, 11).

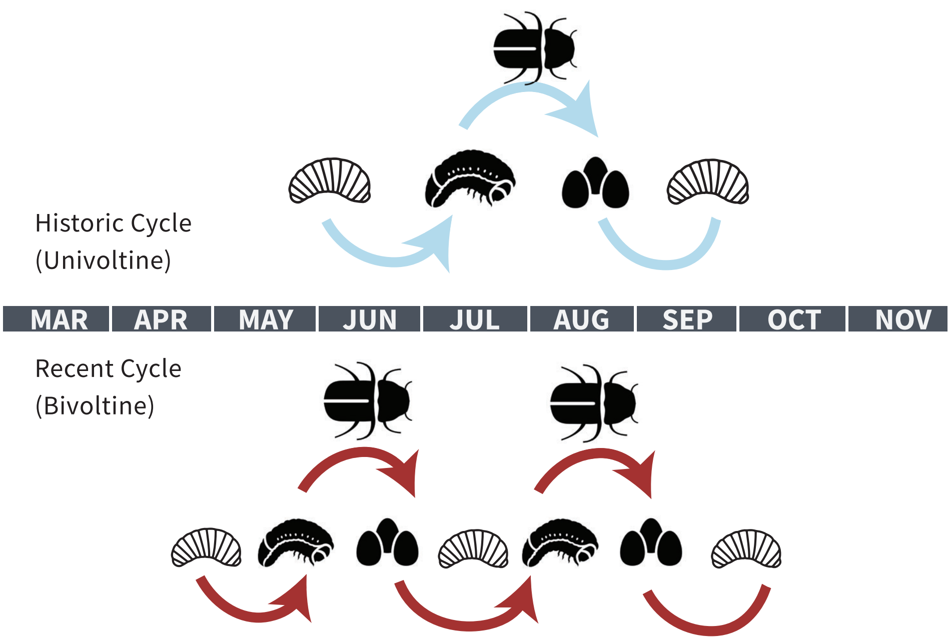
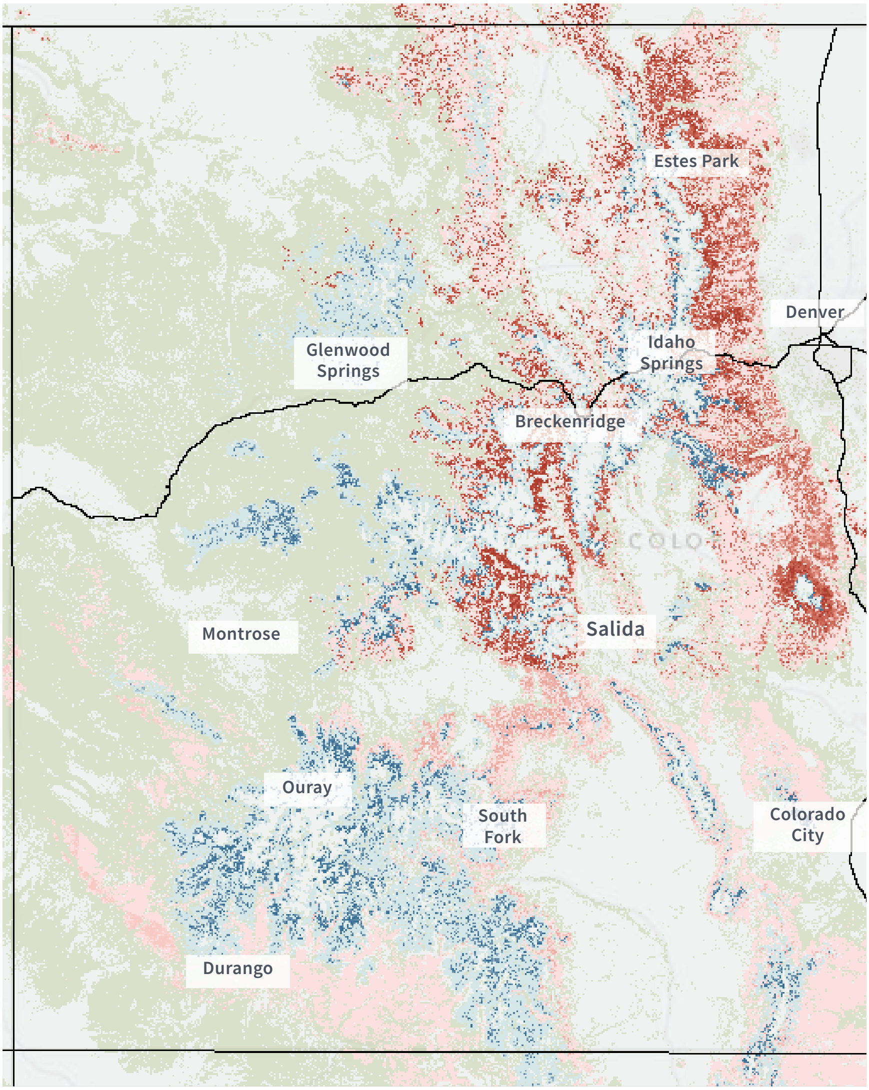


Figure 2.18
Historic vs. recent bark beetle life cycle.
(Hodgson 2020)

Usually, bark beetles in higher elevations produce on a univoltine or semivoltine schedule, a less frequent reproduction of one generation every one or two years. However, increases in temperature and milder winters have shifted the beetle's reproductive schedule to bivoltine, meaning they have produced two generations in a single year, which is drastically increasing the number of adult beetles (see Figure 2.18) (Bentz 2009). Research by Dell and Davis (2019) found that the winter of 2018 in Colorado was warmer and drier, which corresponded to an earlier emergence and flight activity across the region. Thus, higher temperatures allow beetles to cut their reproduction time in half, which leads to explosive population growth (Funk et al. 2014). Research conducted in Colorado to analyze the correlation between temperature and bark beetle patterns showed significant warming from 1970 to 2008. Specific air warming occurred during the spring development phase, where the number of days above 32°F (0°C) before July 1 increased by 15.1 days (Mitton and Ferrenberg 2012).

Following climate change trends, the climate would become less suitable for species such as lodgepole pine, Engelmann spruce, ponderosa pine, and white bark pine (Funk et al. 2014). Increased stress from heat and drought weakens trees and reduces their defenses, such as producing resin, to combat bark beetle attacks (Funk et al. 2014). These stressors are resulting in the unprecedented outbreaks of bark beetles as they are killing trees more quickly and across a wider area. Research conducted by Mitton and Ferrenberg (2012) analyzed mountain pine beetle generation in response to climate change near the University of Colorado's Mountain Research Station in Boulder County, Colorado. Long term temperature data of the area showed significant warming from 1970 to 2008, with specific air warming during the spring development phase, where the number of days above 32°F (0°C) before July 1 increased by 15.1 days (Mitton and Ferrenberg 2012). Due to increasing temperatures, the elevational limit for mountain pine beetle attacks in Colorado have increased from 2,740 meters (8,990 feet) to more than 3,350 meters (10,990 feet). Analysis of trees in outbreak areas revealed that pupae were developing faster and emerging earlier (May and June) and can reproduce that same year and have adults emerge in August and September (Mitton and Ferrenberg 2012).

Projected Spruce Beetle and Mountain Pine Beetle Tree Loss in Western Colorado, 2013-2027



0 10 20 40 mi.

100% / 0% — Projected Percentage Tree Loss To MPB (2013-2027)

100% / 0% — Projected Percentage Tree Loss To Spruce Beetle (2013-2027)

Figure 2.19
Map of spruce beetle and mountain pine beetle projections in western Colorado.

(Hodgson 2020)

Layer sources: USDA Forest Service 2012

2.5 CONCLUSION

Outbreaks of spruce and mountain pine beetle are affecting the relationships that humans share with forests. Though the unprecedented bark beetle outbreak following 1996 has lessened over the past few years, experts predict that stressful conditions prompted by climate change and fire suppression will continue to exacerbate these impacts (Bentz 2009). Bark beetles not only affect the ecological composition of infested forests, but they also have significant consequences for surrounding communities that are influenced by losses of aesthetic value and negative perceptions (Flint 2006). The consideration of aesthetics is subjective and is "one of the major considerations in forest management", but is often set aside by foresters that prioritize utility (Stark 1987, 172). Because there is no cure-all treatment to combat bark beetles once a tree is already infested, preventative measures need to be promoted within more professions that have influence and communication with both the built and natural environment, such as landscape architecture. This report seeks to expand on the information outlined in this section to demonstrate the need for landscape architects (specifically those that work in the Rocky Mountain Region) to be more aware of considerations for landscape management and to help the profession promote discussions regarding the impacts that bark beetles pose in the future.

Figure 3.1
Fall at Bear Lake, Rocky Mountain National Park.
(Collins 2017)

3 METHODOLOGY

3. METHODOLOGY

Two methods were explored to address and inform readers of the severity of bark beetle outbreaks within the Rocky Mountain Region. Understanding the existing and predicted changes of infested forests is used to stress the physical and visual implications of bark beetle infestations and demonstrate the need for greater considerations of human spaces in the wildland-urban interface. Visual representations of important spaces and their relationships with infestation cycles also emphasize the increasingly impacted experience for visitors. Finally, management guidelines were curated from information regarding landscape aesthetics and existing forestry practices.

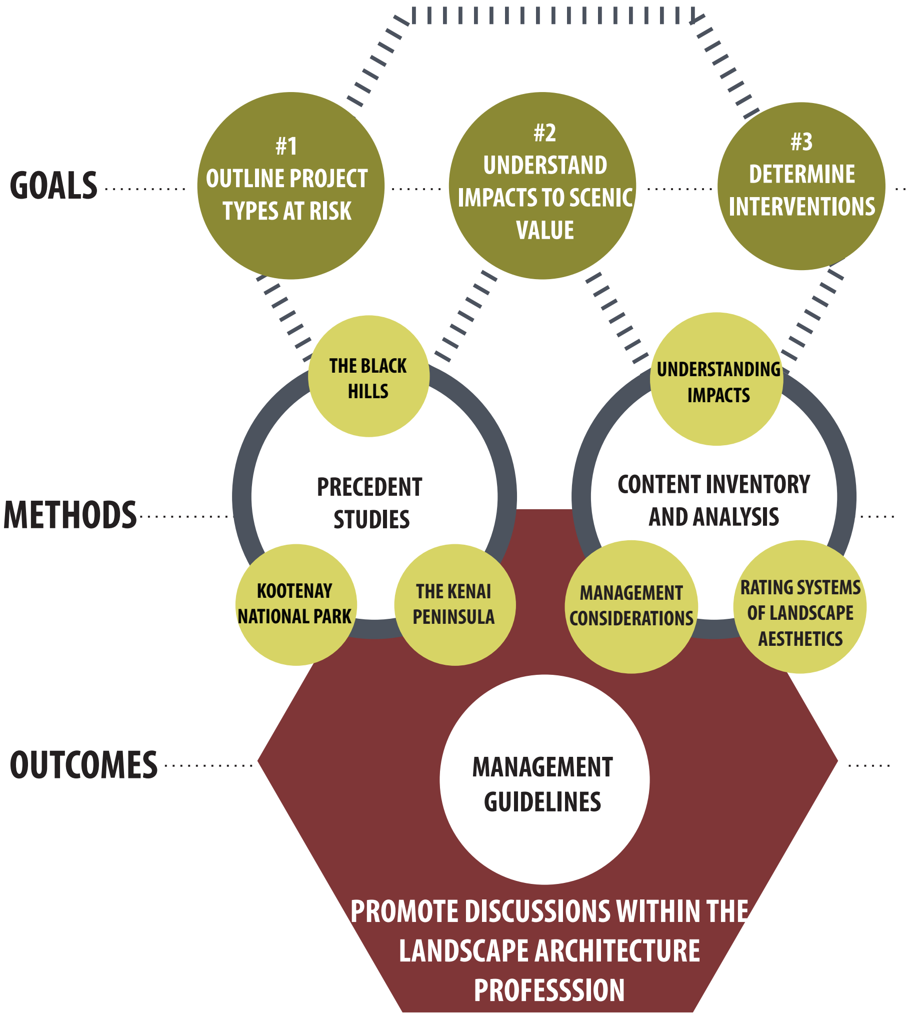


Figure 3.2
Methodology diagram.
(Hodgson 2020)

3.1 CONTENT INVENTORY AND ANALYSIS

This analysis is made up of three different foci of study to paint an accurate picture of bark beetle infestations and their potential impacts. These sections utilize literature reviews, existing studies, and governmental visual resource guides. This information helps stress the severity and danger of infestations to the landscape architecture profession, as well as inform management and aesthetic considerations that will aid in the creation of management guidelines. Topics being investigated in this section include:

- Current and projected impacts to fields related to landscape architecture projects.
- Management considerations of existing methods used to treat bark beetle outbreaks and how those methods impact scenic value.
- Visual resource guides from U.S. agencies which evaluate the aesthetic value of landscapes and their relationship to development.

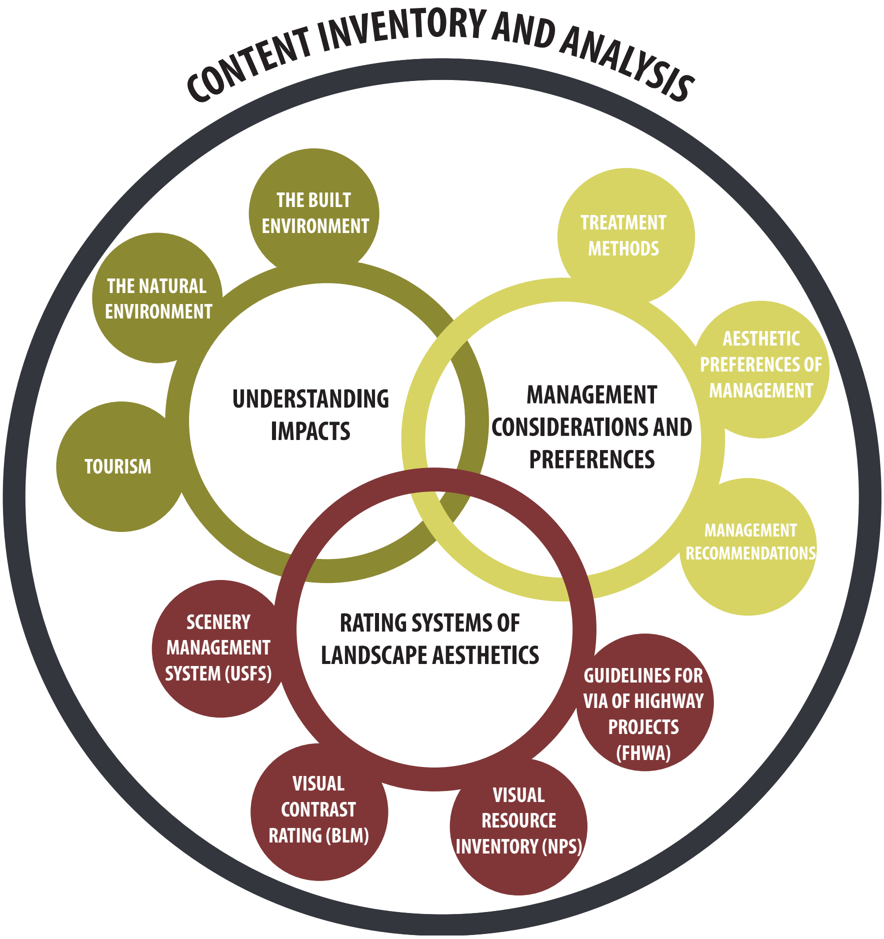


Figure 3.3
Content inventory and analysis diagram.
(Hodgson 2020)

UNDERSTANDING IMPACTS

This section includes existing research that addresses the economic, social, and ecological impacts of bark beetle infestations and its relationship with the landscape architecture profession. Research conducted by experts have analyzed the value of losses to different fields that are relevant to landscape architecture. Information regarding the varied aspects of bark beetle impacts is beneficial in understanding the severity of potential bark beetle epidemics. First, to understand the relationship to landscape architecture, four landscape architecture firms with offices in Colorado were evaluated. These firms include:

- studioINSITE (Denver)
- Design Workshop (Denver, Aspen)
- DHM Design (Carbondale, Denver)
- SE Group (Frisco)

From those firms, all projects within western Colorado that were displayed on their websites as of February 20, 2020, were selected. In total, 71 projects were selected and evaluated based on project type and location. These projects were used to delineate the fields of landscape architecture that would see the greatest impacts based on their percentage makeup and location among prominent mountain communities.

The landscape architecture projects were then mapped alongside GIS data of western Colorado to analyze the relationship between important aspects of intermountain life and predicted mortality maps of spruce beetle and mountain pine beetle-infested trees. Scenarios were then created using management guidelines that focus on landscape architecture fields/project types that are projected to experience effects of bark beetles, as delineated in this section. These fields include:

- Residential
- Recreation (State and Federal public land)
- Skiing

The main topics and relationships being explored include:

- Aesthetic and economic consequences
- Public perceptions associated with bark beetle outbreaks
- Proximity to predicted outbreaks of spruce beetle and mountain pine beetle

MANAGEMENT CONSIDERATIONS

This section utilizes research that addresses measures used to mitigate the spread of bark beetles within a specified infested area. Forestry, silvicultural, and other management techniques were explored. In addition, studies and literature were evaluated that addresses the social response and preferences of specific management methods, which will influence management guidelines. Existing management recommendations that consider landscape aesthetics were also investigated. The treatment methods investigated include:

- Chemical (pheromones, insecticides)
- Thinning, sanitation, and clear-cutting (mechanical)
- Cultural control
- Prescribed fire

This information was used to determine the most important influences to scenic value and to understand when additional aesthetic intervention is required. Positively perceived forest elements were highlighted and implemented into the management guidelines, alongside existing recommendations that promote scenic beauty.

EVALUATIONS OF LANDSCAPE AESTHETICS

Using existing frameworks from four United States' governmental agencies (Forest Service, National Park Service, Bureau of Land Management, and U.S. Federal Highway Administration) that address visual resources and landscape aesthetics, more information can be gathered to inform appropriate management guidelines for bark beetle-infested areas that affect the built environment. Specifically, the visual resource guides evaluated were:

- Scenery Management System (USDA Forest Service)
- Visual Contrast Rating System (Bureau of Land Management)
- Visual Resource Inventory (National Park Service)
- Guidelines for the Visual Impact Assessment of Highway Projects (Federal Highway Administration)

From this data, evaluations were made to inform management recommendations that address considerations of landscape aesthetics and social perceptions of bark beetle impacted areas. Understanding what important elements to emphasize and preserve within affected landscapes benefits the management guidelines.

3.2 PRECEDENT/SITE STUDIES

Three different sites were analyzed to provide insights into the progression of bark beetle infestations over time. Examination of these sites considered the ecological, visual, and social impacts on forests and the surrounding communities that reside nearby. Understanding how infested forests in the past have grown was key in understanding the physical and visual implications of bark beetle infestations in the future, in addition to further examining treatment methods used. The cyclical nature of bark beetle attacks in these locations help demonstrate the potential impacts of outbreaks, which continue to expand over time.

The sites were chosen based on the following criteria:

- Area must be impacted by a spruce or mountain pine beetle (MPB) infestation
- Area is located in North America
- Area needs an estimation of trees/acreage of affected trees
- Information is available regarding post-infestation evolution of the affected area for at least ten years.

Each site studied considered:

- Location
- Size
- Date of Infestation(s)
- Type of Infestation
- Number/Acreage of Affected Trees
- Attributed Causes
- Background Information
- Treatment/Control Measures:
- Timeline of Outbreak(s)

Figure 3.4
Map of precedent study locations
(Hodgson 2020)

SITE #1: KENAI PENINSULA (ALASKA)

Spruce beetles began impacting the Kenai Peninsula of Alaska in the 1980s and lasted for more than 20 years, resulting in spruce mortality over 400,00 hectares of forest (Hayes and Lunquist 2007 and Flint 2006, 207). The outbreak of spruce beetles led to 90 percent mortality in some areas of forest, leading to dramatic changes to the landscape and some of the surrounding communities (Flint 2006, 208). This site is a good representative of the impact of spruce beetle infestations over time and the social perceptions that are associated with outbreaks.

SITE #2: KOOTENAY NATIONAL PARK (BRITISH COLUMBIA)

Following a series of fires, Kootenay National Park was hit by an outbreak of mountain pine beetles in the 1930s that killed almost 80 percent of the lodgepole pine on 25,600 acres along the Kootenay River (Shrimpton 1994). This site is an excellent example of the successional changes of an impacted landscape over time, with specific references to ecological changes of the forests and the relationship with management and tourism.

SITE #3: THE BLACK HILLS (SOUTH DAKOTA)

Mountain pine beetles were documented in the Black Hills approximately 115 years ago in South Dakota and Wyoming (Graham et al. 2016) Plots with densities over 150 square feet of basal area per acre experienced significant mortality as early as 1987, while plots with densities of 90 square feet of basal area per acre experienced severe mortality by 2010 (Graham et al. 2016). This site is a significant and well-documented example of the evolution of bark beetle impacts as one of the first officially documented areas in the United States. It demonstrates relationships between stand age, density, and bark beetle susceptibility that are helpful in predicting bark beetle behavior and impacts.

3.3 CREATING MANAGEMENT GUIDELINES

The purpose of this research is to stress the current and future impacts of bark beetle outbreaks to important fields of landscape architecture to justify the creation of recommendations for landscape architects to help manage and prevent the spread of bark beetles. Landscape architects have a unique position to be able to incorporate silvicultural and landscape management techniques with considerations of landscape aesthetics and social implications of outbreaks and treatments. With this understanding, landscape architects will be able to better communicate with landscapers, clients, and other contractors the necessary steps that should be taken to lessen the impacts of a pending outbreak.

Figure 4.1
Mountain Pine beetle-attacked forest in the red stage.
(Brown 2007)

4 FINDINGS

4. FINDINGS

4.1 CONTENT INVENTORY AND ANALYSIS SUMMARY

This section is divided into three foci: the investigation of threats to areas of landscape architecture, the examination of forest management practices to address these threats, and the exploration of visual resource guides within U.S. agencies. The impacted fields being addressed in the first section are the residential, recreational (public land), and businesses (ski resorts), as they relate most to landscape architecture projects within the Rocky Mountains. Next, by looking at existing management practices and responses, information was gathered that influences management considerations and better inform landscape architects. Lastly, the analysis of the visual resource guides supports management guidelines by supplying aesthetic considerations. Together, the information from this section helps address bark beetle infestations by understanding the risks to prominent landscape architecture fields and management considerations for future projects.

Figure 4.2
Bark beetle damage on the west side of Rocky Mountain National Park.
(Wilson 2010)

4.2 UNDERSTANDING IMPACTS

It is important to understand the relationship between bark beetle impacts and the landscape architecture profession. By understanding the relationship between potential bark beetle outbreaks and existing landscape architecture projects, a more accurate assessment of potential impacts can be estimated. The impacts were explored in this report by analyzing existing landscape architecture firm projects, projected bark beetle outbreaks and tree loss, and existing studies regarding the specific impacts to those project types.

LANDSCAPE ARCHITECTURE PROJECTS AT RISK

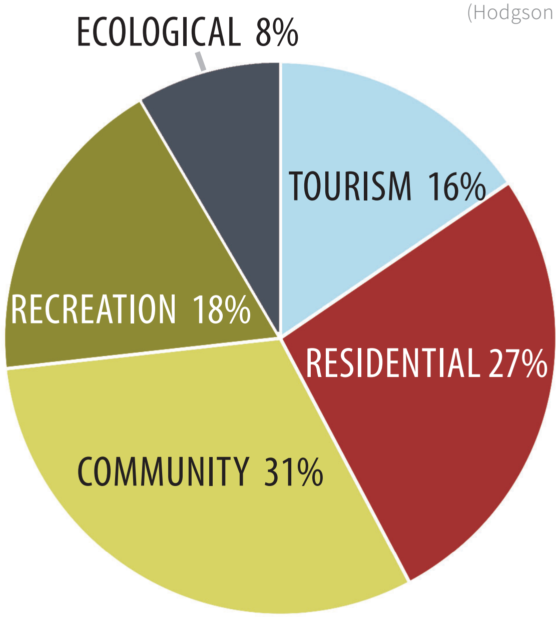
To gain a better understanding of the project types at risk within the Rocky Mountain Region, existing landscape architecture projects were explored to understand the most common and typical project types. This report investigates four landscape architecture firms with offices in Colorado and outlines their projects based on location and project type within western Colorado. The firms that were reviewed included:

- studioINSITE (Denver)
- Design Workshop (Denver, Aspen)
- DHM Design (Carbondale, Denver)
- SE Group (Frisco)

From these firms, 71 projects were selected within the Colorado Rocky Mountain Region and analyzed based on project location and project type (see Appendix D). These projects were sorted into common themes, based on their project types, which were identified as residential, recreation, community, tourism, and environmental. The breakup of these project types is identified as follows:

- 31% community projects (22 total)
- 27% residential projects (19 total)
- 18% recreation projects (13 total)
- 16% tourism/ski resort projects (11 total)
- 8% ecologically focused projects (6 total)

Figure 4.3
Percentage make-up of landscape architecture projects in western Colorado.
(Hodgson 2020)



The most common landscape architecture project type is community-based projects, which includes master-plans and urban designs. The second most common type is residential projects, which included single-family, multi-family, and ranch-style residences. The third most common is recreational projects, which includes trail systems, national parks and forests, and other miscellaneous projects open to the public. The fourth most common project type is tourism-based projects centered around ski resorts, including ski slopes and base villages. The least common, but still prominent, project type is ecological projects, which commonly deal with the preservation and restoration of native ecosystems.

By understanding the most prominent project types from existing landscape architecture firms that interact in the Rocky Mountain Region, more insightful assessments and information can be gathered that directly relates to the landscape architecture profession. The five project types (recreation, ecological, residential, community, and tourism) were separated into three categories for further explanation and exploration of additional impacts. These categories included:

- The natural environment, including recreation and ecological projects.
- The built environment, including residential and community projects.
- Tourism, looking at the ski-industry based projects.

Additional investigation included research regarding the economic and ecological impacts of bark beetle outbreaks within these categories and mapped relationships with predicted spruce and mountain pine beetle mortality.

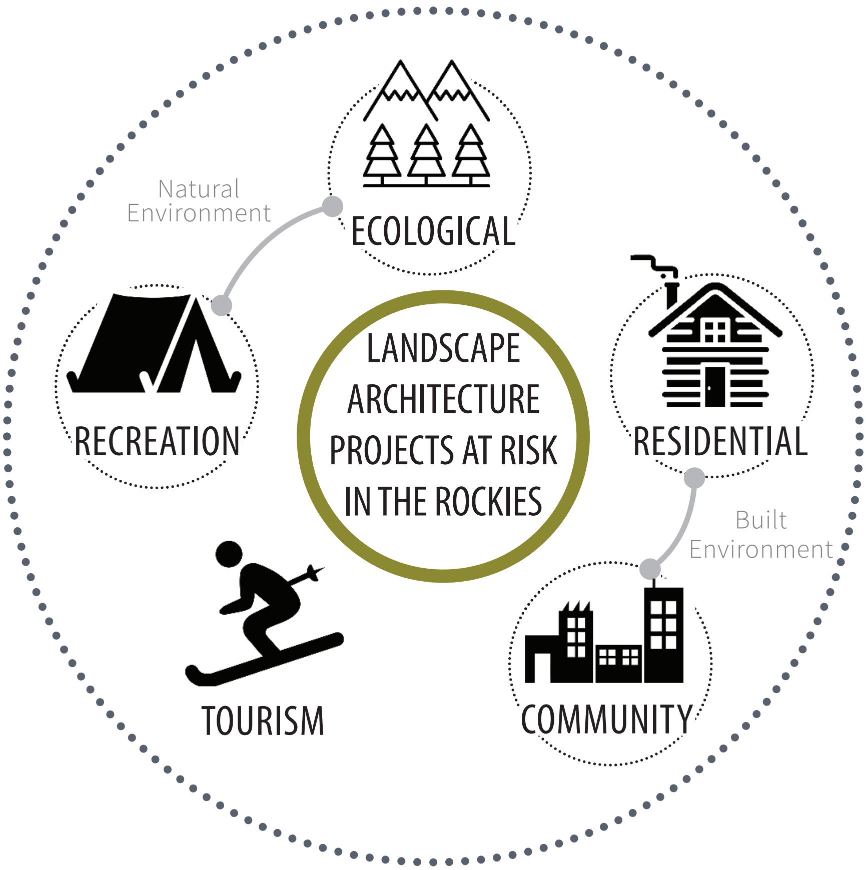


Figure 4.4
Diagram and division of landscape architecture projects at risk.
(Hodgson 2020)

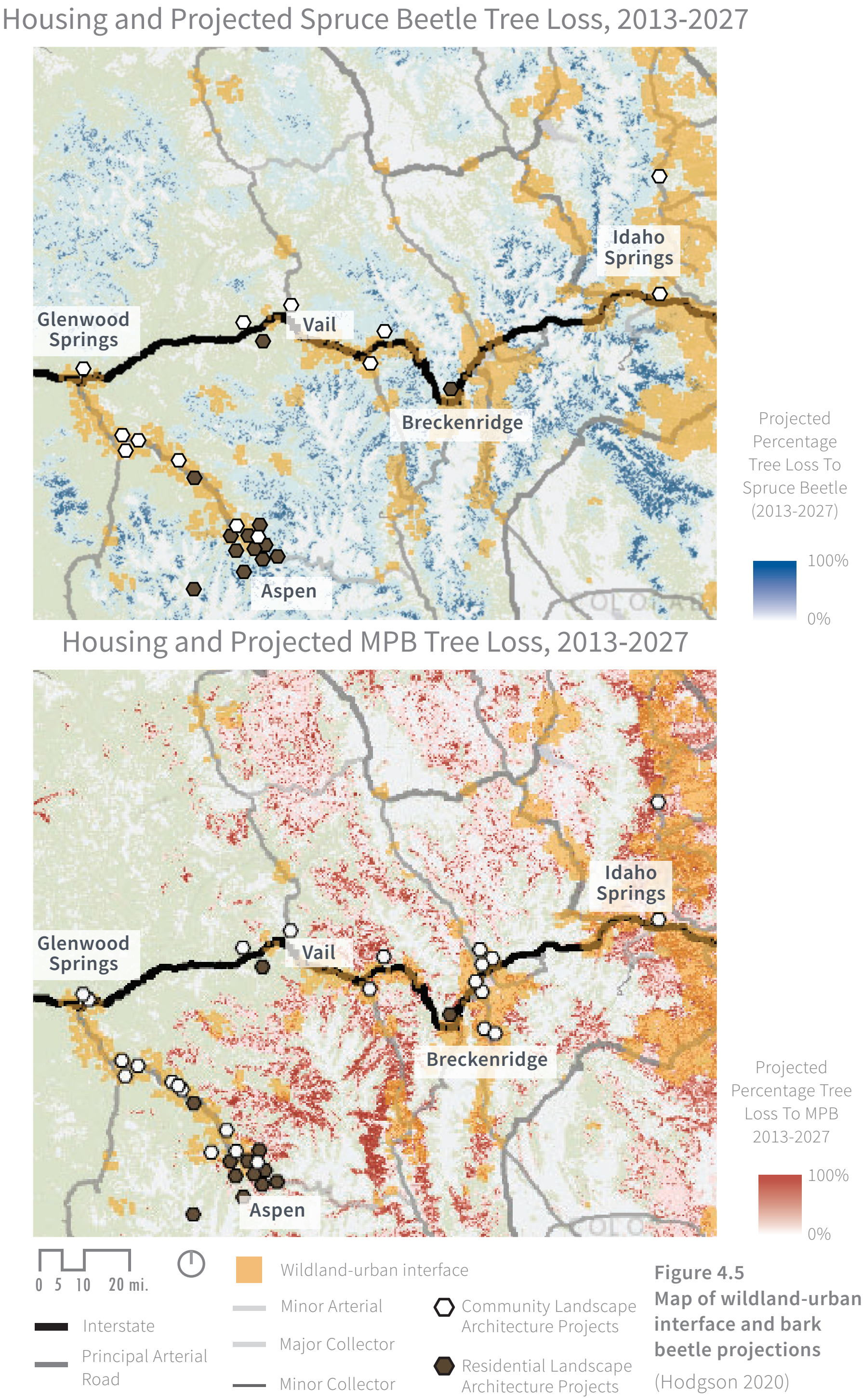


Figure 4.5
Map of wildland-urban interface and bark beetle projections
(Hodgson 2020)

Layer sources: USDA Forest Service 2012, Colorado Department of Transportation 2019, Volker et al., 2017

RESIDENTIAL AND COMMUNITY

Though recent research has largely established that climate and drought have been important factors for the cause of lodgepole pine forest fires in the past century, there is still a dominant public perception that bark beetle impacted areas will increase fire risk in residential areas (Kulakowski and Jarvis 2011). This perception, the aesthetic loss of nearby trees, and safety concerns from falling trees have lead to negative associations to bark beetle infestation to property values. An analysis of the relationship between residential property values and mountain pine beetle infestations by Price et al. (2010) in Colorado used GIS (Geographic Information System) to evaluate the effect of tree mortality on property values. The models indicate a positive relationship with housing prices and the percentage of forest cover and negatively impacted by mountain pine beetle damage. At intervals of 0.10 km, 0.50 km, and 1.0 km, this report found that a tree killed within those intervals will reduce property values by approximately $648, $43, and $17 per tree, respectively (Price et al. 2010). These values are representative of the negative impact that mountain pine beetles pose to properties within the wildland-urban interface and the necessity for beetle management within those zones.

Projected MPB Tree Loss Relative to Housing in the Wildland-Urban Interface in Western Colorado, 2013-2027

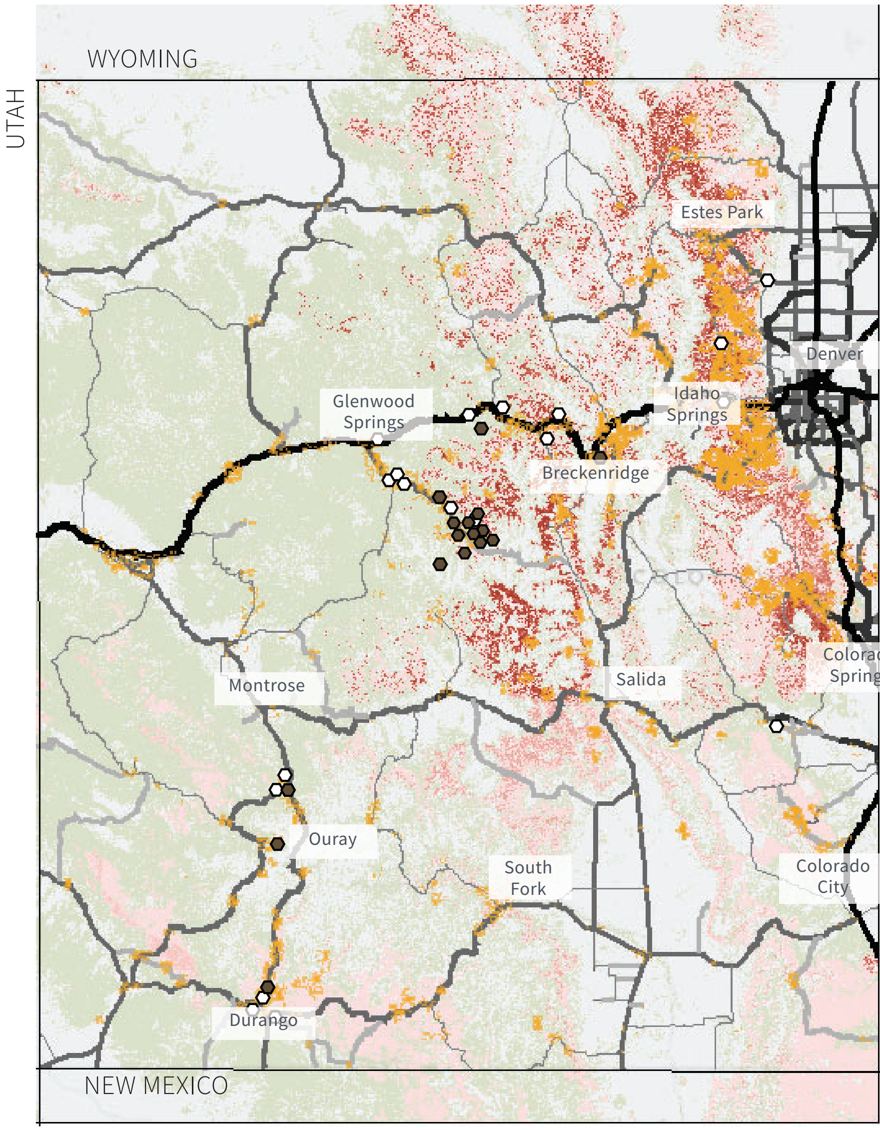


Figure 4.6
Map of mountain pine beetle projections with residences and transportation in western Colorado.
(Hodgson 2020)

Layer sources: USDA Forest Service 2012, Colorado Department of Transportation 2019, Volker et al., 2017

Projected Spruce Beetle Tree Loss Relative to Housing in the Wildland-Urban Interface in Western Colorado, 2013-2027

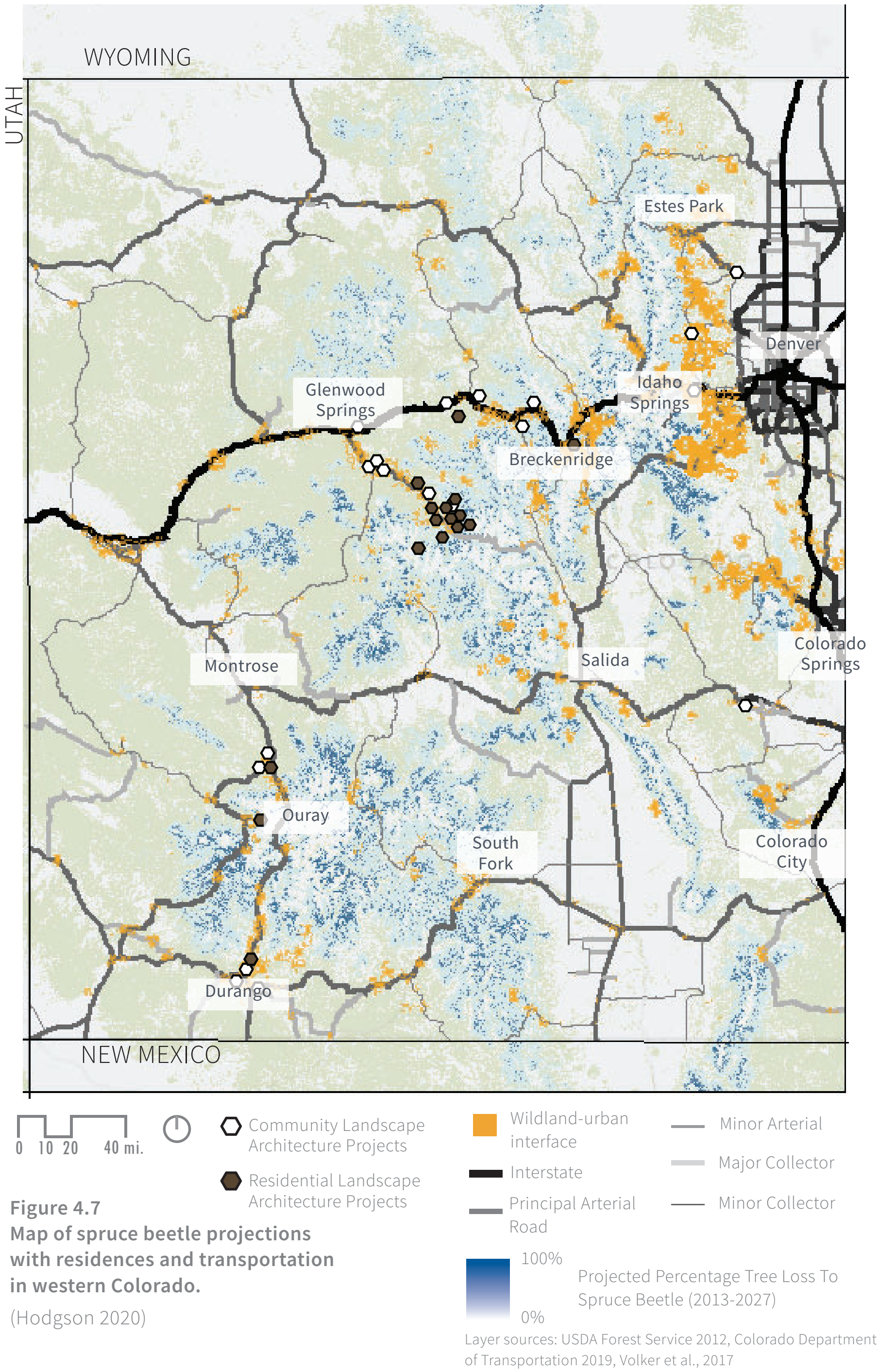


Figure 4.7
Map of spruce beetle projections with residences and transportation in western Colorado.

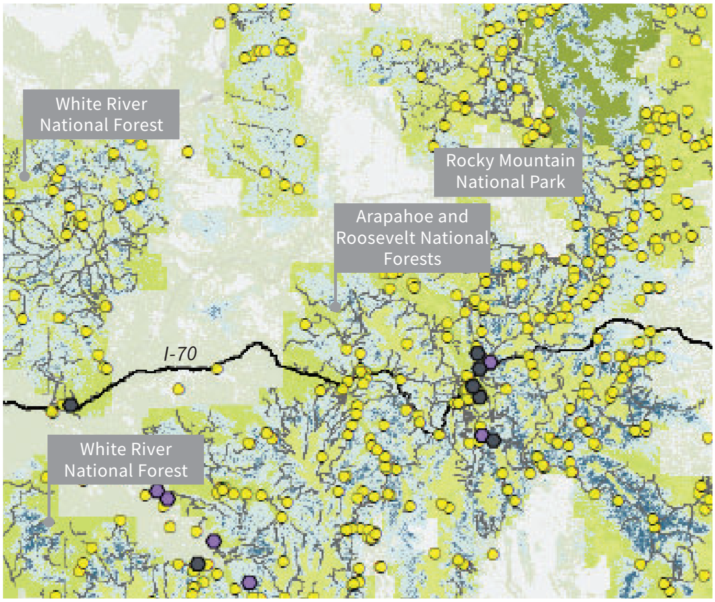
(Hodgson 2020)

RECREATIONAL AND ENVIRONMENTAL

The majority of bark beetle infestations in the Rocky Mountain region affect the scenic landscapes protected by state and federal agencies, such as the U.S. Forest Service and National Park Service. In addition to providing protection for native ecosystems, these lands have important cultural and scenic value for visitors and those that live nearby. Not only does the loss of visual quality affect recreational areas, but affected forests also present safety risks from falling trees. Post outbreak years, approximately 5-20 years after infestation, beetle-killed trees are at risk of blowdown and create hazards for hiking trails, visitor sites, and other trafficked areas (Cerezke 1993). Following a spruce beetle outbreak in the 1990s (see Figure 4.22), campsites in the Kenai Peninsula suffered from a reduction of shade, screening, and aesthetic quality from loss of overstory trees. The campsites then became more exposed to climatic factors such as wind, temperature, and weather, in addition to the danger from moose and bear habitat (Lundquist 2016). Both the visual and physical impacts of bark beetle infestation are important to consider, especially when considering management and treatment options.

By using correlations of reduced live tree density and mountain pine beetle infestation rates, Rosenberger et al. (2013, 32) were able to create estimates for nonmarket goods like recreation. By quantifying the infestation rate of mountain pine beetles, the number of live trees in Rocky Mountain National Park (greater than 5-inch diameter), user days in the park and the value per user day, the researchers were able to calculate the decrease in the number of user days depending on the percent change in tree density. Tree density loss also has a negative association with consumer surplus per day, and when combined with the decline in total user days, results in substantial economic losses. Reductions of 25, 50, and 75 percent in live density amounts corresponded to approximate losses of $5 million, $25 million and $59 million in recreational values, or an annual decrease of $30-$341 per acre year (Rosenberger et al. 2013, 35).

Recreation and Projected Spruce Beetle Tree Loss, 2013-2027

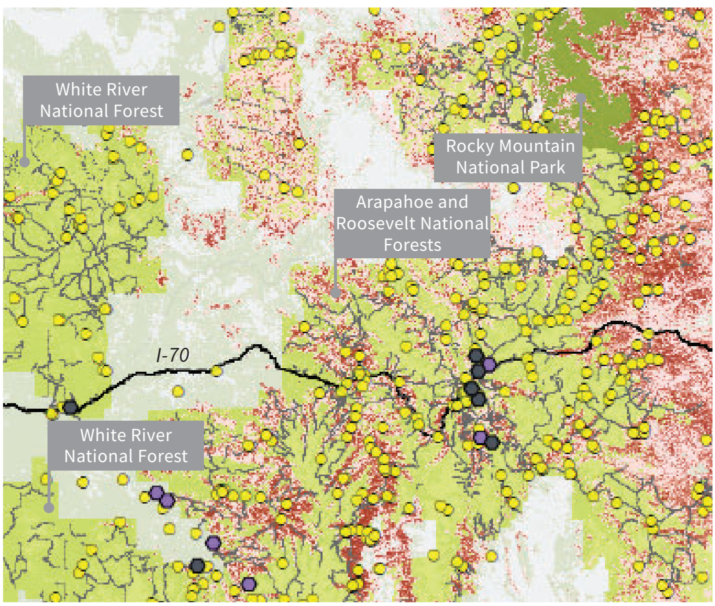


Projected Percentage Tree Loss To Spruce Beetle (2013-2027)

100%

0%

Recreation and Projected MPB Tree Loss, 2013-2027



Projected Percentage Tree Loss To MPB (2013-2027)

100%

0%

0 5 10 20 mi.

Recreational Landscape Architecture Projects

Ecological Landscape Architecture Projects

U.S. Forest Service Proclaimed Forests

National Park Service Operated Land

Recreation Opportunities (Forest Service)

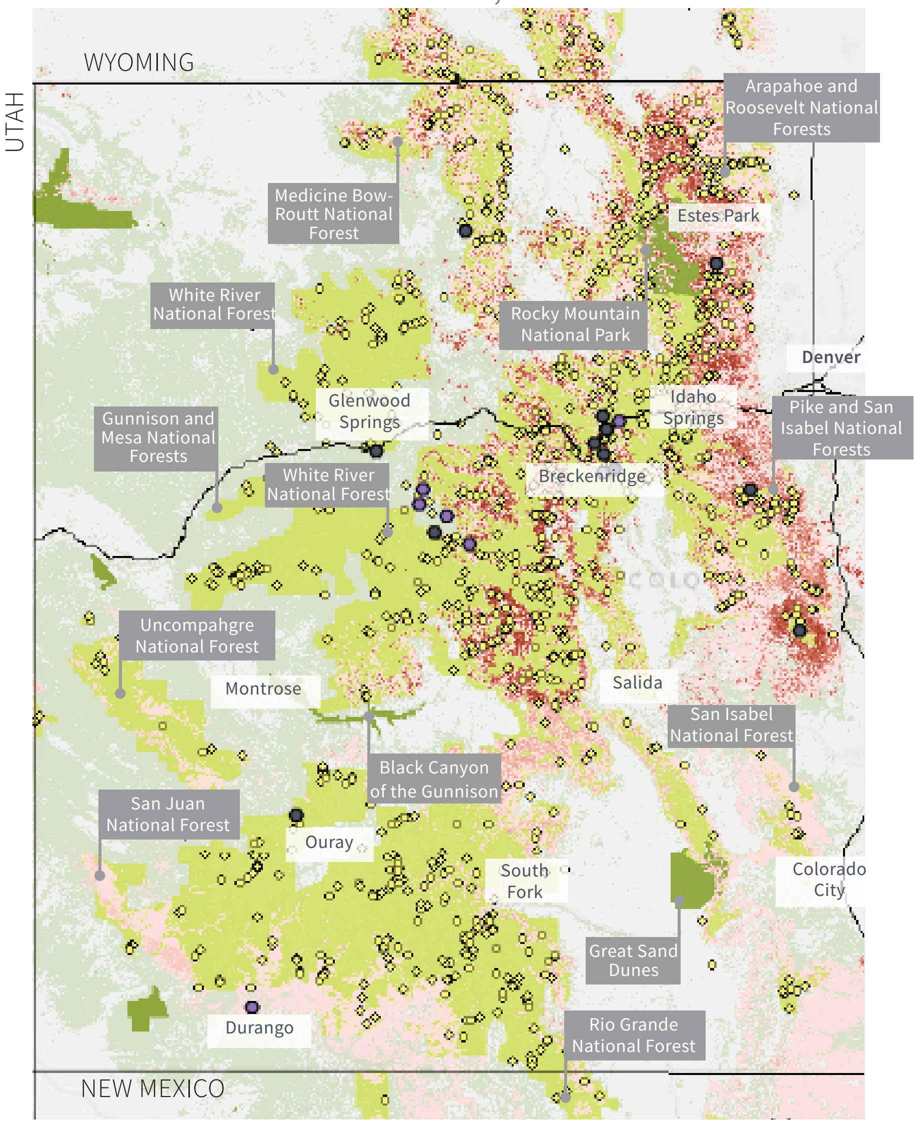
National Forest System Trails

Figure 4.8
Map of public land and bark beetle projections.

(Hodgson 2020)

Layer sources: USDA Forest Service 2012, USDA Forest Service 2020, U.S. National Park Service

Projected MPB Tree Loss Relative to Public Land and Recreation in Western Colorado, 2013-2027



0 10 20 40 mi.

Recreational Landscape Architecture Projects

Ecological Landscape Architecture Projects

U.S. Forest Service Proclaimed Forests

National Park Service Operated Land

Recreation Opportunities (Forest Service)

100% / 0% Projected Percentage Tree Loss To MPB (2013-2027)

Layer sources: USDA Forest Service 2012, USDA Forest Service 2020, U.S. National Park Service

Figure 4.9
Map of mountain pine beetle projections and public land in western Colorado.

(Hodgson 2020)

Projected Spruce Beetle Tree Loss Relative to Public Land and Recreation in Western Colorado, 2013-2027

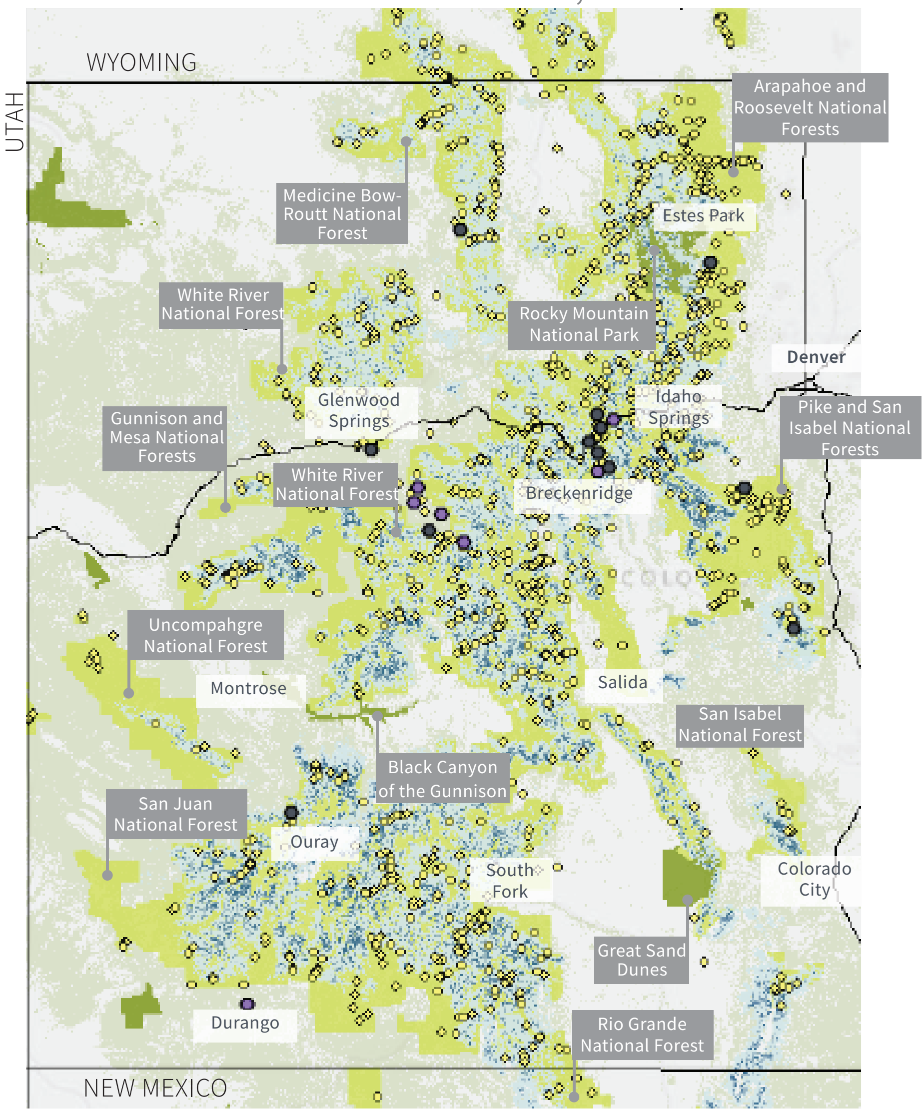
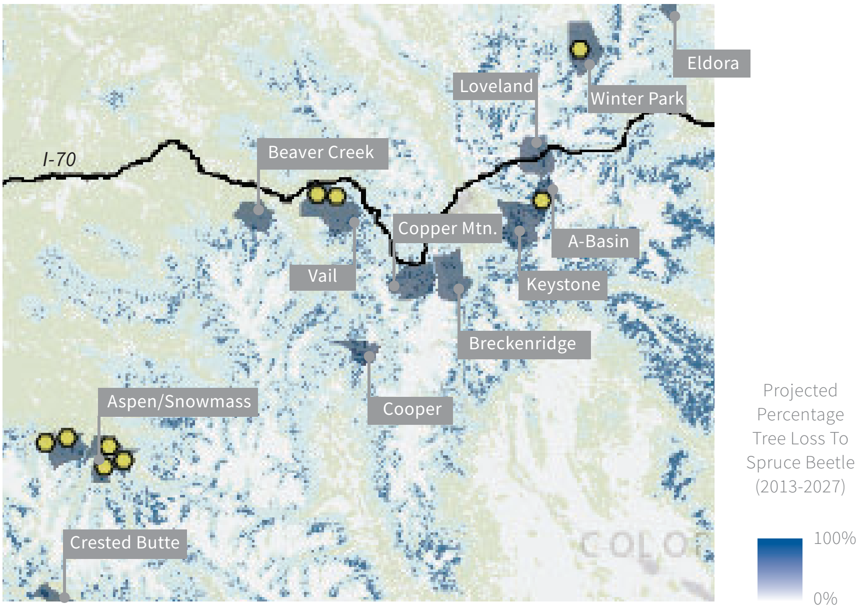


Figure 4.10
Map of spruce beetle projections and public land in western Colorado.

(Hodgson 2020)

Colorado Ski Resorts and Projected Spruce Beetle Tree Loss, 2013-2027



Colorado Ski Resorts and Projected MPB Tree Loss, 2013-2027

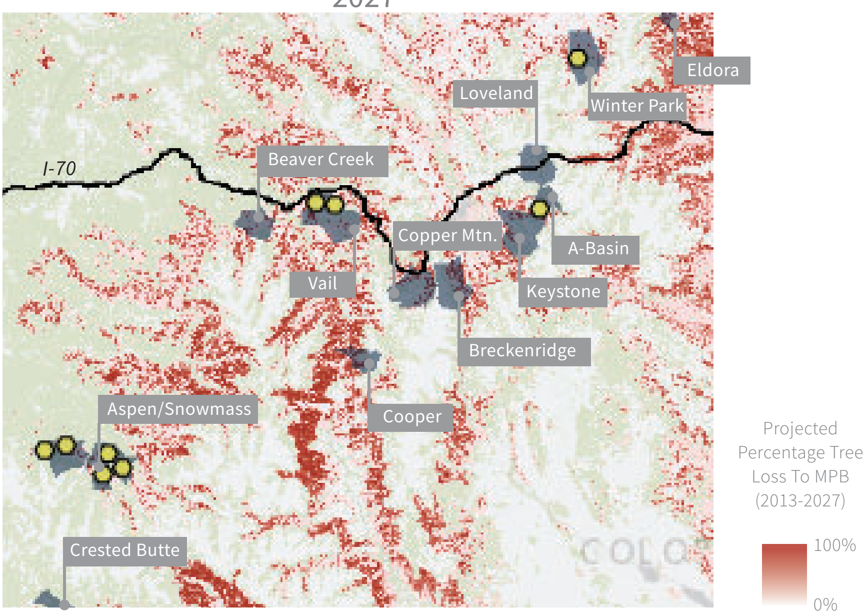


Figure 4.11
Prominent ski resorts and bark beetle projections
(Hodgson 2020)

Layer sources: USDA Forest Service 2012

TOURISM

One of the most prominent and popular industries in the Rocky Mountain region is mountain resorts. However, the effects of bark beetles outbreaks will not only lessen perceptions of scenic beauty, but the experience of skiing and snowboarding will degrade. Not only do the resorts feel the visual impacts of tree losses, but the experience of skiing and snowboarding will see changes as well. Forests play an important role by reducing weak layers of snow formation to prevent slab avalanches, as well as reducing near-surface wind speeds, intercepting falling snow, and balancing surface energy (Teich et al. 2016). As the trees die or are removed as a result of bark beetle induced mortality, greater sun exposure to the normally shaded snowpack on slopes will cause quick spring melt. The infestations create potential avalanche release areas that jeopardize infrastructure, ski slopes, and backcountry areas where recreationists typically interact (Teich et al. 2016). With increasing evidence that outbreaks are moving higher in elevation and increasing in magnitude, more ski resorts will be at risk for outbreaks that present hazardous conditions and negatively impact skiing (Mitton and Ferrenberg 2012, Bentz et al. 2019). Commonly, stands of infested trees are logged for timber products and to reduce hazardous conditions; therefore, forests that serve a protective function require planning and additional protection considerations to prevent avalanches, such as wooden fences (Teich et al. 2016). An example of a heavily impacted ski resort is Brian Head ski resort in Utah, which lost up to 80% of their trees from a spruce beetle outbreak (Wells 2005). Now, popular ski resorts at risk include Vail, Breckenridge, Winter Park, Wolf Creek, and others as the path of bark beetles expands (see Figure 4.11).

Projected MPB Tree Loss Relative Ski Resorts in Western Colorado, 2013-2027

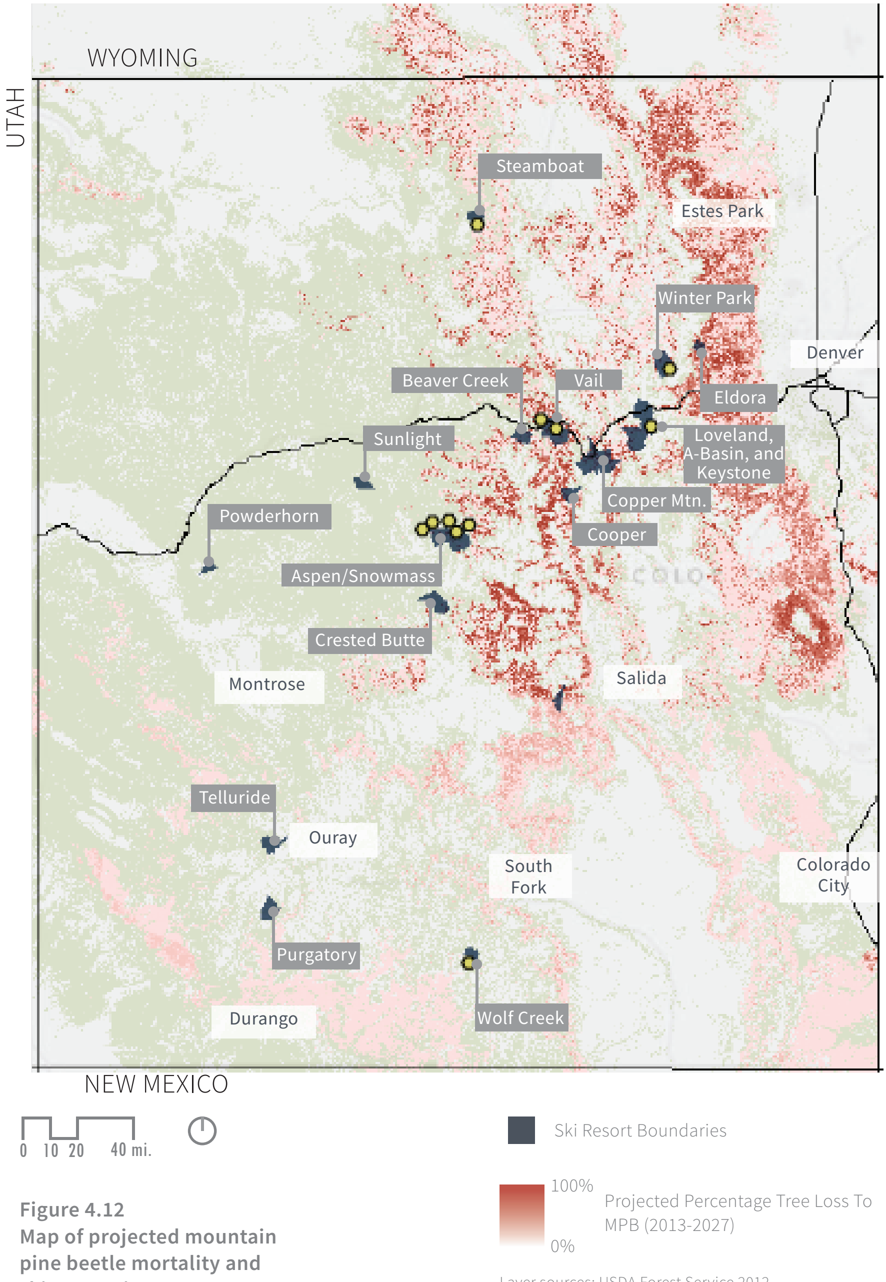
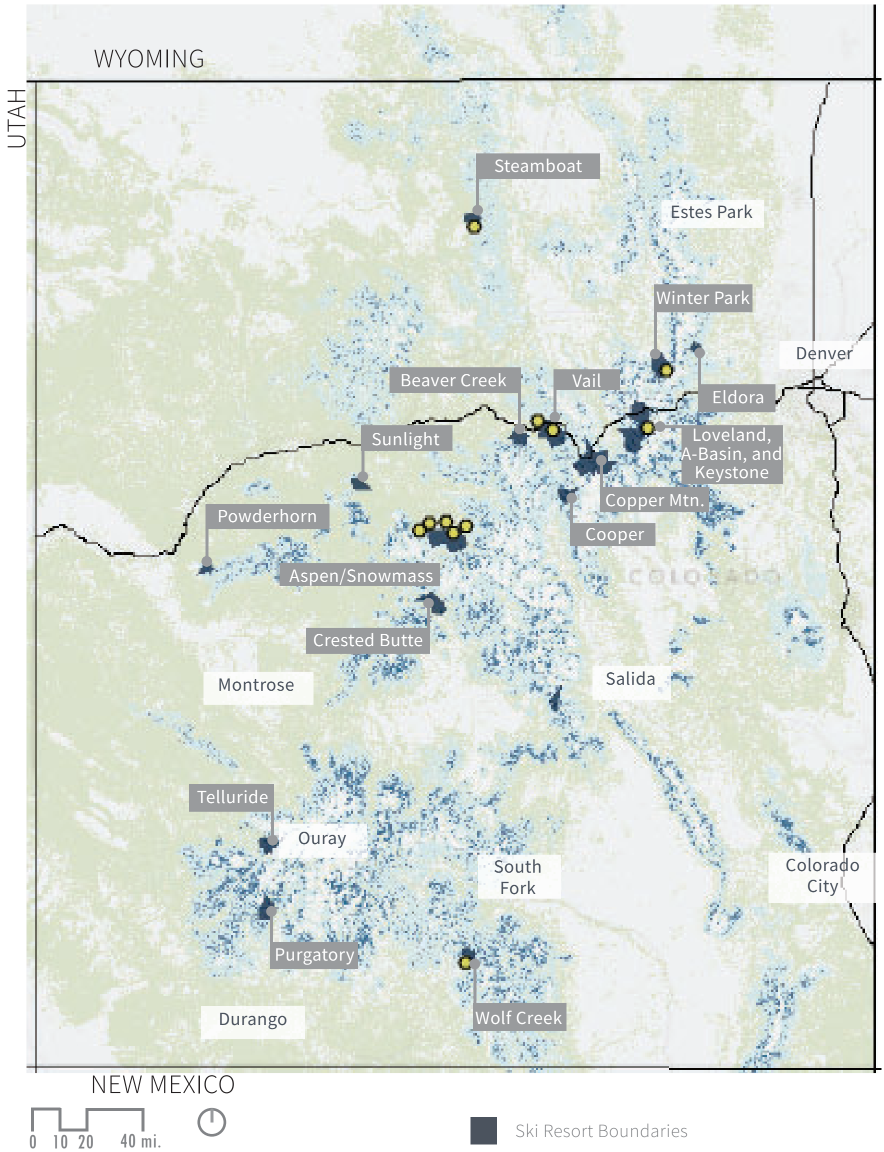


Figure 4.12
Map of projected mountain pine beetle mortality and ski resorts in western Colorado.
(Hodgson 2020)

Projected Spruce Beetle Tree Loss Relative Ski Resorts in Western Colorado, 2013-2027



Ski Resort Boundaries

100%
Projected Percentage Tree Loss To Spruce Beetle (2013-2027)
0%

Layer sources: USDA Forest Service 2012

Figure 4.13
Map of projected spruce beetle mortality and ski resorts in western Colorado.

(Hodgson 2020)

4.3 IMPACT FINDINGS

Information in this section stresses the severity and reality of bark beetle impacts on everyday life. Bark beetles not only impact natural forest ecosystems, but can also have drastic impacts on the built environment due to losses in aesthetic value, and thereby have implications for the landscape architecture profession. Through analysis of fields relative to landscape architecture, specific project types have been identified as being at risk from current and predicted bark beetle outbreaks. This report utilizes these project types as locations for scenarios that demonstrate the use of management guidelines. The main project types at risk include:

- Recreation (campsites, picnic areas, nationals parks, and forests)
- Ecological (preservation and restoration)
- Residential (single-family and multi-family homes/yards)
- Community (master-plans and urban development)
- Tourism (ski slopes and base villages)

Through this identification, the management guidelines can be more easily applied and will become a useful tool for landscape architecture in real-life applications.

Bark beetles impact.....

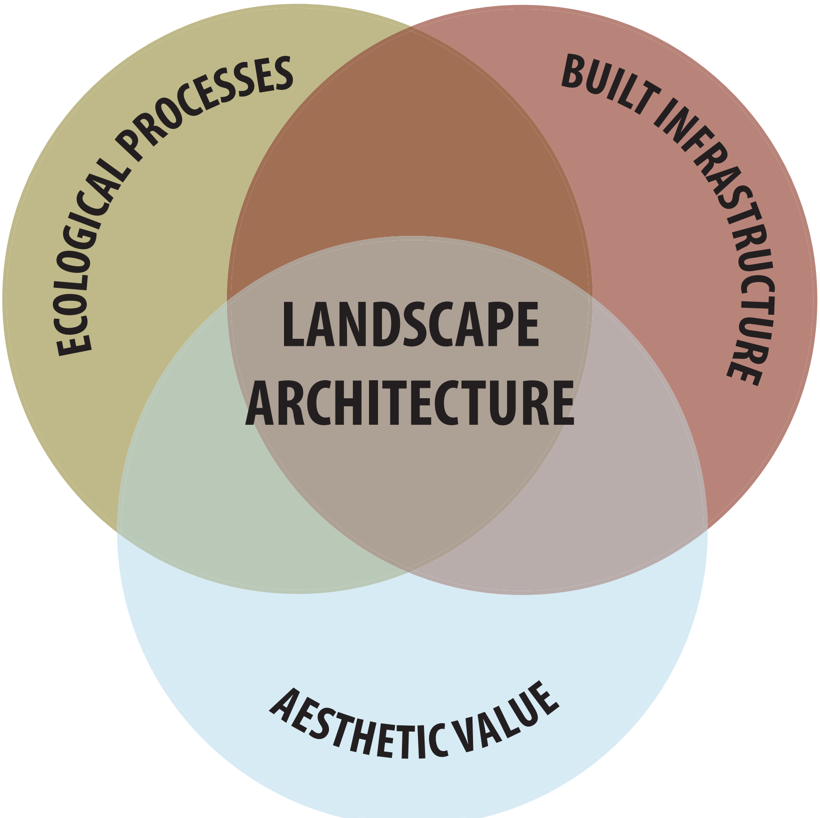


Figure 4.14
Diagram showing how bark beetles impact the landscape architecture profession.
(Hodgson 2020)

4.4 MANAGEMENT CONSIDERATIONS

Integrated Pest Management, as defined by the National Park Service, is a decision-making process that uses knowledge of "biology, the environment, and available technology to prevent unacceptable levels of pest damage" while posing the least possible risk to people, resources, and the environment (2005, iii). The techniques are aimed at prevention (using long-term techniques like thinning to improve the ability to withstand bark beetle outbreaks), suppression (direct control techniques to address short term needs during an outbreak), and restoration (maintaining the bark beetle's role in the natural ecosystem by allowing them to continue) (National Park Service 2005). The four different management techniques are mechanical, cultural, chemical, and prescribed fire (National Park Service 2005).

Figure 4.15
Pheromone packet on mountain pine beetle-infested tree.
(Dewey 1995)

CHEMICAL

Chemical treatments are used as preventative and control measures to address bark beetle outbreaks. The chemical treatments used on trees subject to bark beetle infestations are preventative measures, such as bole sprays, carbaryl, and synthetic pyrethroids (USDA Forest Service 2011). These sprays are applied to the outer bark and act as neurotoxins that deter beetles from host trees (Stephens 2010). These treatments require an annual application and are not appropriate for use near riparian areas (Stephens 2010). Standard preventative treatment for small scale infestations is the use of pheromone packets. These sociochemical treatments utilize the pheromones that beetles use to communicate with one another to send a signal to stay away from the protected trees (Montana DRNC 2019). Verbenone is a short-term treatment that is attached to trees before beetle flight between June 15 and July 1. It deters bark beetle infestations by disrupting the pheromone signals that the beetles use to communicate (USDA "Using Verbenone to Protect Trees from Mountain Pine Beetle"). Phermone packets are applied as time-release capsules or flakes that are attached to at-risk trees, which must be replaced annually and are most successful in low bark beetle populations (Stephens 2010).

In British Colombia, treatment of mountain pine beetle outbreaks has been addressed partially using an organic arsenic pesticide (monosodium methanearsonate, or MSMA) (Morrisey et al. 2008). This pesticide has been used for over twenty years in British Columbia to control mountain pine beetle and spruce beetle infestations. MSMA is injected into trees within 3-4 weeks of infestation, which travels from the xylem into the phloem, killing the trees and poisoning the beetles. This method is favored amongst foresters for its low cost and usability in remote areas when harvesting is not economical (Morrisey et al. 2008). However, the use of pesticides creates ecological disturbances that can negatively impact local ecosystems. As stated in the Background, insectivorous predators like woodpeckers thrive from bark beetle infestations as a source of their food (Morrisey et al. 2008) and bark beetles are natural disturbance agents in these ecosystems. The use of MSMA results in greater arsenic loading into the environment, and elevated arsenic levels have been detected in woodpeckers and other birds breeds next to exposed stands. MSMA has the potential to impact woodpecker populations directly through arsenic poisoning, and indirectly by limiting food availability (Morrisey et al. 2008).

THINNING AND SANITATION

Landscape maintenance techniques are another form of preventative treatment to lessen the impacts of bark beetle outbreaks. The health of trees in both residential and forest settings is promoted by thinning trees or removing selected trees before bark beetles attack, which reduces competition for moisture, sunlight, space, and nutrients (Donaldson and Seybold). Pruning and disposing of bark-beetle infested limbs will help reduce overcrowding and is part of the management process called sanitation (Donaldson and Seybold, Bentz 2009, National Park Service 2005). Sanitation and thinning use mechanical methods of Integrated Pest Management, such as solarizing, burning, chipping, stripping, and hauling (National Park Service 2005).

Spruce and pine forests have varied responses to density reduction practices like thinning. Typically, individual-tree and group-selections are used to regenerate a particular species, while thinning from above and intermediate treatments are meant to enhance the growth of largely commercially focused species by reducing competition (Temperli et al. 2014). For mountain pine beetles, density reduction is effective for reducing pine beetle infestations in lodgepole pine, ponderosa pine, and whitebark pine while beetle populations are in endemic stages and it is conducted rigorously over a large-scale area (Fettig et al. 2014). Research by Temperli et al. (2014), which evaluated the effectiveness of density reduction for spruce beetle disturbance, found that spruce density reduction did not correspond to a reduction in infestation rates for large spruce (>25 cm DBH) during an outbreak. This information demonstrates that large spruce trees and high densities of spruce were still at risk despite thinning efforts and is likely because drought is a much stronger driver of susceptibility than stand structure.

Figure 4.16
Thinned Stand before slash clean-up, Black Hills 1973.
(USDA Forest Service 1990)

In residential landscapes and smaller-scaled projects, treatments include chipping woody materials, debarking, and removing affected or at-risk trees. With trees that have been pruned or thinned, chipping destroys beetles and their habitats. It allows the materials to be scattered as mulch (as long as it is not placed next to a tree of the same species, which would increase the likelihood of re-infestation) (Donaldson and Seybold). Debarking is another technique where the bark is removed to destroy the phloem where adult bark beetles lay their eggs so the trees will no longer support bark beetle reproduction. For the management of forests, much of the mechanical treatments deal with addressing slash, the woody material left behind after commercial logging or thinning operations (Donaldson and Seybold). These techniques include lop and scatter (removing and spreading branches into sunlit areas to dry the inner bark), piling and burning, and removal of infested stems (Donaldson and Seybold). Burning and burying are more labor-intensive and expensive, as are many direct management techniques that make them difficult and impractical for large scale projects.

REGENERATION HARVEST AND CULTURAL CONTROL

A regeneration harvest is ideal in areas where foresters want to promote a fast-growing forest and is accomplished by removing some of the slow old-growth (Samman and Logan 2000). This process includes clear-cutting (removing all trees), shelterwood cuts (removing all but the healthiest trees to protect understory trees), or seed cuts (removing all but the healthiest trees to support reproduction) (Samman and Logan 2000). Cultural control aims at limiting the impacts of bark beetles by considering tree selection and planting species that are appropriately adapted to the area, thereby creating heterogeneous landscapes that contain many sizes, ages, and species of trees. These forests become more resistant and resilient as they receive more sunlight and wind to help disperse pheromones and less competition for resources (Bentz 2009). For small scale areas, irrigating the outer canopy of trees to address natural drought with enough water to reach one foot below the surface (UC IPM 2008). For spruce stands, management practices that enhance the resilience of stands by increasing spruce advance regeneration in the understory (Temperli et al.). Following and responding to infestations, one can promote landscape diversity in species, age, and structure, which will allow bark beetles to occur naturally within the forest without massive losses (Samman and Logan 2000).

Figure 4.17
Prescribed fire of beetle-infested trees.

(USDA Forest Service 1990)

PRESCRIBED FIRE

Prescribed fires are controlled fires that are typically used to reduce the build-up of hazardous fuels, promote wildlife habitats, and restore fire-adapted forest ecosystems (Tabacaru et al. 2016). Beetles have a complex relationship with fire, and much debate has circulated weighing the positive and negative effects of using prescribed fires to address bark beetle infestations. While the fires do reduce the build-up of material and kill beetles within infested trees, prescribed fires also stress uninfested trees, so they become more susceptible to bark beetle attacks (Fettig et al. 2010). In western Canada, Tabacaru et al. (2016) found that for low-density bark beetle populations, prescribed fires act as a short-term resource for bark beetle broods. Trees burned from a prescribed fire were more likely to be attacked than non-burned trees, but the fire did not promote further outbreaks as the attacks declined four years following the fire (Tabacaru et al. 2016)

AESTHETIC PREFERENCES OF MANAGEMENT

Bark beetle infestations have significant impacts on the visual composition of forests. Most visitors and residents are very sensitive to beetle activity, where the greener and more thriving a forest appears, the more it is appreciated whereas dead and dying material negatively affect preferences (Arnberger et al. 2018). Not only does the appearance of the decaying trees influence public perceptions, but so do the forest management techniques of intervention or non-intervention. In a study reviewing social impacts from outbreaks, visitors were surveyed at three different parks that were impacted by bark beetles and chose their most and least-preferred forest environment from a series of photos that depicted beetle impacted forests and management activities. The lowest value of preference was given to scenarios where all trees were dead and where the mortality was followed by clear-cutting that left visible traces of human intervention (Arnberger et al. 2018). Visitors preferred artificial reforestation with young spruce trees of the same age class over a natural succession of mixed pine and spruce. The study deduced that the foreground and near-view of forest surroundings were the most important consideration for recreationists. The study also stated that the focus for forest management should be on the forest surrounding hiking trails and tourism facilities, and clear-cutting should be avoided on trails unless the infested tree poses a danger to visitors (Arnberger et al. 2018).

Fuel and forest management practices are controversial within impacted communities, especially concerning the impacts to the scenic beauty that the natural landscape offers (Ryan 2005). Forest management that embraces landscape aesthetics may promote public acceptance of forest activities and promote forest sustainability (Panagopoulos 2009). Multipurpose forest management and recreational focuses promote greater consideration of people's perceptions of these landscapes. Sustainable forest management looks at long-term management solutions that promote healthy performance in the future, but sometimes these management solutions clash with aesthetic values. As explained by Panagopoulos (2009), woody debris may be beneficial for ecological development, but to the public, it looks messy.

Conversely, if materials were cleaned-up to look more visually pleasing, it would disrupt local habitats. Because many regard landscape aesthetics and beauty to be relative/subjective, not as much emphasis is placed on landscape aesthetics regarding other important aspects of sustainability such as economic, ecological, and social considerations (Pangagopoulos 2009). Ecological and aesthetic focuses tend to clash in forest management and present conflicts. As woody debris is an important source of organic matter and habitat that supports forest health, it lowers the aesthetic value for visitors (Gobster 1999, Ryan 2005). Likewise, fire is a necessary part of some ecosystems but is also disliked by people and has low scenic qualities. Joan Nassauer suggested, “cues to care” to address messier ecosystems through small human interventions, such as fences and planting native flowering plants, to increase appreciation and acceptance for native ecosystems and create “orderly frames” (Nassauer 1995, Ryan 2005).

Regarding forest landscape aesthetics, the greatest importance for preferences is argued as the spatial configuration for space, where the organization and compositions of the landscape are processed (Nielsen et al. 2012). As one walks through a forest, they are continually analyzing their relation to the surrounding environment. In a study by Nielsen et al. (2012), forested spaces that were desired had implied space via the tree canopy, as well as landscape elements and subtle details. The most favored elements were special trees, especially large living trees. Dead wood was the most frequently disliked element, especially if it was in the early stages of decomposition, but was more favored in the intermediate stage where it appeared to be the result of natural causes (Nielsen et al. 2012). Other disliked elements include those made from artificial material such as recreational facilities, food wrappers left on the ground, and ruts left by machinery (Nielsen et al. 2012). The study demonstrated that people are sensitive to human interventions in natural settings, where it is perceived as intrusive. Though people generally prefer more managed landscapes, they prefer no trace of human intervention, so forest management practices should aim to reduce their visual impact (Nielsen et al. 2012).

An analysis of scenic beauty characteristics attributed to ponderosa pine (*Pinus ponderosa*), one of the most common hosts of mountain pine beetle, found that larger trees and herbage contributed to scenic beauty and lower-overstory densities and lower degrees of tree grouping are preferred. Small pine trees and downed wood took away from scenic beauty, with the presence of slash even more detrimental to this perception (Brown and Daniel 1984). As previously stated, large clear-cuts have a negative effect on scenic beauty, but a partial clearing of up to 50 percent of trees in a dispersed pattern may be more acceptable, especially if large trees are saved (Ryan 2005). Visual access and an open forest composition are preferable, as well as mixed-aged forest stands (Gan et al. 2000, Ryan 2005). Providing information regarding management techniques through signage, stewardship programs, newsletters, and brochures increased public acceptance of clear-cut and restoration areas (Ribe 1999; Ryan 2005; Covington and DeBano 1993). Information can be an important tool to display the intent and purpose behind management practices and help visitors become more accepting of natural processes, though perceptions of scenic beauty were still unaffected (Ribe 1999; Ryan 2005; Covington and DeBano 1993).

MANAGEMENT RECOMMENDATIONS

Management plans for different land uses have varying focuses and strategies. Projects within the wildland-urban interface that focus on protecting high-value trees would be too expensive in larger-scale projects (Samman and Logan 2000). In more wilderness and roadless areas, a natural and no-action approach may be appropriate when far removed from developed areas. When closer to development, long-term prevention strategies may be emphasized to reduce the susceptibility of nearby lands. Areas with multiple ownership such as federal, state, and private stakeholders should prioritize partnerships and communication between the groups prior to outbreaks to develop necessary management plans (Samman and Logan 2000).

Strategies for managing fuels and visual quality, outlined by the U.S. Forest Service, are organized around three stages: planning, implementation, and monitoring (Ryan 2005, 2).

1. **Planning.** During the planning phase, the U.S. Forest Service encourages a multidisciplinary team, including landscape architects, to help evaluate visual impacts of management activities. Locations chosen during the planning phase should avoid sensitive areas near homes and scenic roads (Ryan 2005). Natural boundaries should be created, and the public should be involved in the planning and proposal process.

2. **Implementation.** Using careful consideration of tree removal is an important aspect of the implementation phase. Mature trees should be protected. Using "cues to care" demonstrates that the forest is being managed while still preserving the natural integrity of the forest.

3. **Monitoring**. During the monitoring phase, providing information about the management of forest through signage to address the timeline of management efforts and visualization of the future forest. Cleaning up woody debris and slash from tree thinning and enhancing the revegetation of disturbed areas are important to consider as affected areas grow.

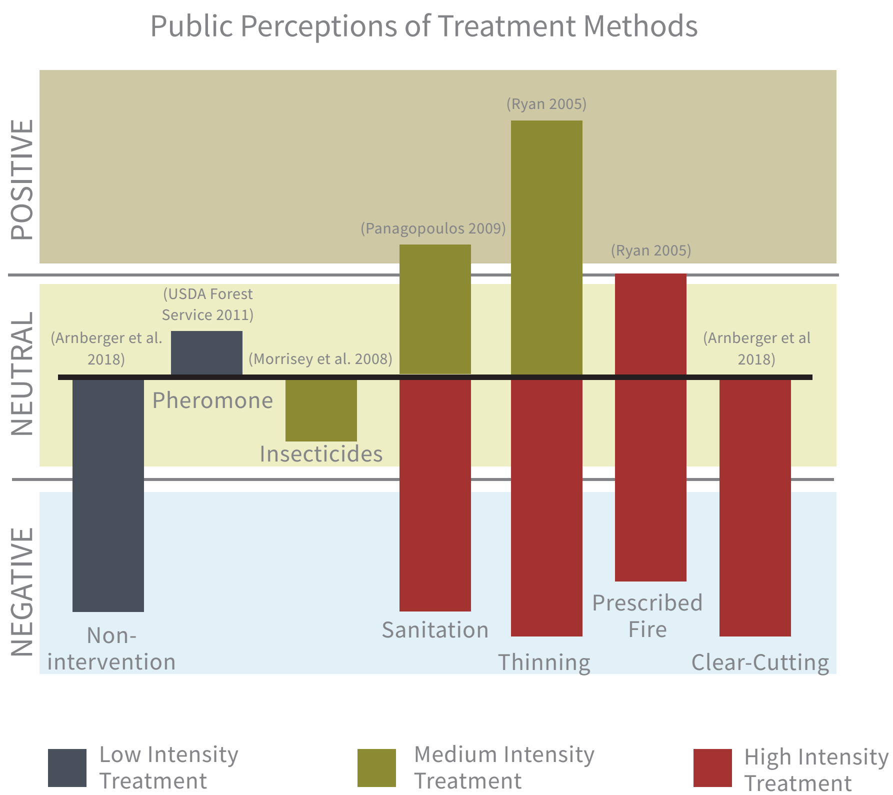


Figure 4.18
Public perceptions of forest treatment methods.
(Hodgson 2020)

4.5 MANAGEMENT CONSIDERATION FINDINGS:

The information gathered in this section provides many insights into the relationship between treatments of bark beetle outbreaks and aesthetic value. The information below represents themes that were found in the section of the content analysis regarding management. This information is outlined below, and make up important considerations of the management guidelines.

Treatment Types. The direct methods of management (mechanical, chemical, and prescribed fire) are intensive, short-lived, and are only effective for a small number of trees (Temperli et al. 2014). Indirect control of bark beetle infestations promote resistance/resilience of stands through the identification of tree and stand characteristics (Graham et al. 2016). Planning and inventory of existing conditions are important to implement and consider when managing a site and overseeing existing vegetation. Important variants to evaluate are the scale of the project, land use objectives, and past trends that need to be taken into consideration for the prevention, suppression, and potential restoration of infested areas to create a cohesive and dynamic management plan (Samman and Logan 2000).

Aesthetic perception of treatments. Most of the common treatments used to address bark beetle outbreaks have negative perceptions of scenic and aesthetic value (see Figure 4.18). Treatments that were perceived positively or had no impact:

- Use of pheromone packets, little to no visual impact (USDA Forest Service 2011)
- Selective thinning, from a decrease in density (Ryan 2005)

Treatments that were perceived negatively and decreased scenic value:

- Clear-cutting and extreme thinning (Arnberger et al. 2018)
- Insecticides, from negative ecological association (Morrisey et al. 2008)
- Clear evidence of human intervention (Nielsen et al. 2012)
- Non-intervention, from dead trees (Arnberger et al. 2018)
- Prescribed fire (Ryan 2005, Covington and DeBano 1993)
- Sanitation and mechanical treatments, from woody debris (Pangopoulos 2009, Brown and Daniel 1984)

Management recommendations. The management recommendations focus on enhancing and preserving the visual and unique characteristics of forests. The type of projects and proximity to the bark beetle outbreak are important elements to consider, as they will heavily impact scenic value. Important elements of the forest that add scenic value include:

- Large and scenic trees (Nielsen et al. 2012)
- Visual access through the forest (Ryan 2005)
- Mixed-aged species (Gan et al. 2000 and Ryan 2005)
- Implied space from the tree canopy (Nielsen et al. 2012)
- Restoration and reforestation (Arnberger et al. 2018)

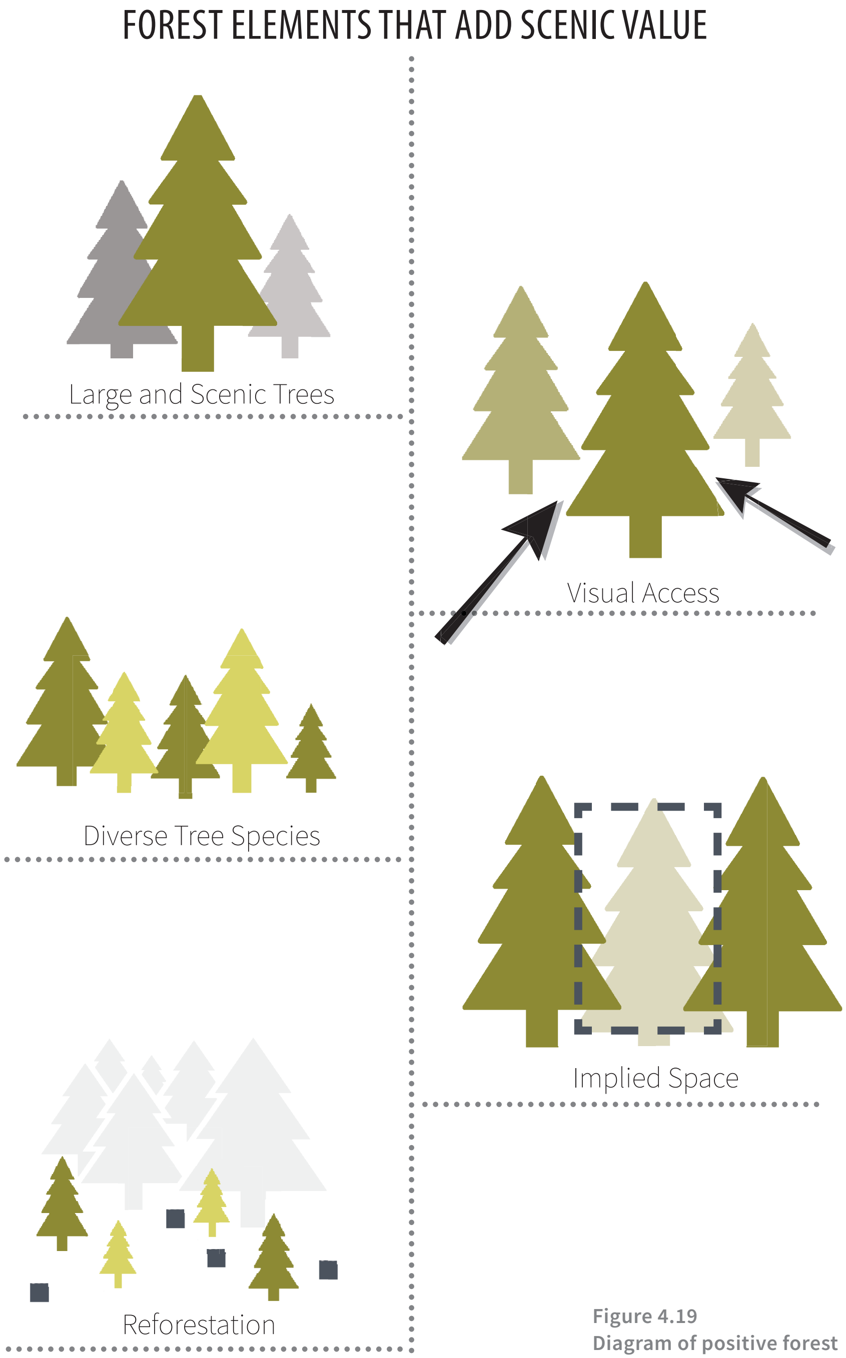


Figure 4.19
Diagram of positive forest preferences
(Hodgson 2020)

4.6 RATING SYSTEMS OF LANDSCAPE AESTHETICS

In compliance with the National Environmental Policy Act (NEPA) of 1970, U.S. government agencies began creating assessments of the environmental effects of proposed projects, including visual impacts, in the form of a Visual Impact Assessment (VIA) (U.S. Department of Transportation 2015, Brown and Daniel 1984). The following agencies (U.S. Forest Service, U.S. National Park Service, U.S. Bureau of Land Management, and Federal Highway Administration) are examined here for their process and evaluation criteria to determine important characteristics moving toward the creation of management guidelines.

SCENERY MANAGEMENT SYSTEM, U.S. FOREST SERVICE 1995

The U.S. Forest Service published the Scenery Management System in 1995, which serves as a tool for evaluating the scenic value and aesthetic preferences for land management planning (USDA Forest Service 1995). It outlines descriptions of scenic attractiveness, which measures the importance of scenic factors based on human perceptions of beauty and indicates levels of long-term appeal (USDA Forest Service 1995). Among these considerations are intactness, harmony, variety, vividness, mystery, coherence, uniqueness, pattern, and balance (USDA Forest Service 1995), which are representative of wholeness and the pleasant arrangement of landscape attributes. Landscape aesthetics also consider landscape visibility of different areas, which are dependent on how space is being viewed and the context concerning the view being providing (USDA Forest Service 1995). By using the scenic attractiveness classifications, distance zones, and concern levels, scenic classes are created, which help determine the importance of landscapes and prioritization of management. The classifications used in this document are helpful for this report to identify the most impacted areas of human and ecological significance in terms of aesthetic value, which can be focused on in developing management guidelines for landscape architects.

VISUAL CONTRAST RATING, BUREAU OF LAND MANAGEMENT (BLM)

The Bureau of Land Management's visual contrast rating process is used as a tool for the planning and design phase of proposed actions to minimize visual contrast with the existing landscape. The steps involved in the contrast rating process begin by first obtaining a project description, then describing the visual resource management (VRM) objectives, usually based on a Resource Management Plan (RMP) that each field office or region establishes for its lands (USDI Bureau of Land Management 1986). Key observation points (KOPs) are selected in areas where people are commonly present or places that have strong public sensitivity, typically located on commonly traveled routes where the project is visible (USDI Bureau of Land Management 1986). Visual simulations are created, typically through computer-generated realistic visualizations, to demonstrate the appearance of the proposed project and surrounding landscape from the selected KOPs. These visual simulations help stakeholders visualize proposals, as well as evaluate the effectiveness of mitigation measures. Lastly, a contrast rating form is completed to record the visual contrast rating for views within the KOPs, used to create ratings by comparing elements of form, line, color of the existing landscape with the proposed development (USDI Bureau of Land Management 1986).

VISUAL RESOURCE INVENTORY, NATIONAL PARK SERVICE (NPS)

The National Park Service's Visual Resource Inventory is a process to support visitor experiences and identify scenic values. The system uses a view as a unit of inventory, which includes a viewpoint, the viewed landscape, and the viewer. Views are identified, mapped, and described from the viewer's perspective to understand its scenic quality and its importance to the visitor experience (U.S. National Park Service 2016). The view is given a scenic quality rating based on three factors: landscape character integrity, vividness (focal points, bold forms/lines), and visual harmony (scale, spatial relativity) (U.S. National Park Service 2016). A view importance rating is also given to identify the natural, cultural, historical, or other resource values. The ratings are given based on the viewpoints, the viewed landscape, and viewer concern. Within both the scenic quality rating and view importance rating factors, a score is given from 1-5 for each section and combines to determine the view's scenic inventory value, which ranges from very low to very high (U.S. National Park Service 2016).

GUIDELINES FOR THE VISUAL IMPACT ASSESSMENT OF HIGHWAY PROJECTS, FEDERAL HIGHWAY ADMINISTRATION

The Visual Impact Assessment process conducted by the Federal Highway Administration addresses the visual impacts and impacts of highway developments. The process contains four phases: Establishment, Inventory, Analysis and Mitigation (U.S. Department of Transportation 2015). During the establishment phase, the Area of Visual Effect (AVE) is determined through considerations of landscape constraints (landform and land cover) and limits of human sight (U.S. Department of Transportation 2015). The inventory phase examines visual quality as the relationship between viewers and their environment. During the analysis phase, impacts on the visual quality of the AVE are analyzed, as impacts to visual resources and viewers are described through the degree of impact as being beneficial, adverse or neutral (U.S. Department of Transportation). Finally, during the mitigation phase, mitigation and enhancement efforts are defined and are typically completed after a preferred alternative is selected. Each phase is based on an interaction between people and the environment, which finds common ground in analyzing their interaction with one another (U.S. Department of Transportation 2015).

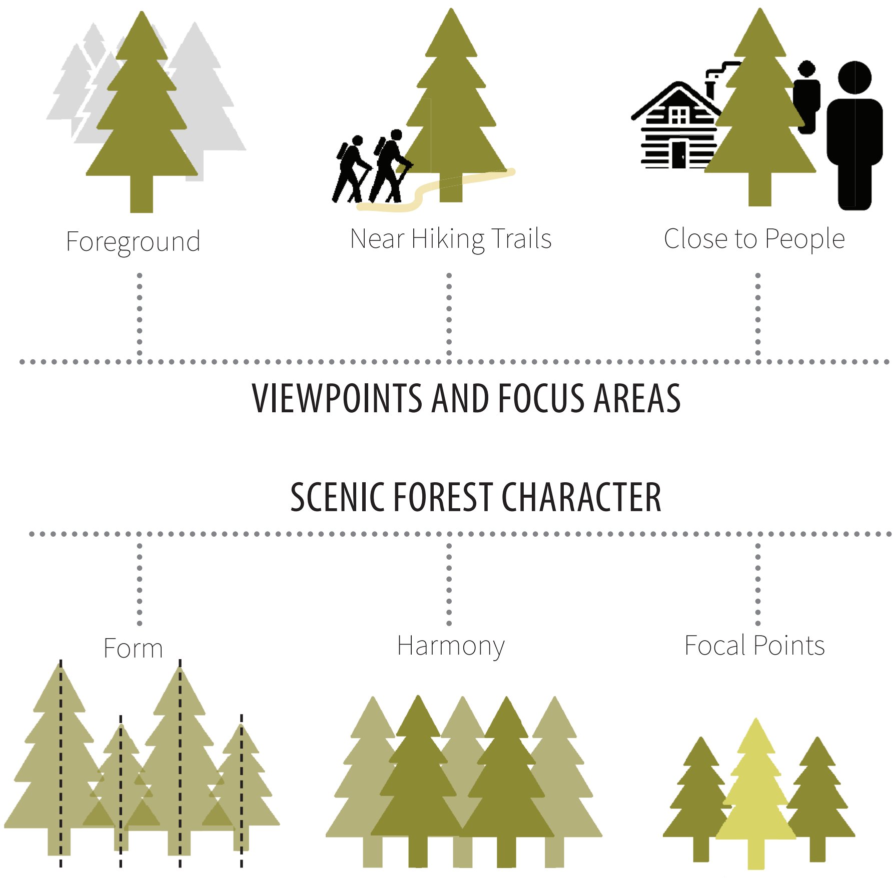


Figure 4.20
Focus area and forest characteristics highlighted by the visual resource guides.
(Hodgson 2020)

4.7 RATING SYSTEMS OF LANDSCAPE AESTHETICS FINDINGS

The rating systems used by different U.S. agencies to address visual importance and scenic quality are important ways to create effective strategies for landscape conservation and measurements. The documents stress the relationship of viewer interaction and perception of forest landscapes, which will be highlighted in the management guidelines created in this report. Repetitive and unifying characteristics between the documents include:

Viewpoints and Focus Areas:

- Foreground and near views of impacted forests
- Areas surrounding hiking trails or tourism facilities
- Areas where people are commonly present or have strong public sensitivity

Scenic Forest Character:

- Form: Defining lines, colors ,and patterns.
- Harmony: Balance, continuous scale, and intactness
- Focal points: Emphasizing uniqueness and variety.
- Slope and topography

These characteristics highlighted by the visual resource guides of the United States are indicative of important considerations that landscape architects will make when managing bark beetle ingestions, through 1) determining the most ideal and appropriate area of intervention to focus efforts at and 2) preserving and enhancing natural forest character for a cohesive and scenically attractive intervention.

4.8 PRECEDENT STUDY SUMMARY

To understand the progression and realism of bark beetle outbreaks, three existing locations were investigated that represent the effects of mountain pine and spruce beetle infestations across the United States. At all locations, the affected forests had been infested at other times in history and speak to the perpetual nature of bark beetle outbreaks. The sites are:

- The Kenai Peninsula (Alaska)
- Kootenay National Park (British Columbia)
- Black Hills National Forest (South Dakota)

These sites reveal the threats of bark beetle infestations and management techniques, present historical impacts, and include treatments that will influence the management guidelines in the next chapter.

4.9 PRECEDENT STUDIES

KENAI PENINSULA

Location: South-central Alaska, United States

Size: 24,600 sq. miles

Date of Infestation(s): 1971-1996

Type of Infestation: Spruce beetle

Forest type: Boreal forest, white spruce forest

Number/Acreage of Affected Trees: Over 500,000 hectares (1.2 million acres)

Attributed Causes:

- Natural occurrences: wind-thrown, fire-scorched and flood-damaged trees (Alaska Department of Natural Resources)
- Warming trend, increased spruce susceptibility to beetle attack, reduced life cycle from 2-years (prior to 1980) to 1-year (1980-2003) (Werner et al. 2006)
- Relatively high densities of large-diameter spruce in an aging forest across the region (Werner et al. 2006)

Background Information:

Research conducted by Flint (2006) sought to understand the socioeconomic impacts of the spruce beetle infestation from the perspectives of community residents. Six communities were evaluated that corresponded to various levels of spruce beetle activity. The social effects considered among the residents were aesthetic and emotional, economic, community conflict, safety, and inconvenience. Researchers found that environmental conditions on the Peninsula were very important to local quality of life and the identity of the community that is dependent on natural resources and scenic quality (Flint 2006, 214)

Figure 4.21
Spruce beetle mortality in the Kenai Peninsula
(Hollen 2017)

Timeline of Outbreak(s):

There were previous spruce beetle outbreaks on the Kenai Peninsula dating back to the 1850s (Berg et al. 2006). A massive outbreak occurred between the 1870s and 1980s. Although not as extensive as the 1990s outbreak, the former outbreak contributed to low beetle infestations levels in the 1910s by killing a majority of the mature spruce trees in the area (Berg et al. 2006). More infestations became prominent in the late 1950s to early 1960s and became more intense in the late 1960s to 1975 (Berg et al.) A spruce beetle epidemic in the 1990s lead to much of the devastating damage that is seen today. Reaching its peak in 1996, the outbreak infested 429,000 hectares of forest (Berg et al. 2006 and Werner et al. 2006). During the late 1970s infestation, 29% of white spruce were killed in Resurrection Creek. The 90s outbreak occurring 16 years later led to a 51% mortality rate of spruces greater than 20 cm in diameter. This outbreak resulted in similar tree species composition, but the size and density of spruce trees were greatly reduced (Berg et al. 2006). The number of understory plants decreased to two species, and grass cover rose from less than 1% to over 50%. A recent outbreak beginning in 2016 has infested 48,000 acres in the northern Kenai Peninsula and almost 900,000 acres in southcentral Alaska (USDA Forest Service 2018, Alaska Department of Natural Resources).

Treatment/Control Measures:

To address the mortality left from the 1990s outbreak, salvage logging and clear-cuts were made throughout the region, which had strong opposition from environmental organizations (Flint 2006, Lundquist 2016). Targeted fuel reduction treatments following this outbreak were conducted in 2000-2002 by addressing downed woody material (Schulz 2003). With the current outbreak, landowners are encouraged to inspect their trees and consider removing infested trees during winter (USDA Forest Service 2018).

Figure 4.22
Timeline of spruce beetle outbreaks in the Kenai Peninsula.

(Hodgson 2020)

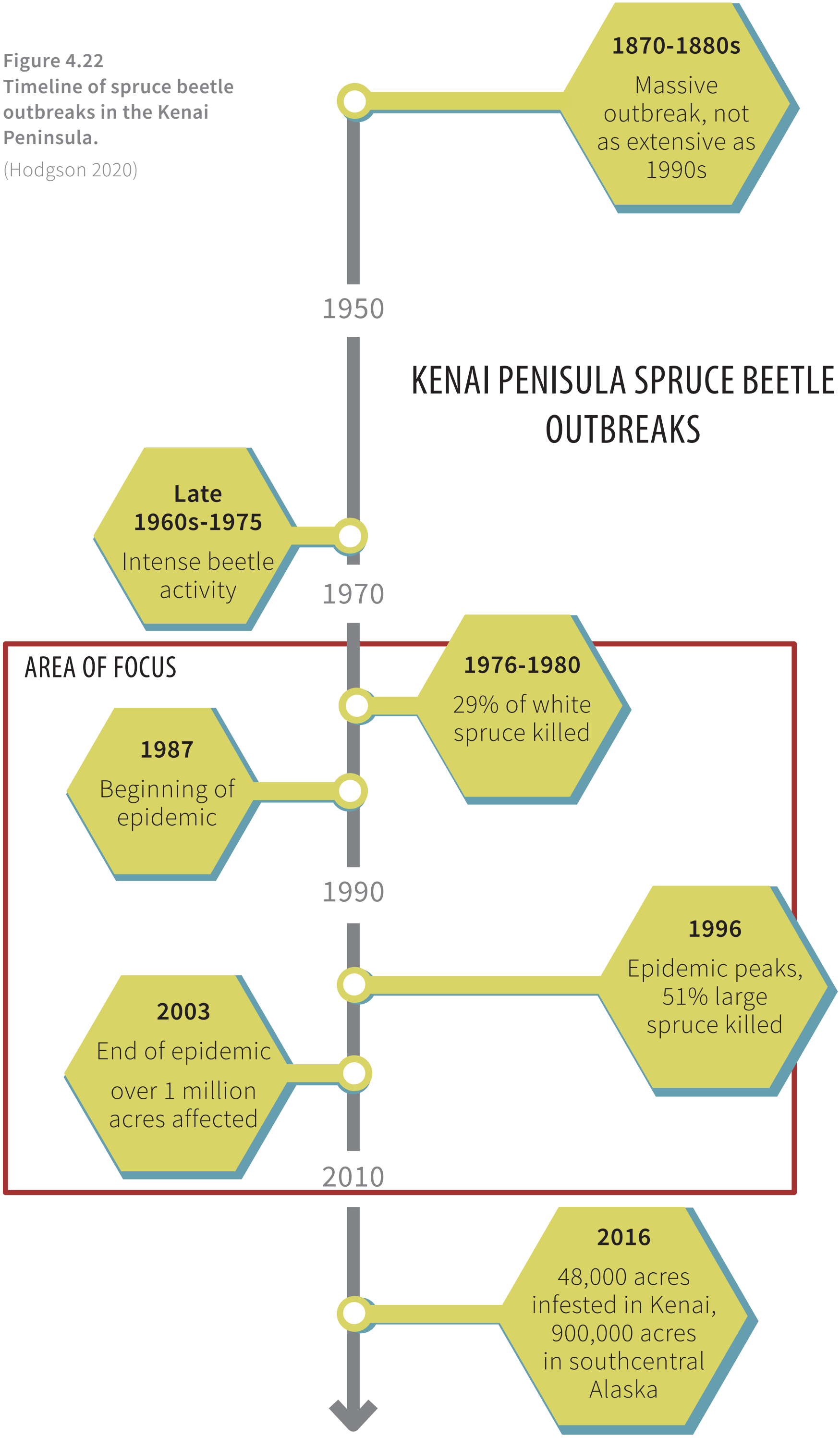


Figure 4.23
Mountain pine beetle damage in Kootenay National Park.
(Skölving 2014)

KOOTENAY NATIONAL PARK

Location: Southeastern British Columbia, Canada

Size: 543 sq. miles

Date of Infestation:

Type of Infestation: Mountain pine beetle

Forest type: Subalpine forest, alpine tundra

Number/Acreage of Affected Trees: 65,000 ha (Parks Canada 2019, Cerezke 1993)

Attributed Causes:

- Old lodgepole pine stands, 160-170 years old
- Drought/dry period between 1919 through 1942 (Hopping and Mathers 1943)

Background Information:

Three even-aged stands of pine were infested: the two oldest (130 and 110 years) sustained the most significant loss, and the youngest (60 years) suffered patches of damage toward the end of the outbreak period (Shrimpton 1994). Next to the highway, tourist traffic along the road generated fire concern and fear that the number of dead trees could lessen the increasing flow of tourist traffic (Shrimpton 1994).

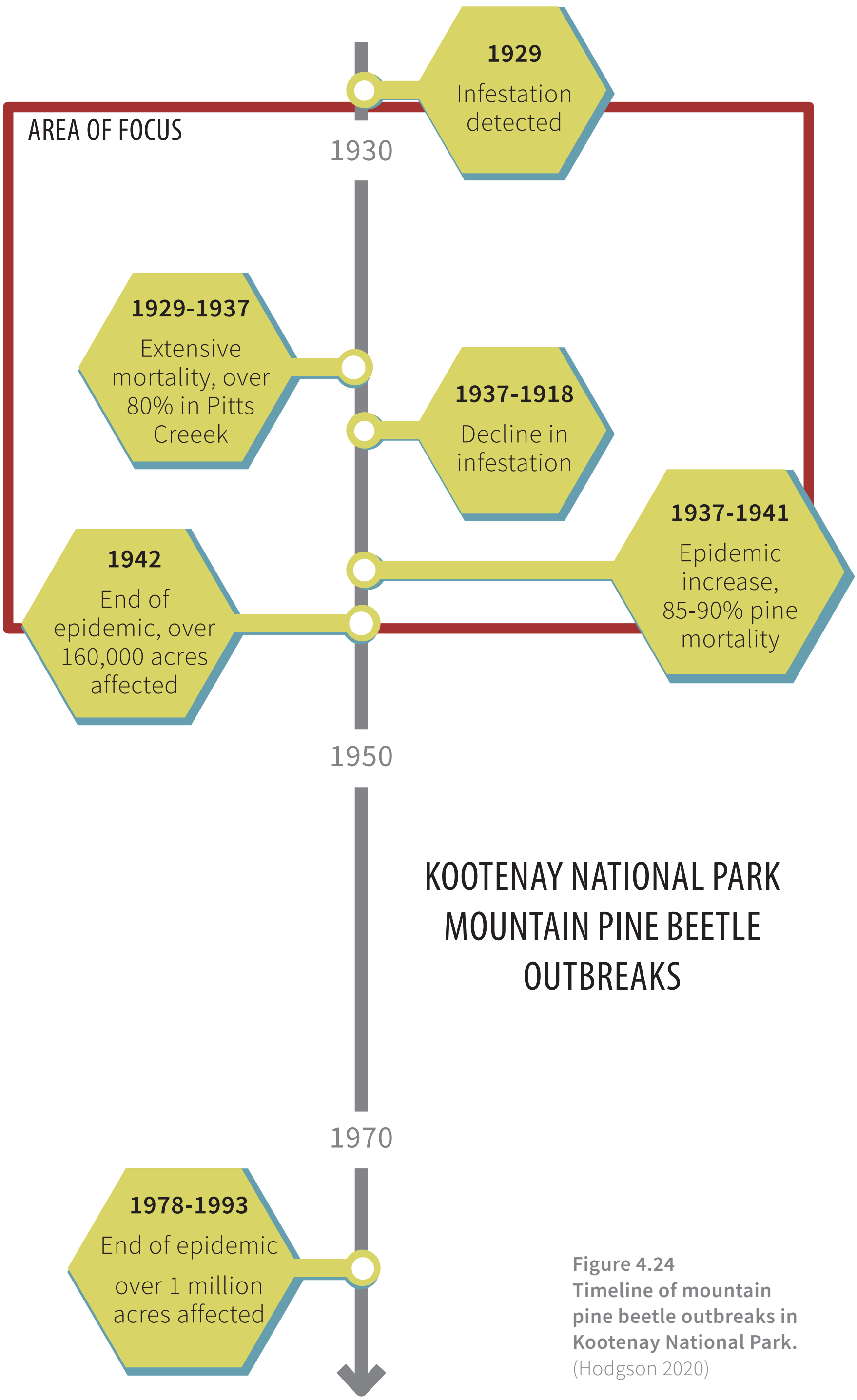


Figure 4.24
Timeline of mountain pine beetle outbreaks in Kootenay National Park.
(Hodgson 2020)

Timeline of Outbreak:

Before the mountain pine beetle outbreak between 1930 and 1942, the stand volume of Kootenay National Park was 350 cubic meters per ha (Shrimpton 1994). In 1929, the infestation was observed on the east side of Kootenay River, where it remained until 1934 and resulted in extensive pine mortality (Cerezke 1993). A 1937 survey shows that pine mortality had exceeded 80% near Pitts Creek and was concentrated in the oldest stands between 130-140 years old (Cerezke 1993). Though there was a decline in pine mortality between 1937-1938, it returned and increased in severity until 1941, with an estimation of 85-90% pine mortality over 65,000 ha. The end of the 1930s outbreak decreased stand volume to 50 cubic meters per hectare (Shrimpton 1994). Fifty years following the outbreak, the affected area has shifted towards an uneven spruce stand that accounts for 88% of the regeneration (Shrimpton 1994). Another outbreak in the 1980s saw mountain pine beetle revisit Pitts Creek and Kootenay Crossing. Between 1982-1987, the infestation became more intense within the south area of Kootenay Crossing (Cerezke 1993).

Treatment/Control Measures:

The bark beetle outbreak that began in 1929 was not brought to attention until 1934, so though control was still possible, there was no money available to treat it (Hopping and Mathers 1943). Surveying and cruising took place during the summer of 1941 to examine trees and promote data collection (Hopping and Mathers 1943). The trees were treated through decking and burning, which involved taking down green infested and red-stage trees (Hopping and Mathers 1943). The construction of the Banff-Windermere highway lead to fire concerns along the highway and that the dead trees would impact tourism, so salvage work began in 1942. Trees were hand-logged, leaving stumps as evidence of the work (Shrimpton 1994).

BLACK HILLS NATIONAL FOREST

Location: western South Dakota and eastern Wyoming, United States

Size: 1,875 sq. miles

Date of Infestation: 1996-2016

Type of Infestation: Mountain pine beetle

Forest type: Montane, Ponderosa pine

Number/Acreage of Affected Trees: 447,00 (1996-2016) (Tan 2016)

Attributed Cause:

- Natural mountain pine beetle cycle, stressed by drought conditions and high stand densities

Background Information:

Bark beetles were first investigated by the Division of Forestry (later the U.S. Forest Service) within the Black Hills, and thus named the insect the Black Hills Beetle in 1901 which attacked and killed ponderosa pines in Wyoming, Utah, Colorado, Arizona, and New Mexico (Graham et al. 2016,8). The Black Hills thrive from abundant seed crops and spring/summer rains, giving it the ability to rapidly regenerate and making it one of the most consistent commercial timber harvesting programs in the United States since 1898 (Graham et al. 2016, 5).

Figure 4.25
Beetle-killed forest in the Black Hills
(USDA Forest Service 2011)

Timeline of Outbreak:

Following the mass outbreak of the 1880s, 10,000 to 15,000 trees had been cut down between 1906 and 1908, and the broods had been destroyed (Graham et al. 2016). Due to the scale of the outbreak, bark beetle levels for the beginning of the century stayed relatively low until the 1940s. Another outbreak between 1970 and 1981 peaked in 1974 and resulted in over 600,000 trees killed (Graham et al. 2016). This outbreak was significant as the last major outbreak of mountain pine beetle in the Black Hills before stand density research was conducted (Graham et al. 2016). The most mountain pine beetle episode occurred between 1981 and 2012. While the period between 1981 and 1997 had low tree mortality and was largely scattered, it soon grew going into the new millennium. Between 2001 and 2008, 222,000 acres were infested, and the infestation later peaked between 2009 and 2012 with an additional 165,000 more infested acres. Logistically, beetles were more likely to attack pines with a diameter breast height (DBH) between 9 and 17 inches, but the pines showed more resistance with 45 to 80 square feet of basal area per acre and a stand density index (SDIs)between 102 and 122 (Sartwell and Stevens 1975, Graham et al. 2016).

Treatment:

Starting in 1906, Black Hills foresters and workers utilized the action of felling, peeling and burning tree stands to combat mountain pine beetle spread throughout the region (Graham et al. 2016, 34). The area saw one of the longest and continuous efforts to control bark beetles in North America, starting in 1901. Initial strategies to address outbreaks began with using trap trees and then moved to felling, peeling, and burning attacked trees (Graham et al. 2016). In 1947, to control a pending epidemic, Congress appropriated $235,000 to use orthodichlorobenzene (an insecticide), which was sprayed on standing trees instead of using peeling, burning, and harvesting.

Between 1946 and 1955, 93,000 attacked trees were sprayed. By the 1960s, indirect methods of control became more popular. Direct control would delay impacts, but once control actions ended, the infestation would be the same as uncontrolled areas and was not economically viable (Amman and Baker 1972, Graham et al. 2016). Stand density control became popular by the 1960s, indicating the movement in treatment methods towards indirect management (Graham et al. 2016).

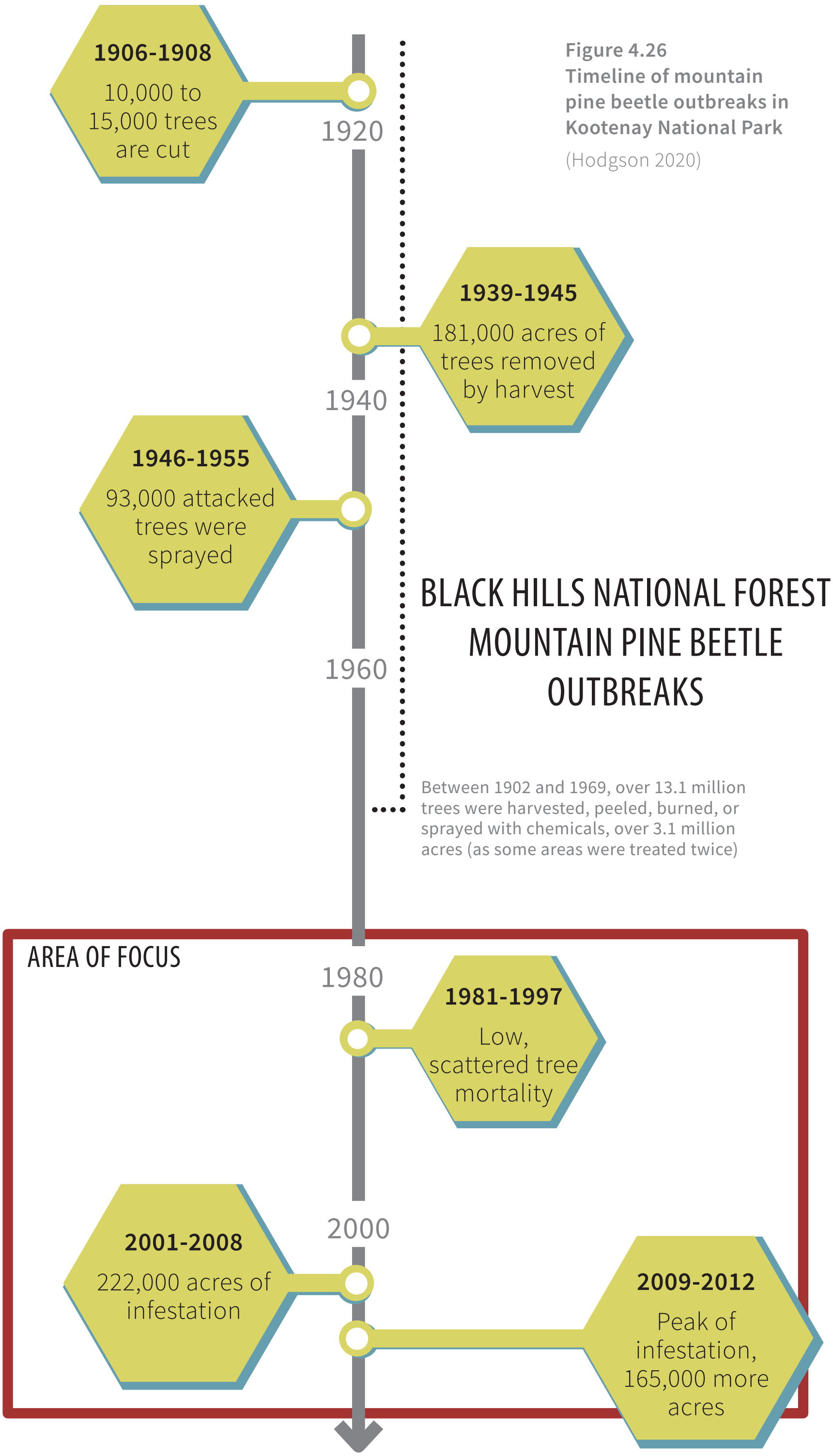


Figure 4.26
Timeline of mountain pine beetle outbreaks in Kootenay National Park

(Hodgson 2020)

PRECEDENT STUDY FINDINGS

TREATMENT

Treatment history is extensive. Moved away from more intensive and mechanical methods of treatment due to cost and labor.

SOCIAL IMPACTS

Most common perceived impacts were falling trees, visual/aesthetic decrease, loss of privacy, and increased fire hazard.

OUTBREAK

Despite treatment efforts, outbreaks were cyclical/repetitive, but differed in intensity based on forest characteristics and climate conditions.

Figure 4.27
Precedent study summary diagram.
(Hodgson 2020)

4.10 PRECEDENT STUDY FINDINGS

The precedent studies helped examine the severity and longevity of bark beetle impacts over time. Because bark beetles are naturally occurring and an important part of the coniferous ecosystem, they will continually attack forests where the beetles can survive. Concentrated applications of management techniques were made in each of the study areas, but the bark beetle outbreaks were repetitive. Treatment decisions were largely made to preserve the timber industries in the outbreak areas, as well as to address safety hazards and perceived fire risk. The causes of the outbreaks in each site were attributed to warming climates, drought, and susceptible stands that were old, large, and dense.

From each precedent study, the following information was gathered:

- Kenai Peninsula: Salvage logging and clear cuts were used, Interviews indicated that most common perceived impacts were falling trees, were visual/aesthetic decrease, loss of privacy, and increased fire hazard.
- Kootenay National Park: Cared for aesthetic and safety concerns around roadway that would also impact tourism. Post-outbreak, the species make-up of the affected forest shifted from pine to an uneven spruce stand.
- Black Hills: Long history of treatment. Showed that direct and mechanical methods were labor intensive and expensive, more indirect methods became popular.

The precedent studies address treatment options, social impacts, and outbreak characteristics (see Figure 4.27), which are important aspects of bark beetle infestations to understand when creating management recommendations. The guidelines created in the next chapter consider the repetitive nature of outbreaks and commonly perceived impacts to create a realistic and comprehensive plan to address bark beetle infestations.

Figure 5.1
Mountain pine beetle devastation in British Columbia
(Huber 2007)

5
MANAGEMENT

5. MANAGEMENT

5.1 CHAPTER SUMMARY

This chapter synthesizes the information gathered throughout *Chapter Four: Findings* to propose management guidelines for landscape architects that unite considerations of forest treatments and aesthetic values. First, impacts and elements that influence public perceptions of forests and treatment options are stated to inform decisions relating to the management guidelines and are used to assess associated visual impacts. Next, the guidelines focus on the design and management of projects that: 1) are at risk, 2) have a low-level infestation, 3) are at epidemic levels, or 4) have been attacked by mountain pine beetles, specifically in Colorado and broadly in the Rocky Mountain region. Finally, these guidelines are demonstrated through four different scenarios that will investigate responses to different project types and stages of bark beetle outbreaks. The management guidelines are recommendations and reminders of important considerations to follow throughout the lifespan of a project. These scenarios are supplemented with visualizations that depict treatment options and aesthetic considerations highlighted in these management guidelines.

The goals of the management guidelines and scenarios are:

- Highlight the differences in treatment recommendations between more public sensitive and less public sensitive areas
- Address management considerations in different phases of the typical landscape architecture design process.
- Present options to enhance scenic beauty qualities during and after forest treatment measures take place.
- Demonstrate the aesthetic considerations of the management guidelines through different scenarios.

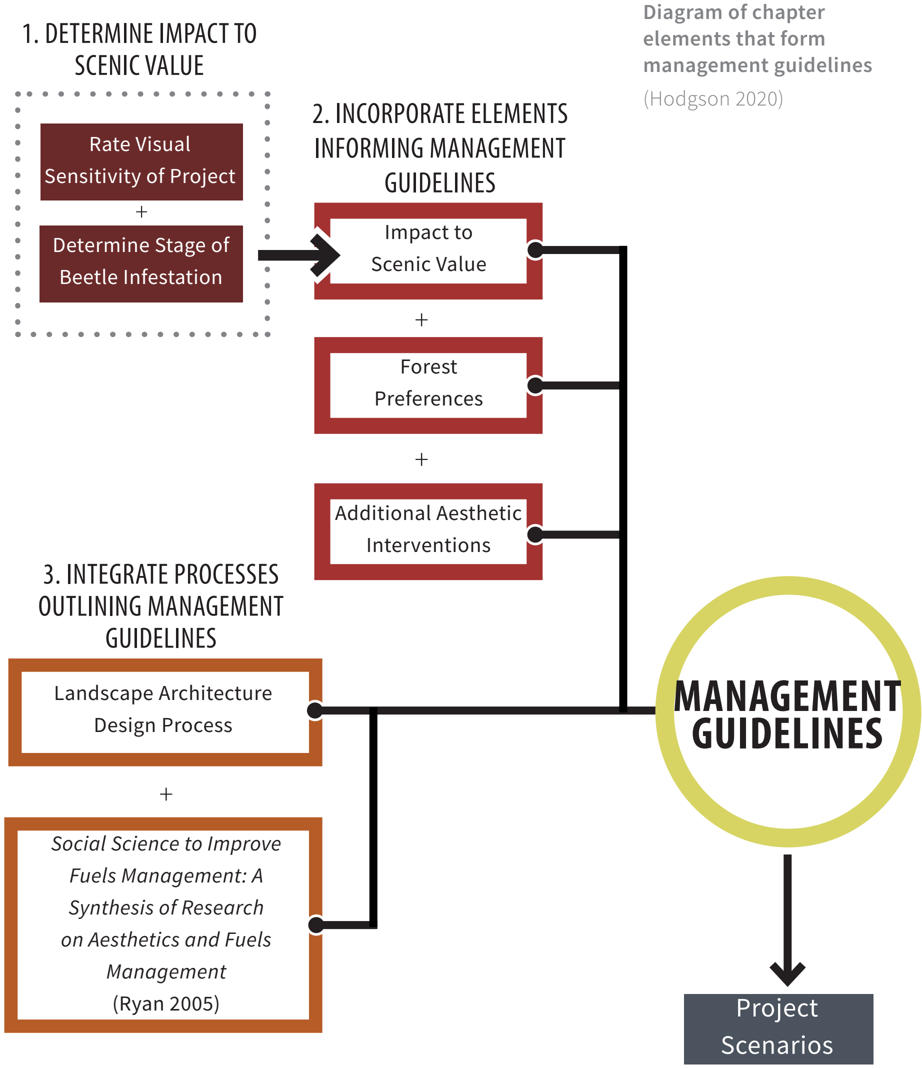


Figure 5.2
Diagram of chapter elements that form management guidelines

(Hodgson 2020)

5.2 DETERMINE IMPACTS TO SCENIC VALUE

The following elements have the strongest influence on recommended treatment options when visual and aesthetic forest qualities are emphasized. These elements should be established before determining treatment and should be discussed with clients and stakeholders at the beginning of the design process. A matrix to describe impacts to scenic value is created to better inform necessary decisions following intensive outbreaks in highly sensitive areas.

LAND USE AND VISUAL SENSITIVITY

Areas that are well-trafficked and have high sensitivity to perceptions of scenic value need more careful considerations of management. In a public land or hiking trail setting where areas are wilder and people have less contact, there is less loss of scenic value from more intensive management options like clear-cutting and salvage logging. In areas designated for recreation like ski slopes and campsites, treatment will heavily impact the scenic value and quality of the site. The intended land use and interaction with humans contribute to the degree of visual sensitivity, defined as having low, moderate, or high sensitivity (see Figure 5.3)

- **Low sensitivity:** Little to no relationship between development and setting; low access and low visibility.
- **Moderate sensitivity:** small to medium relationship between development and setting; available access and visible from location.
- **High sensitivity:** Strong relationship between development and setting; easily accessed and highly visible from location.

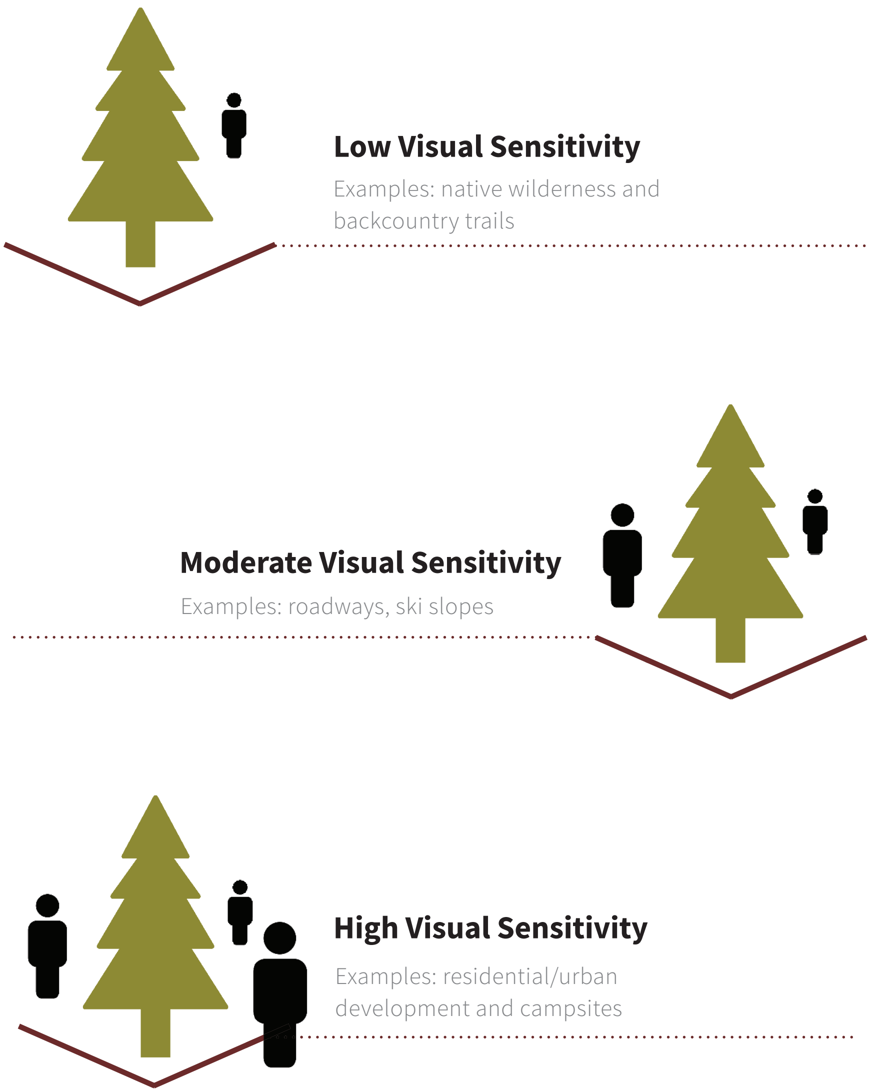
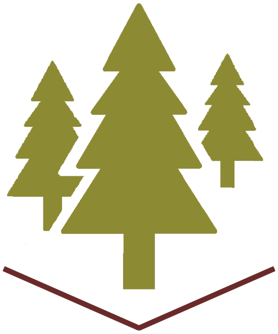


Figure 5.3
Visual sensitivity rating.
(Hodgson 2020)

DETERMINE STAGE OF BEETLE INFESTATION

Depending on the state of bark beetle infestation in and around a project, different treatment approaches will be more appropriate. Large-scale outbreaks and resulting mortality of visible trees will lessen scenic beauty, as well as require more intensive treatments such as clear-cutting, which have a negative public perception. The stages of bark beetle are categorized as follows: Susceptible, Endemic, Epidemic, and post-outbreak mortality (see Figure 5.4). The typical corresponding treatments are listed below that display the increasing severity of treatment required for more intensive stages of bark beetle outbreaks.

- **Susceptible to infestation:** preventative treatments, chemical treatments, selective thinning older and denser stands, promote sustainability, and non-intervention. Treatment intensity: low.
- **Endemic infestation:** selective thinning, mechanical/sanitation, insecticides. Treatment intensity: moderate (if mitigation is desired)
- **Epidemic infestation:** thinning, clear-cutting, prescribed fire, non-intervention. Treatment intensity: high (if mitigation is desired)
- **Post-outbreak mortality:** clear-cutting, thinning, prescribed fire, non-intervention. Treatment intensity: high (if mitigation is desired)



Susceptible to Infestation

Characterized by:

- No bark beetles detected in the area
- Large number of older, denser and more weak stands and/or recent drought

Endemic Infestation

Characterized by:

- One to several trees are attacked per hectare
- Low-level infestation

Epidemic Infestation

Characterized by:

- 80 percent or more of susceptible trees are killed
- Lasts between 5 and 10 years, kills most large-diameter trees

Post-Outbreak Mortality

- Dead trees, 5+ years following infestation
- Trees pose safety risk from falling over

Figure 5.4
Stages of bark beetle infestation.
(Hodgson 2020)

IMPACTS TO SCENIC VALUE

To aid landscape architects to comprehend the visual impacts resulting from bark beetle outbreaks, a matrix was created that evaluates the two most important factors affecting design decisions related to bark beetle infestations. The first factor rates of visual sensitivity (see Figure 5.3), which addresses the relationship between the infested forest and the proposed development. The second factor considers the stages of the bark beetle infestation (see Figure 5.4). Scores have been attributed to these factors in order of severity, with the highest score representing the greatest impact on scenic value. In the matrix table (see Figure 5.5), the scores associated with each factor are multiplied to create product scores that correspond to a composite assessment of scenic value impact. Scores between 1 and 4 signify a limited impact to scenic value, scores between 5 and 7 indicate a moderate impact to scenic value, and scores 8 and above signify significant impacts to scenic values. Moderate impacts to scenic value should consider the addition of aesthetic interventions to increase scenic value, while those that will suffer significant impacts will need to implement those interventions to accommodate for the loss of visual quality and maintain positive perceptions of forests within the project area.

Potential Impacts to Scenic Value

Visual Sensitivity Rating / Bark Beetle Outbreak Stage	**Low Sensitivity** (1)	**Moderate Sensitivity** (2)	**High Sensitivity** (3)
Susceptible (1)	**Limited Impact** (1)	**Limited Impact** (2)	**Limited Impact** (3)
Endemic (2)	**Limited Impact** (2)	**Limited Impact** (4)	**Moderate Impact** (6)
Epidemic (3)	**Limited Impact** (3)	**Moderate Impact** (6)	**Significant Impact** (9)
Post-Outbreak Mortality (4)	**Limited Impact** (4)	**Significant Impact** (8)	**Significant Impact** (12)

Limited Impact
Score: 1-4
Area has small interaction between people and forest, infestation and treatment will have little impact on scenic value

Moderate Impact
Score: 5-7
Area has small to medium relationship between people and forest, infestation and treatment will have noticeable impact on scenic value

Significant Impact
Score: 8+
Area has strong relationship between people and forest, infestation and treatment will have strong impact on scenic value

Additional Aesthetic Interventions Recommended

Figure 5.5
Diagram showing determination of impact to scenic value.
(Hodgson 2020)

5.3 ELEMENTS INFORMING MANAGEMENT CONSIDERATIONS

AREA OF FOCUS AND FOREST PREFERENCES

Within the site and intended land use, focus areas should be delineated to concentrate treatment efforts where they will be most impactful. Representative viewpoints located in the foreground have near views of the forest. Typically, points surrounding areas of public interaction and visual access, such as hiking trails, rest areas, tourism facilities, and other commonly traveled routes like roadways, serve as key focus areas. Viewpoints should be delineated early in the design process, so treatment considerations can be efficient and provided a focus for design interventions.

It is also important to understand the public's aesthetic preferences within forests to better preserve and promote aesthetic values. There are positive and negative public perceptions when it comes to elements found in forest landscapes. Forest elements that are preferred include:

- Large and scenic trees
- Visual access with forests through lower densities
- Mixed-age forest stands
- Implied space created by the forest canopy
- Preservation/enhancement of forest character: Form (line, color, pattern), harmony (scale, balance, intactness), and focal points (uniqueness and variety)

Conversely, some elements of forests and management treatments have a negative public perception. Evidence of human interaction in natural environments subtracts from the scenic beauty, as does the evidence of management and dead trees. Forest elements that are disliked include:

- Evidence of human intervention (trash, views of built facilities, ruts made by machinery)
- Woody debris (thinning, clear-cutting, and natural processes)
- Dead trees
- Evidence of fire

ADDITIONAL AESTHETIC INTERVENTIONS

When intensive forest treatment options are deemed necessary, they have a negative impact on the scenic quality. However, as noted in *Chapter 4: Findings*, there are additional interventions and management strategies to reduce the loss of aesthetic quality associated with bark beetle impacts and treatments. They include:

- **Restoration of clear-cut areas.** Replanting recently-killed or clear-cut areas that support the natural successional process with young trees not only enhances the aesthetic value of impacted areas, but can also support ecological growth through biodiversity with the integration of mixed aged and species stands of trees.
- **Educational information.** Providing information regarding the current landscape near key viewpoints and areas of intervention, whether it be dead trees following a beetle infestation or a clear-cut area devoid of vegetation, will make visitors more accepting of natural processes and feel that the area is receiving attention.
- **Adding orderly frames and “cues to care”.** While preserving the natural integrity of the forest landscape, adding in elements that demonstrate that the forest is being managed will increase scenic value. These management techniques include enhancing paths, adding in natural wildflowers, and placing naturalistic looking fences or benches.

5.4 MANAGEMENT GUIDELINES

This section proposes management guidelines based on typical landscape architecture projects and management recommendations promoted by the U.S. Forest Service (Ryan 2000). By connecting with the landscape architecture process, this portion of the report creates an accessible management guide of recommendations to address current and future bark beetle impacts. The strategies outlined for fuel management and higher visual quality provide more considerations of the management process in addition to examples of techniques to increase aesthetic value (see Figure 5.6). This process is divided into three stages:

1. Inventory, Communication, and Planning
2. Management and Design Implementation
3. Post-Treatment Analysis

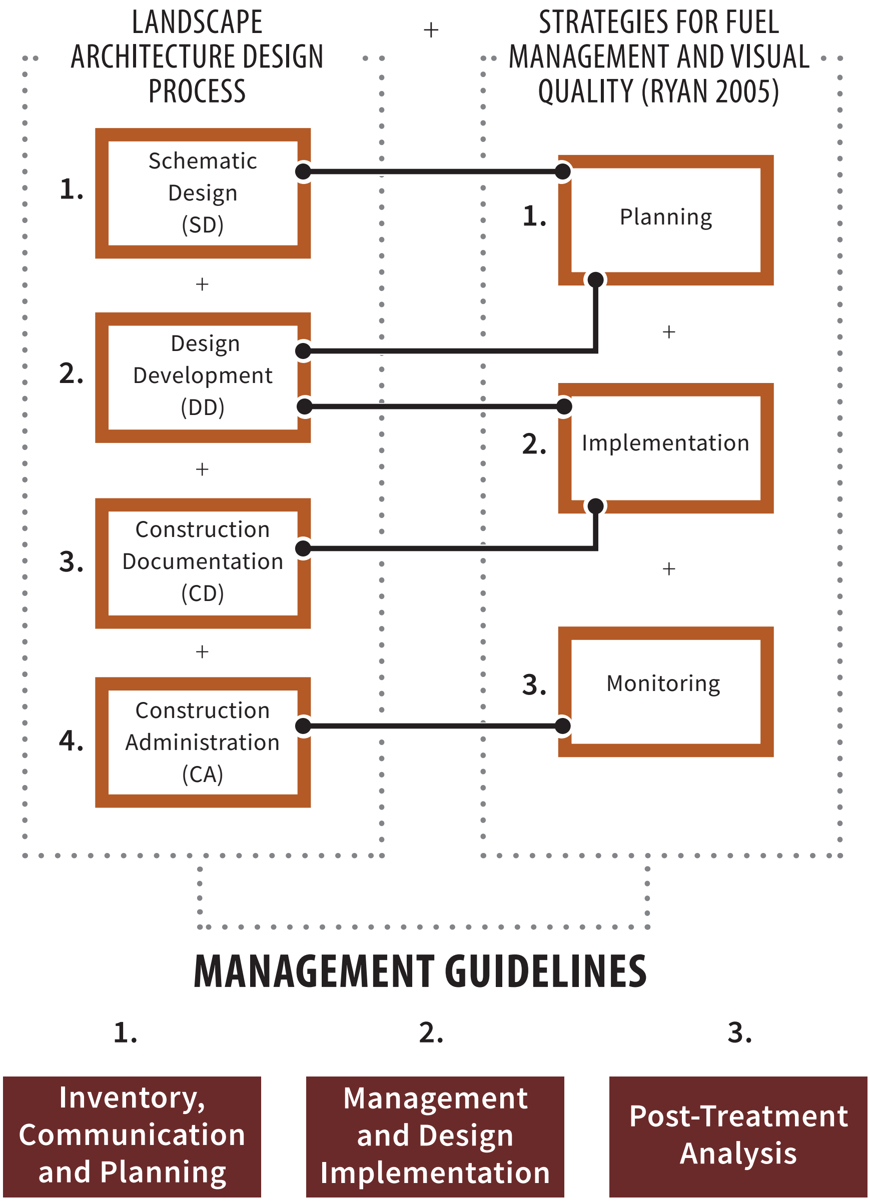


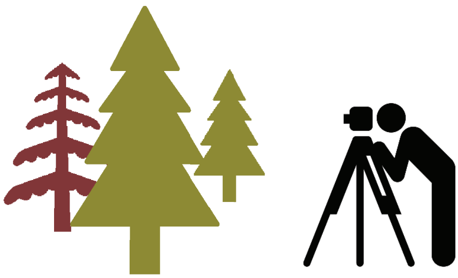
Figure 5.6
Processes influencing management guidelines.
(Hodgson 2020)

INVENTORY, COMMUNICATION, AND PLANNING

Once a project is awarded, preliminary steps should be taken to assess the current conditions and future potential of bark beetle infestations in the area to ensure that the danger is efficiently addressed and the project is able to appropriately achieve its intended purpose. Before the design of the project and during schematic design and design development phases, the following steps should be taken to promote effective planning and treatment before or in response to bark beetle outbreaks associated with at-risk sites. The steps include:

1. Conduct (or research) aerial and ground surveys
2. Create an interdisciplinary team
3. Determine public relationship
4. Establish communication with client(s) and the community

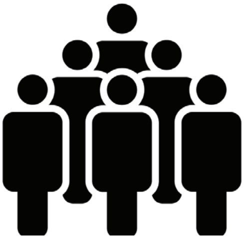
Figure 5.7
(Hodgson 2020)



1. **Conduct (or research) aerial and ground surveys**

It is crucial to document the condition of existing trees to determine potential and existing infestations and susceptible stands. Understanding tree and stand characteristics can support future treatment options and will provide a necessary assessment of required management areas, in addition to learning the existing threat that a beetle outbreak is posing (healthy/at-risk, low-level infestation, epidemic, or post-outbreak mortality). This knowledge can pre-emptively influence design decisions, such as having trails with less visualization of at-risk stands or infested stands that may need to be removed to preserve higher scenic quality.

Figure 5.8
(Hodgson 2020)



2. Create an interdisciplinary team

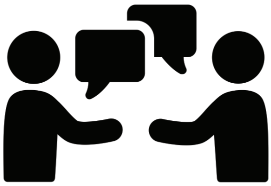
While landscape architects are better equipped to address aesthetic concerns more than other professions, forest-based experts need to be consulted or contracted to ensure that ecological concerns are appropriately considered. Professions that should be included are silviculture, forestry, entomology, hydrology, and conservation. Reaching out to resources such as federal and state forest services will also provide important information regarding surrounding forested areas and the progression of existing outbreaks.

Figure 5.9
(Hodgson 2020)

3. Determine public relationship

Depending on the type of project, interaction with the public will vary and may influence the type of treatment that is used. Projects that are not as visible to public views could utilize more intense treatments such as clear-cutting without the risk of public disapproval and loss of scenic beauty. Areas that are more sensitive to the public will benefit from less extreme and more precise treatment, such as selective and sporadic tree removal. The visual relationship that the project site shares with bark beetle infestations and proximity to the area can be used to determine the level of scenic value consideration. This is assessed through the composite scenic value impact rating (see Figure 5.5.) that establishes thresholds for initiating intervention measures.

Figure 5.10
(Hodgson 2020)



4. **Establish communication with client(s) and community**

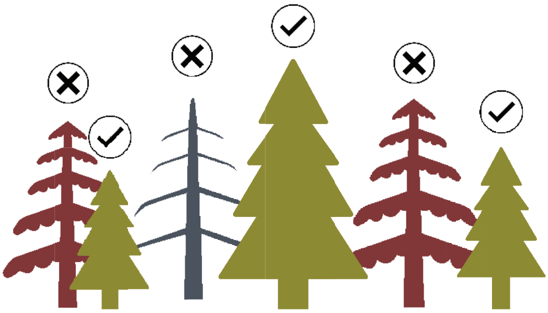
Creating healthy communication with project clients and those influenced by the project will help inform treatment objectives. Working with clients will help determine the amount of attention and financial support to direct towards maintaining high aesthetic quality and ecological sustainability. If applicable, communicating with community members and local stakeholders can inform designers of additional concerns and desires regarding potential treatment actions and cultural landscape values that they wish to be preserved. For projects that involve multiple owners, such as land operated by private landowners and state/governmental agencies, this dialogue will be especially important.

MANAGEMENT AND DESIGN IMPLEMENTATION

Once the first phase is completed, communication with the forestry team should begin to determine the management of the bark beetle threat moving forward. Depending on the visual sensitivity and stage of the bark beetle outbreak, additional steps may need to be taken to mitigate the loss of aesthetic value, which are detailed in Section 5.3 of this chapter. These considerations and design moves should be incorporated and discussed during design development and construction documentation and should showcase considerations for user experience and ecological care. The steps include:

1. Determine forest treatments
2. Strategize treatment to increase and preserve scenic beauty
3. Implementing "cues to care"

Figure 5.11
(Hodgson 2020)



1. **Determine forest treatments**

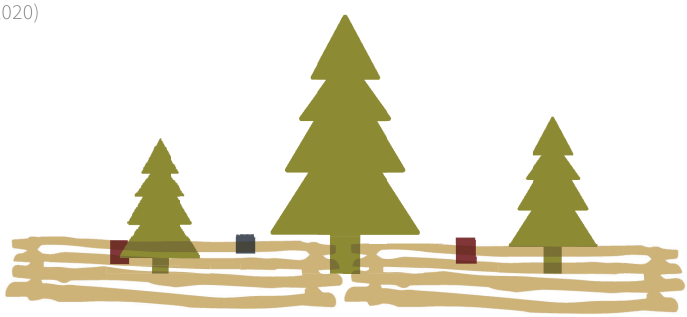
Depending on the stage of the outbreak and goals of the project, treatment options to address the bark beetle threat will vary. Interdiciplinary team members or local forestry professionals can be consulted regarding their recommended best course of action. More visible projects and those that elicit more public response should try to use methods less impactful to scenic quality. However, if more intensive treatment is required due to the severity of the outbreak or killed trees, that should take precedence. If no current outbreaks or mortality are impacting the site, preventative techniques will help reduce the intensity and susceptibility of existing trees to bark beetle infestations. These techniques range from using pheromone packets to keep away beetles, to indirect methods that promote visual access throughout selected viewpoints like thinning.

Figure 5.12
(Hodgson 2020)

2. **Strategize treatment to increase and preserve scenic beauty**

Within more selective treatment and management of infested trees, strategic moves may help preserve existing forest character and scenic beauty. Preservation of large and unique trees will provide interest and a focal point to draw attention, though sometimes this may clash with forestry goals as larger trees are at more risk for bark beetle infestations. Preserving implied spaces from overstories will also promote higher scenic value, in addition to allowing visual access within forested areas (see Figure 4.19)

Figure 5.13
(Hodgson 2020)



3. Implementing “cues to care”

After understanding the visual sensitivity of the project area and determining the stage of bark beetle outbreak, a composite scenic quality impact score can be used to guide potential intervention treatments (see Figure 5.5). Moderate and significant visual impacts will need to incorporate additional elements to increase aesthetic value in infested and treated areas. The strategy of complimenting a messy ecosystem with orderly frames can be utilized when more drastic measures are required in the management of infested or killed trees. Orderly frames are achieved by adding elements that demonstrate consideration of scenic values such as fences, seating, native wildflower plantings, or other additions that increase appreciation and acceptance for native ecosystems. It is important to highlight natural-looking or perceived elements for construction, as artificial construction and development will detract from aesthetic value.

POST-TREATMENT ANALYSIS

Finally, in the construction administration and post-treatment phase, the focus should be on informing the public of the outbreak and treatment methods, promoting forest sustainability, and mitigating the effects of the treatments that were implemented. The steps include:

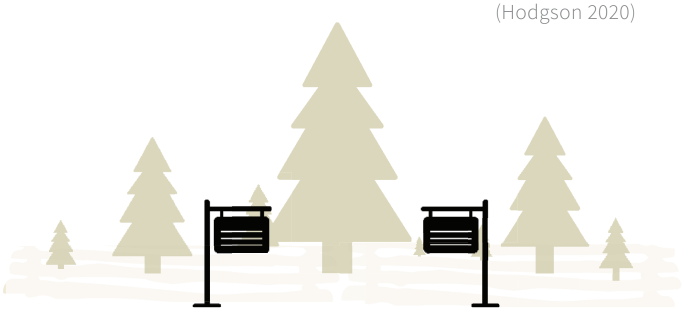
1. Respond to treatment effects
2. Educate the public on treatment and future conditions of the site
3. Evaluate design and treatment interventions

Figure 5.14
(Hodgson 2020)

1. **Respond to treatment effects**

Many treatment methods of bark beetle infestation leave behind disturbed landscapes that are visually displeasing and detract from scenic values. For thinning, sanitation, and other forms of mechanical treatment, cleaning up the woody debris and material will increase aesthetic value, though it may be at the loss of ecological benefits that the debris provides. Reforestation of areas impacted by clear-cutting and promotion of diverse stands will also increase aesthetic value, in addition to strengthening forest conditions through biodiversity that will lessen the impacts of future bark beetle outbreaks.

Figure 5.15
(Hodgson 2020)



2. **Educate the public on treatment and future conditions**

Signage and pictures along traveled and affected areas that address the reasoning behind the dead trees and treatments will help distribute information to visitors. While it may not improve scenic beauty values in impacted areas, the information will promote a greater understanding and acceptance of natural processes that will benefit perceptions of the area and design. Position information in high traffic areas, where the infestation or treatment is in close view and proximity to where visitors are interacting (see Figure 4.20).

Figure 5.16
(Hodgson 2020)

3. **Evaluate design and treatment interventions**

While this responsibility may not fall to the landscape architect following a project's completion, the possibility of re-infestation should be understood and communicated to the client. Also, understanding responses of the environment and human perceptions to applied treatments will help landscape architects learn to better mitigate the future effects of similar bark beetle outbreaks. By continuously being involved in the treatment of bark beetle areas, greater consideration can be given to aesthetic values in hopes of lessening the social and scenic effects, both in the short and long-term lifespan of the forest.

5.5 MANAGEMENT SCENARIOS

To provide an example of how landscape architects can work to implement the management guidelines, three scenarios have been created that address varying land uses and stages of a bark beetle outbreaks. Different project types will be examined within these land uses to exemplify concerns and considerations of treatment options that will be addressed through the guidelines previously established (see section 5.4). As stated in *Chapter 4: Findings,* the areas of work that are prominent in the landscape architecture profession within the Rocky Mountain region and are at risk with future mountain pine beetle and spruce beetle outbreaks include:

- Recreation (campsites, picnic areas, national parks, and forests)
- Residential (single-family and multi-family homes/yards)
- Ecological (preservation and restoration)

SCENARIO #1: RECREATION

Project type: Trail System

Stage of beetle infestation: Endemic, mountain pine beetle

Rating of visual sensitivity: Moderate

As an area with a beautiful view of a far mountain range, this clearing will feel the visual impacts of the infested trees that lie in the foreground and close proximity to the trail. The trees pose a safety risk in the future for hikers along the trail, as well as lowering scenic value.

Figure 5.17
Visualization of a recreation scenario before treatment.
(Hodgson 2020)

GUIDELINE IMPLEMENTATION

1. Inventory, Communication, and Planning

    - Infested and at-risk trees are delineated to understand what trees can be saved
    - Trail visitors are interviewed to understand valued view and spaces to preserve

2. Management and Design Implementation

    - Infested trees are removed via thinning, large and scenic trees are preserved
    - Local stones are used to create frames and seating, adding aesthetic value and accenting views

3. Monitoring

    - Removed woody material and clear traces of treatment
    - Plant new, diverse stands of native trees

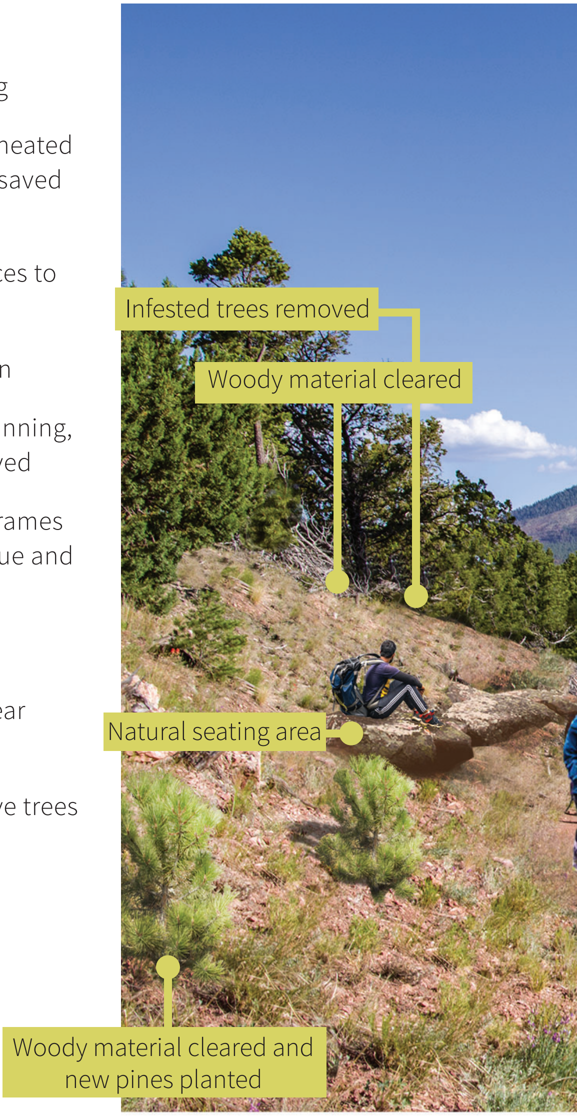
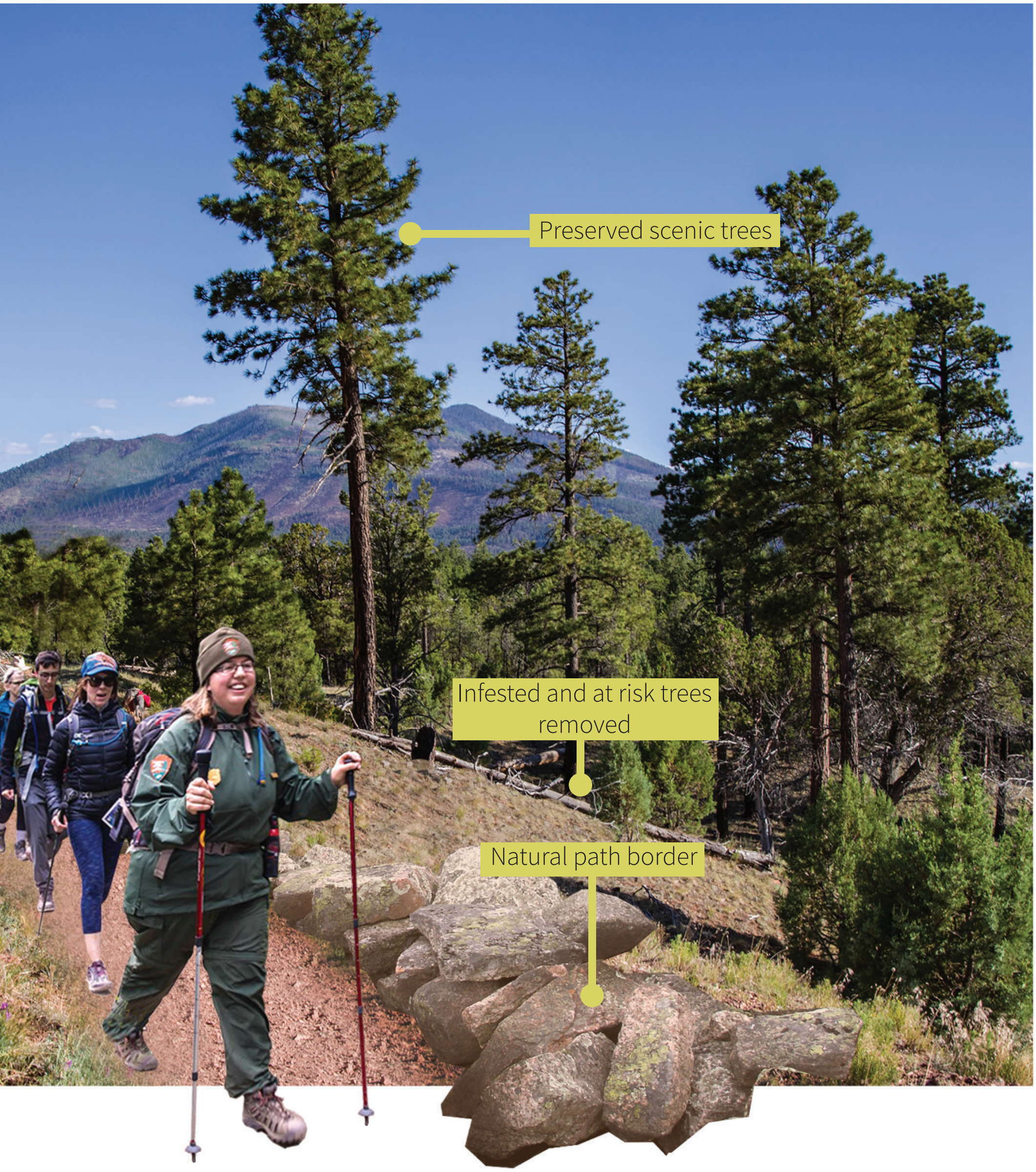


Figure 5.18
Visualization of recreation scenario after treatment.
(Hodgson 2020)



SCENARIO #2: RESIDENTIAL

Project type: Single-family residence

Stage of beetle infestation: Post-outbreak mortality, spruce beetle

Rating of visual sensitivity: Moderate

The immediate and surrounding area of this residence has experienced extensive spruce beetle mortality and has a significant impact on scenic value. The trees in the foreground are the highest priority for removal based on their proximity to the house, which presents a safety risk and greater loss of aesthetic value.

Figure 5.19
Visualization of residential scenario before treatment.
(Hodgson 2020)

GUIDELINE IMPLEMENTATION

1. Inventory, Communication, and Planning

    - Infested and at-risk trees are delineated to understand what trees can be saved
    - Communicate with the homeowner to inform them of the extent of the infestation and learn desired design

2. Management and Design Implementation

    - Infested trees are removed via clearcut, uninfested trees preserved
    - Killed tree stumps used to create property fence
    - Local stones used in landscape design

3. Monitoring

    - Removed woody material and clear traces of treatment
    - Reseed disturbed ground with native grasses
    - Plant deciduous trees in the foreground to hide tree mortality in the background and add more diversity

Figure 5.20
Visualization of residential scenario after treatment.

(Hodgson 2020)

SCENARIO #3: ECOLOGICAL

Project type: Creek restoration

Stage of beetle infestation: Epidemic, mountain pine beetle

Rating of visual sensitivity: Low

This natural area is currently being impacted by an extensive bark beetle epidemic. Due to the low degree of public sensitivity, the impact to scenic value is relatively low, so extensive treatments aren't necessary to preserve scenic value. Interventions should be focused on stabilizing the river, but additional interventions can benefit visitor experiences and inform them of the infestation.

Figure 5.21
Visualization of ecological scenario before treatment.
(Hodgson 2020)

GUIDELINE IMPLEMENTATION

1. Inventory, Communication, and Planning

- Infested and at-risk trees are delineated to understand the extent and growth of the infestation
- Wildlife experts are consulted to understand appropriate design measures

2. Management and Design Implementation

- Due to the intensity of the outbreak, non-intervention is used as the trees are left to naturally experience the outbreak
- The small trail and creek edge is stabilized with native stones
- A bridge is added over the creek to minimize disturbances.

3. Monitoring

- Signage is created along the creek to inform passersby of the visual effect the infestation is having on the forest

Figure 5.22
Visualization of ecological scenario after treatment.
(Hodgson 2020)

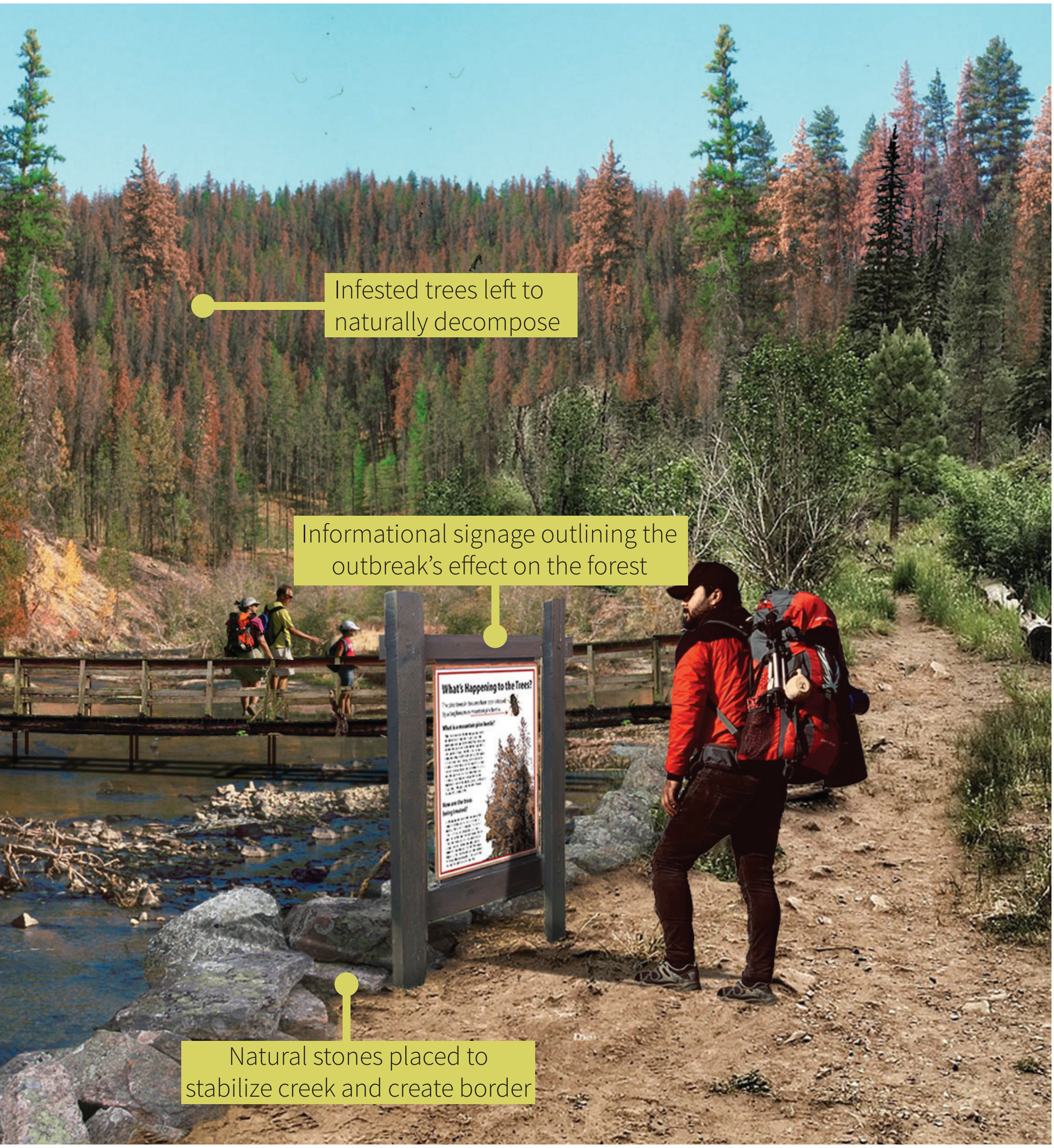
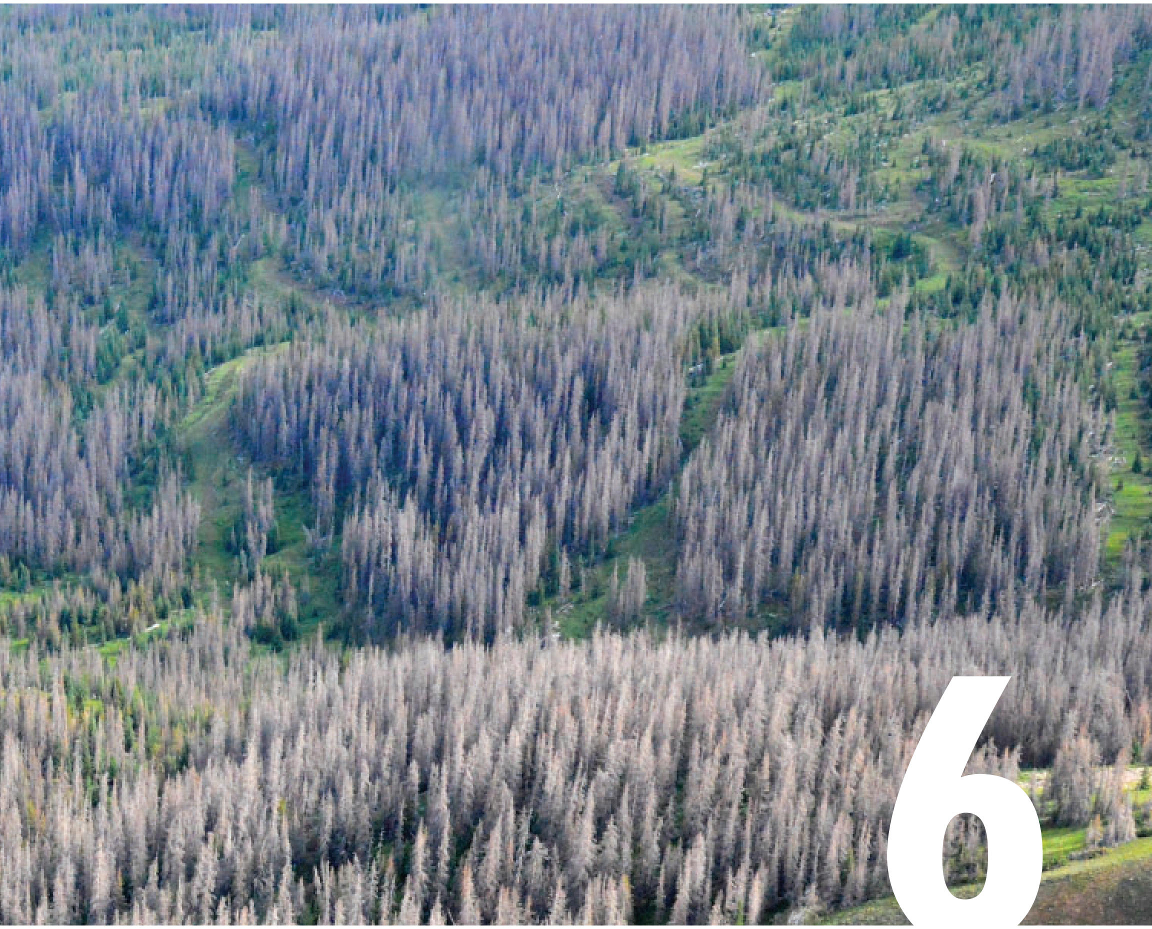


Figure 6.1
Old spruce beetle mortality in La Garita Range, Colorado.
(Ciesla 2015)



6

CONCLUSION

6. CONCLUSION

PROJECT SIGNIFICANCE

The increased spread and intensity of bark beetle infestations across the United States are going to create impacts that many industries and professions will no longer be able to ignore. Bark beetles have recently been more active and causing more tree mortality, as evidenced by the outbreak that impacted North American in the late ‘90s and early 2000s. This increase in severity can largely be attributed to warmer temperatures and drought conditions, which weaken tree defenses and increase beetle life cycles. With temperatures expected to increase over the next few decades, bark beetles will become more prominent than ever. The landscape architecture profession, which unites the built and natural environments together, will undoubtedly see the visual impacts of bark beetle infestations affect projects, especially within the Rocky Mountain region.

As the relationship between landscape architects and bark beetle impacts has yet to be explored in-depth, this report provides an essential initial dive into the topic. This project sought to answer the question: *How can landscape architects address the aesthetic and visual impacts of bark beetle infestations in the Rocky Mountain region?* By understanding the variables of bark beetle infestations and perceptions of scenic value associated with those forest variables, a comprehensive set of management guidelines was created to assist landscape architects in promoting and preserving scenic value in projects that are or may be affected.

LIMITATIONS

The wealth of information behind bark beetle behavior, effectiveness of treatment methods, and landscape aesthetics is staggered and a daunting topic to address. The restriction of time allowed to complete this project limited the amount of research that could be completed, which undoubtedly extends beyond what is mentioned in this report. Personal analysis of bark beetle-infested areas in the Rocky Mountains was not possible also due to the time restraint and the distance between the Rockies and Manhattan, Kansas, where the author currently resides.

The management guidelines and recommendations are based on personal observation from the content inventory analysis between existing landscape management techniques and considerations of landscape aesthetics. Many management practices have both positive and negative aspects in terms of ecological, aesthetic, and economic value, and are constantly being re-evaluated by new research. It is important to understand the varying methods and what will be best for different projects. Several landscape architecture firms that work on mountain based-projects were contacted regarding their interaction with bark beetle infestation and their projects; however, no firms who responded had any interaction or dealt with the management of bark beetle infestations. Major landscape architecture foundations such as the American Society of Landscape Architects (ASLA) and Landscape Architecture Foundation, have not addressed the topic of bark beetle outbreaks and their impacts to public perceptions of scenic value.

FUTURE RESEARCH

Within *Chapter 2: Background* and *Chapter 4: Findings,* this project looks to synthesize the knowledge of bark beetles and their impacts from different professions and fields, including ecology, silviculture, forestry, economics, and landscape architecture. Combined research between the professions will be beneficial in providing more clarity and understanding to the topic and relationship between bark beetles and the landscape architecture profession.

With additional time and resources, impacted communities could be interviewed to gain a more comprehensive sense of the impacts and perceptions that are associated with bark beetle infestations. In addition, more extensive research can be conducted over time (the next 10 or 20 years), to understand the economic losses associated with landscape architecture projects as bark beetle outbreaks evolve over time. Because the relationship between the landscape architecture profession and bark beetles has not been explored in-depth, this research would be extremely beneficial and more definitively analyze how the profession is being impacted.

Analysis of the proposed management guidelines addressed in *Chapter 5: Management* over time is important to understand the success and applicability of the recommended actions on perceptions of scenic value. Monitoring the aesthetic reaction to the proposed guidelines to evaluate their effectiveness will be crucially important moving forward. Also, a greater understanding regarding the notion that aesthetic value can be changed with greater understanding of ecological processes through education should also be further investigated. This research is important to evaluate the benefits of changing aesthetic perceptions through knowledge against a more aggressive approach to change the physical environment itself. These additional considerations would aid application of findings and the development of the guidelines for future use.

FINAL THOUGHTS

Landscape architects are not foresters and do not commonly interact in the realm of forest management practices. However, becoming more involved with professionals directly involved with decision making related to bark beetle infestations can help ensure that scenic quality issues are also considered. Apart from cultural value, high scenic quality also has economic value and it pays to be proactive. Understanding stand and tree characteristics in the project area allows consideration of preventative treatments (pheromone packets, etc.) and promotion of healthier stands (selective thinning of older and denser stands), which maintain higher scenic quality. Epidemics that lead to high levels of tree mortality require more intensive mitigation treatments if changes in scenic quality are of major concern.

Bark beetles are a natural component of the environment, so the future of forest planning and consideration of landscape aesthetics should focus on building stronger and more diverse forests. As bark beetle attacks occur, stronger and healthier stands will able to fight off infestations so that epidemic scenarios are less frequent in the coming future. Even so, many variables are beyond human control. When response resources are limited, it makes the most sense to concentrate effort at the forest-development interface.

APPENDICES

APPENDIX A: GLOSSARY LIST

Bark beetle: tiny insects with hard, cylindrical bodies that reproduce under the bark of trees that act as a natural part of the coniferous ecosystem with over 600 different species across the world (USDA Forest Service 2019, Bentz 2009)

Basal area: The cross-sectional area (square feet) of a single tree at breast height, expresses as per unit of land area. Used to determine forest stand density, timber stand volume and growth (Elledge and Barlow 2010)

Diameter at breast height (DBH): The diameter width of a tree trunk 4.5 feet above the ground (Elledge and Barlow 2010)

Endemic infestation: Low-level populations and infestation, cause tree-killing below a tolerable threshold. The threshold is usually single and widely scattered trees (no exact number, ex: 1 tree per 25 acres) (Bartos and Schmitz 1998)

Epidemic infestation: High-level populations and infestations, usually when bark beetles are present (no exact number, ex: 1 tree per acre) (Byron, 2005)

Forest stand: A small area of trees, ranging in size, where the trees share characteristics such as species, age, size, condition, or location (Snyder 2014).

High-value tree: As defined by the U.S. National Park Service, is a living pine and spruce tree that have the following characteristics: (U.S. National Park Service 2005)

- Provide shade and visual screening for campgrounds, picnic areas, and parking lot structures
- Have cultural significance
- Provide exceptional and irreplaceable habitat for wildlife
- Provide exceptional and irreplaceable seed source
- Have outstanding visual quality

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins*)*: A bark beetle species that attacks and kills live trees species such as lodgepole pine, ponderosa pine, bristlecone pine, whitebark pine, western white pine, sugar pine, limber pine and more (USDA Forest Service 2019, Bentz 2009).

Pheromone plume: A chemical signal released by females or pioneer beetles after they locate a "frail tree" that alerts other beetles to swarm the tree (Oatman 2015).

Phloem: a resinous layer between the outer bark and the sapwood that carries sugars (nutrients) through the tree (Oatman 2015).

Slash: woody material left behind from thinning or commercial logging operations, including branches and small diameter sections of tree stems, that can support breeding populations of bark beetle (Donaldson and Seybold).

Spruce beetle *(Dendroctonus rufipennis* Kirby*)*: Bark beetle species that attacks and kills Englemann spruce, White spruce, Lutz spruce, Sitka spruce, and Colorado blue spruce (Bentz 2009).

Stand density index (SDI): A relative measure of density which combines number per acre with average tree size, and expresses the density of a stand in terms of an equivalent number of 10-inch trees. The higher the SDI, the more crowded the stand (Vanderschaaf 2019)

Wildland-urban interface: The area of development where housing mixes with undeveloped vegetation and wilderness (Radeloff et al. 2005).

APPENDIX B: IMAGE CITATIONS

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APPENDIX D: LANDSCAPE ARCHITECTURE WORK*

FIRM: STUDIOINSITE
OFFICE: DENVER, CO

*based on projects available on every firm's website as of February 20, 2020

Project: Staunton State Park
Location: Pine
Project Type: Recreation (State/Federal Park/Public Land)

Project: Aspen Galena Plaza
Location: Aspen
Project Type: Community/Urban

Project: Viceroy at Snowmass
Location: Aspen
Project Type: Ski Resort

Project: Edgemont
Location: Steamboat Springs
Project Type: Ski Resort/Residential

Project: 6th Street Park,
Location: Glenwood Springs
Project Type: Urban/Public Space

Project: Ever Vail
Location: Vail
Project Type: Ski Resort/Urban

Project: Snowmass Village
Location: Aspen
Project Type: Ski Resort

Project: Village at Wolf Creek
Location: Pagosa Springs
Project Type: Ski Resort

Project: The Cirque at Copper Mountain
Location: Summit County
Project Type: Residential

Project: Idaho Spring East End Master Plan
Location: Idaho Springs
Project Type: Community

Project: Eagle River Corridor Master Plan
Location: Eagle
Project Type: Community

Total Projects: 11
Ski Resorts: 5
Residential: 1
Community: 4
Recreation: 1
Ecological: 0

FIRM: DESIGN WORKSHOP
OFFICE(S): DENVER, ASPEN (+ SIX OTHER OFFICES)

Project: Cascade Garden
Location: Aspen
Project Type: Residential

Project: Riverside Ranch
Location: Pitkin County
Project Type: Residential

Project: Captiol Valley Ranch
Location: Pitkin County
Project Type: Residential

Project: Hotel Jerome
Location: Aspen
Project Type: Resort/Tourism

Project: DBX Ranch
Location: Aspen
Project Type: Residential

Project: Charlie Mountain Ranch
Location: Old Snowmass
Project Type: Residential

Project: Woody Creek Garden
Location: Elk Mountains
Project Type: Residential

Project: West End Garden
Location: Aspen
Project Type: Residential

Project: Paradise Mesa Ranch
Location: Aspen
Project Type: Residential

Project: Gorsuch Haus
Location: Aspen
Project Type: Ski Resort

Project: High Terrace Garden
Location: Unknown (Colorado)
Project Type: Residential

Total Projects: 11
Ski Resorts: 2
Residential: 9
Community: 0
Recreation: 0
Ecological: 0

FIRM: DHM DESIGN
OFFICE(S): CARBONDALE, DENVER, DURANGO (+ BOZEMAN)

Project: Carbondale Recreation Center
Location: Carbondale
Project Type: Civic/Community

Project: Carbondale Library
Location: Carbondale
Project Type: Civic/Community

Project: Three Springs
Location: Durango
Project Type: Community

Project: Durango Library
Location: Durango
Project Type: Civic

Project: Ridgway Streetscape
Location: Ridgway
Project Type: Urban/Community

Project: Aspen Hillside Residence
Location: Aspen
Project Type: Residential

Project: Missouri Heights Residence
Location: Eagle County
Project Type: Residential

Project: Aspen Residence
Location: Aspen
Project Type: Residential

Project: Sunset Ridge Residence
Location: Telluride
Project Type: Residential

Project: Riverside Residence
Location: Unknown (Colorado)
Project Type: Residential

Project: Miners Trail Residence
Location: Aspen
Project Type: Residential

Project: Wheeler Residence
Location: Aspen
Project Type: Residential

Project: Pikes Peak Summit Complex
Location: Pike and San Isabel National Forest
Project Type: Recreation (State/Federal land/Public Land)

Project: Breckenridge Summer Use
Location: Breckenridge Colorado
Project Type: Recreation/Ecological

Project: Glenwood Hot Springs
Location: Glenwood
Project Type: Recreation

Project: Frisco Peninsula Recreation Area
Location: Frisco
Project Type: Recreation

Project: Blue River Trail
Location: Silverthorne
Project Type: Recreation

Project: Brian's Park Ice Rink
Location: Victor
Project Type: Recreation

Project: Lyons Flood Recovery
Location: Lyons
Project Type: Recreation/Community

Project: Ouray Hot Springs
Location: Ouray
Project Type: Recreation

Project: The Arrabelle at Vail Square
Location: Vail
Project Type: Urban/Community

Project: Winter Park Resort
Location: Winter Park
Project Type: Ski Resort

Project: True Nature Healing Arts
Location: Carbondale
Project Type: Public space/community

Project: Lift One Neighborhood Cowop
Location: Aspen
Project Type: Ski Resort

Project: Rocky Mountain Institute
Location: Basalt
Project Type: Ecological/Commercial

Project: Three Springs Stormwater Wetlands
Location: Durango
Project Type: Public Space/Ecological

Project: Roaring Fork River Restoration
Location: Basalt
Project Type: Ecological

Project: Clear W. Ranch Wetlands
Location: Pitkin County
Project Type: Ecological

Project: Double L Ranch
Location: Durango
Project Type: Residential

Project: Fishers Ranch
Location: Western Colorado
Project Type: Residential

Project: Wolcott Planned Community
Location: Wolcott
Project Type: Community

Project: Burlingame Affordable Housing
Location: Aspen
Project Type: Community/ Residential

Project: Camino Del Rio Character District
Location: Durango
Project Type: Community

Project: Haymeadow
Location: Eagle
Project Type: Community

Project: Town of Basalt
Location: Basalt
Project Type: Community

Project: City of Victor
Location: Victor
Project Type: Community

Total Projects: 36
Ski Resorts: 2
Residential: 9
Community: 14
Recreation: 7
Ecological: 4

FIRM: SE GROUP
OFFICES: FRISCO (+ 2 OTHER LOCATIONS)

Project: Estes Valley Trails Master Plan
Location: Estes Valley
Project Type: Recreation

Project: Town of Snowmass Village Parks, Open Space, Trails and Recreation Plan
Location: Snowmass Village
Project Type: Recreation/ Community

Project: Breckenridge Ski Resort Peak 6 Environmental Impact Statement
Location: White River National Forest
Project Type: Ecological

Project: Arkansas River Corridor Master Plan
Location: Canon City
Project Type: Community planning

Project: Town of Frisco Trails Master Plan
Location: Frisco
Project Type: Recreation/ Community

Project: "Blueprint Silverthorne" Comprehensive Plan
Location: Silverthorne
Project Type: Community planning

Project: Town of Silverthorne Parks, Open Space, and Trails Master Plan Update
Location: Silverthorne
Project Type: Recreation planning

Project: Town of Ridgway Land Use Plan
Location: Ridgway
Project Type: Community

Project: Ritz Carlton Residences
Location: Vail
Project Type: Resort

Project: Arapahoe Basin 2006 Improvement Plan Environmental Impact Statement
Location: Arapahoe Basin, White River National Forest
Project Type: Ski Resort

Project: Hunter Creek-Smuggler Mountain Cooperative Plan
Location: Aspen, White River National Forest
Project Type: Ecological

Project: Emerald Mountain Park Master Plan
Location: Steamboat Springs
Project Type: Recreation

Project: Town of Nederland Comprehensive Plan Update
Location: Nederland
Project Type: Community

Total Projects: 13
Ski Resorts: 2
Residential: 0
Community: 4
Recreation: 5
Ecological: 2

Project Totals: 71
Ski Resorts: 11
Residential: 19
Community: 22
Recreation: 13
Ecological: 6