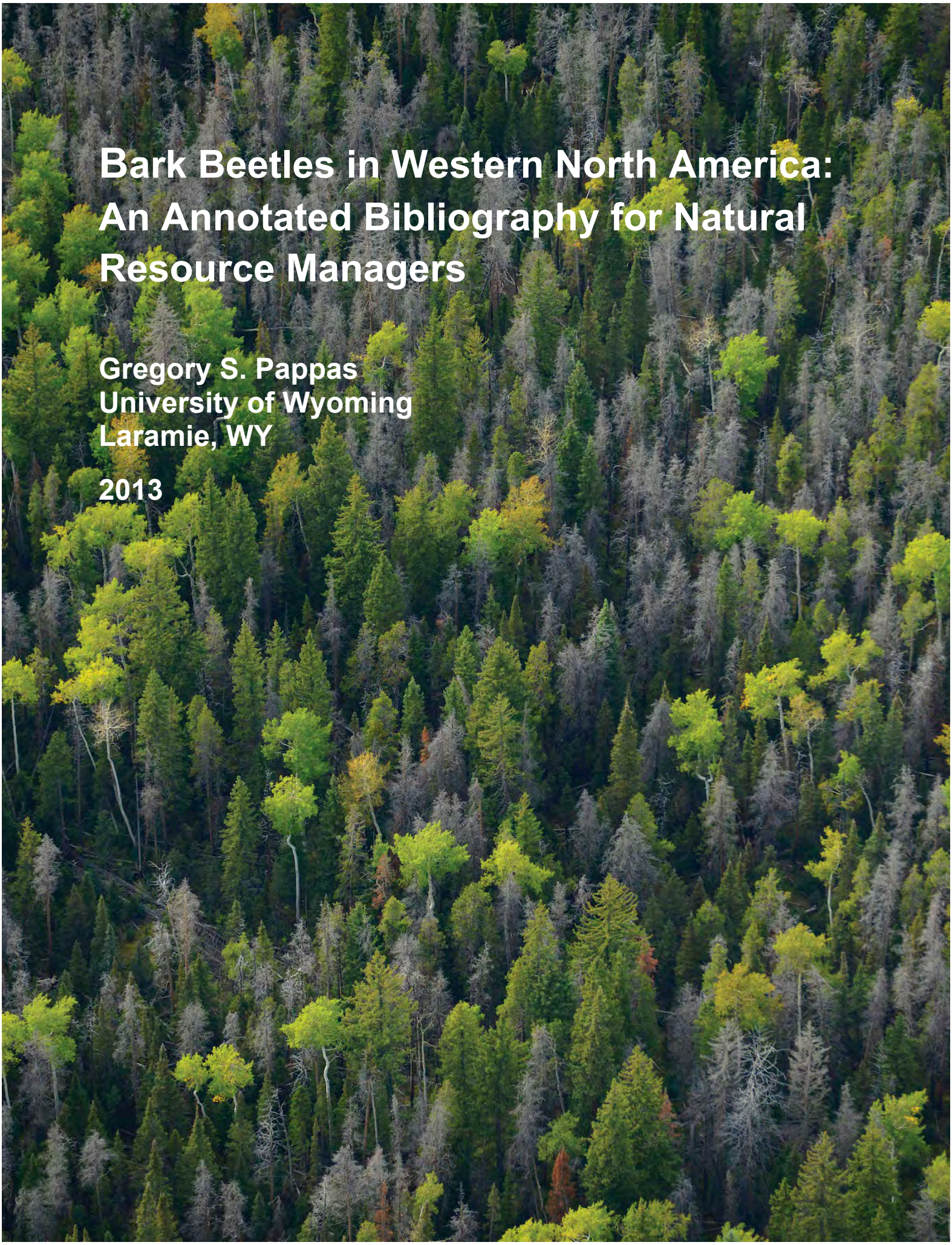

Bark Beetles in Western North America: An Annotated Bibliography for Natural Resource Managers

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Compiled by Greg Pappas, candidate for a master of science in botany and environment and natural resources at the University of Wyoming, as part of "Our Future Forests: Beyond Bark Beetles," a project of the Medicine Bow-Routt National Forests and Ruckelshaus Institute of Environment and Natural Resources conducted in 2013.

The Medicine Bow-Routt National Forests and Thunder Basin National Grassland cover nearly 2.9 million acres from north central Colorado to central and northeastern Wyoming.

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ABSTRACT

An unprecedented multi-species bark beetle epidemic has caused severe tree mortality across western North American forests, prompting concerns about the safety, management, and future health and development of these changing landscapes. The significant ecological and socioeconomic impacts associated with bark beetle outbreaks present issues and challenges best addressed through cooperation among community residents, policymakers, and managers. The public's perception of both the epidemic and ability of resource managers to respond effectively varies considerably depending on location and time since disturbance. A thorough understanding of this and other human aspects of bark beetle outbreaks is necessary to alleviate the potential tension between managers and stakeholders created by management actions. Accordingly, this annotated bibliography emphasizes the social and economic impacts and considerations of bark beetle outbreaks. In addition, it provides relevant information on bark beetle ecology and biology, ecological impacts and responses, and management approaches and implications. It is intended primarily as a reference for resource managers seeking recent scientific findings in order to make informed decisions that are crucial to the well being of both forest and human communities. A varied compilation of resources is provided, such as peer-reviewed scientific literature, symposium proceedings, technical reports, management guides, annotated bibliographies, and internet sources. Included are studies on multiple bark beetle species and outbreaks occurring throughout western North America, with the majority of the studies having been published between 2008 and 2013.

CONTENTS

INTRODUCTION

Forests throughout western North America have experienced widespread bark beetle outbreaks for over a decade. Native bark beetle infestations are a natural regulating process in most western forests, but simultaneous outbreaks of several different species have caused severe tree mortality at a rate and scale that is historically unprecedented. Landscape-level epidemics require a complex suite of factors, occurring when thresholds are exceeded and positive feedbacks amplify across scales (Raffa et al. 2008). In particular, two main factors are largely considered to be driving the ongoing outbreaks: 1) vast concentrations of highly susceptible host trees in the form of homogeneous stands of large, dense, and mature trees with reduced vigor from increased competition (Fettig et al. 2007); and 2) changing climate conditions, chiefly prolonged drought stress and warmer temperatures, which have favored beetle survival and reproduction.

The massive number of dead and dying trees in the wake of this disturbance has elicited concerns regarding the heightened risk of wildfire and possible reductions in critical ecosystem functioning and services, such as nutrient cycling, carbon sequestration, regulation of water, timber production, and provision of recreational and aesthetic values. Research is ever-increasing on these and other management, policy, and socioeconomic issues associated with bark beetle outbreaks. Efforts to distribute and understand new information, along with improved collaboration among stakeholders, will assist in the effective management of post-outbreak forests.

The purpose of this annotated bibliography is to identify, organize, and summarize relevant bark beetle outbreak information for natural resource managers. It is a broad resource containing information on bark beetle ecology and biology, ecological impacts and responses, management approaches and implications, and social and economic impacts and considerations. An emphasis is placed on the socioeconomic impacts and other human dimensions of forest disturbance such as community perspectives and responses. Although created with resource professionals and managers as the focal audience, it may be useful to anyone in the scientific community or the public who is interested in recent bark beetle literature, particularly with regard to human dimensions.

This bibliography includes resources in a variety of formats (e.g., scientific literature, symposium/workshop proceedings, technical reports, websites, webinars, etc.). With only a small number of exceptions, the resources are from the last ten years and the majority from the last five years. The geographic scope of the studies ranges from Alaska and western Canada throughout all of the continental western U.S. and into northern Mexico. There are over a dozen native bark beetle species capable of causing landscape-level tree mortality in western U.S. and Canada (Bentz et al. 2010), but the mountain pine beetle (MPB) is responsible for the majority of mortality from the current outbreaks. Accordingly, this bibliography contains an abundance of MPB information in comparison to other beetle species (although a fair amount of literature is devoted to several others, such as the spruce beetle and Douglas-fir beetle).

USING THIS BIBLIOGRAPHY

The annotated bibliography is organized into five categories: I. Bark Beetle Ecology and Biology; II. Ecological Impacts and Responses; III. Management Approaches and Implications; IV. Social and Economic Impacts and Considerations; and V. Syntheses, Reports, Guides, Bibliographies, and Symposium Proceedings. Annotated citations are numbered and arranged alphabetically by the first authors' last name, and are followed by a concise overview (which may contain important background info, study objectives, and methods employed) followed frequently by key findings and implications. Citations fitting in multiple categories are cross-referenced in a "Cross-Reference" section following the annotated citations. Then, a list of additional non-annotated resources for further reading is included. Appendices contain lists of websites that offer a wide range of bark beetle information, scientific and common names of beetle and tree species referenced in the studies, and acronyms and abbreviations.

Categories

I. Bark Beetle Ecology and Biology – This category contains literature on the biology and ecology of beetle species and their hosts (e.g., habitats, life cycles, pheromones, etc.), with a particular focus on the factors driving outbreaks such as climate change.

II. Ecological Impacts and Responses – This category contains information on bark beetle effects on ecosystem processes and services, wildlife, hydrology, productivity, nutrient cycling, carbon sequestration, fire interactions, and future forest structure and composition.

III. Management Approaches and Implications – This category's resources focus primarily on specific treatments/actions that are used to respond to and mitigate effects of bark beetle outbreaks.

IV. Social and Economic Impacts and Considerations – This category's resources cover bark beetle effects on tourism, recreation, aesthetics, property values, public health and safety, etc., as well as economic opportunity to use beetle-killed forest products, mitigation costs, effects on nonmarket resources, public perceptions, and community action in response to outbreaks.

V. Syntheses, Reports, Guides, Bibliographies, and Symposium Proceedings – This category contains an assembly of resources from the other categories. It provides the reader quick access to larger, synthesis-type sources of information.

Literature Cited in Introduction

Bentz, B. J., Régnière, J., Fettig, C. J., Hansen, E. M., Hayes, J. L., Hicke, J. A., ... & Seybold, S. J. (2010). **Climate change and bark beetles of the western United States and Canada: direct and indirect effects.** BioScience, 60(8), 602–613.

Fettig, C. J., Klepzig, K. D., Billings, R. F., Munson, A. S., Nebeker, T. E., Negrón, J. F., & Nowak, J. T. (2007). **The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States.** Forest Ecology and Management, 238(1), 24–53.

Raffa, K. F., Aukema, B. H., Bentz, B. J., Carroll, A. L., Hicke, J. A., Turner, M. G., & Romme, W. H. (2008). **Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions.** Bioscience, 58(6), 501–517.

BIBLIOGRAPHY

I. Bark Beetle Ecology and Biology

1. Bentz, B. J., Régnière, J., Fettig, C. J., Hansen, E. M., Hayes, J. L., Hicke, J. A., ... & Seybold, S. J. (2010). **Climate change and bark beetles of the western United States and Canada: direct and indirect effects**. BioScience, 60(8), 602–613.

   Overview

   This paper synthesizes the current knowledge regarding the direct and indirect impacts of climate change on bark beetle community ecology, population dynamics, and host interactions in western North America. These impacts are illustrated by two case studies using climate forecasts and population models involving the spruce beetle and mountain pine beetle.

   Key Findings

   - Direct effects of climate change occur primarily through temperature-mediated life history strategies that lead to synchronized adult emergence and life-cycle timing, and enable prevention of cold-temperature-induced mortality.
   - Developmental timing strategies that may be affected by climate change include diapause and direct temperature control. Diapause is a type of dormancy that may be prevented or disrupted by higher temperatures. Rising temperatures could also affect developmental temperature thresholds that aid in synchrony of emergence and prevent transition to cold-intolerant life stages.
   - Because bark beetles introduce a collection of symbionts (e.g., fungi, bacteria, nematodes, and mites) during host tree colonization, their success could be indirectly influenced by the effects of changes in temperature and precipitation on their community associates. Also, non-beneficial community associates such as parasitoids and predators may similarly be affected by climate change factors.
   - Elevated levels of atmospheric CO_2 may negatively impact bark beetle growth and survival. However, this is partially outweighed by other climate change-related impacts such as drought-induced reductions in host tree defenses.
   - Model predictions suggest considerable increases in the probability of spruce beetle offspring developing annually rather than semiannually throughout the century, causing greater outbreak potential and tree mortality across North American spruce beetle habitat.
   - MPB habitat suitable for both adaptive seasonality and cold survival is predicted to increase (but with high spatial variability) across North America through the end of the century, suggesting greater outbreak potential and tree mortality. Models based on MPB response to temperature predict low to moderate probability of range expansion across Canada and into central and eastern U.S. forests.

Implications

- Climate change-driven bark beetle outbreaks have the potential to significantly impact forest ecosystem structure and dynamics, which may propel the system into a state outside the historical range of resilience while producing feedbacks to climate.

2. Chapman, T. B., Veblen, T. T., & Schoennagel, T. (2012). **Spatiotemporal patterns of mountain pine beetle activity in the southern Rocky Mountains**. Ecology, 93(10), 2175–2185.

Overview

This study infers potential drivers of the current MPB epidemic by comparing the spatiotemporal patterns of MPB infestation with weather variability in lodgepole and ponderosa pines from 1996 to 2010 in Colorado and southern Wyoming. Additionally, a meso-scale analysis is used to investigate the potential influences of local weather, topography, forest structure variability, and presence of previous MPB outbreak on the development of an epidemic in lodgepole pine.

Key Findings

- Regional spatial synchrony of MPB activity was greater for lodgepole pine compared to ponderosa pine. The magnitude and extent of synchrony of precipitation and temperature variables (favorable to beetle populations) was high in areas of both pine species.
- Unique spatiotemporal trends in MPB activity were identified both between and within pine species over time. Cluster analysis revealed multiple, disjoined outbreak origin locations in lodgepole pine that coincide with a MPB outbreak from the 1980s. Drought appears to have triggered the outbreak and its continued spread. Outbreak progression was also associated with increased lodgepole pine dominance, lower elevations, and stands containing larger trees and greater canopy cover.
- After reaching epidemic levels, MPB activity was less dependent on drought and more dependent on lack of severe cold temperatures that can cause beetle mortality. At this later stage, the outbreak began to spread to higher elevations and stands previously less susceptible (e.g., smaller trees).

Implications

- Patterns in MPB activity are not the same for different pine forest types. The developmental course of the recent outbreak in ponderosa pine will likely differ from that shown by lodgepole pine, thus requiring further study.

3. Cullingham, C. I., Cooke, J. E., Dang, S., Davis, C. S., Cooke, B. J., & Coltman, D. W. (2011). **Mountain pine beetle host‐range expansion threatens the boreal forest**. Molecular Ecology, 20(10), 2157–2171.

Overview

The MPB in Alberta, Canada has reached lodgepole pine's eastern edge of distribution, where forest composition changes to jack pine through a hybrid zone. This zone has the potential to facilitate beetle expansion into jack pine boreal forest. This study developed a panel of microsatellite markers optimized for both tree species and tested their efficacy at species classification for identification of MPB-attacked trees sampled from the leading edge of the expansion.

Key Findings

- The authors successfully classified lodgepole pine, jack pine, and hybrid ancestry utilizing simulated genotypes and Bayesian cluster analyses.
- Eight pure jack pine trees and 19 hybrid trees attacked by MPB were effectively identified, verifying their vulnerability in this previously unsuitable habitat.

Implications

- Although both hybrids and pure jack pine demonstrate susceptibility to MPB, continued expansion into the boreal forest will rely on multiple factors which must be considered in future management plans, such as: degree of beetle reproductive success, tree-level defenses, density of available hosts, and climate characteristics.
- Since MPB is not endemic to the boreal forest, it should be managed as an invasive species in the event of sustained expansion.

4. Hayes, J. L., & Western Bark Beetle Research Group. (2010). **Annotated bibliography of climate and bark beetles of western forests**. USDA Forest Service, Pacific Northwest Research Station and Western Bark Beetle Research Group. Online at http://www.fs.fed.us/wwetac/projects/hayes2.html.

Overview

This annotated bibliography was created by the Western Bark Beetle Research Group to provide information relevant to climate change and its relationship with bark beetles. Included are close to 300 citations from the bark beetle/climate change rapid threat assessment, each containing a 2–3 sentence annotation explaining the rationale for its inclusion in the bibliography. Abstracts are provided for papers that were either authored by federal employees or published through the government.

5. Raffa, K. F., Aukema, B. H., Bentz, B. J., Carroll, A. L., Hicke, J. A., Turner, M. G., & Romme, W. H. (2008). **Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions**. Bioscience, 58(6), 501–517.

Overview

This paper presents a conceptual framework for understanding fundamental processes and dynamics of bark beetle outbreaks and their management challenges in western North American forests. The framework demonstrates how interactions among thresholds, feedbacks, and mechanisms from different levels of biological hierarchy and spatiotemporal scales interact to produce landscape-level eruptions and fundamental regime shifts associated with anthropogenic and internal drivers. This provides vital information regarding basic ecosystem processes, beneficial to natural resource management and the prevention of ecologically damaging, human-induced regime shifts.

Key Findings

- Recently, bark beetle epidemics have increased in magnitude, expanded to persistent in areas formerly uncommon to infestation, formed associations with new species in previously unaffected habitats, and experienced greater temporal synchrony among different species.
- Landscape-level epidemics occur when a series of key thresholds (i.e., host entry, aggregation, establishment, reproduction, and stand-level outbreak) are exceeded and positive feedbacks amplify across scales, causing impacts from the cellular to landscape level.
- A breach of thresholds, after which most population restraints are eliminated, requires a combination of tree host availability and susceptibility, high beetle density, favorable weather, and escape from historically developed enemies.
- Outbreaks can partially be seen as an assembly of circumstances whereby endogenous positive feedback surpasses negative feedback and intensifies upward across spatial and temporal scales (e.g., when attraction of more beetles via beetle entry exceeds the effect of entry-induced tree defenses that can halt attacks).
- The ability of a beetle population to contribute to landscape-level epidemics after overcoming stand-level outbreak thresholds, depends on the availability of high-nutrition host trees, rate of host depletion, the accessibility and quality of adjacent host stands, and the level of synchrony with nearby populations.
- Various human activities acting at multiple scales can influence how bark beetles and their tree hosts, symbionts, and enemies interact and cause amplifications. Particularly, anthropogenically induced temperature increases and drought coupled with management activities creating homogenous stands of vulnerable hosts can promote widespread outbreaks. This can potentially set the stage for future outbreaks by producing relatively even-aged stands across the landscape.

Implications

- This system of thresholds, multiple causalities, and cross-scale interactions demonstrates the need for management approaches to be process-oriented and tactically applied at the proper spatial and temporal scales. Bark beetle outbreaks are just one of an emerging

number of challenges associated with the interactions of natural and human-induced disturbances and potential regime change.

- This study suggests four important concepts to consider with the objective of beetle suppression:
  - Management strategies should focus on the particular thresholds at play in each system.
  - Since similar damage may occur from various dynamics and causes, a process-based rather than damage-based definition of outbreaks will allow for better decision making. Standardized prescriptions are not likely to be successful.
  - Resource management should be suited to biologically not politically measured scales of space and time. Current approaches responding to shifting political will, based on jurisdictional borders and that do no consideration cross-scale feedback are unbefitting for conifer forest management.
  - It should be acknowledged that these systems, which naturally evolved together, now face potential regime shifts due to human activity. This may alter (and will likely reduce) the capacity to utilize threshold-based management strategies.

6. Romme, W. H., Clement, J., Hicke, J., Kulakowski, D., MacDonald, L. H., Schoennagel, T. L., & Veblen, T. T. (2006). **Recent forest insect outbreaks and fire risk in Colorado forests: a brief synthesis of relevant research**. Colorado Forest Restoration Institute, Fort Collins, CO. 24 p. Online at http://warnercnr.colostate.edu/docs/frs/cfri/cfri_insect.pdf.

Overview

This report is a brief synthesis of the current understanding (in 2006) of insect outbreaks and fires in Colorado forests, written to help inform management and policy decisions. It is broken into two sections: the first addresses nine main questions concerning the basic ecology of insect outbreaks, and the second describes and evaluates the possible effects of six treatment options to mitigate the effects of insect outbreaks and fires.

7. Safranyik, L., & Wilson, B., editors. (2006). **The mountain pine beetle: A synthesis of biology, management, and impacts on lodgepole pine**. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. 304 p. Online at http://www.for.gov.bc.ca/hfd/library/documents/bib96122.pdf.

Overview

Intended as a resource for both researchers and forest managers, this book is a comprehensive synthesis of available MPB information emphasizing lodgepole pine forests of western Canada. It is broken into three parts: MPB biology, management, and socioeconomic impacts. The first part, comprised of chapters 1–3 (p. 3–114), focuses on biology. Chapter 1 provides a thorough review of the biology, habits, and epidemiology of MPB, including distribution, life history, and population processes. Chapter 2 reviews the history of MPB outbreaks in western Canada and explores the influences of forest dynamics

and climate variability. Chapter 3 provides an overview of MPB impacts on lodgepole pine stand structure and dynamics, as well as MPB–fire interactions.

Key Findings of Part 1

- The ability of MPB populations to persevere in lodgepole pine forests and reach the epidemic stage depends on the concurrence of a multitude of susceptible host trees, several years of weather favorable for beetle survival, and the critical interactions among a complex collection of life-history traits.
- Tree host susceptibility to MPB attack may be affected by the age, species composition, and continuity of mature forest stands. Susceptibility may also be influenced by previous outbreak occurrence across the landscape as habitat quality is diminished by MPB. Areas not experiencing outbreaks in the past may be more susceptible than those having recently undergone attack.
- The area of lodgepole pine susceptible to MPB has increased due, in part to the combination of successful fire suppression over the last century and the recent commercial use of lodgepole pine. In the absence of fire, continued MPB infestations will change even-aged, seral stands into those characterized by an uneven-aged climax state. However, pine forests occur across diverse regions composed of a variety of biotic and abiotic characteristics that will likely result in post-disturbance forests that differ in their host and non-host species compositions.

Implications

- The high probability of future severe MPB outbreaks necessitates efficient control strategies focused on early detection and implementation as well as management for lodgepole pine vigor, resistance, and age class.

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Samman, S., Logan, J., tech. eds. (2000). **Assessment and response to bark beetle outbreaks in the Rocky Mountain area**. Report to Congress from Forest Health Protection, Washington Office, Forest Service, U.S. Department of Agriculture. Gen. Tech. Rep. RMRS-GTR-62. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT. 46 p. Online at http://www.fs.fed.us/foresthealth/publications/rmrs_gtr62.pdf. [see citation #22]

Waring, K. M., Reboletti, D. M., Mork, L. A., Huang, C. H., Hofstetter, R. W., Garcia, A. M., ... & Davis, T. S. (2009). **Modeling the impacts of two bark beetle species under a warming climate in the southwestern USA: ecological and economic consequences**. Environmental Management, 44(4), 824–835. [see citation #40]

Additional Ecology and Biology Resources

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Kashian, D. M., Jackson, R. M., & Lyons, H. D. (2011). **Forest structure altered by mountain pine beetle outbreaks affects subsequent attack in a Wyoming lodgepole pine forest, USA**. Canadian Journal of Forest Research, 41(12), 2403–2412.

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USDA Forest Service, Rocky Mountain Region, Rocky Mountain Research Station. (2011). **Review of the Forest Service Response: The Bark Beetle Outbreak in Northern Colorado and Southern Wyoming**, at the request of Senator Mark Udall. 45 p. Online at http://www.fs.usda.gov/detail/barkbeetle/home/?cid=stelprdb5340741.

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Logan, J. A., Regniere, J., & Powell, J. A. (2003). **Assessing the impacts of global warming on forest pest dynamics**. Frontiers in Ecology and the Environment, 1(3), 130–137.

Mitton, J. B., & Ferrenberg, S. M. (2012). **Mountain pine beetle develops an unprecedented summer generation in response to climate warming**. The American Naturalist, 179(5), E163–E171.

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Williams, D. W., & Liebhold, A. M. (2002). **Climate change and the outbreak ranges of two North American bark beetles**. Agricultural and Forest Entomology, 4(2), 87–99.

II. Ecological Impacts and Responses

8. Clow, D. W., Rhoades, C., Briggs, J., Caldwell, M., & Lewis, W. M. (2011). **Responses of soil and water chemistry to mountain pine beetle induced tree mortality in Grand County, Colorado, USA**. Applied Geochemistry, 26, S174–S178.

Overview

This paper explores the possible effects of the MPB epidemic on soil and water chemistry in Grand County, Colorado, and identifies key influences on surface water nutrient and C concentrations. The rationale for this joint study by the USGS and USDA Forest Service is that the N and C released from the decomposition of beetle-killed tree material may be transported to surface waters, potentially altering the quality of drinking water supplies. Methods included taking soil chemistry samples from under trees of varying stages of MPB attack, taking water-quality samples from headwater streams draining basins differing in their magnitude and timing of MPB disturbance, developing stepwise multiple linear regression equations for nitrate (NO_3) and dissolved organic carbon (DOC) stream water concentrations, and evaluating trends in stream water chemistry for the three major lake inlets during 2001–2009.

Key Findings

- Nutrient and soil moisture levels were lower beneath healthy or newly attacked trees compared to those with advanced stages of attack, and extractable NO_3 was significantly lower. This is likely due in part to reduced uptake of water and nutrients following MPB-induced overstory tree mortality.
- Nitrate and DOC stream water concentrations displayed considerable spatial variation, differing more due to factors such as percent forest, basin area, and relief than to percent MPB mortality.
- Both particulate and dissolved total N and P increased in the inlet streams, possibly due to temperature-related increases in productivity or influxes of particulate organic matter derived from the decayed litter of beetle-killed trees.

Implications

- While NO_3 concentrations have not increased following MPB disturbance, the apparent increase in total N and P concentrations may have significant implications for drinking water quality in the study area. Since much of the litter associated with MPB-induced tree mortality has yet to accumulate and decay, surface water NO_3 and DOC concentrations may still gradually increase through time.

9. Collins, B. J., Rhoades, C. C., Hubbard, R. M., & Battaglia, M. A. (2011). **Tree regeneration and future stand development after bark beetle infestation and harvesting in Colorado lodgepole pine stands**. Forest Ecology and Management, 261(11), 2168–2175.

Overview

This study measured the density and growth of new seedlings (trees ≤3 years old) and advanced regeneration (trees <2.5cm diameter at 1.4m and >3 years old) in eight pairs of untreated and adjacent harvested beetle-killed, lodgepole pine-dominated stands within the U.S. Forest Service Fraser Experimental Forest in north-central Colorado. Survey results were incorporated into the Forest Vegetation Simulator to estimate changes in stand structure and composition for two centuries following the bark beetle outbreak. Enhanced understanding of post-disturbance tree regeneration in harvested and untreated forests will assist with forest recovery projections and management priorities.

Key Findings

- Both harvested and untreated stands experienced new seedling recruitment in the years directly following the beetle outbreak. New seedling density was four times greater in harvested compared to untreated stands. Lodgepole and aspen seedlings were less abundant in untreated areas. Subalpine fir and Engelmann spruce recruitment did not differ statistically between treatments, but in untreated stands subalpine fir had the greatest distribution of new recruits.
- Following overstory mortality, annual height increment of lodgepole pine and subalpine fir advance regeneration doubled in untreated stands between 2007 and 2010. In harvested areas, subalpine fir annual height growth declined significantly.
- Total stand basal area and stem density are predicted to return to pre-outbreak levels in untreated and harvested stands after approximately 80 and 105 years, respectively. Lodgepole pine will continue as the dominant overstory species in harvested stands for at least 100–150 years, while subalpine fir will become the dominant species in untreated stands. During the first decades following the outbreak, aspen is projected to become a considerable part of the overstory in both harvested and untreated stands.

Implications

- In untreated stands, well-formed advance regeneration was found in 93% of plots and exceeded 1,000 stems per hectare on 76% of plots, suggesting most stands will be adequately stocked in the future without management intervention. The new forest at this site will develop both from advance regeneration and new seedling recruitment (seedlings established in 93% of untreated plots), but recovery may depend more on advance regeneration than on new seedling establishment in untreated stands.
- Harvested plots with forest floor debris deeper than 5 cm, woody debris deeper than 10 cm, and more than 45% herbaceous cover had no seedling recruits. However, 72% of harvested plots contained new recruits and 63% of individual plots surpassed regional seedling density stocking requirements even in the absence of mechanical site preparation.
- Results indicate that these lodgepole stands and those similar across northern Colorado will generally have ample regeneration to become well-stocked forests, but the most

notable long-term consequences will result from the shift in species composition and related ecosystem responses in untreated forests.

10. Dordel, J., Feller, M. C., & Simard, S. W. (2008). **Effects of mountain pine beetle (*Dendroctonus ponderosae* Hopkins) infestations on forest stand structure in the southern Canadian Rocky Mountains**. Forest Ecology and Management, 255(10), 3563–3570.

Overview

This study tests the hypothesis that MPB infestations enhance forest stand structural diversity in the southern Canadian Rocky Mountains and investigates whether this is confounded by fire history. This is accomplished by examining stand structure parameters (tree species, diameter, height class, density, age class, and coarse woody debris mass) and fire history characteristics (time since fire, fire frequency, and severity) in montane and lower subalpine forests of Banff and Kootenay National Parks that had experienced MPB outbreaks 15, 25, and 65 years earlier.

Key Findings

- Stand structural diversity, measured by the Shannon Wiener Index, increased in stands 15 years after MPB infestation but was unaffected in stands 25 or 65 years after infestation.
- In general the number of live trees, pine species, and small diameter snags decreased with MPB infestation and the number of large diameter snags increased.
- None of the measured stand structure variables displayed a relationship with the number of fires or time since fire, suggesting that differences in fire history between plots did not play a role in the observed effects of MPB on forest structure.

Implications

- Management strategies that incorporate a certain amount of MPB infestation while promoting natural fires of various severities, would provide for more open and diverse forest stands in the southern Canadian Rocky Mountains. Since MPB infestations have similar effects on forest structure (e.g., increased structural diversity and opening of the canopy) to those of fire, infestations may act to somewhat reverse the stand structure alterations associated with the infrequent burning of Banff and Kootenay National Parks within the last century.

11. Griffin, J. M., & Turner, M. G. (2012). **Changes to the N cycle following bark beetle outbreaks in two contrasting conifer forest types**. Oecologia, 170(2), 551–565.

Overview

This study sought to understand how Douglas-fir beetle (DFB) disturbance alters N cycling in Douglas-fir forests and how similar these patterns are to those of MPB-disturbed lodgepole pine forests. Forest structure, soil temperature, litter and foliar N pools, soil N, net N mineralization, and net nitrification were quantified in both undisturbed and gray stage (4–

5 years post-outbreak) DFB-killed forests of the Greater Yellowstone Ecosystem in northwestern Wyoming and compared to similar published lodgepole pine data.

Key Findings

- Despite considerable differences in pre-disturbance stand biogeochemistry, beetle disturbance facilitated similar changes in litter and soil N cycling in both Douglas-fir and lodgepole pine forests, including increased litter N inputs, the doubling of soil N availability, a 20% increase in foliar N concentration of live trees, and a 30–50% increase in understory plant cover.
- Similar changes in foliar chemistry were also evident between forest types including a decline in foliar Mn, which could cause slower litter decomposition and soil N replenishment.
- Some ecosystem responses to beetle disturbance differed between host forest types. Soil temperature declined in lodgepole pine but remained unaltered in Douglas-fir. There was a positive correlation between fresh foliar %N and net N mineralization in lodgepole pine, but no correlation in Douglas-fir. Although there was a doubling of soil inorganic N, net N mineralization, and net nitrification following disturbance, levels remained low in both forest types.
- Douglas-fir stands unaffected by beetle contained larger soil N, net N mineralization, and litter N pools than lodgepole pine stands.

Implications

- Soil and litter N pools in beetle-disturbed forests may have more regulation over N mineralization than temperature or plant uptake of N.
- As a result of comparable disturbance mechanisms and legacies across different host–beetle systems, disturbance type may better predict litter and soil N responses than forest type.

12. Hicke, J. A., Johnson, M. C., Hayes, J. L., & Preisler, H. K. (2012). **Effects of bark beetle-caused tree mortality on wildfire**. Forest Ecology and Management, 271, 81–90.

Overview

The broad and often contradictory conclusions reported in published literature concerning the effects of bark beetle outbreaks on fuels and wildfire characteristics cause confusion and uncertainty about appropriate decisions for fighting fires and implementing treatments to reduce wildfire hazard and impacts. This paper provides a detailed synthesis of this topic, critically assessing 39 studies in order to review their major characteristics. A conceptual framework was developed from these publications describing expected changes to fuels and fire characteristics following bark beetle outbreak. The level of confidence in the framework and agreement among studies was quantified. A description of the relevant challenges and knowledge gaps associated with this topic are included.

Key Findings

- Higher confidence was assigned to the conceptual framework for conditions where the published literature agreed on responses, such as effects in stands with longer times since outbreak. Lower confidence was assigned for conditions with disagreement or gaps in knowledge, mainly during early phases and the responses of crown fire.
- The conceptual framework shows canopy bulk density remains unaffected at the onset of outbreak, declines through the gray phase, and recovers in the old phase as the forest regenerates. This is accompanied by increased fine surface fuels during the gray phase, which then decline with decomposition through time. Significant increases in coarse fuels occur only in the old phase due to fallen snags and branches. Ladder fuels increase throughout the gray and old phases with the growth of shrubs, seedlings, and surviving subcanopy trees.
- The response of fuels impacts fire behavior. Rate of spread, reaction intensity, and flame length increases with surface fuel loads. Lower foliar moisture in the red phase results in increased torching potential, which remains elevated through the gray phase due to greater surface fuel loads and constant canopy base height. Torching potential eventually increases in the old phase with the growth of ladder fuels. Active crown fire becomes more likely in the red phase due to reduced foliar moisture. Its potential declines during the gray phase as canopy bulk density is reduced and gradually increases through time as the forest develops.
- Forest floor burn severity is expected to remain the same in the red phase as fuels are unaffected and increase in the gray and old phases due to greater surface fuel loads and reaction intensity. Canopy burn severity is expected to increase in the red phase due to the increased crown fire potential and torching from reduced foliar moisture. In the gray and old phases, lower canopy burn severity is expected since the effects of reduced canopy bulk density are anticipated to outweigh the increased torching potential.
- Although there was significant agreement among the literature and with the conceptual framework, some disagreement existed for certain characteristics.
- Several studies indicated that other factors were more important drivers of beetle outbreaks than fire behavior, severity, or extent.

Implications

- Some of the controversy regarding bark beetle effects on fire was resolved by recognizing the type of study question and being more specific about time since outbreak, fuels, or fire characteristic. The types of change depend on these considerations, suggesting that generalizations about the response of fire characteristics to bark beetle-induced mortality are unwarranted.
- The wide variability in environmental conditions, rate of mortality, and forest structure within beetle-attacked areas also suggests challenges in generalizing response across forests. Further research across this variability and on the effects of beetle-caused tree mortality in general will provide better understanding and information to resource managers developing fire hazard reduction and firefighting plans in western North America.

13. Kaufmann, M. R., Aplet, G. H., Babler, M., Baker, W. L., Bentz, B., Harrington, M., ... & Veblen, T. T. (2008). **The status of our scientific understanding of lodgepole pine and mountain pine beetles – a focus on forest ecology and fire behavior**. GFI technical report 2008-2. The Nature Conservancy, Arlington, VA. 13 p. Online at http://www.fs.fed.us/rm/pubs_other/rmrs_2008_kaufmann_m001.pdf.

Overview

This is a synthesis of the current (in 2008) scientific understanding of the direct and indirect effects of the MPB epidemic on lodgepole pine forests of Colorado and southern Wyoming, with a focus on ecology and fire behavior. Resulting from a meeting and subsequent dialogue of scientists who study lodgepole pine, this report provides nine key points with explanations to help stakeholders sort out what is known with varying levels of certainty and what is in need of more research. Additionally, a list of suggested reading is provided for further information.

14. Simard, M., Powell, E. N., Griffin, J. M., Raffa, K. F., & Turner, M. G. (2008). **Annotated Bibliography for Forest Managers on Fire-Bark Beetle Interactions**. The Bark Beetles, Fuels, and Fire Bibliography. Paper 207. Online at http://digitalcommons.usu.edu/barkbeetles/207.

Overview

Intended as a resource for managers dealing with increased fires and extensive bark beetle outbreaks throughout western coniferous forests, this annotated bibliography provides a concise summary of relevant scientific literature concerning the relationships between wildfire and bark beetle outbreaks. It is organized into three parts: current trends in fire and bark beetle activity in western forests, beetle effects on fire activity, and fire effects on beetle activity.

Key Findings

- Spruce beetle outbreaks don't affect the occurrence and severity of stand-replacing fires in spruce-fir forests, while results for MPB outbreaks in lodgepole forests are ambivalent.
- Bark beetle effects on fire for other forest types are either unknown or need more research.
- Since fuels change through time, it is important to account for time since mortality in the beetle-fire relationship.
- Douglas-fir beetle attack rates are greater for Douglas-fir trees previously injured by fire.
- The data are inconclusive concerning MPB attack rates for fire-injured lodgepole pines, while other forest systems need more research.
- Fire-injured trees experience elevated attack rates by non-aggressive bark beetles such as wood borers and *Ips*.

15. Teti, P. (2008). **Effects of overstory mortality on snow accumulation and ablation**. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. Mountain Pine Beetle Working Paper 2008-13. 34 p. Online at http://publications.gc.ca/collections/collection_2009/nrcan/Fo143-3-2008-13E.pdf.

Overview

This paper provides watershed modelers with information on the snow hydrology and physical characteristics of managed and unmanaged lodgepole pine stands at various stages of growth and MPB-induced deterioration in British Columbia's Interior Plateau. For six groups of research plots, detailed tree and coarse woody debris surveys were conducted, and fisheye canopy photographs were taken to calculate solar radiation transmittances and other various parameters. Aerial photography and ground surveys were employed to document snow accumulation and ablation rates. These data enhance hydrologic model results and allow for their calibration to new watersheds, enabling prediction of MPB and management associated changes in stream flow.

Key Findings

- The highest snow water equivalents occurred in plots that had been clearcut or burned in a wildfire within the last 10 years.
- Snow accumulation was lowest in old beetle-attacked stands and cut stands over 25 years old. Accumulation in beetle-attacked stands ranged from 77% to 90% relative to nearby cut stands less than 10 years old.
- Snow ablation rates were highest in stands logged 15 years prior. Managed stands greater than 30 years old had ablation rates comparable to those in old intact stands.

Implications

- Logging as opposed to retaining beetle-killed trees will likely produce more and faster spring snowmelt for approximately 15 years unless: "the retained stand experiences extensive blowdown and lacks advanced regeneration, or the retained stand has an unusually small amount of structure and lacks advanced regeneration, or the retained stand burns."

Cross-Reference Citations

Collins, B. J., Rhoades, C. C., Battaglia, M. A., & Hubbard, R. M. (2012). **The effects of bark beetle outbreaks on forest development, fuel loads and potential fire behavior in salvage logged and untreated lodgepole pine forests**. Forest Ecology and Management, 284, 260–268. [see citation #16]

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III. Management Approaches and Implications

16. Collins, B. J., Rhoades, C. C., Battaglia, M. A., & Hubbard, R. M. (2012). **The effects of bark beetle outbreaks on forest development, fuel loads and potential fire behavior in salvage logged and untreated lodgepole pine forests**. Forest Ecology and Management, 284, 260–268.

Overview

This study characterizes forest structure, composition, advance tree regeneration, seedling recruitment, and surface fuel loadings for 24 pairs of salvage logged and untreated lodgepole pine forests 5 years after the onset of MPB infestation in northern Colorado. These measurements were used with the Forest Vegetation Simulator to predict changes in stand structure, fuel loads, and potential fire behavior over the next 110 years of forest development. This provides land managers with a first estimate of the wildfire-related outcomes associated with the harvesting of beetle-killed trees.

Key Findings

- Seedling density was significantly greater in logged stands compared to uncut stands. In particular, lodgepole and aspen seedlings/sprouts were 10 and 7 times more abundant respectively.
- Harvested stands contained a significantly higher mass of fine fuels and sound, coarse fuels than untreated stands, while the mass of rotten, coarse fuels and litter/duff did not significantly differ between the two.
- Modeling predicts aspen density to be higher in cut stands and growth to increase in both cut and uncut stands, peaking after four decades. Harvesting is predicted to favor greater densities of lodgepole pine due to increased pine seedling germination in the exposed mineral soil and simultaneous decline of spruce and fir in the higher light environment. Conversely, untreated stands will have higher density and basal area of subalpine fir, which is predicted to cause a significant increase in canopy bulk density (CBD) compared to harvested stands after six decades.
- Recovery to pre-outbreak conditions is expected after 75 years for uncut and 90 years for cut stands.
- A 5.5-fold increase above pre-outbreak levels in coarse wood mass is expected as trees fall in beetle-killed stands.
- Harvested stands will experience increases in fine surface fuels initially, with decomposition predicted to occur within two decades.

Implications

- Crown fire is more likely in untreated forests due to the authors' projected increases in subalpine fir. This is due to the fact that subalpine fir retains lower branches and has a higher CBD than lodgepole pine, allowing easy transport of fire from the surface into crowns and between canopies. Predicted post-outbreak succession of tree species will determine alterations in wildfire behavior for at least a century in these lodgepole pine forests.
- Salvage logging will also have an impact on future wildfire behavior in these forests. Increased heat release and taller surface flame lengths may be produced in recently harvested areas due to the greater amount of fine surface fuels in combination with the exposed microclimate. Trees are at least 10 times more likely to survive following fire in untreated than in logged stands during the first decade after harvest. However, this trend alternates as the overstory develops, with post-fire tree survival becoming favored in harvested stands containing less subalpine fir and more lodgepole pine and aspen (which deter torching). Also, fewer coarse fuels on the surface within harvested stands will result in reduced soil heating during post-outbreak wildfire and serves to minimize the size and duration of wildfires through decreased smoldering and supply of firebrands. Since stand-scale harvesting will only be employed on a small portion of Colorado forests affected by bark beetles, landscape-level wildfire implications may be modest.

17. Fettig, C. J., Klepzig, K. D., Billings, R. F., Munson, A. S., Nebeker, T. E., Negrón, J. F., & Nowak, J. T. (2007). **The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States**. Forest Ecology and Management, 238(1), 24–53.

Overview

This paper draws extensively from scientific literature to review the tree and stand factors related to bark beetle infestations and examine the efficacy of vegetation management strategies for reducing the harmful effects of bark beetles on coniferous forests of the western and southern U.S.

Main Conclusions

- Trees experience reduced vigor and insect resistance as competition among trees increases, making forests more susceptible to bark beetles. Stand susceptibility must be altered through "reductions in tree competition, disruption of pheromone plumes thus negatively affecting host-finding, and reductions in the fecundity, fitness and survivorship of target bark beetle species."
- Landscape-level efforts to prevent beetle-caused tree mortality should consider the distribution of stand ages and cover types and include treatments to increase heterogeneity.
- Management to reduce forest susceptibility to bark beetles must account for factors associated with tree density. The effectiveness of thinning to prevent beetle infestation is supported by the scientific literature.
- Thinning residues may attract particular bark beetles. This response may be minimized with the help of published guidelines.
- Prescribed fire can be a useful management technique, but must be carefully planned and executed to reduce, not increase stand susceptibility to beetle attack. Increased susceptibility may result from stresses associated with the sub-lethal heating of vital plant tissues.
- Expansion of the southern pine beetle may be reduced through direct control measures as a result of its unique behaviors and life cycle.

18. Gillette, N. E., Hansen, E. M., Mehmel, C. J., Mori, S. R., Webster, J. N., Erbilgin, N., & Wood, D. L. (2012). **Area‐wide application of verbenone‐releasing flakes reduces mortality of whitebark pine *Pinus albicaulis* caused by the mountain pine beetle *Dendroctonus ponderosae***. Agricultural and Forest Entomology, 14(4), 367–375.

Overview

This study tests the efficacy of anti-aggregation pheromones for protecting the endangered whitebark pine from MPB attack. Verbenone-releasing flakes ('Disrupt' Microflake Verbenone; Hercon Environmental, Inc., Emigsville, Pennsylvania) were applied to beetle-infested forest plots via simulated aerial application in Wyoming (i.e., with broadcast spreaders) and helicopter application in Washington without stickers or liquids.

Beetle flight was monitored near each plot with the use of intercept traps baited with MPB aggregation pheromone. End of the season measurements were made of stand structure and composition, and rate of beetle attack for the current and preceding years.

Key Findings

- Verbenone applications in both Wyoming and Washington effectively reduced the number of beetles trapped following treatment (by more than 50% compared to control plots) during the period of peak beetle flight.
- Applications at both sites also significantly reduced beetle attack and pine mortality by over 50% compared with untreated stands.

Implications

- Findings that ground and aircraft applications of verbenone-releasing flakes can effectively control MPB in whitebark pine forests suggest their utility for protecting stands in remote or steep environments.
- Application of the flake formulation could occur post-beetle eruption or pre-eruption when stands are likely susceptible due to stress associated with drought, harvesting, disease, or fire. Ground applications using fertilizer spreaders and/or paint-ball applicators may be particularly suitable for areas of development or seed collection sites.
- This demonstrated pheromone-based approach offers promise for large area treatments of bark beetle infestations and is highly recommended as part of a larger integrated pest management strategy.

19. Hansen, E. M., Negron, J. F., Munson, A. S., & Anhold, J. A. (2010). **A retrospective assessment of partial cutting to reduce spruce beetle-caused mortality in the southern Rocky Mountains**. Western Journal of Applied Forestry, 25(2), 81–87.

Overview

This study evaluates partial cutting as a strategy to prevent stand-level spruce beetle-induced spruce mortality by retroactively examining National Forest stands in Arizona, Utah, Wyoming, and Colorado that have been treated for management reasons prior to beetle activity. Beetle-caused mortality and post-outbreak stand characteristics are compared between partially cut and nearby untreated spruce stands.

Key Findings

- Partially cut stands experienced both fewer and smaller proportions of beetle-killed stems and basal area (BA) than untreated stands.
- As untreated stands started with more stems, they contained more live residual stems and BA than treated stands, of which most were 3–11 inches diameter at breast height (dbh).
- Spruce regeneration did not significantly vary between treated and untreated stands.
- Spruce stand density index, BA, and number of stems more than 11 inches dbh were the stand attributes best correlated with beetle-caused mortality.
- Some treated stands (in districts with the highest levels of mortality) had similar mortality levels to nearby untreated stands.

Implications

- Extensive mortality may result despite prior thinning when population levels are considerably high. Therefore, partial cutting seems to provide the most protection at low to moderate levels of beetle infestation.
- Management treatments that reduce spruce stand density index or BA should offer some protection to residual spruce trees depending on the level of beetle population pressure.

20. Hayes, J. L., & Lundquist, J. E., compilers. (2009). **The Western Bark Beetle Research Group: a unique collaboration with Forest Health Protection—proceedings of a symposium at the 2007 Society of American Foresters conference**. Gen. Tech. Rep. PNW-GTR-784. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 134 p. Online at http://www.fs.fed.us/pnw/pubs/pnw_gtr784.pdf.

Overview

These proceedings are a compilation of papers based on a symposium at the 2007 Society of American Foresters convention in Portland, Oregon. The collection of topics parallels the goals of the Western Bark Beetle Research Group, which aim to describe the emerging research topics and critical management issues associated with bark beetles. Specific paper topics include a description of bark beetle responses to vegetation management and climate change, the interactions between bark beetles and fire, the ecological and socioeconomic impacts of bark beetles, the use of behavioral chemicals for tree protection, and a case study demonstrating a risk assessment for nonnative invasive bark beetles.

Specifically pertinent to this section of the bibliography are the McMillin and Fettig paper "Bark Beetle Responses to Vegetation Management Treatments" and the Gillette and Munson paper "Semiochemical Sabotage: Behavioral Chemicals for Protection of Western Conifers From Bark Beetles."

21. Safranyik, L., & Wilson, B., editors. (2006). **The mountain pine beetle: A synthesis of biology, management, and impacts on lodgepole pine**. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. 304 p. Online at http://www.for.gov.bc.ca/hfd/library/documents/bib96122.pdf.

Overview

Intended as a resource for both researchers and forest managers, this book is a comprehensive synthesis of available MPB information emphasizing lodgepole pine forests of western Canada. It is broken into three parts: MPB biology, management, and socioeconomic impacts. The second part, comprised of chapters 4–8 (p. 117–230), focuses on management. Chapter 4 provides a basic description of the principles and concepts involved in the management of MPB and its host. Chapter 5 reviews the available tools and approaches for the detection, mapping, and monitoring of MPB and provides survey recommendations based on an information hierarchy. Chapter 6 reviews the current

techniques used to control MPB populations and presents a population-based framework for effective control. Chapter 7 describes the basic principles of preventive management of future outbreaks based on an understanding of the MPB–host relationship. Chapter 8 reviews MPB susceptibility and risk rating systems and provides a brief overview of different approaches to simulation modeling, particularly with respect to decision support tools developed for and used in western Canada.

Key Findings of Part 2

- It is necessary for managers to obtain information regarding host characteristics and distribution as well as inventories of MPB infestation in order to determine susceptibility.
- A reduction of susceptibility and maintenance of low beetle populations requires a long-term strategy of stand-level management, including yearly detection and assessment surveys and successful and timely treatment of local infestations.
- Preventative management at the endemic stage can protect against large future losses by preventing infestations from reaching epidemic levels.
- Selection of the appropriate option for detecting and mapping MPB impacts must consider their inherent limitations as well as the information needs of forest managers. Higher-order needs may require an information hierarchy containing nested sets of survey data collected with increasing levels of detail.
- For successful direct control of MPB populations, detection of growing infestations must be made as early as possible, prompt and comprehensive control tactics must be employed, and control measures must continue until the desired population level is attained.
- Preventive management strategies to reduce future susceptibility of replacement stands include conversion to tree species other than pine, density management of pine stands with shorter rotations to control growth, and concentration on stand hygiene.
- Reliable data on the location, size, and host resource of the MPB is essential to decision support systems which can be used to better assign stand or beetle treatment priorities as well as forecast future conditions under various management settings.

22. Samman, S., Logan, J., tech. eds. (2000). **Assessment and response to bark beetle outbreaks in the Rocky Mountain area**. Report to Congress from Forest Health Protection, Washington Office, Forest Service, U.S. Department of Agriculture. Gen. Tech. Rep. RMRS-GTR-62. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT. 46 p. Online at http://www.fs.fed.us/foresthealth/publications/rmrs_gtr62.pdf.

Overview

This report by the U.S. Forest Service is the response to a "Congressional direction in the FY2000 Interior and Related Agencies Appropriations Act asking for the causes, effects, and management options for native bark beetle outbreaks in the Rocky Mountain area." Specifically, it describes the factors affecting bark beetle outbreaks and their role in Rocky Mountain conifer forests, options and future directions for bark beetle prevention and suppression strategies, the response to and outcomes of previous outbreaks, and the concerns and recommendations associated with future responses. This report concentrates on the three

native species responsible for the majority of the beetle-caused mortality in Rocky Mountain forests: mountain pine beetle, spruce beetle, and Douglas-fir beetle.

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Embrey, S., Remais, J. V., & Hess, J. (2012). **Climate change and ecosystem disruption: the health impacts of the North American Rocky Mountain pine beetle infestation**. American Journal of Public Health, 102(5), 818–827. [see citation #25]

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Additional Management Resources

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IV. Social and Economic Impacts and Considerations

23. Buhyoff, G. J., Wellman, J. D., & Daniel, T. C. (1982). **Predicting scenic quality for mountain pine beetle and western spruce budworm damaged forest vistas**. Forest Science, 28(4), 827–838.

Overview

This paper presents predictive models of public opinion regarding the scenic beauty of forest vistas in order to better understand the aesthetic impacts of tree pests. The scenic beauty of Colorado Front Range forest vistas, some of which had experienced MPB or western spruce budworm damage, was evaluated using the Scenic Beauty Estimation Method. Landscape areas classified by topography, vegetation, and relative viewing distance were measured on vista photographs and used as predictors for scenic beauty in multiple regression models. Two models were produced: one for observers informed of the presence of insect damage a priori and another for uninformed (naive) observers.

Key Findings

- Informed observers had a more negative evaluation concerning the red top stage of insect damage and overall scenic beauty in damaged stands compared to uninformed observers. A negative visual impact on naive observers is alleviated by the presence of long viewing distances, dense forests, and mountainous topography.
- Overall, insect damage has a negative aesthetic impact, particularly on sparsely forested vistas with little topographic heterogeneity and a limited view of more distant features.

Implications

- The model for naive observers likely represents tourists and nonresidents, whereas the model for informed observers is better represented by residents on the Front Range and/or other forest visitors aware of the damaging effects of the MPB.
- It is possible that campaigns to increase public knowledge concerning forest pests may diminish perceptions of scenic beauty rather than alleviate them. It is not clear whether these effects on public perception justify the cost of forest treatments to minimize aesthetic impacts.

24. Czaja, M., Cottrell, S., Bright, A., & Clement, J. (2012). **Public perceptions of the mountain pine beetle in three study areas in northern Colorado and southern Wyoming**. Colorado State University, Fort Collins, CO. 126 p. Online at http://frontrangeroundtable.org/uploads/MPB_Tech_Report_11_Dec.pdf.

Overview

This report describes an assessment of public perceptions of MPB's impact on wildland fire management, recreation, and forest resource use (via mailed questionnaires) conducted by Colorado State University researchers in three study areas within northern Colorado and southern Wyoming, with the aim of facilitating improved management and communication strategies.

Key Findings

- Most respondents were male (63%) and currently employed (69%). Respondents represented a range of age, education, and income levels and most often identified their associated stakeholder group as non-commodity resource user (e.g., recreationalist, angler, and hunter).
- Results suggest respondents actively visit their local national forest, view prescribed burning positively, and view the forests as being important (and not valued solely for their provision of products, jobs, income, or recreation).
- Respondents understand fire's natural role on the landscape and support forest management to reduce the effects of wildfire.
- Respondents accept risk for recreating in beetle-killed forests and accept individual responsibility for protecting homes from wildfire, yet don't agree with home building restrictions near national forests.
- 92% of respondents believe that land managers should use beetle-killed trees for wood products and biomass.
- Most (82%) respondents believe that managers know how to successfully conduct prescribed burns and react to natural wildfires (87%). Only 59% of respondents believe that forest managers are doing everything possible in response to the MPB, with significant variation between the study areas.
- The main information source for all study areas is the media. The second most cited source was neighbors, friends, and family members, followed by the Forest Service.
- The highest-rated forest value was life sustainment ("the production, preservation, cleaning, and renewal of air, soil, and water").

Implications

- Identifying perceptions can help managers discern whether or not policies are in agreement with the public and help formulate communication approaches specifically aimed to convey controversial policies.
- These results support the advancement of science-based management options in line with the *US Forest Service's Western Bark Beetle Strategy: Human Safety, Recovery, and Resiliency* (see "Additional Management Resources" section for citation).

25. Embrey, S., Remais, J. V., & Hess, J. (2012). **Climate change and ecosystem disruption: the health impacts of the North American Rocky Mountain pine beetle infestation**. American Journal of Public Health, 102(5), 818–827.

Overview

This paper reviews the ecosystem service disruptions and potential associated human health impacts of the current pine beetle (*Dendroctonus* genus) epidemic within the North American West. The ways in which pine beetles may disturb the regulating, supporting, provisioning, and cultural services provided by coniferous forests are described in the context of public health concerns, and possible methods of preventing contact between humans and these "adverse exposures" are identified.

Key Findings

- Pine beetle infestations alter the capacity of forests to regulate water quality and quantity, potentially increasing human water stress, erosion, and stream sedimentation and turbidity. Human gastrointestinal disorders may increase with turbidity.
- Forests infested with pine beetles may fail to act as carbon sinks and actually reverse to carbon sources as carbon dioxide is released with tree decomposition. This reduction in carbon sequestration coupled with increased greenhouse gas emissions creates a positive feedback to global climate change, amplifying threats to public health such as heat-related death and disease.
- Human health effects may also be mediated through the potential economic losses associated with pine beetle infestations (i.e., from reductions in employment, lumber production, tax revenue, property values, and tourism income).
- Pine beetle infestations may have the potential to increase the risk of forest fire and its associated health impacts, such as threat of physical injury, property loss or displacement, degraded water resources, smoke inhalation, and respiratory and other illnesses.
- The annual value of North American forest ecosystem services is estimated at around $300 billion.
- The psychosocial health of human populations may be impacted by the effect of pine beetle infestations on areas of aesthetic value, by increased anxiety over the perceived greater risk of forest fire, and by the beetles' mere presence in a national park.
- Three orders of pine beetle infestation prevention are identified:
    - Primary – Prevent infestations into new areas by creating barriers with either selective logging or pesticides. Use for targeted, individual communities with the help of early warning systems.
    - Secondary – Strategies used after ecosystem disturbance but before human health has been impacted. Activities intended to maintain ecosystem services and prevent forest fires and degradation of water quality. The infestation should be contained by aiming to prevent further spread and establishment.
    - Tertiary – Interventions include treatment of symptoms caused by adverse exposures such as fire.

Implications

- Humans living both within and beyond the areas of pine beetle infestation face many risks and losses related to degraded ecosystem services, much of which may affect human health. The current pine beetle epidemic illustrates the need for public health to adopt a more interdisciplinary, system-based view for analyzing the effects of climate change dynamics on human health.

26. Flint, C. G. (2006). Community **perspectives on spruce beetle impacts on the Kenai Peninsula, Alaska**. Forest Ecology and Management, 227(3), 207–218.

Overview

This paper evaluates community perspectives regarding the biophysical and socioeconomic impacts of the recent spruce beetle outbreak on the Kenai Peninsula in south-

central Alaska. Interviews and mail surveys were administered to residents in six study communities that varied across a spatial and temporal range of spruce beetle activity.

An understanding of community attitudes and actions in response to the spruce beetle disturbance can help forest managers "(1) identify issues of high concern by local citizens that require management actions; (2) recognize potentially contentious issues that will require special efforts in order to reduce conflicts with community members; (3) facilitate the timely coordination of forest management with like-minded communities and property owners."

Key Findings

- Residents clearly saw and experienced the biophysical, economic, and social effects from the spruce beetle outbreak, such as increased susceptibility to fire and wind, degradation of watersheds and wildlife habitat, economic fluctuations, and emotional loss. Many residents indicated that as time passed and they became accustomed to the beetle-caused changes, their feelings of distress toward the beetle outbreaks diminished.
- The impacts from forest management (e.g., salvage logging and road building) were often perceived greater than the impacts from spruce beetles themselves.
- Combined survey responses indicated that the four most frequently perceived impacts were falling trees (92%), logging (92%), increased firewood availability (92%), and increased fire hazard (88%).
- Perception of fire risk was potentially the largest focal point of discussion, although the perceived likelihood and magnitude varied greatly across the communities.
- On average, falling trees and fire hazard were viewed as negative impacts, as were aesthetic loss, loss of privacy, and alteration of fish and wildlife habitat. Perception of logging was neutral in general.
- The availability of firewood was perceived as a positive impact, along with expanded timber industry, emergent view, increased ecological awareness, and job creation.
- Resident perception of impacts was greater than had been cited in the spruce beetle literature and considerable variation in the extent and level of perceived impacts and risks exists among communities, particularly in regards to their difference in outbreak stage.

Implications

- Public approval and effectiveness of forest management is likely enhanced through the coordination of treatment strategies with community concerns. Evaluating public opinion concerning management strategies prior to implementation may help recognize certain communities in support of or against the management measures. This information can be utilized during management planning to identify concerns and locations in need of additional time and resources to garner public support or those locations where management objectives can be attained rather quickly due to support already present in the community.
- The public-perceived impacts and risks associated with forest disturbances may at times conflict with those identified in scientific studies. A sound understanding of their relationship may allow managers to more effectively mitigate problems and meet management goals.

27. Flint, C. G., & Haynes, R. (2006). **Managing forest disturbances and community responses: lessons from the Kenai Peninsula, Alaska**. Journal of Forestry, 104(5), 269–275.

Overview

This paper discusses the community response dynamics of the recent spruce beetle outbreak on the Kenai Peninsula in Alaska and suggests management strategies related to community risk perception and action regarding forest disturbances. (See Flint 2006, citation #28, for a discussion of the interview and survey results used by this paper.)

Key Findings

- Communities characterized by overall active participation of its residents had a greater likelihood of collective involvement in tackling the impacts and risks associated with forest disturbance.
- While local residents were generally highly concerned with urgent risks such as fire, threats to broader environmental and community values are what drove them to participate in community actions. However, at the community level, this relationship did not always hold, emphasizing the importance of recognizing community differences in response to disturbance.

Implications

- Three strategies are suggested for forest managers faced with a range of community responses to disturbance across the landscape:
  - Listen to the community's risk perceptions and include them in risk assessments in order to develop sound management strategies. Risk perceptions can inspire local action to assist or deter management strategies.
  - Identify capacity for community action and build local relationships, particularly where the capacity for collective action is found deficient.
  - Accept controversy among the community to encourage communication of key issues and local involvement in decision making.
- To make certain that opinions are not being marginalized, it is critical to identify the level of consensus behind community actions. Expensive problems in the future can be avoided by collaborating with communities early on in the management and mitigation process.

28. Flint, C. G., McFarlane, B., & Müller, M. (2009). **Human dimensions of forest disturbance by insects: an international synthesis**. Environmental Management, 43(6), 1174–1186.

Overview

This paper synthesizes information concerning the human dimensions of bark beetle disturbance by analyzing cases studies from forests in north central Colorado, Kenai Peninsula in Alaska, British Columbia in Canada, and Bavarian Forest National Park in Germany. Important lessons learned along with their management implications are highlighted.

Key Findings

- Depending on one's perspective, forest disturbance can have both positive and negative economic consequences. For example, those involved in timber harvest operations may benefit while those dealing with increased fire hazard may incur considerable costs.
- Human response to the aesthetic deterioration of beetle-killed landscapes can be an emotional grieving process characterized by stages of "denial, shock, anger, sadness, resignation, and moving on." For others, the forest renewal characteristics of disturbance may generate a more positive emotional response. Different communities are expected to react and respond differently to forest disturbances.
- Studies from western Canada and Colorado demonstrate that even distant communities or those not directly impacted economically may also be affected by uncertainties associated with beetle infestation, influencing their level of trust in management agencies.
- The case of Bavarian Forest National Park points to the importance of considering the political effects of forest disturbance, such as the restructuring of social life and community identities.
- Attitudes of visitors to beetle-killed recreational areas may vary greatly from those of local residents. Visitors that are well-informed about the function of bark beetles in ecosystems may be willing to accept the visual degradation of landscapes if coupled with the protection of ecosystem integrity.

Implications

- The economic requirements of communities affected by beetle infestations may not be fulfilled by a one-size-fits-all approach.
- Open communication among managers and stakeholders and opportunities for community participation in critical management decisions are likely to help reduce opposition to these decisions.
- It is crucial to assess community capacities and weaknesses early on and provide complete and candid information to residents and tourists. Downplaying consequences is likely to backfire.
- Committees and roundtable discussions can facilitate establishment of formal routines that allow for community participation. Acknowledgement and integration of local opinion is apt to help avert frustrating conflicts.
- Since community residents may not always consider land managers to be unbiased and trustworthy, creation of an independent program, center, or taskforce may assist disturbance management and communication among management agencies and resident stakeholders.
- Expensive conflicts and long-lasting detrimental impacts can be avoided by including community interests, values, and concerns in management plans.

29. Flint, C., Qin, H., & Ganning, J. P. (2012). **Linking local perceptions to the biophysical and amenity contexts of forest disturbance in Colorado**. Environmental Management, 49(3), 553–569.

Overview

This paper investigates the relationships between biophysical, socioeconomic, and perceptual aspects of MPB forest disturbance in north-central Colorado. A mail survey was administered to households in nine study communities that vary in their natural resource–based amenities and socioeconomic consequences in order to gather information on community attitudes and risk and impact perceptions in response to beetle-induced forest changes. Amenity indices were developed through quantitative measurements of forest land cover, water, and recreation sites within a certain distance of each community along with their related socioeconomic characteristics. These were combined with survey findings and indicators of tree mortality to evaluate landscape patterns and degree of correlation between individual perceptions and structural conditions at the community level.

Key Findings

- Results suggest a high negative correlation between community amenity index and tree mortality rankings.
- Communities with lower measured tree mortalities tended to underestimate the level of MPB damage, while those with higher measured tree mortalities tended to overestimate the level of damage.
- Concerns over forest-related risks varied considerably across the study communities. Survey respondents from higher tree mortality–lower amenity communities were more concerned about "the two immediate threats to human safety and property (forest fire and falling trees) and the direct threats to forest-based economic interests (impact on livestock grazing, lost of forests as an economic resource, and impact on property values)."
- Both the amenity index and tree mortality had a significantly positive relationship to risk perception, although the effect was greater for tree mortality. This means that the higher tree mortality–lower amenity community group tended to have a larger degree of risk perception than the lower tree mortality–higher amenity community.
- Respondents from higher tree mortality–lower amenity communities demonstrated greater enthusiasm for human use of forest resources (especially supporting the logging and timber processing industries) and less trust in present forest management than those from the lower tree mortality–higher amenity communities.
- The higher tree mortality–lower amenity communities were more satisfied with local land mangers (i.e., private logging companies) and less satisfied with government land managers (i.e., the U.S. Forest Service and city government).

Implications

- Recognizing both forest composition and community characteristics is important for forest management. The identification of meaningful community groups based on tree mortality indicators, amenity index, and/or other data can be the first step in facilitating linkages between variable human and natural influences on management. Communities located closer to areas with higher levels of tree mortality should not be assumed to encompass greater risk perceptions, sensitivities, and aggressive management demands.

Therefore, consistent communication between communities and forest managers about MPB impacts as they change over time is necessary for organizing appropriate treatments.

- This study's results provide support for the connections between local perceptions and the biophysical–amenity context. This suggests that incorporating human dimensions of forest disturbances can help to explain and interpret heterogeneity assessments across MPB-affected areas beyond that of what solely biophysical indicators may provide.
- Spending time aligning mitigation approaches with community contexts may provide for a mixture of management strategies that best fit the heterogeneity of perspectives present, help ease conflicts, and prompt community support and participation in mitigating risks.

30. McFarlane, B. L., Parkins, J. R., & Watson, D. O. (2012). **Risk, knowledge, and trust in managing forest insect disturbance**. Canadian Journal of Forest Research, 42(4), 710–719.

Overview

This study surveyed residents and land managers from three regions of Alberta, Canada, in order to examine local variation in public risk perceptions, compare public and management perceptions, and investigate how knowledge and trust may shape public perceptions of a MPB outbreak.

Key Findings

- Overall, respondents in all regions had moderate to great concern for most ecosystem and social risks (exceptions being falling trees and loss of forest-connected community identity respectively). In particular, diminished scenic quality was a high concern, followed by loss of the forest as an economic resource and altered wildlife habitat.
- The greatest concerns for land managers were the loss of forest as an economic resource and increased fire risk. Managers showed considerably less concern about wildlife habitat, falling trees, and loss of scenic quality than public respondents.
- Public respondents were rather uninformed regarding basic MPB facts.
- In general, public respondents demonstrated little trust in the provincial government's ability to execute an effective and responsible MPB management plan. Land managers displayed significantly more trust in the provincial government than the public.
- Public trust in the provincial government is positively correlated with five of the eight risk statements. Public trust in the forest industry is positively correlated with six of the risk statements. Public knowledge of MPB is negatively correlated with seven of the risk statements. Thus, in general the higher the perceived risks from MPB the lower the public knowledge and greater the public trust in the government and industry to implement and adjust effective management practices.
- There was some regional variation in perceived risks, knowledge, and trust.
- A positive correlation between trust and risk perceptions appears to contradict the risk literature. This relationship may be influenced by an intervening effect of knowledge.

Implications

- Understanding the public's response and views as the MPB outbreak extends to uninfested areas will be critical for adapting management and communication to local issues.
- The land managers' focus on economic impacts and fire risk will certainly impact management approaches and public messaging. The public might share these concerns, but also have additional concerns that may go unattended to and become a source of discontent regarding response to MPB.
- The positive correlation between public trust and perceptions of risk seems to contradict the risk literature, which the authors attribute to experts' and land managers' risk judgments and their role as risk promoters warning the public of the ecological and economic impacts associated with the MPB through local media sources. Results suggest this relationship may be influenced by the effect of increased knowledge and associated decrease in concern over risks, thereby inducing less support for control efforts.
- This necessitates more consideration of the content of risk messaging and the effects of public trust and knowledge.

31. McFarlane, B. L., Stumpf-Allen, R. C. G., & Watson, D. O. (2006). **Public perceptions of natural disturbance in Canada's national parks: The case of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins)**. Biological Conservation, 130(3), 340–348.

Overview

This study examines public perceptions of MPB and its management among residents living in or near Banff and Kootenay national parks in western Canada. Mail surveys collected information on resident use of the parks, knowledge and salience of MPB, environmental worldview, views on threats to the parks, attitudes toward and control preferences for MPB, information needs, and demographic characteristics.

Key Findings

- Overall, respondents demonstrated a proecological worldview. The MPB issue in national parks was indicated as personally important to all groups, significantly more so for residents living near the parks. However, residents were not very knowledgeable about the beetle.
- Generally, respondents had a negative attitude of the MPB, and became more negative as the issue importance increased. Greater knowledge, lower issue salience, high proecological worldview, and high education level were related with more positive attitudes. Older residents, those with a proecological worldview, and those with more positive attitudes were less supportive of beetle control strategies. Higher personal importance was associated with more support for intervention.
- All groups were in consensus that "allowing the outbreak to follow its course without intervention" was unacceptable. Preferred control measures were "sanitation cutting to remove infested trees from small areas," and "the use of pheromones to attract beetles to one area." Chemical control and proactive treatments in uninfested areas were generally not supported.

Implications

- Survey results suggest lack of knowledge may have a negative impact on attitudes, such that MPB is seen as a disaster and risk to biodiversity in the parks. However, attitudes become increasingly positive as information is acquired, leading to less support for management interventions. This implies that educational programs intended to increase public understanding of ecological responses to MPB may result in less support for control policies in some national parks.
- Communication strategies should include natural ecosystem health, variability, and disturbance information in addition to just MPB facts. Residents should be provided with key MPB information, directed to particular community concerns, which will allow for informed public response to park policy.

32. McFarlane, B. L., & Witson, D. O. (2008). **Perceptions of ecological risk associated with mountain pine beetle (*Dendroctonus ponderosae*) infestations in Banff and Kootenay National Parks of Canada**. Risk Analysis, 28(1), 203–212.

Overview

This study examines the ecological risk perception, their factors, and influence on control strategies associated with MPB disturbance in Banff and Kootenay National Parks in western Canada. Two studies of park visitors that utilized a mail survey and an onsite survey were used to collect the data. The relative ecological risk perception of natural disturbance is compared to that of anthropogenic risks and the social aspects of MPB risk are explored using elements from the perception of ecological risk literature.

Key Findings

- MPB outbreaks were rated in mail surveys as posing a greater risk than anthropogenic hazards as well as other natural disturbances such as spruce budworm and natural forest fires.
- Increased age, self-rated level of knowledge, and being female were associated with higher risk in general.
- Higher risk and being male were associated with greater support for intervening in MPB outbreaks.
- Onsite surveys indicate park visitors with some knowledge of MPB rated the ecological and visitor impacts as negative, eliciting negative emotion, and unacceptable. Overall, rates were higher for risk to ecosystems than the visitor experience.
- Local area visitors perceived ecosystem and the visitor experience impacts more negatively, and were less accepting of these impacts than visitors from other provinces or countries.
- Greater knowledge of MPB was related to positive emotion and assessment and acceptability of impacts. However, local residency of visitors influenced assessments negatively.
- Older visitors rated the impacts less acceptable. Women rated visitor experience impacts more positively than men. Knowledge had the most effect on acceptability and residency the most effect on emotion.

- The greater support for controlling MPB in national parks was associated with more negative emotion and perceived ecological impacts.

Implications

- Findings from the second study suggest that increased ecological knowledge decreases both the cognitive (i.e., perceived impacts and acceptance) and emotional risk judgments, possibly the result of an awareness among informed visitors concerning the functional role of MPB. Therefore, a successful strategy to influence risk perceptions may be to design public communication efforts that incorporate the ecological characteristics and functions of MPB in protected areas such as national parks.
- The fact that visitors' support for control interventions is based on ecosystem impacts, rather than their own experience, suggests that strategies to restore ecosystem health and communicate important ecosystem concerns will be well received by park visitors.

33. Parkins, J. R., & MacKendrick, N. A. (2007). **Assessing community vulnerability: a study of the mountain pine beetle outbreak in British Columbia, Canada**. Global Environmental Change, 17(3), 460–471.

Overview

This paper presents a community-level assessment of vulnerability to climate change for communities experiencing a severe MPB outbreak in British Columbia, Canada. The assessment framework was developed using a participatory and multidisciplinary process, drawing widely from the climate and sociology literature and incorporating public perspectives through focus groups. The framework also integrates information connecting community risk assessment with biophysical exposure to risk. A discussion of how this type of assessment can help link vulnerability research to specific policy recommendations and measures is included.

Key Findings

- On average, the MPB outbreak is perceived to have a significant but only slightly negative impact.
- All communities had moderate levels of political capacity (i.e., high risk awareness and moderate satisfaction with efforts to manage beetle impacts) but low levels of trust in political institutions.
- Vulnerability represents a high level of economic risk for some communities, while for others physical risk is aggravated by political and economic factors.
- There is a wide disparity between risk perceptions and biophysical assessments for communities anticipating future beetle outbreaks.

Implications

- Community-based vulnerability assessments offer important information regarding exposure levels and the strength of adaptive strategies.
- The authors argue that increased community risk perception may provide an incentive to create adaptation strategies, thereby reducing vulnerability.

34. Patriquin, M. N., Wellstead, A. M., & White, W. A. (2007). **Beetles, trees, and people: regional economic impact sensitivity and policy considerations related to the mountain pine beetle infestation in British Columbia, Canada**. Forest Policy and Economics, 9(8), 938–946.

Overview

In an effort to understand the policy implications associated with the MPB outbreak in British Columbia, Canada, this study investigates the economic impact sensitivity in five regions experiencing various levels of beetle-induced mortality. It first provides a baseline snapshot of the regional forest-dependent economies using data collected from primary and secondary sources, then presents results of a sensitivity analysis employed for each region using a computable general equilibrium model. The sensitivity analysis simulates the percentage change in each of a set of economic indicators given a 1.0% change in forestry sector exports in response to MPB-related timber supply fluctuations. This economic impact model is argued to be an important tool that can aid in the development of region-specific forest policy.

Key Findings

- Increases in available timber will cause a short-term boom to the forestry sector, which will cycle through the regional economy to benefit the service and retail sectors. In the long term, timber supplies are expected to fall below the baseline level, causing negative impacts unless regional economies are able to transition to new forms of employment and industry.
- Results display regional variation in the sensitivity to forestry export shocks.

Implications

- The regional economic impact sensitivity estimates the level of vulnerability to MPB disturbance and may assist in formulating a policy response tailored to a specific region.

35. Price, J. I., McCollum, D. W., & Berrens, R. P. (2010). **Insect infestation and residential property values: A hedonic analysis of the mountain pine beetle epidemic**. Forest Policy and Economics, 12(6), 415–422.

Overview

Bark beetle infestations reduce utility (level of satisfaction gained from goods and services) for residents in the wildland-urban interface (WUI) by decreasing the value of forest services and increasing wildfire risk. This paper employs a hedonic property-pricing model to estimate willingness-to-pay (WTP) for MPB damage prevention in Grand County, Colorado. The hedonic model uses variation in housing characteristics (and hence, sale prices) to create a statistical relationship between characteristics and property prices. Using the number of beetle-killed trees within 0.1, 0.5, and 1.0 km of each property (determined with GIS), and controlling for the effects of structural and spatial characteristics, the marginal implicit price of MPB damage is calculated.

Key Findings

- Housing prices are negatively correlated with the number of beetle-killed trees and the greater proximity of an injured tree to a house the greater its effect on price and utility.
- Estimates of the marginal implicit prices of trees killed within 0.1, 0.5, and 1.0 km of a home are $648, $43, and $17 respectively, which can be taken as the homeowners' maximum WTP to avert loss of utility from MPB mortality.

Implications

- This study suggests that at least some funding for programs that maintain forest health and help to ameliorate MPB concerns is available from WUI residents, perhaps through cost-share programs or taxation.

36. Qin, H., & Flint, C. G. (2010). **Capturing community context of human response to forest disturbance by insects: a multi-method assessment**. Human Ecology, 38(4), 567–579.

Overview

This study investigates the community context of human response to MPB forest disturbance using surveys and secondary socioeconomic and biophysical data collected from nine communities in north-central Colorado. The influence of community context on resident actions in response to MPB was explored using multiple analytic techniques including creating contextual variables, ordinary least squares (OLS) regression, and multilevel modeling (MLM).

Key Findings

- When accounting for differences in individual-level predictors, both the biophysical vulnerability indicator and the community amenity index significantly contributed to explaining beetle-related activeness in the full OLS regression model. In the MLM, participation in beetle-related actions was reduced by the effects of both contextual variables. The biophysical indicator was insignificant and the amenity index marginally significant in its impact on beetle-related action in the MLM. In both the OLS and MLM, community amenity index had a greater influence on beetle-related action compared to the biophysical factor.
- The strong correlations between individual-level predictors and community contextual variables demonstrate the importance community context may have in motivating or hindering participation in beetle-related actions.
- Some relationships between several significant variables and beetle-related action were distinctly opposite (i.e., had reverse relationships) for different communities, providing additional support for the community context's ability to impact relationships between individual-level factors and involvement in beetle-related actions.
- Participation in beetle-related actions was directly and significantly affected by community biophysical and socioeconomic characteristics. Results indicate that community context matters in the human dimensions of MPB forest disturbance and suggest the incorporation of diverse community contexts is vital for post-disturbance resource management since the effectiveness of particular actions may vary accordingly.

Implications

- The consideration of human–environment interactions within the context of local communities calls for increased incorporation of public involvement and perspectives in resource management plans, which will assist with implementation and enhance ecosystem restoration efforts and social welfare.

37. Rosenberger, R. S., Bell, L. A., Champ, P.A., & Smith, E. L. (2012). **Nonmarket economic values of forest insect pests: An updated literature review**. Gen. Tech. Rep. RMRS-GTR-275WWW. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 46 p. Online at http://www.fs.fed.us/rm/pubs/rmrs_gtr275.pdf.

Overview

This report synthesizes and assesses the published economic valuation literature on the impacts of forest insect pests on nonmarket ecosystem services (i.e., aesthetics, recreation, and property owner benefits). It presents a conceptual framework (using MPB as an example) to provide context for the valuation studies, describes the main elements of each study, discusses ecosystem services, synthesizes the literature, suggests areas of future research, and includes appendices and tables that provide extended summaries of each study. The estimates of nonmarket values reviewed here can be used in a benefit-cost analysis of management decisions regarding the allocation of resources to protect forest health.

Key Findings

- Overall the literature illustrates that people value quality of forests, among many other traits. Trees provide ecosystem services, enhance recreation experiences, and add to the market value of homes. Therefore, these attributes are negatively impacted by outbreaks of forest pests.

38. Safranyik, L., & Wilson, B., editors. (2006). **The mountain pine beetle: A synthesis of biology, management, and impacts on lodgepole pine**. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. 304 p. Online at http://www.for.gov.bc.ca/hfd/library/documents/bib96122.pdf.

Overview

Intended as a resource for both researchers and forest managers, this book is a comprehensive synthesis of available MPB information emphasizing lodgepole pine forests of western Canada. It is broken into three parts: MPB biology, management, and socioeconomic impacts. The third part, comprised of chapters 9–11 (p. 233–299), focuses on socioeconomics. Chapter 9 provides information regarding the properties of post-MPB wood, its use and marketing, current data gaps, and Safranyik research recommendations to bridge these gaps. Chapter 10 discusses the impact of the MPB's various attack stages on the pulp and papermaking industry and identifies crucial research needs. Chapter 11 reviews the

literature addressing the management of MPB-affected forests from two economic perspectives and identifies areas of opportunity and concern for British Columbia's MPB management strategy.

Key Findings of Part 3

- Timber stands affected by the current MPB outbreak represent a considerable economic resource, yet all phases of the production of solid wood products from these stands are faced with challenges. Many of these challenges are associated with the excessive drying of beetle-killed wood caused by the blue stain fungi, as well as the fungi's effect on the wood's appearance.
- Although wood-energy use can be economically feasible, industrial production of fuel pellets, electricity, and heat from beetle-killed wood is highly dependent on production costs. Future advancements in bioenergy capacity rely on resolving questions concerning transportation and salvage costs, viability of co-firing, deterioration rates of beetle-killed wood, and carbon credit benefits.
- The utilization of beetle-killed wood by the pulp and paper industries is hindered by the blue stain and large amount of extractives contained in green- and red-stage wood, and by the low moisture content of grey-stage wood. These detriments must be overcome through the fulfillment of numerous information gaps currently present.
- Forest economic theory can aid in disturbance management. Standard approaches to dealing with MPB problems have focused on maximizing harvest values of single forest sites threatened by bark beetle. An alternate perspective expands on this approach to include multiple uses and benefits of a larger forest system. This suggests achieving a reduction in risk by reducing impact rather than increasing product.

39. Travis, W., Dickinson, T., Durant, A., & Sharp, K. **Human dimensions of the mountain pine beetle outbreak in the greater Niwot Ridge LTER landscape: Specifying anthropogenic feedbacks and socio-economic impacts in a coupled human-natural system**. Draft report. University of Colorado, Boulder, CO. 49 p. Online at http://spot.colorado.edu/~wtravis/Beetle_Human_Dimensions_report.pdf.

Overview

This draft report summarizes exploratory research undertaken to elucidate the social response to forest change associated with the MPB outbreak underway in the central Rocky Mountains and to establish further analytical methods regarding the human dimensions of the evolving outbreak. The study area includes the Niwot Ridge LTER site near the Continental Divide in Colorado, and western and eastern slope zones in which the outbreak is all encompassing and still invading, respectively. Particularly interested in the physical responses that create feedbacks between natural and human systems, this study draws on the concepts of "coupled human and natural systems" (CHNS) within the framework of the Integrated Science for Society and the Environment (ISSE) model proposed in LTER.

A propositional inventory of perceived MPB effects was obtained from public meetings and media coverage and interpreted using risk perception theory. A list of human responses with potential feedback capability was created and the study area was characterized regarding

land ownership, forest cover, beetle impact, and management. The goal was to provide future analysis and prediction of forest treatment response with the use of GIS data. Agent based modeling and fuzzy set approaches were investigated for making such predictions. Also, economic data were collected for assessment of beetle impact.

Key Findings

- The east-side forest was found to be exceedingly more fragmented in land cover and ownership, which suggests treatments will follow the same fragmented pattern.
- Although revenue from tourism demonstrates some economic decline, little evidence points to MPB as a factor. Similarly, but with the exception of the small resort town of Grand Lake, there's no evidence to suggest the beetle has impacted real estate values. In fact, property values are rising in Grand County, which has been deemed the worst beetle-killed area in Colorado.

40. Waring, K. M., Reboletti, D. M., Mork, L. A., Huang, C. H., Hofstetter, R. W., Garcia, A. M., ... & Davis, T. S. (2009). **Modeling the impacts of two bark beetle species under a warming climate in the southwestern USA: ecological and economic consequences**. Environmental Management, 44(4), 824–835.

Overview

Predicted future warming is expected to have important temperature-mediated effects on bark beetles in the southwestern United States, significantly impacting forest resources and land management strategies. This study evaluates such effects for the southern and Mexican pine beetles (SPB and XPB, respectively) under three climate change scenarios using a degree-day development model to estimate changes in generations per year. The potential economic impacts (i.e., treatment costs and forgone timber revenues) of increased beetle outbreaks in ponderosa pine forests of Arizona and New Mexico are assessed by running simulations with and without basal area reduction treatments using the Forest Vegetation Simulator.

Key Findings

- Considerable increases in the number of generations per year attained by both beetles were predicted, ranging from 1–3+ under the historical average temperature, 2–4+ under the least warming scenario, and 3–5+ under the highest warming scenario.
- Basal area reduction treatments that decrease susceptibility of forests to beetle outbreak result in greater net present values than scenarios with no action taken. Under historical conditions (assumed two bark beetle outbreaks per century), the economic benefits of applying treatments were $95.69 and $7.75 per hectare for Arizona and New Mexico, respectively. Under simulated severe drought conditions (assumed ten bark beetle outbreaks per century), the economic benefits increased to $174.58 and $47.96 per hectare for Arizona and New Mexico, respectively.

Implications

- Since this study considered only timber values, estimates of foregone revenues from taking a no-action management approach are highly conservative. Also, even without

considering the ecological and social values associated with forest ecosystems, analyses show that treatment is monetarily more favorable than non-treatment.

- Forest treatments to reduce vulnerability to bark beetle attack will also help reduce severe wildfire risk and enhance drought resistance.

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APPENDICES

Appendix A: Website Resources

http://www.usu.edu/beetle/wbbrg_bark_beetle.htm – Website of the **Western Bark Beetle Research Group** (WBBRG), whose mission is to serve as an umbrella organization that fosters communication and enriches scientific interactions among Forest Service bark beetle researchers in the western U.S. Lists of all scientific publications and products are provided.

http://www.fs.fed.us/rmrs/events/future-forests/ – This website provides videos and transcripts from the **Future Forests Webinar Series** held from October 2011 through December 2012. It is a series of six webinars with presentations by prominent managers and scientists from the U.S. Forest Service discussing research findings and management implications for MPB affected forests.

http://www.fs.fed.us/rmrs/bark-beetle/ – **U.S. Forest Service Rocky Mountain Research Station** website for bark beetle information.

http://www.fs.usda.gov/barkbeetle – **U.S. Forest Service Rocky Mountain Bark Beetle** website.

http://www.fs.usda.gov/detail/r6/forest-grasslandhealth/insects-diseases/?cid=fsbdev2_027328 – **U.S. Forest Service Pacific Northwest Region** website for bark beetle information. Provides numerous links for information on various bark beetle species.

http://foresthealth.fs.usda.gov/portal – The **U.S. Forest Service, forest insect and disease reporting portal** can be used to access a multitude of state, county, and local-level forest insect and disease conditions data as well as forest disturbance maps.

http://digitalcommons.usu.edu/barkbeetles/ – The **Bark Beetles, Fuels, and Fire Bibliography** is a freely accessible, online bibliography of publications on bark beetle–fire interactions. Searches can be conducted through titles, by author name, or by descriptive words.

http://www.for.gov.bc.ca/hfd/library/lib_MPB.htm – Website providing **Mountain Pine Beetle Publications** available from the Ministry of Forests and Range Library, British Columbia.

http://www.for.gov.bc.ca/hfp/bark_beetles/index.htm – Website for information on **Bark Beetles in British Columbia**. Provides documents such as regulations and management guides.

http://beetles.mt.gov/ – Interagency website providing a wide variety of information on MPB in **Montana**.

http://www.barkbeetles.org/ – Website on **Bark and Wood Boring Beetles of the World**. Provides information and images of economically important bark and wood boring beetles (12,737 images of 911 species from 42 countries).

http://www.nwccog.org/index.php/programs/rural-resort-region/cbbc – **Website of the Colorado Bark Beetle Cooperative** (CBBC), whose mission is to address the environmental, social, and economic impacts of bark beetles on high-altitude forests through place-based collaboration.

http://coloradoforestrestoration.org/ – Website of the **Colorado Forest Restoration Institute** (CFRI), whose mission is to "serve as a responsive, reliable bridging organization among researchers, land managers, and communities dedicated to advancing knowledge and practice of forest restoration and wildfire hazard reduction in the central Rocky Mountain region." CFRI assists with collaborative monitoring and adaptive management, information synthesis and outreach, enhancing wood biomass utilization, and collaboration assistance and support.

Appendix B: Scientific and Common Names of Beetle and Tree Species

DFB – Douglas-fir beetle – *Dendroctonus pseudotsugae*

Douglas-fir – *Pseudotsuga menziesii*

Jack pine – *Pinus banksiana*

Lodgepole pine – *Pinus contorta* var. *latifolia*

MPB – mountain pine beetle – *Dendroctonus ponderosae*

Ponderosa pine - *Pinus ponderosa*

SPB – southern pine beetle – *Dendroctonus frontalis*

Spruce beetle – *Dendroctonus rufipennis*

Whitebark pine – *Pinus albicaulis*

XBP – Mexican pine beetle – *Dendroctonus mexicanus*

Appendix C: Acronyms and Abbreviations

BA – basal area

C – carbon

CO_2 – carbon dioxide

dbh – diameter at breast height

DOC – dissolved organic carbon

GIS – geographic information system

Mn – manganese

N – nitrogen

NO_3 – nitrate

P – phosphorus

USDA – United States Department of Agriculture

USGS – United States Geological Survey

TOPIC INDEX