Annotated Bibliography for Whitebark Pine Ecology
Additions December 2010
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1. **Notes:**
   - **a.** The precarious state of whitebark pine remains distressing and it is critical that we make decisions based on the a scientifically informed and accurate understanding of the life history of whitebark pine, historic disturbance regimes, current conditions, and stressors.
   - **b. Maximum retention of available seed on the landscape– for genetic diversity, natural selection that promotes rust resistance and natural regeneration continues to be a strong theme in all the new research findings.**
   - **c.** If I missed any key work or if you have additional interpretations from any given paper, please let me know.

2. **Kipfmueller, K. and Salzer, M. 2010. Linear trend and climate response of five-needle pines in the western United States related to treeline proximity. Can.J. For. Res. 40:134-142.**

Background & Objectives

This paper presents results from a study that examined growth chronologies from different five-needle pines to assess their use as predictors of past temperatures. The challenges include mixed precipitation-temperature signals, and autocorrelation of ring widths.

Main Findings

- Positive response to previous autumn, winter and spring precipitation.
- Positive response to summer and spring precipitation when temperatures are lower.
- Variation among sites is high; sites within 200m of local climatically determined treeline exhibit consistent results.
- Drought, insect outbreaks, localized disturbances are evident in ring widths.

Implications

- Whitebark pine growth is maximized on years with greater precipitation during fall, winter & spring.
- Significant negative trends in whitebark ring width at beginning of 20th century. Authors suggest grow reduction may be due to blister rust infection.

3. **Macfarlane, W., Logan, J., & Kern, W. 2010. Using the landscape assessment system (LAS) to assess mountain pine beetle-caused mortality of whitebark pine, Greater Yellowstone Ecosystem, 2009: Project Report. Prepared for the Greater Yellowstone Coordinating Committee, Whitebark Pine Subcommittee, Jackson, WY. 69 pages.**

Background & Objectives

Results of an aerial survey conducted during summer 2009 to assess MPB-caused mortality in whitebark pine in the GYE. This project documented mortality in the overstory and the visible understory on a sub-watershed level.

Main Findings

- 2,528 sub-watersheds were sampled by aerial photographs (73% of total area)
- 46% of areas containing whitebark showed high overstory MPB mortality
- 36% of areas containing whitebark showed moderate overstory MPB mortality
- 13% of areas containing whitebark showed low overstory MPB mortality
- 5% of areas containing whitebark showed no unusual MPB activity
- Mortality was distinctly related to geographic location
- Study includes rust, cone, and brood production data for ground verification plots.

Implications

- This aerial assessment system is an effective way of documenting landscape-level disturbance events
- This spatially explicit documentation is integral to future management of whitebark in the GYE.

4. **Barringer, L. 2010. Determining the relationship between whitebark pine stand-level health and seed dispersal by Clark's nutcracker. M.S. Thesis. University Colorado Denver.**

Background & Objectives

Study objectives were to relate whitebark pine health and cone production to the likelihood of Clark's nutcracker occurrence and seed dispersal services to determine if new generations of whitebark pine will develop. Study sites included four national parks: Yellowstone, Glacier, Grand Teton and Waterton.

Main Findings

- Variables related to nutcracker occurrence include: total healthy whitebark, MPB infestation rates, and squirrel abundance.
- Nutcracker occurrence threshold was 70 cones/hectare (compared to 130 cones/hectare in McKinney et al. 2009).
- Among parks sampled Grand Teton and Yellowstone had healthier and more abundant whitebark than Glacier and Waterton.
- Transects with high proportion of dead whitebark had least nutcrackers.
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Implications

- Sites with less than 70 cones/hectare may be candidates for restoration, depending on forest community type.
- Difference between this study and McKinney may be due to sampling methods, geographical or temporal variation.

5. Zeglen, S., Pronos, J. & Merler, H. 2010. Silvicultural management of white pines in western North America. Forest Pathology. 40:347-368.

Background & Objectives

This review examines approaches for assessing and reducing blister rust hazard, regenerating white pine stands, and tending established stands to reduce damage.

Main Findings

- Understanding the rust pathosystem and its consequences on white pine growth and survival is critical.
- Understanding likely outcomes of silvicultural treatments.
- For artificial regeneration, western genetics programs provide improved planting stock.
- Because responses to blister rust are inherited, natural regeneration provides an opportunity to increase seedling survival and rust resistance.
- Selection and retention of well-adapted white pines as seed sources can enhance stand genetics.
- Thinning and pruning are successful tending activities.
- The hazard or favorableness or likeliness of site for development of rust is based on spatial proximity of rust, length of time an area has been infected, and climate and host distributions.
- Site risk incorporates the possibility of loss or resource values or management investments, or the undesired outcome of damage resulting from rust infection.
- A Blister Rust-Forest Vegetation Simulator (BR-FVS) hazard model is available to characterize the environmental potential for rust infection (McDonald et al. 1981).
- Pruning in western white pine has doubled survival in young natural stands. This article includes pruning guidelines.
- The R-gene (*Cr1& Cr2*) carries a hypersensitive reaction in needle tissue when challenged by rust.
- This “R-gene resistance” is a dominant trait, but defected by a virulent race. This means the rust genes, *vcr1* and *vcr2*, differentially neutralize the cognate resistance alleles *Cr1* & *Cr2* (Kinloch et al. 2004).
- Several organisms, such as the purple mold *Tuberculina maxima* which colonizes rust cankers, compete for space and resources with blister rust and may provide biological control in future.
- Reduction of *Ribes* abundance could decrease site hazard.

Implications

- Retention of genetic diversity and resources on the landscape and promotion of natural selection for rust resistance is critical.
- Risk and hazard assessments are a critical element in restoration objectives and site prioritization.
- BR-FVS may be a practical tool for use during site selection and prioritization, and in determining what seed source to use.
- Continued research will provide improved management techniques and pathosystem understanding.

6. Zambino, P. 2010. Biology and pathology of *Ribes* and their implications for management of white pine blister rust. Forest Pathology. 40:264-291.

Background & Objectives

This review summarizes our knowledge of *Ribes* and their role in the blister rust pathosystem. This is an excellent resource on Ribes.

Main Findings

- *Ribes* differ by species in their contribution to initial establishment and subsequent intensification of blister rust.
- Natural selection increases rust resistance in host pines, but also acts on the aggressiveness of blister rust.
- *Ribes* distribution depends on light and moisture and its abundance on forest successional stage.
- Elevated soil nitrogen levels increase pine and *Ribes* susceptibility to rust.
- Spread depends on topography, weather, and air-flow patterns – most pine infection is limited to several hundred meters.

Implications

- Authors suggest management strategies and hazard assessments to rate the potential for infection of pine hosts.
- Because blister rust pathosystems evolve, it is possible that rust and host could coexist with reduced damage.
- Understanding the interactions between natural selection for resistance in rust hosts and adaptations by blister rust is critical to management of white pines.

7. Turner, M. 2010. Disturbance and landscape dynamics in a changing world. Ecology. 91:2833-2849.

Background & Objectives

Synthesis of current understanding of disturbance and its contribution to landscape and ecosystem ecology to address questions: such as recovery patterns, multiple disturbance interactions, ecosystem change, ecosystem vulnerability, and consequences to society.

Main Findings

- Disturbance regimes are changing rapidly.
- Disturbances create vegetation patterns and ecosystem process patterns.
- Disturbance regime is defined by frequency, return interval, rotation period, size, intensity, severity and spatial distribution and residuals survivorship.
- Post-disturbance heterogeneity establishes a mosaic of process rates and feedbacks, even within the same age class.
- Spatial legacies for ecosystem function and structure persist for decades.

Implications

- Climate change can alter disturbance regimes dramatically.
- Biotic invasions and changes in species assemblages will amplify disturbance regime changes.
- Ecosystems not resilient to novel disturbance regimes or types will experience qualitative change.
- For example whitebark pine, blister rust and unprecedented beetle activity is a novel disturbance resulting in ecosystem change.
- Understanding effects of novel disturbances and regimes is critical.

8. Tomback, D. & Achuff, P. 2010. Blister rust and western forest biodiversity: ecology, values and outlook for white pines. Forest Pathology. 40: 186-225.

Background & Objectives

This paper is a review of white pines in the west, their ecology value, threats to and outlook for each species.

Main Findings

- Common strategic goal is to insure that whitebark pine populations remain on the landscape as significant components of high-elevation ecosystems.
- Assessments include:
    1. Distribution and population trends.
    2. Plant associations and successional ecology.
    3. Reproductive biology and regeneration ecology.
    4. Population genetics and genetics for adaptive traits and resistance.
    5. Operational guidelines for selection, screening, breeding, out planting, and protecting genetic resources.
- Management actions being taken:
    1. Preparation of detailed, regional protection and restoration plans.
    2. Proactive interventions to sustain remaining populations.
    3. Restoration projects for severely impacted forests and stands.
    4. Prioritization of forests and stands.
- Common approaches:
    1. Identify and protect trees with rust resistance.
    2. Prepare seedbed and out plant seedlings.
    3. Survey and monitor blister rust, mountain pine beetle, and whitebark pine.
    4. Apply silvicultural treatments that encourage natural regeneration.

Implications

- This paper is a great resource for a summary of the entire situation faced by whitebark pine.
- Management includes reactive and proactive strategies to protect, sustain, or restore whitebark pine.

9. Schwartz, C., Haroldson, M., & White, G. 2010. Hazards affecting grizzly bear survival in the Greater Yellowstone. Journal of Wildlife Management. 47(4):654-667.

Background & Objectives

This paper presents findings from modeling work to assess annual grizzly bear survival in the GYE. Specifically, this work addresses spatial heterogeneity among bear mortality, differences in survival across the GYE, and identifies parameters to demonstrate source and sink habitats.

Main Findings

- Model variables included landscape features such as food, land management policies and human disturbance factors.
- Survival of independent bears >2 years old depended on the level of human development within the bear's home range.
- Survival improved as elevation increased; survival decreased with greater road density, number of homes, and proximity to ungulate hunt areas.

- Analysis did not show a spatial relationship between the distribution of key bear food and survival.
- It is well documented that grizzly bear mortality in GYE is greater during years of low whitebark seed availability.
- Bears suffering mortality on average or excellent pine seed years were, on average (but not significantly), found at lower elevations.
- Bears do shift to lower elevations during poor pine seed years, but this shift does not predispose bears to increased mortality.
- In poor seed years, female bears shifted to ungulate meat, increasing the probability of conflict with hunters.

Implications

- Grizzly bears exhibit dietary plasticity in the GYE.
- Spatial shifts by grizzly bears associated with food abundance did not predict survival, unless the bears shift to habitats with more human disturbance.
- The dynamic between poor seed years and hunter encounters could increase with whitebark pine decline.
- When bears move to lower elevations in poor whitebark seed years, survival is dependent on the density of human-related hazards on the landscape.

10. Haeussler, S. 2010. Exploring whitebark pine at its northwest limit. Nutcracker Notes. 19:11-13.

Background & Objectives

Reports findings from studies of whitebark pine in west-central British Columbia.

Main Findings

- 1977 to 2002 period of decline in whitebark pine.
- No evidence of wildfire during from 1977 to 2002.
- Subalpine fir declined to due balsam bark beetle and budworm.
- Frequency of wildfire on east slopes of mountain ranges has increased since 2003.
- Whitebark regeneration is very low on burned sites. Planting efforts are being planned.
- Many lodgepole stands with extensive beetle mortality in overstory lodgepole, with understory of healthy whitebark seedlings exist.
- 2000s MPB outbreak has exhausted itself.
- Two whitebark stand types remain
  1. Those established 1947-76 with little MPB damage. These stands contain seed-bearing whitebark with little blister rust.
  2. Residual stands near timberline.

Implications

- Stands where lodgepole overstory was lost to MPB which contain significant numbers of whitebark seedlings may now release.
- Nutcrackers appear to be caching in these stands.
- Details from this project at: http://bvcentre.ca/research/project/testing_ecological_resilience_theory_in_pinelichen_ecosystems_of_west_cent/

11. Fothergill, J. 2010. Whitebark pine regeneration in the Greater Yellowstone. Nutcracker Notes. 19:14

Background & Objectives

This article summarizes trends seen in recruitment rates of seedling whitebark pine (<1.4 meters in height) from the 2004 initiated National Park Service Inventory and Monitoring Program for the long-term health of whitebark pine in the Greater Yellowstone.

Main Findings

- A total of 7606 seedlings were sampled in 2008 and 2009.
- Mean seedling density is 43.5 seedlings/500 m^2.
- Seedlings were greatest in cover types dominated by whitebark or lodgepole.
- Seedling density lowest in spruce/fir cover types.
- Among years, the rate of rust infection on seedlings sampled was 2.8%, which is less than overstory trees which are infected at a rate of 20%.
- For 98 transects revisited in 2008 & 2009 –
  1. seedling density increased from 35.7 seedlings/500 m^2 in 2008 to 45.9 seedlings/m^2 in 2009.
  2. seedlings infected with blister rust increased from 2.1% in 2008 to 3.3% in 2009.

Implications

- The reduction in overstory cover may be promoting increased whitebark seedling density.
- The loss of cone-bearing whitebark will decrease seed availability in future.
- Blister rust infection can be expected to increase.

12. Schwanke, R. and Smith, C. 2010. Imitating lightning strikes for whitebark restoration. Nutcracker Notes. 19:12.

Background & Objectives

This article reviews the using of terrestrial torch system to burn small plots that mimic lightning strikes in whitebark pine.

Main Findings

- The probability of damaging and/or killing the last remaining whitebark seed trees during prescribed burns is too great.
- Replicating lightning strikes was approved to burn plots 60 meters in diameter to remove competing vegetation to allow release of whitebark seedlings and to create openings to encourage nutcracker caching.
- Whitebark seedlings were planted following treatment.

Implications

- The use of terrestrial torch system is a viable technique where prescribed burns and other silvicultural techniques are not appropriate or possible.

13. Schwandt, J. Lockman, I., Kliejunas, & Muir, J. 2010. Current health issues and management strategies for white pines in the western United States and Canada. Forest Pathology 40:226-250.

Background & Objectives

This review of white pines in western US and Canada covers all health issues including white pine blister rust extent and severity, root disease, mountain pine beetle, mistletoe, cone and insect disease, fire, climate change, wildlife damage and presents strategies for management.

Main Findings

- Description of blister rust infection and severity by white pine species.
- Strategic goal to sustain or restore viable white pine populations:
    1. Conserve genetic resistance to *C. Ribicola*
    2. Reduce risk of adverse impact in stands currently uninfected
    3. Restore and maintain white pines where rust is causing damage
    4. Assess and monitor health and management of white pines

Implications

- The most fundamental component of managing white pines is to conserve genetic resistance.
- Protect sources from fire, insects, and pathogens.
- Collect seed from trees with known resistance.
- Promote ecosystem resilience by encouraging greater age and size class diversity in white pine stands.
- Promote natural regeneration during rust epidemic to increase resistance in population.
- Plant resistant stock.
- Prune and thin to reduce infection and mortality.

14. Richardson, B., Ekramoddoulah, A., Lui, J., Kim, M., & Klopfenstien, N. 2010. Current and future molecular approaches to investigate the white pine blister rust pathosystem. Forest Pathology 40: 314-331.

Background & Objectives

This review of the molecular genetics approach to ecosystem management of white pine blister rust pathosystems describes the current tools and potential developments for the future.

Main Findings

- Technology has increased the capacity to generate many high-resolution genetic markers.
- Knowledge of genetic structure and genetic diversity of forest tree species is fundamental to genetic resource management.
- Pines inherit mitochondrial DNA maternally & chloroplast DNA paternally.
- Mitochondrial DNA analysis exhibits differentiation among populations.
- Genetic diversity and differentiation among populations of *C. Ribicola* are low, except in rust resistant plantations.
- New genomic and proteomic approaches, called cDNA libraries, are linking molecular and phenotypic bases of plant defenses and pathogen infection.
- There are new tools that characterize white pine R genes in order to understand how these code for pathways that give rise to the hypersensitive (HR) response.
- Population-level studies provide patterns of genotypes that help explain natural selection and demographics.

Implications

- This information helps restoration programs by assessing how to geographically distribute populations used for regeneration.
- Artificial selection for resistance in white pine is met with rapid natural selection, and thus increased genetic diversity and capacity to infect host pines, by blister rust.
- Read this article to understand the proteins and genetic techniques behind the rust resistance program.
- Techniques that help understand resistance and virulence pathways and associated proteins enable molecular-level descriptions of how plant genes code for proteins that provide a defense and how rust genes defeat it.

15. **Bond, C., Champ, P., Meldrum, J., Schoettle, A. 2010. Proactive or reactive? Optional management of an invasive forest pest in a spatial framework. Selected Paper 11633. 2010 AAEA Annual Meeting.**

Background & Objectives

This paper addresses the need for proactive management of forest resources in the presence of invasive species whose spread is unaffected by management actions. Proactive management is treating an uninfected area to encourage healthy ecosystem function.

Main Findings

- Blister rust management is challenging because containment and mitigation actions are often unsuccessful.
- The natural evolution of rust resistance is slow; intervention will preserve naturally resistant seed stock.
- Paper provides a model to calculate the number of stands being managed, their health, and distribution in space and time to determine whether and where proactive treatments should occur.
- This framework must also accommodate resource constraints, uncertain outcomes of actions, and unknown probability of new rust infection.

Implications

- This model showed that proactive management is optimal when:
    1. more resources are available for treatment (i.e., a greater number of stands can be treated in any one decision period)
    2. the costs of treatment are rapidly increasing in forest health, or conversely, the benefits of healthy and unhealthy stands are relatively similar.

16. **Logan, J., Macfarlane, W., & Willcox, L. 2009. Effective monitoring as a basis for adaptive management: a case history of mountain pine beetle in the Greater Yellowstone Ecosystem whitebark pine. iForest 2: 19-22.**

Background & Objectives

This short communication summarizes mountain pine beetle activity in the United States and Canada and presents a summary of methods available to accurately assess the extent of forest canopy loss.

Main Findings

- Current mountain pine outbreaks in lodgepole pine forest are the largest ever recorded involving 13 million hectares of forest (Carroll 2006).
- The invasive range expansion of mountain pine beetle into high elevations and the boreal forest are outside the range of historic variability.

Implications

- The accurate assessment of the extent and severity of is a critical step in effective and adaptive management strategies.
- Tools include satellite imagery analysis, aerial detection by human observer and georeferenced photo points, and on-the-ground observations.

17. **McKinney, S. & Fielder, C. 2009. Tree squirrel habitat selection and predispersal seed predation in a declining subalpine conifer. Oecologia. 162:697-707**

Background & Objectives

There is concern that reduced seed availability and seed predation could reduce whitebark pine regeneration potential. This paper investigates how changes in forest conditions in whitebark pine stands influence red squirrel habitat use and seed predation.

Main Findings

- Red squirrels did not preferentially select whitebark habitat, rather they use whitebark opportunistically, and thus declines in whitebark did not result in proportional declines in squirrel habitat use.
- Predispersal cone predation decreased with increasing relative abundance of whitebark pine.
- Squirrel cone predation was greater where whitebark pine mortality was greater.
- Squirrel habitat use was lower in stands dominated by whitebark than mixed stands.
- As whitebark becomes more dominant, conditions are less hospitable for squirrels (they need enough seeds to survive winter combined with cover and escape from predators) and proportionally fewer cones are depredated.
- In mixed stands, squirrel predation increased with whitebark cone production.

Implications

- Squirrel cone predation may lead to reduced seed availability particularly where whitebark pine abundance is reduced by mountain pine beetle and blister rust mortality.
- Reducing competing conifers to produce stands with greater whitebark dominance may create “suboptimal” squirrel habitat and therefore less seed predation and more seed availability for avian dispersal.
- Whitebark mortality that results in conversion of whitebark forests to mixed forests may result in increased seed predation and decreased natural regeneration.
- This study presents the idea that dominant whitebark stands are critical seed sources for natural regeneration.

18. Hood, S. 2010. Mitigating old tree mortality in long-unburned, fire-dependent forests: a synthesis. USDA RMRS-GTR-238. 71pp.

Background & Objectives

This report addresses the understanding of reintroducing fire in stands and the impacts of these fires on overstory tree injury and mortality.

Main Findings

- Whitebark pine has very low tolerance to fire; it is easily injured by fire.

Implications

- The use of prescribed fire that risks damage or mortality to cone-bearing live whitebark may not be appropriate.

19. Kim, M., Klopfenstein, N., Ota, Y., Lee, S., Woo, K., & Kaneko, S. 2010. White pine blister rust in Korea, Japan and other Asian regions: comparisons and implications for North America. Forest Pathology 40: 382-401.

Background & Objectives

This article reviews the history of white pine blister rust in South Korea, Japan and eastern Asia.

Main Findings

- Asia is a center for blister rust diversity and the source of introduction to North America.
- South Korea –
    1. Reported 1937 in plantations.
    2. Sanitation of infected trees and removal of telial host has maintained low blister rust incidence since 1990.
- Himalaya –
    1. Reported 1923.
    2. Reported sporadically.
- Asiatic Russia –
    1. Severe infection and considerable mortality.
- China –
    1. Reports in 1919
    2. China has 12 taxa of white pines – important center for genetic diversity of resistance.
- Japan -
    1. Reported in 1905, spread to several plantations in 1970s.
    2. No further reports of rust damage to plantations, but populations of native pine stands have been infected.
    3. Damage is not severe and rust not considered a major forest disease.

Implications

- Blister rust in Asia and North America – comparisons and implications –
    - Many Asian pine species display a very high degree of resistance.
    - Collaborative efforts to collect and genetically analyze blister rust could provide answers
    - Understanding a variety of white pine blister rust pathosystems could assist in genetic and silvicultural strategies for sustaining resilient populations of white pines.

20. Keane, R. & Parsons, R. 2010. Restoring whitebark pine forests of the Northern Rocky Mountains, USA. Ecological Restoration 28(1):56-70.

Background & Objectives

This study was initiated in 1993 to investigate the effects of variable restoration treatments on tree populations, fuel dynamics and vascular plant cover. Treatments were combinations of prescribed fire, silvicultural cuttings, and fuel enhancement cuttings. The full guide version of this publication is below.

Main Findings

- No significant whitebark regeneration on any of the sites.
- All burn treatments resulted in high mortality of whitebark and subalpine fir.
- Nutcracker openings were created by treatments.

Implications

- Manual planting is required to adequately restore.
- Reduce seed availability, due to blister rust and MPB, results in nutcracker reclamation of most cached seeds.
- Severe site conditions may have killed emerging seedlings.
- Study period may be too short to effectively evaluate whitebark pine regeneration dynamics.

21. Keane, R. & Parsons, R. 2010. Management guide to ecosystem restoration treatments: whitebark pine forests of the Northern Rocky Mountains, USA. USDA RMRS-GTR-232. 133 pp.

Background & Objectives

This guide is a compilation of potential management techniques for whitebark pine restoration based on study results compiled since 1993 in Western Montana and Central Idaho. This is a reference to identify possible impacts of restoration treatments at a fine scale by matching proposed treatment and stand to examples in this document based on vegetation conditions, fire regime and geographical area.

Main Findings

- The main objective of all projects presented was to enhance whitebark pine regeneration and cone production by emulating natural fire regime.
- Overall whitebark regeneration rates at treatment sites were very low.
- Authors suggest that low regeneration was due to: nutcrackers reclaiming seeds, lack of seed source, severity of sites, lack of plant cover, and relatively short time since disturbance.
- Principles of restoration strategy:
  1. Enhance rust resistance.
  2. Conserve genetic diversity.
  3. Save seed sources.
  4. Employ restoration techniques.
- Proactive restoration actions include:
  1. Assess stand condition.
  2. Gather seed.
  3. Grow seedlings.
  4. Protect seed sources.
  5. Implement restoration projects.
  6. Plant burned areas.
  7. Monitor activities.
  8. Support research.

Implications

- Managers can identify possible treatment effects at their own site by matching it to the most similar site in this guide.
- Many of these studies were conducted in the western portion of whitebark distribution, where the fire regime is likely different than in the GYE.
- The creation of nutcracker openings must be coupled with abundant seed and climate and site conditions that promote whitebark regeneration to result in successful regeneration.
- Copies from: rschneider@fs.fed.us

22. Lantz, G. 2010. American Forests Special Report. 2010. Whitebark pine: an ecosystem in peril.

Background & Objectives

This special report is a summary of the importance and current condition of whitebark pine presented to solicit donations to the nonprofit conservation organization, American Forests. The funds are directed toward planting seedlings.

Main Findings

- The pace at which whitebark are dying is alarming and active planting is one important strategy for conserving the species.

Implications

- This document is a great resource that presents whitebark ecology and the current perilous situation in an attractive handout.
- For copies email: info@amfor.org

23. Hunt, R., Geils, B., & Hummer, K. 2010. White pine, Ribes, and blister rust: integration and action. Forest Pathology. 40:402-417.

Background & Objectives

This article synthesizes the literature on economically and ecologically important white pines and blister rust in North America, Europe and Asia. This paper provides a scientific basis for managing white pines, blister rust, and *Ribes*.

Main Findings

- Goal of genetic improvement is to provide managers with white pine seedlings that have "strong durable resistance"
- Forest management can affect the abundance and distribution of *Ribes*, to reduce blister rust hazard.
- Four host reactions –
  1. Partial resistance (tolerance) such as slowing infection
  2. Ontogenic resistance, where susceptibility decreases with host age.
  3. R-gene resistance provides immunity to pathogen.
  4. Resistance attributed to recessive genes, such as needle-shed response.
- Action priorities –
  1. Role of pathogen – global review of phenology, biogeographical distribution, and life history.
  2. Potential for management by genetic and silvicultural techniques – genetic resource management, determine silvicultural techniques for successful regeneration, develop techniques to reduce rust damage to seedlings and poles, develop models to predict site hazard.
  3. Develop regional and local level plans to assess conditions and trends of white pine ecosystems.

Implications

- Ways to manage white pine blister rust pathosystem –
  - Apply lessons of history.
  - Conserve white pines.
  - Develop strong durable resistance
  - Accommodating climate change
  - Developing and supporting programs to mitigate impacts of blister rust.
- Key is to conserve existing genetic diversity and to protect potential sources of resistance and other adaptive traits. Methods to do this include:
  - In situ, location documented, marked, and monitored.
  - Grafted and banked in seed orchards
  - Stored as candidate seed.

24. Hatala, J., Crabtree, R., Halligan, K., and Moorcroft, P. 2010. Landscape-scale patterns of forest pest and pathogen damage in the Greater Yellowstone Ecosystem. Remote Sensing of Environment. 114(2): 375-384.

Background & Objectives

Presents findings from an analysis to investigate a method that combines field surveys with a remote sensing classification and spatial analysis to differentiate the effects of blister rust and mountain pine beetle on whitebark pine. Using hyperspectral remotely sensed images from the airborne HyMap sensor were classified to determine changes in the locations of stress and mortality in whitebark pine crowns between two images dated September 2000 and July 2006.

Main Findings

- The differences in spatial pattern of blister rust and mountain pine beetle infestations allowed these two disturbance types to be separated during imagery analysis.
- Blister rust is initially identified by small patches and then spreads by "infilling" between infected patches.
- The spatial pattern of mountain pine beetle spread is dominated by the growth of a contiguous patch of mortality.

Implications

- These results yield insight to the relative impacts of blister rust and mountain pine beetle on whitebark populations in the GYE.
- Differences in the spatial pattern of mortality and stress by each agent are illustrated.
- Rates of spread can be calculated for each disturbance separately, or in combination.

25. Geils, B., Hummer, K., & Hunt, R. 2010. White pines, *Ribes*, and blister rust: a review and synthesis. Forest Pathology. 40: 147-185.

Background & Objectives

This review presents a synthesis of international scope on the biology and management of blister rust, white pines, *Ribes*, and other hosts. *Based on 1200 reports on white pines, 400 on Ribes, and 2400 on blister rust, this review is an excellent resource, and this annotation is not inclusive.*

Main Findings

- Blister rust incidence and severity is variable geographically suggesting that local resilience of white pine species is possible.
- Gene-to-environment interactions are important to rust infection success.
- Most host responses are controlled by multiple genes expressed in various responses.
- Rust populations display genetic differences in aggressiveness and virulence at various spatial scales.
- An R-gene codes for synthesis of a protein that recognizes the presence of a pathogen and leads to a cascade of
- resistance responses.

Implications

- This review is an excellent resource.
- Authors encourage proactive management to facilitate whitebark reproduction and natural selection for resistance.

26. McCaughley, W., Scott, G., & Izlar, K. 2009. Whitebark pine planting guidelines. Western Journal Applied Forestry. 24(3):163-166.

Background & Objectives

Revised planting guidelines, which include extensive literature review, field observations, and research findings.

Main Findings

- Cones should be collected when embryo-to-total-seed-length ratios are >0.65 and endosperm-to-total-seed-length ratios are >0.75
- Plant large, hardy seedlings with well-developed root systems.
- Reduce overstory competition to at least 20 feet radius around seedling.
- Plant in whitebark habitat (Pinus albicaulis – *Vaccinium scoparium* & *Luzula hitchcockii*).
- Avoid burned lodgepole stands
- Do not plant in mixed conifer species plantings.
- Reduce understory vegetation competition such as beargrass.
- Plant near grouse whortleberry
- Avoid swales and where soils are deep.
- Provide shade and physical protection such as north side of stumps, logs, rocks.
- Avoid planting near snags, as they fall over and uproot seedlings.
- Plant on north side of stumps, rocks, anchored logs to provide protection from wind, snow, and heat.
- Estimating 50 mortality, initial density should be 15 X 15 feet or 194 seedlings per acre. This yields 85-100 trees per acre.
- Plant in soil that is moist.
- Authors suggest summer and fall plantings.

Implications

- Authors state that planting is only a small part of whitebark restoration; promoting natural regeneration is key.

27. Larson, E., & Kipfumueller, K. 2010. Patterns in whitebark pine regeneration and their relationships to biophysical site characteristics in southwest Montana, central Idaho, and Oregon, USA. Can. J. For. Res. 40:476-487.

Background & Objectives

This research examined patterns in natural whitebark pine regeneration as related to the biophysical environment on 60 plots in Montana, Idaho, and Oregon.

Main Findings

- Whitebark regeneration present on 97% of plots.
- Density varied from 0 to 17000 seedlings/hectare and 0 to 2680 saplings/hectare.
- Regeneration documented indicates multiple episodes of successful whitebark establishment.
- Levels of regeneration were lower on sites affected by multiple, closely timed disturbance events.
- Greater seedling densities on sites with longer, warmer growing seasons and greater sapling densities on colder sites.
- Inverse relationship between whitebark regeneration density and subalpine fir regeneration density.
- Whitebark regeneration positively correlated to overall stand density, and live and dead whitebark density.
- Evidence of fire was found on 35% of sites.
- Advanced regeneration was observed forest gaps caused by prior MPB activity.

Implications

- Whitebark is regenerating in many areas.
- Seedlings are more likely to emerge at warmer sites, they also suffer heat and drought damage and therefore seedlings on colder sites are more likely to survive.
- Mortality from recent MPB outbreaks may provide suitable settings for regeneration, given sufficient seed sources.
- Greater understanding of whitebark regeneration is critical to management and restoration activities.
- Authors suggest that planting beneath mature canopy whitebark experience MPB mortality may be effective and will offer the longest potential disturbance-free growing period for planted trees.
- When planting, targeting stands in colder settings may give seedlings the greatest chance for survival and maturation.
- Because rust resistance has been documented to increase rapidly over only a few generations, high levels of regeneration documented may indicate that rust resistance is increasing within whitebark populations.

28. Gibson, K. 2009. Using verbenone to protect host trees from mountain pine beetle attack. USDA Forest Service, FHP, Missoula, MT. 7 pp.

Background & Objectives

This article reviews the history and use of verbenone to protect host trees from MPB in order to address the lack of consistency in some verbenone efficacy trials.

Main Findings

- In 1988 and 1989 0.5 gram bubble capsules used.
- By 1994 efficacy results were so variable, FHP decided not to use.
- Late 1990s trials with much higher doses were initiated with much more success.
- Inconsistency in efficacy due to beetle behavior, stand structure and host availability.

Implications

- Current status of verbenone = *"sometimes it works".*
- Verbenone not consistently reliable, but can work relatively well.
- Current conclusions:
    - Better than doing nothing.
    - 7.5 gram pouches are much more effective than 5.0 grams.
    - Individual tree protection is typically 80% successful.
    - Rates of application vary from 20 to 40 7.0 gram pouches per acre.
    - Depending on seasonal weather, more than one application may be required to capture entire beetle flight period.
    - Verbenone is one tool on a continuum of short-term protection.
- Current recommendations for use:
    - Some studies show that use of GLVs enhances verbenone efficacy.
    - Stand to be treated needs to be assessed for susceptibility and risk to MPB.
    - If >15% of trees are infested, verbenone may not be effective.
    - For individual trees, use two 7 or 7.5 gram pouches….for trees > 24" DBH 3 to 4 pouches may be needed.
    - On stand-level, areas with <15% infestation rate 20 pouches per acre is sufficient. For areas with >15%, 40 pouches per acre are needed.
    - Annual and site-specific beetle flight patterns must be addressed. For example, early May flights in high elevation forests.

29. Fettig, C., Munson, S., Jorgensen, C., & Grosman, D. 2010. Efficacy of fipronil for protecting individual pines from mortality attributed to attack by western pine beetle and mountain pine beetle (Coleoptera: Curculionidae, Scolytinae). J. Entomol. Sci. 45(3): 296-301.

Background & Objectives

This article suggests that the long-term use of carbaryl to protect against mountain pine beetle attack is uncertain due to the difficulty of use in remote areas and threats of nontarget impacts from spray drift. The authors present findings from research of alternate systemic insecticides.

Main Findings

- Experimental formulas of emamectin benzoate and fipronil was effective for protecting ponderosa pine three years following as single injection.
- These insecticides did not work for Engelmann spruce.
- Fipronil did not protect lodgepole pine from MPB, although brood production and emergence was reduced.
- Conifers did not exhibit external symptoms of phytotoxicity from the injections.

Implications

- Further work on the use of these insecticides may provide tree protection in the future.

30. Raffa, K., Aukema, B., Bentz, B., Carroll, A., Erbilgin, N., Herms, D., Hicke, J., Hofstetter, R., Katovich, S., Lindgren, S., Logan, J., Mattson, W., Munson, S., Robison, D., Six, D., Tobin, P., Townsend, P., & Wallin, K. 2009. A literal use of "forest health" safeguards against misuse and misapplication. Journal of Forestry. 276-277.

Background & Objectives

This article addresses the use of the term "forest health".

Main Findings

- The use of the term "forest health" connects the fragility of health to ecosystems and therefore human values are integrated into this term.
- "Sustainability" refers to human objectives – the degree of utilization of forest services without diminishing the resource.
- "Ecosystem function" is independent of human expectations, rather the processes of resident species interacting with each other and the physical environment.

Implications

- Clear and literal use of these terms is critical in accurate communication of forest conditions to the public.

- Use of the term “forest health” should describe the extent to which ecosystem processes are functioning within natural historical variability.
- Forest health should be evaluated by assessing ecosystem dynamics such as inherent processes and resilience.

31. Logan, J., Macfarlane, W., & Willcox, L. 2010. Whitebark pine vulnerability to climate-driven mountain pine beetle disturbance in the Greater Yellowstone. Ecological Applications 20(4):895-902.

Background & Objectives

This paper addresses the question: are the current MPB outbreaks in whitebark pine truly unprecedented and a threat to ecosystem continuity?

Main Findings

- Comparison of current MPB outbreak to 1930s indicates that 1930s was a result of a short-term weather event. Current outbreak is the result of a long-term weather trend.
- The severity (proportion of canopy loss) of current outbreak is much greater than in the 1930s and 1970s.
- Whitebark pine’s reproductive strategy does not indicate resilience to the current, large-scale MPB disturbance.
- Whitebark pine does not typically produce copious pitch tubes like lodgepole, suggesting whitebark is more vulnerable to attack by MPB than lodgepole.
- Climate change has resulted in MPB success in high elevation forests.
- Synergistic interaction between MPB and blister rust exacerbates damage to whitebark pine.

Implications

- Consequences are certain such as decreased seed abundance and loss of ecological services.
- There are refugia for whitebark pine in the GYE.
- The slow growth rate of whitebark makes them both vulnerable and resilient.
- Krumholtz growth form may be capable of upright grow as climate warming continues.

32. Bentz, B., Regniere, J., Fettig, C., Hansen, M., Hayes, J., Hicke, J., Kelsey, R., Negron, J., & Seybold, S. 2010. Climate change and bark beetles of the Western United States and Canada: direct and indirect effects. BioScience. 60(8): 602-613.

Background & Objectives

This synthesis of climate change effects on native bark beetles addresses the effects of climate on frequency and severity of disturbances that shape the forest. Predicted changes include earlier and longer dry seasons, more frequent and longer duration drought, and increased mean temperatures. Rapid genetic adaptation and range expansion by insects is occurring.

Main Findings

- Projected warming will result in increased population success (including synchronous emergence, duration of development, and cold tolerance) in *Dendroctonus rufipennis* and *ponderosae*.
- Spatial expansion of temperature suitability to include higher latitudes and elevations.

Implications

- Beetle response to climate change is complex and uncertain.
- All climate change is not uniformly distributed across years.
- Significant spatial and temporal variability in thermal suitability.
- Some beetle outbreaks will result in trajectories beyond the historic resilience of some forest ecosystems, resulting in irreversible ecosystem regime and structure shifts.

33. Dennison, P., Brunelle, A., & Carter, V. 2010. Assessing canopy mortality during a mountain pine beetle outbreak using GeoEye-1 high spatial resolution satellite data. Department of Geography, University of Utah.

Background & Objectives

This work presents findings on the use of GeoEye-1 images to map both red and gray conifer canopy. This study included a ground verification effort.

Main Findings

- Close agreement in green, red, and gray percent cover between spatial and ground data.
- Discrepancies include: tree canopy configuration that results in shading
- GeoEye-1 spatial data (0.5 meter pixel resolution) is a promising tool for mapping canopy mortality caused by MPB.
- Gray canopy was distinguishable from green and red.

Implications

- The mapping red and gray canopy, multi-temporal spatial data can be used to monitor the progression of an outbreak.
- GeoEye-1 images are 15.2 meters wide, making regional scale mapping challenging.

34. Simard, M., Romme, W., Griffin, J., & Turner, M. 2011. Do mountain pine beetle outbreaks change the probability of active crown fire in lodgepole pine forests?

Background & Objectives

This study addresses the interaction of two types of natural forest disturbances – beetle outbreaks and wildfire.

Main Findings

- Fires in subalpine forests in GYE are mainly climate (not fuels) driven.
- Dead surface fuel loads did not differ among undisturbed, red, and gray-stage stands.
- Models show that gray-stage stands were unlikely to exhibit transition of surface fires to tree crowns.
- The likelihood of sustaining active crown fire was lower in gray-stage forests than undisturbed.

Implications

- MPB outbreaks in lodgepole forests in the GYE do not increase the risk of active crown fire.
- MPB outbreaks may reduce probability of active crown fire in the short term by thinning lodgepole canopies.