The Western Bark Beetle Research Group: A Unique Collaboration With Forest Health Protection

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Some Ecological, Economic, and Social Consequences of Bark Beetle Infestations[1]

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Abstract

Bark beetles are powerful agents of change in dynamic forest ecosystems. Most assessments of the effects of bark beetle outbreaks have been based on negative impacts on timber production. The positive effects of bark beetle activities are much less well understood. Bark beetles perform vital functions at all levels of scale in forest ecosystems. At the landscape level they influence forest regeneration, and at the stand level they kill mature trees thus creating gaps and forest openings that are beneficial to wildlife. They also cause overall increases in forest and stand resiliency by promoting variability in sizes and ages of trees and in species compositions. The effects of bark beetles on forest ecosystems differ with beetle species, geographical location, host species, stand density and tree age. Whereas ecological consequences are normally beneficial to forest ecosystems, socioeconomic perceptions range from positive to negative. We provide several examples from western regions that illustrate ecological, economic, or social effects of bark beetle outbreaks. These examples include information on management of bark beetle outbreaks and identify research needs for the future.

Keywords: Bark beetles, beetle impact, socioeconomic perception.

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Introduction

Forest ecosystems are comprised of complex labyrinths of plant, animal, and microscopic life interacting with the abiotic environment. When these systems are in good condition from a human perspective, they perform biogeophysical functions that, from the human perspective, maximize the flow of various services and benefits for society. These services include: water and food production; regulating services like flood control and cleaning air; providing cultural, recreational and spiritual benefits; and supporting services such as nutrient cycling that maintain the conditions of life on earth (Millennium Ecosystem Assessment 2003).

Bark beetles, other insect pests, and pathogens are among the most costly of all forest disturbance agents. Combined it is estimated that they cause losses exceeding $2 billion on 20.4 million ha of forests per year (USDA 1997). Bark beetle infestations can have vast and long lasting socioeconomic and ecological consequences on our forest landscapes (Dale et al. 2001). Characterizing and quantifying these impacts on the value of forest goods and services to human society has been a puzzling problem, and remains a significant challenge to forest managers and pest specialists (Dale et al. 2001).

Ecological consequences of bark beetle infestations

Forests are dynamic and constantly changing in response to biotic and abiotic influences generally referred to as disturbances. Disturbances play significant, even critical, roles in ecosystem functioning: both natural and human-induced disturbances shape forest systems at all spatial and temporal scales by influencing their composition, structure, and functional processes. Disturbances affect succession, net primary production, nutrient and hydrological cycling, habitat partitioning, and maintenance of species diversity. From an ecological perspective, disturbance in the forest ecosystem caused by bark beetle activity is commonly viewed as “beneficial”, especially when that disturbance is within its natural bounds (Samman and Logan 2000). Native insects have co-evolved with their host tree species for many thousands or millions of years and are important regulators of native systems.

At the landscape scale, some bark beetle infestations create mosaics of forest patches of various ages, densities, species compositions, and stages of succession. Larger trees with reduced vigor are especially attractive to bark beetles as sites for reproduction. At endemic levels, for instance, bark beetles beneficially remove older, larger, weaker, dominant trees, releasing understory vegetation and catalyzing stand development. Bark beetles impact structure and function (Amman 1977, Schmid and Hinds 1974), biogeochemical and hydrological cycling (Edmonds and Eglitis 1989, McGregor 1985), net primary production and maximal stand volume (Romme et al. 1986), and ecosystem species diversity and abundance (Martin et al. 2006, McMillin and Allen 2003). Bark beetles mine the wood and introduce decay fungi that accelerate decomposition, and increase nutrient release rates from fallen logs (Edmonds and Eglitis 1989); increase nitrogen mineralization and turnover; and contribute to carbon fluxes. Some studies indicate that bark beetle attacks increase stream flow (Mitchell and

Love 1973) though other studies question this. Much about the effects of bark beetles on watershed hydrology is not well-understood (e.g., McGregor 1985). Moreover, bark beetles can be more important than other disturbance agents, including fire, in modifying forest structure because of the scale of their activities (Veblen et al. 1994). The effect of disturbance scale must be considered as there are different ecological outcomes for stand-replacing versus canopy-gap-producing events (Lundquist and Negrón 2000). At the landscape scale, infestations create mosaics of forest patches of various ages, densities, species compositions, and successional stages (Kolb et al. 1999, Schowalter 2006). The beneficial ecological roles played by bark beetles have been much less studied than the negative impacts. Rather than combat bark beetles as pests, we may want to view their population swings as symptomatic of changing environmental and stand conditions and, rather than perceive the beetle as the problem, seek to address the causes of its population outbreaks.

Outbreak dynamics

Insect populations are regulated by the interactions of many factors (Schowalter 2006). At times, beetle populations erupt into outbreaks that impact large tracts of forest at the landscape level. The causes of these sudden increases in beetle population are not well known. In general, however, several factors contribute to the occurrence of an outbreak: local populations of beetles are high; a sufficient number of suitable-sized host trees are present for breeding; host vigor may be reduced, and favorable environmental conditions exist for beetle survival. Abiotic factors like climate, weather related phenomena, geographic location, or natural disturbance, also influence the development of bark beetle populations. Biotic factors like species, age, and distribution of trees, affect bark beetle population development and spread. The likelihood of an outbreak increases when many trees are stressed and their defenses are inhibited by drought or injury.

Significance of spatial scale. The effects of bark beetle outbreaks vary with spatial scale. At the individual tree scale, bark beetles cause death, deformation, and reduced or foregone growth; at the stand scale, they change species composition and forest structure; at the landscape scale, they change patterns and enhance spatial heterogeneity. Because management objectives can occur concurrently at different scales, multiple objectives can be impacted by the same disturbance event (Erdle and MacLean 1999). Relative significance of management objectives determines which of these scales is most important.

Landscape Analysis. Sometimes, whole landscapes can be altered by bark beetles, creating mosaics of forest patches of various ages, densities, species composition, and successional stages (Kolb et al. 1999, Schowalter 2006). Geospatial analyses can highlight patterns of bark beetle effects at large spatial scales, making it possible to understand ecosystem component functions and interactions that may not be apparent at smaller scales (Gamarra and He 2008). Many spatial metrics have been developed to quantify landscape patterns, but much needs to be done on correlating changes in the values of these metrics to bark beetle activity (Keane et al. 2002, Smith et al. 2002).

Socioeconomic Impacts of Bark Beetle—Direct-Use Values

Direct use values
Pearce (2001) defines direct use values as "values arising from consumptive and non-consumptive uses of the forest". The most obvious consumptive use is, of course, timber production. Less-obvious direct uses include tourism, mineral extraction, collection of pharmaceutical supplies, fuel wood harvest, and extraction of other non-timber forest products. Most bark beetle impact assessments have been based on timber production metrics.

Economic consequences
Methods and metrics used for forest pest impact assessment of direct uses are reviewed by Stark (1987). Impact is commonly characterized as number of acres affected or number of trees killed. Sometimes percent of trees infested or destroyed within individual stands is assessed. Less often, wood volume loss is calculated and, less often still, these volume estimates are converted to monetary values.

Valuation of non-timber uses
Healthy forests provide a range of values far more extensive than just those associated with timber and other exploitable resources (Chamberlain et al. 1998), and many of these resources are becoming increasingly scarce (Zhang and Li 2005). When forest health is challenged by bark beetles or other disturbances, these resources are impacted. Assessments based on timber production are inappropriate for most non-timber goods and services. Few nontimber direct uses can be adequately assessed using timber production metrics. Kline (2007) described some of the difficulties in developing metrics useful for measuring, assessing, and appraising various objectives, especially nontimber resources. Alternative value assessment techniques have been suggested for biodiversity (Nunes and van den Bergh 2001), scenic beauty (Rosenberger and Smith 1998), nontimber forest products (Chamberlain et al. 1998), and others. Buhyoff et al. (1982), Hull et al. (1984), Schroeder and Daniel (1981), and Vining et al. (1984), for example, used photos and computer generated view sheds of mountain pine beetle infested landscapes to assess impacts on scenic beauty in Colorado and Arizona. Daniel et al. (1991) conducted a similar study for spruce beetle infestation in Alaska.

Barriers to impact assessments
Several factors complicate impact estimates for bark beetles on direct use values. Some of these include:

1. Forests are usually affected by multiple disturbance agents at the same time. Pests seldom act alone usually interacting sequentially or concurrently with other disturbances, partitioning out relative impacts of co-occurring disturbances presents a significant challenge.
2. Forests grow over large heterogeneous areas, much of which is often inaccessible.
3. Forests develop over long periods of time and go through many stages of development.

4. Forest components commonly respond to stresses and disturbances by compensatory development that mediates ecological impacts.
5. Pest impacts may manifest themselves at different places and different times for different forest resources.
6. Forests are managed for multiple objectives, and bark beetles have negative impacts on some resources but have no or positive impacts on others.

The factors listed above created a set of circumstances making it “extremely confusing to define forest damage” (Alfaro 1991).

Impact assessments involving multiple uses

Impact assessments based on single variables inadequately portray the changes in complex systems. Methods based on multiple variables offer promising alternatives for characterizing pest impacts on multiple objectives. Lundquist and Beatty (1999) developed an impact assessment method and used it in mixed-conifer stands in the Blue Mountains of Oregon. This method was used to show how co-occurring objectives could be both positively and negatively affected simultaneously by the same disturbance (Lundquist et al. 2002). Unfortunately, because these types of analyses are usually abstract, they are seldom easily transferred to the end user. Much more needs to be done on impact assessment and valuation and technology transfer for complex systems associated with bark beetle outbreaks.

Community based perception of risk and loss

Flint (2006) found that different communities differed in their perception of impacts and that different communities have a different “collective experience and community risk perception”. Following extensive outbreaks of spruce beetle in Alaska in the mid-1990s, the collective perception of some was that the spruce beetle was a natural component of the ecosysem and that human intervention was unnecessary. Others felt that the outbreaks were a disaster that greatly impacted their communities, socioeconomically and ecologically. Still others looked on it as an opportunity to generate income by selling and/or processing the dead standing trees. The sociological aspects of bark beetle activities are largely unexplored, and Flint’s (2006) result illustrate an exciting and important avenue for future research.

Existence values

Pearce (2001) lists two additional types of values: nonuse and option. Nonuse values are values associated with a willingness to pay to conserve the forest without concern for future use. The option value is based on alternative choices or options. Option values are values associated with the “willingness to pay to conserve the option of making use of the forest even though no current use is made of it…” An option is a contract that gives its holder the right, but not the obligation, to make a choice among alternatives within a specified period of time (Brigham and Ehrhardt 2002). The concept is based on real option theory (Amram and Kuatilka 1999), which is similar to financial options, differing only in that the former involves real assets rather than financial ones. The price someone is willing to pay to retain this option is its value. Determining this value is not trivial. Black and Scholes (1973) were awarded a Noble Prize for formulating an equation that calculates the value of financial options. Similarly, much work also has been done for real options.

The importance of perception and prediction

Both nonuse and option values depend on the perceived future state of the forest. Bark beetles can alter the direction and rate of stand/forest development or succession or both, and thus the perception as well as the reality of a future condition. Both nonuse and option values seem applicable to bark beetle impact assessments, and will probably become increasingly important in the not too distance future, but to date these have been little studied and their linkages to bark beetle infestations and the impacts caused by other types of disturbances is little understood.

Management Perspectives on the Consequences of Bark Beetle Infestations

The following examples of bark beetle outbreaks in various parts of the western USA show an array of impacts and identify specific needs that managers have encountered while addressing these impacts. In addition, some “success stories” are presented as examples to draw from for dealing with future outbreaks.

Mountain pine beetle— Idaho

In 2004, the Idaho Department of Lands and the USDA Forest Service formed a partnership to help private landowners in southcentral Idaho (Sawtooth National Recreation Area) deal with the effects of a severe mountain pine beetle (*Dendroctonus ponderosae*) outbreak in lodgepole pine (*Pinus contorta*). Both agencies provided technical assistance and financial cost share grants for treating forested lands. The cost share program was based on educating homeowners and contractors in the identification of beetle-infested trees and in understanding the appropriate treatment options. Treatments included removal of infested trees, thinning stands to increase resistance to bark beetles, applying a preventive carbaryl insecticide spray to high-value trees, and applying naturally occurring repellent pheromones to individual trees.

The effort to mitigate the impacts of mountain pine beetle in this one example have cost local, state, and federal land managers approximately 1.5 million dollars in implementation of a program comprising 71 projects over the 3-year period from 2004 to 2006. The program included the following actions: 28,000 beetle-infested trees removed over 486 ha; 32,000 trees sprayed with carbaryl on 400 ha; 17,000 pheromone bubble caps deployed on 243 ha; 149 ha thinned; and 18 ha replanted. The program is still ongoing and has received high praise from agency officials and the affected community. This program, and its grant coordinator, Jim Rineholt, recently received the Regional Forester’s Natural Resource Stewardship Award as an excellent example of the things that can be accomplished through collaboration and a strong commitment to sharing information and technology. Two overriding research and management needs that were identified by Rineholt were:

1. Improve the efficacy of verbenone or other bark beetle repellents in order to reduce the need for spraying carbaryl as a preventive treatment for bark beetles (This would also be useful for protecting high-elevation whitebark pine (*Pinus albicaulis*) stands where spraying is not an option).

2. The need to make USDA Forest Service, State and Private Forestry restoration funds available to prepare and implement vegetation management plans in developed areas.

Spruce beetle—Colorado
Spruce beetle (*Dendroctonus rufipennis*) outbreaks typically occur in dense stands of mature hosts, and the resulting mortality levels are very high. High-elevation stands on the Rio Grande National Forest are currently being affected by the spruce beetle. One particular concern involves the Wolf Creek Pass Ski Area, a popular recreation site in southern Colorado. The forest around the ski area is almost entirely composed of mature Engelmann spruce (*Picea engelmannii*), and could experience major changes if the bark beetle outbreak follows its typical patterns for these kinds of stands. These changes could impact recreation and other cultural services based on the experiences at Brian Head Ski Resort in southern Utah. The forests surrounding this resort were of similar composition to those at Wolf Creek Pass. After removing beetle-killed trees at the Brian Head Resort, the ski runs were no longer well-defined. In addition, the loss of a protective tree cover increased wind through the area and led to early and rapid loss of snow owing to lack of shading. The quality of the ski experience has been compromised because of the beetle outbreak.

Pinyon ips—Arizona
During a severe drought in 2002 and 2003, millions of pinyon pines (*Pinus edulis*) on more then 800,000 ha were killed in the Southwestern US by *Ips confusus* (pers. comm. J.D. McMillan 2007). Droughts have occurred in this area in the recent past, but the outcomes were never as extreme as they were in 2003. The direct and indirect effects of this particular outbreak were far-reaching. Of special concern were the effects on Navajo and Hopi tribal lands where traditional uses of the pinyon resource may be compromised. This loss of a major conifer species also raises concerns about future production of pinyon nuts as a food source for several wildlife species. Other important issues arising from the elevated pinyon mortality include potentially greater runoff and erosion in affected areas, increased near-ground solar radiation, an increased need for preventive sprays or repellants, and irrigation of pinyons on private lands. Several stand-replacing fires (http://wildfirenews.com/archive/070704.shtml) have already occurred across portions of the beetle killed forest and there are elevated fuel loads on other portions. Several management needs arose from this bark beetle outbreak, including the following:

- stand hazard rating systems for pinyon pine under drought and changing climate scenarios
- silvicultural prescriptions for pinyon/juniper woodlands
- information on fuel loading and potential fire behavior following *Ips* outbreaks

- new or improved preventative spray alternatives, or beetle repellents for protecting high-value pinyon and juniper
- techniques to address sociological impacts on traditional Hopi and Navajo uses of the pinyon/juniper resource

It is interesting to note that not everyone viewed the extreme pinyon mortality in a negative way. Some members of the local academic community advocated no management response and viewed the loss of pinyon in former grasslands as a positive outcome.

Western pine beetle—California
A wet period from 1890 through 1960 led to the establishment of extremely dense forests throughout California. Subsequent droughts have had dramatic effects on these forests. The most recent drought in southern California (in 2003 and 2004) has resulted in the mortality of thousands of pine trees over more than 200,000 ha. Over $500 million have been spent to remove dead trees, reduce fuels, and restore these forests. There have been numerous challenges to management of the drought-related mortality caused by the western pine beetle (*Dendroctonus brevicomis*). In particular, the public lacks an understanding of the problem. They think the forests are healthy again once the particular episode of bark beetle or fire-caused mortality has run its course. Nonetheless, there have been some successes including cooperative efforts in forming fire safe councils and area safety task forces that help address local stand thinning, fuels reduction, and restoration needs.

Research and management needs in this area include a continued look at the roles of air pollution and “pest complexes” in the health of pine forests, and making that information available to USDA Forest Service, Forest Health Protection staffs and the public. Funds for thinning treatments in southern California have practically disappeared because the forests are considered recreational rather than timber-producing.

Spruce beetle—Alaska
An outbreak of spruce beetle began in the 1980s on the Kenai Peninsula and lasted for 20 years, with unprecedented levels of tree mortality. The primary concerns from forest management agencies included increased fuel loads from dead trees and rapid growth of invasive grasses (Flint and Haynes 2006). Concerns from affected communities were much broader and included various environmental and community values. This disparity of concerns was seen as a problem by the USDA Forest Service and led to a 3-year study that found communities differed in their perception of impacts (Flint 2006). In general, people acknowledged that spruce beetle is a natural component of the ecosystem, but some felt the outbreak was a disaster that greatly impacted their communities socioeconomically and ecologically. Meanwhile, others considered it an opportunity to generate income by selling or processing beetle-killed trees. The sociological aspects of bark beetle activities are largely unexplored, and Flint’s (2006) results illustrate an exciting and important avenue of research. This type of study should be carried out in other settings in order to identify those areas where public and local community perceptions do not mirror those of resource managers. The resultant

increased dialogue and understanding between communities and managers will lead to better decision making and more appropriate action in response to forest disturbances.

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Literature Cited

Alfaro, R.I. 1991. Pest damage and its assessment. Northwest Environmental Journal. 4: 279–300.

Alfaro, R.I. 1991. Damage assessment and integrated pest management of forest defoliators. Forest Ecology and Management. 39: 275–281.

Amman, G.D. 1977. The role of the mountain pine beetle in lodgepole pine ecosystems impact on succession. In: Mattson, W.J., ed. The role of arthropods in forest ecosystems; Proceedings, 15th International Congress of Entomology; 1976 August 19–27, Washington DC. New York: Springer-Verlag: 3–18.

Amram, M.; Kuatilka, N. 1999. Real options: managing strategic investments in an uncertain world. IEEE Engineering Management Review. 27(3): 94–102.

Black, F.; Scholes, M. 1973. The pricing of options and corporate liabilities. Journal of Political Economy. May/June: 637–659.

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.

Brigham, E.F.; Ehrhardt, M.C. 2002. Financial management. Theory and practice, 10th ed. Mason, OH: Thomson Southwestern. 1051 p.

Chamberlain, J.; Bush, R.; Hammett, A.L. 1998. Non-timber forest products—the other forest products. Forest Products Journal. 48(10): 10–19.

Cleaves, D.A.; Brodie, J.D. 1990. Economic analysis of prescribed burning. In: Walstad, J.D.; Radosevich, S.R.; Sandberg, D.V., eds. Natural and prescribed fire in the Pacific Northwest forests. Corvallis, OR: Oregon University Press: 271–282.

Collins, S. 2005. Putting natural capital to work. Speech at Ecosystem Services Conference, 29 September 2005, Washington D.C. http://www.fs.fed.us/news/2005/speeches/05/capital-work.shtml. (12 January, 2009).

Cummings, R.G.; Harrison, G.W. 1995. The measurement and decomposition of nonuse values: a critical review. Environmental and Resource Economics. 5: 225–247.

Daily, G.D. 1997. Nature's services. Washington DC: Island Press. 392 p.

Daily, G.C.; Alexander, S.; Ehrlich, P.R.; Goulder, L.; Lubchenco, J.; Matson, P.A.; Mooney, H.A.; Postel, S.; Schneider, S.H.; Tilman, D.; Woodwell, G.M. 1997. Ecosystem services: benefits supplied to human societies by natural ecosystems. Issues in Ecology. 2: 1–16.

Daily, G.D. 2000. Management objectives for the protection of ecosystem services. Environmental Science and Policy. 3: 333–339.

Dale, V.H.; Joyce, L.A.; McNulty, S.; Nielson, R.P.; Ayres, M.P.; Flannigan, M.D.; Hanson, P.J.; Irland, L.C.; Luego, A.E.; Peterson, C.J.; Simberloff, D.; Swanson, F.J.; Stocks, B.J.; Wotton, M.B. 2001. Climate change and forest disturbances. Bioscience. 9: 723–734.

Daniel, T.C.; Orland, B.; Hetherington, J.; Paschke, J.L. 1991. Public perception and attitudes regarding spruce bark beetle damage to forest resources on the Chugach National Forest, Alaska. Unpublished report for U.S. Department of Agriculture, Forest Service, Forest Health Management, Region 10. 33 p.

Edmonds, R.L.; Eglitis, A. 1989. The role of the Douglas-fir beetle and wood borers in the decomposition of and nutrient release from Douglas-fir logs. Canadian Journal of Forest Research. 19: 853–859.

Erdle, T.A.; MacLean, D.A. 1999. Stand growth model calibration for use in forest pest impact assessment. The Forest Chronicle. 75(1): 141–152.

Flint, C.G. 2006. Community perspectives on spruce beetle impacts on the Kenai Peninsula, Alaska. Forest Ecology Management. 227: 207–218.

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

Gamarra, J.G.P.; He, F. 2008. Spatial scaling of mountain pine beetle infestations. Journal of Animal Ecology. 77(4): 796–801.

Hull, B.R. IV.; Buhyoff, G.J.; Daniel, D.C. 1984. Measurement of scenic beauty: the law of comparative judgment and scenic beauty estimation procedures. Forest Science. 30(4): 1084–1096.

Keane, R.E.; Rollins, M.G.; McNicoll, C.H.; Parsons, R.A. 2002. Integrating ecosystem sampling, gradient modeling, remote sensing, and ecosystem simulation to create spatially explicit landscape inventories. Gen. Tech. Rep. RMRS-GTR-92. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 61 p.

Kline, J.D. 2007. Defining an economics research program to describe and evaluate ecosystem services. Gen. Tech. Rep. PNW-GTR-700. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 46 p.

Kolb, T.E.; Dodds, K.A.; Clancy, K.M. 1999. Effect of western spruce budworm defoliation on the physiology and growth of potted Douglas-fir seedlings. Forest Science. 45: 280–291.

Lundquist, J.E.; Beatty, J.S. 1999. A conceptual model for defining and assessing condition of forest stands. Environmental Management. 23: 519–525.

Lundquist, J.E.; Negrón, J.F. 2000. Endemic forest disturbances and stand structure of ponderosa pine (*Pinus ponderosa*) in the upper pine creek research natural area, South Dakota, USA. Natural Areas Journal. 20: 126–132.

Lundquist, J.E.; Goheen, E.M.; Goheen, D.J. 2002. Measuring positive, negative, and null impacts of forest disturbances: a case study using dwarf mistletoe on Douglas-fir. Environmental Management. 30(6): 793–800.

Martin, K.; Norris, A.; Drever, M. 2006. Effects of bark beetle outbreaks on avian biodiversity in the British Columbia interior: Implications for critical habitat management. British Columbia Journal of Ecosystem Management. 7(3): 10–24.

McGregor, M.D. 1985. Soil and water quality. In: McGregor, M.D.; Cole, D.M., eds. Integrating management strategies for the mountain pine beetle with multiple-resource management of lodgepole pine forests. Gen. Tech. Rep. INT-GTR-174. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 44 p.

McMillin, J.D.; Allen, K.K. 2003. Effects of Douglas-fir beetle (Coleoptera: Scolytidae) infestations on forest overstory and understory conditions in western Wyoming. Western North American Naturalist. 63: 498–506.

Millennium Ecosystem Assessment. 2003. Ecosystems and human well-being. Washington DC: Island Press. 245 p.

Nunes, P.A.L.D.; van den Bergh, J.C.J.M. 2001. Economic valuation of biodiversity: sense or nonsense? Ecological Economics. 39: 203–222.

Pearce, D.W. 2001. The economic value of forest ecosystems. Ecosystem Health. 7(4): 284–296.

Progar, R.A. 2005. Five-year operational trial of verbenone to deter mountain pine beetle (*Dendroctonus ponderosae*; Coleoptera: Scolytidae) attack of lodgepole pine (*Pinus contorta*). Environmental Entomology. 34: 1403–1407.

Romme, W.H.; Knight, D.H.; Yavitt, J.B. 1986. Mountain pine beetle outbreaks in the Rocky Mountains: regulators of primary productivity? American Naturalist. 127: 484–494.

Rosenberg, R.S.; Smith, E.L. 1998. Assessing forest scenic beauty impacts of insects and management. FHTET 98-08, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Health Protection, Forest Health Technology Enterprise Team. 39 p.

Ross, S.A.; Westerfield, R.W.; Jordan, B.D. 2000. Fundamentals of corporate finance. Boston: The McGraw-Hill Companies. 694 p.

Samman, S; Logan, J. 2000. Assessment and response to bark beetle outbreaks in the Rocky Mountain Area. Gen. Tech. Rep. RMRS-GTR-62. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 46 p.

Schmid, J. M.; Hinds, T. E. 1974. Development of spruce-fir stands following spruce beetle outbreaks. Res. Pap. RM-131. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 16 p.

Schroeder, H.W.; Daniel T.C. 1981. Progress in predicting the perceived scenic beauty of forest landscapes. Forest Science. 27(1): 71–80.

Schowalter, T.D. 2006. Insect ecology: an ecosystem approach. 2nd ed. San Diego: Academic Press. 572 p.

Smith, A.H., Pinkard, E.A.; Stone, C.; Battaglia, M.; Mohammed, C.L. 2005. Precision and accuracy of pest and pathogen damage assessment in young eucalypt plantations. Environmental Monitoring and Assessment. 111: 243–256.

Smith, E.L.; McMahan, A.J.; Eager, T. 2002. Landscape analysis applications of the westwide pine beetle FVS extension. In: Crookston, N.L.; Havis, R.N., comps. Proceedings of the second Forest Vegetation Simulator conference; 2002 February 12–14, RMRS-P-25. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 62–68.

Stark, R.W. 1987. Impacts of forest insects and diseases: significance and measurement. Critical Reviews in Plant Sciences. 5: 161–203.

US Department of Agriculture. 1997. Forest insect and disease conditions in the United States 1996. Washington DC: U.S. Department of Agriculture, Forest Service, Forest Health Protection. 87 p.

Walsh, R.G.; Loomis, J.B.; Gillman, R.A. 1984. Valuing option, existence, and bequest demand for wilderness. Land Economics 60(1): 14–29.

Veblen T.T.; Hadley, K.S.; Nel, E.M.; Kitzberger, T.; Reed, M.; Villalba, R. 1994. Disturbance regime and disturbance interactions in a Rocky Mountain subalpine forest. Journal of Ecology. 82: 125–135.

Vining, J.; Daniel, T.C.; Schroeder, H.W. 1984. Predicting scenic beauty in forested residential landscapes. Journal of Leisure Research. 16: 124–135.

Werner, R.A.; Holsten, E.H. 1984. Factors influencing generation times of spruce beetles in Alaska. Canadian Journal of Forest Research. 15: 438–443.

Wood, S.L. 1982. The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae), a taxonomic monograph. Great Basin Naturalist Memoirs. 6. 1359 p.

Zhang, Y.; Li, Y. 2005. Valuing or pricing natural and environmental resources? Environmental Science & Policy. 8: 179–186.