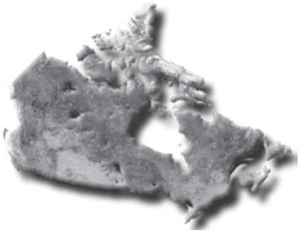

A Synthesis of the Economic Efficiency of Beetle-Proofing Management Options

Mike N. Patriquin; Nancy L. Leake; William A. White

Mountain Pine Beetle Initiative
Working Paper 2005–17

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Abstract

The mountain pine beetle is a naturally occurring forest insect in western Canada that acts as an agent of change and renewal in the forest system. Under certain conditions, the beetle populations expand rapidly resulting in an infestation with the ability to disrupt the future flow of timber used to support human communities. Beetle-proofing is a form of preventative maintenance used to maintain the economic viability of pine forest stands susceptible to mountain pine beetle infestation. This report provides a synthesis of the existing literature that examines the economic feasibility of beetle-proofing methods. The range and scope of the literature is limited, but in general commercial thinning for the purpose of beetle-proofing offers the most promise and in certain conditions was determined to offer positive net benefits. Best practice approaches for examining the economic efficacy of beetle-proofing methodologies are also discussed.

Résumé

Le dendroctone du pin ponderosa (DPP) est un insecte indigène de l’Ouest du Canada qui agit comme vecteur de changement et de renouvellement dans l’écosystème forestier. Dans certaines conditions, les populations du scolyte augmentent rapidement, ce qui provoque une flambée capable de perturber l’exploitation du bois nécessaire au soutien des communautés. Les activités de protection contre le DPP constituent une forme d’entretien préventif permettant de maintenir la viabilité économique des boisés de pins susceptibles d’être attaqués par le scolyte. Le présent rapport offre une synthèse des précédentes études axées sur la faisabilité économique des méthodes de protection contre le DPP. La diversité et la portée des études antérieures sont limitées mais il apparaît en général que l’éclaircie commerciale semble être la méthode la plus prometteuse pour la protection des boisés contre le DPP et qu’elle a offert des bénéfices nets positifs dans certaines conditions. Les meilleures approches pour examiner l’efficacité économique des méthodes de protection contre le DPP sont également abordées.

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1 Introduction

The mountain pine beetle (*Dendroctonus ponderosae)* is a naturally occurring forest insect in western Canada. Mountain pine beetles (MPB) prefer mature lodgepole pine (*Pinus contorta*) forests and, when favorable conditions exist in the forest and climate, act as an agent of natural disturbance and forest renewal. Conditions in the Northern and Southern Interior Forest Regions of British Columbia, Canada have resulted in populations of MPB of epidemic proportions leading to massive lodgepole pine tree mortality. While the MPB is a natural agent of forest change, human systems rely on a steady flow of timber to support economies and communities. Mature pine stands are the most susceptible to beetle damage, but also the most coveted in terms of the economic gains from timber harvesting. The magnitude of the current MPB infestation has the potential to seriously disrupt business-as-usual forest management and timber harvest flows.

MPB must be recognized as a threat to the maximum value or "disturbance free" timber value contained in a forest stand. Left unchallenged, mountain pine beetle populations can mass attack a pine stand, leaving only gray or red dead trees, until the stand can regenerate. This translates into changes in aesthetic and other non-market values and the potential for huge losses in timber market values. In an effort to maintain the economic viability of their stands, many forest license and leaseholders have begun considering or adopting beetle-proofing methods to lessen the impact should the mountain pine beetle attack the stand. Beetle-proofing, regardless of the technique employed, is a form of risk management or a means to optimize timber value returns in the presence of risk.

Beetle-proofing, primarily through silvicultural measures, changes stand characteristics thereby decreasing stand susceptibility to MPB mortality. The goal of beetle-proofing is to optimize timber value returns in the presence of risk and, regardless of the method, is a form of risk management that relates to both public land management objectives and private timber returns. The costs associated with beetle-proofing methods may be higher than business as usual forest management, but may be justified if they prevent extensive damage to public and private forest resources.

This study is a review and synthesis of the existing literature pertaining to assessments of the net benefits derived from beetle-proofing.

2 Literature Review

2.1 MPB Risk and Stand Vulnerability

Mature and over-mature pine stands are relatively abundant in western Canada. For example, successful forest fire suppression and the relatively recent consideration of lodgepole pine as a commercially viable species in the 1970s has resulted in an abundance of mature and over-mature lodgepole pine stands in British Columbia (Whitehead et al. 2001). While mature stands yield the highest financial returns, they are also preferred by MPB. In terms of stand characteristics, the ideal conditions for the development of MPB populations are pure pine stands of even-aged, large trees with a closed canopy (USDA Forest Service 2000). There are four specific characteristics of natural lodgepole pine stands that indicate a high susceptibility to MPB outbreaks: average tree diameters over 20 cm, trees that are more than 80 years old, stand densities between 750-1500 trees per hectare, and a significant proportion of trees over 25 cm diameter at breast height (dbh) (Whitehead et al. 2001).

A high average tree diameter in a stand indicates favorable conditions (food and space) that assist in brood development of an expanding beetle population (Whitehead et al. 2001). Specifically, tree diameter is highly correlated with phloem thickness. Mountain pine beetle population growth requires trees with phloem at least 0.1 inches thick (Amman and Safranyik 1985). However, as trees age in natural stands, their vigor (primary beetle defence mechanism) decreases, leaving their resistance low to the attack of the beetles and their accompanying blue-stain fungi. Younger trees with higher vigor are able to produce more resin that can be used to expel beetles attacking the tree. The stand density affects individual tree vigor and also influences the microclimate within a stand. A more open stand has higher light levels, warmer bark temperature, and stronger winds, all conditions that make the stand less favorable to beetle dispersal, attack, and brood development. However, outbreaks are known to occur in stands with medium to low susceptibility at times when beetle pressure is high, or when location is an influential factor (Whitehead et al. 2001).

A variety of risk rating systems exist and they all serve to determine how susceptible stands are to attack. This is particularly useful for identifying highly susceptible stands that may require management to prevent future attack. Depending on the host pine species, the risk rating systems are based upon characteristics such as: average age or average basal area for a particular stand, average tree diameter, elevation and latitude, and/or stand structure (USDA Forest Service 2000). For example, stand density management diagrams can be used to identify areas of susceptibility by displaying stand characteristics such as density and tree diameters (Whitehead et al. 2001). Two of the most commonly applied risk rating systems are the United States Department of Agriculture (USDA) Forest Service Risk Rating System and the Shore and Safranyik Risk Rating System (USDA 2000; Shore and Safranyik 1992).

The USDA Forest Service Risk Rating System is based on climate factors (a combination of elevation and latitude), average tree diameter and average tree age. While this is a relatively simple framework, it ignores the proximity and size of MPB populations. The Shore and Safranyik Risk Rating System uses components from other risk rating models, but also includes information specific to area-specific beetle pressure. The rating system calculates measures for both stand susceptibility and beetle pressure, which are combined to calculate an overall stand risk rating.

Risk rating systems can be used to direct harvesting to forest stands that have high levels of risk, in an effort to avoid losses. Risk ratings can also help identify stands where beetle proofing techniques might be employed or where the assessment of the economic feasibility of beetle proofing efforts could be targeted.

2.2 Beetle-proofing

Beetle-proofing is a form of preventative maintenance that attempts to maintain the economic viability of pine forest stands susceptible to MPB infestation. Regardless of the type of forest pest, preventative measures are deemed as a better procedure, when compared to trying to control an epidemic (Smith 1990). Beetle-proofing options include patch cutting (relates more to MPB population control), partial cutting or commercial thinning, selective harvest, prescribed fire, insecticide spraying, and other chemical/pheromone trapping or spraying. All of these forms of beetle-proofing are intended to change the stand characteristics alter the susceptibility to MPB populations (ASRD 2002; Whitehead 2002).

Beetle-proofing can be organized into two phases (Amman and Safranyik 1985). The first phase consists of preventative measures that increase stand resistance to beetle mortality. In other words, managing a stand with the expectation of reducing or avoiding future beetle pressure. The second phase consists of activities to control or contain the spread of infestation. Phase one beetle-proofing activities should be considered for young, regenerating stands and in areas where mature pine stands remain highly susceptible but currently unaffected. Phase two beetle-proofing strategies are best implemented in highly susceptible areas adjacent to or located within areas of light infestations. In areas of heavy infestation or reaching epidemic proportions, beetle-proofing is abandoned in favor of salvage operations used to derive some monetary value from infested timber.

The current MPB infestation in British Columbia, Canada is a case study example of an area where beetle-proofing may have been a “good” option (in retrospect) according to both short-term and long-term economic criteria compared to the patch cutting and salvage cutting currently underway. While it may be too late for beetle-proofing in the current interior forests of British Columbia, beetle-proofing options hold potential for regenerating forests and unaffected regions.

The following section contains a detailed review of beetle-proofing methods.

A variety of methods can fit under both Phase 1 and Phase 2 beetle-proofing. Whether partial cutting or applying chemicals, these methods are intended to alter the stand characteristics in a way that makes them less attractive to MPB infestation, but still retain high harvest value. Effectiveness of the methods varies in terms of their ability to appropriately deter infestation and in terms of their economic efficiency. The effectiveness of beetle-proofing methods can be assessed in a number of ways. However, this study focuses on the effectiveness of beetle-proofing methods and their respective cost effectiveness.

2.2.1 Phase 1 Beetle-Proofing

Phase 1 beetle-proofing addresses the characteristics of pine forest stands that are not under current beetle pressure. While prescribed burning may be an effective means to alter stand characteristics, it is recognized that partial cutting (pre-commercial and commercial thinning) can potentially yield higher financial timber returns compared to other beetle-proofing methods in commercial forests (Amman and Safranyik 1985). Managing natural fires and prescribed burns are primarily amelioration tactics for consideration in non-commercial forest beetle-proofing strategies (Amman and Safranyik 1985). For this reason, Phase 1 beetle-proofing is focused on silvicultural manipulation such as partial cutting.

2.2.1.1 Uniform Spacing

Thinning to uniform spacing is a favorable method of beetle-proofing as it improves the vigor of individual trees and alters the stand microclimate by increasing air movement, light intensity, and temperature in the clear bole zone. These conditions make the stand less conducive to mountain pine beetle brood development and population growth. The optimal spacing between trees is 4-5 meters (BC Forest Service 1999; Mitchell 1994). A proven beetle-proofing method is to commercially thin mature stands to a uniform spacing to 400-625 sph. This methodology provides enough wood to make the harvesting a viable control method and temporarily significantly reduces the stand's susceptibility to mountain pine beetles (Whitehead et al. 2001). For instance, spacing in age-class 4 or 5 in predominantly pine stands can reduce its susceptibility for a short amount of time (10-20 years), until it can be harvested (Whitehead 2002). Thus, thinning to uniform spacing should be considered a "holding tactic"(BC Ministry of Forests 1995).

2.2.1.2 Thinning From Below

Thinning from below is also a useful beetle-proofing technique, as it promotes tree vigor, thereby increasing its resistance to beetle attack. To maximize this effect, the larger, healthier trees should be retained (BC Forest Service 1999; Mitchell 1994). Various studies suggest that a specific combination of microclimate and tree vigor can decrease both tree and stand susceptibility to mountain pine beetle attack (Safranyik et al. 1974; Bartos and Amman 1989; McGregor, Amman, Schmitz and Oakes 1987; Mitchell et al. 1983; Mitchell, 1994). Whichever thinning method is used, care should be exercised to avoid damaging the residual trees; damage can put trees under stress, making them more vulnerable to beetle attack (Whitehead et al. 2001).

2.2.1.3 Shelterwood

A beetle-proofing prescription related to commercial thinning, is a two-pass shelterwood system. This method accounts for regeneration objectives set for the time between harvest and entries. Even though harvesting operations kill or damage 50%-70% of the advanced regeneration, studies at Canadian Forest Service research sites show that the characteristics of the undamaged stems measured 5 years after thinning are much more favorable than stems in unthinned blocks. Also, previously beetle-proofed stands that were underplanted with Engelmann spruce by Crestbrook Forest Industries Ltd. have shown that despite a slow start, the spruce grow significantly faster by the third or fourth season after planting (BC Forest Service 1999).

2.2.1.4 Success Factors

While the concept of partial cutting is appealing for beetle-proofing, its success depends on a number of factors. Successful partial cutting requires specific stand and operational conditions if it is to be effective. Stands must have relative windfirmness (ability to withstand blow down), a mean diameter of more than 20 cm, a stand density of 900-1600 sph, no symptoms of mistletoe or root disease, and no greater than 10% of the stand can be presently infested with mountain pine beetles (Whitehead et al. 2001).

It is important that the thinning prescription be compatible with the overall landscape plan (Whitehead 2001). Other necessary factors include clear objectives and criteria, proper cutting layout, experienced loggers, appropriate equipment, continual cooperation from all parties, and a commitment to properly practice the partial cutting prescription required for beetle-proofing. During partial cutting, block layouts have to be defined with careful consideration for terrain and stand structure. Skid trails should be laid out according to operational and silvicultural requirements and block-specific terrain conditions. However, because skidding causes the majority of residual damage, good trail layouts and machine operators, and the use of rub trees are all necessary elements of this method of beetle-proofing. Pre-locating skid trails does help minimize disturbance and residual stem damage (BC Forest Service 1999).

Beetle-proofing (using partial cutting) can help satisfy the integrated resource management objectives that often exist in forests in British Columbia. These objectives are necessary due to the various restrictions The Forest Practices Code of BC places on operational harvesting such as visual quality objectives, and riparian management and adjacency rules. However, integrated resource management can be difficult in pine-dominated stands at risk to mountain pine beetle epidemics. Beetle-proofing high-risk stands can prevent catastrophic loss caused by the mountain pine beetle while meeting objectives such as wildlife habitat or visual quality through the maintenance of mature forest cover. In turn, this permits some mature pine stands to be held in the scheduling queue for 10-20 years (BC Forest Service 1999). For example, landscape level plans should encourage the presence of insectivorous birds, such as woodpeckers, which help to decrease or maintain the level of beetle population in an area (BC Ministry of Forests 1995). If procedures are followed explicitly, partial cutting can also yield other benefits such as (BC Forest Service 1999):

- Increased productivity due to the stability of long-term harvesting of a steady flow of timber.
- Positive impacts on the timber supply, including the recovery of volumes normally lost to natural mortality, timely access to more wood thereby decreasing the incidence of falldown and/or fiber shortfalls through reduced adjacency constraints.
- The value of cultivating stands that have high quality mature trees with layers of established regeneration and no adjacency restrictions.
- Decreases in the downward pressure on fiber flow from the reduced susceptibility or degree of damage of a mountain pine beetle outbreak.
- The ability to achieve other resource management objectives that require the maintenance of a mature canopy cover.

Beetle-proofing by partial cutting produces silviculture challenges such as windfirmness and residual stem vigor. There is also concern for the success of regeneration under partial shading, and the potential for damage to the lower layers while removing the overstory. The lack of skilled workers or respect for the required silvicultural practices can turn all of these issues into consequences.

Licensees who practice partial cutting incur higher forest management costs. The cost of trail construction and other activities related to partial cutting depends on the average volume/tree harvested, volume/ha removed, terrain and soil conditions, and ranges in cost from \$3-6/m^3. This is comparable to other partial cutting systems, but is approximately 40%-50% higher than the cost of clearcut blocks. The total cost of partial cutting is approximately 15%-40% higher than harvesting by clearcut in a similar stand. Along with higher costs, partial cutting carries with it a need for more responsibility and assumption of risks associated with forest health, silviculture, windthrow, and road maintenance (BC Forestry Services 1999). However, Steventon et al. (1998) insist that a lack of experienced personnel and appropriate machinery are factors that drive up the costs of partial cutting. Thus, as crews gain experience and new harvesting machinery is acquired; the overall cost of partial cutting should fall. Also, partial cutting costs include the cost of layout, and road and trail establishment, but this is an investment as well, for an entry is required for the final harvest (Steventon et al. 1998).

There are numerous suggestions in the literature for improving the effectiveness of partial cutting. For example, since partial cutting logging costs are largely influenced by the terrain, average piece size, and volume/ha removed, costs may be minimized by decreasing skid trail spacing, and increasing the road and landing densities (BC Forestry Services 1999). Results from a three-site thinning study in BC in the early 1990s suggested that harvest economics could improve if the following conditions were present (Whitehead 2002):

- If 125m^3/ha is removed.
- If a clearcut close to the thinned stand is included in the contract.
- Experience of crew.
- Shorter hauling distances.
- Large piece size present and wider spacing used.

2.2.2 Phase 2 Beetle-Proofing

Phase 2 Beetle-proofing refers to control strategies used to contain small outbreaks in order to minimize the impact of the mountain pine beetle in attacked areas. An effective Phase 2 beetle-proofing program requires intensive monitoring for new beetle infestations and swift response with control treatments in order to maintain timber harvest schedules and prevent large timber losses (Mitchell 1994). The West-Central B.C. Mountain Pine Beetle Action Plan 2001 identifies 'best beetle practices' as including activities such as small patch harvesting, incremental hauling, hand falling/skidding and long skidding for beetle control (BC Ministry of Forests 2003). Single-tree treatments and prescribed fire are also deemed effective beetle control methods in certain circumstances.

In light infestations, small patch harvesting or single-tree treatments are combined with one or more of the other direct beetle control methods. The idea of direct control is to contain an outbreak by killing the beetles or protecting trees in the area from direct attack. Early attempts of direct control involved the felling, peeling and/or burning of infested trees. Other methods used in recent years include Monosodium Methanearsenate (MSMA) application, the use of trap trees, and the use of insecticides.

Many studies have shown that direct control methods for the mountain pine beetle are feasible and effective (Smith 1990). For example, Whitehead, Martin, and Powelson (2001) state that with close observation and consistent application, direct control methods such as patch logging, or fall-and-burn treatments of infested trees, can greatly prevent or slow landscape-level outbreaks when these control methods are used on initial populations. Since very few direct pest control methods are permanent, the effectiveness of direct control strategies for the mountain pine beetle can be assessed by how long the control's positive effects in the stand last (Smith 1990). In terms of the mountain pine beetle, direct control strategies are effective if they successfully manage the beetle population in the area for 10-20 years, until the stand can be harvested.

Until harvest, most direct control methods require repeated application to prolong their success of containing or managing the beetle population. It should also be noted that some preventative maintenance strategies used in Phase 1 beetle-proofing (such as partial cutting) can still be used in areas of light infestations to help reduce tree mortality in the stand.

Due to the difficulty in detecting green-attack areas, often this first stage of infestation goes unnoticed. However, infestations are clearly visible using aerial surveying in the second year of infestation. Second year infestations are characterized as "red-attack" trees. Once the beetles exit the tree following the first stage of infestation, the trees' needles turn red, indicating that the trees are already close to dying. Thus, there is a time lag in infestation detection when initial detection occurs at the red-attack stage. However, it is better to destroy the infestation at this second stage, rather than leave it undetected and uncontrolled. Once the infestation has been detected in the air, ground surveying is necessary to detect all the infested trees in the area (BC Ministry of Forests 2003). During this process, the underside of the bark must be examined to confirm that the infestation is a result of the mountain pine beetle. Ground-surveying also tries to estimate the success of the attack (Pacific Forestry Centre 2002).

The completion and results of both procedures assist in determining the proper treatment for the area. At the red-attack stage, the infested areas may be small or large. If the latter situation applies, Phase 2 beetle-proofing will likely be ineffective. In large areas of red-attack trees, some trees may have already advanced to the "gray" or dead stage. With an abundance of red-attack trees and some gray trees, the only option for licensees is to salvage the wood to obtain some value from the stand. The salvage of gray trees is more difficult than red-attack trees, and the low value derived from gray trees makes their salvage uneconomical in some cases.

The choice of beetle control method for Phase 2 beetle-proofing depends on the land-use policies, site condition, and level of infestations (CLMA/NFPA Mountain Pine Beetle Emergency Task Force 2000). When choosing the preferred beetle control method, it also must be compatible with the area's comprehensive forest health plan. For example, single tree treatments may not be favorable if root disease or dwarf mistletoe is also present in the stand (CLMA/NFPA Mountain Pine Beetle Emergency Task Force 2000).

2.2.2.1 Patch Cutting

Evidence of light infestation and/or small outbreaks can be found in "green-attack" trees and some areas of "red-attack" trees. "Green-attack" trees refer to infested trees where the beetles are still alive under the bark. This is the first stage of infestation, when the trees are still green. As reported earlier, the presence of green-attack trees often goes undetected. Since green-attack trees are difficult to monitor, licensees must use superior aerial and ground information collection to anticipate the location of green-attacked trees and subsequently respond with rapid harvesting efforts to contain the epidemic. If "green-attack" trees are harvested with first priority, there is a greater chance of controlling an epidemic. Quite often, green-attack trees exist in small areas of less than 2 ha, thus requiring small patch harvesting.

Although small patch cutting is seen as the most effective way to combat the beetles (when the beetles are still in the trees), it can be very labor intensive, and many treatments over several years may be required to ensure that the mountain pine beetle is effectively controlled. Also, industry officials estimate that harvesting numerous small patch areas can increase costs on average by \$10-\$30 per cubic meter. Thus, the most effective method of fighting the mountain pine beetle infestations can also be the most expensive (CLMA/NFPA Mountain Pine Beetle Emergency Task Force 2000). Areas under intermediate level of beetle attack are usually characterized by up to 100 infested trees per patch. In these situations, small-patch logging is an appropriate control method, provided that there is good access to the site, and if the beetle is concentrated in a few areas (Pacific Forestry Centre 1993).

2.2.2.2 Partial Cutting

An older study in Montana examined the effectiveness of partial cutting in reducing the timber losses in mature lodgepole pine stands where light infestations were present. Due to resource management objectives such as the maintenance of forest cover for wildlife and protection of riparian areas, partial cutting was one of the few defence mechanisms that could be used to contain the mountain pine beetle infestations.

From 1978-1980, various partial cutting prescriptions were applied to lodgepole pine stands in the Kootenai and Lolo National Forests in western Montana, and other stands were left unthinned as controls. The partial cutting prescriptions consisted of three levels of mechanically spaced thinnings, and three levels of diameter limit cuts. In the five year period following the thinnings, the results showed that the partial cutting greatly reduced the amount of trees lost to the mountain pine beetle as compared to the unthinned stands.

Post treatment mortality of trees ≥12.7 cm dbh in thinned stands averaged 6%-17.1% in the Lolo forest and 4%-38.6% in the Kootenai forest. In comparison, 73.1% of trees in the Lolo forest and 93.8% of trees in the Kootenai forest were lost to the mountain pine beetle in the unthinned stands. The differences in results among partial cutting prescriptions were not significant. Thus, partial cutting proved to be effective at reducing losses to the mountain pine beetle in lodgepole pine stands, and also allowed other resource values to be protected (McGregor, Amman, Schmitz, and Oakes 1987).

2.2.2.3 Prescribed Fire

Prescribed fire may be used as a type of patch cutting in early stages of infestation. This option is especially useful in protected areas that do not allow commercial harvesting, or in areas where harvesting is difficult (CLMA/NFPA Mountain Pine Beetle Emergency Task Force 2000). However, two conditions are necessary in order for prescribed fire to effectively control the beetle: the fire must have a level 4 intensity to boil the phloem of the pine trees, and the fire must be implemented prior to the annual beetle flight period (Hawkes and Taylor 2002). Since the latter condition can make it difficult to use prescribed fire in the required time frame, this beetle control method is best used to supplement techniques such as single-tree treatments (ASRD 2002).

Prescribed fire can be a used for mountain pine beetle management, but it is not without risk. In 1995 and 1997, the effectiveness of prescribed burns in Tweedsmuir Park was reduced by unfavorable weather conditions. In the 1995 burn, it was estimated that only half of the beetle population was killed (Hawkes and Taylor 2002).

2.2.2.4 Single Tree Treatment

A few spots of infested trees characterize the early stages of mountain pine beetle infestations. Thus, single-tree treatment is a feasible control strategy. Infested trees are felled and debarked at the infestation site. Depending on accessibility issues, the trees can be mechanically debarked or chipped. If the area is fire safe, it is possible to fell, buck, pile and burn the infested trees at the infestation site. The bark of every felled tree must be burnt, and the remaining stumps must be debarked or burned. Even though it can be labor-intensive, single-tree (spot removal) treatments are preferable in the sense that they conserve both timber and non-timber values, and promote the regeneration of species other than lodgepole pine. Due to the methodology and consequent effects on the forest, the single-tree treatment is used as the main control strategy in lightly beetle-infested environmentally sensitive areas (ASRD 2002).

2.2.2.5 Chemicals

Since the beetles attack under the bark of the trees, aerial spraying of pesticides is not a valid option (CLMA/NFPA Mountain Pine Beetle Emergency Task Force 2000). However, in areas of light infestation, insecticides can be used as a beetle control method. Three options exist for the use of insecticides. The first option is to apply insecticide to the bole of infested trees prior to beetle emergence (Pacific Forestry Centre 1993). The second and third way to use insecticides as beetle control methods are both population control methods that work best in combination with another beetle control strategy. Infested trees can be treated with Monosodium Methanearsenate (MSMA). This herbicide has insecticide properties, and must be injected into infested trees within three to four weeks of the initial beetle attack.

Although MSMA is designed to kill the tree and the beetles in the tree, there are two drawbacks to this control option. First, it is difficult to completely control the entire beetle population in the area with this method, especially if the infestation area is large. Secondly, MSMA serves mainly to temporarily slow infestations. Thus, this treatment is best considered as a population control method during the second stage of beetle infestations. Two advantages for using MSMA are cost effectiveness and the fact that dead trees are made available for wildlife habitat (ASRD 2002). However, as the size of the infested area increases, the cost effectiveness of MSMA decreases; MSMA treatment costs may be higher than the value of the wood saved (Amman et al. 1997).

The third way to use insecticides for mountain pine beetle control is to establish trap trees in lightly infested stands. These trap trees are baited with pheromones and treated with silvicide to attract and concentrate the beetles in one area of the stand. However, this method is only effective at reducing populations when the number of beetles in the area is manageable to begin with (Pacific Forestry Centre 1993).

Like insecticides, synthetic pheromones are also most effective when used in combination with other applied beetle control methods. The pheromones are useful in identifying newly attacked trees or for containing the attack to a certain area (Pacific Forestry Centre 1993). Containment of small infestations in this manner can prevent the outbreak from spreading into adjacent, susceptible areas, as well as control the beetle populations until there is suitable access to allow for more aggressive stand management (Amman et al. 1997).

Borden, Chong, and Lacey (1986) studied the use of pheromones to concentrate attacks in lightly infested areas. This was one of the first studies that tested the use of pheromones to attract and contain beetles in lightly infested stands before any logging took place, and one of the first that tried to attract the beetles from within a forest stand.

The study took place in the valley of Summers Creek, an area between Princeton and Merritt, British Columbia. The ravine in this area was heavily infested with mountain pine beetle. Areas adjacent to the ravine were characterized as high hazard stands of mature or over-mature lodgepole pine. Some of these adjacent stands were either lightly infested or not infested, but all were threatened by the intense infestation in the ravine. Borden et al. (1986) attempted to use pheromone-baited trees in three different blocks to shift the loci of the ravine infestations into the baited blocks, during the mountain pine beetle annual flight period. The authors hoped that the baited blocks would sufficiently contain the mountain pine beetle population in order to prevent it from reaching epidemic proportions.

Borden et al. (1986) surveyed the incidence of attacked trees versus those not attacked. The results showed that the pheromones were effective as a Phase 2 beetle-proofing technique. More specifically, when pheromones were used in high hazard stands prior to any logging activity, they were effective in attracting and containing the mountain pine beetles to areas in and around the baited areas. The authors identified factors that compromised the pheromone's effectiveness. If the pheromone was applied to trees at a level within the understory canopy, the beetles merely flew above the canopy (and the pheromone plumes) and attacked trees according to their own pattern. The authors also found that if the beetles had escaped the original heavily infested ravine and already traveled 100 or 200 or more meters from the baited blocks, the baited blocks were only moderately or not successful at all in diverting beetle populations into the baited blocks (Borden et al. 1986).

2.2.3 Summary

After reviewing Phase 1 and Phase 2 beetle-proofing methods and their effectiveness, the literature suggests that the best prescription for reducing future losses from mountain pine beetle infestations is to combine silvicultural methods that decrease the stand's susceptibility to beetle attack with direct procedures that control beetle pressure. For example, in lightly infested stands, prevention tactics can be used in combination with control strategies to reduce the chances that the infestation readily spreads to adjacent, healthy trees. In British Columbia, the Ministry of Forests and the Ministry of Environment, Lands and Parks have committed to implementing a variety of initiatives to combat mountain pine beetle infestations. These include the following (CLMA/NFPA Mountain Pine Beetle Emergency Task Force 2000):

- Increased emphasis on tactics to reduce mountain pine beetle populations, rather than just trying to salvage damaged wood;
- More frequent aerial and ground information collection in order to develop aggressive and jointly developed management plans;
- Rapid road construction to access stands most susceptible to infestation and stands already infested;
- Increased regulatory flexibility to speed approval of beetle-proofing measures;
- Improved efficiency of government processes in order to modify existing permits or plans.

2.3 Economic Feasibility

The mountain pine beetle outbreaks impose many short and long-term economic impacts. In the short term, licensees face preventative maintenance costs, increased harvesting expenses to aggressively combat light infestations, and lost or decreased value of infested growing stock. In areas of uncontrollable outbreaks, there are also increased costs for salvaging operations, and increased losses of growing stock. In the long-term, some of the impacts include potential costs of rehabilitating damaged areas over the next rotation, and concern for the future timber supply to meet forecasted consumption levels. Also, if the loss of growing stock is sufficiently large that future timber supply falls short of prior expectations, there may be long-term impacts on the timber industry and the economy as a whole (Milne 1986).

Due to the numerous impacts from mountain pine beetle infestations, the economics of beetle-proofing is difficult to assess. The costs of beetle-proofing or the costs of decreasing beetle induced losses must be weighed against the risk of the monetary and social environmental losses resulting from beetle damaged trees (Alberta Energy and Natural Resources 1981). Also, the costs and benefits of beetle control strategies accrue over many years. Many early economic feasibility assessments compared the cost of the beetle control method against the value of the timber saved (Renzie and Han 2000). In almost all of these studies, the value of timber saved was much more than the control costs. There are many studies that compare the costs and productivities for various silviculture practices. However, this methodology should be supplemented with measures of opportunity costs, long-term costs, and non-timber values in order to guide beetle-proofing assessments (Renzie and Han 2000).

However, a proper assessment must measure the Net Present Value (NPV) of the costs and benefits of beetle control for all the years until the stand is harvested (Smith 1990). Although a comprehensive assessment of the economic feasibility of beetle-proofing accounts for the costs and benefits over many years, some studies have shown cost/benefit analyses for a point in time. These oversimplified studies merely calculate the profit (negative or positive), for an acre or hectare of land, by subtracting their total costs/ton from their revenue/ton (Biltonen et al. 1976). The assessment of the economic feasibility of beetle-proofing is further complicated by the valuation of the impact the mountain pine beetle has on non-market values. Water quality and quantity, recreation, wildlife habitat, and environmental services are very difficult to value.

Market conditions are a large determinant of the economic feasibility of commercial thinning (for beetle-proofing purposes). Commercial thinning becomes more attractive as the prices for pulp and wood products increase. However, in order for beetle-proofing to maintain a priority with licensees, regardless of current market prices, the long term benefits for the licensees must be enough to offset any break-even or short-term losses that might occur. Another complicating factor is the uncertainty of whether individual licensees will realize the future benefits of beetle-proofing under the current tenure arrangements. Other determinants that affect the viability of beetle-proofing include stumpage rates, flexibility of operating policies, and the quantity of timber whose value is preserved (Boswell 1998).

While the majority of Phase 1 beetle-proofing presently occurs in mature or over mature stands, practicing this type of commercial thinning in younger stands may be a future consideration. This not only decreases their susceptibility to the mountain pine beetle as they age, but the thinning improves stand growth so that it may be harvested earlier (Holmsen, 1990).

Commercial thinning in these young stands has many benefits. The volume harvested can help alleviate timber shortages, decrease fire hazards in the stand, and improve access for wildlife and livestock (Holmsen, 1990). The greatest incentive to practice this type of commercial thinning is beetle-proofing in pure lodgepole pine stands. However, in these young stands, the threat of the mountain pine beetle may seem distant and abstract to some licensees, who might reject Phase 1 beetle-proofing and “take their chances”. If the harvesting and processing practices are made more efficient, and there is improved utilization and marketing of the wood, the economics may improve to the point where the licensees carry out commercial thinning for their own short-term and long-term benefit. An important condition for the economic viability of this type of commercial thinning is that the stands are accessible and relatively close to the processing facilities.

A market study performed by Forintek Canada Corp. in the Lakes, Morice and Okanagan timber supply areas (TSAs) examined the current and future markets for the smaller-diameter lodgepole pine produced through these thinnings. One of the study’s main conclusions was that the economics of the utilization of this wood depends on quality control, sawing technology, cutting pattern, and product price. Another study by the Forest Engineering Research Institute of Canada (FERIC) and the Forest Resource Development Agreement (FRDA) examined the economics of commercial thinning in field trials in British Columbia. After observation, the main conclusions were that commercial thinning in stands nearing maturity would be constrained by site selection, stand characteristics, forest management goals, harvesting methods, and the availability of skilled personnel. This study, as summarized in Holmsen (1990) also made the following recommendations:

- An improved inventory of immature forest types is necessary to facilitate timber and silviculture planning.
- If the timber appraisal system is used for commercial thinning in lodgepole pole pine stands, it needs to include some incentives to encourage the practice of this silviculture method.
- Instead of the timber appraisal system, this type of commercial or pre-commercial thinning could be administered by special silvicultural contracts that would use the value of the wood harvested to offset the commercial thinning costs. (This option would be especially attractive where the thinning provides no immediate economic benefits, but is attractive for stand health and growth).
- Further studies are needed to determine the most efficient equipment for harvesting.

Harvesting costs and financial returns are specific to each operation applied to a specific stand because there are many factors that can influence the costs and returns. These factors include the efficiency and experience of the operating crew, timber size, species, quality, equipment choice, labor-payment methods, and weather conditions (Filip 1967). Thus, only the methodologies for determining profit margins and economic feasibility can be transferred from one unit to another for application.

2.3.1 Applied Economic Feasibility Studies

2.3.1.1 Partial Cutting

In 1992, researchers from the Canadian Forest Service (CFS) collaborated with Crestbrook Forest Industries Ltd. (CFI), Galloway Lumber Company Ltd., the British Columbia Forest Service, and FERIC to investigate how commercial thinning and fertilization affected the susceptibility of lodgepole pine to mountain pine beetle attack, and how thinning can increase access to fibre.

Three different sites in the East Kootenay region of BC were chosen for study. Stands within each site had to have a large pine component, be between 70 and 100 years old, have an average dbh of >15 cm, be on uniform terrain, be at elevations less than 1500 m and be close to beetle infested stands (but not currently under attack). The first site was part of the Tree Farm License (TFL) 14 area in the Invermere Forest District. This 151,000 ha area was predominantly pine leading or pure pine landbase of mostly Age Class 5 or older. Thus, this area was highly susceptible to mountain pine beetle attack. Much of the beetle-proofing on TFL 14 has occurred in the Bench North planning cell, which has an individualized Resource Management Plan (RMP).

The objectives under this plan included goals such as producing high-quality timber, providing employment stability, diversifying stands to address mountain pine beetle concerns, and managing the landscape for ungulates, biodiversity, water quality and quantity, and Partial Retention Visual Quality Objectives. The specific beetle-proofing prescription for TFL 14 had the following cut-and-leave specifications that are essential to beetle-proofing success:

- Beetle-infested pine trees must be harvested.
- Pine will have first priority for removal, followed by other species, as available
- Target spacing of leave trees is approximately 5 x 5 m.
- Leave trees are preferably of good form, vigor, and windfirmness.
- Patches of small pine (12.5-17.5 cm dbh; 15-20 cm dsh) may be removed due to potential wind and snow damage.

These specifications usually would result in retention of approximately 50% of the pre-harvest basal area and 400 stems/ha. This was still intended to provide adequate flexibility to allow for natural inter- and intra-stand variations, and to address worker safety and harvesting efficiency. On TFL 14, beetle-proofing was performed to three inter-tree spacings: 4 m, 5 m, and 6 m. The 5 m and 6 m spacings are more economical to harvest, and more efficient operationally, but the risk of windthrow under this spacing is high. The 6m spacing was used in areas with abundant advanced regeneration, which provided wind flow resistance and additional shading. Areas that were prescribed 4 m spacing were generally dense stands with smaller average diameters and poorer height:diameter ratios (which increases the risk of wind and snow damage). Later research proved that all of these spacing prescriptions have led to the desired changes in stand and tree microclimate (BC Forest Service 1999).

The success of beetle-proofing in areas of TFL 14 was highly dependent on various factors including clear management objectives, proper layout of blocks, treatment units and access, availability of appropriate equipment, and cooperation and commitment between all parties at various stages of the harvesting process. The costs of beetle-proofing in the TFL 14 were 15%-40% higher than clearcutting in similar areas. In stands where the average piece size was $0.2m^3$ or less, or where volume removal was under $100m^3$/ha, managers in the TFL 14 area considered beetle-proofing to be only marginal or else uneconomical in the present market, unless the pulp markets became very high. Otherwise, the thinning prescriptions were deemed profitable (BC Forest Service, 1999).

FERIC was responsible for monitoring the other two sites in the study, which were situated in the Galloway Lumber Company's operating area near Cranbrook, BC, and in CFI's operating area close to Elkford, BC. On each site, two commercial thinning prescriptions of 4 m and 5 m spacing, and a third prescription of clearcutting were each performed and compared to an uncut control area. While performing the different thinning treatments on both sites, the primary objective was to achieve the preferred spacing, but care was taken to avoid damaging the residual trees (which would increase their susceptibility to the mountain pine beetle). Among all treatments in all areas, damage to leave trees ranges from 19%-28%, with the majority of damage occurring along the edges of the skid trails. Although the damage was minimal, it was suggested that the amount of damage could be further decreased on future sites by improving skid trail location and orientation, skidding in the summer, increasing supervision of falling and skidding, and allowing for rub trees along skid routes.

Although the costs of spacing were found to be 33%-55% higher (stump to truck) than the costs incurred under clearcutting on both sites, all of the prescriptions were deemed profitable. On the Elkford site, FERIC calculated the harvesting costs to be $18/m^3$ on the areas with 4 m spacing, and $16/m^3$ with the 5 m spacing. This was compared to the clearcuts in the area with overall harvesting costs of $12/m^3$. The harvesting costs for the 4 m and 5 m spacing on the Cranbrook site were $11/m^3$ and $12/m^3$, respectively, while the clearcut costs were $8/m^3$. There were many factors that were responsible for the cost differential between the two sites. For example, differences in site conditions dictated the use of different equipment, and the total harvesting costs were affected by differences in average piece size and total volume removed between the sites. Also, in the Elkford area, thinning operations were plagued with problems in the skid trail layout, crew turnover, and harsh weather conditions. However, when comparing the spaced stands to those that were clearcut, most of the higher thinning costs were attributed to the extra time needed to develop and supervize these spaced sites, as boundary and skid trail layout was necessary. Nonetheless, all of these costs were similar to other commercial thinning operations, and those performed on low-volume pine stands (Mitchell 1994).

After the operations were complete on both sites, the stands were surveyed to assess whether the post-harvest conditions shared characteristics of a successfully beetle-proofed stand. The inter-tree spacing was performed correctly, and the amount of damage to leave trees was deemed acceptable. In addition, the number of stems/ha and the basal area of each site were reduced to levels acceptable as beetle-proofing practices. On the Elkford site, the number of stems/ha was decreased from 990 stems/ha to 440 and 360 stems/ha for the 4 and 5m inter-tree spacings, respectively. Furthermore, the basal area in the 4m spacing was reduced from $44m^2$/ha to $22m^2$/ha, and the basal area in the 5 m spacing was decreased to $18m^2$/ha from $42m^2$/ha. On the Cranbrook site, the 4 m and 5 m spaced stands were thinned from 1100 and 1400 stems/ha to 460 and 350 stems/ha, respectively. Residual basal area on this site was reduced from 40 and $37m^2$/ha on the 4 m and 5 m stands to 20 and $13m^2$/ha, respectively (Mitchell, 1994).

While it is evident that commercial thinning operations are more costly than clearcutting, the costs are justified if mountain pine beetle attack is expected on the stand before the block is ready for harvest. Thus, commercial thinning can be an investment if light infestations are contained, which protects the stand from large volume losses.

2.3.1.2 Chemicals (Pheromones)

Although exact costs and benefits were not determined in the Borden et al. (1986) study that examined the use of pre-logging pheromone baited trees, the authors did provide some of the cost information. An average of 5.2 trees/ha were baited in the three blocks at a cost of $6 per bait[1]. Thus, the cost/ha would be $31.20/ha without labour. If labour was

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[1] All of the dollars in this example were quoted as 1984 prices. Price adjustments are necessary in order to incorporate these estimates into any current cost/benefit analysis.

included, this baiting program should cost around $40/ha. Since this type of baiting was successful in attracting and containing the beetles in and around the baited blocks, the authors hypothesized that the costs of the program would break even if it saved the disposal of two trees/ha outside of the block (at an average disposal cost of $20/tree). Also, after the infested trees in the baited blocks are logged, a large proportion of the area's beetle population would be removed. This would decrease the expected future costs of surveillance and any remedial action taken to obliterate the remaining beetles (Borden et al. 1986). Thus, Borden et al. (1986) felt that the methodology used in their baiting program would be cost-effective. The cost information provided in this study could also be incorporated into the beetle-proofing cost estimation of a cost/benefit analysis.

2.3.1.3 Assessment of Overall Control Programs

In 1992-1993, the Government of British Columbia implemented a $4.5 million control program (based on proven effective control methods) to mitigate the impacts of the mountain pine beetle. Even though many forestry personnel believed these costs were justified, there had not been any economic or social assessments of the derived net benefits from such beetle control programs. Thus, in the early 1990s, the BC Ministry of Forests funded a social and economic cost/benefit assessment of the mountain pine beetle control program (Miller, Carlson, and Stemeroff 1993).

The study was limited in scope to the existing, mature, lodgepole pine-dominated stands in British Columbia, and sought to compare the impacts of the current beetle control program with the impacts of a 'no-control' option and an enhanced program option. These comparisons allowed the estimation of the costs and benefits of the current program. The current program had three main components: survey and detection, single-tree/spot treatments, and large-area treatments. The single-tree and/or spot treatments of the current control program fought light mountain pine beetle infestations using techniques such as fall and burn, selective tree removal, or pesticide application, either alone, or in combination with pheromone baiting. Large-area treatments were performed where infestation levels were high enough to warrant clearcutting.

Each component of the current control program received different levels of support each year depending on existing infestation levels, stand susceptibility, land-use strategies, and the magnitude of potential impacts. The hypothetical 'no-control' option left beetle epidemics to run their course without any direct human intervention. The other hypothetical, enhanced program was only distinctive from the current program by the addition of selective harvesting in non-infestation periods. These preventative measures helped to reduce stand susceptibility, thereby reducing the potential future impacts of the mountain pine beetle. In the current program, such selective harvesting only occurs in infestation periods.

The cost of the current program was the same as the cost for the enhanced program, because the criteria for stand selection was the same in both programs. The authors did not note that this ignored the increased cost of selective harvesting during non-infestation periods. Although the current program was necessary, there was the potential for preventative maintenance (as emphasized in the enhanced program) to take top priority when mature lodgepole pine stands were less abundant. However, since this study compared three beetle management control programs, the main objectives were to minimize the potential consequences of shortfalls in timber supply, and to perform a socio-economic impact assessment for each of the three programs (Miller et al. 1993).

Miller et al. (1993) used a multiple accounts approach, similar to Holman (1992) and Holman and Cooke (1992), which focused on regional evaluation accounts for the socio-economic impact assessment. Therefore, an initial assessment of the mountain pine beetle impact on lodgepole pine stands was needed. This was estimated by combining information on mountain pine beetle population dynamics with estimates of the effectiveness of the current beetle control program on existing mature lodgepole pine stands. Estimates of the monetary impact on government and industry were determined with respect to timber values. Each impact was derived from a short-term model, which was subsequently discussed with the relevant stakeholders (Miller et al. 1993).

The direct financial impacts on government and industry were determined by the impact on timber supply from the mountain pine beetle. These impacts were determined with a 40-year, short-term model for the Merritt and Morice TSAs. Hence, all economic assessments were conducted on the basis of these impacts. Major issues included in the analysis were: government revenues from stumpage royalties, and timber industry revenues as determined by lumber recovery at the mills, grade output, and lumber value. Time and data constraints prevented the inclusion of other sources of government revenue, such as taxes from income and user fees (Miller et al. 1993).

As seen in Table 1, the government revenues under the current and enhanced programs are significantly higher than under the 'no-control' option in both TSAs (Miller et al. 1993):

Table 1. Summary of stumpage and program costs.

	Merritt TSA			Morice TSA		
Variable[a]	No-control	Current	Enhanced	No-control	Current	Enhanced
Stumpage royalties ($M)	49	66	67	130	151	151
Gain over no-control ($M)	-	17	18	-	21	21
Control costs ($M)	-	3	3	-	7	7
Net benefit ($M)	-	14	15	-	14	14
Benefit cost ratio	-	5	6	-	3	3

[a]All values in $million ($M) and discounted to 1993 by 5% annually.

Under the 'no-control' option for a 40-year period, the present values of stumpage revenues were $49 million and $130 million in the Merritt and Morice TSAs respectively. Thus, the benefit to the BC government of the yearly expenditures of $186,965 and

$409,142 in the Merritt and Morice TSAs for mountain pine beetle control was evident (Miller et al. 1993).

As reported in Table 2, the current and enhanced programs were also very beneficial to the timber industry:

Table 2. Summary of industry revenue and program costs.

	Merritt TSA			Morice TSA		
Variable[a]	No-control	Current	Enhanced	No-control	Current	Enhanced
Industry revenues ($M)	562	629	629	900	944	945
Gain over no-control ($M)	-	67	68	-	44	45
Control costs ($M)	-	3	3	-	7	7
Net benefit ($M)	-	64	65	-	37	38
Benefit cost ratio	-	21	21	-	6	6

[a]All values in $million ($M) and discounted to 1993 by 5% annually.

The industry revenues under the 'no-control' program were $562 million and $900 million in the Merritt and Morice TSAs respectively. The benefits significantly outweighed the costs for the current and enhanced programs. It is also important to note that conservative estimates of timber values were used in the assessments. Even though there was a potential of 15%-20% of harvested lodgepole pine to be sold in off-shore markets, these markets usually will not accept the lower quality wood that is associated with beetle-killed pine. Thus, this analysis assumed that all timber harvested was sold in the North American markets. Hence, the revenue losses estimated under the 'no-control' program were actually underestimated. Note that this analysis did not account for the significant decrease in value that occurs when timber is used for chips instead of lumber. This is a common occurrence when processing old-infested lodgepole pine. Hence, this study most likely overestimated the lumber revenues that could be obtained from old-infested timber. This, in turn, suggests that if the real scenario was implemented with market factors not accounted for in this analysis, the net benefits accrued under the current or enhanced programs would be even higher than stated in this analysis.

In the Merritt and Morice TSAs, the government would incur yearly losses of stumpage revenue of approximately $35,000 under the 'no-control' program, while industry revenues would decrease by $1.0-1.6 million per year. The current and enhanced programs in these TSAs provided significant benefits to both the BC government and the timber industry. The difference in benefits between these two programs is minimal, which is expected from the small differences in timber impacts. In order to extrapolate the values derived from the two TSAs, a factor of 10 was used to reflect the fact that 9% of the total provincial volume of lodgepole pine was derived from the Merritt and Morice TSAs together.

2.3.2 Summary

Table 3 summarizes the findings of the existing single beetle-control method applied economic feasibility studies. The partial cutting studies yield mixed decision rules in the short-term depending on the conditions of the market at the time of the study, but in general, the costs of partial cutting were found to range from 15% to 55% higher than the comparable cost of clearcutting. None of the studies considered longer-term decision rules or the opportunity cost of beetle damage.

Table 3. Snapshot summary of single method applied economic feasibility studies.

Study	BC Forest Service (1999)	Mitchell (1994)	Mitchell (1994)	Borden et al. (1986)
Location	Invermere, BC	Elkford, BC	Cranbrook, BC	
Treatment	Partial cutting – 4 m, 5 m, and 6 m spacing trial stands	Partial Cutting – 4 m and 5 m spacing	Partial Cutting – 4 m and 5 m spacing	Pheromone – 5.2 trees/ha
Costs	15%-40% than baseline clearcutting	33-%55% higher than baseline clearcutting clearcut = $12/m3 4 m = $18/m3 5 m = $16/m3	33%-55% higher than baseline clearcutting clearcut = $8/m3 4 m = $11/m3 5 m = $12/m3	$40/ha (including labour)
Decision rule (short-term)	Marginal to uneconomical in the 1999 market	Profitable in the current market	Profitable in the current market	-
Long-term	-	-	-	-
Opportunity cost of beetle damage	-	-	-	-

Table 4. Snapshot summary of the impact of MPB control programs on government and industry.

Variable[a]	Current	Enhanced
Gain in government revenues ($M)	380	390
Control costs ($M)	100	100
Net benefit ($M)	280	290
Benefit cost ratio	4	4
Gain in industry revenues ($M)	1 110	1 130
Net benefit ($M)	1 010	1 030
Benefit cost ratio	11	11

[a]All values in $million ($M) and discounted to 1993 by 5% annually.

From Table 4, it is clear that both the industry and the province benefit under the current and enhanced provincial beetle control programs. For every $1 invested in the current or enhanced management program, government revenues increased by $2-$4, and industry revenues rose by $11. Thus, if all stakeholders support either management program, they all stand to benefit as well (Miller et al. 1993).

One of the study's final conclusions was that in addition to promoting forest health, the practices of mountain pine beetle detection, control, and management are economically beneficial. An annual harvest of 70 million m^3 can yield $97/$m^3$ in 'value-added' benefits. Also, the $4.5 million annual program aimed at beetle management provided a net benefit of $72 million in stumpage and lumber value recoveries province-wide (Miller et al. 1993).

2.4 Best Practice Methodologies for Assessing the Economic Efficacy of Beetle-Proofing

The financial impact of mountain pine beetle damage can be determined by relating the amount of damage to the monetary timber values. However, estimating economic losses can be more difficult. Most often, the impact is represented by the difference between the value of the area's resources, which have been subject to mountain pine beetle infestations, and the estimated forest value in the absence of the mountain pine beetle. However, many parts of this analysis are only estimated at best or subjective at worst. For example, how much of the loss of timber resources or decline in non-timber resources can be attributed to the mountain pine beetle infestation? How accurate is the estimate of the area's total foregone value (had it not been infested)? How well do stumpage values act as a proxy for the true timber values? Are the non-market valuations used considered acceptable?

Current policy analysis and decision-making favour quantitative estimates of value for economic appraisal, which usually entail studies of cost-benefit and cost-effectiveness. Cost-effectiveness studies are most appropriate for determining the most efficient way of achieving a desired outcome. Cost-benefit studies account for both the costs and benefits associated with a proposed project, making them ideal for evaluating forest management alternatives (Willis and Garrod 1991).

2.4.1 An overview of benefit-cost analysis and discounting

Benefit-cost analysis is a systematic means of identifying and evaluating the relative net benefits of alternative investment opportunities (Fraser 1985). Appraisals evaluate net benefit to a region, province or country as a whole. Thus, benefit-cost analysis attempts to include measures of social benefits and social costs. Including all costs and benefits makes this different from a financial analysis that includes only dollar values. As well, by measuring social values the analysis goes beyond the cost and benefits to a particular firm but includes society at large. However, it is difficult to produce a full cost-benefit analysis since it includes measures that often pertain to non-market goods (Bradbury and Loasby, 1977). Long time periods associated with forestry also increase the difficulty of conducting cost-benefit analyses.

When managing a stand over one rotation, the benefits and costs are incurred at different times in the rotation. As well, when comparing two different management options, they often differ in the time flow of benefits and costs. These problems can be addressed by using a discount rate in the benefit-cost analysis to adjust all of the future costs and benefits to their value at the present time. Thus, competing alternatives can be compared on the basis of their net present value (NPV). Benefits occurring in the future are considered less valuable due to the fact that they are unavailable for immediate consumption or reinvestment. Similarly, any costs in the future also carry less weight when discounted back to the present.

There is considerable debate as to the correct procedure for discounting, and choosing the appropriate discount rate. The discount rate is very influential in determining the financial viability of different forest management alternatives. Economic theory postulates that individuals and firms have a preference for present versus future consumption. This preference is reflected in the discount rate, which represents compensation for foregoing something in the present in order to save it for future consumption. In this way, resources can be wisely invested to increase future consumption possibilities.

An alternative to this view is reflected in the social discount rate. This rate is normally less than the private discount rate discussed above. Society as a whole is more willing than individuals to forgo consumption today for the good of future generations. The social rate would be the best one to use where the province is investing on Crown land while the private rate would be ideal for a firm investing on its own land.

What is the appropriate discount rate to use? It is best to use a range of discounts rates when taking a broad look at investments such as beetle-proofing. Some have advocated a rate of 0 percent as a social discount rate arguing that future generations are just as important as current ones. Private discount rates based on the opportunity cost of capital (the rate at which funds could be invested if not invested in the proposed forestry investment) can be as high as 10% or even higher. Based on current market conditions, a discount rate of 3%-5% is broadly accepted as the social rate of time preference. Higher rates should also be used in a broad analysis to look at potential private rates.

Higher discount rates are also used in situations of risk. Heaps and Pratt (1989) however, stress that the nature of silviculture investment does not justify the use of a risk-adjusted social discount rate in the calculation of net present value. Using a risk-adjusted rate undervalues the net benefits of silviculture investment. For a more detailed discussion and critical analysis of the proper social discount rates, see Heaps and Pratt (1989).

The attempt to attain a monetary value for every element in benefit-cost analysis is sometimes criticized, especially when the valuation of non-market goods is inadequate or absent altogether. Forest licensees often have concerns other than profit maximization or economic efficiency, such as the maintenance of forest cover for wildlife (Fraser 1985). Thus, if one management alternative will generate social benefits, but is less economically efficient than another alternative, this option may still be preferred and implemented so that social efficiency is maximized (Fraser 1985).

There are two solutions to address the fact that benefit-cost analysis does not include provisions for social and environmental concerns: try to include them, or accept that they cannot be included. For instance, project benefits can be weighted so that effects that are more socially beneficial are recognized. As well, non-market valuations can be performed in attempts to place monetary values on the environmental effects from the management option.

If social and environmental impacts are included in a benefit-cost analysis, they should be recognized as estimates. As with discount rates, a range of values should be included to provide decision makers with a range of possible outcomes. Another approach would be to accept that social and environmental impacts cannot be adequately accounted for in the benefit-cost analysis. Since these impacts need some representation, they can be sufficiently documented, and presented along with the economic results from the benefit-cost analysis.

As long as the attributes of social and environmental efficiency are defined, each management option can be compared, not only on economic terms, but also on how well each meet the social and environmental objectives (Fraser 1985). For more information on how this latter procedure was adopted in evaluating a salmon enhancement program in BC, see Friedlaender and Fraser (1981). In any case, benefit-cost analysis does allow the relative merits of various forest management options to be examined.

2.4.2 Net Present Value

The practice of commercial thinning as a beetle proofing activity provides value at the time of the thinning, and value for the whole stand at the time of harvest. However, the licensee practicing commercial thinning also incurs various costs associated with stand management at different points in time. Thus, in order to assess the viability of commercial thinning, we must choose a method that accounts for the various costs and benefits that occur at different times (Stone 2002).

One method of assessing the economics of silviculture investments is the calculation of Net Present Value (NPV). Calculation of NPV converts the future benefits and costs (that are incurred at their respective points in time) to their equivalent present values. Thus, these costs and benefits are discounted by a rate that reflects society's or the firm's (as discussed above) preference for present versus future consumption. Thus, the NPV of a particular silviculture investment would be the sum of the discounted benefits minus the sum of the discounted costs. This can be represented as the following formula:

$$NPV = \sum_{i=0}^{A} R_i (1+r)^{-i} - \sum_{i=0}^{A} C_i (1+r)^{-i}$$

where R_i = revenue (benefit), received at stand age i, C_i = cost incurred at stand age i, r = discount rate, and A = age of stand harvest.

An alternative approach is to use a measure of Site Value (SV) instead of NPV. The value of a site (SV) is the maximum amount that an individual is willing to pay for bare land, provided that the land will be used to produce an infinite number of rotations of the exact same forest management system. Thus, SV is equal to the net present value of the infinite series of growing regimes. This can be represented as the following:

$$SV = \frac{\sum_{i=0}^{A} R_i (1+r)^{A-i} - \sum_{i=0}^{A} C_i (1+r)^{A-i}}{(1+r)^{A} - 1}$$

The SV is maximized by a specific harvest age, which is known as the economic rotation age. Different forest management regimes can be compared by the SV's of each option (which are calculated at their individual economic rotation ages). Consequently, the option with the highest SV is considered to be the optimal regime. In the case where a stand (under a certain management option) must be harvested at an age other than the economic rotation age, then the site values of the alternative options need to be compared at the desired rotation age (Stone 2002).

When calculating NPVs and SVs, typically all of the benefits and costs are discounted to a base age of zero. However, in some cases (as in deciding on beetle-proofing options), there may be a need to examine only the impact of a particular forest management option (such as commercial thinning). When various types of thinning are compared, the calculation of the SV involves discounting the costs and benefits back to the stand age when the thinning would take place. Any costs incurred up to the thinning are considered sunk costs, and therefore these costs are not included in the SV calculation (Stone 2002).

2.4.3 Commercial Thinning – Applied Net Benefit Analysis

The Tree and Stand Simulator (TASS) program is useful for assessing the economic benefits of various types of commercial thinning in British Columbia. TASS is an individual tree distance dependent growth and yield model, which simulates the growth of trees in three dimensions (Stone 2002). The BC Ministry of Forests developed this model for application to even-aged, pure coniferous stands, and there are separate model specifications for eight tree species (including lodgepole pine). Some of the primary uses of TASS include the following:

- Stand level silvicultural treatment decision-making (e.g., spacing, commercial thinning);
- Pest and disease yield impact predictions;
- Generating stand density management diagrams (SDMS).

A limitation of the TASS model is that the stand size in the model is limited to a maximum of 5 ha, and each run (that individually simulates trees) is limited to a maximum of 32,000 trees (BC Ministry of Forests 2002). For more information on the development of the TASS model, see Mitchell (1969), Mitchell (1975), Mitchell and Cameron (1985), Mitchell (1986) or BC Ministry of Forests (2002).

2.4.3.1 Simulations – Thinned versus Unthinned Stands

Stone (2002) used the TASS model to simulate the development of lodgepole pine stands of natural origin that had an initial density of 5000 stems per ha and had a site index of 20, 18, and 16 m. TASS then simulated commercial thinnings at age 40, 50, 60, and 70 years, which left the residual densities at 900 and 600 stems per ha. The results of these simulations showed that the commercial thinning could result in a decrease in the cumulative merchantable volume in the stand if the thinnings were planned or implemented incorrectly. In the best-case scenario, the thinnings could marginally increase the cumulative volume of the stand over one rotation. However, if this was the case, the final harvest of the thinned stands was still less than the final harvest of an unthinned stand. These results indicate that commercial thinning must be justified either on the basis of an increase in the stand’s value resulting from the concentration of the stand’s growth on fewer trees, or on the value of the return from the earlier thinning(s) (Stone 2002).

The SV was calculated at 40 years for each thinning intensity and growing regime. These results indicated that the economic feasibility of commercial thinning in lodgepole pine was strongly influenced by the choice of the rotation age for the final harvest. If the site value of an unthinned stand is compared to that of a thinned stand using their respective optimal rotation ages, the unthinned stand proves to be more economical. This comparison is relevant if the objective was strict maximization of economic return. However, most licensees in British Columbia (and in other areas as well) operate under many objectives, including the maintenance of non-timber forest values, and the maximization of sustained yield. Thus, the rotation age usually extends past the optimum economic rotation age. (This also occurs when the licensees can not harvest their over-mature forests fast enough, as in the case of British Columbia.) In this case, the licensee should choose the forest management regime that maximizes the site value at a rotation age beyond the economic rotation age. Thus, the TASS simulations show that when the chosen rotation ages are beyond 80-90 years, the SVs for the thinned stands would exceed those for an unthinned stand.

The simulations by Stone (2002) also show that once a stand passes its economic rotation age, its SV declines quickly over time. Although this is the case for all growing regimes, the decline in SV happens more slowly in the thinned stands than in the unthinned stands. This result can be reflecting two factors. In a commercially thinned stand, the stand's growth is concentrated in larger trees, which produce a higher value (per m) of wood grown. As well, commercial thinning also produces interim revenues from the harvest of trees whose values would otherwise grow at a rate lower than the social discount rate (Stone 2002).

2.4.3.2 Simulations – Thinned Stands Only

If commercial thinning is considered absolutely necessary (as in the case of beetle-proofing), it is useful to examine how the above TASS simulations fare when examining only the thinned stands. Thus, in thinned stands where the final harvest was planned to be earlier than 90-100 years, the lighter thinning regimes provided the highest SVs. However, if the final harvest was planned to be higher than 90-100 years, the highest SVs corresponded to the heavier thinning treatments (Stone 2002).

If the simulation results were compared on the basis of initial site index, it was found that a light or heavy thinning at age 50 was the optimal regime for site index 20. For site index 18, the optimal strategy could be either a light thinning at age 50, or a heavy thinning at age 60. Either a light or heavy thinning at age 60 was considered optimal for a site index of 16 (Stone 2002).

In standard economic analyses of forestry investments, there is usually a low return of investments due to the fact that the revenues at stand harvest are heavily discounted. Thus, all of the commercial thinning results under the TASS model may seem surprising. Discounting favours any early profits delivered by thinning relative to those received later in the rotation. The evaluation period begins at the time of thinning (when revenue is produced, but not discounted), while the costs associated with the final harvest are incurred at the end of the analysis period and they are heavily discounted (Stone 2002).

However, even though most licensees do not harvest at the optimum economic rotation age, the concept, with respect to SV, is still important. The difference between the SV at economic rotation age and the SV at the actual harvest age represents the opportunity cost of extending the harvest age past the economic rotation age. On the other hand, the opportunity cost of selecting an alternative forest management strategy can be determined by comparing the SV of an unthinned stand at its economic rotation age with the SV of the same, but thinned, stand at its actual harvest age (Stone 2002).

The outcomes under the TASS model are dependent on a large number of interrelated factors, including site-specific data. Thus, the net benefits (SVs) for different beetle-proofing options will be different for each stand. In fact, Stone (2002) found that the economic outcomes for the commercial thinning simulations were very dependent on the following four factors:

(1) Prices Received for Trees with Small Diameters – commercial thinning may only be feasible in pulp log and sawlog markets when prices are high.

(2) Planned Rotation Age – the economic rotation age is the optimum time for harvest. If this option is not feasible, then commercial thinning options are economically more attractive at longer rotation ages.
(3) Road Development Costs – the economic benefits from commercial thinning will be lost if road development costs are high or if the road used for thinnings is not available for use during the final harvest. However, a commercial thinning may still be warranted in stands that have to be left unharvested in roaded areas (adjacency constraint).
(4) Future Price Expectations – if real timber prices are expected to rise in the future, it is better to not thin the stand, and harvest the whole stand later when prices are high.

In determining the financial viability of commercial strip thinning, Smith and Oerlemans (1988) compared the NPV of the thinned stand to what the NPV would have been if the stand were not thinned. However, the authors noted that when assessing benefits and costs over time, there is always uncertainty regarding the growth projections and financial variables (harvesting costs, and market prices). In order to account for this in their study, an acceptable range of values around the most probable estimates for the financial and growth projection variables were used in the NPV calculations. Thus, the impact of changes in these variables on the NPV over one rotation is estimated.

If economic feasibility studies do not account for the allowable cut effect (ACE), the Net Present Values (NPV) of the management alternatives are almost always negative. The ACE refers to the immediate increase in the current allowable cut that occurs due to an increase in the expected future yields. The inclusion of the ACE in economic analyses is particularly relevant when choosing the best management strategy to implement under harvesting constraints and within a given budget. If a particular beetle control method will increase the stand's yield at the time of harvest, this expected gain could be equally distributed as the ACE for each year following the implementation of the strategy until the time of harvest. This ACE can then be properly valued using the stumpage rates to determine the increase in NPV that would occur if the analysis does account for the ACE (Sassaman, Barrett, and Smith 1972). In a commercial thinning survey performed by FERIC in Alberta and BC, 27 out of 38 respondents indicated that the recognition of the ACE effect might motivate them to begin practicing commercial thinning (Sambo and Clark 1996). One should remember that ACE is only appropriate when the forest in question is managed under a regime that allows for it. It distorts investment decisions in favour of carrying out silviculutre activities but this is reasonable if ACE is included in the regulatory environment where the investment is taking place.

2.4.4 Difficulties in Calculating Net Benefits

There are many factors that affect the uncertainty of forestry investments and these should be accounted for in the analysis. These include the discount rate, changes in the unit cost and unit prices at the time of final harvest, and final stand size and composition (Smith and Oerlemans 1988). Technological change can also influence estimates of NPV, as it can decrease harvesting and transportation costs (Fraser 1985). Value estimates should also be adjusted to account for insect, fire, and disease risks. This is especially true when evaluating beetle-proofing options.

Risk and uncertainty mean that expected value calculations are appropriate. The use of decision trees would allow decision makers to look at a number of possible outcomes and the probability of each occurring (Pearse 1990; White 1993). Calculations of the NPV for any forest management option are challenging due to the difficulty in accounting for all of these factors. The table below outlines the information required to conduct a comprehensive benefit cost analysis of a beetle proofing operation from both society's and a private firm's point of view.

Table 5. Information required to conduct a comprehensive benefit cost analysis of beetle-proofing options.

	Comments	
Factor	Social	Private
Existing stand characteristics Probability of beetle attack Cost of thinning or other beetle proofing activity		
Expected future state of stand	This will be an estimate based on output from a model such as TASS. Estimates will be required in the presence and absence of a beetle attack.	
Values and costs at harvest	Stumpage values; tax revenues	Net end product values for firms with processing facilities; based on salvage values for scenarios with beetle damage.
Discount rate	Social discount rate	Private discount rate or opportunity cost of capital.
Non-timber values		Included only if part of licence agreement; may also take the form of a constraint on harvest and therefore affect harvest costs.
Social values and concerns	These must be documented and may influence final decision.	Firm may decide to include these.
Risk and uncertainty	Expected values should be used in the analysis to account for risk of fire, market and price uncertainty, future stand state and other uncertainties. Key probabilities would be required. Another possibility is to use sensitivity analysis to ascertain how the values change as key values (e.g., discount rate) change.	

Table 5 indicates that the requirements for a full and proper analysis are enormous. In reality, decision makers will have to decide where the cost of obtaining and analyzing all this information exceeds the expected benefit.

The majority of this discussion on the economics of beetle proofing has been from the stand perspective. A more realistic but more complicated view would be from the forest or multi-stand level. The basic principles remain the same but details such as road networks and spreading risk across stands would need to be included.

3 Summary

The purpose of beetle-proofing, regardless of the method, is to alter forest stand characteristics to reduce the susceptibility to mountain pine beetle. A variety of beetle-proofing methods exist including a range of silvicultural and harvest treatments, prescribed fire, and chemical treatments. From an economic perspective, beetle-proofing attempts to provide optimal timber value returns in the presence of risk. The extra effort and cost required may be justified if beetle-proofing reduces damage to public and private forest resources and the net benefits are positive.

Past studies indicate that thinning according to beetle-proofing prescriptions was effective, however costs varied from 15% to 55% higher than business-as-usual clearcutting and profitability varied with the conditions of the current market. A study of the overall mountain pine beetle control program in British Columbia from 1993 indicates that the current control program and an enhanced control program provide both private industry and the government with significant net benefits. Past findings also indicate that regardless of the type of forest pest, preventative measures are preferred over trying to control an epidemic.

Unfortunately, in many timber supply areas in the British Columbia interior it is already too late for beetle-proofing and the focus has shifted to salvaging as much timber value as possible. However, phase 1 beetle-proofing methods should be considered as the forests regenerate as a means to avoid future epidemics. In addition, phase 2 beetle-proofing should be given more consideration in jurisdictions with lighter infestations or that are adjacent to areas of infestation. For example, the natural range of the mountain pine beetle might expand further north and east as a result of climate change. Forest tenure holders and agencies should investigate the economic feasibility of beetle-proofing options prior to the outbreak of an epidemic. Risk rating systems can help to determine areas where beetle-proofing efforts should be focused or where, at the very least, benefit-cost analysis could be performed to determine the net benefits of beetle-proofing.

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