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Storing beetle-killed logs under snow to reduce losses after mountain pine beetle attack

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Canada

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Abstract

To assess the potential to store beetle-killed logs under insulated snowpacks in British Columbia to preserve wood quality and maximize value recovery, we reviewed the literature and visited operations in eastern Canada, where the technique has been recently adapted to routine operations, and in Finland, where 3.5 million m^3 of timber are stored under snow annually. We also visited storage terminals in Sweden where very large volumes of sawtimber have been stored since 2005. We identified three roles that cold storage could play in responding to the current mountain pine beetle outbreak: (1) where the outbreak is expanding rapidly and green-attack volume exceeds capacity of mills to process all logs prior to dispersal flight, cold storage can prevent development and dispersal of beetles before milling late in the season; (2) where significant value is lost between harvesting and processing due to checking after delivery to the mill, cold storage can maintain moisture content and extend the time frame for achieving higher economic recovery; and, (3) where there is an opportunity to store large volumes of quality logs, doing so for an extended period (more than one year) may help defer or moderate anticipated social, environmental and economic impacts in the areas most affected by the mountain pine beetle outbreak. We report on discussions with woodland and plant managers in British Columbia on how the technique might be adapted to western Canadian operations and possible impediments to implementation, and we present recommendations.

Résumé

Pour évaluer la possibilité de stocker sous de la neige isolée les grumes tuées par le dendroctone du pin ponderosa en Colombie-Britannique afin de conserver les qualités du bois et de maximiser sa valeur, nous avons étudié les documents existants et visité des exploitations dans l'Est du Canada, où cette technique a récemment été adaptée aux opérations courantes, ainsi qu'en Finlande, où 3,5 millions de mètres cubes de bois en grume sont stockés sous la neige chaque année. Nous avons également visité des terminaux de stockage en Suède où l'on stocke de très gros volumes de bois de sciage depuis 2005. Le stockage à froid peut jouer trois rôles dans la réponse à l'attaque actuelle du dendroctone du pin ponderosa : (1) lorsque l'attaque se propage rapidement et que le volume de bois attaqué au niveau vert dépasse la capacité des scieries à traiter toutes les grumes avant le vol de dispersion, le stockage à froid peut éviter la propagation et la dispersion du ravageur avant l'usinage tardif dans la saison; (2) lorsqu'on perd une grande valeur entre la récolte et le traitement en raison de la vérification après livraison à la scierie, le stockage à froid peut conserver la teneur en humidité et prolonger la durée d'utilisation du bois pour en obtenir un meilleur rendement et (3) lorsque la possibilité existe de stocker de gros volumes de grumes de qualité, le faire pendant longtemps (plus d'un an) peut contribuer à retarder ou limiter les répercussions sociales, environnementales et économiques prévues dans les régions les plus touchées par l'attaque du dendroctone du pin ponderosa. Enfin, nous offrons un compte rendu des discussions que nous avons eues avec les gestionnaires des zones boisées et les directeurs d'usines en Colombie-Britannique sur la façon dont la technique peut être adaptée aux exploitations de l'Ouest du Canada et sur les obstacles potentiels à sa mise en œuvre, et nous présentons des recommandations y afférentes.

Key points

1. Storage to prevent or delay insect development

- The efficacy of log storage under snow in preventing development of mountain pine beetle in green-attack logs has a sound basis in theory and has been demonstrated in preliminary results of one study in Alberta.

- At the leading edge of the mountain pine beetle outbreak, creating snow caches can significantly benefit spread control efforts when harvest, transportation and milling cannot be coordinated in time to prevent dispersal of beetles from green-attack logs.

2. Short-term storage to maintain log quality

- The efficacy of snow storage to maintain sapwood moisture content of stored logs and potential positive effects on overall costs and value return has been clearly demonstrated in other jurisdictions.

- Key elements in the successful implementation of storage into European operations include a focus on storing only fresh, high-quality logs in quantities suitable for a typical mill run on processing lines that produce higher-value products.

- Key elements in the successful implementation of snow storage in Eastern Canada have also included a focus on storing winter-cut, high-quality logs for specific processing lines that allow mills to fill market demands in summer and fall for high-value end products at lower cost than their competitors.

- In both cases, the savings in both woodland and mill operating costs and the benefits in volume or value recovery and flexibility to market demands were identified and weighed against incremental costs of storage. This analysis played a key role in successful implementation.

- Unless operations in British Columbia shift paradigms from minimizing delivered wood cost to maximizing overall profit margin, inertia will be a major impediment to adoption of storage to improve value return from beetle-killed wood.

3. Long-term storage to extend shelf-life

- The Swedish forest sector took extraordinary measures in response to catastrophic windstorms in 2005 and 2006 by creating large stockpiles of the most valuable logs for use up to four years later. Government, industry and landowners collaborated in implementation of these measures to further their diverse interests.

- A similar harvest-for-storage programme could be used to slow progress of the outbreak in British Columbia, preserve Crown asset values, and modify timber flows to buffer impacts on communities in affected areas.

- The most significant factor impeding long-term log storage in British Columbia is the requirement to carry costs of development, stumpage, harvest, transportation, storage and silviculture without any return until the stored timber is manufactured into products and sold in the market.

- Longer-term log storage is not likely by licensees of the Crown because carrying the combined cost of stumpage, logging, transportation, storage and silviculture obligations over multiple seasons until logs are processed and sold in the market is an untenable investment for a publicly traded company under the current business model.
- While current market conditions require curtailment of production in lumber mills processing beetle-killed timber, the social, economic and environmental costs of not harvesting in areas where the outbreak is expanding are significant and sustaining harvests on the periphery of the outbreak is in the public interest.
- To serve their complementary interests, the Crown and its licensees should consider innovative ways to facilitate a continued harvest of fresh, high-value logs to create stockpiles for future use when market conditions improve.

Introduction

Lodgepole pine (*Pinus contorta* Dougl. ex Loud) is a major component of mature forests in the interior of British Columbia. In recent years, it has provided half the interior's annual timber harvest, which is critical to the social and economic well-being of the province. Since 1995, these forests have experienced unprecedented mortality during the largest outbreak of mountain pine beetle ever recorded. Current projections by the British Columbia Ministry of Forests and Range indicate that high levels of mortality will continue for several more years (Walton et al. 2007). Rapid depletion of the mature pine inventory over such a short time has made it imperative to investigate all potential options to extend the economic shelf-life of beetle-killed trees and to mitigate anticipated mid-term shortfalls in timber supply.

Harvesting recently killed trees and storing the logs between harvest and processing under conditions that preserve freshness (e.g. under sprinklers or submerged in lakes) is a concept that has received some attention during this outbreak, but limited application (Rogers Consulting 2001; MacDougall 2005). Cold storage is another option. Snow caching of logs is a well established technique in eastern Canada and Europe to preserve moisture content and freshness of high-value, winter-harvested logs until they are processed later in the summer and fall. The principle is relatively simple (Figure 1). Logs manufactured in winter are tightly decked on frozen ground and then covered with an insulated layer of packed snow to keep them frozen until the mill is ready for them. The insulation is then removed, the snow is allowed to melt, and the logs are processed.

Usually the period of storage is one spring and summer, with all the wood retrieved in the same year, but there have been cases where wood was unintentionally stored through two full summers with no loss in wood quality and little change in the insulated snow pack[1].

The Canadian Forest Service (Canadian Wood Fibre Centre) and FPInnovations (FERIC Division) examined the potential, requirements and limitations of this storage technique for log inventory management in interior British Columbia forest operations to meet three principal goals:

1. to prevent development and dispersal of beetles from green-attack logs until transport and milling can be coordinated;
2. to maintain fibre quality to extend the time frame for economic recovery from affected stands; and,
3. to defer or moderate an expected timber supply fall down in the areas most affected by the mountain pine beetle outbreak.

In the course of the study, we broadened the latter goal to include a more general suite of social, environmental and economic impacts of the epidemic. Our intention was to evaluate the strategic potential to integrate log storage under insulated snowpacks into harvest scheduling and log inventory management in mountain pine beetle-affected areas by identifying critical factors for success, and any information gaps or potential impediments to implementation.

[1] Pierre Despatie, Woodlands Manager, Columbia Forest Products, Hearst, ON. Personal communication.

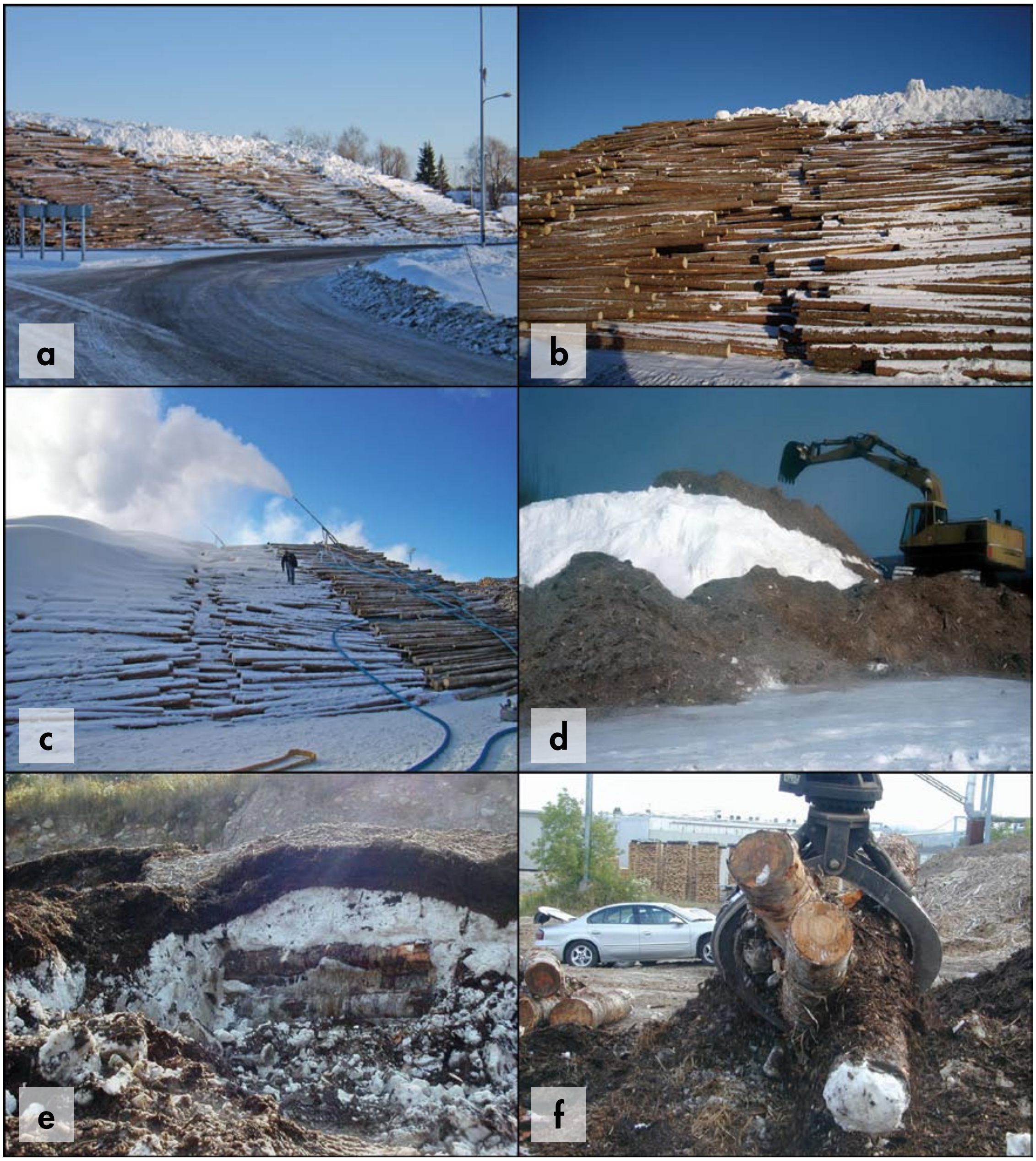

Figure 1. (a and b) In late winter, frozen logs are decked on level, frozen ground at Myllykowski Paper Oy near Simpele, Finland. Note that the sides of deck are angled to prevent sloughing of snowpack, the logs are tightly packed, and gaps between rows on the top layer are covered to prevent development of sinkholes. Photos: R. Whitehead. (c) A 50,000-m^3 cache is being covered with a 0.75-m-thick layer of artificial snow at UPM-Kymmene Oy near Kaipola, Finland. Photo: R. Whitehead. (d) A 0.7-m layer of spruce bark is being added to insulate a snow cache at the Kruger Sawmill in Parent, QC. Note that the insulation must protect from both rain and solar heating. Photo: J. Nader. (e and f) At end of the summer, when insulation is removed to allow snow to melt and to recover logs for processing at Produits Forestiers Bellerive Ka'n'enda Inc. near Mont-Laurier, QC, the snowpack is still intact and logs are still frozen and fresh. Photos: J. Nader.

Souces of Information

We collected and reviewed available literature on the observed and projected course of the current epidemic, shelf-life of beetle-killed wood, and sawlog storage to preserve wood quality with emphasis on large volumes or on storage under snow. We interviewed woodland, mill and mill yard managers in beetle-affected areas of British Columbia to gather current experience with handling of beetle-killed timber to focus our investigation on the key elements of log inventory management and to identify factors that might aid or impede integration of log storage in forest operations in western Canada.

We visited operations in eastern Canada where preliminary testing of log storage under snow by FPInnovations – FERIC Division led to integration of the technique into routine operations, and we interviewed forest, mill and storage yard managers to determine what made that integration successful. Storage terminals and processing facilities in Finland where cold storage has been operational on a large scale for about 10 years were visited to gain an understanding of why the technique is used, how it is applied and to identify critical factors for success. We also visited log-storage terminals in Sweden to explore their experience with storing very large volumes of storm-damaged timber over multiple years.

We discussed preliminary results with woodland and mill yard managers during mill visits in British Columbia and western Alberta and supplemented their input with telephone consultations. This was done to get local perspectives on how the technique might be adapted to western Canadian operations and to identify any impediments to successful implementation that must be addressed.

Discussion

Shelf life and storage of beetle-killed timber

Since 1995, lodgepole pine forests in the interior of British Columbia have experienced the largest outbreak of mountain pine beetle ever recorded. Although lodgepole pine is the principal species used in SPF (spruce/pine/fir) lumber, cumulative volume mortality has already far exceeded the British Columbia industry's capacity to access, harvest and process timber from all affected stands while the wood is still fresh. Current projections suggest that very high levels of new mortality will continue for several more years, contributing to a growing inventory of standing dead pine at varying ages since death (Walton et al. 2007). Interior sawmills will be processing beetle-killed timber in varying conditions (depending on time since death) and at varying proportions of total feedstock (depending on location of their source stands) for many years to come.

There has been much discussion regarding the "shelf-life"[2] of beetle-killed timber. Most literature was published at least 20 years ago from studies well to the south of the current outbreak, but several recent studies have supplemented this record with recent data and local experience (for example, Byrne et al. 2006; Hartley and Pasca 2006; Orbay and Goudie 2006; Lewis and Hartley 2005; Lum 2005; Barrett and Lam 2007). There is general agreement that the presence of bluestain and reduced moisture content of sapwood are the principle factors affecting wood quality of beetle-killed timber.

The importance of bluestain varies with product and market, but is generally less important in sawlogs for construction-grade lumber products that are the principal output of mills affected in this outbreak.

[2] "Shelf life" of standing beetle-killed timber has been defined as the "length of time it will remain commercially viable for a given product" (British Columbia Ministry of Forests and Range 2007a)

FORINTEK reviewed the impact of bluestain on suitability of lumber for construction uses and Lum (2005) looked at MSR grade recovery in beetle-damaged wood. Both studies confirmed that the presence of bluestain has no impact on mechanical properties of lumber. However, reduced moisture content of beetle-killed logs reduces both volume and value recovery in sawmills, affects log transportation (Jokai 2006a; Jokai 2006b) and increases processing and conversion costs.

In modern SPF sawmills, where settings are finely-tuned to maximize production, frequent switching between live (fresh) and dead (dry) logs is problematic and was a frequent complaint from the sawmill operators we interviewed. Because dry wood is harder to saw, there is increased wear on the saw and more energy consumption, both of which raise processing costs. In addition, if sapwood moisture content drops below the fibre saturation point (approximately 30%) as logs dry, seasoning checks (cracks) develop. This leads to increased breakage during handling and processing (lowering volume recovery), increases the proportion of small-dimension products (lowering value recovery) and leads to more frequent downtime for maintenance. Lewis and Hartley (2005) noted that the greatest losses in value and volume recovery for solid wood products occur due to seasoning checks, and suggested that first occurrence of checking will be a key determinant of shelf life for solid wood products.

Trent et al. (2006) assessed wood quality associated with site and time since death. Of all variables measured, only moisture content showed a significant trend when compared with time since death. Other wood and fibre properties fundamental to both solid lumber and pulp and paper production (including length weighted fibre length, coarseness, wood density, microfibril angle, wood stiffness and decay) did not appear to be affected by beetle-induced tree death up to 5 years after mortality.

This suggests that shelf life of beetle-killed timber for sawlogs could be extended if sapwood moisture content could be maintained above the fibre saturation point by storage under moist conditions. “Wet storage” (under sprinklers) and “water storage” (immersion in lakes or reservoirs) have been proposed and discussed in the context of this outbreak (e.g., Rogers 2001; MacDougall 2005); however, environmental concerns (such as riparian zone damage and raised biochemical oxygen demand in lakes or reservoirs, or high water demand and leaching of toxic substances from storage piles under sprinklers) and logistical drawbacks (such as transport and drying of saturated logs) are likely to limit their use. Cold storage (snow caching), presents an option for maintaining moisture content that does not entrain these concerns.

State of the Pine Forest

The state of pine inventory in the interior forests of British Columbia was described in the recent update of the outbreak in the province and the Chief Forester’s review of expected timber supply impacts; the condition of the pine inventory, timing of the peak in mortality, and projected severity of impacts on mid-term timber supply vary widely. Walton et al. (2007) tabulated observed volumes of annual green-attack mortality to 2006 and expected volumes up to 2011 in 20 Timber Supply Areas (TSAs), noting that the peak in mortality occurred in some TSAs two to four years ago but will not be seen for three or more years in others (Table 1). The same report estimates 530 million m^3 of merchantable pine has already been killed, and projects that very high levels of new mortality will continue for at least five more years, contributing to a growing inventory of standing dead pine at varying ages since mortality. Depending on location and species compositions of their source stands, interior sawmills will be

Table 1. Observed (2004–2006) and projected (2007–2011) annual green-attack volume (millions m^3) for the 20 most affected timber supply areas and three forest districts. Volume killed in the year with peak annual mortality is highlighted in bold type. Source: Walton et al. (2007).

	Year							
Pine Unit	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Vanderhoof (District)	**24.5**	6.6	4.5	2.6	1.3	0.6	0.3	0.2
Quesnel	**23.7**	11.3	5.4	2.0	0.6	0,2	0.1	0.1
Lakes	**15.1**	9.5	6.9	3.5	1.8	0.9	0.5	0.2
Prince George (District)	**12.5**	7.7	7.6	5.0	2.8	1.5	0.8	0.4
Williams Lake	19.2	**19.5**	15.9	12.9	9.3	5.8	3.3	1.8
100 Mile House	8.6	**17.5**	6.5	3.7	2.0	1.1	0.5	0.3
Kamloops	5.9	**8.6**	7.1	6.2	4.7	3.2	2.0	1.2
Morice	3.8	6.1	**8.4**	7.8	6.0	4.1	2.5	1.4
Ft. St. James (District)	10.7	7.2	11.4	**12.1**	10.9	9.4	7.4	4.9
Merritt	1.3	2.3	4.6	7.6	**9.1**	8.4	6.1	3.9
Lillooet	0.4	0.9	1.6	2.6	**2.9**	2.6	1.8	1.1
Arrow	0.5	0.6	0.7	0.9	**1.0**	0.8	0.5	0.3
Golden	0.2	0.3	0.3	0.5	**0.6**	0.5	0.4	0.3
Okanagan	1.0	1.3	2.2	4.2	6.6	**7.5**	6.5	4.7
Cranbrook	0.5	0.5	0.7	1.5	2.6	**3.5**	3.3	2.8
Bulkley	0.1	0.0	0.3	0.9	1.9	**2.5**	2.0	1.3
Boundary	0.1	0.2	0.3	0.8	1.6	**2.1**	2.0	1.5
Kootenay Lake	0.3	0.4	0.6	1.0	1.4	**1.7**	1.5	1.1
Invermere	0.2	0.3	0.4	0.9	1.3	**1.4**	1.1	0.8
Robson Valley	0.1	0.2	0.3	0.6	0.7	**0.8**	0.6	0.4
Mackenzie	0.7	2.1	4.7	8.6	10.5	12.1	**13.5**	12.1
Dawson Creek	0.0	0.1	0.3	0.7	1.6	3.2	4.7	**4.9**
Total	**129.5**	**103.1**	**90.9**	**86.4**	**81.2**	**74.0**	**61.6**	**45.6**

processing beetle-killed timber in varying condition (depending on time since death) and in varying proportions of total feedstock for several years to come.

How long the industry can use standing dead lodgepole pine will be a major factor influencing the economic impacts of the epidemic. Storage to extend the window for economic recovery requires fresh logs, or at least logs which have not lost sufficient moisture to develop radial checks. There will be limited (if any) opportunity to profitably implement cold storage to prolong shelf life of beetle-killed trees in management units where mortality peaked early and much of the standing inventory has already dried to the point of checking. In the west–central interior, where the outbreak began, the challenge is rapidly shifting to harvesting and processing dry and dead timber before the economics of recovery become entirely prohibitive.

In the Vanderhoof and Prince George Forest Districts, and in the Lakes, Quesnel, and 100 Mile House TSAs, 65% to 80% of the total merchantable pine volume had been killed by 2006, and annual green-attack volumes are projected to decline in these areas. By the time operations could test and implement cold storage, there may be little fresh wood to store locally. On the other hand, depending on local shelf life of standing beetle-killed trees, these areas could face a very significant drop in timber supply within five years. Early in the epidemic, records of the British Columbia Ministry of Forests and Range Harvest Billing System show that these areas harvested pine well above the volumes that were processed locally for several years, whereas other operating areas (such as the Mackenzie, Peace or Okanagan Forest Districts) processed pine at volumes well above their local pine harvest levels. If the annual allowable cut is increased in these latter areas as the epidemic expands, transfers of fresh logs in the opposite direction will likely play an important role in mitigating early effects of the expected timber supply falldown. Should cold storage prove a viable option, these areas may also be the most likely source of suitable timber for storage.

In parts of the central and southern interior, the outbreak is already well established but a large portion of the pine volume has not yet been killed (such as the Fort St. James Forest District, and the Merritt, Okanagan, Williams Lake, Kamloops, Lillooet and Morice TSAs). Here, there will be increasing pressure to concentrate harvest on stands with a higher proportion of green and red attack before the proportion of trees with checks makes recovery of sawlog grades entirely uneconomic. Depending on local conditions, short-term storage (for less than one year) which preserves moisture content may play an important role. In other parts of the southern interior (such as the Cranbrook TSA) and at the northern and northeastern periphery of the current outbreak (such as the Peace and Mackenzie TSAs), mortality is still increasing, and operators face the challenge of limiting beetle population growth and impact through aggressive harvesting and processing of green-attacked timber to slow the spread of the outbreak. Timber supply areas, including the MacKenzie, Fort St. James (District), Okanagan, Merritt, Dawson Creek, Cranbrook and Lillooet TSAs, are all expected to suffer significant green attack to 2010 (and in some cases beyond). Uplifts (increases in annual allowable cut) are still possible in some cases, and these management units have the highest potential to be a source of fresh logs that could placed into longer-term (multi-year) storage for later processing in areas facing local timber shortages.

Potential Roles for Cold Storage

We identified three scenarios in which cold storage could play a role in responding to the current mountain pine beetle outbreak:

1. Where the outbreak is expanding rapidly, and green-attack wood volume exceeds capacity of mills to process all affected logs prior to dispersal flight, cold storage until milling later in the season may prevent development and dispersal of beetles;
2. Where significant value is being lost in the short-term between harvesting and processing due to checking after delivery to the mill, cold storage may maintain moisture content, effectively extending the time frame for higher-value recovery; and,
3. Where there is opportunity to store large volumes of quality logs, doing so for an extended time frame may help defer or moderate anticipated social, environmental, and economic impacts in the areas most affected by the mountain pine beetle outbreak.

In the following sections, we discuss each of these cases, referring to what we found in the literature or observed in eastern Canada and in Europe, suggesting scenarios where the role may be appropriate in British Columbia, and pointing out where the current business paradigm or market pressures affect how, where or by whom the technique might be applied effectively.

Storage to prevent or delay insect development and assist spread control

The 2006–2011 British Columbia Ministry of Forests and Range Beetle Action Plan lists "Preventing or reducing damage to forests in areas that are susceptible but not yet experiencing epidemic infestations" as one of its major objectives (British Columbia Ministry of Forests and Range 2007b). Reducing the spread of beetles from infested areas into unaffected stands by processing green-attacked trees prior to beetle emergence and dispersal plays a critical role in preventing or reducing damage from expanding beetle populations (Carroll et al. 2006; Whitehead et al. 2006).

By the time green-attack logs are harvested, most beetles are overwintering as third- or fourth-instar larvae, and further development (including pupation and feeding as teneral adults prior to emergence) does not begin until spring when temperatures rise above about 5.6°C (Safranyik and Carroll 2006). It normally takes about 6 to 8 weeks before insects are ready to fly, and dispersal is normally observed on days when temperatures exceed about 18°C. Where it is not possible to process all green-attack logs before the dispersal flight, storage under conditions that prevent insect development would help control the spread of the outbreak. Wet storage (under sprinklers) has been successfully employed to keep logs cool and prevent or delay emergence of adult beetles for dispersal; however, demand for fresh water during the dry season, and concern for handling of toxic run-off from log decks tended to limit the use of this technique by mill managers we interviewed. With snow storage, there is no conflict with other water users in summer drought periods; there is also very little meltwater to deal with during a very short recovery phase, which greatly reduces potential for leaching of toxins from bark.

European operations we visited had focused on cold storage of healthy timber, so there were no examples where the technique was used specifically to prevent insect development and emergence, although the prevention of attack by wood borers was frequently mentioned as a benefit of cold storage. However, we found two examples of cold storage in Canada, one at Chapais, Quebec and one at Grande Prairie, Alberta, where preventing development of insect larvae already present in logs was a primary objective. In both cases, within-deck temperatures were monitored throughout storage, insect development was evaluated at end of storage, and observations confirmed that insect development was effectively halted.

Fire-damaged spruce sawlogs were stored as tree-length logs under an insulated snowpack at a stud mill in Chapais, Quebec[3]. After timber was killed in the 2005 fire season, two-year-cycle longhorned beetles established but entered winter dormancy without excavating large galleries. Aware that not all wood salvaged in the winter could be processed before the insects resumed activity in the spring when logs reached a threshold temperature of about 8 °C, the company snow-cached more than 60,000 m^3 in several decks to be opened as required for processing in summer. In air-stored piles maintained for comparison, the threshold temperature was reached by the end of April; beetles became active, and subsequent insect damage reduced final product grades. Logs stored under snow remained frozen (< 0°C) until removed from storage at various times from May through July; insects remained dormant and caused no further damage, and the mill realized a higher recovery of premium grade studs.

In a small-scale research study initiated by the Canadian Wood Fibre Centre and FPInnovations with Canadian Forest Products Ltd. at their sawmill in Grande Prairie, Alberta, green-attack logs containing mountain pine beetle larvae were stored under an insulated snowpack in early March, 2007[4]. Temperatures in the storage deck remained below freezing throughout the summer and, when piles were opened August 28, there was no evidence of any development by surviving larvae throughout the spring and summer months[5]. The wood appeared fresh, and all logs were processed before beetles could pupate.

Cold storage can delay insect development if required to prevent dispersal; however, the need for this will vary with level of green attack relative to local harvesting, transportation and processing capacity. Successful implementation at millyards requires planning far enough ahead that decks can be built when both the ground and logs are still frozen, and either natural snow is available or ambient temperatures are low enough to allow snowmaking.

Early break-up of winter roads can result in green-attack logs being inadvertently left at the harvest site until summer hauling commences[6]. With sufficient foresight, these logs could be stacked in shaded depressions or at roadside under whatever natural snow and insulating materials are available (branches, etc.) while equipment is still on site. Such improvised snow caches may not be optimum for preserving wood quality, but should keep under-bark temperatures low enough to slow insect development and allow operators a longer window to return for these logs.

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[3] Pierre Lemelin, Barrette-Chapais Lteé, Chapais, QC. Personal communication.
[4] Brian Martell, Operations Supervisor, Canadian Forest Products, Grande Prairie, Alberta. Personal communication.
[5] Richard Krygier, Intensive Fibre Management Spec. Canadian Forest Service., Canadian Wood Fibre Centre, Edmonton, Alberta. Personal communication.
[6] Rod DeBoice, Provincial Bark Beetle Coordinator, Emergency Response Team, British Columbia Ministry of Forests and Range, Kamloops, British Columbia. Personal communication.

- At the outbreak's leading edge, creating snow caches can significantly benefit spread control efforts when harvest, transportation and milling cannot be coordinated in time to prevent dispersal of beetles from green-attack logs.

Short-term storage to maintain log quality and capture highest-value returns

Sawlogs generally pass through several activities between the forest and the head rig at the mill, including harvesting/felling, skidding/forwarding, storage at roadside, long-distance transportation and finally storage at the mill. In some cases, there may also be storage at an intermediate terminal (a sortyard or logyard). Wherever road transportation networks have allowed, operations around the world have increasingly adopted a "just-in-time" delivery emphasis, with minimal inventories maintained in storage at all phases. However, just-in-time delivery systems developed with an implicit assumption that storage on the stump will not result in significant loss of quality, value or volume. In much of the lodgepole pine forest in British Columbia, this assumption is no longer valid.

Woodland and mill managers in Scandinavia emphasized that recognition of the importance of "fresh" logs for achieving the highest yield of higher-value end products at reduced processing cost was the principal driver behind just-in-time delivery in Europe (Jonsson 2007). However, difficulty guaranteeing a supply of fresh wood with the most desirable fibre attributes at all times, especially between the end of winter hauling and the start of summer harvest, requires storage in many operations. Although storage incurs additional costs, Scandinavian operations are fully integrated and focus on increasing *overall* profit margin rather than on minimizing costs of *individual* phases.

For example, spruce logs cut in winter, when inherent brightness (a measure of quality) is highest, yield higher-value products at lower processing cost than logs cut in summer. However, if cut in winter and stored without protection, logs dry out and discolour. This increases bleaching requirements, frequency of saw or chipper maintenance, and energy demand. As a result, most mills store winter-cut logs under water, sprinklers or snow for processing in summer and fall. Similarly, although most pine stands which yield higher value as sawlogs grow on ground suitable for summer logging, the lower cost of winter road maintenance presents a case for storage. According to the last Swedish Sawmill Inventory (for the year 2000), 84% of sawmill operations producing more than 100 000 m^3/yr protect their wood with wet storage (Staland et al. 2002). Metsäteho Oy reports that more than 3 million m^3/yr are now typically stored under snow in Finland [7]. These statistics suggest that there is a strong business case for maintaining wood quality through storage, although we were unable to assess it quantitatively.

Our contacts frequently emphasized that properly executed storage preserves inherent quality of stored wood, but will do little if anything to improve it and that this is the principal reason for concentrating on storing logs with inherent high value. Sorting at the storage terminal was common practice, with the best logs for specific processing lines placed in storage decks constructed in sizes suited for a typical mill run. In the cases of snow storage we saw, individual piles ranged from about 15 000 m^3 to 60 000 m^3 depending on the mill lines targeted. Apparently, larger piles may create difficulties during recovery because they take longer to fully melt.

[7] Antii Korpilahti. Senior Research Specialist. Metsäteho Oy. Helsinki, Finland. Personal communication.

- Key elements in the successful implementation of storage into European operations include a focus on storing only fresh, high-quality logs in quantities suitable for a typical mill run on processing lines that produce higher-value products.

Nader (2003; 2005) reported on early tests of short-term cold storage in eastern Canada. We visited Columbia Forest Products' operations in Ontario, where cold storage was subsequently implemented as part of routine log inventory management. These mills produce aspen-based plywood, with sub-flooring or hardwood veneer panels producing the highest value. Until snow storage was implemented, the mills were forced to produce lower-value construction sheathing in summer and fall, because they were unable to produce enough face sheets from dry peeler logs due to end-checking when the logs were held in storage without protection. In addition, storing hardwood logs under snow allowed a rapid response to specialty orders when competing suppliers had difficulty obtaining fresh peelers at low cost. Logyard and woodland managers commented on how the combination of higher yields and reduced processing costs due to reduced energy consumption and maintenance requirements during summer mill runs had greatly improved their popularity with plant managers, and that reduced summer logging and hauling had also led to savings in their own costs, as well as reduced risk of fire, conflict with recreational users, and site disturbance.

- Key elements in the successful implementation of snow storage in eastern Canada have also included a focus on storing winter-cut, high-quality logs for specific processing lines that allow mills to fill market demands in summer and fall for high-value end products at lower cost than their competitors.
- In both cases, the savings in both woodland and mill operating costs and the benefits in volume and/or value recovery and flexibility to market demands were identified and weighed against incremental costs of storage. This analysis played a key role in successful implementation.

In sharp contrast to our discussions in Europe and eastern Canada, woodland and plant managers in British Columbia made it clear that the primary driver behind just-in-time delivery in British Columbia is minimizing costs of carrying inventory after incurring stumpage, logging and transportation costs. However, as in other jurisdictions, guaranteeing log supply between the end of winter hauling and the start of summer harvest still necessitates storage at the mill site in many operations. Although water storage (in lakes) or wet storage (under sprinklers) have been applied in some operations, logs are simply decked without protection until processed in most cases, and any losses or increased processing costs as a result of time in storage are reluctantly accepted by mill managers as a seasonal problem. In some operations, the thinking in woodland or plant operations has not yet shifted to an objective of realizing an overall profit margin for the integrated operation by delivering higher-quality logs to the mill at somewhat higher initial cost. Reluctance to accept a carrying cost of keeping logs in storage was by far the most frequently mentioned factor when managers were asked what impediments they foresaw in adopting cold storage to extend the window for economic recovery of beetle-killed wood. Although this factor is more important in consideration of long-term storage (discussed below), it was often presented as a limiting factor even when storage for a single season was discussed.

- Unless operations in British Columbia shift paradigms from minimizing delivered wood cost to maximizing overall profit margin, inertia will be a major impediment to adoption of storage to improve value return from beetle-killed wood.

The efficacy of snow storage to maintain sapwood moisture content of stored logs and potential positive effects on overall costs and value return has been clearly demonstrated in other jurisdictions (STODAFOR 2005; Nader 2003; 2005). Trials in both current harvest and salvage operations at mills in Manitoba, Ontario and Quebec (Nader 2003), showed that wood stored under snow retained uniformly high moisture content and developed no decay or insect damage. Nader (2005) documented the incremental costs of snow storage and recovery, and the benefits reported in both woodland operations and at the mill. Using data supplied by mills participating in the study in 2004, costs ranged from \$1.20/m3 to \$3.30/m^3 for constructing snow caches and from \$0.30/m^3 to \$1.20/m^3 for recovery. Savings and profits attributed to snow storage ranged from \$5.00/m^3 to \$6.10/m^3, leaving net benefits of \$1.10/m^3 to \$2.60/m^3, depending on the specific situation. Companies involved in these trials have since implemented snow storage operationally.

Whether an individual firm should undertake short-term storage depends upon its own internal supply-chain economy and is beyond the discussion presented here. However, the business case for short-term storage needs to be demonstrated for British Columbia operations. Preventing loss in both volume and value recovery from checked sawlogs is key. For example, Barrett and Lam (2007) compared conversion of green or grey SPF stud-length logs into 96-inch or shorter lumber products in a modern high-speed stud mill near Vanderhoof and reported lower lumber volume and value recovered from grey logs (94.3% and 87.5%, respectively) than from green lumber. The combination of lumber recovery and value recovery (\$US/Mfbm) for the grey beetle-killed lumber products was 82.5% of lumber and value recovered from the green SPF logs. Similar losses can be anticipated, as much of the already affected volume is salvaged two or more years after peak mortality in the stand; however, in those areas where substantial volumes are still being killed each year, snow storage may have a role in avoiding this type of loss.

- The efficacy of snow storage to maintain sapwood moisture content of stored logs and potential positive effects on overall costs and value return has been clearly demonstrated in other jurisdictions. Whether an individual firm should undertake short-term storage depends upon its own internal supply-chain economy.

The potential for application of short-term storage will depend largely on the area and the type of operation. For example, in the driest southern interior management units, where operators have not traditionally been faced with the spring break-up issues that necessitate storage of larger inventories for summer processing further north, hot-logging (logging such that logs are processed immediately after harvest) has been relied upon to provide fresh logs in summer and fall. By late summer of 2007, operators in some of the hottest and driest management areas (e.g., Merritt and Boundary TSAs) were reporting checking in logs from green-attacked stands soon after summer logging and sometimes even between scaling at the mill and processing. Some felt it could be associated with very rapid drying caused by a combination of high temperature, low relative humidity and wind during transportation to the mill and during the short period of storage at the millyard. If this is the case, shifting to increased harvest activity in winter and storing these green-attack logs under insulated snowpacks may substantially increase both volume and value recovery.

- Cost/benefit studies in specific operations where significant loss can be attributed to checking between harvest and processing are needed to determine if there is a compelling business case for short-term snow storage in British Columbia operations.

Long-term storage to extend shelf-life of high-value timber assets and soften social, environmental and economic impact on affected areas

Multi-year storage of logs (fresh green-attacked trees and uninfested trees at risk) under insulated snowpacks is a promising option to preserve wood quality. Furthermore, it does not entail most environmental concerns associated with other options such as storage in lakes or under sprinklers.

Storing very high volumes of logs for more than a single season is an extraordinary measure, but extraordinary events engender extraordinary responses, and examples of significant volumes of sawtimber and pulpwood stored for up to four years have been reported in the literature. There are, for example, records of wet storage after storms in Germany and Denmark in 1967, 1972 and 1990 (Moltesen 1977; Liese and Peek 1984; Bues and Läufer 1993), and in Great Britain in 1987 (Webber and Gibbs 1996). Wet storage of fire-damaged pine sawlogs in South Africa was reported by von dem Bussche (1993).

The largest-scale multi-year storage event was associated with the "Gudrun" hurricane of January 2005, which blew down 75 million m^3 of timber in southern Sweden (Jonsson 2007), with an estimated gross value of more than €20 billion (Björheden 2007). The volume of storm-damaged timber was approximately equal to a normal year's harvest for the entire country; in some areas, the equivalent of 20 years of harvest were felled in a single night (Donoghue et al. 2006). The Swedish forest sector, including forest companies, government and land and mill owners, immediately cooperated in reducing harvests in unaffected stands, maximizing consumption of storm-damaged timber in mills across Sweden, and stockpiling some of the higher-value sawlogs under sprinklers for future use. Plans for widespread lake storage met with local resistance; this option was implemented only in one lake (Sodra 2006). Roughly 90% of the affected volume was salvaged by the spring of 2006 (Skogsstyrelsen 2006), with a net loss[8] estimated at €1.7 billion to €3.2 billion (only 8% to 16% of gross value). Most logs were processed in Sweden and some were exported, but several million cubic metres of the highest quality logs were put into storage for processing over a four-year period. In December of 2006, a further 12 million m^3 of timber was blown down. Most of that volume was placed in storage until earlier stockpiles were processed.

The forest sector is regarded by Swedes as important to Sweden. To avoid loss of jobs and bankruptcy of many traditional, private, non-industrial forest owners and to preserve export incomes and reduce risk of wildfire and insect outbreaks, the enabling of prompt and efficient use of the most valuable wood was identified as being 'in the public interest' (Björheden 2007). Government programs that favoured public economy or avoided market distortions were implemented promptly, including public grants for road maintenance and tax exemptions for operations that would not otherwise be economically feasible (e.g., on diesel used in salvage operations and on pre-storm roundwood value).

[8] Estimates (from National Board of Forestry and Swedish Federation of Forest Owners, respectively) of the difference between net revenue that storm-felled timber would have generated at normal felling cost and timber pricing prevalent in 2004, and the costs and actual revenues generated by the timber felled by the storm after considering higher felling costs, lower prices, storage, replanting and non-recovered losses.

These government measures were based on cost/benefit studies, and assistance was focused on the most valuable forest products — sawtimber and pulpwood. Labour and equipment from other countries across central and eastern Europe were imported and allowed to operate until salvage was complete.

We visited several large storage terminals in Sweden, including the Byholma airstrip where VIDA Oy stockpiled 1 million m^3 of spruce sawtimber (Figure 2). This state-owned airstrip was made available for the company's use within weeks of the storm, and is only one of several storage terminals operated by that company [9]. They do not intend to start using the timber stored at Byholma until 2008. Similarly, we visited terminals operated by Södra, who increased their storage from their usual level of about 1.5 million m^3 to 10 million m^3 by the end of 2005; some 30 new terminals were established, and they intend to hold wood for up to three years (Södra 2006).

Figure 2. Approximately 1 million m^3 of Norway spruce sawlogs are being stored up to four years under sprinklers at an abandoned airstrip near Byholma, Sweden, by Vida Oy. The storage piles are about 13 m high, and the area used for log storage is about 60 m wide and 2.3 km in length.

- The Swedish forest sector took extraordinary measures in response to catastrophic windstorms in 2005 and 2006. Labour and machines were imported from other parts of Europe, and harvest was reduced in unaffected stands and focused instead on damaged wood for processing as quickly as possible and for creating large stockpiles of the most valuable logs for use up to four years later. Government, industry, and landowners collaborated in the implementation of these measures to jointly further their diverse interests.

[9] Johann Lisemark, Manager, Alvesta Timber, VIDA Group, Alvesta, Sweden. Personal communication.

To the best of our knowledge, log storage under snow has never been intentionally used for long-term storage; there are therefore no data to conclusively evaluate how long logs may be stored. However, in both eastern Canada and Finland, we encountered cases where logs were inadvertently kept in cold storage for two full seasons because of production delays or because unseasonably cold fall weather prevented recovery in the first season. Terminal managers commented that there was very little change in the insulated snowpack and no discernible change in wood quality after two years, and they were willing to speculate that, if piles are well constructed, snow cover well packed, and insulation well applied, decks could be stored for even longer periods. Further, they suggested that time in cold storage could be extended by temporarily removing insulation in mid-winter, adding more snow and then replacing the insulation. As long as the wood remains frozen, there should be no loss in quality. In fact, Nader (2003) presented evidence that snow-cached logs may slowly take on moisture through osmosis as the snow undergoes repeated subtle changes from liquid to solid state when temperatures remain at the freezing point during the summer.

Stora-Enso Oy scaled up to store 250 000 m^3 annually at a single large terminal intended to feed several mills near Anjalakowski in the south of Finland, but have recently reduced the size of the inventory held in one block because of difficulty getting very large storage piles to melt when processing is required [10]. Insulated snowpacks do not melt easily.

- There are no data to determine how long snow caches can be maintained because no studies have been undertaken. The experts we consulted speculated that storage for up to three years may be feasible without additional inputs, and that storage might be extended indefinitely if the snowpack was periodically replenished in subsequent winters.

In British Columbia, mountain pine beetle-induced tree mortality at comparable levels to storm damage experienced in Sweden during hurricane Gudrun is expected to occur annually for at least four more years, suggesting that a sustained extraordinary response of similar magnitude is required to capture values at risk. Early responses in British Columbia included maximizing harvest and processing of affected trees through AAC uplifts and cut transfers, encouraging special measures for spread control in Emergency Beetle Management Areas, and provision of favourable timber pricing for salvage (MacDougall 2005); however, long-term storage of beetle-killed sawlogs for future use has not been implemented at a large scale.

Rogers (2001) evaluated economic feasibility of longer-term storage by licensees operating in the west–central interior and, under conditions at that time, concluded that water storage may allow positive operating earnings for a few years, but would not generate adequate return on capital investment at typical discount rates. Under conditions prevailing three years later, MacDougall (2005) concluded that lake storage could generate sufficient return on capital to be viable for up to five years, using a 4% discount rate.

Crown licensees we spoke to did not consider longer-term storage possible without some assistance or changes to stumpage and silviculture obligations and much more favourable market conditions. However, anything that appears to be a government subsidy to industry is unlikely (and probably undesirable) because of the Softwood Lumber Agreement, and market conditions have not improved since those discussions.

[10] Samuli Hujo, Researcher, Metsäteho Oy, Helsinki, Finland. Personal communication.

- Longer-term log storage is not likely by licensees of the Crown because carrying the combined cost of stumpage, logging, transportation, storage and silviculture obligations over multiple seasons until logs are processed and sold in the market is an untenable investment for a publicly traded company under the current business model.

MacDougall (2005) considers economic feasibility of longer-term storage to depend on the answer to a simple question: "Is it profitable to make investments in the storage of timber in order to increase the supply of merchantable timber in the future?". In his discussion, MacDougall points out that "the interests of the Province may diverge from the interests of a company", suggesting that the answer to that question depends very much on the frame of reference.

Declining lumber prices associated with the recent downturn in the American housing market, coupled with effects of the Softwood Lumber Products Export Charge Act (Parliament of Canada 2006) and recent appreciation of the Canadian dollar against the U.S. dollar, compound the affects of mountain pine beetle on the forest sector in the interior of British Columbia. The public forest landlord and its licensees are faced with a dilemma: current economic conditions dictate that production should be curtailed, but capturing the most value from beetle-killed forests requires processing the affected pine inventory as rapidly as possible.

There are likely to be more mill closures due to the pressures discussed above, and the harvest, log transportation and silviculture capacities in affected communities will not be fully used. The resulting substantial socioeconomic impacts will include unemployment or displacement of skilled labour and capital equipment, which may not be available for start-up when markets improve. Such displacement could lead to a permanent reduction in economic activity associated with forest harvest and conversion. However, if mills curtail production, timber projected to be affected by mountain pine beetle could be harvested and stockpiled for later use, and this infrastructure might be sustained until market conditions are favourable for production to resume.

Significant stumpage values in unaffected pine forests on the periphery of the outbreak (e.g., Mackenzie, Merritt, Dawson Creek and Boundary TSAs) will not be fully realized by the Crown if the outbreak is allowed to proceed without management, as projected by Walton et al. (2007). Further, if affected trees are not harvested within the shelf-life for economic sawlog recovery, there will be greater losses associated with taxes on corporate profits, employee payrolls, fuel consumption, purchases and other activities associated with harvest and transport of timber. The social costs of economic collapse is small timber-dependant communities would be high. Cost of salvaging these uneconomic stands and returning them to productive status will be significant, and any regeneration delay will have a negative effect on timber supply.

Harvest for storage could be specifically targeted to freshly attacked stands and used to break up the continuity of susceptible pine types as part of an organized control effort. This could slow the spread of the outbreak, extend time available for using that volume economically, and reduce the projected amount of area requiring salvage. Sites which would otherwise not have been harvested can be returned to a fully stocked condition to contribute to future timber supply at an earlier date. Such a response generates substantial benefit in both the short and longer term to the provincial economy and to the stability of communities in affected areas.

- The most significant factor impeding long-term storage in the current business model is the costs that must be carried until the timber is manufactured into products and sold (i.e., costs of development, stumpage, harvest, transport, storage and silviculture obligations).

While licensees operating in pine forests of British Columbia may well see significant downstream benefits in stockpiling quality logs for future processing under favourable market conditions, and delaying the rate at which pine stands in their operating area are killed by beetles, they must act in the best interests of their shareholders considering all issues, and the current situation and business model simply do not favour licensee investment in long-term storage.

On the other hand, the Crown must act in the public interest and the social, economic and environmental costs of not harvesting in the expansion zone of the outbreak are significant from that perspective. The potential benefits to the Province (and to individual communities in affected areas) of implementing a large-scale harvest to storage program to buffer short-term disruptions caused by mill closures, and to protect the market value of a valuable Crown asset, are likewise significant.

- The social, economic and environmental costs of not harvesting in areas where the outbreak is expanding are significant, and sustaining harvests on the periphery of the outbreak is in the public interest.

In addition to moderating potential social costs in affected communities, stored logs sold into a market where high quality logs are in short supply should generate substantially higher revenues for the Crown than if the inventory is allowed to deteriorate on the stump. In the area affected by mountain pine beetle during the past 10 years, forest product manufacturers would welcome an opportunity to bid on high-quality logs when markets are favourable and opportunities to harvest fresh sawlogs from their Crown timber licenses are much reduced.

- A similar harvest-for-storage programme could be used to slow progress of the outbreak in British Columbia, preserve Crown asset values, and modify timber flows to buffer impacts on communities in affected areas.

Given recent changes in forest policy relating to use requirements, appurtenance and cut control, there may be innovative ways to modify the current business model to achieve some of these benefits. Where licensees are not meeting their AAC, and there is significant accumulated undercut that reverts to the Crown, it may be possible to re-allocate that cut to a contractor for storage and sale in future auctions. A logical choice may be B.C. Timber Sales, which has much of the required infrastructure already in place.

- To serve their complementary interests, the Crown and its licensees should consider innovative ways to facilitate a continued harvest of fresh high-value logs to create stockpiles for future use when market conditions improve.

Summary and Conclusions

The efficacy of log storage under snow to prevent development of beetles in stored green-attack logs has a sound basis in theory and has been clearly demonstrated in preliminary results of at least one study in Alberta. In British Columbia, creating snow caches could slow the spread of the mountain pine beetle outbreak when harvest, transportation and milling can not be coordinated in time to prevent dispersal of beetles from green-attack logs.

Similarly, the efficacy of snow storage to maintain sapwood moisture content of stored logs and generate substantial positive effects on overall costs and value return has been clearly demonstrated in Finland and in eastern Canada. Key elements in the successful implementation of short-term storage under snow into operations in both cases include focusing on:

- storing only fresh, high-quality logs
- targeting processing lines that produce higher-value products to allow mills to cost-effectively fill specific market niches with greater flexibility than their competitors; and,
- creating individual caches of suitable size for a typical mill run.

In both Finland and eastern Canada, savings in woodland and mill operating costs, improved volume and value recovery, and increased flexibility to market demands were identified and weighed against incremental costs of storage. This analysis played a key role in successful implementation. Whether an individual firm should undertake short-term (less than one year) storage to preserve moisture content depends upon its own internal supply chain. Inertia could be a major impediment to adoption of snow storage to improve value return from beetle-killed wood. Cost/benefit studies in specific operations where significant losses can be attributed to checking between harvests and processing are needed to determine if there is a compelling business case for short-term snow storage in British Columbia operations. Operations in British Columbia need to shift from a paradigm of minimizing delivered wood cost to one of increasing overall profit margin.

There are precedents for successful implementation of longer-term (multi-year) storage of logs to buffer social, environmental and economic impacts of natural disasters. In response to catastrophic windstorms in 2005 and 2006, the Swedish forest sector took extraordinary measures to rapidly harvest and process storm-damaged timber and to stockpile very large volumes of the most valuable wood under conditions that would prevent deterioration. Government, forest industry, and landowners collaborated in implementation of these measures to further their diverse interests. Mortality to the mountain pine beetle in British Columbia is expected to continue for at least four more years, at comparable levels to the storm damage experienced in Sweden during hurricane Gudrun; a sustained extraordinary response of similar magnitude is required to capture values at risk.

Multi-year storage of logs (fresh green-attacked trees and uninfested trees at risk) under insulated snowpacks is a promising option to preserve wood quality that does not entail most environmental concerns associated with other options such as storage in lakes or under sprinklers.

There are no data to determine how long snow caches can be maintained because there are no recorded attempts to extend storage beyond two years. The experts we consulted speculate that storage for up to three years is feasible without additional inputs, and that the period of storage might be extended indefinitely if the snowpack was periodically replenished in subsequent winters.

Long-term log storage by licensees of the Crown is not likely, because carrying the combined cost of stumpage, logging, transportation, storage and silviculture obligations over multiple seasons until logs are processed and sold as products in the market is an untenable investment for a publicly traded company under the current business model. However, the social, economic and environmental costs of not harvesting in areas where the outbreak is expanding are significant, and the potential benefits, to both the industry and the Province, of sustaining harvests on the periphery of the outbreak to slow impacts on the as-yet uninfested pine are high. To serve their complementary interests, the Crown and its licensees should consider innovative ways to facilitate a continued harvest to create stockpiles of fresh, high-value logs for future use when market conditions improve.

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