Extension Note

BC Journal of Ecosystems and Management

Considerations for rehabilitating naturally disturbed stands: Part 2 – Stand-level treatments and hydrological equivalent clearcut area

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Abstract

This extension note examines hydrological equivalent clearcut area (ECA) for stands affected by the mountain pine beetle infestation in British Columbia and decisions about salvage and rehabilitation. Contributions to reducing ECA from beetle-killed trees, surviving overstorey, advanced regeneration, and natural or planted seedlings are explained. Projections compare ECA trajectories and total "ECA years" for different stand types under different management options, suggesting conditions where salvaging and planting produce greater or lesser ECA effect over time. Factors influencing decisions about delaying underplanting are also illustrated. Considerations concerning ECA for stand-level decisions, when a detailed hydrological assessment is not possible, are summarized in a decision key.

KEYWORDS: *equivalent clearcut area; hydrological values; mountain pine beetle; naturally disturbed stands; rehabilitation; stand-level treatments.*

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Huggard, D. 2011. Considerations for rehabilitating naturally disturbed stands: Part 2 – Stand-level treatments and hydrological equivalent clearcut area. *BC Journal of Ecosystems and Management* 11(3):66–79. http://jem.forrex.org/index.php/jem/article/view/50/50

Introduction

Large wildfires near communities in southern British Columbia and the extensive outbreak of mountain pine beetle throughout pine forests of the province's Interior have created many new issues for forest managers. A particular concern is managing the cumulative effects of large natural disturbances in combination with forest management activities. In the past, planning for multiple values focussed on forest development plans for normal commercial forest harvest in landscapes dominated by mature forest. Now, increasing pressure to recover disturbed stands for biofuels (B.C. Ministry of Energy, Mines and Petroleum Resources 2008) has resulted in multiple overlapping volume-based tenures and an increased rate and extent of large-scale commercial salvage.

Adding to this complexity, large natural disturbances can themselves affect mature forest reserves intended to meet objectives such as wildlife habitat and water supply. With large disturbed areas, managing for these values is not simply a matter of adequate retention of mature forest. Forest rehabilitation activities, such as those conducted by the Forests For Tomorrow program (B.C. Ministry of Forests and Range 2006), are now expected to actively contribute to recovering forest values negatively affected by fires and the mountain pine beetle outbreak. Decisions about which stands to rehabilitate with Forests For Tomorrow funding are based on an economic return on investment for timber of at least 2% per year (see *http://forestsfortomorrow.com/fft/tool/return-investment/222*), but the program also includes a multiple accounts decision analysis to incorporate non-timber values (Forsite 2008). Forests for Tomorrow will fund activities that do not reach the silvicultural return on investment criteria if the activities make a strong contribution to other values. Additionally, reducing impacts to non-timber values should be integral to Forests For Tomorrow activities and salvage decisions because the expense of repairing those impacts could outweigh the economic benefits of timber production.

Recent concern about the effects of large natural disturbances in combination with timber harvesting has centred on watershed management (B.C. Ministry of Forests and Range 2004). A critical social value within community watersheds is maintaining high-quality water for domestic and agricultural use. Forest licensees also make a commitment to not degrade water quality in any watershed. In addition, protecting downstream structures (e.g., buildings, roads, and bridges) and conserving other aquatic resources including fish are important values in many watersheds. If these values are affected by resource development activities, economic gains from silviculture may be outweighed by associated impacts, such as costs of increased water treatment or flood control, liabilities for damaged human health or property, or stream rehabilitation. On the other hand, wise forest management practices can reduce the risk to these values from the natural disturbances themselves.

In this extension note, operational guidance for reducing risk to hydrological values relies on equivalent clearcut area, a simplified management tool that should not be confused with a full hydrological assessment.

This extension note reviews how stand-level forest operations can affect hydrological values in forests affected by natural disturbances. In this note, operational guidance (see sidebar) for reducing risk to hydrological values relies on equivalent clearcut area, a simplified management tool that should not be confused with a full hydrological assessment. An accompanying extension note reviews the watershed-level context for these stand management decisions (see Milne and Lewis 2011, page 55 in this issue).

Improving operational implementation of stand-level treatments in watersheds

To improve the operational implementation of stand-level treatments in watersheds, the following important points should be kept in mind.

- Be careful not to do the same thing everywhere within a watershed/landscape.
- Look at existing watershed assessments, watershed risk analyses, and terrain stability surveys that apply to your operating areas.
- Be aware of overlapping values for a range of concerns (e.g., water, wildlife, non-timber forest products).
- Consult qualified professionals when necessary.
- Be aware that stand-level activities aggregated over a watershed or landscape can have cumulative effects.
- Be aware of proposed activities of major licensees in landscape-level plans.

Stand disturbance and equivalent clearcut area: What is the connection?

Milne and Lewis (2011) have summarized how forestry affects hydrological values, particularly peak flows and total water yield (see this issue, pp. 55–65). One simple indicator of the potential effects of natural disturbances and forestry on hydrological values is the equivalent clearcut area (ECA) (B.C. Ministry of Forests 1999; Lewis and Huggard 2010). At the stand-level, ECA is 100% for a clearcut, 0% for mature forest, and has intermediate values for regenerating or partially disturbed stands. At the watershed level, ECA is simply the area-weighted average of the ECA values for individual stands. If the watershed has significant topography, the ECA of the upper part of the watershed, where snow accumulation and melt drive spring streamflow, is most relevant for hydrology.[1] The ECA value of young or partially disturbed stands is determined by field studies that measure peak snow accumulation and ablation rates (melt, plus some evaporation and sublimation) (Winkler and Boon 2010). These measurements are compared to values in clearcuts and mature forest in the same forest type. Using snow accumulation and ablation as the basis for ECA means that it is most relevant for spring peak flow and total water yield. Other hydrological processes such as evapotranspiration, which can affect late summer flows, depth of water table, and other hydrological values, are not typically used to calculate ECA for stands.

Few studies have measured stand-level ECA directly. Operational use of ECA in forest stands as they develop over time must therefore rely on stand-structure correlates of ECA, mainly tree height, percent of full canopy closure, and structural decay of snags. Pooled results from several studies show that ECA in regenerating clearcuts drops from 100% as growing trees first exceed the height of the snowpack to near 0% when trees reach about 12 m (B.C. Ministry of Forests 1999).[2] Any cutblock area that is not restocked contributes proportionally to ECA. For example, if 10% of a block is in roads or other unplanted area, ECA only declines to 10%, not 0%, when the seedlings in the rest of the block reach 12+m. In recent partially cut stands that retain mature trees, ECA is roughly equal to the percent canopy (or basal area) removal (Bunnell et al. 1985).[3] Again, these average relationships are a simplification of the spatial and temporal variation seen in field studies.

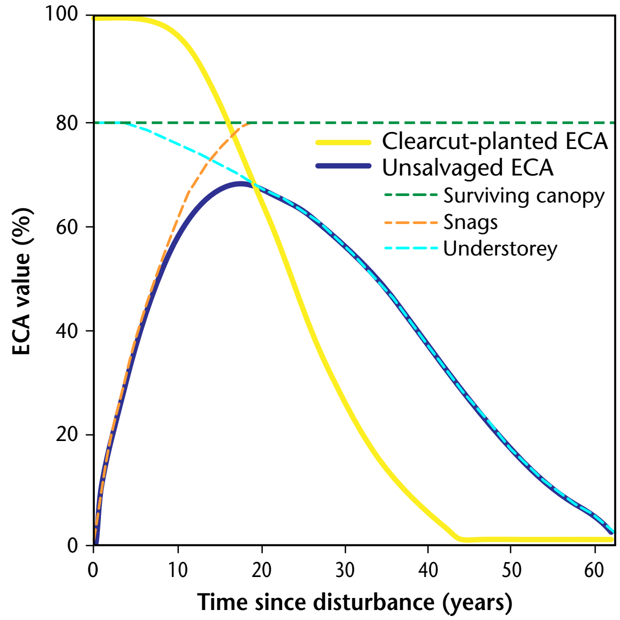

FIGURE 1. Projected ECA over time in a typical pine stand with 20% non-pine overstorey. The ECA in the unsalvaged stand is determined by surviving overstorey, snags, and understorey (advanced regeneration and natural infill).

Based on these relationships with tree height, canopy closure, and snag decay, the ECA value of a naturally disturbed stand is projected to change over time as several components of the stand increase or decrease after the disturbance (Figure 1).[4] These components include surviving overstorey, snags, advanced regeneration, and natural regeneration infill.

Surviving overstorey

Live overstorey trees often survive low-intensity fires or in areas skipped by high-intensity fires (DeLong and Kessler 2000). Non-pine trees, not affected by mountain pine beetle, make up 40–50% of pine-leading stands in some high-elevation forest types and

[1] Equivalent clearcut area is used as a coarse management tool and is not a substitute for a detailed watershed risk assessment by a professional hydrologist. See, for example, Grainger and Bates (2010).

[2] Huggard, D.J. 2008. Effects of salvage options for beetle-killed pine stands on ECA: December 2008 update. Prepared for B.C. Ministry of Environment, Kamloops, B.C. Unpublished report.

[3] Ibid.

[4] This and the following section are based on the literature synthesis and modelling in Huggard (2008; see footnote 2, above). This work is summarized in Lewis and Huggard (2010).

20–40% in many mid-elevation types (Vyse et al. 2009). Canopy pine trees can also survive beetle outbreaks that are less intensive than the current one (Shore and Safranyik 1992) and possibly around the periphery of the current outbreak such as in the Okanagan area.[5]

Snags

Trees killed in natural disturbances continue to make contributions to reducing ECA as snags.[6] When trees are first killed by mountain pine beetle, they maintain the same structure as live trees, with similar effects on snow accumulation and ablation. Over time, those hydrological functions are reduced as needles fall (usually in about 3 years), branchlets break off (3–7 years), and larger branches decay (within 20 years). The reduction in ECA also decreases as snags fall, many within 20 years of death, especially for smaller-diameter snags. Snags created by fires have a much greater range of initial structures, from nearly intact to just the main trunk remaining, with high fall rates if the fire is intensive enough to damage the base of the trunk or roots.

Advanced regeneration

Subcanopy or understorey trees are usually eliminated in fires, except in fire skips; however, attack by mountain pine beetle leaves most of the understorey, which is often dominated by non-pine species or by pines small enough to resist beetle attack. Understorey not susceptible to beetle attack—often called "secondary structure"—along with non-pine overstorey is most abundant in higher, wetter forests, with as much as 50–76% of high-elevation pine-leading forests meeting silvicultural stocking standards (Coates et al. 2009; Vyse et al. 2009). The contribution of advanced regeneration increases as understorey trees release and grow over 20+ years. Nevertheless, uncertainty about how well the understorey will release after beetle attack and how fast growth will be with the patchy distribution of these trees (Griesbauer and Green 2006) is a source of uncertainty in projecting ECA.

Natural regeneration infill

Natural regeneration from seedfall can be abundant after fires, with several species benefiting from exposed mineral soil; however, extensive hot fires can reduce seed sources, and seed consumption by small mammals can eliminate regeneration in some burned areas (Huggard and Arsenault 2009). The prospect for infill by natural regeneration after mountain pine beetle attack in different forest types is not well known, and is a large source of uncertainty in ECA projections.

What factors will affect equivalent clearcut area trajectories in unsalvaged and clearcut-planted natural disturbances?

The relationships of stand-level ECA with tree height, canopy cover, and snag decay help predict how ECA will differ over time in different stand types, as the following examples show (Figure 2).

Proportion of surviving overstorey

The most influential factor affecting ECA over time in unsalvaged natural disturbances is the proportion of original canopy trees surviving the disturbance (Figure 2a). Basal area is the best measure of proportion surviving because it is directly related to the amount of canopy. With intensive beetle-induced mortality, proportion surviving is usually just the proportion of basal area composed of non-pine species. Any live canopy trees that are retained during salvage or rehabilitation harvests similarly lower ECA in proportion to basal area retained. An assumption is that the surviving canopy remains roughly constant over time, reflecting a balance between increased windthrow and increased growth after release from competition (Kremsater et al. 2009:5–12).

Site index

Site index[7] is an important factor in ECA recovery because it provides a direct measure of how fast trees grow in height, and tree height is directly related to ECA recovery (Figure 2b). In a beetle-killed stand with high site index, regenerating trees can substantially reduce ECA before the original snags have completely decayed, reducing the peak ECA and time with high ECA values compared to low site index stands.

Secondary structure

Where understorey trees are abundant and not eliminated by the disturbance, this layer makes a moderate contribution to reducing ECA immediately after disturbance, and potentially large contributions later when the trees release and grow (Figure 2c).

5 Projected mortality rates from mountain pine beetle across British Columbia are available at: *http://www.for.gov.bc.ca/hre/bcmpb/BCMPB.v6.2017Kill.pdf*
6 For a review of empirical results in beetle-killed stands, see Winkler and Boon (2010).
7 Site index is the height trees are expected to grow by some age, typically 50 years, as an index of site productivity.

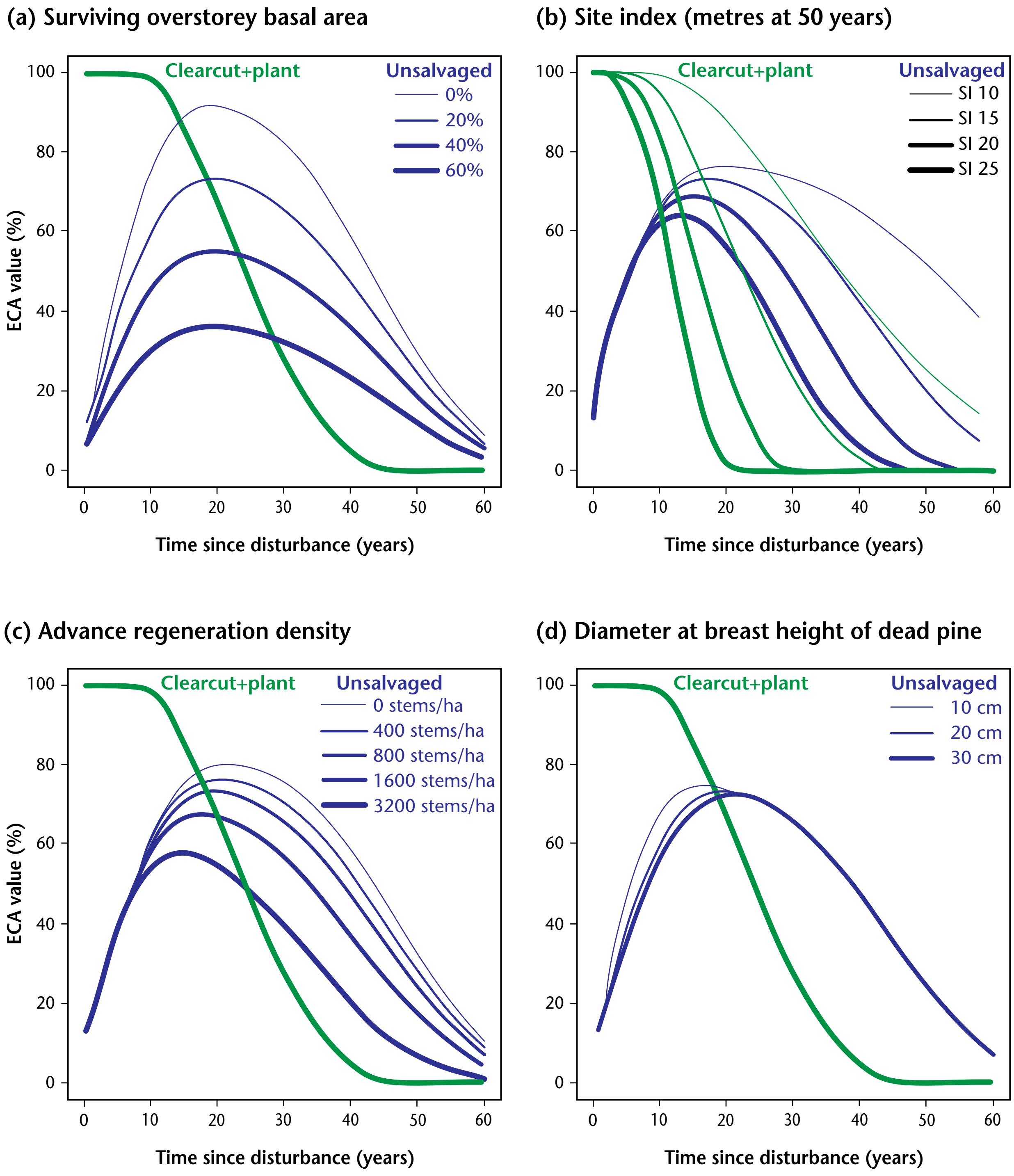

FIGURE 2. Projected ECA of "typical pine stands" that are clearcut and planted or unsalvaged at: (a) four percentages of overstorey surviving disturbance; (b) four site index levels; (c) five initial densities of advanced regeneration (including saplings and seedlings); and (d) three diameters at breast height (DBH) of dead overstorey pine. The clearcut and planted ECA results are only affected by site index. These results are based on average or assumed values for a "typical pine stand" (see text); results may differ substantially in actual stand types if these values are not applicable.

Wetter and higher-elevation biogeoclimatic subzones tend to have more understorey trees, particularly where subalpine fir is present; however, much variation exists among stands within a subzone, suggesting the value of conducting surveys of secondary structure in stands that are under consideration for management (Forest Practices Branch 2008).

Size of snags

The size of the dead trees created by a disturbance affects projected ECA because large snags remain standing longer than small snags (Figure 2d). With mountain pine beetle, a stand with 10 cm dbh snags produces a slightly higher and earlier peak ECA value than stands with 20 cm dbh snags. Further increases in snag size have little effect because loss of needles and branches reduces the hydrological function of the snags even if when still standing.

The projections illustrated in Figure 2 assume that:

- the average relationships of ECA with tree height and canopy closure apply to any trees including advanced regeneration, natural infill, and planted seedlings;
- natural infill produces complete stocking in 20 years, and clearcuts are planted to complete stocking immediately with no later widespread mortality;
- advanced regeneration experiences 50% mortality when the beetle infestation occurs, then 50% mortality of the remaining trees over 30 years; and
- no subsequent large disturbances occur in the unsalvaged or clearcut stands.

The projection results shown in Figure 2 therefore reflect a "typical pine stand" in the Interior. Managers should be cautious about applying the numbers directly for particular stand types where these assumptions might not be met.

How do "ECA years" compare in unsalvaged and clearcut-and-plant options?

Putting the different stand components together, stand-level ECA after an unsalvaged beetle attack or low-severity fire is expected to increase to a peak after about two decades as snags decay and fall, then decline as advanced and new regeneration grows. The initial ECA would be higher and the peak occurs earlier after a higher-severity fire because few live trees remain and needles and branches are lost on dead trees. Recovery rates after fires depend on how well new regeneration establishes. Clearcut harvested or salvaged stands begin with ECA at 100% unless a substantial area is in retention, then decline as the planted seedlings grow.

One useful summary of these different-shaped ECA curves is "ECA years," or the sum of the ECA values in each year from disturbance until the stand is fully recovered. This is equal to the area under the ECA-versus-time curve. It is one index of the total hydrological effect of a disturbance or management event through to complete hydrological recovery.

Table 1 shows predicted ECA years for unsalvaged beetle-killed stands at site index values of 10, 15, 20, and 25 (metres at 50 years), with four levels of surviving overstorey (from either non-pine species or overstorey pine that escapes infestation) and five levels of advanced regeneration.[8] The ECA years for the unsalvaged scenarios are compared to the ECA years for clearcutting and planting at each site index level. Green cells show where clearcutting and planting results in at least 10% lower ECA years than leaving the stand unsalvaged; orange cells show where ECA years in the unsalvaged option are at least 10% less than clearcutting and planting; uncoloured cells are where the two options are within 10% of each other.

In this analysis, when little surviving overstorey and limited advanced regeneration is evident, the clearcut-and-plant option is better for reducing ECA, unless the watershed is particularly sensitive to the immediate effects of clearcutting. Otherwise, with little surviving overstorey or advanced regeneration, only the contributions from snags and sparse secondary structure are lost in the clearcut, and these are more than compensated for over time by the better growth of the open-grown, planted seedlings. With abundant surviving overstorey and (or) advanced regeneration, the unsalvaged option has lower ECA years. In those stands, the faster growth of planted seedlings does not make up for the loss of ECA reduction from the snags

8 The advanced regeneration is assumed to include one-third saplings (> 1.3 m tall but < 7.5 cm dbh) and two-thirds seedlings (10 cm to 1.3 m tall). The average height of the saplings is 3.2 m. The density of saplings greater than 3 m tall would therefore only be roughly one-fifth of the total advanced regeneration densities shown in these tables. Densities of saplings greater than 4 m or greater than 6 m—values sometimes used for secondary structure surveys—would be much lower than the densities of all advanced regeneration used in these tables.

TABLE 1. Projected total ECA years for unsalvaged, beetle-killed "typical pine stands" at four levels of site index (SI), four percentages of surviving overstorey, and five densities of advanced regeneration (including seedlings and saplings).[a] Total ECA years for the clearcut-and-plant option is shown for each SI level above the table. Note: Green cells = clearcut and plant has greater than 10% fewer ECA years than unsalvaged. Orange cells = clearcut and plant has greater than 10% more ECA years than unsalvaged.

SI = 10
Clearcut and plant = 3939 ECA years

Advanced regeneration (stems per hectare)	Surviving overstorey (%) 0	20	40	60
0	5000	4000	3000	2000
400	4800	3800	2900	2000
800	4600	3700	2700	1800
1600	4200	3300	2500	1700
3200	3400	2700	2100	1400

SI = 15
Clearcut and plant = 2469 ECA years

Advanced regeneration (stems per hectare)	Surviving overstorey (%) 0	20	40	60
0	4100	3200	2400	1600
400	3800	3000	2300	1500
800	3600	2800	2100	1400
1600	3100	2500	1900	1200
3200	2300	1800	1400	900

SI = 20
Clearcut and plant = 1767 ECA years

Advanced regeneration (stems per hectare)	Surviving overstorey (%) 0	20	40	60
0	3200	2600	1900	1300
400	3000	2400	1800	1200
800	2700	2200	1600	1100
1600	2300	1800	1400	900
3200	1600	1300	1000	600

SI = 25
Clearcut and plant = 1335 ECA years

Advanced regeneration (stems per hectare)	Surviving overstorey (%) 0	20	40	60
0	2600	2100	1600	1000
400	2400	1900	1400	1000
800	2200	1700	1300	900
1600	1800	1400	1100	700
3200	1100	900	700	500

[a] These results are based on average or assumed values for a "typical pine stand" (see text); results may differ substantially in actual stand types if these values are not applicable.

and abundant secondary structure. The same overall pattern holds at different site index values, but the clearcut-and-plant option is preferred under a greater range of stand conditions when site index is high. Again, even in this case, a professional hydrologist may declare that the watershed is too sensitive for any clearcutting at all, although this will increase the total ECA over time. Seedlings planted in the open can take better advantage of the high site index compared to the unsalvaged stands, where advanced regeneration experiences a release delay, shade in the initial post-disturbance stand, and a delay before natural infill completely stocks the stand.

Table 1 shows broadly how the relative ECA effects of the management options differ under various conditions for a typical pine stand. The values will change for particular stand types if the assumptions underlying the projections do not apply well. The ECA-years summary also hides the very different trajectories of ECA over time in unsalvaged versus clearcut-and-plant options. With a detailed watershed assessment, these differences in trajectories may be an important tool in desynchronizing ECA effects of large disturbances and reducing peak ECA values in watersheds, although some hydrologists consider this as only a theoretical concern. Additionally, a few years with high ECA may also be a more serious concern for watersheds with some characteristics, sensitivities, and hydrological values than many years at low ECA, even if the total ECA years is the same. An assessment by a professional hydrologist is always more valuable than ECA calculations.

How can underplanting and delayed planting affect equivalent clearcut area?

When live or dead overstorey is retained for ECA reduction or other objectives—such as ungulate winter range, slope stability, visual quality objectives, habitat for snag-users, or simply economic costs of removal—a common management question is whether to plant seedlings under the canopy. There is clearly no issue when the stand is already stocked by advanced regeneration, but often understorey trees will be sparse or patchy. A central concern is how well underplanted seedlings will survive and grow.

I reviewed studies of performance of seedlings under canopies in British Columbia[9] (see also review and references in Kremsater et al. [2009:33–46] and detailed modelling results in Coates and Hall [2005]), relating growth rates to light level in the studies, and then modelling seedling growth over time in beetle-killed stands as the light levels increased under the decaying and falling pine snags. The expected growth of the underplanted seedlings was compared to growth rates in clearcuts. The modelling examined stands with different pre-disturbance canopy closures, size of snags (which affects their persistence), and seedlings planted at different times after the beetle attack. One useful summary variable is the growth delay; that is, the number of years in which growing underplanted seedlings have fallen behind open-grown seedlings after 40 years. Table 2 shows predicted growth delays for lodgepole pine and Engelmann spruce underplanted 0–15 years after beetles kill dense and moderately open pure pine stands.

In stands with dense canopies (10% above-canopy light) before beetle attack, lodgepole pine seedlings planted immediately after beetle attack grow slowly in the dark conditions. These seedlings are projected to lag open-grown seedlings by 12.1 years after 40 years (Figure 3). When planting is delayed for 10 years, the seedlings are not exposed to such dark conditions, so the projected growth delay was only 14.3 years: 10 years because of the 10-year planting delay and 4.3 additional years because of the reduced initial growth under a more open, dead canopy. Delaying planting 10 years

TABLE 2. Projected diameter growth delay (years) compared to open-grown seedlings for seedlings underplanted 0, 5, 10, or 15 years after beetles kill pure pine stands. Results are shown for lodgepole pine and Engelmann spruce seedlings, with dense canopy (10% above-canopy light) or moderate canopy (30% above-canopy light).

	Pre-beetle light (%)			
	10	30	10	30
Underplanting delay (years)	Lodgepole pine		Engelmann spruce	
0	12.1	8.6	9.2	6.0
5	12.7	10.2	10.4	8.4
10	14.3	12.8	12.8	11.7
15	17.1	16.4	16.3	15.9

therefore only delays eventual seedling growth by 2.2 years in these dense stands. The growth delay is less:

- in more open stands;
- for Engelmann spruce seedlings compared to pine;
- for stands with smaller dead pines, which fall faster; and
- for height growth compared to diameter growth (shaded seedlings grow relatively more in height than diameter).

In all situations, however, a substantial part of a 10-year planting delay is "recovered" by better seedling growth without the dark conditions in the understorey immediately after beetle-induced mortality.

Information on mortality of underplanted seedlings is sparse. The best guess is that mortality would be high for seedlings planted immediately after disturbance in stands with dense canopies (10% above-canopy light), and moderately high for seedlings underplanted in those dense stands 5–10 years after disturbance or planted immediately after disturbance in moderate closure stands (30% above-canopy light). This initial mortality is attributed purely to low light levels. Additional direct mortality to underplanted seedlings may be attributed to falling snags; however, no studies appear to have been undertaken, making prediction of this direct mortality difficult (Kremsater et al. 2009:3–4).

[9] Huggard, D.J. 2008. Projected performance of seedlings planted under mountain pine beetle stands. Prepared for B.C. Ministry of Environment, Kamloops, B.C. Unpublished report. *http://www.for.gov.bc.ca/ftp/HFP/external/!publish/fft_standards_on_cms_web/Adaptive%20Management/Synthesis%20Papers/Projected%20Growth%20of%20Seedlings%20Planted%20under%20Mountain%20Pine%20Beetle%20Stands_By%20Dave%20Huggard.pdf* (Accessed February 2011).

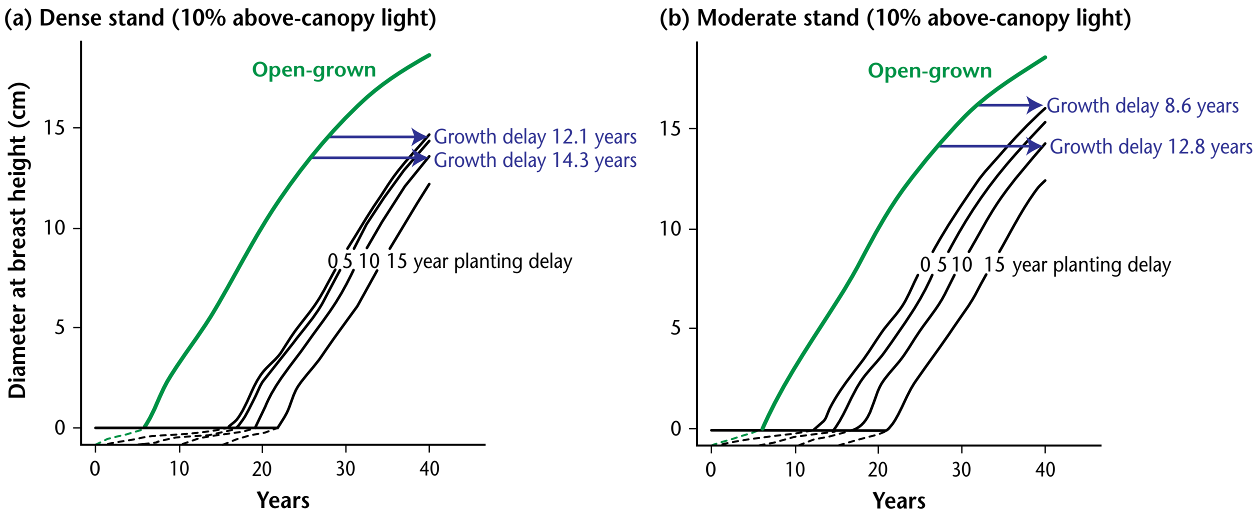

FIGURE 3. Diameter growth of open-grown lodgepole pine seedlings compared to seedlings underplanted in beetle-killed stands with (a) dense canopy, or (b) moderate canopy. Diameter growth is shown for seedlings underplanted 0, 5, 10, and 15 years after mountain pine beetle attack. Resulting growth delay after 40 years is illustrated for 0- and 10-year planting delays.

The option to delay underplanting until snags have decayed or fallen enough to provide high light levels for seedlings is therefore most feasible in dense stands, where the additional planting delay is mostly compensated for by avoiding the very slow initial growth under low light conditions. Delayed planting also reduces the important but poorly known risk of high mortality of shaded seedlings. Clearing remaining snags for planter safety after 10 or 15 years would have less incremental effect on ECA than clearing shortly after harvest. Additionally, delaying planting allows an assessment of where natural regeneration is adequate, avoiding unnecessary planting costs and promoting natural diversity.[10] Nevertheless, vegetation management may become more necessary when grasses or shrubs have established on the sites.

Partial overstorey removal immediately after beetle attack, with a focus on falling dangerous snags, is another option for improving seedling success while retaining some hydrological function in disturbed stands. Based on the relationship of seedling growth and light, roughly 50% of basal area would need to be removed to avoid substantial growth delay of underplanted trees. The overstorey snags would make a proportionately reduced contribution to lowering ECA. Worker safety would be a primary issue during snag falling.

How can management decisions be improved to address hydrological values?

The following decision tree (see Figure 4, next page) summarizes the considerations involved in management actions in naturally disturbed stands where hydrological values are important. This decision tree, which focusses on managing stand-level ECA in a watershed context, provides an operational tool to reduce the increased hazard caused by potentially higher peak flows. Detailed hydrological evaluations should be used in high value or highly sensitive watersheds, or where other hydrological values such as late-summer flows are important.

Management decisions clearly also incorporate other values. The most basic of these for the Forests For Tomorrow program is timber supply and the associated economic return on investment (see *http://forestsfortomorrow.com/fft/tool/return-investment/222*). Synthesis of existing information and practical guidance have been provided for other values affected by rehabilitation, such as worker safety (Manning et al. 2006), fire hazard risk (Kremsater et al. 2009:71–79), wildlife habitat (Manning, Cooper and Associates 2006), vegetation competition (Kremsater et al. 2009:47–58), and tree disease management (Kremsater et al. 2009:65–70).

10 Delaying planting can also be used to wait until temporary regeneration concerns have abated, such as snowshoe hare feeding on seedlings (Ransome and Sullivan 2008; Kremsater et al. 2009:13–24).

Decision tree for management actions in naturally disturbed stands with important hydrological values

Is the stand in a reserve that restricts cutting?
(e.g., old-growth management area, ungulate winter range, visual quality retention, etc.)?

- **YES** → Could planting, with little or no overstorey cutting, enhance the reserve's important values (e.g., ensuring forest cover in the medium term)?
  - **YES** → Has a survey of secondary structure been completed in the stand?
    - **YES** → Is advanced regeneration adequate to meet re-stocking goals?
      - **YES** → Do not treat
      - **NO** → Is average above canopy light < 30%, or do snags make the stand unsafe for planting?
        - **YES** → Consider delayed planting in 10+ years
        - **NO** → Consider underplanting
      - **NO** → Survey secondary structure, then return to above question
    - **NO** → Do not treat
  - **NO** → Consult major licensee's forest development plan. Will additional harvesting compromise the objectives and *Forest and Range Practices Act* results for the watershed?
    - **YES** → Plan cumulative effects with major licensee's planned activities. If adjacency constraints are a concern and advanced regeneration in the stand is low, consider for delayed planting.
    - **NO** → Has a watershed assessment been completed?
      - **YES** → Is the current watershed ECA low enough to allow harvesting, given the stand's position (e.g., above versus below a lake or reservoir) and the overall watershed sensitivity? Note that the watershed assessment may have reached different conclusions for different sub-basins within the watershed.
        - **YES** → Is there a large area of recent naturally disturbed stands that will not be salvaged and that will have a high ECA in approximately 20 years?
          - **YES** → Is the natural disturbance due to mountain pine beetle or low-severity or patchy fire?
            - **YES** → Has a survey of secondary structure been completed in the stand?
              - **YES** → Is there > 25% surviving overstorey basal area, or abundant advanced regeneration?
                - **YES** → Low priority for treating
                - **NO** → The higher the site index, the greater the priority for cutting and planting to possibly desynchronize watershed ECA and for timber.
              - **NO** → Priority for survey. Meanwhile, use forest cover information and knowledge of the natural disturbance to predict surviving overstorey basal area and biogeoclimatic subzone average for advanced regeneration. Repeat above question but allow flexibility in treatment as better stand information is developed.
            - **NO** → (moderate- or high-severity fire) ECA already probably high, so the priority is to plant (if high site index) for timber reasons and to desynchronize watershed ECA. Cut remaining snags for safety reasons. Lower site index sites with more snags should be considered for retention for wildlife over 5–10+ years.
          - **NO** → Is extensive harvesting proposed by the major licensee, or is much of the watershed still susceptible to large natural disturbances (e.g., pine stands not affected by mountain pine beetle, extensive spruce at risk for spruce beetle, etc.)?
            - **YES** → Consider delayed planting to allow more future flexibility.
            - **NO** → Use ECA-years tables to determine priority for harvesting and planting. Low priority stands can be re-assessed in 10–20 years to check whether overstorey survived and advanced regeneration released and is filling in.
        - **NO** → Consider delayed harvesting for stands with little surviving overstorey, when the snags have fallen and are no longer reducing ECA.
      - **NO** → Is < 30% of the watershed and each of its major sub-basins in young harvested areas and recent natural disturbance?
        - **YES** → Timber and other values are priorities for treatment decisions.
        - **NO** → Have a professional hydrologist conduct a watershed assessment.

FIGURE 4. Decision tree for management actions in naturally disturbed stands with important hydrological values.

A decision key can also lead to the same management option being used in all stands of a particular type. Given uncertainty in the underlying field information and about future conditions, basic risk minimization suggests maintaining a diversity of management options across a watershed and over larger regions.

What are some additional within-stand decisions to consider?

Minimizing increases in stand-level ECA is an important management objective in watersheds affected by large disturbances and salvage operations; however, additional management decisions within stands affect other aspects of hydrology, such as shading streams, preventing bank erosion, maintaining nutrient inputs from adjacent vegetation, avoiding soil compaction and channelization, limiting site preparation impacts, and planting for diversity.

Shading streams

Stream shading from adjacent riparian areas is most important in preventing high water temperatures, increases in ultraviolet radiation, and decreases in dissolved organic carbon, which are detrimental to fish and other aquatic animals (Krauskopf et al. 2010; for general reviews of stream ecology and fish habitat, see Richardson and Moore [2010] and MacIsaac [2010], respectively). Trees are more likely to survive fires along riparian areas, and non-pine overstorey in beetle-affected stands is also more likely along watercourses. Retention of these live trees is crucial for shading riparian areas. Fire- or beetle-killed snags can also provide stream shading (Leach and Moore 2008) for 10 or more years, allowing riparian vegetation, particularly deciduous trees and shrubs, to respond. Beetle-killed snags could also be used to buffer retained live trees from windthrow, decaying slowly enough to allow live trees to adapt to increased wind. Where severe fires have destroyed riparian vegetation, planting deciduous trees should be considered to provide rapid bank stability, shading, and nutrient inputs to streams.

Preventing bank erosion

Live trees, roots of dead trees before these decay, and understorey vegetation all contribute to preventing bank erosion, which can harm aquatic ecosystems and water quality (Eaton and Giles 2009). Extensive salvage, brushing, and site preparation should be avoided adjacent to watercourses. Soil disturbance from windthrow in narrow riparian strips can be a concern. Most snags fall when the roots or lower trunk have rotted rather than uprooting, so snags are less likely than live trees to cause extensive soil disturbance.

Maintaining nutrient inputs from adjacent vegetation

Riparian vegetation, especially deciduous trees and shrubs, also provides nutrient inputs for aquatic ecosystems, indirectly contributing to the maintenance of water quality and aquatic resources (Richardson and Moore 2010).

Avoiding soil compaction and channelization

Soil compaction from logging on wet summer soils and channels created by machinery can increase overland flow and potentially contribute to flood events from rainstorms. These can also increase erosion and sedimentation of streams thereby increasing the risk of slope failure on steep slopes. These events reduce drinking water quality and affect fish and other aquatic organisms (e.g., see Pike et al. [2010]). Compaction and channelization are more likely where disturbances have killed trees, because reduced evapotranspiration raises water tables and creates wet summer soils even where dry summer logging is the norm.

Limiting site preparation impacts

Site preparation can often improve seedling survival and growth, enhancing hydrological recovery. Nevertheless, site preparation that exposes mineral soil in riparian areas can also increase sedimentation and should be kept to the minimum disturbance that provides planting spots.

Planting for diversity

For stand-level ECA recovery, planting should use the species and densities that most quickly produce full stocking of 12 m tall trees; however, planting only fast-growing pine increases the risk of complete plantation failure and susceptibility to future insect and pathogen outbreaks. A well-interspersed mixture of two or more appropriate species will reduce this risk. Deciduous trees are less effective at snow interception and shading in spring but should be considered for rapidly restoring cover to riparian areas.

How can monitoring help and what should be considered within a monitoring program?

The uncertainties highlighted throughout this extension note suggest that monitoring should be an essential part of any rehabilitation program. For hydrological values, few opportunities exist to design watershed comparisons of rehabilitation options, especially with the effects of past harvesting and current commercial salvage in most watersheds. Spatial and temporal variability in streamflow makes it difficult to interpret watershed data that are not part of an experimental design. However, continuing measurements in watersheds and streams that have long-term stream gauge information and are affected by disturbances and management responses may eventually help provide some direct information on hydrological effects at this scale (e.g., Moore et al. 2008).

A more feasible monitoring priority is to reduce the uncertainty around regeneration in areas of unsalvaged natural disturbances. Questions include the performance of advance regeneration and natural infill in unsalvaged stands, growth and survival of seedlings underplanted at different times after mountain pine beetle-induced mortality, and effects of thinning the dead canopy on natural and underplanted seedlings. A good monitoring design would include thinned (approx. 50% removal of unsafe snags) and unharvested pine-dominated stands with and without planting, with a clearcut-and-plant comparison. Comparing species of seedlings could be done in smaller plots.

Standard features of experimental design are important for providing definitive answers, including replicating the treatments, blocking treatments within comparable stand types, and actively assigning treatments to available stands randomly (rather than based on operational preferences). Regular standardized measurements of seedling survival, diameter, height, and condition should be planned until the dead overstorey has fallen or decayed. Results of this monitoring will likely not help operational response to the current mountain pine beetle outbreak but will be available for improving response to future crises. This monitoring is also a way of contributing to the large knowledge bank needed for any science-based management.

The uncertainties highlighted throughout this extension note suggest that monitoring should be an essential part of any rehabilitation program.

Acknowledgements

This review was funded by Forest For Tomorrow and the B.C. Ministry of Environment through a contract with FORREX. I am grateful for the support and input of Doug Lewis (B.C. Ministry of Environment) and many reviewers.

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ARTICLE RECEIVED: **September 6, 2010**
ARTICLE ACCEPTED: **January 18, 2011**

FIA Forest Investment Account Forest Science Program

Production of this article was funded, in part, by the British Columbia Ministry of Forests, Mines and Lands through the Forest Investment Account–Forest Science Program.

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Test Your Knowledge . . .

Considerations for rehabilitating naturally disturbed stands:
Part 2 – Stand-level treatments and hydrological equivalent clearcut area

How well can you recall some of the main messages in the preceding Extension Note?
Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Equivalent clearcut area (ECA) in unsalvaged stands affected by mountain pine beetle differs from ECA in clearcut-and-planted stands because of:
   A) Initial contributions from beetle-killed snags
   B) Surviving non-pine canopy components
   C) Different regeneration rates of planted and natural seedlings
   D) All of the above

2. According to projections in this extension note, what effect is underplanting likely to have on ECA:
   A) A large effect, where it is safe and operationally feasible
   B) Effects ranging from substantial to minor, depending on stand condition and planting delay
   C) A negligible effect, but it may be useful for other values

3. Equivalent clearcut area is a rough index; in high-value watersheds practitioners should consult:
   A) A professional hydrologist
   B) A professional bryologist
   C) A professional apologist

ANSWERS

1. D 2. B 3. A