The Economic Benefits Of Planting Weevil Resistant Sitka Spruce Through Somatic Embryogenesis

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ABSTRACT
Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is the fastest growing species on many sites in the Coastal Western Hemlock, wet humid subzone of British Columbia, when compared with the alternatives, hemlock (*Tsuga heterophylla* (Raf.) Sarg.), amabalis fir (*Abies amabalis* (Dougl.) Forbes), and western red cedar (*Thuja plicata* Donn). However, it is seldom used in regeneration programs due to the high risk of damage by the white pine terminal weevil (*Pissodes strobi* Peck). The recent discovery of weevil resistant Sitka spruce has increased its potential as a preferred crop species rather than resorting to other, less commercially valuable species. The use of the somatic embryogenesis technology has enabled the production of large quantities of resistant planting stock from many parents. This technology may be used to reduce the time required for the delivery of stock with high levels of resistance when compared with conventional tree breeding delivery methods. In this paper, an economic framework for evaluating investments in the deployment of weevil resistant stock is presented. The incremental economic value of deploying weevil resistant seedlings is estimated as follows: a) directly, according to the net present value realized from planting and harvesting the resistant crop minus the value of the next best alternative, plus b) indirectly, by determining the realized gain in value of adjacent stands that may not be cut until the newly regenerated stand reaches a minimum height (e.g. 3 metres) in Coastal British Columbia (this regulation is referred to as “the green-up constraint”). The production of weevil resistant trees could accelerate the time taken for adjacent stands to become available for harvest. Provided that the net present value of the cost of producing weevil resistant trees is less than the incremental value, then an investment of this kind is worthwhile.

Keywords: Sitka spruce, white pine weevil, resistance, somatic embryogensis, economic evaluation, net present value.

INTRODUCTION
One of the most important decisions in forest management is to select one or more species for growing in a particular site. This decision is influenced by: 1- the potential growth rates, 2- the economic and environmental values of the species under consideration, and 3- the risk of (not) producing the desired end products. In Coastal British Columbia, there are two highly valued species, western white pine (*Pinus monticola* Dougl. Ex D. Don) and Sitka spruce (*Picea sitchensis* (Bong.) Carr), that have a low likelihood of producing the desired end products due to the probable effects of pests. In the case of western white pine, blister rust (*Cronartium ribicola* J.C. Fisch), an introduced pathogen to the West Coast of North America, infects and ultimately kills this species making it very difficult to realize end product objectives. Similarly, a native

pest known as the white pine terminal weevil (*Pissoides strobi* (Peck)) attacks Sitka spruce thus increasing the risk for not meeting end product objectives. The weevil has been found to exist throughout the ranges of the Sitka, white (*Picea glauca* (Moench) Voss) and Englemann (*Picea engelmanii* Parry) in British Columbia (Finck et. al. 1989). In the spring, adult weevils lay eggs below the apical shoot of the main stem (leader) and the developing larvae feed under the leader bark killing one or more inter-nodes (Silver 1968). Repeated weevil attack causes tree deformity and growth loss and has resulted in a significant reduction in the regeneration of Sitka spruce (Hall 1994).

BACKGROUND

The objective of this study is to provide a framework to determine the economic potential for producing weevil resistant stands of Sitka spruce (Figure 1). Resistance herein is defined as the proportion of the total potential (future) stand volume that is merchantable, after the effects of weevil have been accounted for. Susceptibility is the converse of resistance, this being the potential proportion of merchantable timber lost due to the impacts of weevil. Resistance to weevil attack is a combination of various attributes that work individually and/or in concert in a complex fashion (see Alfaro et al. 1994).This study pertains to the utilization of resistant Sitka spruce stock regenerated through Somatic Embryogenesis (SE). In this process, SE technology is used to produce clonal material from seeds produced through sexual reproduction among putatively resistant trees. Each cross produces a full-sib family (represented by several seeds). Each seed produces a single clone that can be regenerated through the SE technology to produce any number of seedlings. These seedlings are then evaluated in a clonal trials to verify the presence/absence of resistance. Resistant clones are selected for mass production of seedlings for reforestation. Thus, SE is being utilized as a propagation system to capture the natural resistance of Sitka spruce trees to the weevil.

METHODS

Sites within the **C**oastal **W**estern **H**emlock **v**ery wet, **h**ypermaritime subzone (CWHvh) were evaluated for the economic feasibility of producing weevil resistant Sitka spruce plantations. The biogeoclimatic characteristics of this subzone are described by Green and Klinka (1994). On many sites[3] in the Submontane variant (CWHvh1) Sitka spruce is identified as a "secondary conifer species" with an attendant remark that there is a "***risk of weevil damage***" (Ministry of Forests, 2000a). Secondary species are described as being, "*… ecologically acceptable, but rank lower than primary species for one or more of silvicultural feasibility, reliability, or productivity.*" The Ministry of Forests' species selection guidelines further state that, "*Depending on the nature and extent of these limitations, secondary species can be managed as either a major component or minor component in a stand.*" Amabalis fir (*Abies amabalis* (Dougl.) Forbes), western red cedar (*Thuja plicata* Donn), western hemlock (*Tsuga mertensiana* (Bong.) Carr.), and yellow cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) are identified as being "primary conifer species" for establishment in one or more of the same sites. "*Primary tree species are ecologically acceptable and have a high rating for silvicultural feasibility, reliability, and productivity under the average conditions for a site series. Primary species can be managed as a major component in a stand if the restrictions have been adequately addressed.*" In similar sites within the Central variant (CWHvh2) Sitka spruce is identified as a

[3] The 04, 05, 06 and 07 site series (see Table 1).

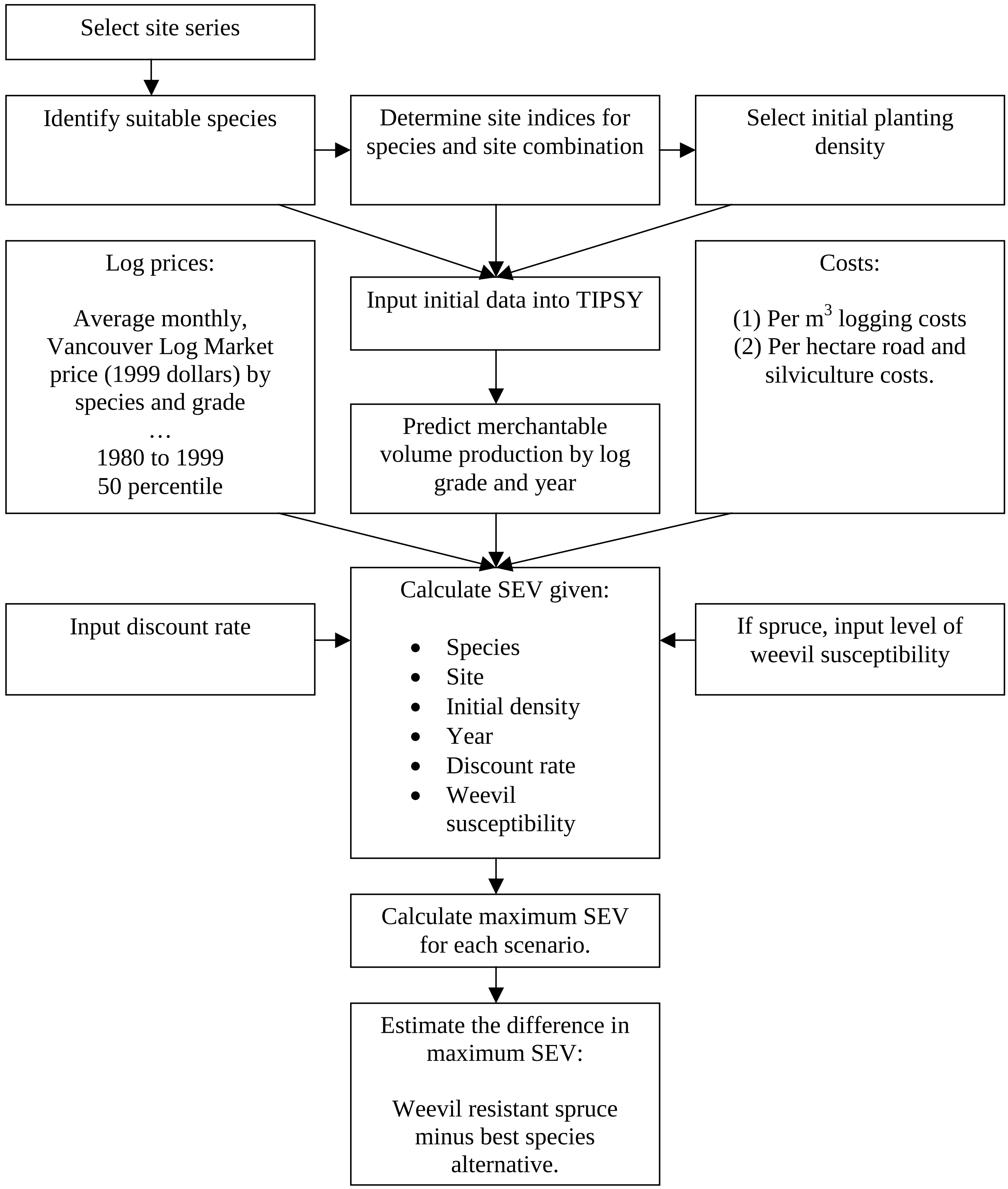


Figure 1. Economic analyses framework.

primary tree species, implying that the weevil is of little or no concern there[4]. Nevertheless, silviculturalists may have reason for concern given that warmer temperatures in the spring may lead to an expansion of weevil populations that in turn, may cause one to question the advisability of the current guidelines.

Table 1 describes the site series upon which the economic analyses were based, as well as the site indices that one might reasonably expect for each of the species growing in those sites (Ministry of Forests, 1998). Site index is determined according to the definition of a top height tree, this being defined as the height of the largest diameter tree (it must be undamaged) in a 1/100th hectare plot. A site index of 30 indicates that the dominant trees of the same species are expected to reach a total height 30 metres at 50 years of age (the age being determined at 1.3 m or breast height). The indices provided in the Table are rated as being of either low or moderate reliability, indicating that there may be considerable variation in this estimate when applied to any given site, and that the estimate is derived from a small data-set. These figures are suitable for evaluating the potential benefits of a broad level strategy designed to deploy weevil resistant Sitka spruce, and it is the best information currently available.

Now to turn to the question of how to evaluate the benefits of establishing weevil resistant Sitka spruce. The potential value of weevil resistant stands is measured in accordance with the level of resistance/susceptibility, minus the maximum value that could be produced by establishing an alternative species.

Table 1. Site indices by site series and species selection.

Site Series	Name[1]	Species			
		Ss	Cw	Hw	Ba
CWHvh / 04	HwSs - Lanky Moss	30	20	24	24
CWHvh / 05	CwSs - Sword Fern	30	24	28	28
CWHvh / 06	Cw Ss – Foamflower	32	24	24	24
CWHvh / 07	Cw Ss - Devil's Club	32	24	28	28
CWHvh / 08	Ss - Lilly-of-the-valley	28	24	28	28
CWHvh / 17	Ss – Sword Fern	28	12	20	na

[1] Tree species – dominant vegetation, Hw: western hemlock, Ss: Sitka spruce, Cw: western red cedar, Ba: amabalis fir.

For each of the species identified in Table 1, other than amabalis fir, a projection was made of the log quality assortments (BC Ministry of Forests' letter grades) that would be produced over time using the **T**able **I**nterpolation **P**rogram for **S**tand **Y**ields (TIPSY: Ministry of Forests, 2000b) starting with the planting of 1200 stems per hectare and assuming a "fall-down" in the production of volume by 5%[5]. TIPSY does not produce yield tables for amabalis fir; the hemlock tables were used instead, in combination with amabalis fir site indices (Table 1).

For Sitka spruce the volumes predicted by TIPSY were further reduced by a factor relating to the proportion of the stand that was deemed to be susceptible to damage, and ultimately damaged, by terminal weevil. The levels of susceptibility were characterized as being

[4] Sitka spruce is the most productive and valuable choice for most sites and there are no limitations with respect to the feasibility of establishing spruce in plantations.
[5] Operational Adjustment Factor number one (OAF1) was set to 0.95, with the net effect that expected merchantable volumes are reduced by 5% for all species across all ages.

equivalent to 0, 6, 9, 12 and 15% loss in stand volume (or value) without any changes to the log quality profile. TIPSY provides information on the expected volumes by log grade that would be produced every 10 years (or as required by the user) given the species, site index and initial stand density (Table 2).

Log prices were estimated based on one-month, Vancouver Log Market prices from December 15, 1980 to August 15, 1999 (received from the Council of Forest Industries (COFI)), after being adjusted to 1999 dollars using the Statistics Canada, annual Forest Industry Producer Price Indices covering the same period of time (pers. comm., J. Hackett, Forest Economist, D.R. Systems Ltd. Nanaimo, B.C.). The price representing the mid-point (the 50th percentile or median) of the range of prices observed during that period were then applied to each of Sitka spruce (after adjustment for losses due to the weevil), western red cedar, western hemlock, and a mixture of hemlock and balsam ("Hembal") and with respect to the log grade distributions specified in the TIPSY output (Table 3). Hemlock prices were applied to the expected hemlock yields by log grade and Hembal prices were applied when considering amabalis fir.

Table 2. Definitions of coastal log grades (Ministry of Forests, 2000b).

Grade[1]	End Product	Minimum Top Diameter (cm)	Minimum Log Length (m)	Minimum Rings per 2 cm dbh (number)	Maximum Knot Size[2] (cm)
H	Lumber	38	5.0 (4) [3]	5	4-5
I	Lumber	38	3.8 (4)	na	8-10
J	Lumber	16	5.0 (4)	na	4-6
U	Lumber	10	5.0	na	4-14
X	Lumber	10	3.0	na	4-14
Y	Pulp	na	na	na	na

[1] Log quality classification.
[2] Range of knot size varies by top diameter.
[3] Parenthesis indicate special requirements for spruce.

Table 3. Median log prices by species and grade.

	Species			
Grade	Ss	Cw	Hw	HB[1]
H	171.32	120.26	98.68	99.99
I	125.79	95.98	87.18	86.69
J	65.31	76.41	61.92	63.48
U	53.19	52.24	47.58	47.69
X	47.21	49.73	44.93	45.10
Y	32.26	20.55	35.91	35.39

[1] A mixture of hemlock and balsam.

The costs of logging were estimated using Ministry of Forests (2001) appraisal procedures (Table 4). Road construction costs were estimated based on a general knowledge of the industry and for the purpose of ensuring that these remained fixed. Assuming that on average timber is accessible within 200 meters either side of a road, and that road costs are 30,000 $/km, then road construction costs are estimated as being equal to 750 $/ha. For silviculture, it was assumed that for all species, across all sites, a total of 1200 trees were established per hectare. Seedling production costs were assumed to be 0.12 $/tree and planting costs, 0.25 $/tree, for a total of 0.37 $/tree or 444 $/hectare. This price does not include any added cost for the production of SE. Planting was assumed to occur 1 year after harvesting, this being the regeneration delay after the harvesting was initiated. No other silviculture costs, such as brushing and weeding, were considered although they might reasonably be applied for some combinations of species and sites considered herein.

Table 4. Assumed road construction, harvesting and silviculture costs.

Cost Item	Cost
Tree-to-truck: Conventional Logging	20.14 $ m^{-3}
Truck Hauling	9.46 $ m^{-3}
Water Transportation - towing	10.85 $ m^{-3}
Road Maintenance and Deactivation	2.33 $ m^{-3}
Corporate Overhead	12.83 $ m^{-3}
Crew Transportation	4.04 $ m^{-3}
Total Logging Plus Overhead	*59.66 $ m^{-3}*
Road Construction	750.00 $ ha^{-1}
Silviculture (Planting)	444.00 $ ha^{-1}
Total Costs Assuming 1000 m^3 ha^{-1} (without discounting)	*60.85 $ m^{-3}*

A Soil Expectation Value (SEV) was calculated in association with each scenario, this being defined by a combination of site and species (and therefore site index, yield projection, costs and revenues), susceptibility to weevil (for Sitka spruce only) and discount rate (2, 4 or 6%). SEV is the net present value (NPV) derived from growing and harvest crops repeatedly and in perpetuity. A scenario begins with bare ground, just after logging has been completed. SEV is calculated as follows:

$$S_1 = \frac{C_R}{(1+r)^d} + \frac{\dfrac{C_R}{((1+r)^{(AGE+d)}-1)}}{(1+r)^d} \qquad \text{Equation 1}$$

where,

S_1 : is the initial, NPV of the cost of establishing a plantation,
C_R : is the regeneration cost (444 $/ha),
r : is the interest rate (e.g. 0.06 / y),
d : is the regeneration delay (y) or years after harvesting is started and until the completion of planting, and
AGE : is the age of the stand at the time of harvesting, estimated from the years since planting.

$$SEV = \frac{\frac{R_H}{((1+r)^{(AGE+d)}-1)}}{(1+r)^d} - S_1 \qquad \text{Equation 2}$$

where,

R_H : is the harvest revenue, net of harvesting, road construction and overhead costs.

Finally the benefits from establishing Sitka spruce with various levels of resistance to damage were assessed relative to the benefits from establishing the best alternative species in a given site.

RESULTS

Historically a price premium has been available for Sitka spruce H and I log grades, whereas lower grade logs tend to be of comparable value to those of the other species (Table 3). The proportion of the stand that produces logs in the higher grades is directly related to site productivity and stand density.

The analyses indicated that the maximum mean annual increments (MAI) are substantially higher for Sitka spruce, even with 15% reduction in stand volume caused by the weevil, relative to the other species. For example, MAI of 14.1 and 12.8 m^3 ha^{-1} y^{-1} were obtained for Sitka spruce and the next best alternative, amabalis fir, respectively, in CWHvh /08 site series where the site indices for both species are equal. This implies that even though the stands may be at the same height at age 50, Sitka spruce will produce more volume than any of its alternatives. This is expected since Sitka spruce is less shade tolerant in comparison with the other species (Krajina et al. 1982).

The SEV is consistently higher for all Sitka spruce scenarios when compared with its alternatives (Table 5). It can be concluded that establishing weevil resistant plantations will produce a positive return within the range of discount rates applied (2 to 6%). When a discount rate of 8% was used the SEV's were negative for all species and site combinations (data not shown).

Discount rates of 2 to 6% were used to provide a range of outcomes in accordance with the concept of financial rotation age (Table 5). It is noteworthy to mention, at this stage, the concept of physical rotation because it has been the policy of the Ministry of Forests to limit the harvest of stands until after they have reached the point of maximum mean annual increment. In order to be consistent with this policy, a financial analyst should choose a discount rate such that the financial rotation equals the physical rotation. This can only be accomplished with discount rate less than or equal to 2% (see Tables 6, for the CWHvh /08 below). This concept is illustrated in Figure 2.

Given that the 2% discount rate produces a financial rotation that is consistent with government policy, a comparison was made between the SEVs of deploying Sitka spruce with a range of weevil susceptibilities (0 to 15%) relative to the other alternative species (Figure 3). The results indicate that for all levels of susceptibilities and across all site series Sitka spruce surpassed the other alternative species in SEV.

A comparison was made between the SEVs of deploying Sitka spruce with a range of weevil susceptibilities (0 to 15%) with the other alternative species. The results indicate increases in SEV ranging from 9,347 to 3,720 \$/ha, from 1,957 to 690 \$/ha, and from 542 to 132 \$/ha using 2, 4, and 6% discount rate, respectively, across all sites.

Table 5. Maximum soil expectation values ($ ha^{-1}).

Species:		Ss					Cw	Hw	HB
Susceptibility		0	6	9	12	15			
Site Series	Discount Rate								
CWHvh / 04	2	14,415	13,506	13,051	12,596	12,142	2,795	2,550	2,726
CWHvh / 04	4	2,417	2,242	2,154	2,066	1,979	166	84	134
CWHvh / 04	6	396	345	320	294	269	-245	-274	-256
CWHvh / 05	2	14,415	13,506	13,051	12,596	12,142	5,987	4,602	4,828
CWHvh / 05	4	2,417	2,242	2,154	2,066	1,979	722	528	586
CWHvh / 05	6	396	345	320	294	269	-52	-130	-96
CWHvh / 06	2	17,711	16,604	16,051	15,497	14,944	5,987	2,550	2,726
CWHvh / 06	4	3,248	3,021	2,907	2,793	2,679	722	84	134
CWHvh / 06	6	657	590	557	524	490	-52	-274	-256
CWHvh / 07	2	17,711	16,604	16,051	15,497	14,944	5,987	4,602	4,828
CWHvh / 07	4	3,248	3,021	2,907	2,793	2,679	722	528	586
CWHvh / 07	6	657	590	557	524	490	-52	-130	-96
CWHvh / 08	2	11,539	10,807	10,440	10,074	9,708	5,987	4,602	4,828
CWHvh / 08	4	1,750	1,614	1,547	1,479	1,411	722	528	586
CWHvh / 08	6	174	136	117	98	80	-52	-130	-96
CWHvh / 17	2	11,539	10,807	10,440	10,074	9,708	-11	1,090	na
CWHvh / 17	4	1,750	1614	1,547	1,479	1,411	-382	-191	na
CWHvh / 17	6	174	136	117	98	80	-412	-361	na

Table 6. Physical and financial rotation age comparison in the CWHvh /08 site series across species.

Rotation	Discount rate (%)	Ss	Cw	Hw	HB
Physical	na	91	111	81	81
	2	91	101	81	81
Economic	4	71	61	71	71
	6	61	51	51	51

DISCUSSION

One the basis of results presented in Table 5 and Figure 3 it is clear that producing weevil resistant Sitka spruce plantations will produce substantial benefits. The vast difference in SEV between establishing weevil resistant Sitka spruce plantations and those of alternative species would justify the deployment even if the susceptibility level far exceeded the 15%. Using the CWHvh/04 site series with a 2 % discount rate, the ratio of the value obtained using western red cedar, relative to resistant Sitka spruce (0 susceptibility), is 81 % ((1 – 2795/14415) x 100; from Table 5) suggesting that 81% of the volume could be lost in the spruce stand and one would still break even with the next best alternative. In fact, this kind of interpretation is not likely to hold since such high levels of damage would be accompanied by a shift toward a poor quality log grade distribution.

One might speculate that dominant trees are more susceptible to attack by weevil, perhaps because they are less obscured by shade. However, such trees may also be the most resistant. Therefore the assumption that the log grade distribution is unaffected when losses in volume are less than 15% seems to be reasonable. Any process designed to select trees for weevil resistance would also be designed to select for other desirable traits depending of the nature of the genetic correlations.

The choice of the appropriate discount rate is always a difficult task; a range of rates is commonly used, enabling decision-makers to make the most appropriate choice. A 2% discount rate cannot be considered as unreasonable since it is a better reflection of current policies and practices on public lands when compared with higher rates. On this basis the value of establishing weevil resistant stock is substantial. Then applying additional resistant Sitka spruce plantation management regimes, if necessary, that considers considerable added costs for site preparation, brushing and weeding would have no affect on the conclusion made herein.

The observed differences in SEVs between Sitka spruce with 6, 9, and 15% susceptibility level and the other alternative species is encouraging and should be considered in the deployment strategy of resistant Sitka spruce. The use of high-level of resistant stock will apply high selection pressure on the insect and that will ultimately lead to the evolution of mechanisms that overcome this resistance known as the evolution of counter-resistance or pest virulence. This can be easily accomplished by the insect since the number of insect-generations per one resistant-generation of tree is often much higher, thus the rate of insect adaptation is rapid. Reduced selection pressures are expected to maintain virulence allele frequencies at a sufficiently low level and help in maintaining the balance between the pest-host system.

The establishment of weevil resistance stands of Sitka spruce may have additional benefits relative to the other alternative species. These benefits accrue as a result of forest management policies in effect in British Columbia. A brief description is provided below as to how these benefits might be evaluated within an economic framework.

The first policy to be considered is the requirement that in each stand a minimum number of trees must obtain a minimum height within a maximum number of years. These are the requirements required under the "***free growing***" policy. In return for long-term licenses to cut timber on Crown land, licensees agree to meet these requirements. In so doing, the licensees must keep a ledger describing their free growing liability, this being an account that describes the future costs that are anticipated as being necessary to meet the standard for every unit of area that has been harvested and not yet declared as meeting the standard. The basic point to be made is that this liability can be significantly reduced by: a) reducing the time taken to reach the standard

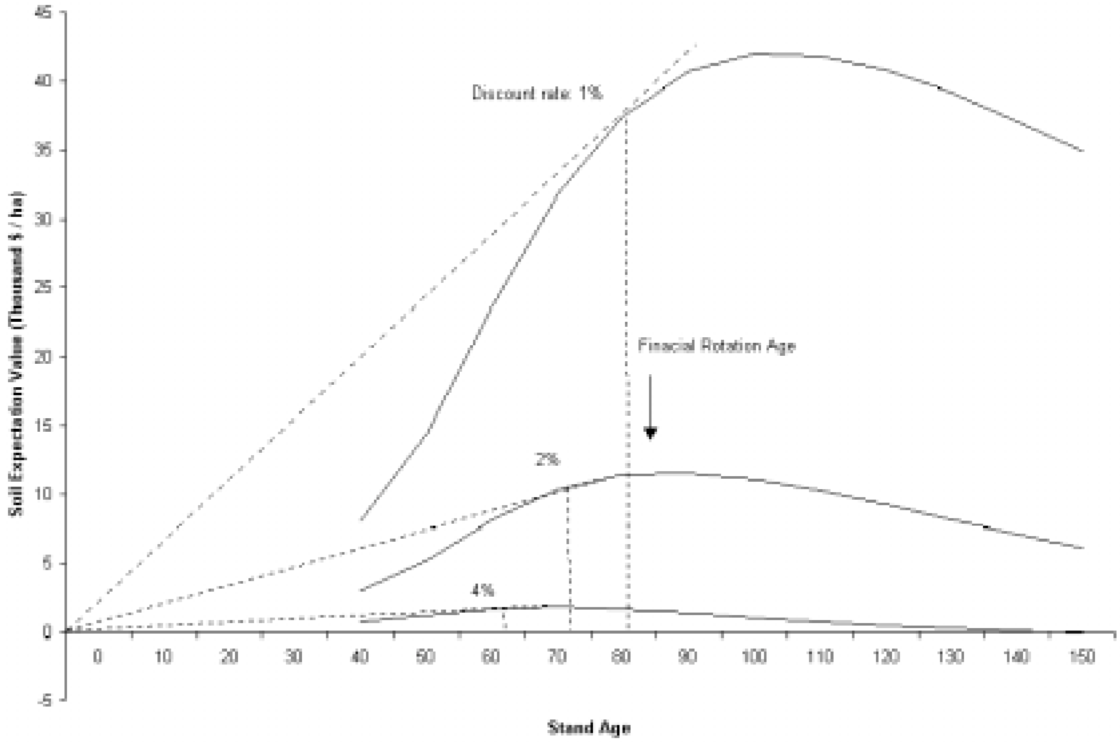
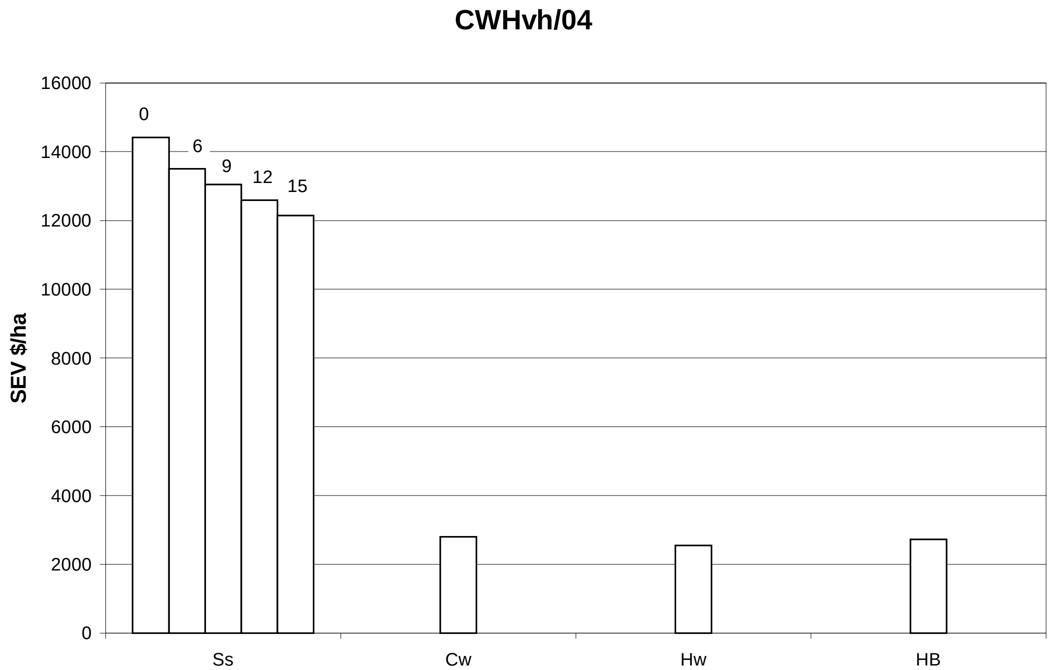


Figure 2. Financial rotation age and its relationship to discount rate (the sloping dash lines intersect the solid lines at the maximum mean annual rate of financial gain).

(by planting a faster growing species), b) reducing the risk of failure to meet the standard (for which financial penalties or expenditures may be required to remedy the problem), and c) by reducing the cost of meeting the requirement. The planting of Weevil resistant trees may make positive contributions in terms of a) and b), but there may be some additional costs incurred (c) to obtain those contributions. It is possible to determine the value of weevil resistant stock relative to a reduction in current levels of free growing liability using a silviculture investment analyses framework.

The second policy to be considered, after free growing criteria have been met, is the requirement that a minimum number of trees per hectare obtain a minimum height of 3 meters before adjacent stands can be harvested. This is referred to as the "***green-up***" or "***adjacency***" constraint. Insofar as this constraint causes a reduction in the amount of wood available for harvest, activities designed to reduce the green-up/adjacency constraint can produce a net benefit. Once again the establishment of faster growing, weevil resistant trees may provide such benefits and could be evaluated.

In conclusion, the investment analysis completed herein indicates that there is substantial value associated with the establishment of weevil resistant Sitka spruce plantations in all sites within the CWHvh subzone. There may be additional benefits that accrue when considering the deployment of this kind of planting stock relative to the "free growing" and "green-up" policy requirements. These potential benefits could be evaluated in an expanded silviculture investment analyses framework.



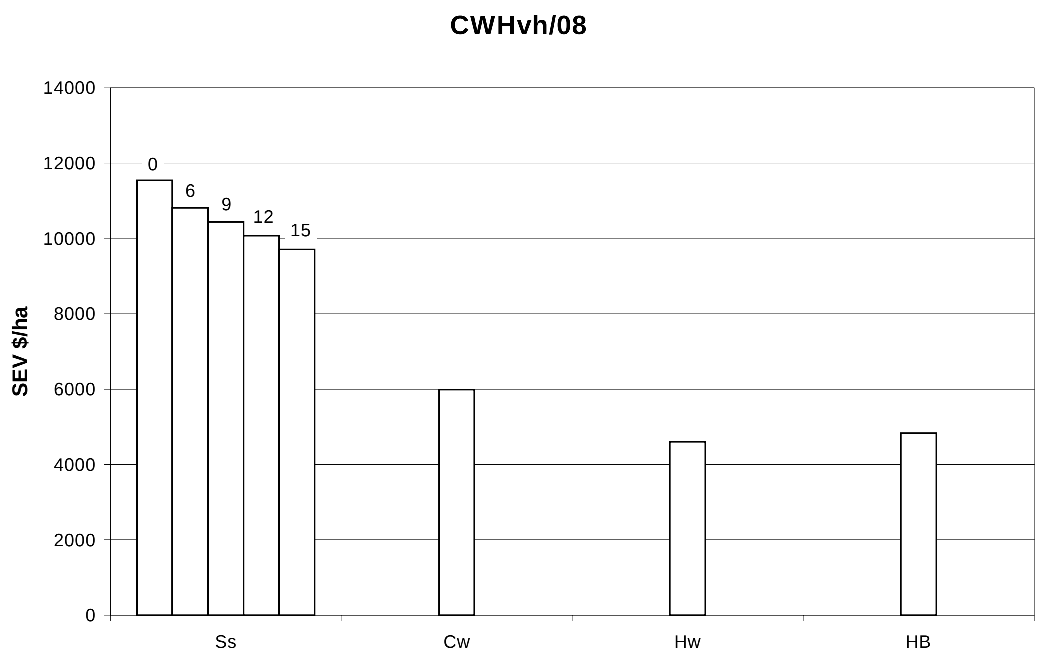


Figure 3. The SEW associated with deploying Sitka spruce (Ss) with a range of weevil susceptibilities (0 to 15%) relative to the other alternative species (Cw, Hw, HB) using 2% discount rate (CWHvh /04 and /08 represents the range of outcomes with respect to maximum SEVs).

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