Functions contained in the Douglas-fir calculator Version 2

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FUNCTIONS CONTAINED IN THE DOUGLAS-FIR CALCULATOR VERSION 2

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Abstract

Version 2 of the Douglas-fir calculator, which has been jointly developed with the New Zealand Farm Forestry Association, and released for testing in July 2004, utilises some 62 algebraic functions or groups of functions that are embedded directly within it. This report describes the functions used, their sources, and if relevant provides ancillary background, including Visual Basic for Applications (VBA) code, permitting their implementation within EXCEL 2000®. The functions described are as incorporated in the calculator as at July 2004, and in all cases are derived from NZ-wide data bases.

KEY WORDS
Pseudotsuga menziesii, growth, yield, site index, site basal area potential, decision support, modelling,

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Introduction

In version 1 of the Douglas-fir calculator, some of the functions were embedded in the calculator, however most of the calculations were estimated from regressions fitted to a database of output generated from STANDPAK runs (Knowles et al, 2002). In version 2, all functions are embedded directly in the calculator.

Most of the 62 functions or groups of functions the calculator utilises are available to Cooperative members and researchers though the published literature or Cooperative reports, although some reside in rather obscure places, and collating them together can be time consuming. This report is designed to provide ready access to the functions to facilitate future maintenance of the Douglas-fir calculator version 2. It is also expected access to the functions in a single report may provide obvious benefits to Cooperative members for application in their day-to-day work.

Table 1. Summary of functions used in the Douglas-fir Calculator Version 2

Topic	Function Numbers	When developed	Developed by	Reference
Stand growth- DF NAT growth model	1-21	1995-2004	Douglas-fir Coop	Knowles and Hansen, 2004, Knowles, Kimberley and Hansen (pending)
Tree-level volume/taper (T139)	22-27	1984	Forest Research	Katz et al, 1984
Stand level volume (S39)	28	1990	SGMC	Law, 1990
Height/age	29	2004	Douglas-fir Coop	van der Colff and Knowles, 2004.
500 Index	30-31	2004	Douglas-fir Coop	Knowles and Hansen, 2004
Diameter distribution	32-35	1990	Forest Research	Lawrence, 1990
Diameter over stubs	36-37	1993	Douglas-fir Coop	McInnes, 1997
Pruned Log Index	38-41	1989	Jim Park, Interface Forest & Mill Ltd	Park, 1989.
Branches	42-44	1994	Douglas-fir Coop	McInnes, 1997
Model for maximum branch	45	1994	Douglas-for Coop	McInnes, 1997
Mean log stiffness	46	2004	Douglas-fir Coop	Knowles et al 2002, D-fir Coop proceedings, Feb, 2004
Wood density	47-48	2001	Douglas-fir Coop	Page 8, this report
Juvenile wood %	49	2004	Douglas-fir Coop	Page 9, this report
Labour content of silvicultural operations	50-58	1975	NZ Forest Service, South Island Work Study Section.	Unpublished
Root biomass	59	1990	Landcare Research	Kuiper and Coutts, 1992.
Root biomass decay	60-61	1979	Landcare Research	O'Loughlin and Watson, 1979

Stand growth- the DF NAT growth model

The following description is adapted from that given in Knowles and Hansen (2004).

The New Zealand National Douglas-fir silvicultural growth model (DF NAT) is a system of equations that estimate the behaviour of key stand parameters for intensively managed Douglas-fir plantations throughout New Zealand. The model is based around two main sub-models, one for predicting height growth and the other for predicting basal area growth. The main purpose of the model is to utilise stand-level information, such as current condition and management regime, including pruning, to predict future growth from stand ages of around 5-10 years up to 80 years or more. In the calculator version 1, surfaces were fitted from some 244 runs of DF NAT version 6.2. In the calculator version 2 the most up-to-date DF NAT growth model (6.43) is fully embedded, and is used to grow the stands directly.

A summary of the functionality of the growth model suite is as follows [1]:

- Total stand crown length (CRL_0) is estimated from stand mean height (MH_0), mean height to crown base (CRH_0), and stocking (N_0). Both height to crown base and stocking can be split into pruned and unpruned elements, thus accounting for pruning treatments applied to various stand elements.
- If not measured, the stand mean height (MH_0) is estimated from mean top height (MTH_0)
- If not measured, the mean height to crown base (CRH_0) is estimated from mean top height (MTH_0) and stocking (N_0).
- The height growth model (height/age-curve) is a direct function of stand age and site index, with a small effect attributed to latitude. Site index (mean top height in metres at age 40 years, *SI40*) is an indicator of the potential for height growth on a particular site, forest, or region (depending on modelling resolution). Site index needs to be determined *a priori* from height/age data.
- Basal area (BA_1) at stand age T_1 is predicted from an earlier basal area value (BA_0) using total stand crown length (CRL_0), stand age, site basal area potential (SBAP) and a competition term consisting of basal area/ha relative to SBAP. The current parameterisation requires the model to work in time-steps of one month.
- SBAP is an index of a site's ability to support basal area growth. It is site, forest or region-specific (depending on modelling resolution) and needs to be determined *a priori* from growth data.
- For thinned stands, the thinning intensity must be expressed either as the number of trees removed, or by the amount of basal area removed. The thinning function then partitions either basal area removed to a number of trees, or a number of trees removed to a basal area. The parameter of the thinning function (termed the thinning coefficient) can be management-specific (e.g. 'thinning-from-below' as opposed to 'thinning-from-above'), and needs to be determined *a priori*. The default value for conventional thinning-from-below in New Zealand is 0.705.
- For unthinned stands the stocking (mortality) model predicts the stocking (N_1) as a function of an earlier stocking (N_0), quadratic mean diameter (D_0) and mean top height (MTH_0). The inherent logic of the density dependent mortality model is Reineke's –3/2-power rule (Reineke, 1933).

The model suite was originally developed and parameterised using growth information from some 550 permanent sample plots in the NZ Forest Research permanent sample plot system (Fight *et al.* 1995). Subsequently, the model has been progressively refitted using data from some 1,300 sample plots.

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[1] $_0$=beginning of the increment step, $_1$ = end of the increment step.

DF NAT growth model can be calibrated for any given site using the two site productivity indices of *SI* (mean top height at age 20 years) and the SBAP.

The equations for this model are as follows.

To convert Mean Top Height to Mean Height

MH=MTH*1-(a*(1-exp(b*N-100)/100)) (1)

Where a=0.106 and b= -0.228, and N is trees/ha

Prediction of Crown length/ crown height

The following describes how crown length is calculated when there is a single pruned element in the stand. The method can be expanded to include multiple pruned elements. Begin by setting max_unprC and max_prC to 0. (2)

Then for each monthly step, perform the following:

1. Calculate mean height (MH) using the above model
2. For unpruned trees, check C against maxC from previous steps:
   unprC = max(C, max_unprC) (3)
3. For pruned trees, check C against maxC from previous steps and pruned height:
   prC = max(MH-CL_t, max prC, prH) (4)
4. Calculate crown length:
   CL = unprnN*unprC + prN*prC (5)
5. Update max crown heights:
   max_unprC = max(max_unprC,unprC)) (6)
   max_prC = max(max_prC,prC)) (7)

where unprN and prN are stocking of pruned and unpruned elements, respectively and prH is pruned height of the pruned element.

Crown length model

$CL_t = \min(CL_{pre},CL_{post})$ (8)

and where

$CL_{pre} = k\ (\ MTH - 0.1\ )$ (9)

$CL_{post} = a + b/SPH$ (10)

Parameters for New Zealand and the PNW: k = 0.8429, a = 6.9833, b = 2028.

The above model has been fitted according to the method developed by Turner (1998).

Basal area increment model

Basal Area Incr. (BAI) =BA0+SBAP*crown term*age term*competition term*(T1-To) (11)

where BA1, BA0 are basal area (m^2/ha) and age at times 0 and 1, SBAP is site basal area potential and CL is crown length (m/ha) at time 0.

crownterm = (1-exp(b*CL)) (12)

ageterm = max(1,c+(1-c)/d*T0) (13)

(Note that d is fixed at 50 years)

compterm = 1-exp(f+g*BA0/SBAP)/(1+exp(f+g*BA0/SBAP)) (14)

b = -0.0002059, c = 3.0955, d = 50, f = -5.46, g = 0.1217

Mortality function

X = exp(b+c*(ln(N0)+d*ln(H0*D0^2))) (15)

Y = a+(1-a)*X/(1+X) (16)

N1 = N0*(1-Y*(T1-T0)) (17)

where N0, N1, T0, T1 are stocking (trees/ha) and age at times 0 and 1, and D0, H0 are quadratic mean DBH and MTH at time 0.

a = 0.000070, b = -20.43, c = 1.517, d = 0.3714

Thinning coefficient

$$BA1 = BA0*(N1/N0)^{a} \qquad (18)$$

where BA0, BA1, N0, N1 are basal area and thinning before and after thinning.
a = 0.705 as the NZ default.

***Start values for BA* (only used when the user does not have starting values)**

Mean DBH = a*(MTH-1.4)^b*(1+c*(SBAP-1.9))*(1+f*T*N^g) (19)

Where T is age, N is stocking, MTH is mean top height, and SBAP is site basal area potential. This equation is reliable for ages 10 to 20 and stockings less than 3000sph.
a = 4.56, b = 0.372, c = 0.149, d = - 0.275, f = 0.627, g = - 0.427

Model for distributing basal area increment to elements

Once the total stand basal area increment is calculated, the basal area increment to individual elements is distributed proportional to the total crown length of the element, i.e. the one-to-one rule.

$$\Delta BA_{\text{pruned}} / \Delta BA_{\text{stand}} = CL_{\text{pruned}} / CL_{\text{stand}} \qquad (20)$$

Model for distributing already grown basal area when pruning

A pruning operation selects superior individuals in proportion comparable to a thinning. The basal area of the pruned element is therefore larger than were the pruned trees selected randomly. The model used is similar to the thinning function, i.e.

$$BA_{\text{pruned}} = BA_{\text{stand}} * (SPH_{\text{pruned}}/SPH_{\text{stand}})^{\alpha} \qquad (21)$$

Where α is a constant, for New Zealand usually set at 0.705 (see thinning function for further comments)

Volume/taper functions

Tree volume function (T136)

$$TreeVolume = DBH^{a1} * (MTH^{2} / (MTH - 1.4))^{a2} * \exp(a3) \qquad (22)$$

Where *DBH* is diameter at breast height (cm) and *MTH* is mean top height (m).
$a1$ = 1.8281198, $a2$ = 1.102592, $a3$ = -10.19719

Taper function (T136)

$$L = (MTH\text{-}h) / MTH \qquad (23)$$

$$D_2 = 40000\, V / (\pi MTH) * (a_1 L + a_2 L^2 + a_3 L^3 + a_4 L^4 + a_5 L^5) \qquad (24)$$

$$DiameterUnderBark = D_2^{0.5} \qquad (25)$$

$a_1 = 0.319071$, $a_2 = 0$, $a_3 = 23.9972$, $a_4 = -47.47884$, $a_5 = 26.02156$

Where h is the height at which the calculation takes place, V is tree volume (m^3), *MTH* is mean top height (*m*) and h is the height (m) at which one wishes to calculate the diameter under bark (cm).

Partial tree volume function (T136)

$$PartTreeVolume = V - V * (c_1 L^2 + c_2 L^3 + c_3 L^4 + c_4 L^5 + c_5 L^6) \qquad (26)$$

Where h is the height beneath which the volume is calculated, *MTH* is mean top height (m), and V is total tree volume (m^3).

$c_1 = 0.319071 / 2$, $c_2 = 0 / 3$, $c_3 = 23.9972 / 4$, $c_4 = -47.47884 / 5$, $c_5 = 26.02156 / 6$
and $L = (MTH - h) / MTH$ (27)

Stand volume function (36), based on tree volume function (T136)

$$StandVolume = BA * (a + b * MTH + c * SPH * MTH / BA) \qquad (28)$$

Where *BA* is stand basal area (m^2/ha), *MTH* is mean top height (m) and *SPH* is stocking (stems/ha).
$a = 0.8502$, $b = 0.33337$, $c = 0.00004725$

Height Age Function

$$MTH = 0.25 + (MTH_{40} - 0.25)\left\{\frac{1-\ell^{-\ell^{a}T}}{1-\ell^{-\ell^{a}40}}\right\}^{\frac{1}{[b+((p+q.latitude).MTH_{40})]}} \quad (29)$$

where MTH40 is site index (MTH in metres at age 40).
a = -3.7082, b = 0.3844, p=0.0338, and q=-0.00057
See van der Colff and Knowles (2004) for more details.

500 Index
Detailed analysis of output from multiple runs of DF NAT covering the NZ site productivity surface has shown that if SBAP and SI are multiplied together in the following format, the *500 Index* can be obtained (Knowles and Hansen, 2004):
500 Index = $a*SI^{b}*SBAP^{c}$ (30)
where a=0.107, b=1.33 and c=0.96.

This index is directly related (r^2 = 0.9996) to the MAI as generated by DF NAT, of a stand of Douglas-fir planted at around 1650 stems/ha, thinned to waste to a stocking of 500 stems/ha at around 15m MTH, and grown to 40 years. Because the NZ height/age curve has a latitude term, the average latitude of 42^0S for NZ Douglas-fir plantations was used to derive the above function. The following function which includes latitude as a variable, is contained within the calculator:
500 Index = (latitude*d)+e)*$SI^{b}*SBAP^{c}$ (31)

where b=1.33, c=0.96, d=-0.0008, e=0.14

Diameter distributions
The probability of each diameter class is modelled using the probability density function of the three-parameter Weibull distribution:

$$W_{pdf}(x) = 1 - e^{-\alpha(x-\gamma)^{\beta}} \quad (32)$$

The coefficients (α, β, and γ) are estimated iteratively from stand minimum DBH ($DBH_{\min}$), maximum DBH ($DBH_{\max}$) and the DBH variation (Var_{DBH}) following the approach of Goulding and Shirley (1979), and utilising the STANDPAK Weibull function no 2- Psmen, all NZ.

Model for predicting the minimum DBH
$DBH_{\min}$ =0.712273 * *DBH* - 0.23117 * *Age* - 0.165277 * *MTH* + 2126.31 / *SPH* - 0.001549 * *SPH* + 0.003263 * Age^2 (33)
Where *DBH* is stand mean diameter at breast height (cm), *Age* is stand age (years), *MTH* is stand mean top height (m), and *SPH* is stocking (stems/ha).

Model for predicting the maximum DBH
DBH_{max} =*2.5576* + *1.09442* * DBH + *0.462807* * MTH - *2261.14* / SPH + *0.001204* * SPH (34)
Where *DBH* is stand mean diameter at breast height (cm), *Age* is stand age (years), *MTH* is stand mean top height (m), and *SPH* is stocking (stems/ha).

Model for predicting diameter variance
Var_{DBH} = 0.801521 * ((($DBH_{\max}^2$ - $DBH_{\min}^2$) * 0.0000785398) / 4)^2 (35)

Model/algorithm for estimating the Weibull distribution parameters
The following VBA (Visual Basic for Applications) implementation determines through iteration the Weibull parameters from the *DBH*, *SPH*, $DBH_{\min}$, $DBH_{\max}$ and Var_{DBH}

```
Function Wparms(minDBH, maxDBH, DBH, SPH)
  Dim Out(0, 2)
  Pi = 3.14159265359873

If DBH > 0 Then
   DBHvar = Wvar(minDBH, maxDBH) 'Estimate DBHvar
   BA1 = DBH ^ 2 * Pi / 40000
   BA2 = minDBH ^ 2 * Pi / 40000
   hat = DBHvar / ((BA1 - BA2) ^ 2)
   counter = 0
   betad = 0.5
   betau = 15
   While Abs(betau - betad) > 0.00001 And counter < 200
      beta = 0.5 * (betad + betau) 'guess halfway between up and down, i.e. binary search
      g1 = Exp(Excel.WorksheetFunction.GammaLn(1 + 2 / beta))
      g2 = Exp(Excel.WorksheetFunction.GammaLn(1 + 1 / beta))
      diff = (1 / (SPH ^ (-1 / beta) - 1) ^ 2) * (g1 / g2 ^ 2 - 1) - hat
      If diff < 0 Then
         betau = beta
      Else
         betad = beta
      End If
      counter = counter + 1
   Wend
   If Abs(betau - betad) < 0.00001 Then 'make sure the search has converged
      beta = 0.5 * (betau + betad)
      k = Abs((BA1 - BA2) / (1 - 1 / SPH ^ (1 / beta))) / g2
      Out(0, 0) = 1 / k ^ beta 'Estimate alpha parameter
      Out(0, 1) = beta 'Estimate beta parameter
      Out(0, 2) = BA1 - k * g2 'Estimate gamma parameter
   End If
End If
Wparms = Out 'Return parameters
End Function
```

The cumulative density function (cdf) for the Weibull distribution is

$$W_{cdf}(x) = 1 - \exp(-\alpha(x - \gamma)^{\beta}) \qquad (36)$$

Where α, β and γ are parameters

Model for calculating DOS

This function is based on the work of McInnes (1997)

$$DOS = -0.697 + (1.08 * dados) + (0.118 * max\_branch) - (0.0009 * max\_branch * max\_branch) + (0.555 * Dos\_ht) - (0.04 * Dos\_ht * Dos\_ht) \qquad (37)$$

Where *max_branch* is the maximum branch, *DBH* is diameter at breast height at pruning, *MH* is tree mean height at pruning, and *Dos_ht* is the average height of the largest whorl (This is set at 0.2 m above the previous pruned height).

max_branch is set at 40. $Dados = DBH * (MH - Dos\_ht) / (MH - 1.4)$ (38)

Model for predicting the pruned log index (PLI)

Pruned log index is estimated using the approach of Park (1989), i.e.

$$PLI = \left(\sqrt{\frac{D_{13} - D_c}{10}}\right)\left(\frac{D_{13}}{D_c}\right)V_R^{1.6} \qquad (39)$$

Where D_{13} is the diameter (mm) of the log 1.3 m from the large end, D_c is the diameter of the defect core (mm), and V_R is the ratio between the common volume and the log volume, where common volume is the volume of the log not intercepted by the defect core. The coefficients were estimated from a matrix of output generated from an Excel implementation of the PLI calculator (Park 2004)

D_{13} is estimated from the small-end diameter (*SED*) (mm), the length of the log (*L*) (m) and the taper (Δt) (mm/m) as

$$D_{13} = SED + (L - 1.3)\Delta t \qquad (40)$$

D_c is estimated from sweep (*SW*) (mm/m) and diameter-over-stubs (*DOS*) in mm, as

$$D_c = a + bSW + DOS \qquad (41)$$

Where the coefficients are $a = 46.375$, and $b = 1.841$.

V_R is calculated as a multiple linear regression using log length (*L*) (mm), small-end-diameter (*SED*) (mm), sweep (*SW*) (mm/m) and taper (Δt) (mm/m) using the following equation:

$$V_R = aL + bSED + cSW + d\Delta t + e \qquad (42)$$

With coefficients $a = -0.008$, $b = 0.00019$, $c = -0.0093$, $d = -0.00354$, and $e = 0.8694$.

Models for predicting branch index (BIX)

These are based on the work of McInnes (1997).

$$\text{Second log } BIX = 2 + b * \log(1 + \exp(c/b + d/b * DBH_{30} + e/b * THINHT + f/b * SI)) \qquad (43)$$

Where DBH_{30} is the stand mean diameter at breast height at age 30, *THINHT* is the stand mean top height at thinning, and *SI* is the stand site index.

$b = 2.743$, $c = -5.776$, $d = 0.288$, $e = -0.096$, $f = -0.127$

$$\text{First log } BIX = BIX_2 * (a - b^{cSPH}) \qquad (44)$$

Where BIX_2 is the *BIX* of the second log (as from the formula above), *SPH* is the stand stocking (stems/ha).

$a = 1.66$, $b = 0.98$, $c = 0.01$

$$\text{Nth log } BIX = 1.07 * BIX_2 \qquad (45)$$

Where BIX_2 is the second log BIX (as from the formula above).

BIX class distribution

The branch index for the *n*'th log of a model tree in the *i*'th diameter class is assumed normal distributed with a mean of $BIX_{i,n}$ as given in the equations above, and a standard deviation of $\sigma = 0.6$. The effects of this distribution on the log cutting are simulated through cutting model trees in 10 different BIX classes with boundaries from -2σ to 2σ, in steps of $\sigma/2$. The probability and mean value for each class is determined from the normal distribution, and the mean for each diameter class.

Model for maximum branch (Br_{max})

Maximum branch diameter in the log (as against BIX) is used to determine the log grade. The size of the maximum branch for the *n*'th log of the *i*'th model tree ($Br_{i,n,\max}$) is modelled from the BIX (BIX_n) of the mean tree, and the difference between the DBH (cm) of the model tree (DBH_i) and the mean tree ($\overline{DBH}$), i.e.

$$Br_{i,n,\max} = a + bBIX_n + c(DBH_i - \overline{DBH}) \qquad (46)$$

Where the coefficients are a = 0.133, b = 1.111, and c = 0.05.

Model for predicting log mean stiffness (MoE)

$$MoE = 2.66 + 0.03\,\rho_{bhow} - BIX \qquad (47)$$

Where ρ_{bhow} is the breast height outerwood density. The formula is based on results from the Rotoehu study, minus 3 units. (Knowles et al 2002)

Model for predicting breast height outerwood density from an earlier measurement

$$a = \rho_{Tmeas} / (450.1 - 220.5 * \exp(-0.0644T_{\mathrm{meas}})) \quad (48)$$

$$\rho_T = 0.96\, a\, (450.1 - 220.5 * \exp(-0.0664T)) \quad (49)$$

Where ρ_{Tmeas} is the breast height outerwood density at time T_{meas} and ρ_T is the breast height outerwood density at time *T*.

Model for predicting juvenile wood percentage

This model works off the temporal steps of the model. For each age *T* a corresponding mean top height is calculated from the height/age curve. That mean top height is subsequently converted to the mean height (MH_T). The logic is that at *T* years of age the stem consists of only ten rings exactly at the mean height ten years prior ($MH_{T\text{-}10}$). Hence, the diameter ($DBH_{\mathrm{T\text{-}10}}$) at $MH_{T\text{-}10}$ at time *T* is exactly the diameter of the 10 innermost rings. The volume of juvenile wood from time *T-1* to time *T* is then calculated as:

$$\pi/4\ (MH_{\mathrm{T}}\text{-}MH_{\mathrm{T\text{-}1}})DBH^2. \quad (50)$$

The total juvenile volume is then calculated as the sum of over all *T*, and expressed relative to total stem volume.

```
'This function calculates the juvenile wood percentage
Function CalcJuvenile(SI, Ages, DBHs, Ns, Lat)
Dim VolSum As Double

MaxMTH = MTHcalc(SI, Excel.WorksheetFunction.Max(Ages), Lat)
maxDBH = Excel.WorksheetFunction.Max(DBHs)
MaxVol = TreeVolume(maxDBH, MaxMTH)

j = 1
While Ages(j, 1) > 0
   If (Ages(j, 1) > 10 And Ages(j + 1, 1) > 0) Then
      MTH = MTHcalc(SI, Ages(j, 1), Lat) 'Tree mean top height
      MTH10 = MTHcalc(SI, Ages(j, 1) - 10, Lat) 'Tree mean top height 10 years ago
      TreeVol = TreeVolume(DBHs(j, 1), MTH) 'tree volume
      MH10 = MHcalc(MTH10, Ns(j - 10, 1))
      Dj = CalcDub(TreeVol, MTH, MH10) 'Calculate diameter at MH 10 years ago
      Df = CalcDub(MaxVol, MaxMTH, MH10) 'Calculate final diameter at MH 10 years ago
      MTHjm = MTHcalc(SI, Ages(j - 1, 1), Lat)
      MHjm = MHcalc(MTHjm, Ns(j - 1, 1))
      MHj = MHcalc(MTH, Ns(j, 1))
      W = MHj - MHjm
      VolSum = VolSum + W * (Dj ^ 2) / (Df ^ 2) 'Volume of segment
      Weights = Weights + W
   End If
   j = j + 1
Wend
CalcJuvenile = VolSum / Weights
End Function
```

Labour content of silvicultural operations – Waste thinning times

Fell time per tree (minutes per tree):

DBH < 5 cm:	*FellTime* = 0.07	(51)
5 cm <= *DBH* < 32 cm:	*FellTime* = 0.0696 + 0.0008 * *DBH* + 0.0004* *DBH*^2	(52)
DBH >= 32 cm:	*FellTime* = 0.5	(53)

Where *DBH* is diameter at breast height before thinning (cm).

Hang-up time (minutes per tree):

$$HT = 0.069098 - 0.00771*Age - 0.00026*SPH + 0.00003431*Age*SPH \quad (54)$$

Where *Age* is stand age (years) and *SPH* is stocking before thinning (stems per ha)

Walk-and-select time (minutes per tree):

$$WST = 0.0198*H\text{^}2 - 0.0552*H + 0.1658 + 4.83*H\text{^}2 / SPH \quad (55)$$

Where *H* is hindrance on a scale from 1 to 4 (1=no hindrance, 4=very heavy hindrance), and *SPH* is stocking (stems per hectare).

Clear-away time (minutes per tree):

$$CT = 0.02 * H - 0.01 \quad (56)$$

Where *H* is hindrance on a scale from 1 to 4.

Slope allowance (multiplier):

$$SA = 1 + 0.0029*Slope - 0.0001*Slope\text{^}2 + 0.000005*Slope\text{^}3 \quad (57)$$

Where *Slope* is the slope in degrees.

Hindrance allowance (multiplier)

Slope <=20, *H*<=2:	*HA* = 1.643	(58)
Slope <=20, *H*>2:	*HA* = 1.653	
Slope >20, *H*<=2:	*HA* = 1.653	
Slope >20, *H*>2:	*HA* = 1.663	

Where *Slope* is the slope in degrees and *H* is hindrance on a scale from 1 to 4.

Total time per tree waste thinned is:

$$\text{TotalTime} = (FT + HT + WST + CT) * SA * HA \quad (59)$$

Log cutting overview

The total standing volume is distributed to log grades through simulated log cutting of model trees. To simulate the distribution of tree and branch sizes the cutting simulation is iterated for model trees in each diameter class (2 cm steps) across the diameter distribution, and for each BIX class (steps of $\sigma/2$) within each diameter class (σ is the standard deviation). The result from each simulation is multiplied by the probability of finding a tree in that particular diameter and BIX class. Once the volume is distributed to log grades across both distributions, a user-input percentage of each grade is downgraded to the poorest grade (usually pulp), and the total merchantable volume across grades is automatically adjusted to fit the user-input conversion percentage.

Root biomass

Root biomass is a useful surrogate for estimating the effect of a stand of trees on slope stability, and is predicted from stand stocking and mean DBH using the following function provided by Kuiper and Coutts, (1992):

$$\text{RootBiomass} = \text{SPH} ((10 \text{^} (2.63 \log_{10}(\text{DBH}) - 2.00)) / 1000) \quad (60)$$

Where RootBiomass is the root biomass in tons/hectare, SPH is the stocking in stems/ha, and DBH is the stand quadratic mean DBH.

Root decay

Root decay following logging is based on results from Coastal Oregon (O'Loughlin and Watson 1979):

$$S_{t2} = S_{t1} e^{-bt2} \quad (61)$$

Where S_{t1} is root tensile strength (MPa) at clear-felling, *t2* is the time since clear-felling (months), and the coefficient *b* is 0.018.

Compared to *Pinus radiata*, Douglas-fir has less root weight for a given tree DBH, but the roots have relatively higher tensile strength and a much slower decay rate. If it is assumed that over any given period, loss in root strength and loss in root weight will have an equivalent effect on soil stability, the magnitude of the root effect after clearfelling can be estimated from the following equation :

$$D_{t2} = M_{t1}(S_{t2}/S_{t1}) \qquad (62)$$

where: D = weight of decaying tree roots (t/ha), a value equivalent to root tensile strength in terms of its effect on soil erosion, M = weight of all tree roots prior to the onset of root decay (t/ha), S = tensile strength of roots (MPa), $t1$= time at beginning of period (yr), $t2$ = time at end of period (yr).

These equations can be used to estimate changes in total tree root weight over the course of one or more rotations, including the effects of pruning and thinning.

Conclusions

From the above, it is clear that considerable functionality exists to readily enable modelling of stand level growth and quality of Douglas-fir at the national level in New Zealand. Where obvious gaps have presented themselves, for example to predict stand mean density from breast height density at a previous time, a new function has been fitted. Several NZ-wide functions have been incorporated which have not previously been employed in decision support systems, or have been updated so they can be utilised at the national level. These include the recently developed national height/age curves with latitude as a variable (van der Colff and Knowles, 2004), and 500 Index (Knowles and Hansen, 2004).

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