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Original article

Estimation of total yield of Douglas fir by means of incomplete growth series

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Summary – This study establishes and validates a method that takes into account yield levels and permits the reconstruction and modelling of the evolution of total yield based on incomplete growth series. The calculation of total yield of Douglas fir (*Pseudotsuga menziesii* (Mirb) Franco var *menziesii* Franco) is carried out by integrating the equation of volume increment per metre dominant height growth. The model utilized explains 94.8% of the variation in volume increment per metre height growth of the 14 experimental plots. The evolution of total yield is calculated for 4 current increment levels. The concept of current increment levels is similar to the concept of yield levels, and corresponds to the value of volume increment per metre height growth, at a height of 30 m. At an equivalent yield level, the calculated total yield curves correspond closely to those calculated by Bergel (1985).

total yield / yield level / current increment level / volume increment / Douglas fir

Résumé — Estimation de la production totale du Douglas vert au moyen de séries de croissance partielles. *Cette étude établit et valide une méthode qui tient compte de niveaux de production et qui permet de reconstituer et de modéliser l'évolution de la production totale à partir de séries de croissance partielles. Le calcul de la production totale du Douglas vert* (Pseudotsuga menziesi *(Mirb) Franco var* menziesii *Franco) s'effectue en intégrant l'équation de l'accroissement en volume par mètre d'accroissement en hauteur dominante. Le modèle utilisé explique 94,8% de la variation de l'accroissement en volume par mètre d'accroissement en hauteur des 14 placettes. L'évolution de la production totale est calculée pour 4 niveaux d'accroissement courant. Le concept de niveau d'accroissement courant s'apparente au concept de niveau de production et correspond à la valeur de l'accroissement en volume par mètre d'accroissement en hauteur, à une hauteur de 30 m. À niveau de production égal, les courbes de production totale calculées correspondent étroitement à celles de Bergel (1985).*

production totale / niveau de production / niveau d'accroissement courant / accroissement en volume / Douglas

INTRODUCTION

For decades, yield tables have served as a basic tool for forest site management. In the European context, foresters are mainly interested in total yield, *ie* the total standing volume at a specific moment in time, to which one adds the production harvested by thinnings since the stand was established.

Classic approach

The classic approach to modelling total yield is based on Eichhorn's extended law, which states that: "the total crop yield is without exception a function of the mean height" (Assmann, 1970).

Yield levels approach

Mitscherlich (1953), and then Assmann (1954), demonstrated that instead of a single relationship between total yield and dominant height, there exist several relationships, which must be expressed in terms of different yield levels. Assmann (1955) termed the total yield attained at a certain dominant height as the general yield level *(allgemeine Entragsniveau)* and termed the variation in total yield within the same site index, *ie* for a specific height–age curve, as the specific yield level *(spezielle Ertragsniveau).*

An important variability in total volume yield was also reported by Schmidt (1973) for Scots pine *(Pinus sylvestris* L), Kennel (1973) for beech *(Fagus sylvaticus* L) and finally Schütz and Badoux (1979) for oaks (*Quercus petraea Lieb* and *Quercus robur*). According to sereval authors, this variability can be as high as 14–25% of the mean value (Assmann and Franz, 1965; Kennel, 1973; Schmidt, 1973; Schütz and Badoux, 1979; Bergel, 1985).

Estimation by means of incomplete growth series

In the absence of complete growth series, Magin (1963), Prodan (1965), Decourt (1967) and Decourt and Lemoine (1969) proposed different approaches to estimate total yield from plots measured only once or from growth series. These are generally based on the ratio of the volume of the mean tree harvested by thinning to that of the mean tree remaining on the site (or the mean tree before thinning). However, these approaches confound the yield levels and thus force an acceptance of the validity of the Eichhorn's law (Eichhorn, 1904).

Faced with different yield levels, the calculation of total yield imposes methodological constraints that result in problems for researchers who have only incomplete growth series (growth series for which the volumes from the first thinnings are lacking) available to them. This situation justifies the development of an alternative approach to that of Assmann and Franz (1963).

Objectives

The objectives of this study are to establish and validate a method, incorporating yield levels, which permits the reconstruction and modelling of the evolution of total yield using incomplete growth series. The study concerns Douglas fir (*Pseudotsuga menziesii* (Mirb) Franco var *menziesii* Franco) because an important variability in yield levels has been observed for this species (Kramer, 1963; Hamilton and Christie, 1971; Bergel, 1985; Christie, 1988).

MATERIALS AND METHODS [1]

The region studied extends over the Swiss plateau, to the west of Zürich. The stands of Douglas fir studied are found on the flat plain or on hillsides, at altitudes varying between 450 and 750 m. All stands are included in vegetation associations of beech (Ellenberg and Klötzli, 1972).

Material

The data are from 14 experimental plots of the Swiss Federal Institute for Forest, Snow and Landscape Research of Birmensdorf. Of these plots, 8 were established at the beginning of the century, with a first inventory at an age ranging from 10 to 42 years. The 6 other plots are from 2 thinning experiments established in the mid-sixties and measured at 3 different times. Of the original experimental design, we retained the 6 plots where the thinning intensity best corresponded to that of the older stands studied.

These plots were measured on average every 5 years. At each sampling time, the diameter at breast height of all stems was measured with a precision of 0.1 cm. Observations were also made to establish the height–diameter relationship serving to calculate the dominant height and stem volume (top diameter: 7 cm over bark) of trees.

A comparison with data from Bergel's (1985) table indicates that these 14 experimental plots were generally subject to thinning regimes ranging from light to moderate. The site index values (h_{100} at 50 years) vary between 30.8 and 36.4 m ($\bar{x}$ = 33.2 m, s_x = 1.4 m). The variation in the estimate of site index of each plot, as a function of age, is generally not more than ± 1.5 m once the period of juvenile growth has terminated. Table I presents the principal characteristics of these growth series.

Methods

The total yield corresponds to standing volume at a specified time to which is added the sum of volumes harvested by thinnings since stand establishment. It is also expressed as the sum of volume increments per metre height growth. Total yield is then calculated by integrating the equation for volume increments per metre height growth as a function of dominant height (equation [1])

$$TYLD = \int VI \, dH \quad [1]$$

where *TYLD* is total yield (m^3/ha) and *VI* is volume increment per metre dominant height growth (m^3/ha/m).

Volume increment per metre dominant height growth

Volume increment per metre height dominant growth (*VI*) is the volume increment corresponding to a difference of 1 m of dominant height. It is established by deriving the equation for total yield as a function of dominant height (equation [2]).

$$VI = \frac{d}{dH} TYLD \quad [2]$$

Etter (1949) proposed model [3] to calculate the evolution of total yield from a complete growth series. The model of *VI* then becomes (model [4]):

$$TYLD = \beta 1 \, H^{\beta 2} \quad [3]$$

$$VI = \beta_1 \beta_2 H^{\beta_2 - 1} \quad [4]$$

In the case of incomplete growth series, the total yield curve is subject to a downward displacement equal to the yield not accounted for in thinnings (*NRYLD*, equation [5]). To take into account this displacement, a constant β_0 (model 6) must be added to model 3 under the restriction $\beta_0 \leq 0$. However, this constant does not affect the derivative of the equation of recorded yield (model [7]), which provides values of volume increment per metre height growth identical to those obtained by model [4]. In fact, the non-recorded yield in thinnings does not affect the rate of change in volume per metre at a given height.

$$RYLD = TYLD - NRYLD \quad [5]$$

$$RYLD = \beta_0 + \beta_1 H^{\beta_2} \quad [6]$$

$$VI = \beta_1 \beta_2 H^{\beta_2 - 1} \quad [7]$$

[1] See Bégin (1992) for details of methods.

Table I. Principal characteristics of the growth series.

Plot	Location	Site index (m at 50 years)	Age at first measurement (years)	Age at last measurement (years)	Height at first measurement (m)	Height at last measurement (m)
1	Bienne	33.7	17	76	13.6	42.4
2	Kuessnach	33.1	41	104	29.8	47.9
3	Fribourg	33.8	22	58	16.5	36.9
4	Le Mont	35.3	28	89	22.1	47.1
5	Cheseaux	36.4	35	55	26.5	38.4
6	Rotkreuz	32.4	42	100	28.6	46.5
7	Neuendorf 1	33.2	11	20	6.4	13.5
8	Neuendorf 2	32.6	11	20	6.0	13.0
9	Neuendorf 3	32.6	11	20	5.6	13.0
10	Neuendorf 4	32.5	11	20	5.6	12.8
11	Buron 1	32.9	11	20	4.5	13.2
12	Buron 2	33.8	11	20	5.4	14.1
13	Bois-désert 1	31.9	10	23	4.2	15.0
14	Bois-désert 2	30.8	10	23	4.0	13.9

where *RYLD* is recorded yield (m^3/ha) and *NRYLD* is non-recorded yield from thinnings (m3/ha).

For the purpose of this study, the values of volume increment per metre height growth are estimated by dividing the volume increment between 2 measurements by the corresponding dominant height increment.

Substantiation of yield levels

If complete growth series are utilized, a comparison of the evolution of yield since establishment as a function of dominant height reveals the importance of variability in total yield. For a single yield level, in the absence of a relationship with site index, the total yield curves should be grouped around the average curve.

In the situation of incomplete growth series, the evolution of total yield in each plot is unknown, due to volumes from thinnings that are unaccounted for. If the hypothesis of a single yield level is valid, the incomplete growth series increase by the same volume between 2 heights, but differ by the coefficient β_0 (model [6]). By means of binary variables, the coefficient β_0 is allowed to vary with each growth series (model [8]). The coefficients β_1 and β_2 of model [3] can then be estimated and used to calculate the evolution of an average yield level.

$$RYLD = \beta_{01} + \ldots + \beta_{0k} + \beta_1 H^{\beta_2} \qquad [8]$$

where β_{01} is coefficient β_0 for series 1 and β_{0k} is coefficient β_0 for series *k*.

An examination of the residuals of model [8] allows either a confirmation or a negation of the hypothesis of a single yield level. The hypothesis of a single yield level can be reasonably accepted if the residuals are distributed around zero without an evident pattern. On the other hand, an apparent distribution pattern in the residuals of model [8] may indicate a relationship between the evolution of total yield and the site index. If there is no such pattern, one should then account for more than a single yield level.

Modelling of volume increment per metre height growth

Model 4, which applies to a given growth series, can be generalised to all the growth series by replacing the coefficient β_1 with binary variables. Each coefficient β_{1k} then corresponds to a given growth series, while β_2 is common to all growth series (model [9]).

$$VI = (\beta_{11} + \beta_{12} + \ldots + \beta_{1k})\, \beta_2\, H^{\beta_2 - 1} \qquad [9]$$

where β_{11} is coefficient β_1 for series 1 and β_{1k} is coefficient β_1 for series *k*.

The approach used to calculate the base-age invariant site index (Goelz and Burk, 1992) appeared adequate to model the evolution of curves of volume increment per metre height growth. This approach permits the modelling of volume increment per metre height growth independently of the reference height. Model [10] is the difference form of the model 9 based on solving for all parameters β_{1k}. VI_1 and H_1 represent the predictor volume increment per metre height growth and height, respectively; VI_2 represents the predicted volume increment per metre height growth at height H_2.

$$VI_2 = VI_1 \frac{H_2^{(\beta_2-1)}}{H_1^{(\beta_2-1)}} \quad [10]$$

Levels of current increment

The evolution of curves of volume increment per metre height growth, taking into account different yield levels, resembles in some ways that of dominant height; the curves have a common origin and then spread out progressively. By analogy with the concept of general yield levels of Assmann (1955), we are using the concept of levels of current increment to characterize each curve of volume increment per metre height growth. More specifically, the current increment level is the value of volume increment per metre height growth corresponding to a dominant height of 30 m. This reference height of 30 m seems to be appropriate because it is attainable on the majority of sites, and corresponds approximately to the mid-rotation of Douglas fir.

Once the coefficient β_2 is calculated, the volume increment per metre height growth can be calculated by attributing to variables VI_1 and H_1, respectively, the values of currrent increment level (*CIL*) and the reference height of 30 m (equation [11]).

$$VI = CIL \frac{H^{(\beta_2-1)}}{30^{(\beta_2-1)}} \quad [11]$$

where *CIL* is current increment level (m^3/ha/m).

Calculation of total yield curves

Integration of the function of volume increment per metre height growth (equation [11]), for a given current increment level, gives the change in total yield between 2 heights. Because the yield in Douglas fir stem volume (top diameter: 7 cm over bark) begins only at a dominant height of 4 m, the total yield can be calculated at a given dominant height, by fixing the lower limit of the integral at 4 m (equation [12]).

$$TYLD = \int_4^x CIL \frac{H^{(\beta_2-1)}}{30^{(\beta_2-1)}} = CIL \frac{H^{\beta_2}}{\beta_2\, 30^{(\beta_2-1)}} \Big|_4^x \quad [12]$$

Validation of total yield curves

The validation of the equation [12] is based on a comparison of results with the total yield curves of Bergel (1985). The latter are supported by a large data base, independent of the data utilized in the present study, and originate from a geographic region that is comparable to that of the present study.

RESULTS AND DISCUSSION

Substantiation of yield levels

The evolution of recorded yield in experimental plots as a function of the dominant height is presented in figure 1. The plots for which the volumes from first thinnings are lacking are represented by dashed lines. Differences in yield levels are apparent from the different slopes of the curves.

The fit of observations of recorded yield from model [8] appeared at first view to be excellent ($R^2 = 0.996$, $s_e = 62.1$ m^3/ha; table II). However, the plot-by-plot examination of residuals revealed a marked pattern in prediction errors, as well as significant discrepancies as great as 250 m^3/ha (fig 2). The observed trends indicate that the volume increment per metre dominant height growth of plots 4 and 6 is on average different from that of plots 1 and 2 (fig 2). This distribution of residuals demonstrates that a model incorporating a single yield level cannot take into account the different growth rhythms observed in the experimental plots.

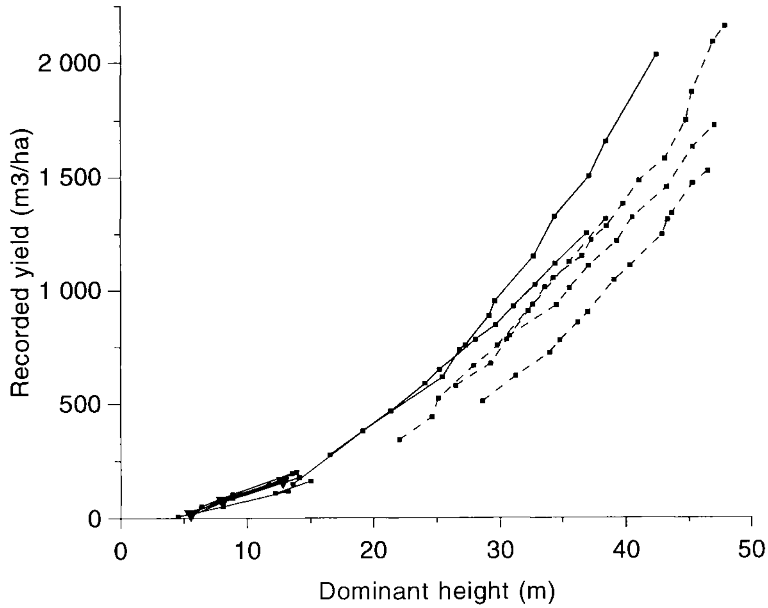

Fig 1. Recorded yield of the 14 experimental plots in relation to dominant height. Complete (solid line) and incomplete (broken line) growth series.

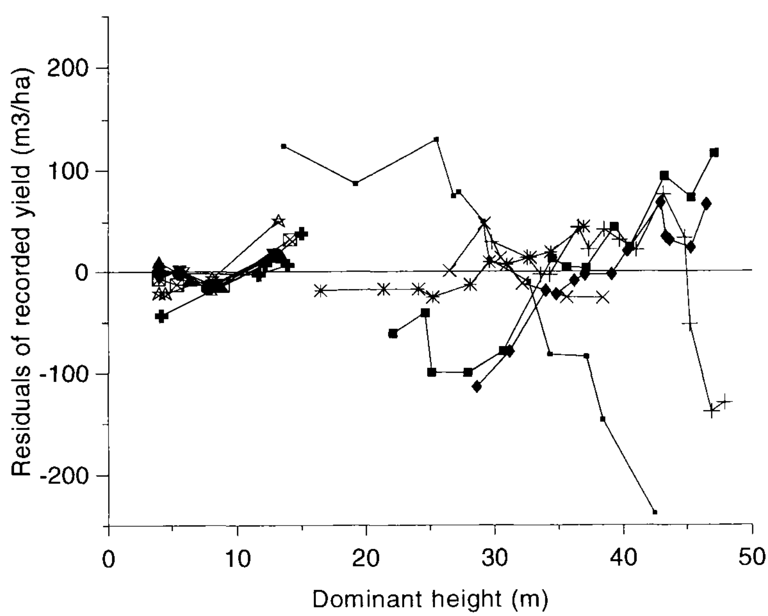

Fig 2. Residuals of the recorded yield (model 8) of the 14 experimental plots in relation to dominant height. Growth series: —■— 1; + 2; —✳— 3; —■— 4; —X— 5; —◆— 6; —▲— 7; —X— 8; —●— 9; —▼— 10; —✡— 11; —⊠— 12; —✚— 13; —✚— 14.

In an attempt to improve the predictive capacity of model [8] the variable site index was added in different forms, but did not explain a significant proportion of the observed variability. Because the intensity of thinnings is relatively light, it is reasonable to suggest that the residual variation is attributable to the existence of more than one yield level. These result tend to support the observations of Kramer (1963), Hamilton and Christie (1971), Bergel (1985) and Christie (1988) relative to yield levels of Douglas fir.

Modelling of volume increment per metre dominant height growth

Figure 3 presents the evolution of values of volume increment per metre height growth as a function of dominant height. The dispersion of curves and the differences in the slope of growth series for a given height also confirm the existence of different yield levels.

Model [9] fits well (R^2 = 94.8%; s_e = 14.7 m^3/ha/m) the values of volume increment per metre height growth calculated from the recorded yield (table III). A plot- by-plot comparison of the evolution of the residuals demonstrates no distinct pattern (fig 4). This tends to confirm that a single coefficient β_2 can be used for the 14 growth series considered.

The total yield curves are obtained by integrating the equation of volume increment per metre height growth (equation [11]) for different values of height and current increment levels. The evolution of total yield as a function of dominant height and of 4 current increment levels is illustrated in figure 5, in which the differences in yield levels can be observed.

Validation of total yield curves

The comparative evolution of total yield curves and curves of recorded yield is

Table II. Characteristics of the fit of the model 8 used to calculate the evolution of recorded yield of the 14 experimental plots.*

Plot	*Location*	*Number of observations*	b_{0k}
1	Bienne	12	45.0
2	Kuessnach	14	–141.8
3	Fribourg	10	–65.0
4	Le Mont	13	–261.3
5	Cheseau	6	–173.7
6	Rotkreuz	13	–468.3
7	Neuendorf 1	4	–15.6
8	Neuendorf 2	4	– 22.7
9	Neuendorf 3	4	– 26.1
10	Neuendorf 4	4	–32.2
11	Buron 1	4	–46.8
12	Buron 2	4	–32.6
13	Bois-désert 1	3	–71.3
14	Bois-désert 2	3	–29.3

* b_1 = 2.1351; b_2 = 1.7897; mean square of residuals = 3 859.5; R^2 = 0.996.

Table III. Characteristics of the fit of model 9 used to calculate the evolution of volume increment per metre dominant height growth of the 14 experimental plots.*

Plot	*Location*	b_{1k}
1	Bienne	2.3205
2	Kuessnach	1.8720
3	Fribourg	1.5727
4	Le Mont	1.5182
5	Cheseau	1.8379
6	Rotkreuz	1.3652
7	Neuendorf 1	1.7895
8	Neuendorf 2	1.7830
9	Neuendorf 3	1.7523
10	Neuendorf 4	1.6011
11	Buron 1	1.1995
12	Buron 2	1.5294
13	Bois-désert 1	1.1492
14	Bois-désert 2	1.6044

* b_2 = 1.8504; number observations = 73; mean square of residuals = 214.9; R^2 = 0.948.

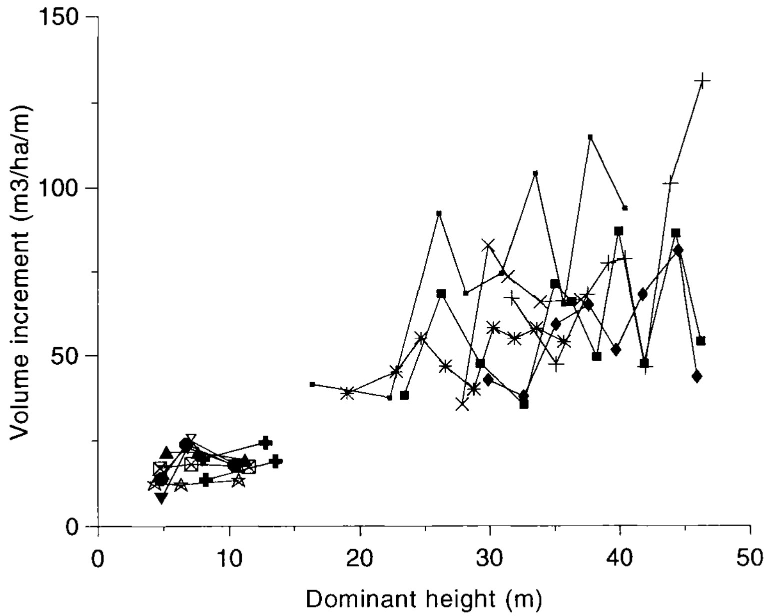

Fig 3. Volume increment per metre of dominant height growth of the 14 experimental plots in relation to dominant height. Growth series: —■— 1; + 2; —✳— 3; —■— 4; —X— 5; —◆— 6; —▲— 7; —⧗— 8; —●— 9; —▼— 10; —✡— 11; —⊠— 12; —✚— 13; —✚— 14.

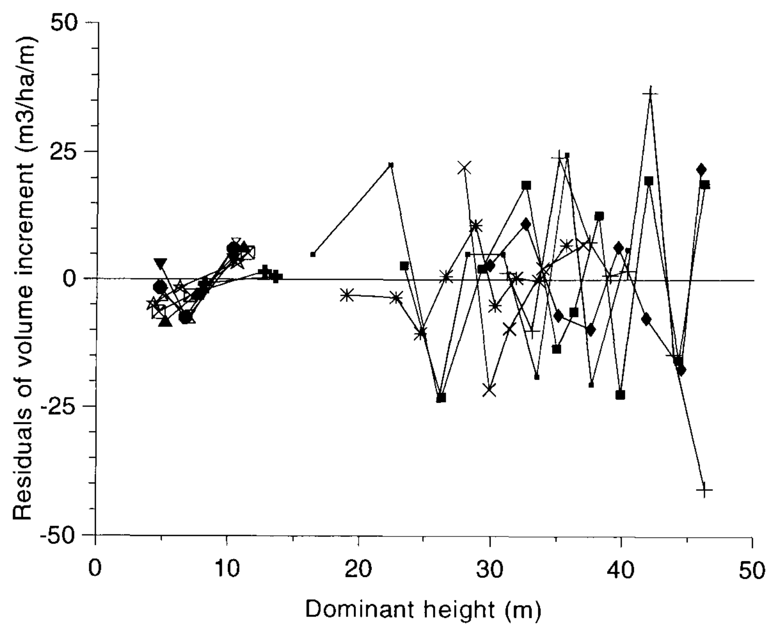

Fig 4. Residuals of the volume increment per metre of dominant height growth, of the 14 experimental plots, in relation to dominant height. Growth series: —■— 1; + 2; —✳— 3; —■— 4; —X— 5; —◆— 6; —▲— 7; —⧗— 8; —●— 9; —▼— 10; —✡— 11; —⊠— 12; —✚— 13; —✚— 14.

presented in figure 5. The growth series for which the volumes from first thinnings are lacking are represented by dashed lines and should be shifted upwards by values of 50–200 m^3/ha, corresponding to the volumes unaccounted for from thinning. Although certain growth series are incomplete, the fit already appears to be adequate. These 14 plots cover a range of current increment levels varying from 45 to 70 m^3/ha/m.

Figure 6 shows, at a given yield level, a fair agreement between the calculated total yield curves and those of Bergel (1985). For 3 of the 4 current increment levels, the calculated total yield curves conform closely to the corresponding yield levels of Bergel (1985) reported for the site indices of 35, 40 and 45 m at 100 years. This close similarity, supported by the importance of the dendrometric data base used by Bergel (1985), seems to confirm the soundness of the method applied in the present study and the validity of the curves obtained. We cannot, however, comment on the apparent difference in yield level between the Swiss curves and those of Bergel, due to the limited number of growth series at our disposal.

CONCLUSION

The objectives of the present study were to establish and validate a method based on yield levels, which permits the reconstruction and modelling of total yield from incom-

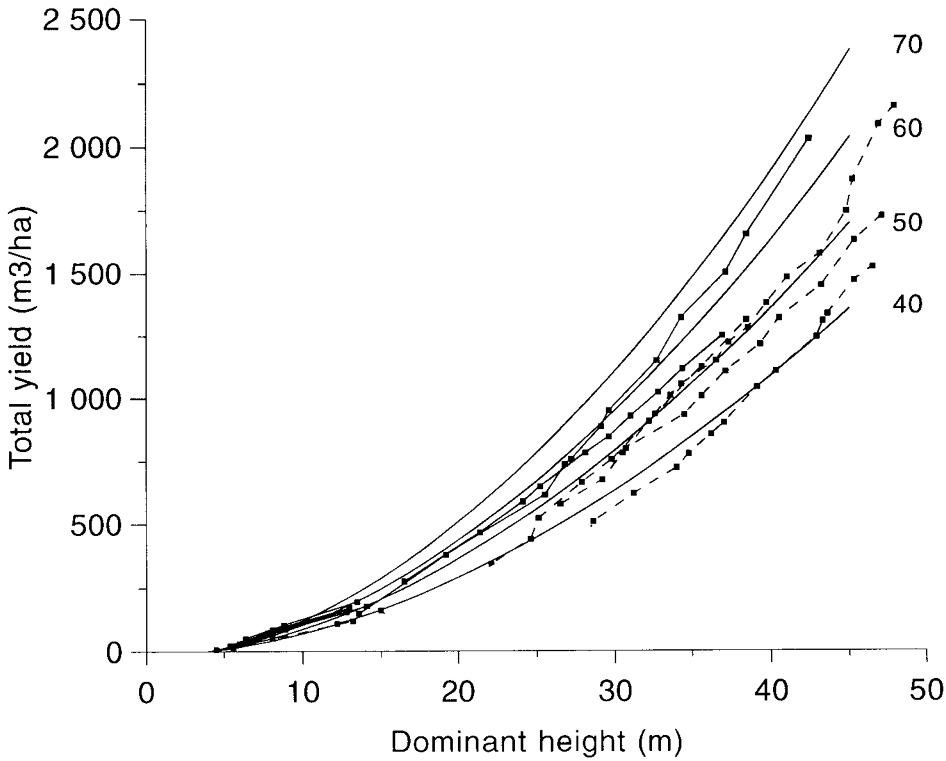

Fig 5. Comparison of calculated total yield curves (equation [12], ———) with complete (—■—) incomplete (---■---) growth series.

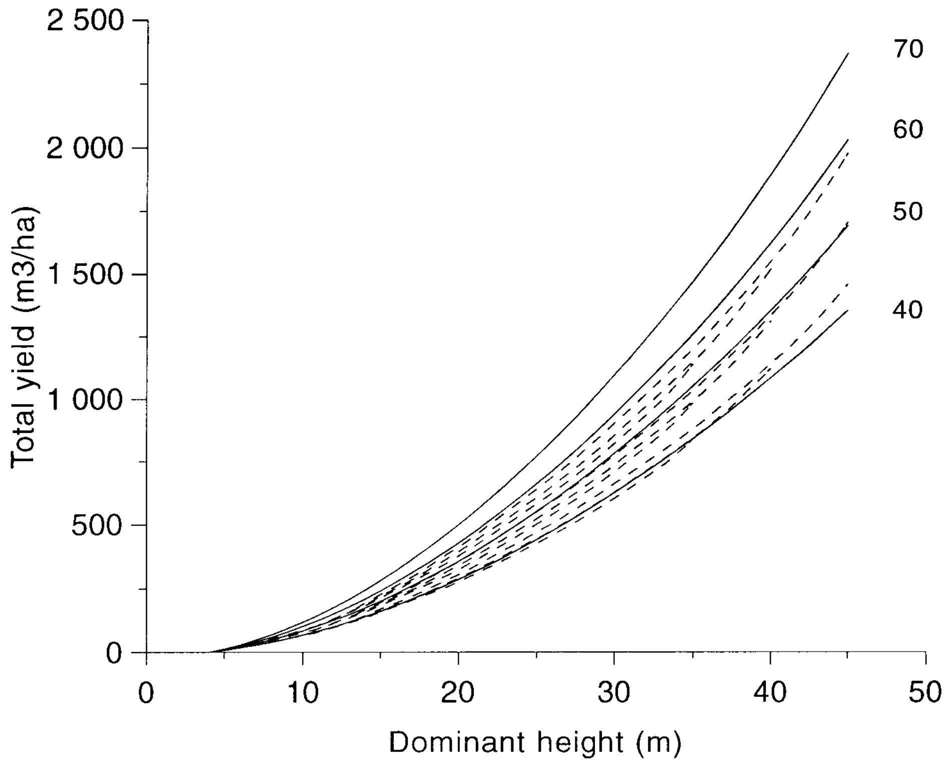

Fig 6. Comparison of calculated total yield curves (equation [12], ———) with those of Bergel (1985) (broken line).

plete growth series. The marked pattern in the residuals of the equation of recorded yield, as a function of dominant height in 14 experimental plots, supports the hypothesis of different yield levels. The study confirms the existence of different yield levels reported by several authors for Douglas fir, and underlines the necessity of taking these differences into account in the construction of yield curves. For a given yield level, the strong similarity between the calculated curves and those of Bergel (1985) seems to confirm the validity of the method utilized. The important dendrometric base of Bergel further supports this validity.

The proposed method for the calculation of total yield constitutes an alternative approach to that of Assmann and Franz (1963). It permits a reconstruction of total yields from incomplete growth series, which also takes into account different yield levels. Its principal advantage resides in a decrease in the length of time required to estimate total yield and yield levels.

This approach permits the re-examination of existing yield tables to verify the presence of different yield levels, and in such instances, to improve their precision. The proposed method also opens the opportunity to use maximum current annual increment as a dependent variable in the study of site–productivity relationships. The prediction of this variable is more interesting than the simple prediction of site index because it integrates the potential production of the site. Calculation of this variable becomes simple once the site index and the current increment level are known.

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REFERENCES

Assmann E (1954) Grundflächenhaltung und Zuwachsleistung Bayerischer Fichten- Durchforstungsreihen. *Forstwiss Centrabl* 73, 257-271

Assmann E (1955) Die Bedeutung des «erweiterten Eichhornschen Gesetzes» für die Konstruction von Fichten-Ertragstafeln. *Forstwiss Centrabl* 74, 321-330

Assmann E, Franz F (1963) Vorläufige Fichten-Ertragstafel für Bayern. Institut für Ertragskunde der Forstlichen Forschunganstallt, Munich, 112 S

Assmann E, Franz F (1965) Vorläufige Fichten-Ertragstafel für Bayern. *Forstwiss centrabl* 84, 13-43

Assmann E (1970) *The Principles of Forest Yield Study.* Pergamon Press, 506 p

Bégin J (1992) Productivité du Douglas vert (*Pseudotsuga menziesii* (Mirb) Franco var *menziesii* Franco) en relation avec des caractéristiques stationnelles. *Mitt. Eidgenöss Forsch anst Wald Schnee und Landsch* 67, 173-313

Bergel D (1985) *Douglasien-Ertragstafel für Nordwestdeutschland.* Göttigen, Niedersächsische forstliche Versuchsanstalt 72S

Christie JM (1988) Levels of production class of Douglas fir. *Scott For* 42, 21-32

Decourt N (1967) Le Douglas dans le nord-est du massif central. Tables de production provisoires. *Ann Sci For* 24, 45-84

Decourt N Lemoine B (1969) Le pin maritime dans le sud-ouest de la France. Tables de production provisoires. *Ann Sci For* 26, 3-44

Eichhorn F (1904) Beziehungen zwischen Bestandeshöhe und Bestandesmasse. *Allg Forst Jagdztg* 80, 45-49

Ellenberg H, Klötzli F (1972) Waldgesellschaften und Waldstandort der Schweiz. Mitt. Eidgenöss. Forsch anst. *Wald Schnee und Landsch* 48, 589-930

Etter H (1949) Über die Ertragsfähigkeit verschiedener Standortstypen. *Mitt Eidgenöss. Forsch anst. Wald Schnee und Landsch* 26, 91-152

Goelz JCG, Burk TE (1992) Development of a well-behaved site index equation: jack pine in north-central Ontario. *Can J For Res* 22, 776-784

Hamilton GJ, Christie JM (1971) Forest Management Tables (metric). *For Comm Bookl* 34, 201 p

Kennel R (1973) Die Bestimmung des Ertragniveaus bei der Buche. *Forstwiss Centrabl* 92, 226-234

Kramer H (1963) Der Einfluss von Grossklima und Standort auf die Entwicklung von Waldbeständen am Beispiel langfristig beobachteter Versuchsflächen von Douglasie, Fichte, Buche, und Eiche. *Schr Forst Fak Univ Gött* 31/32 140 S

Magin R (1963) Standortgerechte Ertragsermittlung als Teil des Forsteinrichtung. *Allgemeine Forstzeitschrift* 8, 128-130

Mitscherlich G (1953) Der Eichenbestand mit Buchen- und Tannenunterstand.*Schr reihe Bad Forstl Vers Anst Freiburg* 9, 3-35

Prodan M (1965) *Holzmesslehre.* Frankfurt aM, Sauerländer. 644 S

Schmidt A (1973) Ertragsniveau und standort, dargestelt am Beispiel der Kiefer. *Forstwiss Centrabl* 92, 268-274

Schütz JP, Badoux E (1979) Production de jeunes peuplements de chênes en relation avec la station. *Mitt. Eidgnenöss Forsch anst Wald Schnee und Landsch* 55, 1-177