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# Short Note: Index Selection with Restrictions in Tree Breeding

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### Summary

Index selection is discussed for circumstances where restrictions can be imposed to either (1) limit changes in certain traits to zero, or (2) limit changes to a specific amount, or (3) maximise response in traits which for some reason are not included in the index. Mention is made of a computer program which will evaluate these restricted indices. Worked examples are given to illustrate their use in tree breeding.


*Key words:* Index selection, gain restrictions, computer program.


### Zusammenfassung

Die Arbeit diskutiert die Index-Selektion, wobei folgende Einschränkungen gemacht werden können:

(1) Für bestimmte, der Selektion unterworfene Merkmale darf der genetische Gewinn (response) Null als Grenzwert nicht unterschreiten.

(2) Der Grenzwert wird auf einen bestimmten Betrag festgesetzt.

(3) Für Merkmale, die aus bestimmten Gründen nicht Bestandteil des Index sind, wird der Gewinn maximiert.

Es wird auf ein Rechenprogramm in FORTRAN IV hingewiesen, das diese eingeschränkten Indizes berechnet. Für einige Merkmale und zwei verschiedene ökonomische Gewichtungen ausgearbeitete Beispiele illustrieren die Anwendung in der Fortspflanzenzüchtung.


### Introduction

Index selection was first described by SMITH (1936), and later HAZEL (1943), as a method of simultaneously selecting for many traits and is now widely used in tree breeding. Gains in total value form index selection are never less, but usually greater than, gains from comparable methods of selection (HAZEL and LUSH, 1942; YOUNG, 1961). However, in the long run index selection can sometimes lead to deterioration in individual traits. Under these and other circumstances restrictions may be imposed on the outcome of selection (JAMES, 1968). For instance, changes in certain traits may be restricted to zero (Kempthorne type restriction: KEMPTHORNE and NORDSKOG, 1959) or to a specific amount, perhaps to an optimum value determined by the market (Tallis type restriction: TALLIS, 1962), while maximum possible gains are made in the other traits. In another type of restricted index, gains can be maximised in traits which are of value but for some reason not included in the index (Binet type restriction: BINET, 1965; JAMES, 1968).

Index selection with restrictions is known to tree geneticists (NAMKOONG, 1979) but not commonly used. This note outlines a computer program which will evaluate selection indices with and without restrictions. Examples of index selection with restrictions are given for *Pinus radiata* D. DON in South Australia.

### Computing

The junior author has written a FORTAN IV computer program which uses the algebraic methods of JAMES (1968), amended by MALLARD (1972), to evaluate both unrestricted and restricted indices in one extended computation scheme. The program is called RESI and a version which can combine up to 50 traits into one index occupies 29 k bytes of store (without overlay) on a 6 bit byte machine. A listing of RESI, a guide to its use, and test examples can be obtained from the senior author.

As input variables, RESI requires heritabilities, phenotypic variances and economic weightings for each trait to be combined in the index and genetic and phenotypic correlations between traits. Numerous sets of these parameters may be entered. Coefficients for index equations, expected responses in individual traits to selection on the index, and other variance and covariance information are determined for the unrestricted index, as well as any combination of Kempthorne, Tallis or Binet type restrictions.

An alternative method of computing restricted indices is given in CUNNINGHAM, MOEN and GJEDREM (1970).

### Worked Examples

Unrestricted and restricted indices have been constructed by combining some or all of the following traits: diameter (underbark at 1.3 m) and volume, stem straightness and branch quality (measured as five-point visual scores: 1 = worst, and 5 = best straightness or best branching), and wood density (determined from torsiometer readings using the method of NICHOLLS and ROGET, 1977). Estimates of genetic and phenotypic parameters (*Tables 1* and *2)* used to determine these indices are from COTTERILL and ZED

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*Table 1.* — Estimates of phenotypic, genetic and economic parameters for traits measured at 7 to 10 years in open-pollinated progeny tests of *Pinus radiata* in South Australia.

| Trait | Mean | Variance | Heritability | Economic weight[a] | |
|---|---|---|---|---|---|
| | | | | Set 1 | Set 2 |
| Stem volume ($dm^3$) | 80 | 826.7 | 0.28 | 3 | 3 |
| Stem diameter (cm) | 15.4 | 5.65 | 0.25 | 25 | 25 |
| Stem straightness (point)[b] | 2.8 | 0.71 | 0.21 | 20 | 20 |
| Branch quality (point)[b] | 3.0 | 0.71 | 0.21 | 20 | 20 |
| Wood density ($kg\ m^{-3}$) | 345 | 714.6 | 0.19 | 1 | 4 |

[a] Determined as the relative economic value (in monetary units) of an increase in a particular trait by one unit of measurement. *Set 1* is for sawn-timber production, *set 2* for pulp production

[b] Measured as five-point visual scores: 1 = worst; 5 = best straightness or branching

(1980) or unpublished data. All have been calculated from results of open-pollinated progeny trials of *P. radiata* in South Australia. Most trials were assesssed at 10 years after planting, but one was assessed at 7 years. Diameter and volume were adjusted for maternal and nursery effects (COTTERILL and ZED, 1980). Two sets of economic weights have been used *(Table 1)*, both of which take into account the range of the data. *Set 1* is based on a survey of managers and foresters employed in the South Australian sawn-timber industry (ZED, 1978). *Set 2* contains weightings which we consider to be appropriate for pulp production where greater importance is usually placed on density. No doubt these weightings will differ from those used elsewhere but they are sufficient for the purpose of these worked examples.

Selection for an unrestricted index combining volume, straightness, branch quality and wood density, with *set 1* economic weightings, was found to have a slightly deleterious effect on the wood density of *P. radiata* grown in South Australia. *Table 3* shows that, when the intensity of selection on this unrestricted index is one in 1000, density would be expected to decline by approximately 3 kg $m^{-3}$ (or 1% of the mean, *Table 1*) per generation. An alternative index, listed in *Table 3* for *set 1* economic weights, restricts the change in wood density to zero (Kempthorne type restriction) while yielding much the same gains in the other traits. When the relative economic importance of density is higher (*set 2* economic weights), selection on an unrestricted index combining volume, straightness, branch quality and wood density is expected to cause a positive response in density, no detectable change in straightness, but a 0.21 point (7% of the mean) per-generation decline in the branch quality of *P. radiata* in South Australia (*Table 3*). In this instance Kempthorne restrictions might be imposed on both stem straightness and branch quality *(Table 3)*.

Binet type restrictions could be used when, say, diameter is measured rather than volume, perhaps because of limited labour resources, but maximum possible gains are still required in volume. *Table 3* lists indices which combine stem diameter, straightness, branch quality and wood density with Binet restrictions on volume and Kempthorne restrictions on wood density or form traits (depending on economic weights). With *set 1* economic weights there is a slight deterioration in branch qualitiy, which could be checked by further restrictions, but in all cases the indirect gains in volume are high *(Table 3)*. Binet restictions

*Table 2.* — Estimates of genetic (upper diagonal) and phenotypic (lower diagonal) correlations for traits measured at 7 to 10 years in open-pollinated progeny tests of *Pinus radiata* in South Australia.

| Trait | Volume | Diameter | Stem straightness | Branch quality | Wood density |
|---|---|---|---|---|---|
| Volume | | 0.99 | 0.43 | −0.23 | 0.02 |
| Diameter | 0.97 | | 0.48 | −0.28 | 0.01 |
| Stem straightness | 0.21 | 0.19 | | 0.11 | −0.42 |
| Branch quality | −0.48 | −0.49 | −0.01 | | −0.38 |
| Wood density | 0.04 | 0.01 | 0.04 | 0.06 | |

*Table 3.* — Expected responses in individual traits following selection for restricted and unrestricted selection indices, using different sets of economic weights.

| Type of selection index | Expected response in traits after selection for index at an intensity of 1 in 1000 | | | | Index equations[a] |
|---|---|---|---|---|---|
| | Stem volume (dm³) | Stem straightness (point) | Branch quality (point) | Wood density (kg m−³) | |
| Using set 1 economic weights determined for sawn-timber production | | | | | |
| Unrestricted — | 28.6[b] | 0.44 | 0.08 | -3.14 | $I = 1.03 X_1 + 5.42 X_2 + 13.3 X_3 + 0.03 X_4$ |
| Kempthorne restriction on density — | 28.1 | 0.36 | 0.01 | zero | $I = 1.00 X_1 + 3.60 X_2 + 11.1 X_3 + 0.16 X_4$ |
| Binet restriction on volume, Kempthorne on density — | 26.5 | 0.40 | -0.05 | zero | $I = 18.0 X_5 + 7.70 X_2 + 13.8 X_3 + 0.26 X_4$ |
| Using set 2 economic weights determined for pulp production | | | | | |
| Unrestricted — | 22.4 | 0.09 | -0.21 | 9.70 | $I = 0.92 X_1 - 2.70 X_2 + 3.23 X_3 + 0.63 X_4$ |
| Kempthorne restrictions on straightness and branching — | 19.9 | zero | zero | 8.71 | $I = 0.91 X_1 - 9.90 X_2 + 15.9 X_3 + 0.57 X_4$ |
| Binet restriction on volume, Kempthorne on straightness and branching — | 18.4 | zero | zero | 8.03 | $I = 14.7 X_5 - 15.5 X_2 + 22.1 X_3 + 0.68 X_4$ |

[a] $X_1$ represents the phenotypic value for volume; $X_2$, straightness; $X_3$, branch quality; $X_4$, wood density; $X_5$, stem diameter
[b] Figures are in actual units of measurement per generation

might also be useful in early selection on juvenile traits where the aim is to improve mature traits (say volume, form or wood at final harvest) which, in the interests of reducing generation intervals, are not measured.

In conclusion there seems to be considerable scope in tree breeding for the use of index selection with restrictions. Of course the previous applications of restrictions are for a specific species and environment, but computer programs such as RESI can make it relatively easy to evaluate restricted and unrestricted indices and their respective advantages under differing sets of circumstances.

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