COMPETITION QUOTIENT IN YOUNG *PINUS RADIATA*

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For the construction of yield models on an individual tree basis a measure of the competitive stress experienced by an individual tree is required. Many such measures have been suggested. Brown's (1965) Area Potentially Available (APA) is an example. It is in effect the inverse of the stocking at the point occupied by the subject tree. The method is objective, as no decision needs to be made on the competitive effect of neighbours. But the APA does not account for differences in tree size, and so fails to account for difference in competitive ability of neighbours.

A different family of competition indices has been developed since the advent of electronic data processing, based on Staebler's (1951) premise. Staebler's index was based on the assumption that the growing space occupied by an individual tree is a circular area whose radius is related to the tree's diameter at breast height (d.b.h.) by a (usually) linear function. Staebler hypothesised that the area of overlap of the competition circles so constructed for adjacent trees would supply a direct measure of competition (see Fig. 1). As the mathematical formulae which measure the overlap

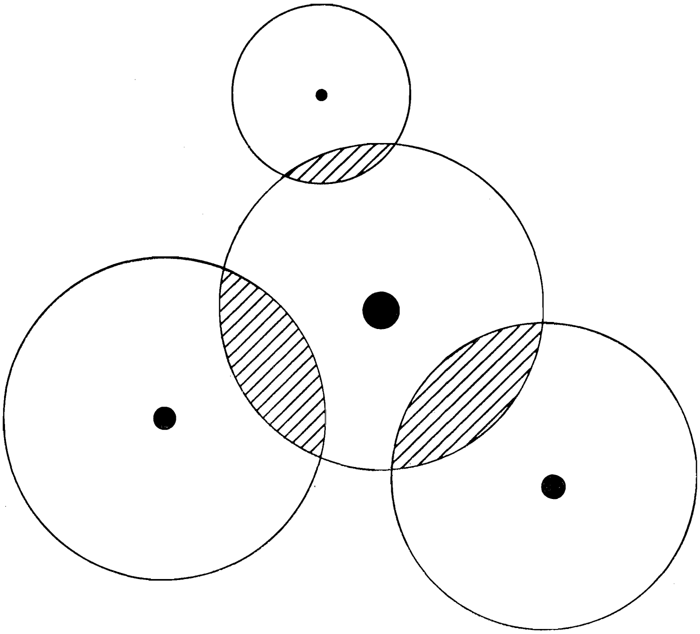

FIG. 1—The overlapping of competition circles of adjacent trees.

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area are relatively complex for manual calculation Staebler adopted the linear overlap (i.e. the radial width of the overlap region) as his index.

Intrinsic to all such indices is the function used to define the competition circles. Various attempts to model physical conditions have been made. The competition circle radius has been related to rooting area radius, and, most commonly, the radius of open-grown crowns. Bella (1969) and others have used functions which relate the crown radius of open-grown trees to d.b.h., e.g.

$$CR = 1.815 + .805\,D$$

where CR = crown radius (ft)
D = d.b.h. (in.)

The competition circle is then defined by the open-grown crown radius the subject tree would have had, had it been open-grown. However, such methods overlook the fact that a stand-grown tree with a similar d.b.h. to an open-grown tree may have already had its d.b.h. growth restricted through competition, and as such its hypothetical "open-grown crown radius" bears little relationship to its competition zone.

Gerrard (1969) developed a similar index which is related to the subject tree's size. His revision of Staebler's premise was:

> "The competitive stress sustained by a tree is directly proportional to the area of overlap of its competition circle with those of its neighbours and inversely proportional to the area of its own competition circle."

This in effect assumes that the larger the tree the more intense the competition it should be able to endure. His index, termed *competition quotient,* is defined by:

$$\text{Competition Quotient} = \frac{1}{A}\sum_{k=1}^{n} a_k$$

where n = number of competitors
a_k = area of overlap of the kth competitor
A = competition circle area of the subject tree

Gerrard's index differs little from the general family of indices, except for the use of the actual overlap area.* However, his study was of interest because of the manner in which he defined his competition circle. He reasoned that the constant (termed *competition radius factor*) which when multiplied by a tree's d.b.h. gave the most significant measure of competition should be used for any future analysis. He examined a range of competition radius factors to discover the optimum competition radius factor for a variety of species in a mixed-age, mixed species stand on a varying site. He concluded: ". . . further investigations . . . should be directed at pure stands, preferably plantations, wherein the factors controlling the performance of individual trees are far less numerous and more susceptible to measurement".

Examination of the effectiveness of competition quotient was conducted using data collected from a Nelder design spacing trial, analysed elsewhere (Tennent, 1973). The trial was used as it was considered to suit the recommendations made by Gerrard. It is a pure *Pinus radiata* planted trial, occupying 1 ha on a uniform site. The planting

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* J. E. Opie (1968) has independently developed a similar index, differing mainly in definition.

spacings vary uniformly from 1 × 1 m to 4 × 4 m. D.b.h. vary from 3 to 18 cm, and data were available for two increment periods, age 4 to 5 years, and age 5 to 7. The top height at age 7 was 10 m.

The investigation followed Gerrard's closely. A second order model was constructed and the analysis run at different competition radius factors. The model used is given below:

$$DI = b_0 + b_1D + b_2D^2 + b_3C + b_4C^2 + b_5\,C \times D \qquad (1)$$

where DI = mean annual d.b.h. increment (cm)
D = d.b.h. at start of growth period (cm)
C = competition quotient
b_i = regression coefficient.

The model is not claimed to be anything other than a first approximation of the relationship between diameter increment, diameter and competition quotient. All terms were included regardless of their significance. The analysis consisted of varying the competition radius factor in the assessment of competition quotient over a range of .15 to .31 for the age 4 to 5 increment period, and from .1 to .35 for the age 5 to 7 increment period. The analysis was also conducted on an abbreviated model,

$$DI = b_0 + b_1D + b_2D^2 \qquad (2)$$

to examine the effectiveness of competition quotient.

Figs. 2 and 3 show the effect of varying the competition radius factor on the coefficient of multiple determination, R^2, of the full model for the growth periods age 4 to 5 and age 5 to 7 respectively.

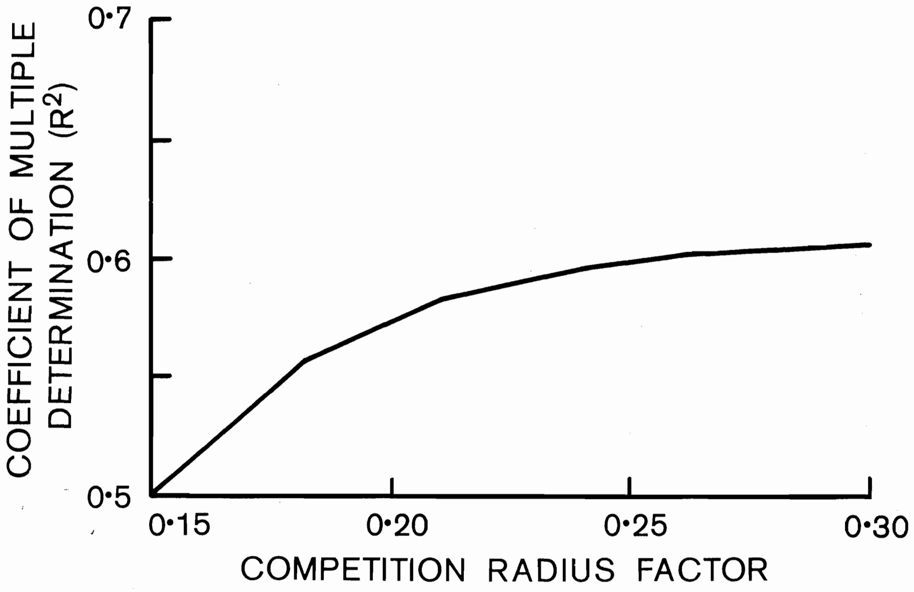

FIG. 2—The effect of varying competition radius factors on the significance of competition quotient for the growth period age 4 to 5 years.

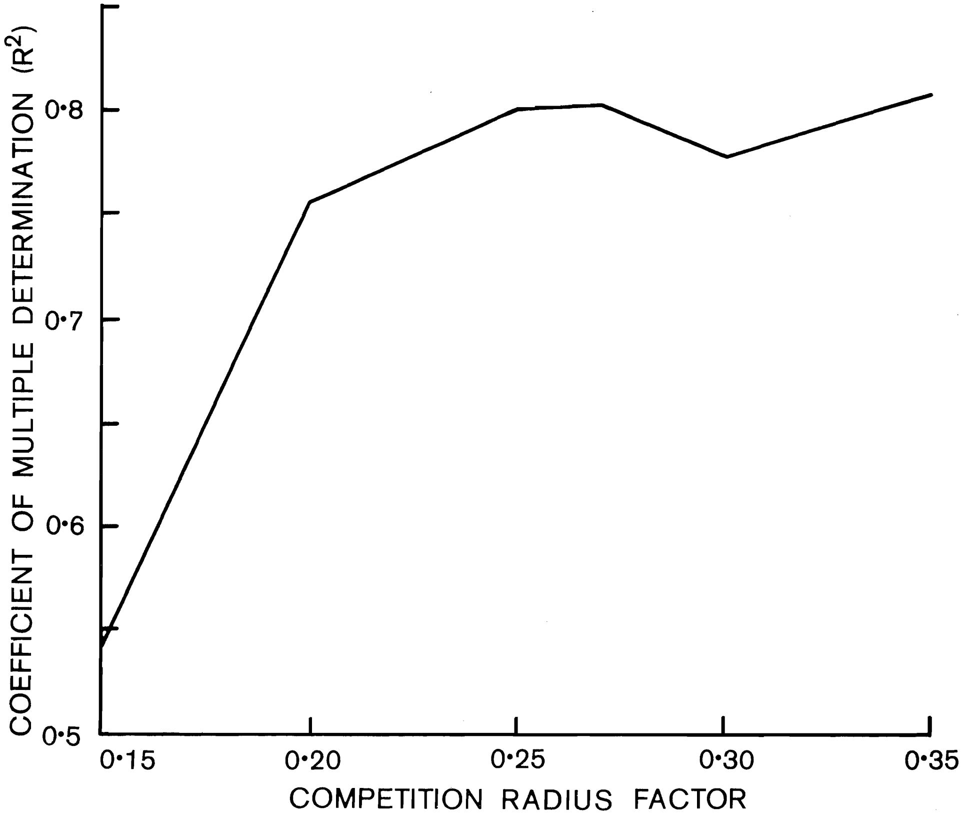

FIG. 3—The effect of varying competition radius factors on the significance of competition quotient for the growth period age 5 to 7 years.

Table 1 shows the standard error and R^2 values for equation 2, the abbreviated model, and equation 1, the full model, with a competition radius factor of .21 for both increment periods.

The asymptotic maximum reached in both increment periods can be explained as follows. Intuitively the most suitable competition radius factor would be that which results in no overlapping of competition circles for trees which are not under competi-

TABLE 1—The improvement in regression significance from the addition of competition quotient

Age at start of growth period	Equation 2		Equation 1		N
	Standard error	R^2	Standard error	R^2	
4	1.010	0.055	0.671	0.584	1102
5	0.958	0.275	0.497	0.805	1096

tive stress. However, the effect of increasing the competition radius factor over this level is to increase the magnitude of the competition quotient in all cases. As the regression analysis relies on the relative magnitude of the competition quotient term, and not the absolute magnitude, the effect on the R^2 value becomes minimal. The process can be likened to the scaling of a variable in an analysis, which changes the value of the regression coefficients, but not the significance of the actual regression.

This has an important consequence for future work. As the analysis at this stage involves only two increment periods in young stands the findings are tentative, as a time-dependent series of optimal competition radius factors is likely. However, the apparent asymptotic nature of the R^2 analysis indicates that such a series would not present a problem. The question is only to define the largest competition radius factor required over the life of the tree species. This competition radius factor could then be used for all ages of the species, as the asymptotic nature of the analysis ensures that a significant competition relationship can be found.

In both increment periods studied the asymptotic maximum is reached at a competition radius factor slightly above .2. Indications are that a competition radius factor of .21 would be suitable for any further analysis. This would ensure that competition is accounted for, and also prevent the boundary of the analysis of the competition of any individual tree becoming too wide.

The effectiveness of competition quotient in accounting for differences in diameter increment can be judged from the dramatic increase in the value of R^2 and drop in the standard error of the model (shown in Table 1) with the addition of the last three terms in Equation 1. For the second growth period 80% of the variation in diameter increment can be explained by initial d.b.h. and competition quotient. A more vigorous model could no doubt account for more.

CONCLUSION

Examination has shown that competition quotient is a useful concept for analysis of the competition experienced by individual trees. The effectiveness of the index is dependent on the competition radius factor used to define the competition circles of each tree. At present no firm statement of a suitable competition radius factor for *Pinus radiata* can be made, but indications are that a competition radius factor of .21 may be acceptable for stands which have experienced the onset of competition. Repetition of the analysis at a later stage will provide additional information.

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