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DESCRIPTION AND ASSESSMENT OF STEM FORM IN RADIATA PINE

BY

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DESCRIPTION AND ASSESSMENT OF STEM FORM IN
PINUS RADIATA

by

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INTRODUCTION

The most highly desirable form for a *Pinus radiata* D. Don tree is a vigorous, straight, single stem with slight branches that leave minimal knot formation following pruning. Undesirable growth characteristics, here referred to as defects result in poor form, lower the quality of stemwood and potentially reduce the overall merchantability of a stand. Poor form includes multiple leaders, dead leaders, sweep, lean, wobbles or ‘sinuosity’, and excessive branching. Young trees on ex-pasture sites are frequently bushy and exhibit tip die-back associated with boron deficiency is relatively common (Fig. 1).

Plantations established on purchased ex-pasture country and old farmlands in south eastern N.S.W. have developed widespread form problems not previously observed in *P. radiata* planted on non-pasture sites, most of which carried native forests prior to conversion to pine. In recent harvesting operations in the Albury Region, rough stands have been clearcut at 15 and 25 years of age due to the lack of suitable stems. As a result there have been considerable reductions in royalty on pulpwood and significant future losses in sawlog prediction. Current yield predictions and product scheduling based on historical expectations of defect levels in radiata plantations appear to be inappropriate for previous pasture sites and there are few quantitave assessments of stem and branch defects in radiata plantations and their frequency either on or off previous pasture sites, and little information is available on the relationship between form in young stands and future marketability.

The extent to which poor form is a problem depends on the type of defects, their frequency and severity, the area of plantation affected and the management objectives for that area. Early detection of form problems is desirable because suitable management practices could be adopted to minimize defects and maximize potential yield in problem stands.

This paper provides basic information on tree form characteristics observed in New South Wales radiata pine plantations, and a method for quantifying and comparing stem and branch defects in different stands. Descriptions of stem and branch defects are accompanied by photographs taken in both young (< 6 years) and mature (post-crown closure) stands. The photographs serve to standardise each type of defect, and in particular to standardize the extreme forms of characteristics which are continuous (e.g. sweep) rather than discrete (e.g. forks). All assessments are limited by some degree of subjectivity in the scoring of the severity of a defect, but the provision of reference sets of photographs reduces variability between assessors and maximizes comparability across broad areas in both time and space. This contrasts with the approach used in tree breeding trials in which the extreme forms of each characteristics are redefined for every trial. Standardized characteristics are essential for comparisons to be meaningful.

Assessing form is time consuming if carried out in detail, and this reinforces the need to clearly define the objectives of form assessment in advance. In the context of wood utilization, the limited information available on recovery of timber in relation to defects means that it is not feasible at present to clearly define the relative importance of individual defects for different end products. In some instances it appears that individual trees or whole stands may be non-commercial due to excessive branching alone, even though other defects in stem quality might also limit utilization.

The form assessment procedure outlined in this paper was designed with particular reference to the acquisition of baseline information on deformation in radiata pine stands.
Description and Assessment of Stem Form in Radiata Pine

across a range of sites. The procedure described below has several important features.

1. It is **comprehensive**. That is, it includes all possible characteristics of form regardless of whether or not they reduce the commercial value of an individual tree or stand. Since an important aim in form assessments is to record as completely as possible those features which reduce the overall quality of a tree, there is a high level of detail in the procedure.

2. It is **quantitative**. The frequency, severity and size (where appropriate) of individual defects are determined.

3. It is **portable** and the results are comparable across a wide range of stands.

4. The defect **data can be integrated** into a "deformity" index which provides an overall score or single index of the form of a stand. A deformity index is useful in comparative situations both within and among stands.

5. The **assessment can be modified** to suit different management aims by increasing or decreasing the level of detail or the types of defects recorded.

**DESCRIPTION OF TREE FORM**

The following descriptions of tree form characteristics emphasise deviations in form from straight, single leader trees. For descriptive purposes form characteristics are grouped into three major categories:

1. Leader characteristics or defects.
2. Stem characteristics or defects.
3. Branch characteristics or defects.

Most defects are the result of growth malformations, that is, defects which arise during stem and branch development in response to site and/or genetic controls. Other defects arise from damage incurred though extreme climatic conditions such as snow, hail and wind, chemical sprays e.g. herbicides, disease (Fig. 2) and mechanical injury resulting from grazing animals and harvesting equipment. While the distinction between malformation and damage is frequently obvious, as in broken tops and dead tipping, this will not always be the case, particularly if the problems develop in the first few years of growth. In some cases the same symptoms develop from various types of malformations or damage. For example, curvature of the leader occurs when the cambium is partially damaged through hail damage or grazing animals and the stem bends toward the damaged side. Sinuous growth forms also result from herbicides, and copper deficiency, and they are common in trees on some ex-pasture sites. To assess form it is not essential to know the factors causing the problems, although this knowledge will aid in the interpretation of results.
1. **Leader Defects**

The leader is the terminal section (approximately 2 m) of the dominant stem in a tree (Fig. 3). Defects associated with the leader arise from death, damage or suppression of the terminal or apical bud. Dead or broken tops in the absence of new leaders are indicative of recent changes in the leader, whereas replaced leaders and basket whorls are more advanced stages of leader defect. These latter forms of leader defects are not limited to the top 2m because they may have developed some time prior to the assessment.

Death of the apical tissues, often called tip or top dieback, can result from frost, drought, nutrient deficiencies (e.g. boron) and fungal infections (e.g. *Diplodia pinea* (Desm.)). Broken tops are often caused by animals, particularly birds and insects, as well as wind stress, hail and snow storms. In most cases dominance is usually re-established by one or more competing laterals. A leader may be suppressed by vigorous laterals which extend during late season flushing in autumn whilst the terminal but remains dormant. Double or multiple leaders can develop if the main stem does not regain dominance the following spring. Where a single lateral gains dominance, the leader defect is described as a displaced or replaced leader (Fig. 4a, 4b). Multiple laterals competing for dominance after tip death or damage are referred to as a 'basket whorl' (Fig. 5a, 5b). A kink or crook usually develops along the stem wherever dominance is re-established by one or more lateral branches.

Forks represent another form of leader defect (Fig. 6), but they generally develop during formation of the terminal bud. That is, two buds are formed rather than one. If two lateral branches achieve equal dominance following death or damage to a leader the defect could also be described as a fork.

In contrast to damaged leaders, "foxtails" are leaders which become unusually elongated, extending to a length which is equivalent to about 2 years' growth in one season without the normal initiation and development of lateral branches (Fig. 7).

2. **Stem Defects**

Stem defects are associated with stem straightness and therefore include all characteristics which deflect the stem from a vertical position. They include lean, sweep, kinks, and sinuosity.

Lean describes the deviation of a major portion of a stem away from the vertical position (Fig. 8). Some stems become arched as they lean away from the vertical as though they are unable to stay straight, whereas other forms of lean include more or less straight trees that probably were planted at an angle and never became vertical.

Butt sweep is limited to the first metre or so at the base of the stem and may reflect stem position at planting. Mild cases have no significant affect on straightness and utilization of the butt log (Fig. 9a, 9b). In moderate cases (Fig. 10a, 10b) the sweep may end with a kink, whereas in severe cases, multiple sweeps and bends may develop before the stem becomes vertical (Fig. 11a, 11b).

Sinuosity is a complex defect ranging from single, minor deflections or curves in the stem to multiple, sweeping curves, bends and twists in successive stem internodes and branches (Fig. 12, 13, 14). The severity of this type of defect is determined by the frequency of bending and twisting in internodes and the magnitude of the displacement from vertical.
In its least severe form sinuosity occurs as single, slight displacements or bends in the internodes of a distance less than the stem diameter. Close examination of sinuous trees, particularly mature ones, shows that some single and multiple bends are restricted to a single plane, whereas others are obviously twisted and spiral through several planes. Distinguishing among the various sinuous formations is often difficult because they are expressions of ever increasing degrees of severity rather than discreet changes in form. Bends and twists particularly the minor displacements, become visually obscured with time because the displacement from vertical decreases as the stem cross-section increases, but compression wood formed in the curves probably reduces wood quality in the long term.

Kinks are abrupt alterations in stem straightness and usually occur at branch nodes, particularly where a change in the leader has occurred (Fig. 15a, 15b, 16). Superficially it may appear that the stem has deflected away from a cluster of branches. Kinks that develop in the internodes are usually associated with some kind of sweep and are distinct from the sinuous bends and curves, described above.

3. Branch Defects

Branches are an important aspect of tree form because they affect stem utilization. Large branches (Fig. 17) are difficult to prune, and to delimb during harvesting. Knots that form at the base of large branches and ramicorns are defects that have to be serviced out of a log. Branching problems are more severe in open poorly stocked stands, and particularly in very fertile sites.

A ramicorn branch is a limb which is substantially larger than other branches in a whorl and which extends at an angle of 30° from the main stem (Fig. 18). Ramicorns may compete with the leader (Fig. 19) but unless the leader is broken or dies, a ramicorn is unlikely to become a leader.

Like sinuosity, branching is not a discrete, easily definable characteristic, but increases along a continuum from fine, widely spaced, relatively flat branches to numerous, closely spaced, thick branches, with short internodes, and steep angles to the stem. Swelling at the nodes often occurs in trees with excessive numbers of large branches and large knots result from persistent, large, steeply angled branches. The term 'branch-form' collectively describes the combined features of branch number, size and angle. Although 'branch-form' is a subjective assessment of branch form, the extreme sites will be evident from the proportion of trees with either fine or excessive branches (see later discussion).

Double whorls and steeply angled branches (Fig. 20, 21) result from late season flushing of the terminal bud and/or the lateral buds directly below the terminal bud (lammas branching and prolepsis). Multiple whorls can be produced in the one growing season separated by short internodes (see Fig. 6 also). These branching characteristics are indirectly accounted for in the branch-form assessment.
TRE FORM ASSESSMENT

A tree form assessment is carried out according to the following procedure. Each characteristic or defect is recorded separately for each tree in an assessment area, and when appropriate, scored to indicate the level of severity. The assessment record sheet has been prepared as a LOTUS 1-2-3- spread sheet and each line represents a record for an individual tree or sub-section of the stem (see example Appendix 1). For example, the butt log may be assessed separately from the remainder of the stem. This level of detail is probably not warranted unless the stand is at or approaching thinning age. If more detail is required the stem can be assessed in lengths equivalent to timber company log specifications, for example, 5 metres.

1. Growth

Plot growth data are an integral part of any assessment. Site factors have a significant effect on survival and productivity in addition to stem and branch defects, and all parameters influence future products and yields.

1. The height of all trees is measured in stands less than 2m tall. Otherwise determine mean dominant height.
2. The diameter at breast height (over bark) is recorded for all trees in stands 2m in height.
3. Stand density (stems per ha) is calculated by dividing the total number of stems by plot area.

2. Defects

(a) Leader damage and malformation. Although the leader is technically the top 2 metres of the main stem, a form assessment restricted to this section of the stem does not provide a realistic indication of form problems that have arisen from earlier leader defects, particularly repeated instances of leader defects. To address ‘historical’ leader defects, the type of leader defect which has had the most significant impact on the potential utilization of the tree is recorded. For example, a recently dead terminal bud on an otherwise normal stem could be significant, but a basket whorl at 6 m height on a 15 m tree would have more impact on utilization than a dead tip or subsequent displacement in one or more of the new leaders.

(i) Leader condition (as noted above) is recorded as:

0 = Undamaged (Fig. 3)
1 = Dead apical bud(s) as in "dead tipping" (Fig. 1)
2 = Broken leader (recent damage)
3 = Displaced/replaced leader (Fig. 4a, 4b)
4 = Multiple leaders as in a "basket whorl" (Fig. 5a, 5b)

(ii) The total number of leaders (including those that have subsequently died) is recorded.
(b) The total number of forks (Fig. 6) is recorded. For trees with forks < 1.3 m height from the ground, the form of both stems is measured and assessed individually as in normal plot measurements.

(c) The presence or absence of a foxtail in either the current year's extension or in previous periods of leader extension (Fig. 7) is recorded as:

0 = Absent
1 = Present

(d) The presence or absence of lean or arching of the stem (Fig. 8) is recorded as:

0 = Absent
1 = Present

(e) Butt sweep (approximately lowest metre of the stem) is scored according to the degree of deflection away from vertical.

1 = Tree vertical or with minimal deflection causing no commercial loss (Fig. 9a, 9b).
2 = Up to 30° deflection from vertical causing commercial loss. A line extended to the ground from the inside curve where the stem straightens will fall outside the stem at ground level (Fig. 10a, 10b).
3 = More than 30° from vertical resulting in total loss of butt. This class includes trees with double or triple sweep in the butt (Fig. 11a, 11b).
   - Other defects in the butt section are scored separately.

(f) The total number of kinks is recorded (Fig. 15a, 15b, 16). Do not count kinks associated with other defects, for example, a kink at the base of a ramicorn, or a kink where the stem straightens from butt sweep.

(g) Sinuosity includes both bending and twisting and is scored according to the degree of severity. Although it is frequently possible to visually distinguish between bends and twists, it is not necessary to record this detail.

Sinuosity is scored in the following classes:

1 = Slight deflection (bend or twist) of the stem away from and return to vertical (Fig. 12, 22). The number of minor deflections is recorded.
2 = Major bend or twist displaced from vertical by an amount equal to or greater than the diameter. Bends in this category are often U shaped and twists spiral through a 90° angle (Fig. 13, 23a, 23b, 24a, 24b). A stem would have to be cross-cut to remove these defects. They are unlikely to become obscured with increasing stem diameter. The number of major deflections is recorded.
3 = Multiple continuous curves or spirals in the stem resulting in a complete loss of all or a major section of the leader(s) (Fig. 14, 25a, 25b, 25c). The presence or absence of continuous sinuosity is recorded as:
   O = absent
   1 = present

(h) The total number of ramicorns and the number which are > 5 cm diameter are recorded. Small ramicorns generally do not affect utilization (Fig. 18), but stems with large ramicorn branches (usually more than 5 to 10 cm diameter) have to be cross-cut to remove the knot.

(i) Branch measurements are limited to the size and number of branches in the two whorls nearest 1.3 m height from the ground. Branch numbers and diameters in young stands are important indicators of future form. In older stands it may be sufficient to assess trees for 'branch-form' only (see (j) below).
The number of branches in the two whorls nearest to 1.3 m height from the ground is recorded. The diameter (3 cm distant from the stem, using calipers) of the two largest branches in each of these two whorls, is recorded.

(j) **Branch-form** is rated on a scale from 1 to 3. This score integrates branch density, size and angle to the stem as these characteristics appear to be closely related.

Branch-form is scored as:

1 = Small, fine branches, horizontal or > 60° from vertical, with widely spaced whorls (Fig. 26a, 26b).

2 = Branch angles < 60° from vertical, with a wider range in diameter and variable internode lengths (Fig. 27a, 27b).

3 = Numerous, large branches, short internodes (possibly double whorls), and branching angles often much < 60° (Fig. 28a, 28b).

(k) Written comments on individual trees and on the stand as whole are extremely useful in subsequent interpretation of the data. Photographs can also be useful.

**DATA ANALYSIS AND INTERPRETATION**

Several levels of detail can be obtained from the deformity assessment, as indicated below. Data obtained from a number of stands of *P. radiata* ranging from 4- to 20-years-old are summarised to demonstrate the following approaches to data analysis.

1. **Basic Summary**

The following parameters are to be determined:

1. The proportion of trees affected by each type of defect.
2. The number of trees with each defect per hectare.
3. The frequency of each category of scored characteristics (butt sweep, branch-form and sinuosity) For example, the number or percentage of trees with butt sweep 1, 2 and 3 respectively.
4. The number of non-deformed or "perfect" trees per hectare.

The definition of "non-deformed" trees is arbitrary because minimal defects may be acceptable for some products, and not others. For example, trees with a butt sweep of class 1, and branch-form class 2 may be suitably classed as potential saw log trees and therefore for all practical purposes "perfect". Obviously, this type of working definition must be determined in the context of the assessment objectives and product specifications, but as noted above the defect limits for most products are not well defined. Two examples of non-deformed trees (groups 'A' and 'B') are included in this report. The trees in group 'A' are non-deformed to the extent that they have sweep class 1 and branch-form class 1 or 2, and ramicorns less than 10 cm diameter. Trees in group 'B' have the characteristics of group 'A' and up to 2 kinks in the stem.
2. **Deformity Indices**

While comparisons of the relative frequencies of individual defects are informative, a deformity index integrates the different defects and their levels of severity into a single score. Based on a system of allocating points for defects, low scores indicate high quality trees and high scores indicate severely deformed trees. The data from the above assessment can be summarised into two deformity indices as follows:

(a) **The General Deformity Index (G.D.I.)** is suitable for stands of all ages and includes all defects scored on the assessment sheet. Every defect (e.g. every fork) is counted separately, with more points being allocated for increasing degrees of severity (e.g. branch-form 3 versus branch-form 1). Some defects such as excessive branching and sinuosity appear to have an overriding impact on the commercial value of a tree, but the approach adopted in this general index does not include an assessment of the relative impacts of defects on utilization.

Points are allocated for each defect as indicated below to determine the G.D.I.:

1 point for:

(i) Butt sweep class 1  
(ii) Lean class 1  
(iii) Leader damage or malformation (classes 1 - 4)  
(iv) Foxtail class 1  
(v) Branch-form class 1  
(vi) Each fork  
(vii) Each leader  
(viii) Each minor bend-twist (sinuosity class 1)  
(ix) Each major bend-twist (sinuosity class 2)  
(x) Each kink  
(xi) Each ramicorn

2 points for:

(i) Butt sweep class 2  
(ii) Branch-form class 2

3 points for:

(i) Branch-form class 3  
(ii) Repeated bends and twists (sinuosity class 3)

The G.D.I. equals the mean score per tree.

(b) **The Non-Utilization Index** is limited to those defects known to severely limit the commercial value of a tree and include heavy branching (class 3), continuous sinuosity (class 3), severe sweep (class 3) and lean.

Points are allocated for the occurrence of these defects as follows:

1 point for each of the following:

(i) Branch-form class 3  
(ii) Lean class 1  
(iii) Sinuosity class 3  
(iv) Sweep class 3

The non-U.I. is the mean score per tree expressed as a proportion or a percentage (i.e. total number of points/total number of trees).
The non-U.I. is also expressed in terms of the approximate number of trees per hectare affected by severe form problems by dividing the total number of points per tree summed for all trees per plot by the plot area. In stands with severe form problems this value will be higher than the actual number of trees per hectare affected, but the higher numbers will be indicative of the potential problem to be experienced in harvesting these stands.

EXAMPLES OF DEFORMITY ASSESSMENTS

Summaries of assessment data (Table 1, 2) have been abstracted from assessments carried out in Buccleuch S.F. (1982, 1984, and 1979 age classes) and in Sunny Corner S.F. (1968 age class). Complete deformity results from all plots assessed at these sites will be published elsewhere. Their purpose in this paper is to demonstrate the variability in form and defects that can be encountered in *P. radiata* stands and some likely values for deformation indices. There are some inconsistencies between the example data sheet (see Appendix) and the assessment procedure described in this paper because the procedure has been modified since these data were collected, however, the changes are relatively minor.

1. **Growth**

General growth parameters (Table 1) provide baseline information for the plots assessed. Broad differences between and within age classes are evident, particularly in the 20-year-old stands (1968 A.C.) Stocking is an important parameter in interpreting form and the prevalence of form problems in a particular area.

Branch diameter and mean number of branches per whorl (at 1.3 m height) showed general trends towards more numerous and larger branches on trees in ex-pasture sites. These data are optional and could be replaced by the ‘branch-form’ assessment.

2. **Defects**

Defect results are expressed in terms of the percentage of trees affected and number of trees per hectare affected (based on stocking) (Table 2). The incidence of individual defect types was not constant across age classes, but in almost all cases the defects appeared to be more prevalent on ex-improved pastures, and least prevalent overall on the ex-native forest site at Sunny Corner. This is not to say that all defects are directly due to pasture site factors, but such an association is suggested by the results. The frequency of more severe forms of defects such as branch-form also increased with the degree of previous pasture improvement.
Table 1. Summary of growth parameters.

<table>
<thead>
<tr>
<th>Location</th>
<th>Age class</th>
<th>Previous land use</th>
<th>Stocking (stems ha⁻¹)</th>
<th>M.D.H. (m)</th>
<th>DBHOB (cm)</th>
<th>B.A. (m² ha⁻¹)</th>
<th>Volume (m³ ha⁻¹)</th>
<th>Branches per whorl</th>
<th>Branches diam (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buccleuch 1984</td>
<td>S.T.</td>
<td>1375</td>
<td>2.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8.8</td>
<td>3.0</td>
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<tr>
<td>Buccleuch 1982</td>
<td>S.T.</td>
<td>1100</td>
<td>6.4</td>
<td>9.4</td>
<td>7.98</td>
<td>-</td>
<td>-</td>
<td>8.7</td>
<td>2.6</td>
</tr>
<tr>
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<td>13.7</td>
<td>17.7</td>
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<td>184.7</td>
<td>-</td>
<td>8.2</td>
<td>3.4</td>
</tr>
<tr>
<td>Buccleuch 1984</td>
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<td>1400</td>
<td>2.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9.5</td>
<td>2.8</td>
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- N.F. Native forest
- S.T. Scattered timber
- I.P. Improved pasture
- H.I.P. Highly improved pasture

Notes:
- M.D.H. Mean dominant height
- DBHOB Diameter breast height (1.3 m) over bark
- B.A. Basal area
### Table 2. (Cont.)

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<td>H.I.P.</td>
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<td>50</td>
<td>700</td>
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<td>615</td>
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<td>B (%)</td>
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<td>54</td>
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<td>7.5</td>
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<td>11</td>
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<td>75</td>
<td>50</td>
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<td>100</td>
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<td>General deformity</td>
<td>Index&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>5.6</td>
<td>7.8</td>
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<td>9.7</td>
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<td>55</td>
<td>52</td>
<td>60</td>
<td>86</td>
<td>6</td>
<td>24</td>
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<td>50</td>
<td>750</td>
<td>725</td>
<td>600</td>
<td>1425</td>
<td>75</td>
<td>275</td>
<td>325</td>
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<sup>a</sup> Same as Table 1  
<sup>b</sup> See text for explanation  
<sup>c</sup> Utilisation Index expressed as a percentage and number of trees per hectare.
Table 2. Summary of deformity data and deformity indices.

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<th>Sunny Corner</th>
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<td>H.I.P.  H.I.P.  H.I.P.</td>
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<td>1400  1025  1650</td>
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<td>Ramicorns (%)</td>
<td>64  64  63</td>
<td>84  68  85</td>
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<td>(# ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>880  700  825</td>
<td>1176  680  1400</td>
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<td>Forks (%)</td>
<td>9  5  19</td>
<td>9  23  24</td>
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<td>(# ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>124  55  250</td>
<td>126  230  400</td>
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<tr>
<td>Leader damage (%)</td>
<td>44  11  13</td>
<td>59  33  21</td>
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<td>(# ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>606  120  175</td>
<td>826  330  350</td>
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<td>Kinks (%)</td>
<td>76  80  91</td>
<td>89  95  9</td>
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<td>(# ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>1045  875  1225</td>
<td>1246  950  1600</td>
</tr>
<tr>
<td>Butt sweep 1 (%)</td>
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<td>89  78  96</td>
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<td>(# ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>1290  1075  1325</td>
<td>1246  800  1525</td>
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<tr>
<td>2 (%)</td>
<td>6  2  2</td>
<td>11  20  4</td>
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<tr>
<td>(# ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>80  25  25</td>
<td>154  200  75</td>
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<td>3 (%)</td>
<td>0  0  0</td>
<td>0  2  0</td>
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<td>(# ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>0  0  0</td>
<td>0  25  0</td>
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</table>

<sup>a</sup> Same as Table 1
3. Indices

The defect data are summarised into three integrated values, or indices (Table 2), namely:

1. The number of non-deformed trees per hectare ('A' and 'B').
2. The General Deformity Index.
3. The Non-Utilization Index.

It should be stressed that these integrated values, particularly (a) and (c), are subjective because they are based on a general appreciation of those aspects of form which limit merchantability, not product specifications. The usefulness of such indices will depend largely on the specific objectives of each individual assessment.

The number of non-deformed trees represents the number of trees per hectare or the percentage of trees which have the potential to become high quality saw or veneer logs, and as such are limited to the absolute minimum of defects. Results for the two populations of non-deformed trees ('A' and 'B') show that there are very few trees in any site with light to moderate branching, straight stems, minimal butt sweep and no defects except ramicorns less than 10 cm diameter ('A'). Less than 30% of the trees in the ex-native forest stand at Sunny Corner (350 stems ha⁻¹ at a stocking of 1125 st ha⁻¹) were non-deformed. The absence of any 'non-deformed' trees in some previous improved sites appears to be a significant site effect. By including a small degree of crookedness ('B' - up to 2 kinks in the stem), more than 50% of the trees in the ex-native forest site were of reasonably good quality, but this relaxation of form had little effect in some improved sites. A closer examination of actual defects recorded in the respective plot sheets will help to identify reasons for site-to-site discrepancies.

The General Deformity Index is expressed as a mean deformity score per tree which is not biased by the variations in stocking. The General Deformity Index indicates the mean number of defects per tree, and ranged from about 4 to almost 10 in these examples. Some individual highly deformed trees had values closer to 20, but the overall plot scores is of more interest for comparing sites.

As noted previously, the General Deformity Index includes all the defects recorded in a stand, whereas the non-Utilization Index includes only those defects which are almost guaranteed to limit utilization. The non-Utilization Index is calculated as a proportion (e.g., 0.34 or 34%) indicating the percentage of trees which are not likely to be commercial, and as a value approximating the number of trees per hectare affected. Since the score for an individual tree can range from 1 to 4, high non-Utilisation Index values can result from many trees with one severe defect and fewer trees with multiple severe defects. In the sites summarised here, most trees had non-Utilisation Index values of 1, largely due to heavy branching, but several trees in the 1979 age class on ex-highly improved pasture, had values of 2 due to heavy branching and sinuosity. The potential commercial value of this stand (non-U.I. = 0.86) is low. In contrast, two plots had very low non-Utilization Indices: 1968 A.C. ex-native forest (non-U.I. = 0.06) and 1982 ex-unimproved pasture (non-U.I. = 0.05). Their General Deformity Index values were not equal, however, because trees in the ex-unimproved pasture site had more defects overall. This is evident from the numbers of non-deformed trees per hectare (class 'B') for these plots.
CONCLUDING COMMENTS

The summarised information is representative of some of the patterns of growth and form observed in a range of sites with differing patterns of land use prior to conversion to *P. radiata* plantations. These data sets were included for illustration purposes only and are not meant to be a representative analysis of form in relation to land use.

One aspect of form assessment not addressed in this paper concerns the change in tree form and associated deformity indices with stand age. Definitive data are not yet available to provide comment on change with age, but some changes are inevitable. Before about 3 to 4 years of age, many form changes can occur which will not be evident in a 15-year-old tree, and vice versa. For example, trees can develop more forks and ramicorns as leader extension continues, while one leader developing from a fork formed in the first year may become dominant, and the defect reassessed within a few years as a displaced leader plus ramicorn. By thinning age, this kind of defect may be totally obscured. Minor kinks, bends and twists appear to become obscured with age as the stem diameter increases, which suggests that defect scores may be inflated in young stands with lots of bendy stems. Such patterns, however, have yet to be verified.

Each assessment should have a clearly defined objective, and the defects scored should be selected to suit these objectives. At the detailed research level a complete assessment of form is highly desirable, but broader surveys to determine the potential stocks of high quality timber or areas of major commercial loss, would be better served by more limited form assessments. In every situation, however, regardless of the final objective, it is important to use consistent standards in the rating of different levels of severity. The descriptions and photographs in this report have been provided to establish these guidelines for form assessment.

ACKNOWLEDGEMENTS

The assistance of several people is acknowledged. Hans Porada, Col Wilkinson, Jeff Whiting and Ian Hides of the Tumut Research Centre and Des Gibbons, now at the Coffs Harbour Research Centre helped refine the assessment procedure. Valerie Bowman of the Wood Technology and Forest Research Division assisted with the data analysis.
Fig. 1
Bushy form of young *P. radiata* pine trees observed in some ex-improved sites, including tip death or dieback due to boron deficiency (leader class 1).

Fig. 2
Leader damage, possibly due to disease. Leader replaced by basket whorl (leader class 4).

Fig. 3
Reasonably normal form for a young *P. Radiata* tree; straight stem, single leader (leader class 0) well spaced branches. Contrast with Figure 1.
**Fig. 4a**
Displaced leader (leader class 3). Sinuosity (class 1) in new leader.

**Fig. 4b**
Displaced leader (leader class 3). One lateral attained dominance following death or suppression of the leader.

**Fig. 5a**
Basket whorl formed after tip death (leader class 4).

**Fig. 5b**
Basket whorl formed after the leader was broken (leader class 4).
Fig. 6
Fork. Note the short internodes, numerous branches (possibly double whorls) and tip die-back.

Fig. 7
Foxtails in both the current and a previous period of stem extension. Note also the minor sinuosity (class 1) in the long internode.

Fig. 8
Lean, or arching of the stem. Note needle death due to *Dothistroma*.
Fig. 9a

Mild butt sweep (class 1), no commercial loss to the butt log expected.

Fig. 9b

Mild butt sweep (class 1), no commercial loss to the butt log expected.

Fig. 10a

Butt sweep class 2 (<30° angle); some commercial loss expected. A line extended from the inside curve at the point at which the stem straightens falls outside the stem at ground level.

Fig. 10b

Butt sweep class 2 (<30° angle) commercial loss in butt section expected. A line extended from the inside curve at the point at which the stem straightens falls outside the stem at ground level.

Fig. 11a

Severe butt sweep (class 3).

Fig. 11b

Severe butt sweep (class 3) including double sweep in the butt log. Note the large ramicorn branch.
Fig. 12

Mild sinuosity (class 1) in the internode (foxtail section of the stem).

Fig. 13

Sinuosity (class 2); major bend (U-shaped) beneath the node, plus a minor deflection (class 1) above the node.

Fig. 14

Severe sinuosity (class 3); multiple twists (not evident in the photo) in both leaders.

Fig. 15a

Kink at the node due to leader displacement. The original suppressed leader is still evident.

Fig. 15b

Kink in the stem probably due to a leader displacement.

Fig. 16

Kinks in stem at each node. There is no obvious reason for these deflections but they appear to be the result of sinuosity in the internodes that has become obscured with age.
Fig. 17
Thick branches on a 6-year-old tree; too thick to be pruned by normal means.

Fig. 18
Ramicorn branch; no commercial loss.

Fig. 19
Ramicorn branch competing with the leader.

Fig. 20
Prolepsis (lateral extension with a dormant leader). Note the steep branch angle.

Fig. 21
Double whorls and short internodes, probably due to late season flushing.
Fig. 22
Sinuosity class 1. Twist at base of the new leader plus bend in the long internode.

Fig. 23a
Sinuosity class 2 (bend). This is border-line with class 1 sinuosity.

Fig. 23b
Sinuosity class 2 (twist), also bordering on class 1 sinuosity.

Fig. 24a
Sinuosity class 2 (more severe bend).

Fig. 24b
Sinuosity class 2 (very severe U-shaped bend).

Fig. 24c
Sinuosity class 2 (major twist).
Fig. 25a
Sinuosity class 3 (multiple bends).

Fig. 25b
Sinuosity class 3 (twists and bends of varying severity).

Fig. 25c
Sinuosity class 3 (multiple twists).
Description and Assessment of Stem Form in Radiata Pine

Fig. 26a
Branch-form class 1. Flat, well spaced, fine branches.

Fig. 26b
Branch-form class 1. Flat, well spaced branches. Large branch diameter suggests branch-form is bordering on class 2.

Fig. 27a
Branch-form class 2. Branch angles 60° from vertical, some double whorls.

Fig. 27b
Branch-form class 2. Relatively large branches.

Fig. 28a
Branch-form class 3. Numerous large branches, short internodes, steep angles.

Fig. 28b
Branch-form class 3. Numerous large branches, short internodes, steep angles.

Forestry Commission of New South Wales.
Technical Paper No. 46
APPENDIX: RADIATA PINE FORM ASSESSMENT SHEET

STATE FOREST:  
AGE CLASS:  
COMPARTMENT:  
PLOT:  
DATE:  
ASSESSORS: (*quotes plus minor bends and twists were counted together in this assessment)  

Count the number of branches in the 2 whorls nearest 1.3 metre height. Measure diameters of 2 largest branches in each whorl counted (4cm from stem)  

1 = single, minor deviations from straightness either bends or twists  
2 = single, significant bend or twist  
3 = continuous sections of sinuosity  

LEADER  
(main leader only)  
0 = normal;  
1 = dead top 2 = broken top;  
3 = displaced 4 = 'basket'  

LEAN & FOXTAIL: 0 = absent 1 = present  

BUTT SWEEP: 1 = absent or minimal 2 = < 30 angle with loss  
3 = > 30 angle with loss  

BRANCH-FORM: 1 = fine, widely spaced 2 = moderate density  
3 = excessive size, density & angles.  

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<th>Tree Section</th>
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<th>Sweep (1-3)</th>
<th>Lean Cond'n (0-4)</th>
<th>Leader No.</th>
<th>Forks No.</th>
<th>Branch No. Whorl</th>
<th>Branch Diameter (1-3 cm) Whorl</th>
<th>Branch Form (1-3) Whorl</th>
<th>No. Ramuncorns (0-1) Total &gt;5cm</th>
<th>No. Sinuosity</th>
<th>Kinks</th>
<th>Fox Tails</th>
<th>Comments</th>
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