DEVELOPMENT OF A DATABASE, AND ITS USE TO QUANTIFY INCIDENCE OF DEFECTS IN RANDOM-WIDTH *PINUS RADIATA* BOARDS

RADO GAZO

Purdue University, 1200 Forest Products Building,
West Lafayette, Indiana 47907-1200, U.S.A.

SCOTT MITCHELL*

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

and ROBERT BEAUREGARD

Forintek Canada Corporation, 319 Franquet,
Sainte-Foy, Quebec G1P 4R4, Canada

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ABSTRACT

A database was developed containing 392 digitised boards, volume 17.10 m^3 (7245 board feet), from 10 different clones of New Zealand *Pinus radiata* D. Don. Thirty-one percent of the boards came from pruned logs, and the remainder from unpruned logs. Nine defect categories were identified, the most frequent defects in boards from pruned logs being bark pockets and blemishes and the largest-sized defects on average being areas containing needle flecks. The most frequent defects in boards from unpruned logs were knots, and they were also the largest-sized defects in these boards.

The database can interface with all common simulation and modelling programs. It can be used to establish basic relationships between New Zealand *P. radiata* tree characteristics and board characteristics for prediction and planning purposes.

Keywords: random-width boards; database; defect frequency; defect area; pruned log; *Pinus radiata*.

INTRODUCTION

The overall objective of this project was to optimise remanufacturing technologies to improve recovery from *Pinus radiata* logs and enhance product values.

Several types of questions are commonly asked when improvement of recovery is discussed with people involved in breeding, growing, and processing *P. radiata* in New

* Current address: Orica Chemicals, Mt Maunganui, New Zealand

Zealand. Geneticists ask which tree clones and what clonal characteristics are most suitable or desired for specific products or markets. Tree growers, on the other hand, ask which tree characteristics and what parts of the tree (butt, second, intermediate, top log) are most desirable for specific products (lumber, veneer, paper, etc.). Sawmillers want to know which sawing strategy provides optimal recovery and product value; and remanufacturers want to know what recovery yields they can expect, which processing method is most suitable for a specific order, what distribution of part sizes can be obtained from *P. radiata* boards of given characteristics, etc.

Given the broad scope of this project, it was decided to publish the results in several papers, each dealing with a specific area. This paper is the first in a series and it has two objectives: (1) to describe the development of a database of digitised random-width *P. radiata* boards, and (2) to analyse the incidence of defects in *P. radiata* random-width boards.

For the first objective, a computer database of digitised random-width *P. radiata* boards was developed. In the past, United States remanufacturers of hardwood lumber have had questions about yield, processing methods, parts distribution, etc., answered by computer modelling tools which utilised databases of digitised lumber (Anderson 1983; Araman 1987; Gatchell *et al.* 1993, 1995; Gazo & Steele 1995; Harding 1991; Harding *et al.* 1993; Steele & Gazo 1995; Steele *et al.* 1994; Steele & Lee 1994; Wiedenbeck & Araman 1995; Wiedenbeck *et al.* 1995). A similar approach could help answer many questions for New Zealand *P. radiata* remanufacturers. Statistical models were developed to address the types of questions asked by geneticists, growers, and sawmillers, and the database developed provided a common thread.

Pinus radiata was chosen for the development of the database because it forms up to 90% of plantation forest in New Zealand (New Zealand Forest Industries 1996). According to Turland *et al.* (1993), the annual harvest of *P. radiata* was 11.9 million m^3 in 1991 and 16 million m^3 in 1995. This annual harvest will increase to 25.3 million m^3 by the year 2005 (38 million m^3 by the year 2025) if the current new-planting rate of 50 000 ha per annum is maintained. This makes it by far the most important commercial species in New Zealand.

Random-width boards were chosen because random-width lumber is requested by the United States millwork industry. Millwork is one of the growing market segments for *P. radiata*. Millwork sales were predicted to increase by 56% in 1995 to NZ$64 million (Siegfried *et al.* 1995). The United States is a major customer in this market, taking one-quarter of all millwork lumber produced in New Zealand, but cutting and processing such lumber is quite a new concept in this country. To address some of the questions arising, the database was constructed for random-width *P. radiata* lumber.

For the second objective, the incidence of defects—expressed by frequency of defects, average defect size for each defect type, and percentage of clear surface area—was analysed for boards from both pruned and unpruned logs.

METHODOLOGY

Sample Material

A large proportion of the future forest in New Zealand will be established from progeny of the best seed orchard clones. This select group of parents is different in terms of growth and form from that currently being utilised by industry. It is known that intrinsic wood properties vary widely between clones; we actually know, for example, how wood density and branch cluster frequency vary in different seed orchard seedlots. Little is known, however, about how this variation can be used to advantage during solid-wood processing.

The trees selected for these studies were required to show a range of qualities typical of the crop being harvested now and in the near future. An additional requirement was the need to sample matching stems for various processing pathways to be investigated, particularly Saw-Dry-Rip and cant sawing. A unique early clonal test in Compartment 1350 of Kaingaroa Forest, planted in 1968, could provide several stems of the same genotype (clones) and it was sufficiently large and mature for the study. Of the original 216 clones selected from felled "old crop" trees (effectively "felling select*") in the Cpt 1350 trial, 175 of the faster-growing clones remained. Forty-six of these clones had adequate replication for study purposes, and selection excluded the smaller stems (diameter at breast height 1.4 m (dbh) < 300 mm).

Silvicultural history of the stand was: establishment at 1370 stems/ha, waste thinning initially to 700 stems/ha at 7 years of age and to a nominal stocking of 350 stems/ha at 13 years of age, with a two-lift pruning to 4 m. This regime is not representative of usual forest practice, but facilitated research priorities while maintaining tree growth and form. Nevertheless, according to the FRI Permanent Sample Plot database (Dunlop 1995), the average final stocking in Kaingaroa Forest at the time was 318 stems/ha (range 30–1492 stems/ha), which points to a wide variation in silvicultural regimes.

Ten of the 46 available clones were selected to cover a range of dbh, internode length, branch size, and outerwood density at breast height. The selected clones were believed to be representative of the main body of the population as well as of more extreme values of stem parameters present in current plantations.

In November 1995, at stand age 27 years, two replications (trees) of each of the 10 selected clones were harvested—a total of 20 trees. The two replications were needed so that each clone could be processed by two different sawing strategies (live and cant).

Log Making and Sawing

Four logs were cut from each tree; these included the pruned butt log, the second log, one intermediate log, and the top log. The butt logs were on average about 4 m long and the rest of the logs were about 4.9 m long. A top log from one tree was not suitable for sawmill processing and one extra intermediate log was taken from two trees. This resulted in 20 butt logs, 20 second logs, 22 intermediate logs, and 19 top logs—a total of 81 logs.

The first 40 logs (one tree from each of 10 clones) were live sawn into boards 40 mm thick (Fig. 1). This method targets the US $^5/_4$ inch random-width Shop boards. The second 41 logs (second replicate set of 10 clones) were cant sawn by flat sawing 40-mm boards leaving the central cant. Logs with small-end diameter between 200 and 300 mm were sawn with a 100-mm cant and larger logs with a 200-mm cant. The cants were reduced to 100 × 40-mm Australian structural stock before being dried (Fig. 1). One butt log was of inferior quality and did not yield any random-width boards. This log was excluded from further analysis.

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* Felling select = seed collected from good phenotypes felled in unimproved plantations.

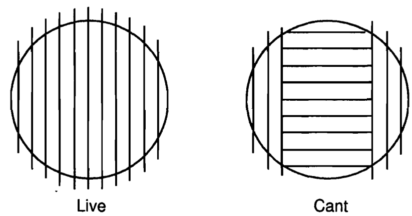

FIG. 1–Live and cant sawing strategies.

The 81 logs were processed in Vanner sawmill at Reporoa, New Zealand, to produce 392 random-width boards. All boards were dried in a commercial dry kiln on a high-temperature schedule (120°C) and surfaced on both faces to allow easier defect identification for digitising purposes.

Board Digitising

Board digitising consisted of manually recording the board dimensions (width and length), defect positions, and defect types for each face of the board. A set of rules was developed to achieve consistent and accurate readings as it is important to maintain consistency in positioning the boards, marking defects, and recording co-ordinates when digitising a large number of boards.

Firstly, a digitising table was built consisting of a flat top and two guard rails along the length of the table top. A steel measuring tape was attached to one of the rails for measuring the length (x co-ordinates). A fixture that could slide on the top of the rails along the length was constructed and another steel measuring tape was attached to it for width readings (y co-ordinates).

Each board was placed on the table representing the xy co-ordinate system. A similar procedure was used by Lucas (Lucas & Calron 1973). Information about the log position within a tree as well as board position within a log were recorded during tree harvesting and log processing. Boards were placed on the digitising table with the "butt" end at the initial [0,0] point and were pushed flush against the rail and square with the end of the table (Fig. 2).

Most boards, however, are not perfectly rectangular. If a board did not have a straight sawn edge, it was placed so that it touched the rail with at least two points. Boards with crook were placed so that there was an equal gap between the table and the board edge at either end

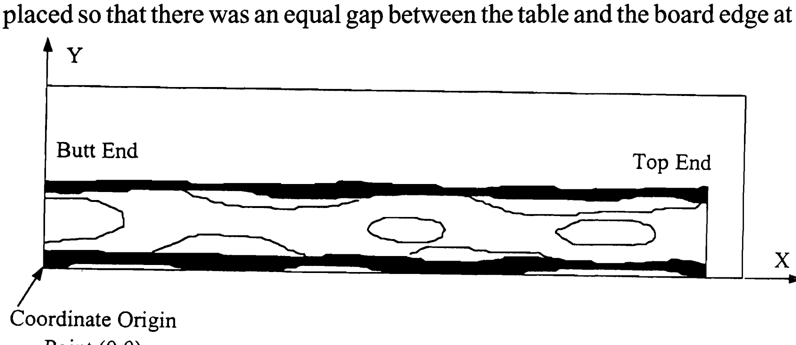

FIG. 2–Placement of the board on the digitising table.

of the board. Tapered boards were placed so that one edge of the board was flush against the edge of the table. Boards with out-of-square ends were positioned so that one of the corners of the board was at the edge of the table.

Once the board was properly positioned on the table, the dimensions and defects were identified and marked. Length of the board was measured from the [0,0] point of the co-ordinate system to the most distant point at the other end of the board. Width of the board was measured at the widest point.

Defect Types

Defect types were organised into nine categories (Table 1) and codes were used to record these defects in a data collection sheet. For the proper identification of the defects, the following definitions (from New Zealand Ministry of Forestry 1994) were used:

Intergrown knot — A knot that is wholly intergrown with fibres of the surrounding wood.

Partially intergrown knot — A knot that has not more than half its perimeter separated from the surrounding wood by bark.

Tight knot — A knot that is fixed by growth, shape, or position, which remains firmly fixed within the piece. In general, knots exceeding 12 mm (1/2") diameter require some degree of intergrowth to remain tight.

Loose knot — A knot that is loose or likely to became loose in drying or machining. Generally includes any knot exceeding 12 mm (1/2") in diameter that is fully enclosed in bark.

Hole — A hole extending partially or entirely through the piece and attributable to any cause.

Spike knot — A branch cut longitudinally by the plane of the face and extending to the edge of the piece but also including knots that would have been spike knots had they not been occluded.

Pith — The central core of the stem consisting mainly of parenchyma or soft tissue.

Bark pocket — A patch of bark partially or wholly enclosed in the wood

Resin pocket — A cavity that contains or has contained resin, either solid or liquid.

Needle fleck — Specks in a diamond pattern on flat-sawn timber, or as fine radial lines on quarter-sawn timber.

Wane — The presence of the original underbark surface, with or without bark, on any face or edge of a piece of lumber

TABLE 1–Defect types and codes

Defect type	Defect code
Intergrown knot	1
Partially intergrown knot / tight knot	2
Loose knot / hole / cone hole	3
Spike knot	4
Pith	5
Bark pocket / blemish	6
Resin pocket	7
Needle fleck	8
Wane / Void (missing wood)	9

Defect Recording

Each surface defect was identified and the smallest possible rectangle was pencilled around it. When spike knots and wane were being marked, a significant amount of clear wood was included within the boundaries of the defect rectangle. To achieve a better representation of these defects, the original rectangle defect was broken down into a series of smaller rectangles (Fig. 3), the width of which was set to 25 mm (1").

Needle fleck defect was usually present as a frequent occurrence over an area of the board and so the whole area was marked as a needle fleck defect. The rectangle could overlap with other defects, which were marked independently (Fig. 4).

Wane and void (missing wood) defects were also marked as a series of rectangles (Fig. 5). The number of rectangles was dependent on the slope of the wane or void. For example, if the wane was relatively uniform along the length of the board, fewer rectangles were marked.

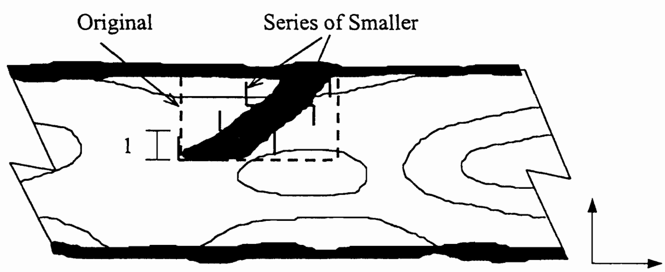

FIG. 3–Breakdown of large spike knot rectangle into series of smaller rectangles.

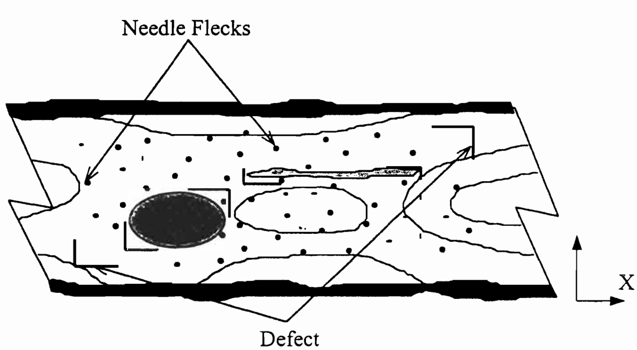

FIG. 4–Needle fleck area.

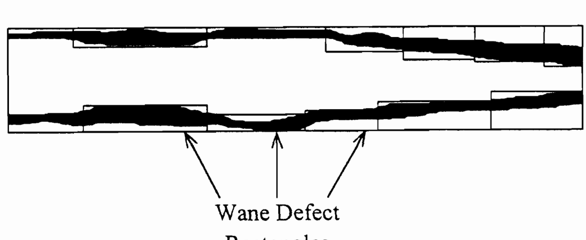

FIG. 5–A typical wane marking.

Some boards tapered rapidly and the defect rectangles were made at intervals no less than 300 mm in order to minimise the amount of clear wood included in the defect rectangle. Again, the 25 mm (1") width increment rule was used for achieving a more realistic board profile for breakdown of wane into multiple rectangles.

Once all the defects were identified and marked, the data were manually recorded on a data sheet (Fig. 6). The lower left and upper right corners identified the perimeter of every board and every defect in the database. The *x* and *y* co-ordinates for each of the corners were recorded, and the defect type and face of the board that the defect was on were recorded as well.

Initially, the board was positioned on the table with Face 1 up and against the right-hand rail. Face 1 was defined as the outside face of the board (the face which contained wane). The other side of the board was defined as Face 2. After all the information from Face 1 was recorded, the board was turned Face 2 up and pushed against the left rail (Fig. 7). The co-

Board No 1 Actual Board No. 1J
Length: 3990 mm Width: 255 mm

Board Defects: Total No. of Board Defe 27

	Start		Stop					Start		Stop			
	Y(cm.	X(cm.	Y(cm.	X(cm.	Side	Type		Y(cm.	X(cm.	Y(cm.	X(cm.	Side	Type
1	105	1810	112	1820	1	1	26	78	2362	110	2417	2	2
2	157	1890	165	1911	1	6	27	119	3943	138	3960	2	1
3	68	2390	110	2446	1	2	28						
23	39	1850	75	1885	2	1	48						
24	123	1860	157	1902	2	1	49						
25	132	2330	146	2346	2	1	50						

1. Boards with wane record a defect and draw board Heart color [N]
2. Crook ____ mm, if crook present draw board Sloping grain [N]
3. Corewood: Y_1 50 mm Y_2 220 mm Surface Chec [N]
Y_3 0 mm Y_4 220 mm

Diagram of Side 1:

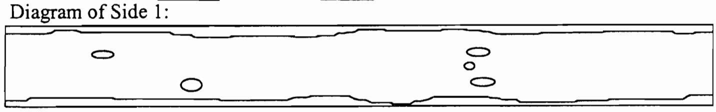

FIG. 6–Digitising record data sheet.

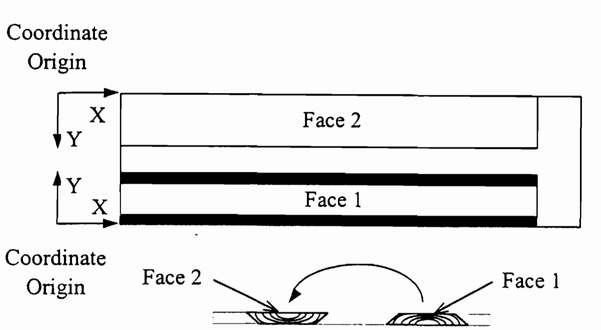

FIG. 7–Digitising Face 2.

ordinate origin had now moved (Fig. 7) and the lower right corner of the board became the [0,0] point. To keep the measurements from Face 2 compatible with those from Face 1, the co-ordinates of lower right and upper left corners of the defect rectangles were recorded on Face 2.

The following board properties were also recorded: crook (maximum deviation); corewood (distance from the *x* axis for the first 10 growth rings from both ends of each board); presence of heart colour, sloping grain (if angle was greater than one in six), and surface checks (indicated with a "yes" or "no" on the data sheet). Each board was sketched with relative positions of wane and knot groups on Face 1. In addition, the percentage of corewood contained in each board and the radial distance from the centre of the board to the pith were calculated. All the measurements were recorded in millimetres.

Computer Database

Information about the clone, tree, log position within a tree, sawing strategy, board location within a log, board grade, board dimensions, defect locations, and defect types was entered into a computer file. The format of this file was developed to be compatible with other programs and to keep size to a minimum (for increased processing speed). Once all the data were entered, they were checked for typing errors and corrected. The file was in TAB delimited ASCII format with designated sdf extension.

A user-friendly interface was developed for displaying and sorting the database information, plotting the boards, calculating various database parameters, and exporting information into file formats for use with existing modelling programs. The interface was written for the Windows® operating environment using Visual Basic® programming language. The program can be driven either by a mouse or through the menu system.

Once the database file is open from the initial screen (Fig. 8), information about the board number, the corresponding log number, the position of the board within the log, and the corresponding tree number, the board grade, width, length, and total number of defects (including wane and spike knot sections), corewood percentage, and radial distance from the pith are displayed, one line per board. Next to individual board information is a check box. If this box is marked, the marked board will be included in any display, count, or export operation on the database.

The total number of boards in the database is given, as well as the count of checked boards. Checking or unchecking of the "Invert Selection" button will cause inverting of all individually checked boxes into unchecked status and vice versa. Selection of one of the *Board, Log, Tree, Grade, Percentage of Corewood,* or *Distance from Pith* sorting options will display the boards in the database according to the selected criteria.

Filter function displays all the defect types found in the database and their total count. Checking or unchecking of individual defect types controls the inclusion of these defects in further operations on the database. Different defect types are coded using different colours which correspond to colour codes used when plotting the boards.

Plot function (Fig. 9) plots the image of the selected board. A board is selected by clicking on the appropriate board number before clicking on Plot button. Plot window can be re-sized using the mouse to accommodate any monitor size. A relative scale is provided next to the board image. Defects on Face 1, Face 2, or both faces of the board

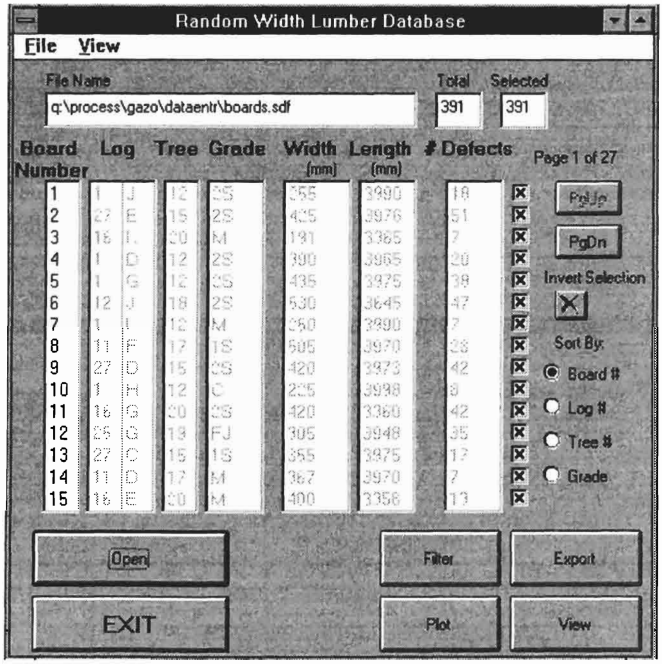

FIG. 8–Random-width lumber database opening screen.

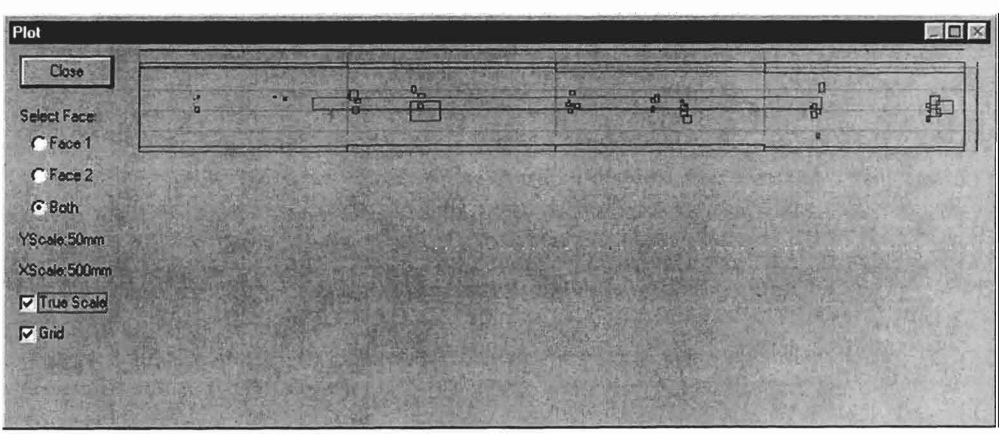

FIG. 9–Board plot screen.

can be plotted by selecting the appropriate option. Different defect types are plotted in different colours which correspond to colour codes in the filter function.

View function allows the co-ordinates of defect rectangles, defect type, and boarding face on a selected board to be viewed. The board is again selected by clicking on a board number prior to clicking on the View button.

Export function allows selected boards and selected defects to be saved in one of several available formats. These include ROMI-RIP (USDA rip-first simulation program—Thomas 1995a, b), CORY (Oregon State University crosscut-first simulation program—

Brunner *et al.* 1989; and RAM Rough Mill Analysis and Modelling program—Gazo & Steele 1995), FLGRADE (New Zealand Forest Research Institute AUTOSAW's random-width lumber grading routine—Todoroki 1995), and sdf database format. For ROMI-RIP and CORY programs all the measurements are converted to 1/4" units. If the *statistics* option of the export function is selected, then a comma-delimited ASCII file is created. This file is best viewed as an Excel spreadsheet. The file contains statistics on boards and defects previously selected. These include: total number of boards; minimum, maximum, and average board width and length; and total board volume in cubic metres and board feet. The following information is also listed: board number, width, length volume in board feet and cubic metres, total surface area, total defect area, percentage of clear area, count of each of the nine defect types, and cumulative area for each of the nine defect types. Above-mentioned data can be calculated for Face 1 or Face 2 only, or for both faces combined.

When board information is exported into another format, boards are placed in the file in ascending order of board number. Some modelling functions require several files which contain the same boards but with random order of boards within each file. This can be achieved by clicking on the *Randomise* option in the export screen and by specifying the number of files.

Board Grading

A large volume of random-width factory lumber produced in New Zealand is exported to the United States for remanufacture. This lumber is graded using the Western Lumber Grading Rules (WesternWood Products Association 1991) which classify according to the potential recovery of clear cuttings by combinations of ripping and cross cutting. The sequence of these combinations is established for some grades (for example, Finger Joint Shop Common requires that pieces be ripped full length before being cross-cut) whereas others permit either rip-first or cross-cut-first combinations. In order to determine the lumber grade, areas of placements of potential clear cuttings are considered. As the boards are intended for subsequent remanufacturing into door and window frames, moulding, and millwork items, individual cuttings must also satisfy both size and quality criteria.

According to the Western Lumber Grading Rules the lumber is graded into the following factory lumber grades: Mouldings, Factory Select, No. 1 Shop, No. 2 Shop, No. 3 Shop, and Finger Joint Common Shop. The main requirements for these grades are summarised in Table 2. The requirements are based on the percentage of potential cuttings that can be obtained from the board. Cutting dimensions and quality criteria for the main cuttings are illustrated in Table 3. In general, a piece of No. 1 Cuttings quality is free from defects on both sides of the board, whilst a piece of No. 2 Cuttings quality can admit minor imperfections. A detailed account of the grading rules is given in the grading handbook (New Zealand Ministry of Forestry 1994; Western Wood Products Association 1991).

Prior to digitising, all boards were manually graded according to the Western Lumber Grading Rules by an experienced grader.

After the computer database was constructed, the boards were re-graded by a computerised grading program FLGRADE (Todoroki 1995), which is a random-width board grading routine. It is a part of AUTOSAW software (Todoroki 1990) previously developed at the New Zealand Forest Research Institute.

TABLE 2–Main grade requirements for Factory lumber

Lumber grade	Grade requirements—*each board must contain at least...*
Mouldings	⅔ of the surface area in clean cuttings, 3 m (10') and longer, 25 mm (1") and wider. Up to 10% of a consignment may contain 1.8 m (6') to 2.7 m (9') lengths
Factory Select	70% of No. 1 Door Cuttings. Subject to: a maximum of two muntins; no board may contain muntins only; if one No. 1 Stile, or two or more No. 1 Door Cuttings, one No. 2 Stile is permitted.
No. 1 Shop	50% of No. 1 Door Cuttings. Subject to: a maximum of two muntins; if one or more No. 1 Door Cuttings, one No. 2 Stile is permitted
No. 2 Shop	25% of No. 1 Door Cuttings or 33⅓% of No. 1 and No. 2 Door Cuttings or 40% of No. 2 Door Cuttings
No. 3 Shop	30% of any combination of No. 1 and No. 2 Door Cuttings, sash cuttings, moulding rips, or jamb and sill cuttings
Finger Joint Common Shop	50% of Finger Joint Cuttings

TABLE 3–Dimensions and quality criteria of main Factory grade Cuttings.

Cutting	Length	Width	Quality
Moulding rips	3 m (10') and longer	25 mm (1") and wider	No. 1 Cutting
Stiles	2 m (80") to 2.25 m (90")	125 mm (5") or 150 mm (6")	No. 1/No. 2 Cutting
Bottom rails	0.7 m (28") to 0.9 m (36")	225 mm (9") or 250 mm (10")	No. 1/No. 2 Cutting
Muntins	1.05 m (42") to 1.2 m (48")	125 mm (5") or 150 mm (6")	No. 1/No. 2 Cutting
Top rails	0.7 m (28") to 0.9 m (36")	125 mm (5") or 150 mm (6")	No. 1 Cutting counted as No. 2 Cutting
Sash	0.7 m (28") and longer	63 mm (2.5"), 88 mm (3.5"), 113 mm (4.5") and wider	No. 1 Cutting
Jamb and sill	0.9 m (36") and longer	125 mm (5") and wider	No. 1 Cutting best face No. 2 Cutting worst face
Finger Joint	225 mm (9") and longer	63 mm (2.5") and wider	No. 1 Cutting

The computer grading results were compared to manual grading and, if different grades had been assigned to the same board, they were checked and a correct grade was assigned. This double grading was done to ensure the best possible accuracy when assigning a grade to the board.

Several assumptions had to be made when deciding which grade (manual or computer) was correct. Firstly, during the manual grading boards without any defects were assigned to Clear grade without regard to board dimensions and potential cuttings. According to the Western Lumber Grading Rules there is no Clear grade, and so these boards were assigned the grade determined by FLGRADE.

Secondly, during the manual grading Finger Joint Common Shop grade was considered to be the lowest grade. FLGRADE, however, checked the percentage of Finger Joint Cuttings in each board and if a board did not meet the Finger Joint criteria, Box grade was assigned to that board. The computer grade Box was thus assigned to boards with manually assigned Finger Joint grade.

Thirdly, when grades of several boards which differed one grade between FLGRADE and manual grading were compared, it was found that FLGRADE was more accurate in fitting required cuttings into clear board sections. Therefore, if the board grade differed by only one (for example, manual grade of No. 1 Shop and FLGRADE grade of No. 2 Shop) the FLGRADE grade was assigned to those boards.

Fourthly, the FLGRADE program allowed grading with or without "scaling off". "Scaling off" is allowed according to the rules in order to upgrade the board if a certain percentage of wane is exceeded (scaling off the board volume increases the percentage of cuttings over the total board area). Because of the nature of digitising, missing wood and wane were recorded as one defect type. When the results of FLGRADE grades were compared with and without scaling off, we identified boards which were likely to benefit most from scaling off. Then, for these boards we assigned grades from the manual grading because the grader, unlike the computer, could see the difference between wane and missing wood.

Incidence of Defects

In order to analyse the occurrence of defects in random-width *P. radiata* lumber, two variables were considered: frequency of defects and average area of the defects. The defect frequency was defined as the number of occurrences of a defect per square metre of board surface area, and computed on a per tree basis. The number of defects of each type for each board was recorded and divided by the board surface area of each tree. The board surface area was calculated as length of the board × the greatest width of the board. Frequency of defects was calculated for all defect types except wane. Wane can be found on every random-width board. The defect area was defined as the area (in square centimetres) of a defect type per square metre of board, on a per tree basis. The average defect area was calculated for all the defect types, including wane. Because of the nature of the needle fleck defect, the frequency and area of needle flecks were not recorded individually, but rather in the aggregate as an area affected by needle fleck occurrence. The total defect area per defect type was calculated for each tree. This defect area was then divided by the total board surface area of that tree. When frequency and area of the defects were calculated, only defects on Face 1 (worse face) were considered.

Clear Surface Area

Percentage of clear surface area was calculated as the ratio of board clear area (board surface area minus total defect area) to board surface area. In addition, for the boards from the pruned butt logs only, two clearwood-related variables were introduced. The first was the yield in clear boards, which was defined as the ratio of the surface area of the boards with no defects other than wane and void (defect 9) over the surface area of all the boards. The second was the yield in boards with no knots, which was defined as the ratio of the surface area of the boards with no knots (defects 1 to 4) over the surface area of all the boards. These two variables allowed the analysis of production of clear wood from pruning.

RESULTS

Incidence of Defects

The first objective of this project was to create a database of digitised, random-width, *P. radiata* boards. Processing the 20 trees resulted in 392 boards. Cant-sawn logs did not yield any random-width boards from the "cant" zone of the log, and the cants were immediately processed into structural lumber. Therefore, the random-width boards which came from the same "cant" zone of live-sawn logs were excluded (Fig. 1) from the statistical analysis in order to provide a sample of two replicates (trees) per clone with comparable wood characteristics. This in turn decreased the variation between the replicates and, for future analyses, increased the likelihood of establishing differences between trees of different characteristics. Furthermore, all the analyses were performed separately on pruned and unpruned logs, which were considered to be material of different nature. Hence from the original 392 available boards, 133 boards were excluded resulting in 259 boards used for this analysis. The total volume of boards in the database was 17.10 m^3 (7245 board feet). The volume of boards included in this analysis was 10.45 m^3 (4429 board feet). Because the centre boards were not analysed, the pith defect did not appear in the analysis.

Defect Frequency

The most frequent defect type in boards from pruned logs was bark pocket or blemish with 1.369 defects/m^2 (Table 4). In this category, the blemishes were much more frequent than bark pockets. The exact origin of blemishes was uncertain. In fact it was a category into which every unidentifiable defect was assigned. Some markets do not accept blemishes in the clear grades. The second-most-frequent defects were intergrown knots, with 0.849 defects/m^2. Other defects were much less frequent in boards from pruned logs.

The most frequent defects in boards from unpruned logs were intergrown knots, with 7.804 defects/m^2 (Table 4). Partially intergrown knots and loose knots were second and third most frequent with 2.295 and 2.346 defects/m^2 respectively. Fourth, and of the same order of magnitude was the bark pocket and blemish category with 1.973 defects/m^2. Other defects were much less frequent in boards from unpruned logs.

TABLE 4–Frequency of defects by pruning method and by defect type

Logs	Defect frequency (No. defects/m^2 boards)						
	Intergrown knot	Partially intergrown knot	Loose knot/ hole	Spike knot	Bark pocket/ blemish	Resin pocket	Needle fleck area
Pruned	0.849	0.338	0.198	–	1.369	0.186	0.080
Unpruned	7.804	2.295	2.346	0.043	1.973	0.024	0.083

Percentage of Clear Wood Area

The boards from pruned logs had an average 76.96% of clear wood area from total board surface area as compared to 75.74% for boards from unpruned logs (Table 5).

TABLE 5–Clearwood percentage and defect area by pruning method and by defect type

Logs	Clear-wood area (%)	Defect area (cm^2/m^2)							
		Inter-grown knot	Partially intergr. knot	Loose knot/ hole	Spike knot	Bark pocket/ blemish	Resin pocket	Needle fleck area	Wane/ void
Pruned	76.96	5.66	3.37	4.52	–	10.41	1.74	45.75	2235.46
Unpruned	75.74	118.32	39.89	17.24	1.07	9.89	0.07	82.43	2156.81

Average Defect Area

The defect with the largest average size in boards from pruned logs was needle fleck with 45.75 cm^2/m^2 (Table 5). Needle flecks tend to appear in long bands on the board. In New Zealand they are not considered a defect in appearance grades but in various foreign markets, such as the United States, they are considered defects in random-width grades. Second largest were bark pockets and blemishes with 10.41 cm^2/m^2. All knot-related defects summed up to just 13.55 cm^2/m^2. Other defects were much less frequent in boards from pruned logs.

The defect with the largest average size in boards from unpruned logs was the intergrown knot, with 118.32 cm^2/m^2 (Table 5). Second were needle flecks with 82.43 cm^2/m^2. Third and fourth were partially intergrown and loose knots with 39.89 and 17.24 cm^2/m^2 respectively. Bark pockets and blemishes were fifth with 9.89 cm^2/m^2. Other defects were much less frequent in boards from unpruned logs.

Pruning *v.* Non-pruning

It is generally accepted that after a pruning treatment, trees grow clear wood on the pruned log. To explore this assumption, clear boards (boards with no defects other than wane) were compared to boards with no knot-related defects. Boards from the cant zone, the zone containing most of the defect core, were excluded. Twenty-seven boards (26.64 m^2 of surface area or 16.7% of all side boards) had no defects. Forty-seven boards (53.25 m^2 or 33% from pruned logs) had no knots. The ratio of the area of boards without defects to the area of boards without knots was 52% ± 22% (95% confidence limits). This seriously challenges the generally accepted assumption that, after pruning, trees grow only clear wood.

From close examination of the database, it appears that all the boards with some defects but without knots contained bark pockets or blemishes; 5% contained resin pockets; 5% contained needle flecks; and no boards without knots were totally clear boards (although they would be accepted by the market as "clear" boards). The issue of blemishes is worth deeper investigation. At present it is unknown if bark pockets and blemishes are extensions of pruning scars, or scars from animal or wind damage, etc. This issue is important as it challenges generally accepted perceptions about what clear wood is and about the quality or value of the pruning treatment. It must be noted that this conclusion is based on very limited data and further research should be conducted to confirm this point.

CONCLUSIONS

The most frequent defects found in boards from pruned butt logs were bark pockets and blemishes and the largest average size defects were areas of needle flecks. It also appeared that in boards from pruned butt logs only 52% ±22% of boards without knots were clear of other defects. All non-clear boards without knots contained bark pockets and blemishes. The most frequent defects in boards from unpruned logs were knots, and they were also the largest sized defects in these boards.

These results should be used with caution as they come from only 259 boards. The purpose of this database was to establish basic relationships between New Zealand *P. radiata* tree characteristics and board characteristics for prediction and planning purposes. Later, the database will be expanded with more boards in order to draw more general conclusions about the New Zealand *P. radiata* resource for the production of appearance boards and millwork componentry.

There are many questions left unanswered. In future studies data will be explored on grade outturn and on defect frequencies and areas within trees. The database of digitised random-width boards will also be used in another series of studies to analyse the component recovery potential of this resource. The boards will be further remanufactured, defected, finger jointed, and edge glued. Remanufactured products will then be assessed for appearance and stability. The analysis of relationship of these product characteristics to the tree characteristics will complete the scope of this trial.

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