HEART SHAKE IN SOUTH AFRICAN-GROWN *PINUS ELLIOTTII*

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ABSTRACT

Heart shake, internal cracks in the radial and longitudinal planes of standing trees, is the most common and serious defect of South African-grown *Pinus elliottii.*

A series of experiments sampled immature and mature trees throughout the Eastern Transvaal region of South Africa. The objectives of these studies were to determine the distribution of heart shake within and among trees, whether the physical characteristics of the trees or any environmental factors were associated with heart shake, the age at which heart shake begins, and the factors that initiate heart shake.

Heart shake was found in all locations sampled. No physical characteristics of the trees or environmental factors could be associated with the incidence of heart shake, although the rate of growth and exposure to strong winds did influence the severity of heart shake in a tree. Within trees most of the heart shakes were located in the butt, extending downward into the stump. Heart shake is initiated in a tree by various types of wounding, particularly by mechanical damage during nursery and field planting stages. Damage to the root collar zone causes a point of weakness that enlarges longitudinally and radially into a heart shake as the tree grows. There is a possibility that there are genetic differences in the incidence of heart shake among families of *Pinus elliottii.* There are very large differences among trees in the severity of heart shake and the degree of resinosis associated with heart shake that cannot be presently explained.

Keywords: Heart shake, *Pinus elliottii.*

INTRODUCTION

Pinus elliottii is the second most commercially important coniferous tree species planted in South Africa (Poynton 1979). When this study was terminated in 1981, a total of 138,022 hectare of this species was then planted in all twelve of the forestry zones of the Republic (Department of Environment Affairs 1982).

In the Eastern Transvaal zone, *P. elliottii* has been grown since the 1920s for both sawtimber and pulpwood production, with the major emphasis on state forest lands being high quality sawtimber production on 30- to 35-year rotations. The basic pine silvicultural system used in South Africa was described in Darrow (1979).

The value and yield of these sawtimber stands have been adversely affected by the presence of resin-infiltrated heart shakes in many of the trees (Fig. 1). Because of the loss in timber value, foresters have been reluctant to reforest with *P. elliottii* despite its generally good growth, strong timber, and resistance to disease and insect pests.

The then South African Directorate of Forestry (now the Forest Bureau of the Department of Environment Affairs) was, and continues to be, the major grower of long rotation *P. elliottii* sawtimber. Thus it has suffered the largest financial losses due to timber degrade caused by heart shake. As a result, the Directorate commissioned a study in the late 1970s to discover the causes of these heart shakes

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FIG. 1. Severe wet-type heart shake in 45 cm diameter butt log from *Pinus elliottii* grown in South Africa (label is 10 cm long).

and to recommend measures to eliminate them in future plantations.

LITERATURE REVIEW

Shake is a defect of standing trees that results from the rupture of the wood structure parallel to the grain and should not be confused with check, which occurs only after the stem is severed from the stump (Wilhelmy and Kubler 1973).

Shake is divided into two types: 1) ring shake, which is a separation between and parallel to the growth rings (Meyer and Leney 1968); 2) and radial or heart shake, which is a separation that occurs across part or all of the diameter of a tree or log. If there is one major crack, the shake is a simple heart shake; if there are more than two shake radii extending outward from the pith, it is a star shake (Panshin and de Zeeuw 1964).

Radial shakes are known in hardwoods (McGinnes 1968; Shigo 1972; Ward et al. 1972) as well as conifers (Koehler 1933; Mayer-Wegelin 1955; Konig 1957; McIntosh and Szabo 1972; Hillis et al. 1976). A recent summary of many of these articles was presented by Kubler (1987). This report, however, is concerned only with the genus *Pinus*.

Volkert (1940), who studied the occurrence of heart shake in *Pinus sylvestris* in Germany, was the first to attempt to discover the cause of the shakes. Other reports of the occurrence of heart shakes in pines have been published since then (Scott 1952; Streets 1962; Queensland Department of Forestry 1962; Barnes and Mullin 1976), but these reports were mainly descriptive. Only Smith (1965) and van der Syde (1976) attempted to explain the origins of heart shake, apart from Volkert.

In South Africa, heart shakes have been

found in *Pinus elliottii, P. palustris, P. roxburghii,* and *P. caribaea* var. *hondurensis,* although only the first species is of economic importance in the Republic (Darrow 1982).

The effect of heart shake on the economic value of *P. elliottii* sawlogs was studied by Smith (1965); Laurens (1977); and Malan and de Villiers (1976). The general conclusion was that although heart shakes did not greatly reduce the volume of sawtimber recovered from logs, they caused a substantial reduction in the value of this timber because of the need to resaw the larger boards into smaller and less valuable pieces to eliminate the defect. The grade of the timber could also be reduced by the presence of resinous patches on the board surfaces that adversely affected the ability to accept paint or glue.

There are three theories about the cause of heart shake: 1) the bending and twisting stresses created when the trees are exposed to strong winds (Koehler 1933; Volkert 1940; van der Syde 1976); 2) long-term stresses such as leaning stresses (Volkert 1940) and growth stresses (Laurens 1977); 3) biological factors such as initial wounding that creates a weak point at which shakes and checks may begin (Mayer-Wegelin and Mammen 1954; Shigo 1972). The possibility that microorganisms can play a role in the creation of ring or heart shakes is mentioned by Shigo (personal communication 1977). Some published information exists to support such a theory (Ward et al. 1972; Chauret and Perem 1976; Hillis et al. 1976; Sachs 1978).

MATERIALS AND METHODS

Research into the origins of heart shake was divided into several stages. First, sixty-five compartments of mature *P. elliottii* were selected in a systematic fashion in eight state forests in many different areas of the Eastern Transvaal to give as full a coverage of the environmental and growth conditions of *P. elliottii* in the Eastern Transvaal as it was possible to estimate.

A large sample of 825 mature trees were felled and cut up into logs of minimum commercial length (2.5 m for sawlogs or 2.6 m for peeler logs) to determine the extent of heart shake within and among trees and locations. The number of logs per tree was dependent on the total commercial length. The small end diameter of each log, called a "face" for purposes of this study (including the stump face), was examined for heart shakes.

Measurements of site variables (such as aspect, slope, altitude, degree of exposure, and slope position), tree physical variables (height, DBH, stem form) and soil variables (soil depth, rooting depth, clay, sand and silt content) were made to determine if any of the variables might have a correlation with the existence of heart shake.

Following analyses of the data by various methods, separate investigations were undertaken to examine different aspects of the problem that had become evident as work progressed. Each investigation was based on different study material and had different methods. [Refer to Darrow (1982) for a detailed description of materials and methods of these studies.]

RESULTS

Distribution of heart shakes among locations

Statistical analyses of the occurrence of heart shake revealed that there were no important differences among geographic locations in the occurrence of heart shakes.

Differences in the estimates of the linear quantities of heart shake (measured as the sum in centimeters of all shake axes visible on log faces) also were not statistically significant, despite the use of mean tree volume as a covariable to eliminate the effect of tree size on the measurements of heart shake quantity.

Association of heart shake with site

No important relationships existed between any of the locational or soil variables studied and the measures of the occurrence of heart shakes or of their linear quantities.

Distribution of heart shakes within trees

Of the 825 trees sampled, 425 (54.8%) had at least one face with a visible heart shake. However, only 782 (10.9%) of the 7,153 faces viewed had a visible heart shake.

The stump zone had the greatest concentration of heart shakes. No less than 49.7% of the visible heart shakes were located on the stumps of the trees studied.

Above the stump face, the occurrence of heart shake dropped rapidly. By the top of the second log (5 m above the stump), the frequency of heart shake was only 13.3%; by the top of the fifth log (12.5 mm) 4.4%; and above the ninth log (22.5 m), no shakes were found.

Association of heart shake with tree characteristics

Based on the sample of 825 mature trees, neither tree size nor form factor had any significant influence on the occurrence of heart shakes within trees nor the linear quantity of heart shakes seen.

A study of the effect of branch size, angle, and frequency along the stem revealed that heart shakes were often found in association with branch stubs, but in most cases only minor radii of major heart shakes were associated with branches. The major shake axes ran between branches and only accidentally included some stubs or branches. Where heart shakes did begin at stubs, the branches or stubs were generally large, steeply angled, and had signs of severe wounding or in-grown bark.

The possible existence of a link with genotype of a *P. elliottii* and its susceptibility to heart shake was raised by the study of two young progeny trials of *P. elliottii.* Using the occurrence of heart shakes visible on the stumps of trees removed in a thinning operation as a criterion, statistical analyses showed that there were no significant differences among families in their susceptibility to heart shake. However, determination of the family heritability of susceptibility to heart shake gave values of 0.433 and 0.349 for the two trials, thus raising the possibility that certain families might be more prone to develop heart shakes than others.

Heart shakes and tree defects

One of the theories about the origin of heart shake is that the shakes are initiated by the wounding of trees in various ways (Shigo 1972). Once a point of weakness has been created by a wound, a shake will form from this point either through the application of stresses within the tree or by the invasion of organisms that weaken the structure of the wood. This idea was also listed by Kubler (1983) as one of the "triggers" for releasing frost cracks in trees.

To test this theory, an attempt was made to associate various tree defects with heart shakes in the mature sample trees. When the logs were cut from each tree and the incidence and linear quantity of heart shake were recorded for each log face, a note was made of any defect present within 0.5 m of either side of the cross-cut. If more than one defect was observed, the one subjectively determined to be more important was recorded.

Defects, as defined by Darrow (1982), were relatively rare. Only 11.9% of all logs studied had a defect near the cross-cut ends. But of 849 recorded defects, 463 (54.5%) were found on or just above the stumps of the trees.

At the stumps the major defects were:

Defect	Frequency
1) severe resin infiltration	291
2) discolored wood	76
3) internal wounds	50
4) rot	23

All of these defects can be associated with some type of mechanical or biological damage to the trees. Rot and severe resin infiltration are reactions to injury (Shigo 1972; M. Taras personal communication 1977). Internal wounds are obvious injuries, and discolored wood in conifers is generally indicative of incipient rot (Shigo 1966).

Above the stump zone, the number of log positions with a defect declined rapidly. The most significant defects in the region of the third to the sixth logs (7.5 to 15.0 m) were those associated with branching, i.e., large forks, coarse knot whorls, and resinous branch stubs.

Only severe resin infiltration was a comparatively common defect and one in which a large majority of the sample was associated with heart shakes. Resinous branch stubs, the next most common defect, were only one-half as frequent.

Severe resin infiltration is a reaction to some other factor and thus cannot be considered the cause of heart shake itself. Nevertheless, the high frequency with which the defect was associated with heart shake, particularly with severe shake, did indicate that the cause of this defect should be found on the off-chance that the same factor caused the associated heart shakes.

The predominance of heart shakes and defects in the lower ends of tree stems, particularly on the stumps, indicated that more detailed explorations had to be made into the origins of heart shakes within stumps. Several exploratory studies, in which stumps of mature and immature trees were excavated and split open with wedges, revealed that all heart shakes visible on the stump progressed downward into the stump to the vicinity of the root collar zone. In almost all cases, the heart shakes were found in association with three conditions, either singly or in combinations: 1) nursery soil encased in the root mass; 2) distorted taproots; and 3) small dead, resinous roots (mostly taproots) originating from the root collar (Figs. 2 and 3).

To confirm the repeated evidence that there was a close association between these factors and heart shakes, an investigation of the relationship of heart shakes and abnormalities within tree stumps was organized. Twenty-five stumps from one *P. elliottii* compartment in each of four state forests were excavated and dissected. The compartments chosen were widely scattered and represented different site conditions.

Table 1 presents a summary of the four compartments and shows clearly that only embedded nursery soil and dead roots by themselves are well associated with the presence of heart shakes in the tree stumps. Distorted tap roots play a minor role unless coupled with embedded nursery soil. The frequency of heart shakes then increases to over 90% in those trees in which both abnormalities are found.

The R × C test of independence using the *G*-test (Sokal and Rohlf 1969) showed that the abnormalities "dead roots only" and "nursery soil plus distorted roots" had statistically significantly higher levels of heart shake occurrence than the mean of all abnormalities while "no abnormalities" and "distorted roots only" had significantly less. Three of the abnormalities could not be classified because they had too few values to be analyzed correctly.

To find further proof that the presence of embedded nursery soil was important for the initiation of heart shakes, ten young, naturally regenerated trees from Wilgeboom State Forest and twenty-five trees from a five-year-old bare-rooted seedling planting experiment in Tweefontein State Forest were excavated.

The ten naturally regenerated trees were aged six to nine years. Three trees had small shakes inside their stumps. Two of these shakes were directly associated with wounds at or near the root collar, and the third was a shake 26 cm below the root collar where three vertical roots fused, trapping natural soil among them.

One only of the trees planted as bare-rooted seedlings had shake—just above fused vertical roots below the root collar. Others displayed wounds at the root collar (probably rat or planting damage), embedded forest soil, and severe root distortions. Some resinous tissue was present where such defects occurred, but no shakes were found. These trees, however, were still very young and thus may not have been representative of more mature bare-root planted *P. elliottii* trees.

Association of a heart shake with defects at the same log position is an indicator of a possible cause for that heart shake. However, this association left 274 log faces with shakes that could not be associated with any defect in their logs.

Research showed that heart shake systems (vertical extensions of shake axes through the

FIG. 2. Clods of nursery soil trapped in young stump near root collar. Note associated heart shake and resin infiltrated zone that extends to the stump surface (label is 10 cm long).

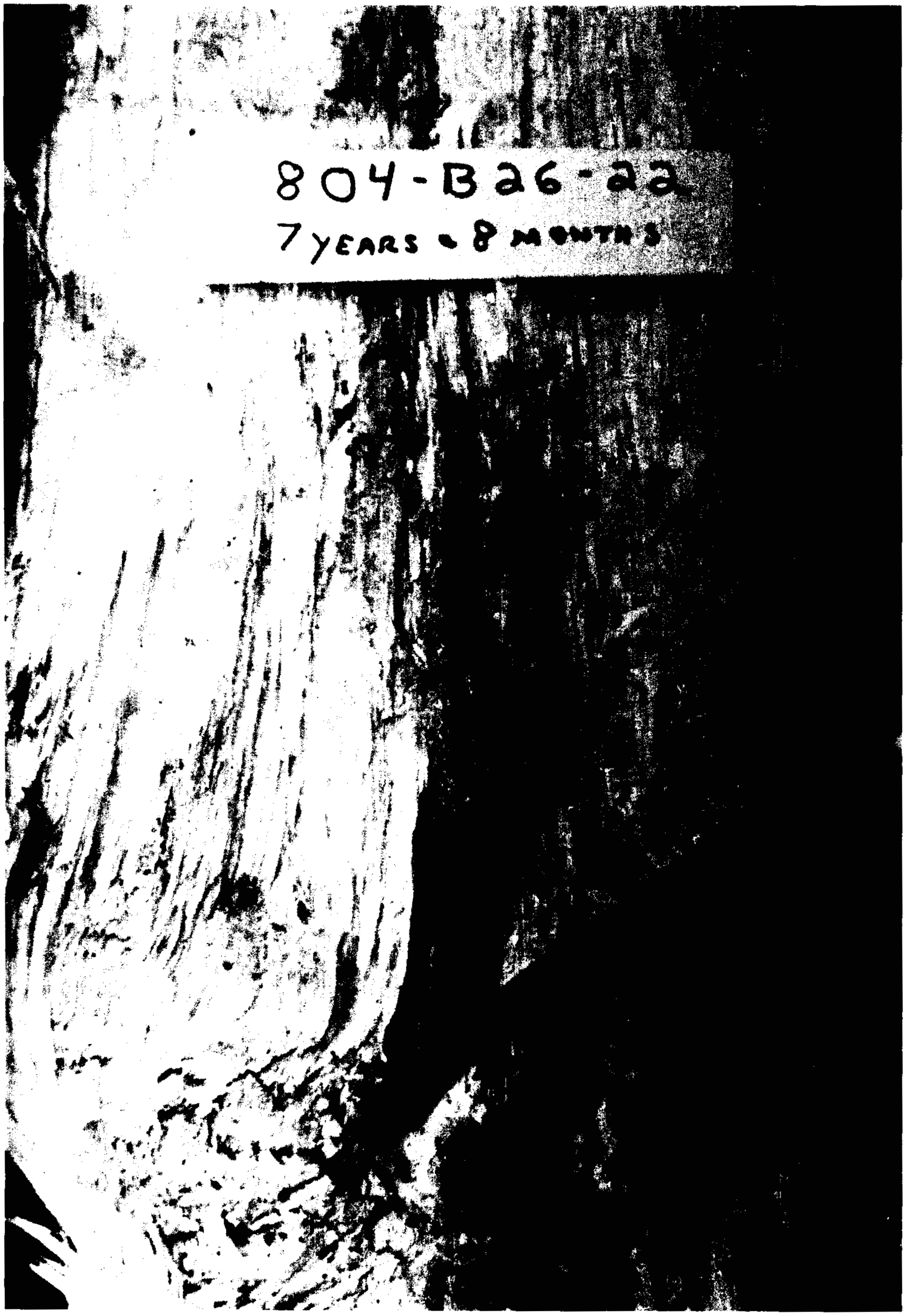

FIG. 3. Dead, resinous taproot of young pine associated with heart shake and resin infiltrated zone extending upward from root collar (label is 10 cm long).

TABLE 1. *Association of abnormalities with the presence of heart shake in planted* Pinus elliottii, *Eastern Transvaal, South Africa.*

Abnormality	Trees with shake	Trees without shake	Total trees	Trees with shake as percent of total
No abnormality	2*	18	20	10
Nursery soil only	5	3	8	63
Distorted roots only	2*	27	29	7
Dead roots only	6**	2	8	75
Wounds only	6	9	15	30
Nursery soil and distorted roots	10**	1	11	91
Nursery soil and dead roots	4	0	4	100
Nursery soil and wounds	1	0	1	100
Distorted roots and dead roots	0	1	1	0
Dead roots and wounds	2	1	3	67
	38	62	100	$\bar{x} = 38$

* Significantly less trees with heart shake.
** Significantly more trees with heart shake.
Significance of abnormalities based on R × C test of independence using the *G*-test (Sokal and Rohlf 1969).
N.B. Nil values cannot be used in this analysis.

stem of a tree) joining more than one log position could exist. Thus, the probable cause of a heart shake in the second log—a large side branch for example—may be the cause also of heart shakes on the third and fourth log faces because all three shakes were part of one unified system. As no defects were noticed in the immediate vicinities of the heart shakes in these log faces, they would be considered as unassociated with defects. If, however, it is known that all three heart shakes formed part of the same system, then one could assume that the defect associated with the second log is the possible cause of the entire heart shake system.

The association of defects with heart shake systems was clearly shown by a study of the 169 isolated (not associated with stump shakes) heart shake systems. Seventy-seven percent of these systems were associated with some defect, the most common being resinous branch stubs and coarse knot whorls (Table 2). This degree of association of isolated heart shake systems with branch-related defects is understandable because most of the isolated shake systems began or at least extended into the unpruned zone of the trunks above 7-m height.

Only one third of the isolated heart shake systems (56), comprising 67 log faces could not be associated with any defect. Such associations might have existed, however, because the method used for listing defects only considered 0.5 m either side of the cross-cut. Defects may very well have existed within the logs or on the log surfaces not observed.

DISCUSSION

The basic premise of this study about the cause of heart shake is based on Shigo's (unpublished) theory of defect initiation. First, the tree must have a propensity for a defect, most often expressed in the genetically controlled properties of the wood. Second, there must be a wound to weaken the wood structure or to expose it to a microorganism that will weaken

TABLE 2. *Association of isolated heart shake systems with log defects in* Pinus elliottii.

Defect	Number of systems	Percentage
No defect	56	33.1
Large side branch	20	11.8
External scar	3	1.8
Fork	4	2.4
Knot whorl	26	15.4
Rot pocket	0	0.0
Resinous stub	32	18.9
Stained wood	1	0.6
Internal wound	4	2.4
Resin infiltration	23	13.6
Total	169	100.0

it. Last, there must be some extreme condition that will release the factors that lead to the shake. This can be a climatic condition or the appearance of a microbiological agent that invades the tree and causes the defect.

The evidence collected from the various field experiments pointed out the importance of wounding as the major possible cause of heart shake in South African-grown *P. elliottii.*

What caused the abnormalities that were considered as possible causes of heart shake, particularly those associated with the stump? A close examination of traditional nursery and planting practices in South Africa revealed some likely causes.

For over sixty years, plants grown in South African forestry nurseries were transplanted from germinating beds into wooden boxes that held 25 to 36 seedlings. The seedlings grew in these boxes until ready for planting out.

In the early days of forestry in South Africa, and particularly in the 1920s and 1930s when the large scale pine afforestation programs in the Eastern Transvaal were underway, large seedlings were favored because most planting was then done in virgin grasslands. Because few methods of weed control were available, tall seedlings were needed that could quickly outgrow the weed competition.

If seedlings were allowed to remain in boxes for more than a few months, root distortion was inevitable. Tap roots bent sideways to follow the bottom of the box. When the plants were lifted from the box by a laborer with a planting trowel, some of the tap roots and large side roots were wounded or severed. Because it was standard practice when using the box method, to take some of the nursery soil with the seedling, the laborer would fold loosely hanging roots around the ball of soil. This clump of soil was effectively trapped within the root mass. Damaged roots were also hidden within the soil ball.

When the seedling was placed in the planting hole, loose roots were bent or turned upwards as the seedling was pressed into the hole. Following the placement of the seedling, the laborer would stand up and firmly tamp the soil around the seedling with the soles of his boots. This action enhanced the root distortion.

As the trees grew, the developing roots enclosed the dead root ends or nursery soil. The foreign body or dead tissue thus encased within the stump was a likely agent for the initiation of a heart shake.

It should be emphasized that such wounds or embedded soil must occur near the root collar zone of the original seedling. For some reason, soil or dead roots trapped within the root mass after the first few years become isolated within the mass of wood tissue and do not cause many, if any, heart shakes. Dissection of stumps showed that unless the abnormalities occurred at or near the original root collar zone, the initial tiny shake and accompanying resin infiltration rarely occurred.

The importance of the presence of wounding of the roots as a cause of heart shake was further emphasized by the consideration of the phenomenon of root distortion itself. Root distortion is almost always the result of tree planting. In no case, however, did either forestry literature or this study point to any relationship between the presence of heart shake and severely distorted roots alone. Recent results from a trial planting in 1980 to determine whether production types of seedling (wooden box, plastic sleeve, or bare-root) or method of handling at planting (gently, normally, or roughly handled) had any effect on the incidence of heart shake concluded that type of planting stock, and not handling method, could cause or aggravate heart shakes (Christie and Tallon 1991).

Other sources of wounding to seedlings were:

1) scraping of the stem or root collar of the seedling with the planting trowel;
2) damage to the seedling by the boot of the laborer as he pressed the soil down around the plant;
3) feeding damage by rats or mice who eat the bark near the root collar of the newly planted seedlings particularly in areas where grass and weed growth is heavy and cleaning operations are delayed.

The detailed physiological study of precisely how heart shakes develop, once the initial wound has been created, lay outside the scope of this study. A review of how other factors, such as wind, growth stresses, and biological agents, could influence the size and distribution of heart shakes found in trees was presented by Darrow (1982).

Particular emphasis was laid in the dissertation on how the mechanics of wood cleavage, acting together with growth stresses and those caused by wind, could lead the initial small wounds to develop into large shakes.

CONCLUSIONS

The overall conclusion of this study is that wounding is the initiating factor for heart shake in South African-grown *Pinus elliottii,* whether in the stump or in the stem above it. Once the originally small heart shake is formed, by some so far unknown response of the tree to wounding, environmental conditions and physical characteristics of the tree influence the number, location, and linear quantity of heart shakes found.

The most important causes of stump-related heart shakes were the traditional South African nursery and planting practices, particularly the use of planting stock in which nursery soil was trapped within the root mass of the seedling. Damage caused to the main roots of large planting stock also contributed to the incidence of heart shake.

Since this study was concluded in 1981, South African commercial tree nurseries have changed mainly to the use of various types of plastic or styrofoam containers and composted bark rooting medium for the production of forestry seedlings. Some older nurseries continue to use polythene sleeves filled with topsoil, while a few bare-root pine nurseries are functioning. It is thus likely that the most of the conditions under which the trees of the original study were produced and planted will not be repeated.

Care must still be taken, however, in the handling and planting of seedlings to avoid root damage and severe distortion. Dead roots are closely associated with heart shakes.

Heavy early pruning of the stems of trees should reduce the severity of branch-related heart shakes, at least in the zone pruned.

Care should also be taken in early thinning operations in pine stands to avoid wounding of the upper stems of remaining trees and of the butt zones during extraction. Such wounds might induce ring or heart shakes.

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