ECOLOGICAL TRENDS IN THE WOOD ANATOMY OF *Leptospermum scoparium* J. R. et G. FORST (MANUKA) FAMILY: MYRTACEAE

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ABSTRACT

The wood anatomy of manuka growing in five different habitats was analysed to establish whether or not different anatomical forms exist. The study involved the use of the light microscope for obtaining vessel and fibre quantitative data such as their length, width, wall thickness, density of vessel elements in a transection and average grouping of vessels. The confocal microscope was used to measure the area of perforation plates of fibriform vessels and wide vessels. The study also involved the use of the scanning electron microscope for determining the presence of cell wall sculpturing in the walls of wide vessels. The data was analysed by univariate analysis to determine any variation of wood characters within a population and between populations in the five habitats. The habitats were margins of lowland forests, swamp, sand dune, subalpine and hot thermal soils.

The study has established variations within each population in all the cell types. The study showed that plants differed anatomically in the average sizes of their cell length, width, wall thickness, abundance of vessels, area of perforation plates and the average grouping and the type of grouping of vessels. There was also variation of wood anatomy between populations in most cell characters except for the length of wide vessels, length of fibriform vessels and wall thickness of fibre-tracheids. In these characters the wood anatomy of manuka was more homogeneous.

The significant trends were that margins of lowland forests had wide and thick walled cells in all the cell types and also had high average group of vessels and large area of perforation plates of fibriform vessels and small area of perforation plates for wide vessels. It had short libriform fibres and fibre-tracheids. The swamp habitat seemed to follow margins of lowland forests except that it had the longest fibre-tracheids and libriform fibres and had the greatest area of perforation plates for wide vessels. Both of these habitats had the lowest density of wide vessels. Sand dune, hot thermal soils and subalpine habitats had on average the smallest vessels in terms of diameter and wall thickness and area of perforation plates, but had high abundance or density of wide vessels. Sand dune had wide and thick walled libriform fibres like margins of

lowland forests. Subalpine and hot thermal soils had comparatively small fibres in all dimensions.

Even though variations were established in most of the cell characters, the correlation of wood with ecology was less pronounced as compared to that found in families and genera in past research. Significant trends were manifest in diameter, wall thickness and density of wide vessels. The margins of lowland forests and swamp (more mesic habitats) had great diameter and cell wall thickness. They also had low density of cells. The other habitats, sand dune, subalpine and hot thermal soils (less mesic habitats) had comparatively narrow diameter of wide vessels, thin cell walls and high levels of wide vessels densities. It was found that the other characters such as length, width, wall thickness of fibriform vessels, libriform fibres, and fibre-tracheids, grouping and area of perforation plates of wide vessels showed complex and overlapping ranges between the habitats and had no significant correlation with ecology. From this research it is clear that general trends of ecological adaptation were evident and also that manuka has its own specific ecological trends.

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1.0 INTRODUCTION

1.1 Wood anatomy and ecology

Pioneer plant anatomists have long acknowledged the relationship between wood anatomy and environmental factors. Research conducted over many decades has shown that plants actively change their pattern and form of development in response to environmental variations rather than resist the effects of such environmental changes. Some well-known adaptations to the environment, especially to dryness, include dying back of branches, deciduousness, crassulacean acid metabolism, stomatal closure, heavy cuticle and extensive root system.

Recent anatomical studies have shown that xylem structure also alters as a response to variations in rainfall, water availability in the soil, temperature, humidity, exposure to the sun or shade (Carlquist, 1980). Those wood anatomical features which have been shown to correlate with a species habitat include length and diameter of vessel element, numbers of vessels per millimetre squared of transection, degree of grouping, pit density and diameter, number of bars per perforation plate, and wall thickness. Qualitative characters correlated with ecology include growth ring type, presence of helical thickening, presence of warts on the internal wall of tracheary elements and the presence of vestures in their lateral pits (Esau, 1959; Lindorf, 1994; Carlquist, 1980, Carlquist, 1988; Baas, Werker and Fahn, 1983; Mauseth and Plemons-Rodriquez, 1998).

Several investigators have hypothesized that xylem anatomy is an important factor that influences not only species distribution among communities in different sites, but also ecological dominance within and among communities (Guthrie, 1989). The broad conclusion is that selective forces for evolution of the different wood features in different habitats exert an adaptation for conductive safety, conductive efficiency and mechanical strength (Carlquist, 1988).

This study on manuka is one of the few that involves the investigation of ecological trends in wood within a species growing in different natural habitats. Most of the mentioned studies involve the assessment of ecological trends within families and within and between genera. Some early investigations such as those of Sastrapradja and Lamoureaux (1969) and of Graaff and Baas (1974 in Noshiro et al. 1994) did not succeed in finding a correlation between wood structure and non-anatomical factors such as altitude and they concluded that wood structure within a species was constant. But Noshiro et al. (1994) pointed out that some of these studies used too few specimens; in other cases only one specimen from a locality and in some other cases the variation was not assessed within a population at each locality.

Noshiro et al. (1994) studies on *Alnus nepalensis* showed that altitude had the greatest effect on wood structure, especially on vessel element length, perforation plate bar number and fibre-tracheid length. Noshiro and Suzuki (1995) found that *Rhododendron arboreum* showed marked correlation of wood characters with altitude. They pointed out that a significant correlation is found only in studies carried out in a small region. In a significant study, Bissing (1976 in Carlquist, 1980) collected wood samples from selected species cultivated in Rancho Santa Ana Botanic Garden. He compared these with samples collected for each of these species from the wild populations from which the Garden plants were derived. His studies showed increase in ring porosity in *Lupinus albifrons* plants cultivated in more xeric conditions in the garden than in a mesic condition in the wild. There was a decrease in the density of vessels in mesic sites than in xeric sites. *Rhododendron* plants cultivated in xeric conditions in the garden showed a decrease in bars per perforation plate.

1.2 Morphology of Manuka

L. scoparium, manuka, tea tree, an indigenous species of New Zealand and Australia, varies in form from a semi-prostrate shrub to a tree of up to 4 m to 12 m tall. The stem's diameter is up to 20 centimetres (Ronghua, Mark and Wilson, 1984). Its bark shreds in long strips. Branchlets and young leaves are clothed in silky hairs. It has sub-sessile

leaves that are narrow lanceolate to ovate in shape, with a pungent smell. Its sessile flowers are solitary borne axillary or occasionally terminal on branchlets. Its seeds are enclosed within a 5-celled woody persistent capsule. Manuka flowers in September through to March (Webb, Sykes and Garnock- Jone, 1988).

1.3 Wood Anatomy of Manuka

Meylan and Butterfield (1978) and Patel (1994) describe the wood anatomy of manuka as follows:

1.3.1 Vessels

The wood has a tendency towards ring porosity. Growth rings are mainly distinct. The grouping is described as solitary, oblique chains and clusters of 2-5 cells. The perforation plate is a simple perforation (rarely scalariform perforation plate). Simple perforations in many vessels studied by Patel had slightly irregular to markedly irregular outlines. Vessels are narrow and are of medium length, average of 0.48mm in length and width of 0.22-0.80 mm. The walls of vessels are mostly smooth but a light warty layer can overlay some. The lateral pits are alternating, vestured, bordered, and oval to circular in outline. Average diameter of pits ranges from 4-7 um. The vessel to axial parenchyma and vessel to ray pits are similar to intervessel pits though larger. The vestures do not spread beyond the pit apertures on to the lumen surface of the vessels. Helical thickenings are absent. Tyloses are sometimes present. The outline of vessels is more or less oval to circular tending towards angular.

1.3.2 Imperforate tracheary elements

Imperforate tracheary elements are libriform fibres, fibre-tracheids, vasicentric tracheids and vascular tracheids. The fibres are moderately thick to very thick walled, angular in transverse outline, non-septate. Their pits are small and apertures are slit like. They are bordered and sometimes vestured. Vestures are inconspicuous and helical thickenings are

absent from fibres. Vasicentric tracheids have bordered pits abundant in tangential and radial walls, vestures inconspicuous, helical thickening absent. Fibre-tracheids have an average length of 0.91 mm with a range from 0.39-1.69mm. Bordered pits with lenticular pit aperture present in tangential and radial walls, vestures are inconspicuous, absent helical thickenings, non-septate in fibre-tracheids. Fibriform vessels have small to very small perforations that are often axially elongated. They have one perforation at each end or two randomly arranged on the lateral wall. Axial Parenchyma is described as scanty paratracheal (distributed around vessels) and diffuse (scattered randomly) to diffuse in aggregate apotracheal (distributed without relation to vessels (Carlquist, 1988). The rays are uniseriate and multiseriate average 0.24 mm in height. The rays consist of heterogeneous type II and III and are 1-3 cells wide. Ray pits are small, circular in outline and simple. Large crystals are present in chambered axial parenchyma strands. One large crystal is often present per chamber.

1.4 Distribution of Manuka in New Zealand

The ability of manuka to grow in a wide variety of habitats makes it an interesting plant for this eco - wood anatomy study. Its growth extends throughout the two main islands of New Zealand and beyond the three King Islands in the north to Stewards Island in the south. It tolerates a wide variety of soil conditions. It usually dominates gumland scrub on highly depleted soils in the North Island (Esler and Rumball, 1975). Manuka is a characteristic of edaphically dry pumice on Central North Island's volcanic plateau (Elder, 1962) (in Rongua et al. 1984). It is also found in permanently wet terraces in southern Fiordland (Wardle, Mark and Baylis, 1973), lake shores, margins of tidal rivers (Morton and Miller, 1968) as well as in low land to montane peat mires particularly in Southern New Zealand (Rongua et al. 1984). It also grows in some thermally active sites in the Central North Island. In Karapiti steam fields, manuka has been found to grow in hot mud of temperatures of 60–80 degrees Celsius (Given, 1980). Watson and O'Loughlin (1985) describe it as a plant that grows in areas throughout New Zealand where low fertility or dry soils tend to limit competition from other pioneering tree species. Manuka is generally plentiful and wide spread dominating early phases of

succession in forested areas. It occurs as an important member of climax woodland in semi arid areas (Cook, Mark and Shore, 1980). Manuka invades grounds disturbed by fire and grazing in many parts of New Zealand (Primack and Lloyd, 1980). Esler and Astridge (1974) describe manuka as a plant that is much more resistant to wind borne salt than kanuka. These authors described manuka probably as the most widely distributed and abundant and environmentally tolerant member of the New Zealand wood flora. It is one of the most plastic species and very suitable for this study.

1.5 Rationale:

It is a fundamental tenet of Darwinian evolution that species possess morphological and anatomical features that reflect adaptation to their environment. Manuka is a plastic species that grows in a wide variety of habitats in New Zealand. Plasticity is regarded as a mechanism compensating for lack of locomotion in plants and supplementing the role of genetic variation as a determinant of wide ecological amplitude and persistence in fluctuating conditions (Grime, Crick and Rincon 1986). This study hypothesizes that manuka may show variation in wood anatomy in plants that grow in widely different habitats.

1.6 Aim:

The primary aim of this study is to compare the wood anatomy of manuka from a wide variety of habitats to establish whether or not different anatomical forms exist. This study is geared at comparing wood variation within a population and between populations growing in a wide variety of habitats.

1.6.1 Null Hypothesis

The null hypothesis for this study is as follows:

There are no differences in wood anatomy of manuka within and between populations growing in distinctly different habitats. The study predicts that there will be no significant differences in wood anatomy of manuka growing in different habitats.

The study involves the use of light microscopy for obtaining vessel and fiber quantitative data, such as the length, width, density of wide vessel element in a transection, wall thickness. The confocal microscope will be employed for measuring the area of perforation plates. It also involves scanning electron microscopy for establishing the presence and variability of vestures in lateral pits in the wall of vessel elements. The data will be analyzed statistically using analysis of variance to find any variations. The study covers five habitats, and these are, margins of low land forests, dry sand dune country, hot thermal soils, sub-alpine and wet swampy habitats. In the following chapters the literature behind this research, the methods, results, discussion and conclusions are extensively discussed.

2.0 LITERATURE REVIEW

2.1 Historical overview of ecological adaptation of wood

Throughout the history of wood anatomy, ecological influences have been investigated rather intermittently. The few researchers cited in the literature make this evident. Carlquist (1975) cites Sanio (1872) who made an early contribution to this field. Sanio studied Pinus *sylvestries* and found that tracheids of secondary wood were shorter in the early growth rings and increased towards the outside. Sanio also found that the length of tracheids increased from the base of the plant to the top. Bailey and Tupper (1918) (in Carlquist, 1975) observed that there was a decrease in tracheid length in outer most annual rings of conifers. The same trend was later observed in numerous studies conducted by Spurr and Hyvarinen (1954), Di woodie (1961) and Dezeeuw (1965) (all in Carlquist, 1988). Bannan (1965)'s study on mature conifer trees observed shorter tracheids in wider growth rings.

The earliest attempt to relate ecology to wood was that of Mell (1910) (in Carlquist 1975) who observed longer libriform fibers in individuals of *Junglans californica* in more mesic sites. Another pioneer was Starr (1912) (in Carlquist 1975). Starr conducted studies on *Alnus incana*, in which he found that mesic plants had fewer vessels per square mm compared to xeromorphic ones. The works of Chowdhury (1939, 1940, 1947) (in Carlquist 1988 and in Metcalf and Chalk 1979) showed a relationship between growth rings in some species and the sequence of climatic events in which the growth rings were produced. Chowdhury compared growth rings to temperature, rainfall, and humidity and Chowdhury made it quite evident that in essence a growth ring contains within it contrasting modes of adaptation to different climates.

However, Carlquist (1975) pointed out that Baily and Tupper (1918) were the first to come up with the major comparative investigation on sizes of xylem cells. They actually provided an important tool, the tracheary element length, which was thereafter used to relate wood anatomy to ecology. Other researchers in the past

decades like Webber (1936) (in Carlquist 1975), studied desert and chaparral shrubs of southern California, and found species with notably short lengths of vessel elements. Cumbie and Mertz (1962) related xylem anatomy to habit of growth. Tabata (1964) (in Carlquist 1975) related number of bars per perforation plate and number of vessels per unit area of transection to habitat.

Novruzova (1968) (in Carlquist, 1975) observed shorter narrow vessels with simple perforation plates in plants of drier habitats as compared to plants from wetter habitats, which had longer wide vessels. Mesic areas had plants with a higher proportion of scalariform perforation plate. Novruzova also observed the absence of borders on pits of imperforate elements in plants of drier habitats as compared to those of mesic habitats. Species of drier habitats had fewer bars on their perforation plates. His observations closely agreed with those of Carlquist (1966) who made similar investigations on the wood of the following families, Goodeniaceae, Asteraceae, Companulaceae, Brassicaceae and their wood features correlated with ecology. Carlquist found that narrow vessel elements, shorter vessel elements, more numerous vessels per group, shorter imperforate elements and shorter rays correlated with an increased xeromorphy. His study on Asteraceae showed that there is a distinct decrease in both vessel diameter and vessel element length with increasing aridity. Banaan (1965) found that trees that inhabited favourable sites tend to have longer tracheids compared to those in less favourable sites. Dadswell and Ingle (1954) found longer wider vessel elements in tropical species compared to those of temperate species for *Nothofagus.*

These early contributions were not without serious difficulties or limitations of which some still show up in current work of eco-wood anatomical studies. But it should be mentioned that these early findings provided an excellent foundation for subsequent studies on eco– wood anatomical studies.

2.2 Difficulties in establishing ecological trends in wood anatomy.

Correlating tracheary element characteristics with the ecological conditions has always been extremely difficult. This could be due to the fact that there are many variables associated with the problem, which leads to an extremely complex system of interrelating factors. Below is a detailed overview of the various difficulties encountered in relating ecological factors and wood anatomy.

2.2.1 Interrelated Ecological parameters

Tracheary elements transport water under tension and pressure from the soil to the transpiring foliage apparatus, i.e., leaves and stems. The ecological factors directly related to them are:

Rainfall or water availability
Temperature
Humidity
Exposure to the sun and shading
Soil conditions such as texture and structure of the soil, nutrient availability, soil pH and drainage
Seasonality
Presence of other organisms, for example, mycorrhizal associations (Carlquist, 1975)

All or at least many of these factors modify xylem formation in plants.
Roberts (1988) stated that during plant growth, environmental changes have an effect on the cell expansion rate, wall thickening and duration of cytodifferentiation. Figure 1 below shows how the above factors may interrelate and leads to a series of complex effects on the plant that eventually result in xylem modification.

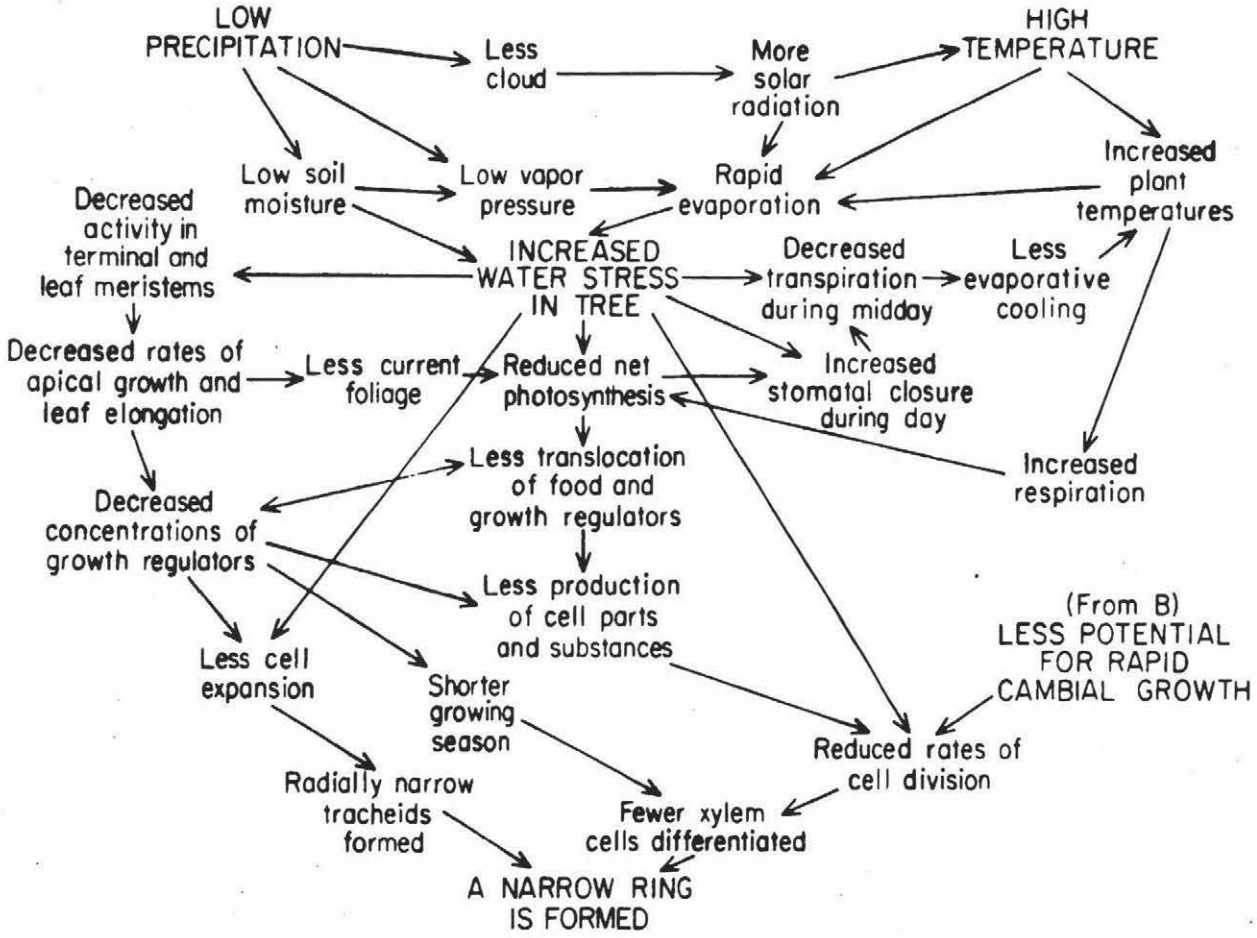


Figure 2.1. Relationships that cause climatic factors of low precipitation and /or high temperature during the growing season to lead to the formation of narrow growth rings. (Adopted from Fritts, 1976)

From this figure, it can be seen that low precipitation results in low soil moisture, which then causes increased water stress in the tree. As a result there is less translocation of nutrients and growth regulators, decreased concentration of growth regulators, resulting in less expansion of cells. Narrow tracheids are formed as a result and thus the formation of narrow growth rings (Fritts, 1976). Since there are numerous interrelating variables, it is quite difficult to identify which variables are in operation at a time and their extent of influence.

Due to the above difficulties, researchers resort to a less thorough approach in describing ecological conditions than this theoretical ideal. For example Baas, Werker and Fahn (1983) in their study in the Middle East, use the broad ecological categories, arid, Mediterranean, hygrophyllic and synanthropic to distinguish the woody flora of the Middle East. The flora of Java was divided into rain forest and monsoon categories. For the northern temperate region no ecological divisions were recognized. While this approach certainly simplified matters, such less thorough identification of variables may not provide the necessary degree of precision required in pinpointing all potentially recognizable differences between tracheary elements derived from differing ecological conditions.

2.2.2 Overriding factors in the effect of ecology on wood

In relating wood anatomy to ecology, Carlquist (1988) stated, "one must remember that the plant habit and foliar apparatus can be overriding in their effects". Overriding factors can be one or more of these in a plant: deciduousness, die back of branches in response to periods of dryness, extensive root system (deep or superficial), mycorhaezal association, and mid-day stomatal closure. Carlquist states that mycorrhiza serve as a kind of enormous extension of roots, they are also effective in transmitting quantities of some elements such as phosphorus to vascular plants. These are particularly effective ways of management of water stress (Carlquist, 1988). The characteristics of a plant's leaves will have an effect on the characteristic of the attendant xylem. For example, in a plant with leaves that have a low transpiration due to a thick cuticle cover, a less efficient conduction system may be required, compared to a plant with leaves more prone to water loss. Lindorf (1994) and Carlquist (1994) noted that xerophytic adaptations such as assimilating stems, succulence, and a deep

root system might mitigate the xeromorphic wood appearance and to some extent lend it a mesormophic characteristic. Carlquist (1988) advised that a researcher should be well versed with the plant to be able to identify its multiple ways of adapting to a single ecological factor and to eliminate the effect of the hidden overriding factors. Integrating leaf types and their physiological characteristics with xylem and with ecology at the same time represents a definite challenge (Carlquist, 1980).

2.2.3 Difficulties related to species.

Differences between species

Within a specific environment, different species of plants may have quite different xylem characters, which, as mentioned by Carlquist (1980), enable them to exploit the habitat differently. For example, *Rhododendron*, *Myrica* and *Sequoia*, grow together in the red wood forest of Northern California. These have very different xylem characters but grow in the same environment. Phylogenetic differences would probably account for a great deal of the disparity between tracheary elements of these unrelated genera. It is apparent that the evolutionary level attained by these plants must be considered (Carlquist, 1988).

Differences within a species

Plant characteristics, including those of xylem may be quite variable due to genetic variation within a species. For example, in some species of conifers, trees of similar age are known to have variable tracheid lengths (Carlquist, 1975). Generally trees growing in a "more favourable" site tend to have longer tracheids compared to those in less favourable ones (Bannan, 1965). Additionally plants that are genetically very similar, or even identical may display marked phenotypic plasticity in response to varying environmental conditions (Harlow, Harrar, Hardin and White, 1996; Baas et al. 1983). This phenomenon of phenotypic plasticity was clearly shown by studies on *Helianthemum scoparium* and *Leptodactylon californicum.* These species lost the diffuse porous condition in favour of distinct growth rings when reestablished and cultivated in the xeric conditions of Rancho Santa Ana Botanic Garden compared to the same species growing in their mesic native habitat (Bissing, 1976 in Carlquist, 1980)

Differences within an individual

Vessel may change markedly from inside to the outside of a woody stem. Cheadle (1942) (in Carlquist, 1975) observed that vessels tend to be shorter in roots and progressively longer in stems, inflorescence axes and leaves. Vessels tend to be shorter in branches than in the main stem. From the pith to the cambium, vessel element length changes markedly during a juvenile period, which may be brief or prolonged. They tend to be wider in roots than in the stem of a given species but there could be exceptions (Carlquist, 1988). There are marked differences in dimensions of tracheids in branch tips, mature stems, main roots and lateral roots (Bannan, 1965). For instance tracheid length increases from the base of the plant towards the top up until a certain height; above that height they tend to shorten again (Carlquist, 1975). Injured or stunted conifers have shorter tracheids. Further more there is even considerable variation in tracheary element length within a single growth ring. For example, latewood tracheids have a greater length than those of early wood (Carlquist 1975). Tracheary elements at the internode are smaller in diameter than nearby elements (Roberts, 1988). In ferns according to White (1963) (in Carlquist 1975) tracheids are longest in petioles, intermediate in roots and shortest in rhizomes. This is attributed to the various portions of a plant differing in efficiency in conduction and of safety in the conductive system (Carlquist 1980). The above statements call for consistency in sampling a plant for comparative reasons.

2.2.4 Difficulties in measuring tracheary elements.

From the above discussion, it is quite evident that taking measurements from different parts of a plant for comparative purposes is inappropriate. Comparing quantitative measurements of tracheary elements from the stem of one plant and from the roots or even the branches of another in an attempt to show their ecological trends is a futile exercise. Lack of sampling replication has been noted in some papers and it is statistically unacceptable. For example, Lindorf (1994) took measurements from only one specimen in a species.

Zimmerman (1983) noted that tracheids become longer and wider with increasing age. This means that the age of plants should be taken in to consideration when

investigating ecological trend. Carlquist (1980) mentioned that authors measure the diameter of vessels differently, others measure the lumen, while others include the walls even though the International Association of Wood Anatomists has standardized the method of making measurements.

Carlquist (1988) states that vessels of lianas (wood vines) are wider than in closely related trees. Noshiro and Suzuki (1995) suggested that there should be a consideration of plant size in taking measurements. It is important that specimens are from the same position in the different plants, from plants of similar age where applicable and are from plants of the same habit.

2.3 Ecological trends in xylem

Despite the difficulties stipulated above, there is still ample evidence on ecological trends in wood anatomy. In this section an attempt is made to show the relationship between characters of tracheary elements and the ecological conditions as demonstrated by numerous researchers.

2.3.1 Xeric and mesic xylem vessel characters:

The ecological habitats that plants may adapt to has been basically classified into two extremes, xeromorphic and mesomorphic. Xeromorphic habitat, according to Baas et al. (1983) study in the Middle East includes arid areas, which could be salt mashes, steppes and sand dunes. Areas with low humidity and also those that experience frost are included here. Here there is low rainfall and species are subjected to very prolonged dry periods. Salt marshes and alpine are included because they cause physiological drought. The mesic habitats include areas with temporary streams or along lakes or oases, rain forests, monsoon forests, areas receiving various amounts of irrigation, and any other area that has sufficient rainfall and relatively uniform rates of transpiration. According to Carlquist (1970) the most important underlying factors are rainfall and temperature.

Characters or features of the vessel elements can often be matched to a specific habitat type (Heenan, 1997). Baas et al. (1983) and Carlquist (1975) and authors cited therein have observed that arid flora or flora from xeric habitats, are characterized by vessels with narrow short vessel elements. The vessels occur at high densities, a greater percentage of them are clustered rather than solitary and the flora has pronounced growth rings. Walls of vessels tend to have minute lateral pits and the walls of the cells are thick. Spiral thickenings are both frequent and infrequent in arid flora (Baas et al. 1983). Carlquist (1980) observed that arid flora possess vessel elements with predominantly simple perforation plates in response to adaptive selective pressure. Also those plants with scalariform perforation plates have a reduction in bar number. Mesic habitats' flora are characterized by long wide vessels and because the vessels are wider they occur in low densities, they do not have pronounced growth rings and have thin vessel walls. Those with scalariform perforation plates have more number of bars.

2.3.2 Ecological trends of vessel element characters

Length and Diameter

Vessel diameter and length are the two most important parameters determining the efficiency of xylem conduction in plants and there is evidence that at least in large woody plants xylem conductivity may be an important factor constraining plant growth development and distribution in nature (Ewers et al., 1990). As a result, most investigations have been carried in plants concerning these two parameters or features. Bailey and Tupper (1918) (in Carlquist, 1975) showed that vessel-bearing dicots have a wide range of vessel element lengths. There has been a continued drop in length of fusiform cambial initials during phylesis of woody dicots, which is thought to have resulted in evolution of short vessel elements. Carlquist (1970) and Carlquist (1975) in his studies with Micronesian species of *Euphobia,* found that they adapted themselves in mesic environments by evolving long vessels and in xeric conditions, short vessel elements. *E. degeneri* with average vessel elements' length of 206 um grew in the driest localities, a coastal zone of Oahu where there is only about 15 inches of rainfall per year. The other extreme is represented by *E. rocki* with long vessel elements averaging more than 600 um in length (Carlquist, 1970). This species

was confined to the wettest area of Oahu, the upper Punaluu valley of the Koolau Mountains where rainfall averages about 250 inches per year. Between these extremes the species' vessel length range approximately as expected. Indeed Carlquist (1970) commented that one could estimate rainfall with reasonable accuracy sorely from vessel element length.

Webber (1936) (in Carlquist, 1975) performed some studies on *Larrea* genus, which is a desert shrub that had short narrow vessel elements. For example *L. divaricata* has average vessel length of 123 um and another desert shrub *Artemisia arbuscula* has vessel elements with average length of 116 um. These also have narrow diameters of averages of 39 and 26 um respectively. Pressures in vessels of *L. tridentata,* measured by Dadswell and Ingle (1954) were -60 to -80 atm. These were quite high negative pressures.

Nothofagus, tropical species had longer wider vessel elements compared to their temperate species. Carlquist (1995a) in his studies of wood anatomy of Ranunculaceae and Glaucidiaceae found that they have numerous narrow vessels, which he considered was probably an adaptation to cold weather more than drought. Baas et al. (1983) found mesic flora that were hygrophylic and synanthropic shrubs had rather wide vessels in hot climate of the Middle East. Their findings on vessel length agree with those of other workers that vessel lengths are shortest for arid flora and longest in the mesic or hygrophylic species. This is shown perfectly well in fig. 2.2 from Baas et al. (1983). They found that the trend was uniform in their overall data for trees, shrubs and intermediate habitats. Table 2.1 from Baas et al. (1983) shows that statistical analysis of vessel element length between the arid species and mesic species are significantly different. Within the Middle East flora studies by Baas et al. (1983), the hygrophylic elements showed high values for maximum vessel diameter. These had high transpiration rates in the hot summer and ample water supply to the root system, which then allows efficient water supply. The temperate arctic flora had lowest average values for maximum vessel diameter. Carlquist (1995b) in his studies of wood of Berberidaceae found that the genus *Berberis* have a large number of narrow vessels showing a xeromorphic adaptation. *Amorpho fructosa, Ammopiptanthus mongolias, Halimodendron* and *Robinia pseudoacarcia*

(Leguminosae) growing in the desert regions of China had short vessels, a xeromorphic feature (Zhang and Cao, 1993).

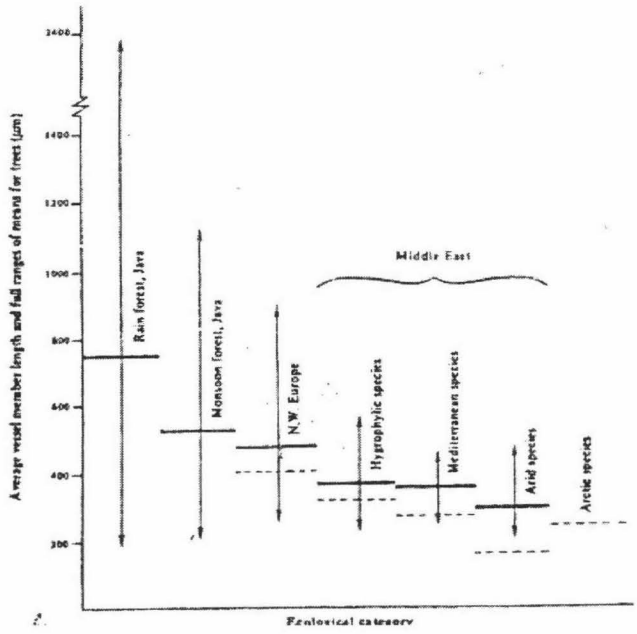


Fig. 2.2 Average values for vessel member length (um) in different ecological categories. Solid bar: for trees; broken line: for shrubs. For trees the full range of average species values is given. Adapted from Baas et al. (1983)

Mauseth and Plemons-Rodriguez (1998) like the above investigators, presumed that these character states are adaptive relative to the wood's conductive capacity and conductive safety. Negative pressure is common in xylem of trees that undergo periods of rapid transpiration. These negative pressures cause compressive strains in the walls of the vessels and might result in cavitation (Romberger, Hejnowicz and Hill, 1993). Cavitation means collapsing under high pressure. Embolism is the process by which a functional vessel loses its conductive capacity after the formation of an air embolus (Mencuccini and Comstock, 1997). The more negative the water pressure, as is the situation in xeric environments, the more likely air bubbles are formed. Once formed a bubble can expand as water vaporizes and continue to expand until the moving gas water interface encounters a porous barrier having high adhesive forces in its pores. Short vessels prevent such embolism from spreading because the bubbles are trapped faster at the blind ends formed by the perforation plates. If the negative pressure in the vessel is not strong enough to draw the bubble through the pore, it stops.

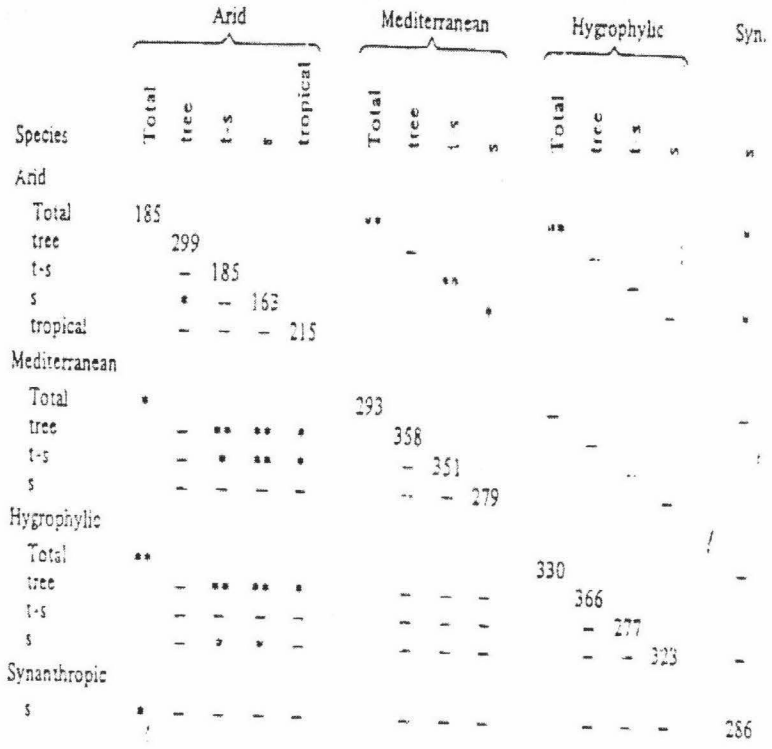


Table 2.1 Comparison of vessel member lengths in different ecological and habit categories from Israel and adjacent regions. * = Difference significant at the 95% probability level; ** difference significant at the 99% probability level; - = difference not statistically significant; bottom left: result of simultaneous testing; top right: result of pair-wise t-tests. (t-s = ibid for trees; s = ibid for small trees to shrubs). Adapted from Baas et al. (1983)

Wide vessel elements are said to be susceptible to gas embolism and are less capable of recovery from this condition while narrow ones are less susceptible to gas embolism and therefore more safe (Ellmore and Ewers, 1985 in Carlquist, 1988). A possible explanation for this phenomenon could be that the tensile strength of water in narrow compartments is higher than in wide ones thus reducing the risks of embolisms due to extreme negative pressure (Bass et al. 1983; Carlquist, 1988). Narrow vessels are also safer because of their much higher number and as such local embolisms do not incapacitate major parts of the conductive system.

Wider vessels according to Carlquist (1975) are of positive value because they offer less friction in conduction and therefore are more suitable to mesic flora. Wider elements represent a capacity for greater volume of flow (Carlquist, 1975).

Zimmermann (1983) noted that wider conduits permit a greater flow because according to the Hagen-Poiseville law, conductance per tube is proportional to capillary diameter raised to the fourth power. Upon freezing and thawing long and wide vessels are more prone to embolism than short and narrow ones. Smaller conduits tend to produce tiny quickly soluble bubbles upon thawing whilst large conduits produce larger more stable bubbles in the freeze thaw process. Narrow conduits are said to be better to refill following embolisms than the wide ones (Hargave, Kolb, Ewers and Davis, 1994). Longer elements may not have a positive selective value by themselves in mesic sites but are at least a product of longer fusiform cambium initials which produce also longer imperforate elements, which have a positive value (Carlquist 1975).

Vessel Groupings and Density

Grouping of vessels is regarded as a way of providing alternative conduits whereby water can be carried in the same pathway in case one or several vessels in a group are incapacitated by air embolisms (Carlquist, 1984a). Therefore grouping tends to provide conductive safety. Species with over 80 % of their vessels in multiples are most common amoung arid flora especially shrubs. For the hydrophytes of the Middle East as well as for the tropical temperate and arctic flora, high degree of grouping is quite rare Baas et al. (1983). Zhang and Cao (1991and 1993) found that desert species of *Caragana* had high frequency of vessel number per millimeter squared. In Asteraceae the degree of vessel grouping rises markedly with relation to dryness of the habitat (Carlquist, 1988). Carlquist (1988) gives example of *Olearia argophylla,* fig. 2.3.4 that was growing in wet forest of coastal southeastern Australia. It had mostly solitary vessels. Fig. 2.3.5, *Olearia avicenniaefolia* has grouped vessels and it was growing in sunny but seasonally moist scrub of New Zealand and fig. 2.3.6 shows that *O. muelleri*, which was growing in dry interior scrub of South Eastern Australia, had more vessel groupings.

The nature of vessel grouping has different correlation with the type of imperforate tracheary elements. Families and genera with true tracheids have solitary vessels. Vessel grouping occur to various degrees in taxa with fibre-tracheids or libriform fibres. Presence of vascular tracheids if sufficiently abundant is correlated with smaller degree of vessel grouping because they form a subsidiary conductive system.

Small number of vascular tracheids and vasicentric tracheids do not affect vessel grouping (Carlquist 1984a). Large grouping of vessels are indicative of xeromorphy in species in which vessels are accompanied by fibre-tracheids and libriform fibres rather than a background tissue of tracheids (Carlquist, 1984a). When comparing groupings in the wood, latewood and earlywood should be analyzed differently because groupings always vary between the two.

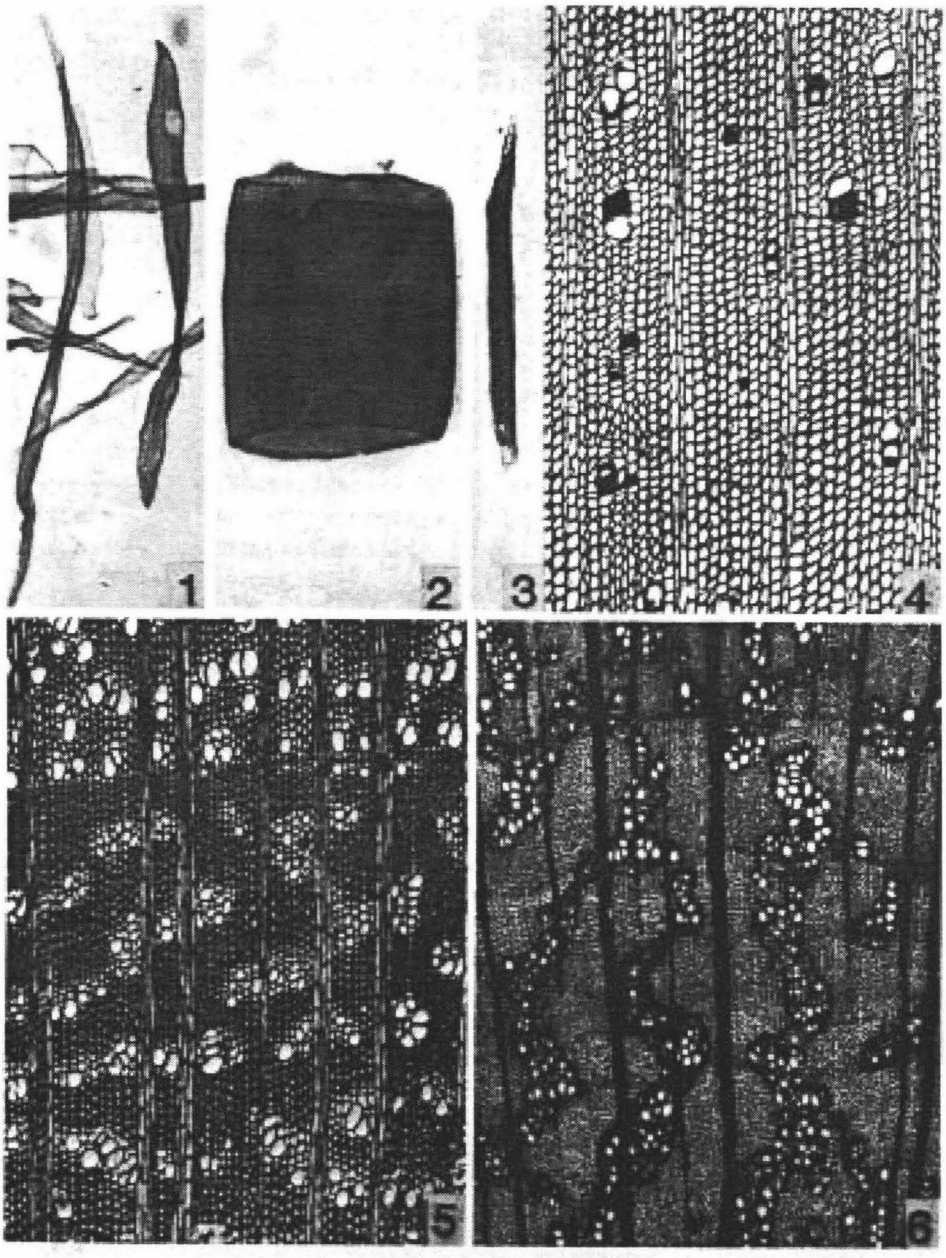


Figure 2.3. Vessel grouping related to ecology. 4 Solitary vessels of *Olearia argophylla* (Asteraceae). 5 Clustered groups of vessels of *O. avicenniaefolia*. 6 Chains of grouped vessels of *O. muelleri*. Adapted from Carlquist (1988).

Vessel Wall Thickness

Baas et al. (1983) found that arid species on average have thicker walls. The xeric species *L. divaricata* and *A. arbuscula* had exceptionally thick walls (Carlquist, 1975). The same trend of thick vessel walls was shown in mangroves, which experience greater negative pressures between -40 and -60 atm. In contrast the Hawaiian *Metrosideros*, a mesic plant possessed thin walls. Carlquist (1980) considered wall thickness functionally significant in offering conductive cells sufficient mechanical strength to withstand strong negative pressures. However, he pointed out that it is not yet known what strength in the vessel walls is necessary to sustain the range of normal tensions. Therefore it cannot be estimated what thickness might be of value in plants in which strong tensions develop. He also suggested that vessel wall thickness is probably of significance in comparative studies other than those that are primarily concerned with ecology.

Lateral wall pitting of Vessels

The need for an increase in mechanical strength was suggested by Carlquist (1988) as the reason why vessel walls have undergone the shift from scalariform to alternate pitting. Alternate pitting tends to increase mechanical strength to lateral walls. Usually alternate pitting (especially minute pitting) is found in vessels with simple perforation plates and short vessel elements. These features characterize arid flora. Carlquist (1994) also reported minute intervessel pits in xeromorphic plants. Zhang and Cao (1991 and 1993) found that the arid flora that they studied had alternate wall pitting. Table 2.2 from Carlquist (1988) shows that short vessels tend to have alternate pitting, while long vessels tend to have scalariform pitting. But according to Carlquist, 1988) pitting cannot be explained on the basis of conductive efficiency and safety.

Table 2.2 Vessel element length compared to vessel-vessel pitting types (Frost 1930b)

Vessel-vessel pitting type	No. of species	Vessel element length (um)
Scalariform	15	1130
Transitional	28	1070
Opposite	33	790
Alternate	183	460

Table reproduced from Carlquist (1988)

Perforation Plate

Carlquist (1988) hypothesized conductive efficiency as the force responsible for evolution of the simple perforation plate while mechanical strength as the factor leading to change in lateral wall pitting. For Cornaceae and Nyssaceae families which have scalariform perforation plates it appears the pressure of removal of the bars in the plates is minimal since they grow in environments where slow conductive rate suffice for successful plant growth. They grow in areas that have constantly moist soil and high humidity (Carlquist 1975). Zhang and Cao (1991 and 1993) found that desert plants have simple perforation plates. Baas and Schweingruber (1987) also found that the incidence of scalariform perforation strongly increases from dry to mesic habitats.

Wall Surface Sculpturing

Helical thickenings and surface sculpturing such as warts, grooves and vestures increase wall surface area. This results in increased bonding of water molecules to the vessel wall (Zimmermann and Jeje, 1981). As a result there is an increase in the tensile strength of water column in a vessel and thus reduction of the risks of embolisms). Vestured pits according to Carlquist, (1984b) and Zweypefenning (1978) (in Lindorf, 1994) prevent excessive deflection and rupture of the pit membranes in case of pressure drop due to embolisms. Presence of helical sculpture in vessels of dicots correlate generally with dryness i.e., low soil moisture, low humidity and physiological drought.

For example, Asteraceae desert plants possess a higher percentage of helical thickening (68%) than mesic flora (49%) (Carlquist, 1975). Ma, Wu and Wan (1994) found spiral thickenings and vestured pits in the walls of *Calligorum* species growing in the desert region of Gansu, China.

On the contrary Baas et al. (1983)'s study found that helical thickening was common in less arid flora and more in mesic cool temperate flora. Baas and Schweingruber (1987) found that spiral thickening was present in plants growing in temperate regions. Zhang and Cao (1991) found the presence of thickening in *Caragana* species. Considering all of the above data, Carlquist (1988) concluded that vestures tend to characterize an entire family irrespective of the habitat.

2.3.2 Growth rings

A single growth ring can illustrate contrasting modes of adaptation to different climates. For instance, early wood of a particular species may be likened to the wood of a tropical rainforest tree in which wide vessels accommodate large volumes per unit of water to suit transpiration. But such wood is low in conductive safety. Late wood resembles wood of a desert shrub, in which a large number of narrow vessels offer greater resistance to embolism formation, which means it has greater conductive safety and redundancy in case some of them do become embolized (Carlquist 1988). In fact occurrence of marked growth rings suggests that the plants experience fluctuation in physiological drought (Carlquist, 1984b). Desert shrubs form wide vessels during moist conditions that permit greater flow of water. Later on during the dry period, they form narrow late wood vessels that resist higher tension and suffice for conducting smaller water volumes available then (Carlquist, 1975). This could explain the formation of ring porous wood by arid flora. Mesic floras for example, Fabaceae and Meliaceae have mostly diffuse porous wood. These are found in the tropics. It should be noted that not all tropical evergreen species (mesic flora) lack growth rings.

Guthrie (1989) hypothesized that deciduous dicot tree species with diffuse porous xylem are the most adapted to hydric to mesic sites and those with ring porous xylem

to xeric to mesic sites. His studies on deciduous trees within the Eastern Deciduous Forest supported his hypothesis. He found that diffuse porous species were dominant on the flood plain and the ring porous were dominant on the spur that is, the dry area. Arnold and Mauseth (1999) found that annual rings of trees in temperate forests are broader if produced during favourable years than during times of water stress. The conclusion that can be drawn here is that the width of a growth ring correlates with ecology.

Before Carlquist's (1988) description of growth rings, most wood was described as ring porous or diffuse porous and some as semi-ring porous. Carlquist provided a useful comprehensive system of categorising growth ring types found in plants. This comprises 15 categories of which 1, 2, 3, and 5 are the most common ones (fig.2.4 from Carlquist, (1988)). Type 1 represent the bulk of wood termed semi- ring porous. Type 2 has wide tracheids in early wood and narrow tracheids in latewood. This is the common growth ring type seen in temperate conifers and temperate vesselless dicots like *Trochodendron*. Type 3 has wide vessels in early wood and for imperforate tracheary elements it has libriform fibers and fiber-tracheids. Majority of ring porous dicots fall into this category. Carlquist said the presence of this growth type is probably a major factor allowing the wide spread success of dicots in the world flora. Type 5 has significantly wide vessels in early wood, narrow vessels in latewood and tracheids as its imperforate tracheary element type. Tracheids are said to offer potential safety because pit membranes in tracheids prevents spread of air embolisms.

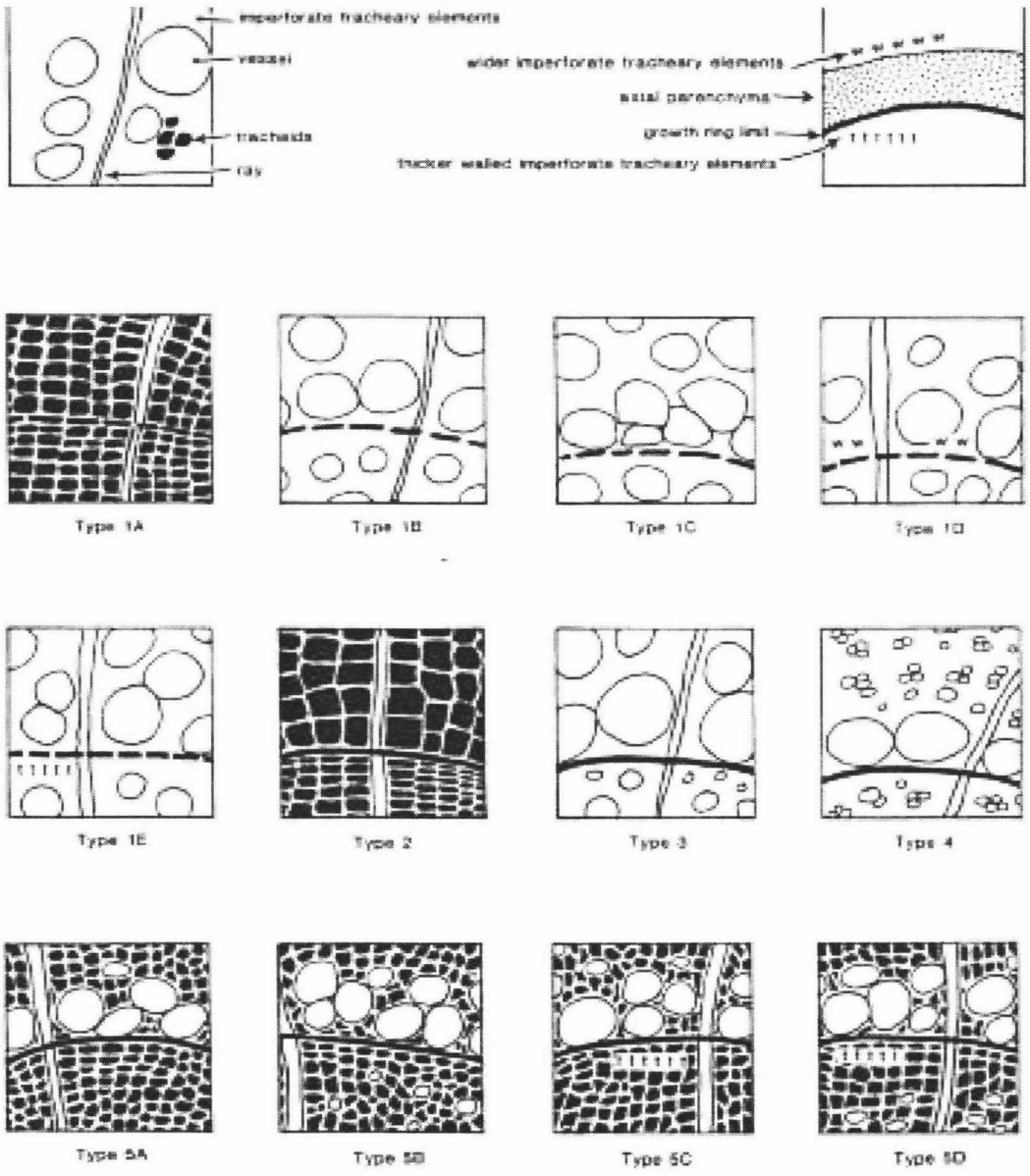


Fig.2.4 Diagrams of growth ring types. The two upper pictures are conventions. The order of labels on the upper left diagram are, imperforate tracheary elements, vessels, tracheids and rays. The labels on the upper left diagram are; wider imperforate tracheary elements, axial parenchyma, growth ring limit, thicker walled imperforate tracheary elements. The diagrams are labeled, Type 1A-1E, 2, 3, 4 Type 5A-5D. Adapted from Carlquist (1988).

2.4 Vessel Dimensions with relation to other factors:

Altitude, latitude and vessels characters:

Altitude and latitude are not ecological features in themselves; i.e. they are not direct indicators of ecology. The correlation between vessel element length and altitude or latitude should be traced to water availability and temperature (Carlquist, 1988). Noshiro and Suzuki (1995) data of *Rhododendron lepidotum* and *Rhododendron arboreum* found that pore density correlated positively with altitude as shown in fig 2.5 and 2.6, from Noshiro and Suzuki, (1995). The correlation was significant at 5 % level. As altitude increases, pore density increases moderately in *R. lepidotum* and slightly in *R. arboreum*. Again Noshiro et al. (1994) found that altitude has greatest effect on the wood anatomy of *Alnus nepalensis* in East Nepal, which has a monsoon climate. Altitude in Nepal Himalaya varied from 500 to 3000 m above sea level. They found that pore density increased as the altitude increased.

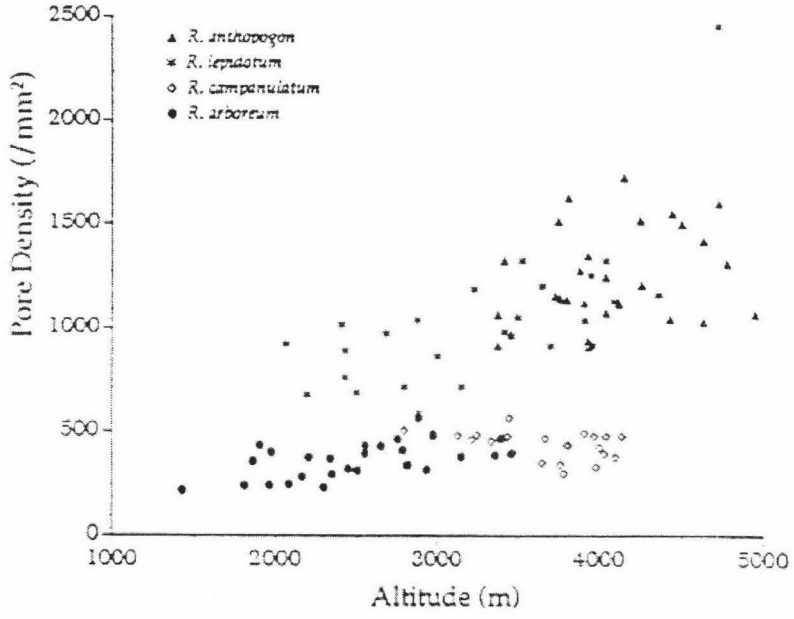


Fig. 2.5 Variation of pore density against altitude for four Rhododendron species. Adapted from Noshiro and Suzuki (1995)

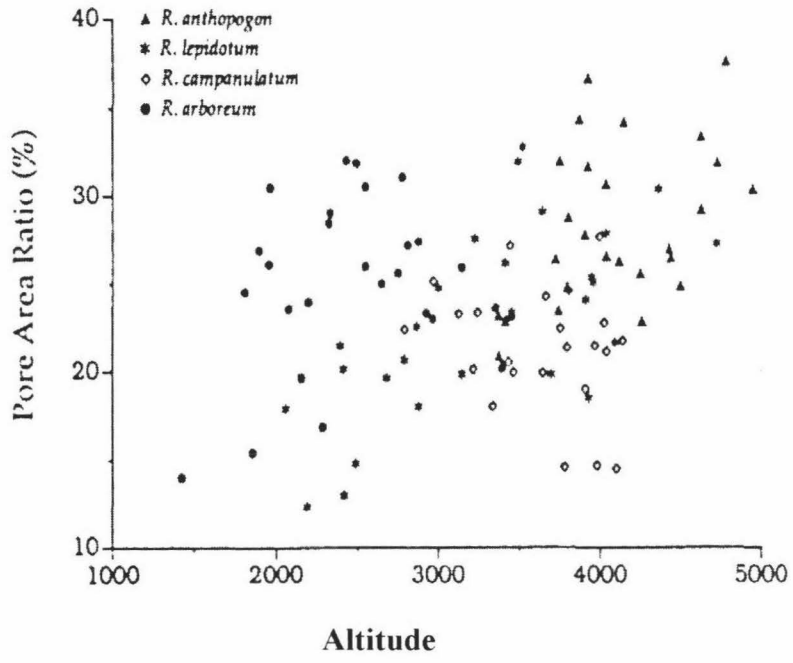


Fig. 2.6 Variation of pore area ratio against altitude for four Nepalese Rhododendron species. Adapted from Noshiro and Suzuki (1995)

Zhang, Deng and Baas (1988) took samples of wood from *Syringa oblota* in northwestern China at altitude intervals of 50 m between 1000 and 1800 m above sea level and found positive correlation with altitude in average annual ring width, percentage of solitary vessels, member length and diameter. In another study Carlquist (1975) found that there is a decrease in the number of bars on the scalariform perforation plate with increase in latitude in *Ilex* genus. This is because higher altitudes have higher degree of fluctuation in transpiration rates

Relation of Vessel elements' dimension to position in plant.

From pith to cambium, vessel element length changes markedly during a juvenile period, which may be brief or prolonged. Vessel diameter may change markedly from inside to the outside of woody stems and this allows increased volumes of water as the plant forms a large leafy crown. Vessel elements tend to be shorter in branches than in the main stem. Where as they tend to be longer and wider in the roots than in the stem of a given species (Carlquist, 1988). The longer wider vessels of roots would suggest that the roots experience less water tension than the stems.

Habit and Vessel element characters:

As already stated, habit is correlated with vessel length and diameter. These parameters are greater in woodier plants than in their more herbaceous relatives. They are also greater in species that are taller than in their shorter relatives. Vessel element length and diameter are greatest in trees, intermediate in shrubs and least in sub shrubs. But herbs fall between trees and shrubs, (Calquist, 1988)

2.5 Ecological trends of imperforate tracheary elements

A search of the literature has revealed that there is not much information related to ecological trends of imperforate tracheary elements. It appears that most of the work has been done on vessel elements.

2.5.1 Tracheids

Tracheids offer a plant maximum protection against embolisms since air bubbles are prevented from spreading from one tracheid to another by the pit membranes (Carlquist, 1988). In vesselless dicots and gymnosperms, tracheid length is related to plant size. Tracheid length is also thought to increase with age in vesselless dicots. In conifers the length is related to height of plant or size of branch bearing it (Carlquist, 1975). This implies that shrubs tend to have shorter tracheids than trees. For example, Lim and Soh (1993) in their study of *Pinus koraiensis* grown in arid soils found that dwarf trees had shorter thick walled tracheary elements than normal trees. Short, narrow and thick walled tracheids are common in plants growing in situations where there are high negative pressures; low transpiration causing lowered conductivity values. This shortening is attributed to short cambial initials (Lim and Soh, 1993).

In mesic conditions, long wide tracheids with thing walls are to be expected in early wood and late wood, radially narrow and thick-walled tracheids. This is the situation in *Taxodium mucronatum* (Calquist 1975). Winteraceae, a vessel-less dicot family, has notably narrow tracheids and it grows in areas subjected to frost (Carlquist, 1988). *Araucaria cunninghamii* grows in very amiable conditions with high rainfall and high humidity (Francis, 1981). It has an average tracheid length of 11 mm (Jane, 1956).

Phyllocladus asplenifolius var. alpinus is a small tree up to 9m tall; it generally grows in a harsh montane habitat of New Zealand (Salmon, 1980). Its tracheid length was 1.1 mm. As it is the case with vessels, the major selective force in shortening and lengthening of tracheids is for conductive efficiency and safety.

2.5.2 Fibre-tracheids

These are imperforate tracheary elements in which pit diameter; pit border width and density of pits are reduced below those characteristics of tracheids (Carlquist, 1988). Like tracheids, the length correlates with organ size or plant size. The wall thickness and the diameter of the fiber-tracheids vary a lot within a single cell. The wall thickness is greater in the upper portion of trees than in lower parts (Sastrapadja and Lamoureux, 1969) (in Noshiro, 1994). This is thought to compensate for less amount of secondary xylem in upper branches. Wall thickness also increases from the inner to outer portions of the trunk (Carlquist, 1975).

2.5.3 Libriform fibres

These are cells usually have thick walls and have pits that are narrow and slit like as compared to fibre-tracheids. Not much is mentioned about their correlation with habitat, but it might suffice to mention the following about them: their length parallels that of vessel elements in any given species. Longer fibers confer greater strength (Carlquist, 1982). Narrow fibers are thought to be stronger than wide ones (Carlquist, 1975). Libriform fiber length correlates with the size of organ bearing them. At higher levels in the plant, the fibers tend to get longer. For example in *Echium pininana* (Boraginaceae), length of the fibers increases from roots to the highest level in the stem. It is considered that the longer fibres at the top compensate for thinness of the woody cylinder (Carlquist, 1975). Wall thickness is also very characteristic of taxa. For example, *Ochrona* (balsa)'s fibres have very thin walls while those of *Diospyros* (ebony) have thicker walled fibers.

2.5.4 Vascular tracheids and Vasicentric tracheids

These together with true tracheids bear relatively large bordered pits approximately of the same size and density as those on lateral walls of vessels (Carlquist, 1985). Vascular tracheids are described by Carlquist (1988) as those tracheids formed at the end of late wood with narrow vessels transitional to those in woods where fibre tracheids and, or libri-form fibers are present. Like tracheids they lack perforation plates. Their formation at the end of the growth ring is thought to guard cambium during the dry season. They provide the last formed and safest conductive protection against embolisms. Most dicots under going water stress at the end of growing season possess these cells. Vasicentric tracheids are defined as tracheids that occur adjacent to vessels in woods that also possess fibre-tracheids or libriform fibres as imperforate tracheary elements (Carlquist, 1985). Their occurrence suggests that they maintain a three-dimensional conductance in case vessels get embolised. These two kinds of cells, like narrow vessels are a form of adaptation to dryland existence (Carlquist, 1988). Carlquist (1985) stated that many drought-tolerant evergreen shrubs possess vasicentric tracheids.

3.0 MATERIALS AND METHODS

3.1 Habitat/Ecology

The study is based on Five Habitats: see figure. 3.1

1. Margins of lowland forest

The area selected for this habitat was Otaki forks in Otaki, North Island. This area is located within Tararua district (38.01), Wairarapa plains. Rainfall ranges from 1600 to 10 000 mm annually. It has steep land hill soils.

2. Dry sand dune country

The stand of trees sampled was located at the junction of Pyke, Taikorea and Tangiotu roads in Rangiotu. The area is located in the border of Foxton district 31.02 and Manawatu plains 31.02, within Manawatu ecological region. The area has a long belt of sand dune country. This is an exposed sand dune area in which the plants are exposed to strong winds. The area consists of mainly sandy soils in a major coastal complex.

3. Hot thermal soils

The area selected for this habitat was Tokaanu thermal reserve located within Taupo district, 16.02 in Central volcanic plateau region. The area has cool winters. The area has coarse textured volcanic ash soils. The area has mainly erotic forest with mostly shrubs. Manuka and *Kunzea ericoides* (Kanuka) are the dominant plants in this geothermal reserve.

4. Cold subalpine habitat

Rangipo/Desert road junction was selected for this habitat. This area is located within Tongariro district, 18.01 in Tangariro region. The area consists of andesitic volcanoes including the highest North Island Mountain Ruahepu, which is about 2797m high (New Zealand topographical map, 1987). Nearby is the active Mt. Ngauruhoe strato-volcano and ring plain. The area is covered with snow in winter; it freezes at night

and thaws during the day. The climate is cool to subalpine. The soils are strongly leached steep land soils from variable cover of recent andesitic and rhyolitictephas.

5. Wet swampy habitat

The swampy area located at the entrance of Whenua Tapu cemetery near Plimmerton at the northern end of Taupo swamps was selected for this habitat. This area is located within Wellington district, 39.01 in the Sounds Wellington Region. The area is in a large river valley, which is frequented by westerly winds. The soils are grey wacke, pleistocene drift material and loess and alluvial peaty stony soils in the valley.

In addition, some samples of prostrate manuka were collected at Waimangaroa, happy valley from Ngakawau ecological district in South Island. The landform is a plateaux with mosaic of bare outcrops of quartzite sandstone. The soils are characterized by high acidity and low natural fertility, which reflect strong leaching under the high rainfall. The topsoil has pH as low as 4.2. The area is covered with sandstone pavement. Annual rainfall averages 6m/annum. Snowfall is infrequent and snow lie on the ground for only short duration in most winters (Robyn Simcock, personal communication)

Figure 3.1 Map of New Zealand showing the distribution of the study areas. The black dots represent the study areas.

3.2 Sources of data for determining variations

From each habitat wood samples used were collected from mature trees and shrubs growing naturally in native forest and scrubland within their normal distribution range. From each habitat (except for the prostrate manuka) a total of ten (10) plants (from a stand of trees assumed to be of the same unknown age) of approximately 15 cm in stem circumference were selected and from each plant small pieces of wood were removed from the outside of main trunks using a hammer and chisel. The wood was removed from the outside to make sure that only sapwood was used. Three samples from different locations in the stem were collected from the main trunk of the stem above knee height from the ground. Samples were fixed immediately in Formacetic alcohol (FAA) in separate labelled viles. For each habitat a total of 30 samples were studied. A leafy shoot was cut from each tree and was later pressed, dried and mounted as a voucher herbarium specimen stored in the Massey University Herbarium for verifying the identification of the plant. Full collection data records were kept. Due to the hardness of manuka wood it was not possible to obtain cores of wood with a core borer, which could help to approximate the age of the trees and shrubs sampled. Felling was out of the question because most of the habitats are located within conservation areas. The wood for the prostrate manuka was provided through the kindness of Robyn Simcock (from Landcare Research NZ Ltd). Four trees were sampled and three pieces of wood were cut from the main stem. The samples were subjected to the same treatment as the other habitats.

3.3 Microtechniques

3.3.1 Maceration of Tissues

After washing the samples through a series of water changes, samples were radially sectioned into slivers using a rotating microtome at 30 to 45 micrometers. The sectioned slivers were then boiled in water and cooled repeatedly to remove air and to thoroughly saturate them with water (Radford, Dickison, Massey and Bell, 1994). Then it was transferred into labelled viles and macerated in Jeffrey's fluid (10% chromic acid and 10% nitric acid) to separate cells (Johansen, 1940). The samples

were placed in an oven set at temperature of 60 degrees Celsius for a minimum of 24 to 96 hours. The time varied with the hardness of the wood. The macerated material was then washed through a sieve under running water to remove all traces of the acids. The material was centrifuged to speed up the process. It was then stained with safranin stain and left for a few minutes before mounted on glass slides with water and covered with cover slips. Cover slips were fixed to the slides with nail vanish.

3.4 Light microscope measurements

Measurements under the Carl Zeiss light microscope were facilitated by the use of an eyepiece micrometer, which was calibrated by a stage micrometer. The slides were scanned from edge to edge until 10 measurements were obtained for each character. All dimensions were taken as recommended by Carlquist (1988) and as agreed by Association of Wood Anatomists (Carlquist, 1980) except for the length of vessels, which was taken from one perforation to another instead of including the tails for those with tails. This was to avoid inaccurate measurements as a result of missing tails of some of the vessels. For each of the xylem characters 10 measurements were taken. Measurements were all in micrometers.

3.4.1 Xylem Vessels

Length was measured from one perforation plate to another; the radial diameter at the widest point of vessel including the wall and the thickness of the wall was measured at the widest point too.

3.4.2 Fibriform vessel

The measurements were done as in vessel elements except that the length was measured from one end to another.

3.4.3 Fibre-tracheids and libriform fibres

The length was measured from one end to another, the radial diameter and the thickness of the wall at the widest point including the walls.

3.4.4 Density and grouping

Each sample was sectioned transversely using the rotating microtome and were stained with phloroglucinol stain for observation. With the use of a grid fitted on the microscope eyepiece, density of wide vessel elements along a transection, based on several counts in areas of 1 mm2 each, was determined. The degree of grouping was obtained by calculating the mean number of vessels per group. Here a solitary vessel was counted as one, a pair of vessels in contact as 2, etc., and these figures were averaged (Carlquist, 1988). For the density and grouping only wood of early wood was considered. For each sample wide vessels were scored as to whether they occurred in clusters, solitary and chains.

3.5 Confocal scanning laser microscope (CLSM)

Preparation of slides performed as for the light microscope before scanned under a confocal laser-scanning microscope. For each sample one vessel and one fibriform vessel were selected randomly for scanning. With the help of the Image Space software measurements of the diameter (the shortest and longest diameter) of each perforation plate was taken. Then the area was calculated using the formula; pi multiplied by longest and shortest radius of perforation plate (1/2xAB x pi). Due to time constraints measurements were made for the five habitats excluding the prostrate manuka.

3.6 Scanning electron microscope (SEM)

The Cambridge Stereo scan 250 Mark 3 scanning electron microscope from SEM unit, HortResearch, was employed to find out if there were any vestures in the lateral

pits of wide vessels and whether there was a difference in the vestures of cells from the different habitats. From each site two samples were used, i.e., two trees were used. The cutting technique employed for preparation of samples for observation under the SEM was done as in Exley, Meylan and Butterfield (1977) and Meylan and Butterfield (1978). The technique is as follows; wood was soaked in distilled water, then it was cut to cubes of about 5mm with a razor blade onto a white tile. The specimen was held firmly between thumb and first and second fingers under a binocular microscope. Final cuts were then made with a fresh razor blade for each cut. Thin sections of wood were trimmed off the cubes. Final cuts were made to the transverse face of the cube before longitudinal face was cut. Cuts were made in longitudinal radial and tangential sections. Then the cuts cubes were soaked for 30 minutes in 20% solution of sodium hypochlorite until the surfaces lost their colour. This improves the photographic appearance of wood and reveals the fine details of small features. Then the cubes were washed in several changes of distilled water to remove the sodium hypochlorite. Then the cubes were transferred to viles with 100% methanol leading to 2 x 30 minutes washes. These were finally allowed to dry between two filter papers overnight. It was then mounted on SEM specimen stub using a double-sided tape. The stub was then left in a closed jar with silica gel crystals for 24 hours for drying. The stub was taken to SEM unit for sputter coating with gold before SEM observation. High-resolution micrographs were produced.

3.7 Statistical analyses

Initially the data were inspected to see if the variability was similar from habitat to habitat and whether the measurements were roughly normally distributed. Following this univariate Analysis of Variance was performed on each variable (Length, width, thickness of cell wall, abundance (for wide vessels only)) for each cell to find out if there was any variation between trees within each population and whether there was any variation between populations. Following this analysis, a multivariate ANOVA was performed combining the data from the characters or the variables. The analysis was performed with Proc GLM in SAS/Stat (version 6.12, Gary, North Carolina, 1996).

4.0 RESULTS

4.1 Field observation of habitats

Sand dune habitat

Figure 4.1 shows the stand of trees sampled from this habitat. The trees were bent to one side showing signs of being blown by wind coming from one direction. The trees were growing on the elevated parts of the sand dunes. There were relatively few trees within this stand.

Hot thermal soil habitat

Manuka and *Kunzea ericoides* (kanaku) species were the most dominant species in this habitat. This was an area with lots of steaming pools, figure 4.2A and hot boiling mud as shown in fig.4.2B Temperatures taken adjacent to tree trunks and 1 m away from tree trunks of some of the sampled trees at a depth of 7 cm are as in table 4.1 below:

Table 4.1 Soil Temperatures in Degrees Celsius in the hot thermal soils habitat

Tree	Temp. adjacent tree trunk	Temp. 1 m from tree trunk
1	25	26
2	25	26
3	26	33
4	41	94
5	35	Boiling mud pool
6	33	67
7	33	88
8	48	95

A

B

Figure 4.1 Shows a stand of trees of manuka from where the samples were obtained for the sand dune habitat.

A ·

B

Subalpine habitat

This habitat as shown by figure 4.3B was located on the flanks of Mt. Ruapehu as shown in fig.4.3A. The area is often covered by snow in winter. Fig. 4.3 shows the stand of trees sampled. The plants were mostly tree-shrubs. They were stunted in height as compared to those of the other habitats (fig 4.3B).

Margins of low land forest

The trees sampled here were growing at Otaki forks along the river-bank. Figure 4.4 shows the stand of trees sampled.

Swampy habitat

Trees were growing on a marshy area. Fig. 4.5 shows the stand of trees sampled. The trees were tall in height as compared to those of the other habitats.

For each habitat a specimen was dried and pressed and then deposited in Massey University herbarium. The herbarium specimen voucher numbers are as follows: Sand dune 24657-2466, Hot thermal 24627-24636, Subalpine 24637-24646, Margins of lowland forest 24647-24656 and Swamp 24617-24626.

A

B

Figure 4.3 Shows stand of manuka from where samples were obtained for subalpine habitat. (B) Area from where trees were growing with Mt. Ngauruhoe covered with snow in the background.

A

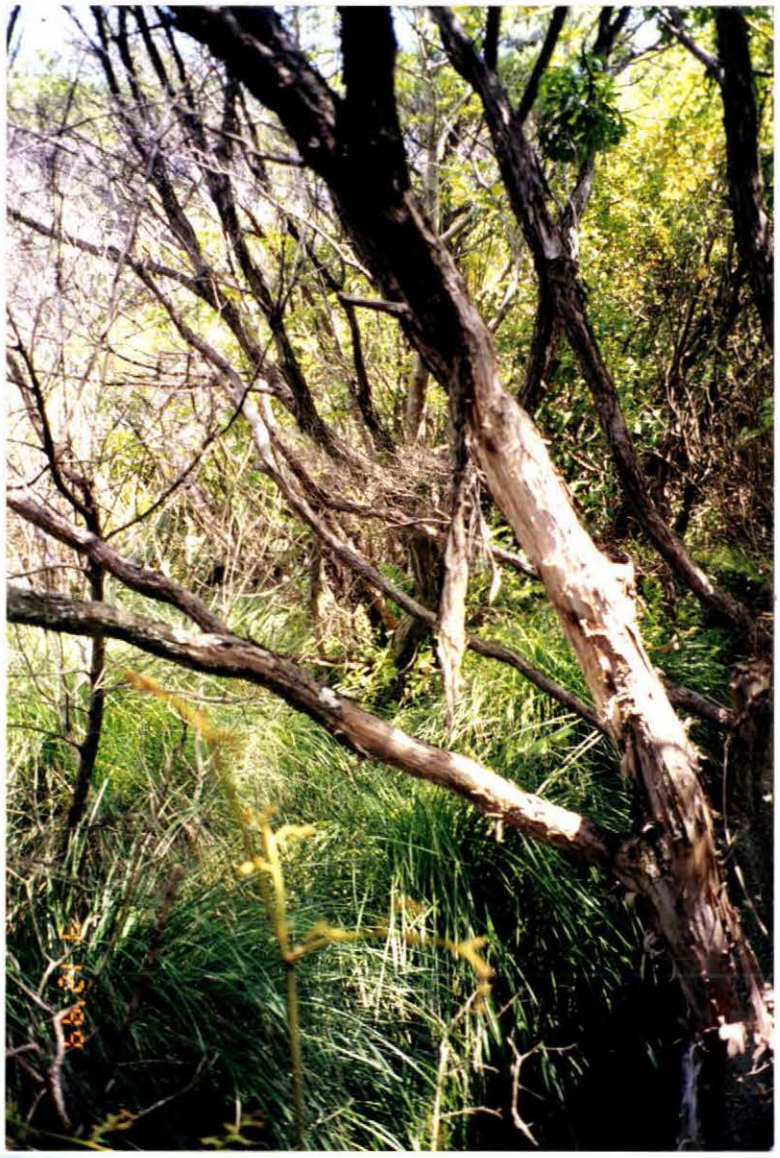
B

C

D

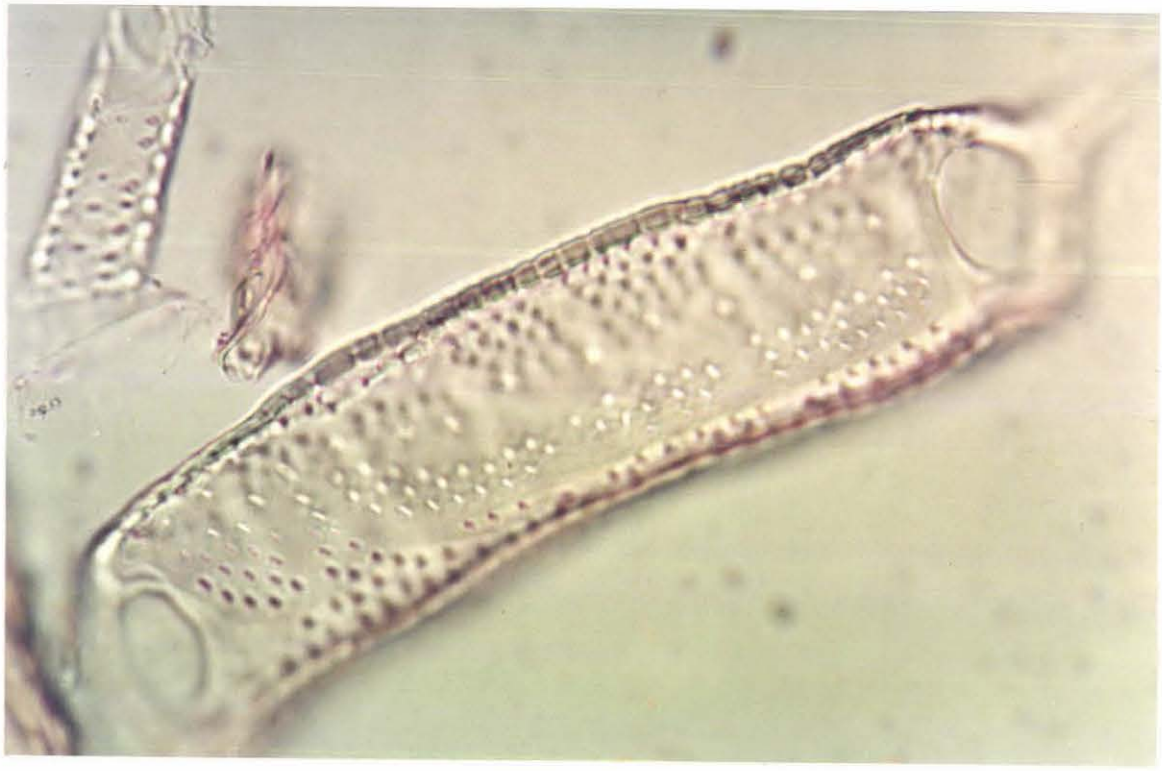
Figure 4.4 (A) Shows the stand of manuka from where samples were obtained for margins of lowland forests habitat. (B) shows scaly trunk of one of the sampled trees (C) shows a flowering manuka tree.(D) Close view of manuka flowers

A

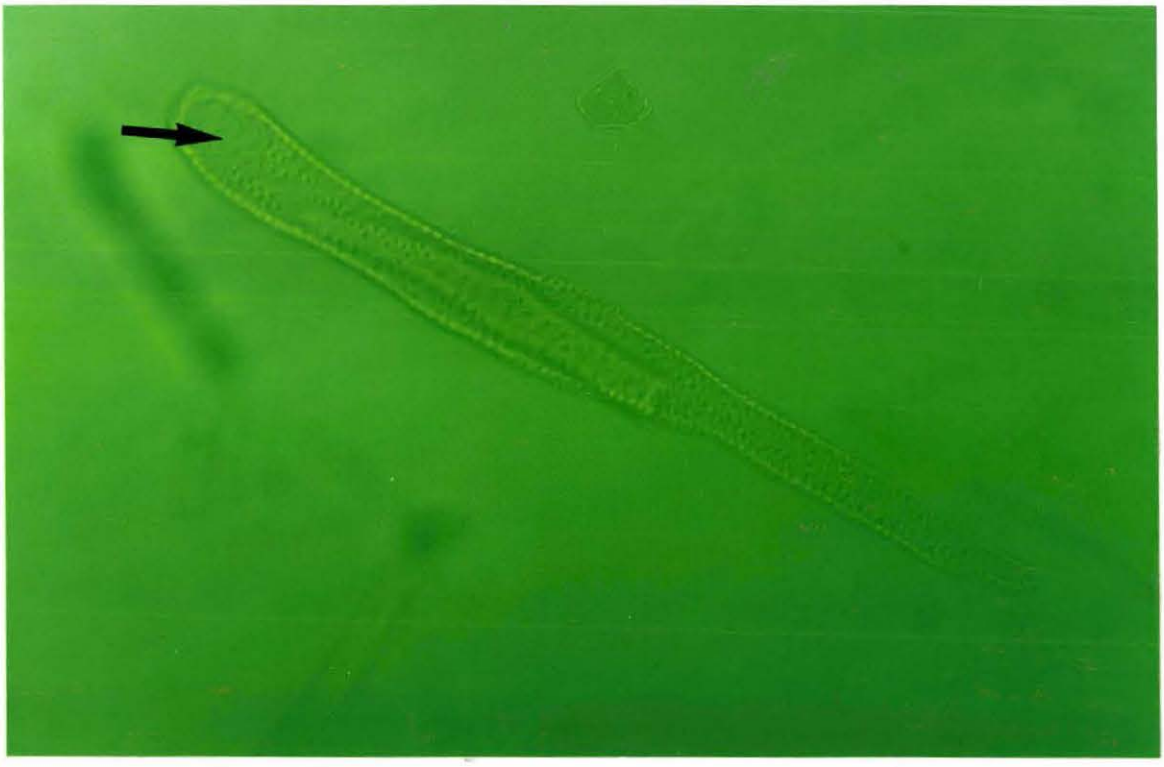


B

Figure 4.5 (A & B) Shows stand of manuka trees growing in a swamp.



A



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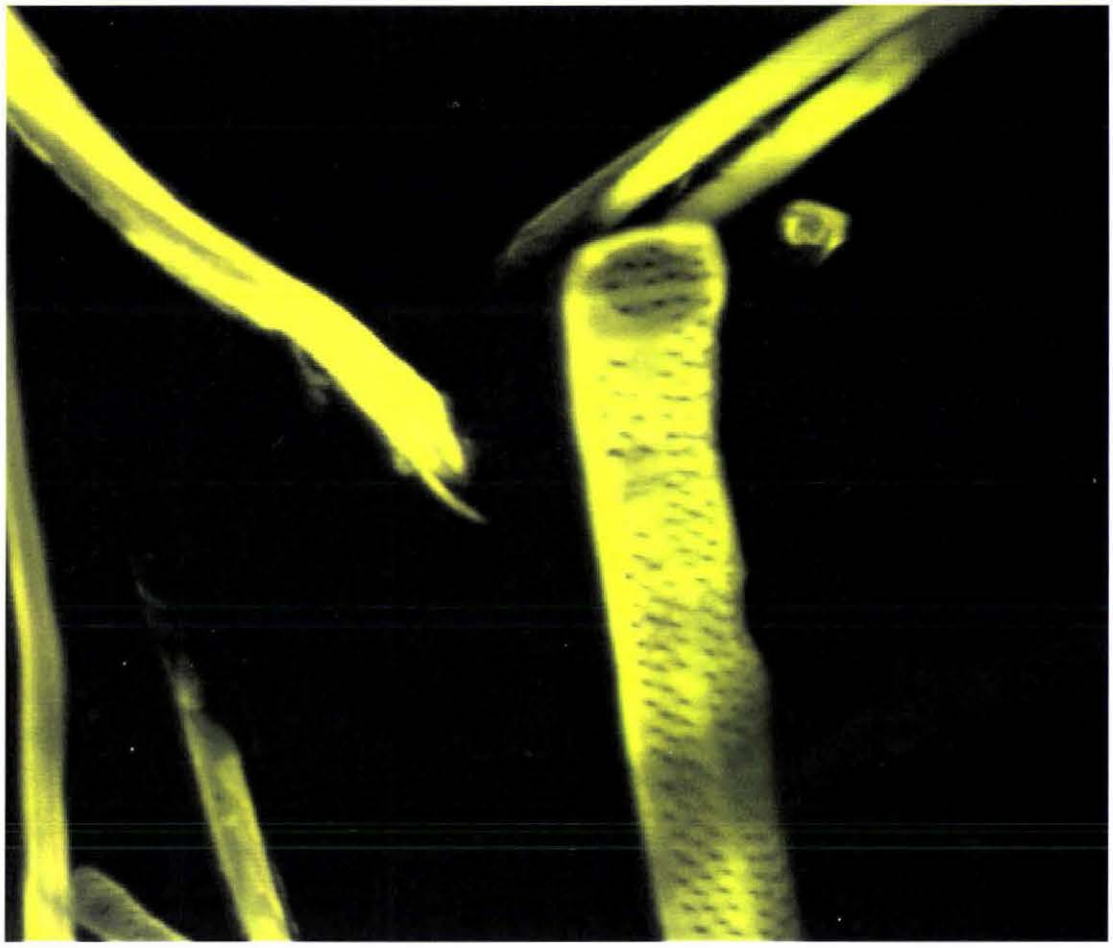
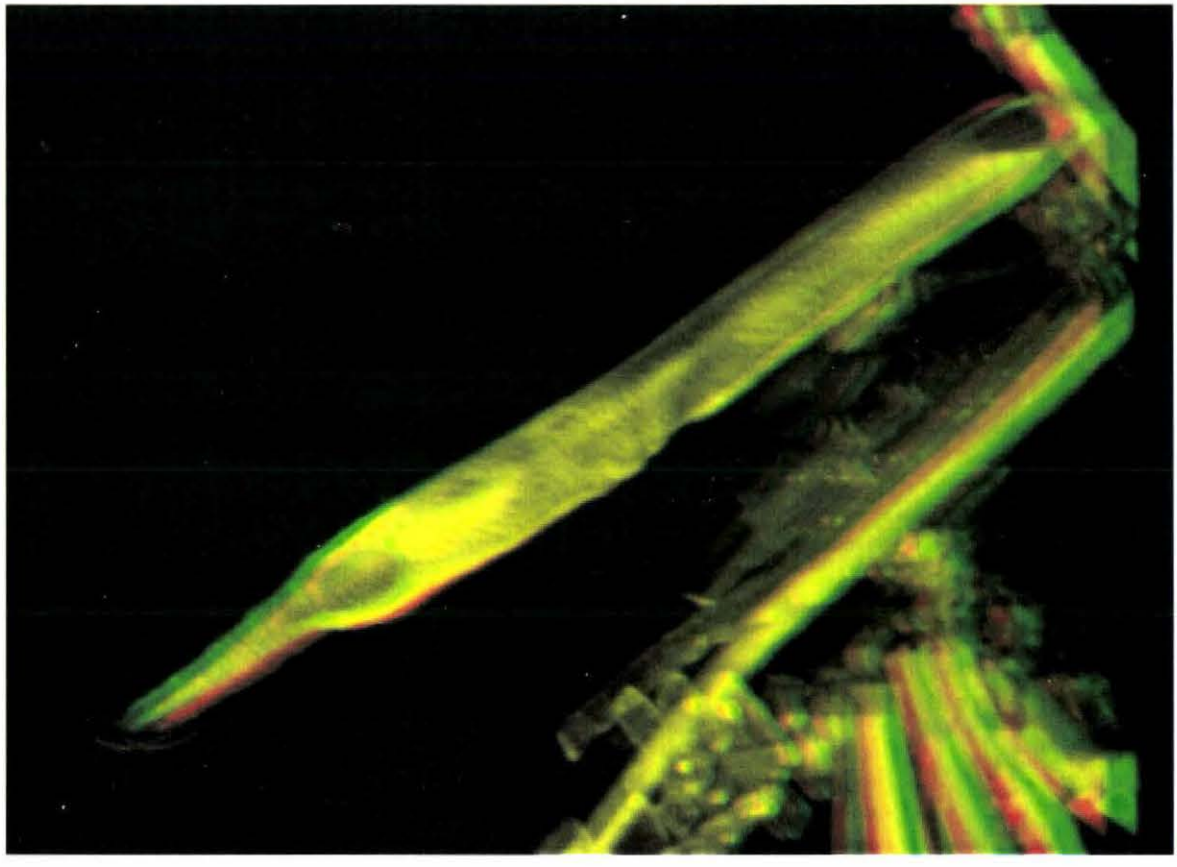
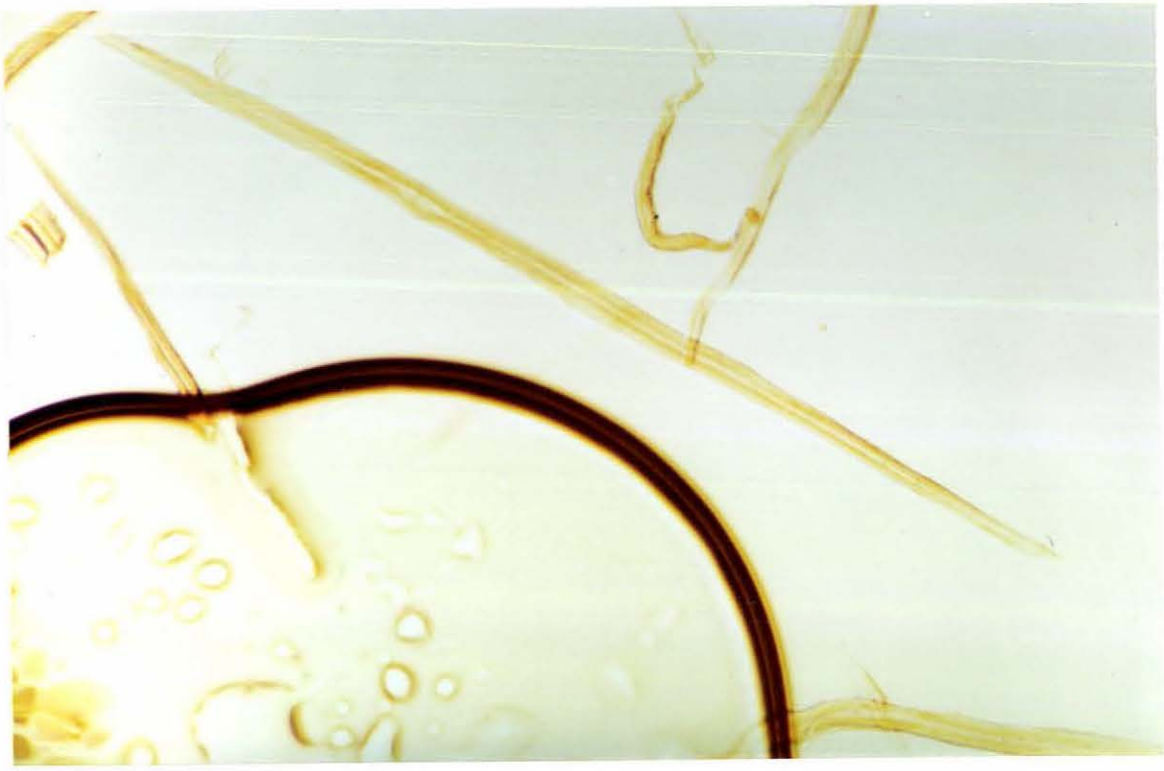
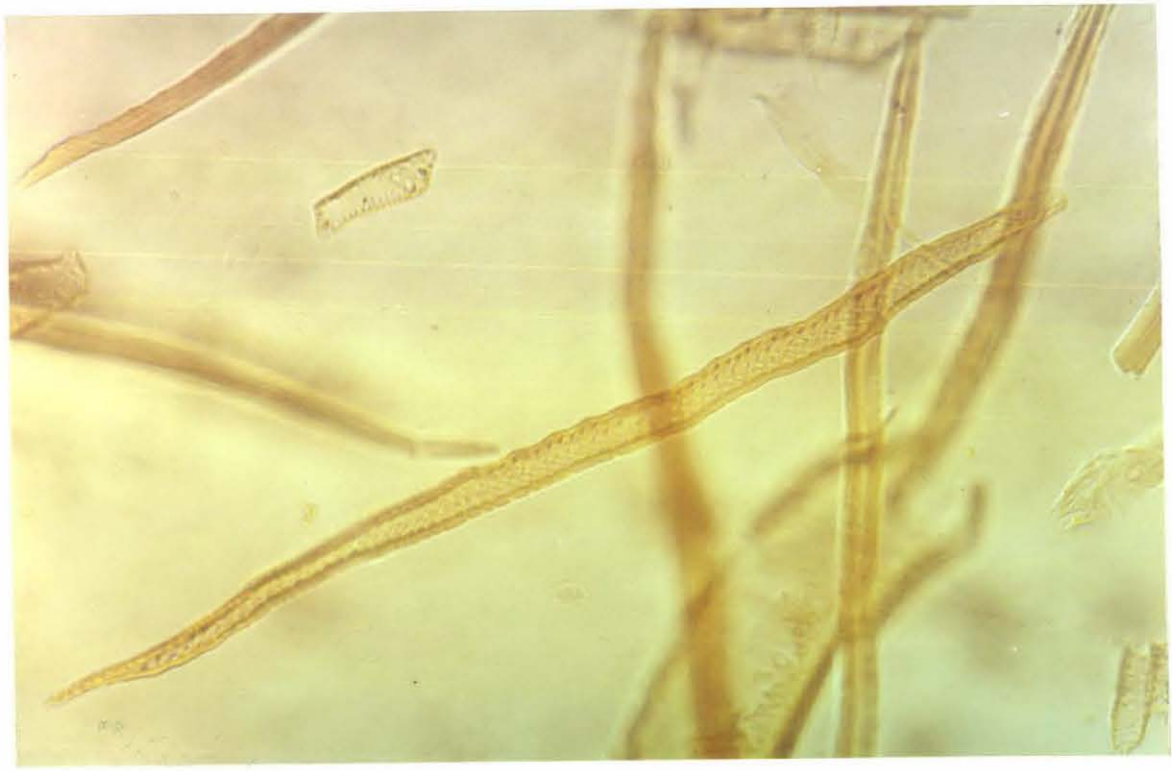




L R

D





E

Fig. 4.6 shows photographs of different cell types of the wood of manuka from which measurements were obtained. A shows a wide vessel, B is a fibriform vessel cell (arrow: perforation plate), C is confocal microscope 3D pictures of vessels (L: left, R: Right). D is a libriform fibre and E is a fibre-tracheid cell.

4.2 Analysis of cell types in the habitats

The study was focussed at establishing any wood anatomical variation within a population and between populations of manuka growing in a wide variety of habitats. The results of analysis of variation performed on data from the different habitats are as outlined below. The habitats were abbreviated as follows; A= Sand dune, B= hot thermal soils habitat, C= cold sub-alpine, D= margins of lowland forests, E= swampy habitat. In addition the prostrate (F) manuka was investigated too.

Although the variables for example, lengths and widths, appeared to be normally distributed, the variance of their data did not appear constant (cells which were longer, or wider, on average showed more variation in their lengths or widths). Therefore to satisfy the requirements of analysis of variance, the logs of the variables were analysed; the logs were normally distributed, and had more constant variance. This procedure was performed for all the cell types except for data of wall thickness of libriform fibres, whose data already showed normal distribution, with a constant variance.

4.2.1 Wide Vessel Elements

4.2.1.1 Vessel Length

Analysis of variance as shown in the ANOVA table in appendix 1, showed that the differences in the mean length of wide vessel elements between habitats were not significant. The gradients of the above graphs in figure 4.7 for the different populations were similar showing the insignificance of the differences between the populations. See table 4.2 below.

Table 4.2 Mean lengths (original scale) (um) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	245.26	234.03-257.02
B	242.97	225.13-262.23
C	239.54	225.96-253.94
D	239.39	223.16-256.81
E	257.72	236.29-281.10
F	253.88	207.19-311.08

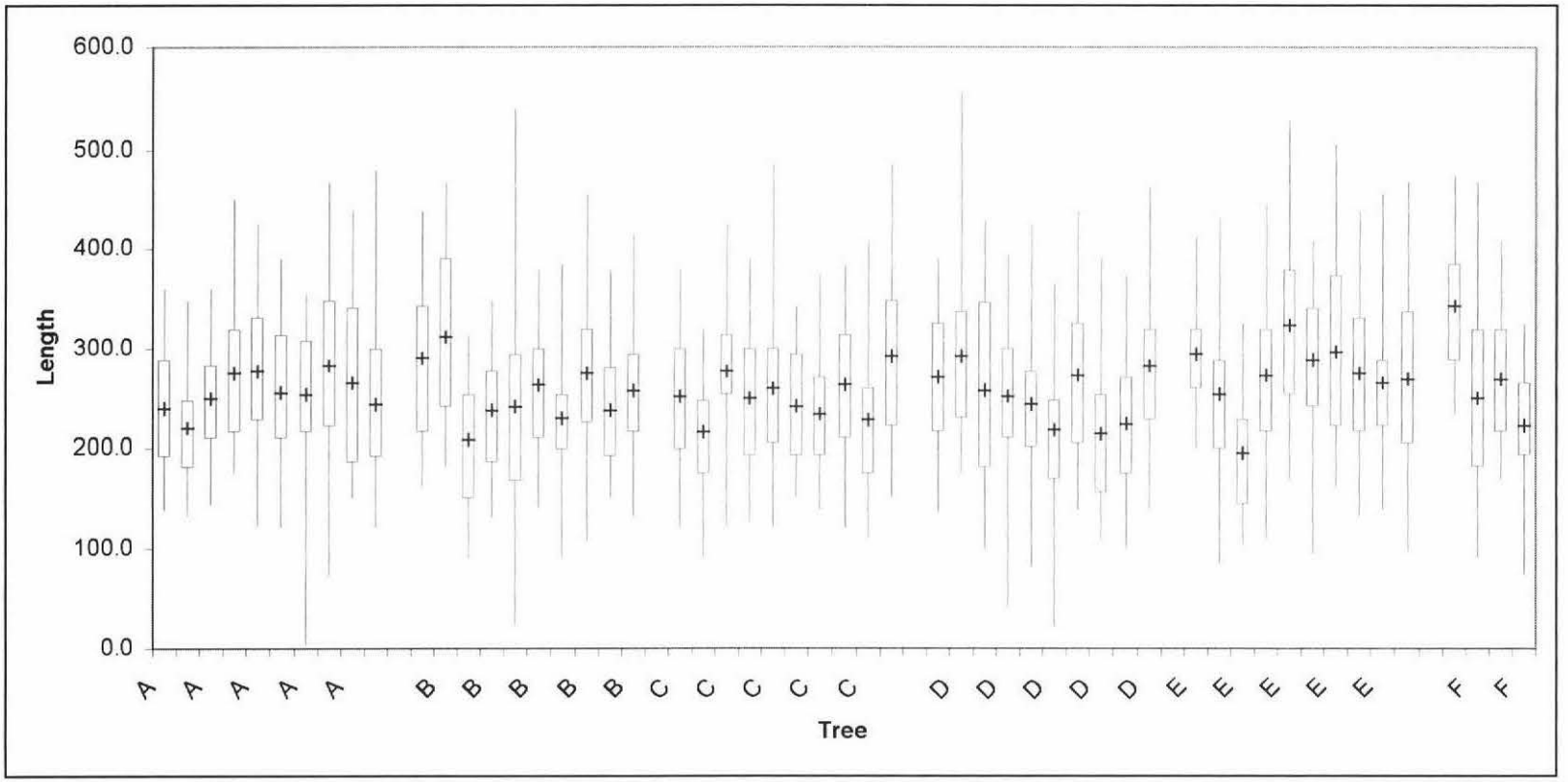


Figure 4.7 Mean lengths (micrometers) of wide vessels. Note A, B, C, D and E represent the different habitats. F represents prostrate manuka. This is a box whisker plot of the mean, upper and lower quartiles and minimum and maximum values for each tree in a habitat. The cross represents the mean value, the upper end of the box is the upper quartile and lower side of box is the lower quartile. The whiskers or vertical lines extend to the minimum observed value and up to the maximum value. This applies to all graphs that follows.

4.2.1.2 Vessel Width/Diameter

The ANOVA table in Appendix 2 showed that there were significant differences between the habitats. Tukey's HSD test showed that habitat D had significantly wider cells than the other habitats; habitat E had significantly wider cells than habitats A and C. Habitats A, B, and C do not differ significantly, Table 4.3 and fig. 4.8 below.

Table 4.3 Mean Widths (original scale) (um) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	58.54 c	53.38-64.20
B	61.62 c	57.78-65.73
C	59.24 c	55.82-62.86
D	66.41 a	61.88-71.28
E	64.98 b	60.04-70.32
F	46.46 d	41.65-51.83

Note: For this table and the rest that follows the figures marked with the same letters denotes that the means were not significantly different from each other ($p<0.0001$)

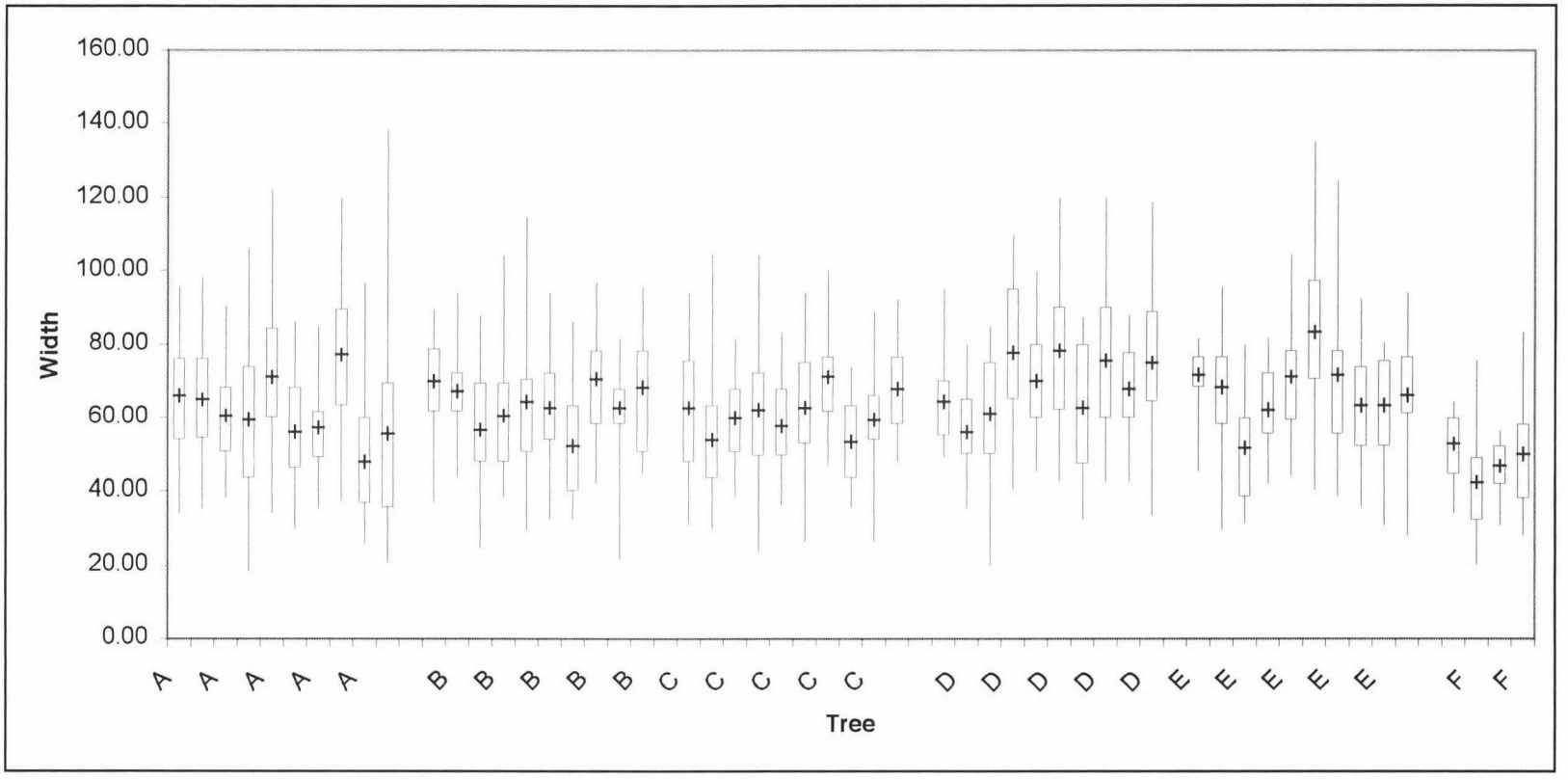


Figure 4.8 Mean widths 9 (um) of wide vessels (Legend refer to figure 4.7 above)

4.2.1.3 Vessel wall thickness

In order to ensure reasonable constant variance, the logs of the wall thickness were analysed. From the ANOVA table in appendix 3 there were significant differences between the habitats. The Tukey's HSD test showed that habitat C, D and E had significantly thicker walled cells than habitats A and B. Habitat B had significantly thicker walls than A. See table 4.4 below. Fig.4.9 also shows the differences.

Table 4.4 Mean wall thickness (original scale) (um) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	3.92 c	3.67-4.18
B	4.24 b	4.03-4.46
C	4.65 a	4.44-4.87
D	4.75 a	4.50-5.00
E	4.70 a	4.27-5.18
F	3.80 c	3.22-4.50

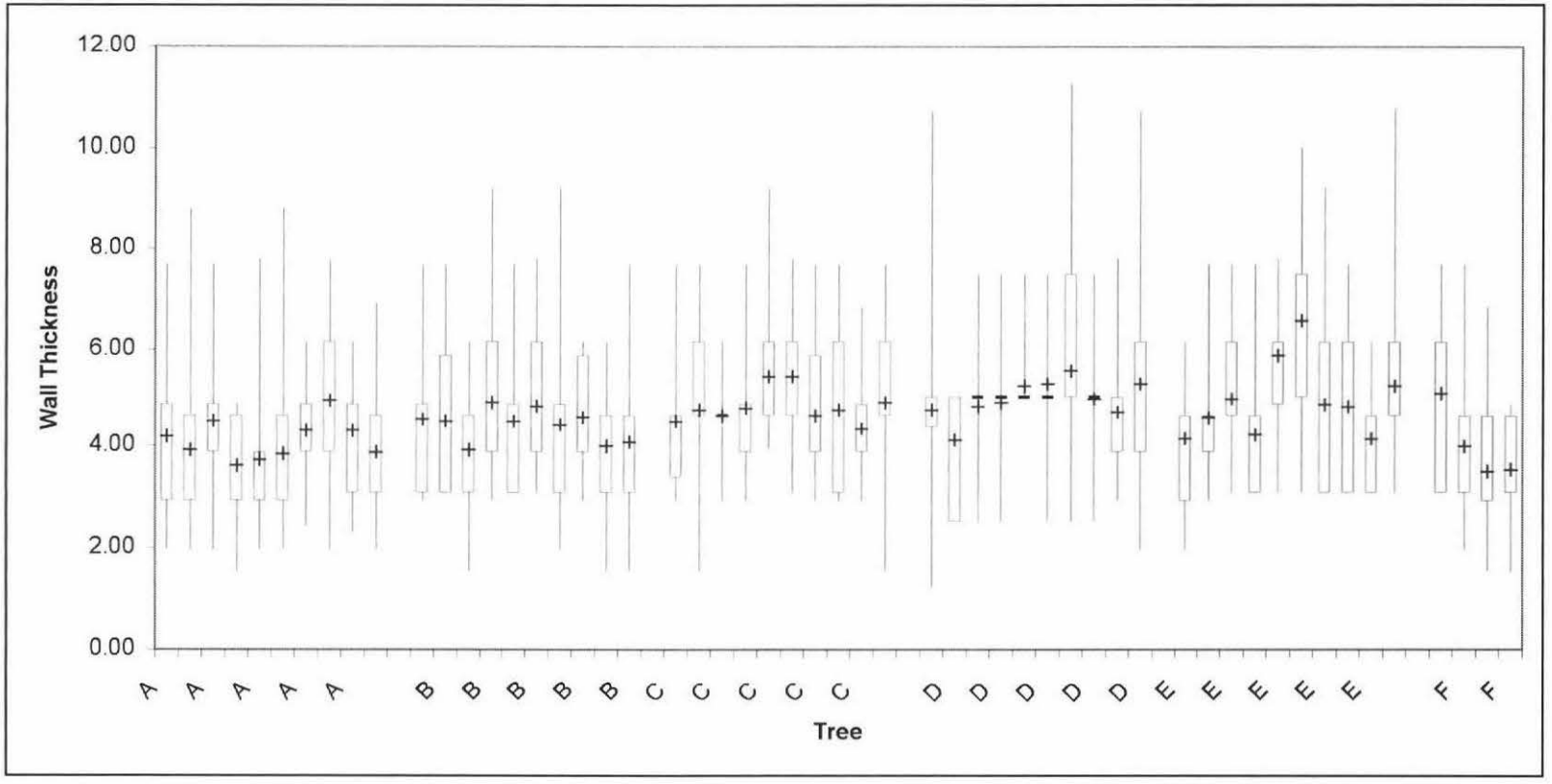


Figure 4.9 Mean wall thickness (um) of wide vessels (legend is as in fig.4.7)

4.2.1.4 Vessel density or Abundance

In order to ensure reasonable constant variance, the logs of the abundance values (number of cells per square mm) were analysed. The ANOVA table in appendix 4 showed that there were significant differences between the habitats. Habitat A and B had similar levels of abundance and had higher levels than habitat C, D and E. Habitat D had a significantly higher level of abundance than C and E, which had similar levels. See table 4.5 and figure 4.10 below.

Table 4.5 Mean abundance (original scale) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	61.07 b	47.39-78.71
B	59.99 b	50.34-71.50
C	50.14 d	46.11-54.53
D	55.92 c	45.78-68.29
E	52.03 d	43.57-62.14
F	26.78 a	106.80-150.49

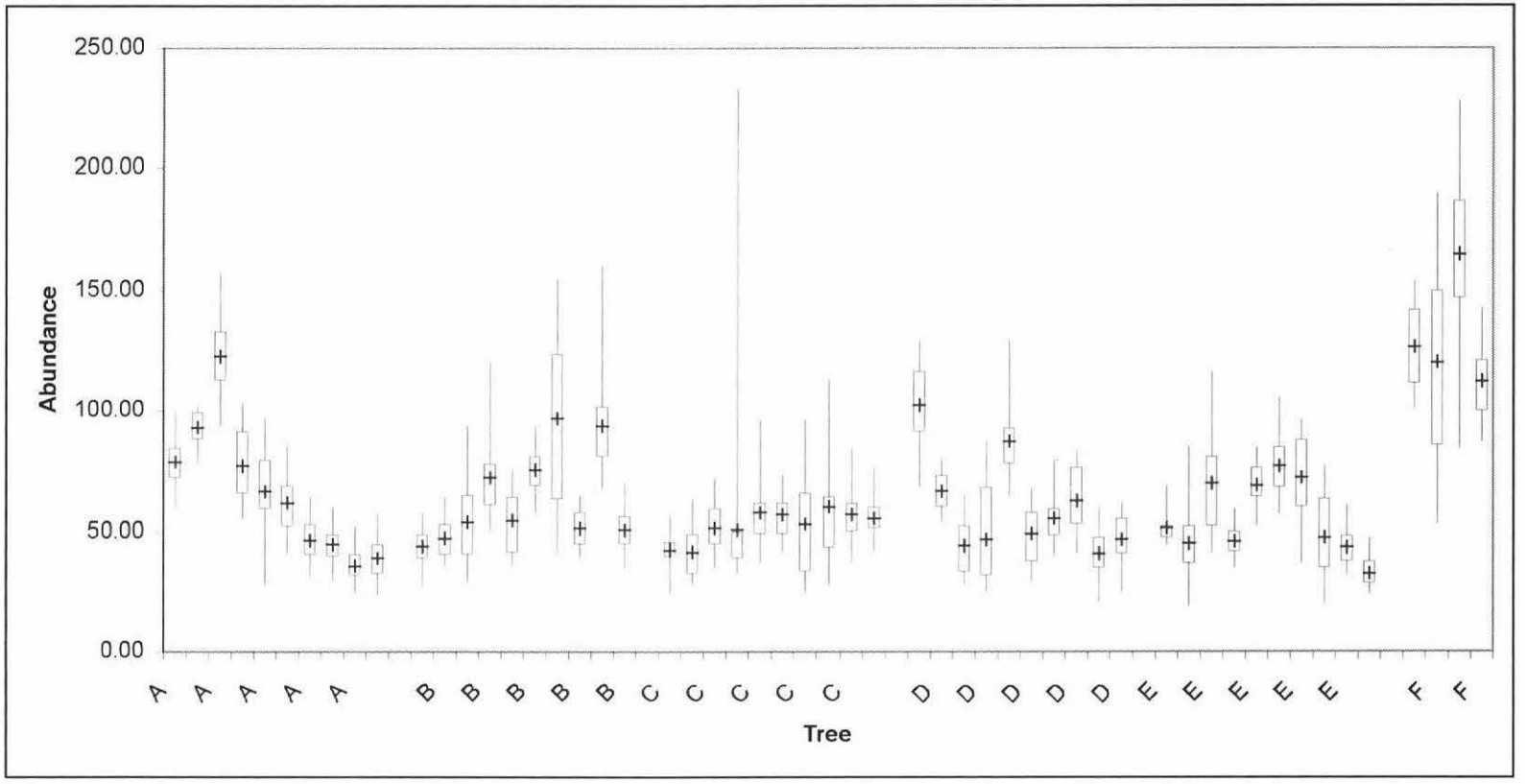


Figure. 4.10 Mean abundance of wide vessels (legend as in fig. 4.7)

4.2.1.5 Area of perforation plates of wide vessel elements

From the analysis of the logs of the data it was found that the differences between the habitats were significant (p=0.039). Tukey's test showed that habitat E had marginally bigger perforation plate area than D. A, B and C were not significantly different from either D or E, see table 4.6 below.

Table 4.6 Mean Perf. Plate Area (original scale) (um)and their confidence intervals

Habitat	Mean (log scale)	95% Confidence interval for mean
A	749.9 ab	574.9-978.3
B	888.9 ab	763.6-1034.7
C	845.6 ab	681.9-1048.6
D	720.5 b	634.9-817.8
E	1053.6 a	964.3-1151.3

4.2.1.7 Vessel grouping

Trees in the different habitats showed a combination of all types of groupings, for example solitary (one cell per group), clustered where cells were in groups of two or more joined wall to wall or chains where the cells made a chain of cells joined wall to

wall. Habitat A had oblique chains and clustered grouped cells, B had solitary but also clustered and oblique chains, C and E had mostly solitary, D had more clustered cells (see appendix). Analysis of variance showed that there was a significant difference in the grouping between the different habitats. Habitat D showed high level of grouping and habitats A and B were not significant from each other and also C and E were not significant from each other, table 4.7.

Table 4.7 Mean and standard deviations of wide vessel grouping

Habitat	Mean group	Standard Deviation
A	1.601 b	0.336
B	1.570 b	0.332
C	1.323 c	0.191
D	1.979 a	0.574
E	1.293 c	0.173
F	1.204 c	0.108

4.2.2 Fibriform vessel elements

4.2.2.1 Length

ANOVA table in appendix 6 showed that there were significant differences between the habitats. Tukey's HSD test showed that habitat D had a significantly lower mean, that is, it had shorter cells than all the others. The rest were not significantly different from each other as shown in table 4.8 and fig. 4.11.

Table 4.8 Mean length (original scale) (um) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	394.2 a	381.4-407.3
B	414.4 a	389.8-440.6
C	377.8 a	362.4-393.8
D	340.7 b	326.9-355.0
E	415.5 a	385.5-447.9
F	389.0 a	334.8-451.9

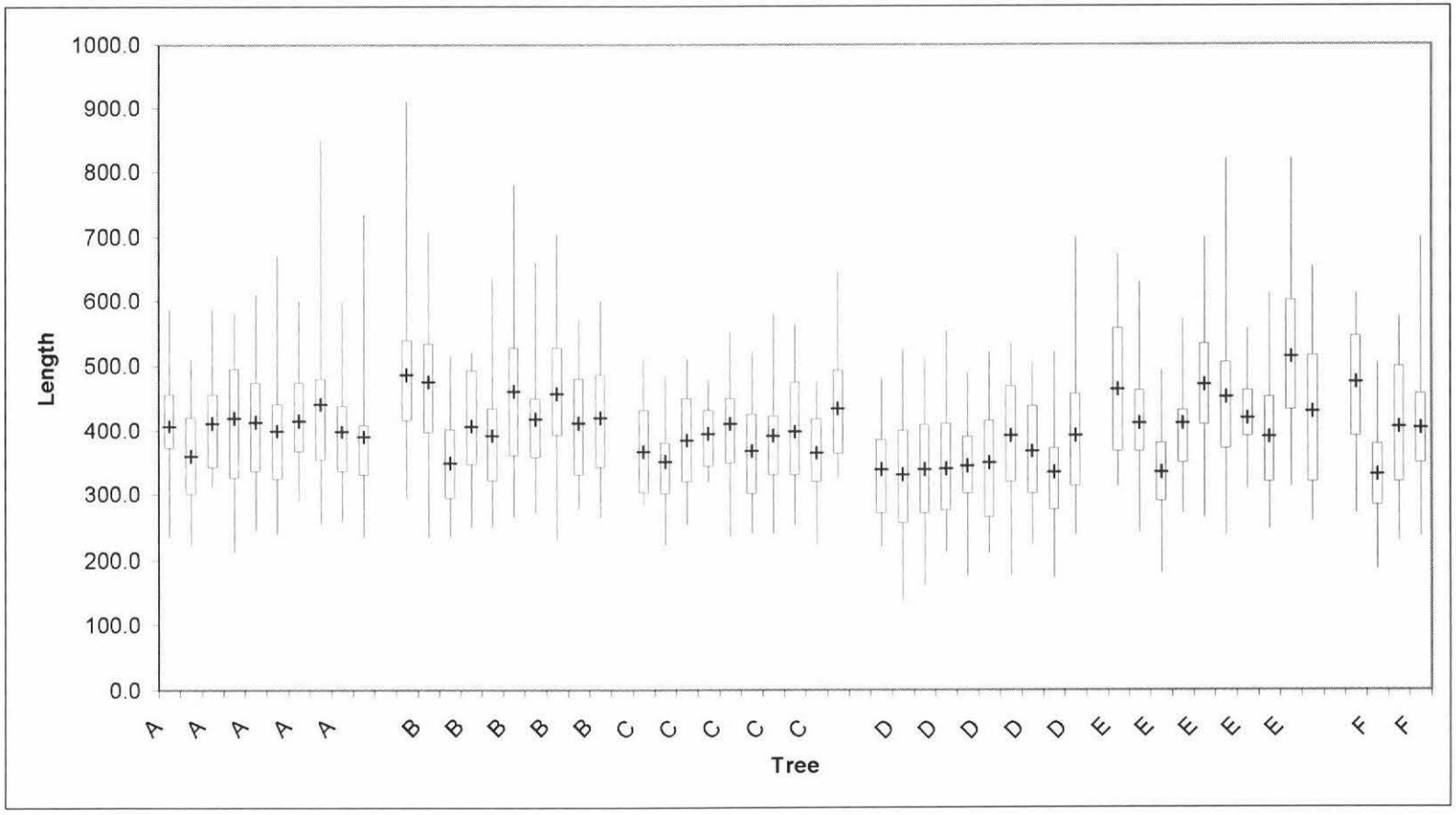


Fig 4.11 Mean Lengths (um) of fibriform vessels (legend is as in fig. 4.7)

4.2.2.2 Width

Analysis of variance as shown in the ANOVA table in appendix 7 showed that there were significant differences between the habitats. Tukey's HSD test showed that habitat D has significantly wider cells than the other habitats. Amoung the other habitats (A, B, C and E), A has wider cells than C. The others differences were not significant. Table 4.9 of means shows these differences. Also see fig 4.12.

Table 4.9 Mean Width(original scale) (um) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	24.66 b	23.91-25.43
B	23.25 bcd	22.67-23.85
C	22.30 cd	21.47-23.17
D	27.28 a	25.89-28.75
E	22.86 bcd	21.83-23.94
F	18.90 e	17.97-19.88

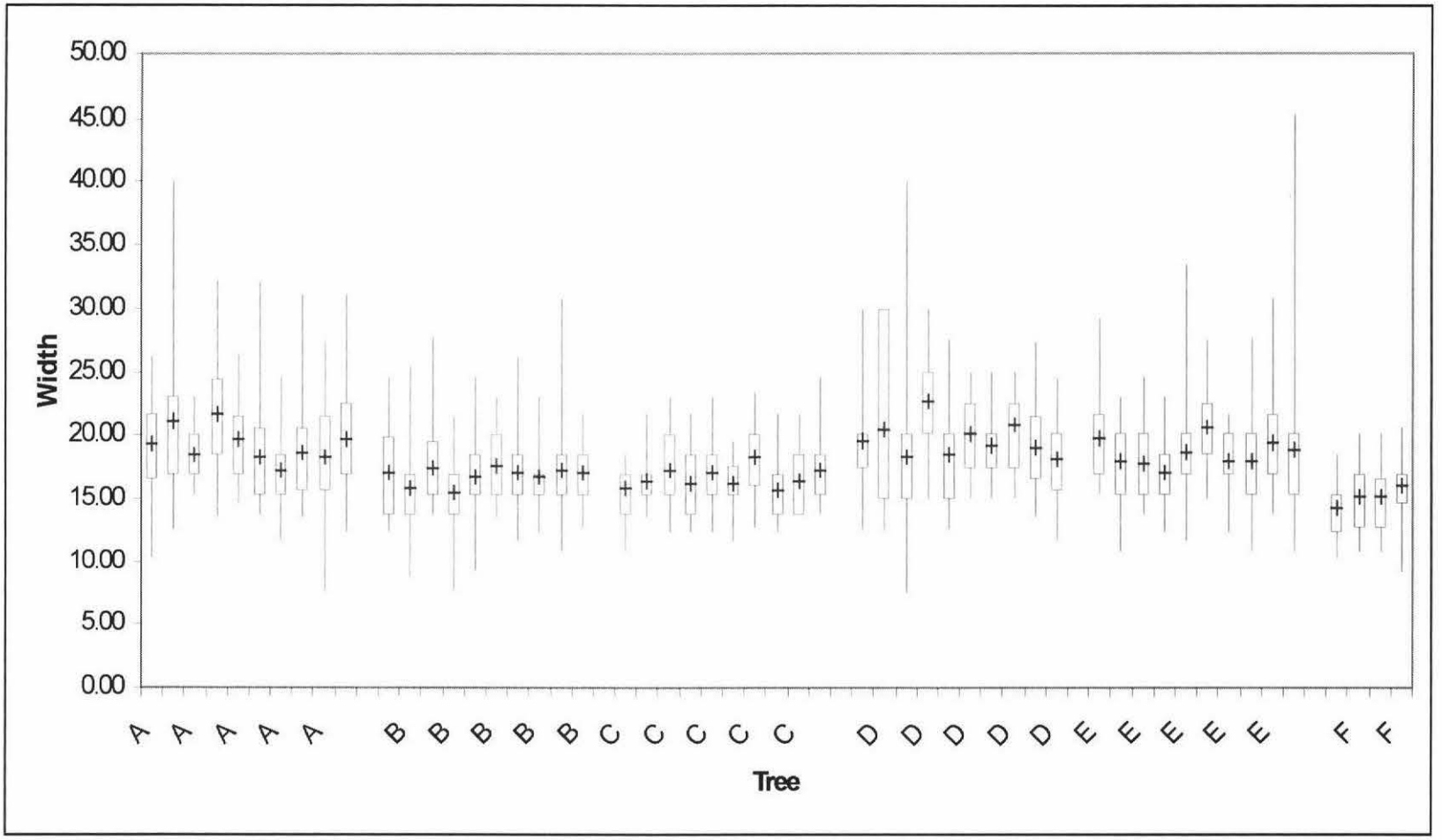


Figure 4.12 Mean widths (um) of fibriform vessel. (legend is as in fig 4.7)

4.2.2.3 Wall thickness

Analysis of variance showed that there were significant differences between the habitats. This is shown in the ANOVA table in appendix 8. Tukey's HSD test showed that habitat D had significantly thicker walled cells than any other habitat. C and E cell wall thickness did not differ significantly. A and B did not differ significantly. This is shown in table 4.10 and fig. 4.13 below.

Table 4.10 Mean Wall thickness(um) (original scale) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	3.41 c	3.27-3.55
B	3.28 c	3.03-3.53
C	3.61 b	3.43-3.80
D	4.18 a	3.91-4.47
E	3.54 b	3.34-3.75
F	2.95 c	2.53-3.44

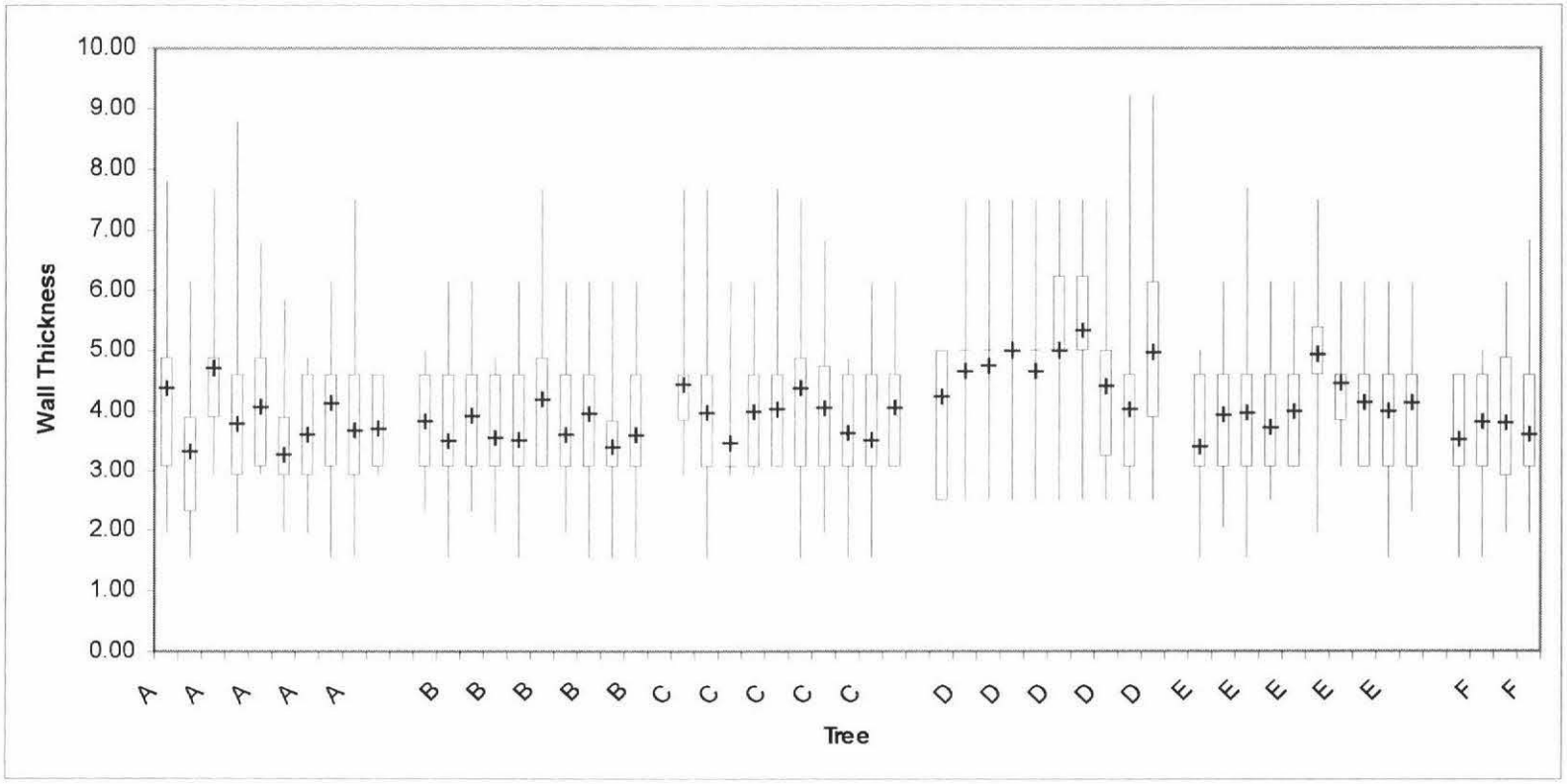


Figure 4.13 Mean wall thickness (um) of fibriform vessels (legend is as in fig. 4.7)

4.2.2.4 Area of perforation plates of fibriform vessels

From the analysis of the logs of the data it was found that the differences between the habitats were marginal at P=0.081. From Tukey's test, habitat D had marginally bigger perforation plates than habitat C. Habitats A, B and E were not significantly different from either C or D. This is shown in table 4.11 of mean logs below.

Table 4.11 Mean Perf. Plate Area (original scale) and confidence intervals

Habitat	Mean (um) (original scale)	95% Confidence interval
A	103.5 ab	88.4-121.3
B	84.8 ab	63.8-112.7
C	73.7 b	57.6-94.3
D	134.3 a	96.0-187.8
E	90.9 ab	59.9-138.1

4.2.3 Libriform fibres

4.2.3.1 Length

Univariate analysis of variance, ANOVA table in appendix 9, showed that there were significant differences between the habitats. Tukey's HSD test showed that habitat E had significantly longer cells than other habitats. Habitats B, C and D had similar cell mean lengths. A had significantly shorter cells on average than all the other habitats. Table 4.12 of means above shows these differences. Fig 4.14 shows the same differences.

Table 4.12 Mean Length (um) (original scale) and confidence intervals

Habitat	Mean (log scale)	95% Confidence interval for mean
A	667.22 c	630.22-706.39
B	741.81 b	677.29-812.47
C	726.50 b	685.78-769.64
D	709.81 b	664.84-757.82
E	825.34 a	783.73-869.16
F	531.05 d	494.27-570.57

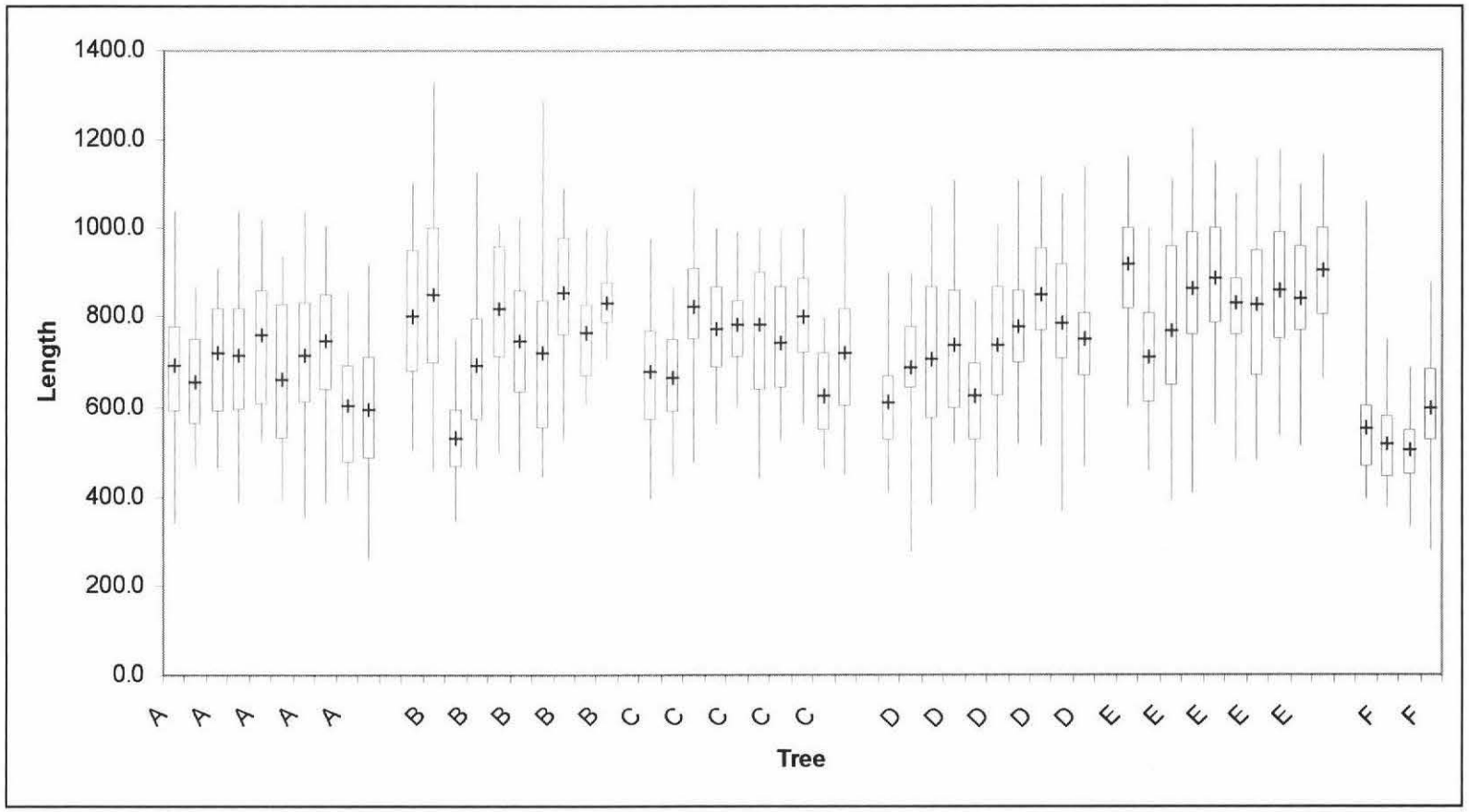


Figure 4.14 Mean lengths (um) of Libriform fibres (legend is as in fig. 4.7 above)

4.2.3.2 Width

The ANOVA table in appendix 10 showed that there were significant differences between habitats. Tukey's test showed that habitat D had significantly wider cells than the other habitats apart for A. A had significantly wider cells than B and C. B and C do not differ significantly. Habitat E was not significantly different from habitat A and D. See table 4.13 above.

Table 4.13 Mean Width (um) (original scale) and confidence intervals

Habitat	Mean (log scale)	95% Confidence interval for mean
A	18.80 a	18.01-19.63
B	16.55 b	16.13-16.98
C	16.49 b	16.03-16.97
D	19.16 a	18.33-20.01
E	18.24 ab	17.61-18.89
F	14.93 c	14.24-15.66

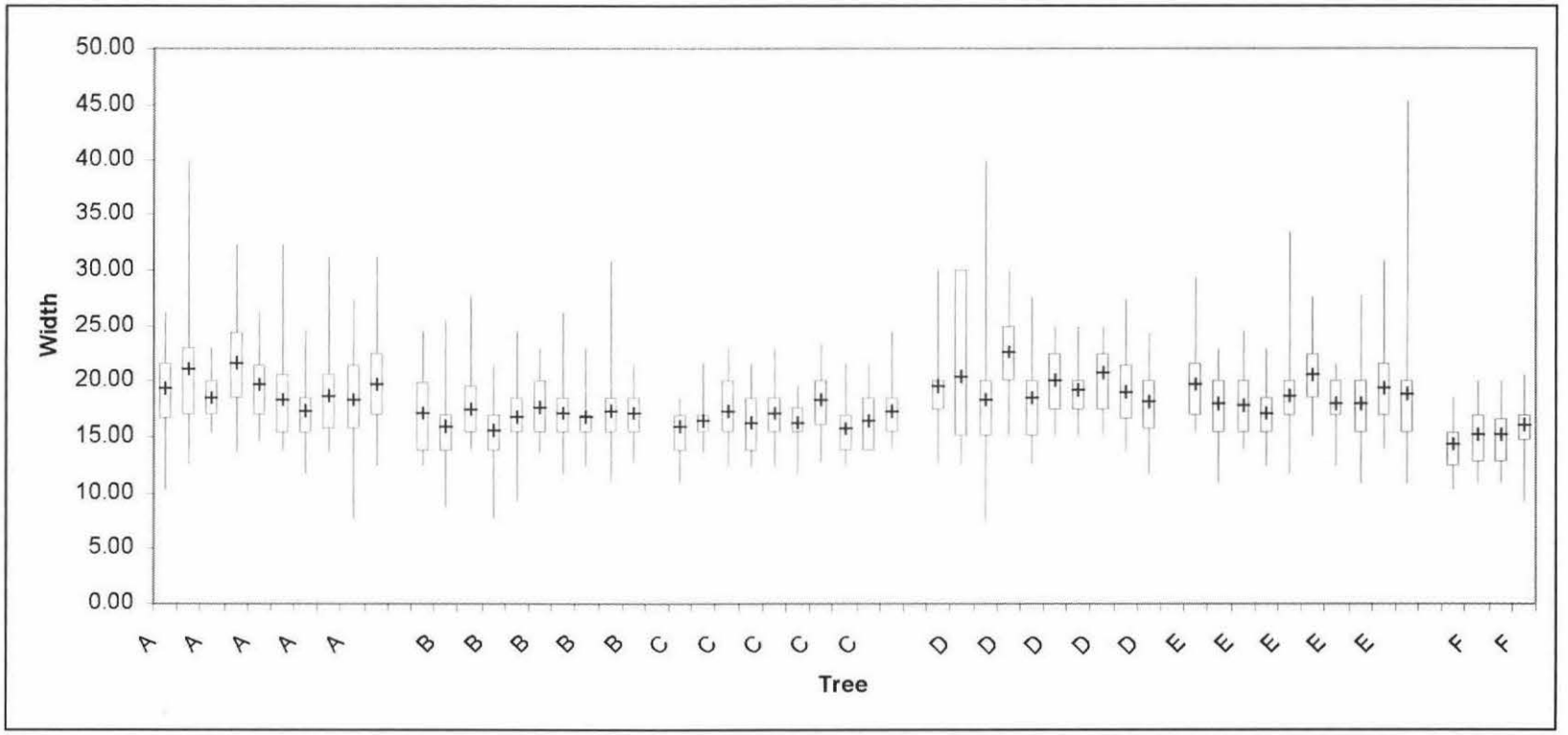


Figure 4.15 Mean width (um) of Libriform fibres (legend is as in fig. 4.7 above)

4.2.3.3 Wall thickness

The raw data appeared was normally distributed, with constant variance; as such there was no transformation of the data. The ANOVA table in appendix 11 showed that there were significant differences between the habitats. Tukey's test showed that habitat A and D had significantly thicker walled cells than B and C. Habitat E had significantly thicker walls than C. This is shown in the above table 4.14 and fig. 4.16 below.

Table 4.14 Mean Wall thick., Standard Deviation (SD) and confidence intervals

Habitat	Mean + SD (um)		95% Confidence interval for mean
A	6.38 a	0.88	5.82-6.930
B	5.98 b	0.43	5.71-6.25
C	5.69 b	0.50	5.37-6.01
D	6.38 a	0.59	6.01-6.76
E	6.20 a	0.65	5.79-6.61
F	4.68 c	0.44	4.25-5.12

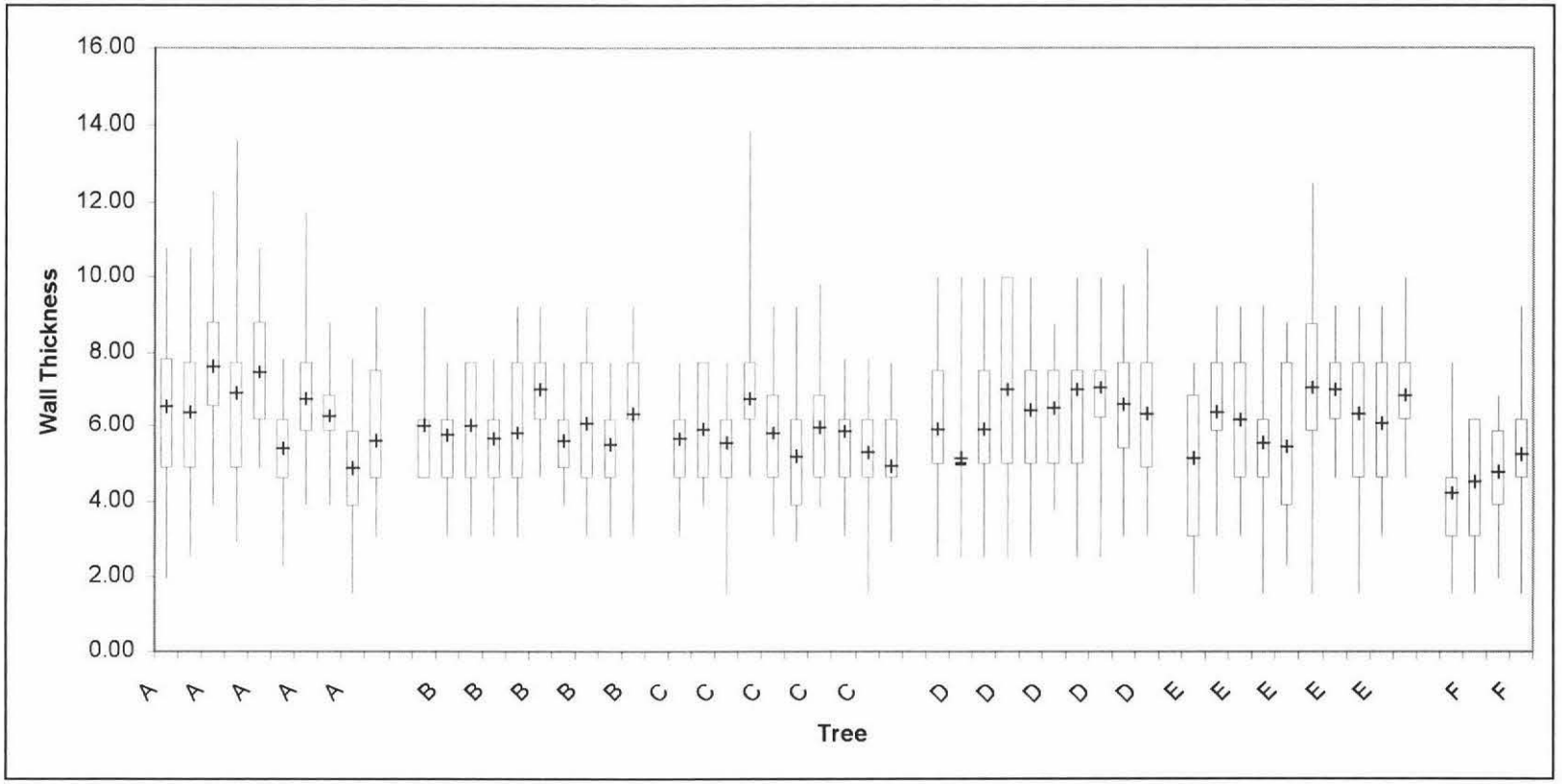


Figure 4.16 Mean wall thickness (um) of libriform fibres (legend is as in fig.4.7)

4.2.4 Fibre tracheids

4.2.4.1 Length

ANOVA table in appendix 12 showed that there were significant differences between the habitats. Tukey's test showed that habitat E had significantly higher means or longer cells than A, D and F. B cells were significantly longer than those of habitat D. This is shown in fig. 4.17 and table 4.15 above.

Table 4.15 Mean Length (um) (original scale) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	457.4 bc	432.20-476.60
B	499.4 ab	469.90-530.80
C	467.6 bc	453.90-481.70
D	433.2 c	414.70-452.50
E	515.3 a	486.20-546.20
F	442.9 bc	415.40-472.30

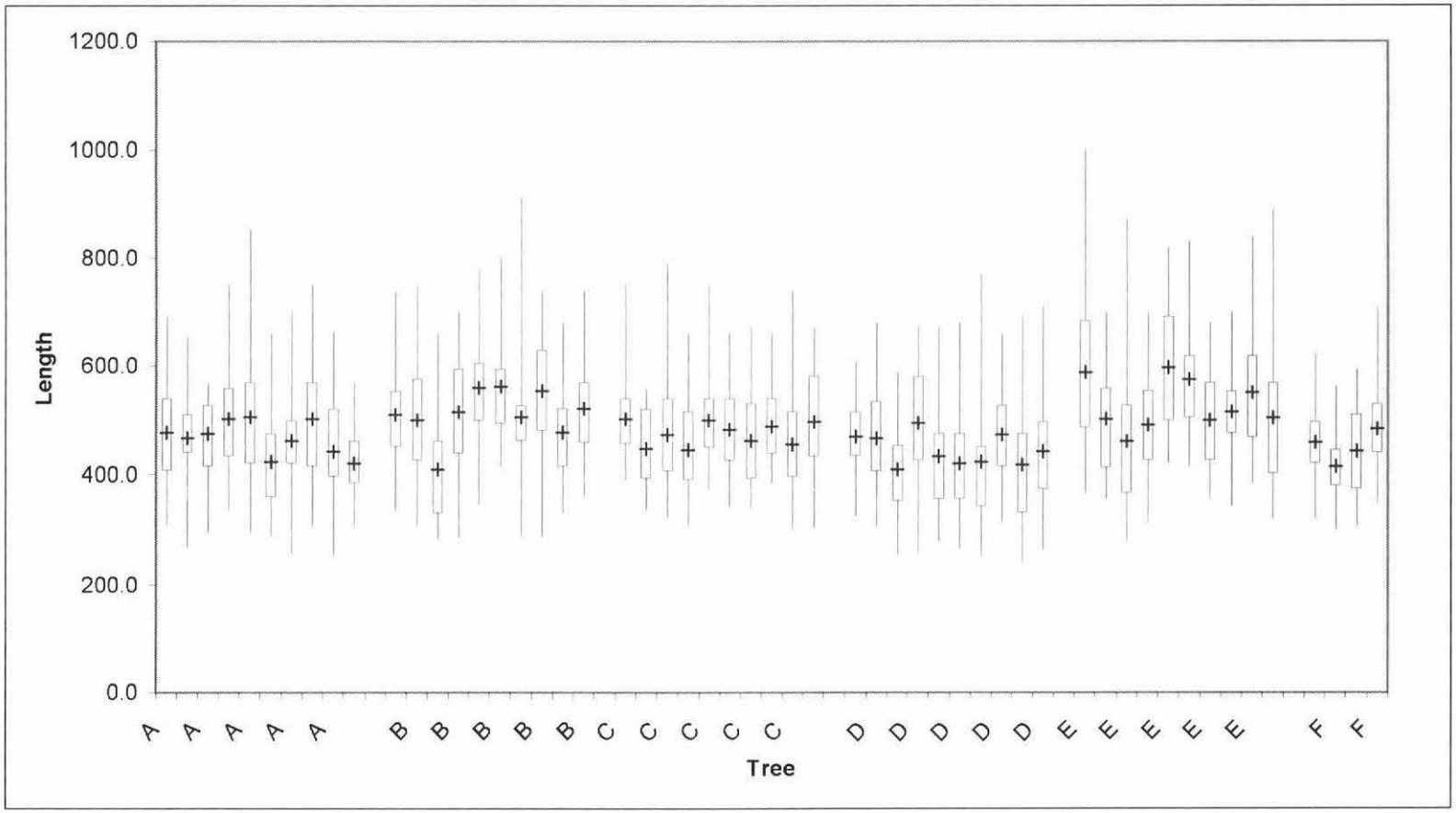


Figure 4.17 Mean lengths (um) of fibre-tracheids (legend is as in fig. 4.7)

4.2.4.2 Width

ANOVA table in app. 13 showed that there were significant differences between the habitats. Tukey's test showed that habitat D had significantly wider cells than all the other habitats except site A. A had wider cells than B and C. C had the narrowest cells. This is shown in the above table 4.16 and in fig 4.18.

Table 4.16 Mean Length (um) (original scale) and confidence intervals

Habitat	Mean (original scale)	95% Confidence interval for mean
A	20.83 a	19.82-21.89
B	18.48 b	17.93-19.05
C	17.91 c	17.22-18.64
D	21.66 a	20.83-22.52
E	19.42 b	18.76-20.11
F	16.26 c	15.22-17.37

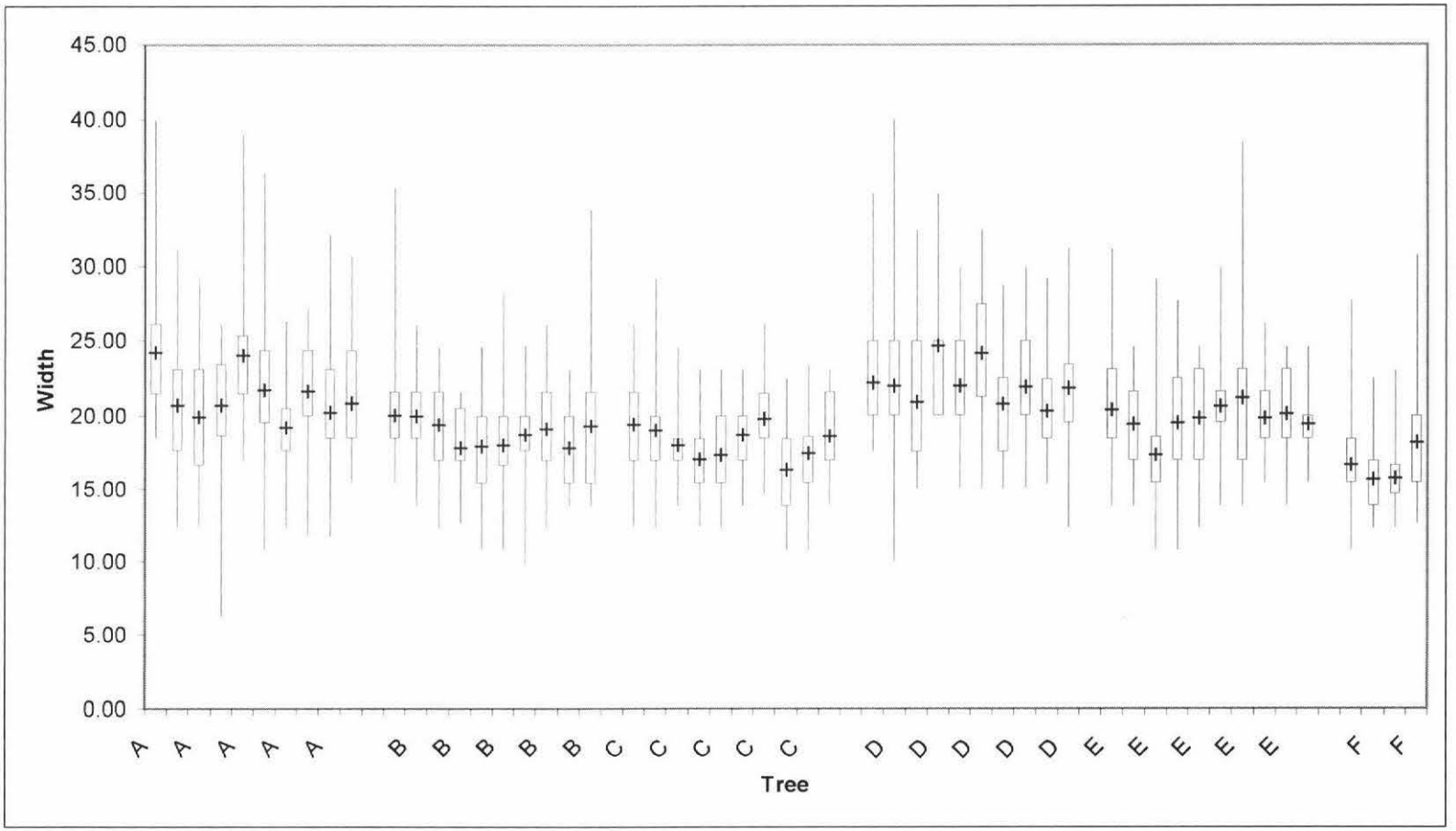


Figure 4.18 Mean widths (um) of fibre-tracheids (legend is as in fig. 4.7)

4.2.4.3 Wall thickness

From the ANOVA table in append. 14 it was shown that there were significant differences between the habitats. Tukey's test showed that habitat D had significantly thicker walled cells than all the other habitats. The others do not differ significantly amoung themselves. This is shown in table 4.17 below where those that do not differ significantly are marked with the same letter. See also fig. 4.19 below.

Table 4.17 Mean Wall thickness (original scale) and confidence intervals

Habitat	Mean (um) (original scale)	95% Confidence intervals
A	3.69 b	3.41-3.99
B	3.56 b	3.40-3.73
C	3.80 b	3.60-4.00
D	4.50 a	4.26-4.75
E	3.91 b	3.68-4.17
F	3.55 b	3.42-3.68

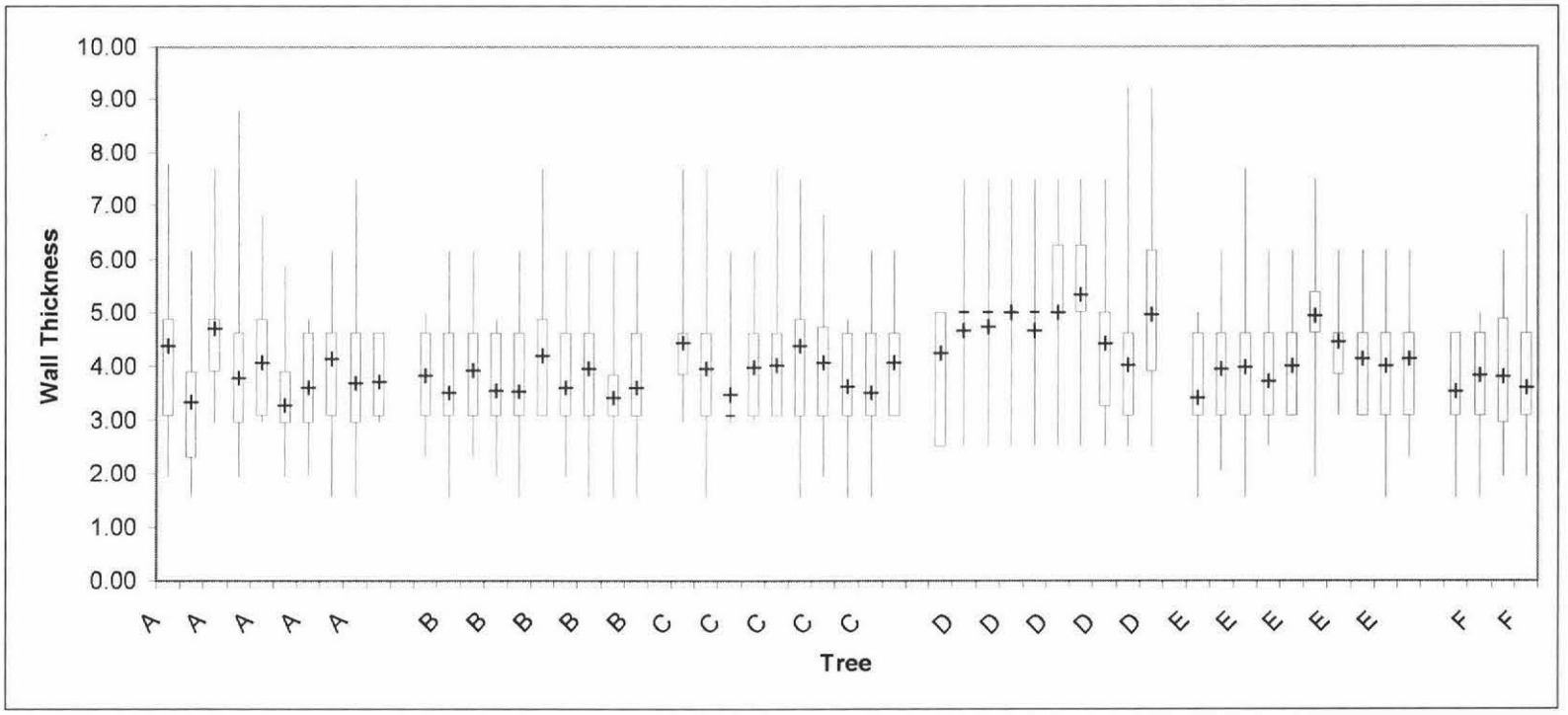


Figure 4.19 Mean wall thickness of fibre-tracheids (legend is as in fig. 4.7)

4.2.5. Presence of vestures and wall thickening in wide vessels

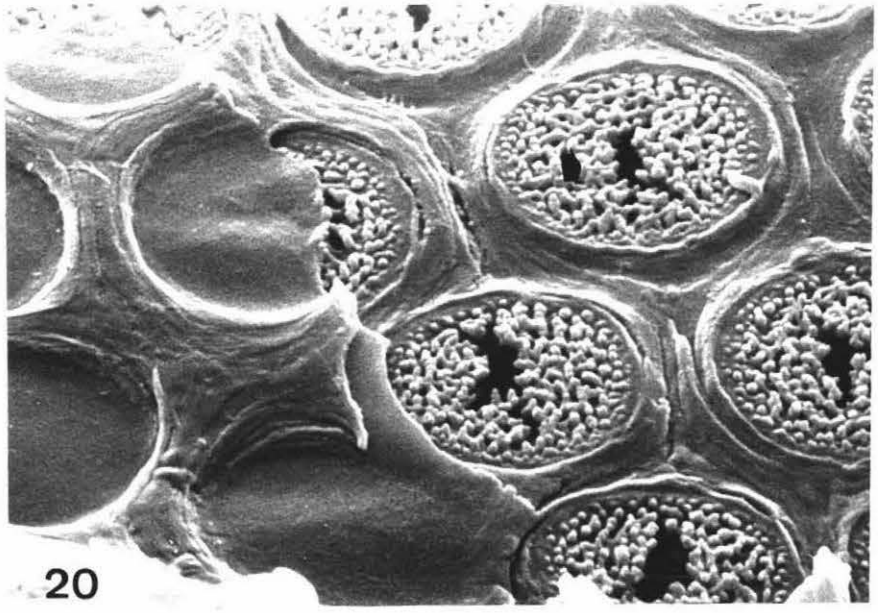
The presence of vestures and wall thickenings were investigated with the help of the scanning electron microscope. From each habitat two samples were examined. Wide vessels examined from all the habitats had vestures in the pit cavities and also some appeared on the inner surface of the walls of vessel elements but to a lesser scale than in the pit cavities. There were no vessel wall thickenings.

4.2.5.1 Margins of lowland forest

Vestures of vessels from this habitat were quite distinct from those of the other habitats. See figs.4.20 and 4.21 (arrow heads). When the pit membrane was peeled away, it was found that the vestures extended from the inner surface of the pit cavity near the aperture and terminated just short of the pit membrane. Vestures were quite dense and branched spreading on the pit apertures. They appeared to leave a small opening in the centre of the aperture as shown in fig. 4.22 (arrow). When the membranes were not tampered with, the pits appeared smooth without any vestures or some with very small vestures deep inside the pit as shown in fig. 4.23. The walls of these vessel elements were not very smooth although not warty (see fig. 4.24).

4.2.5.2 Hot thermal soils habitat

Some of the pits from this habitat were more elongated in shape and there was an occurrence of short grooves interconnecting pit pairs, see figs. 4.25 (arrow). Some of the pits were curved at the ends fig. 4.25. The elongated pits showed no sign of vestures while the more circular ones were vestured. The inner walls were smooth except on the areas around the pits, fig.4.26. The vestures on the border of the pits were very minute and appear more like warts. The vestures were branched like those of sand dune and swamp habitats but less branched and less dense as compared to those of margins of lowland forest fig. 4.26 (arrow head). They covered the pit aperture but left some openings but not as in the centre of the pit cavity as it was the case in margins of lowland forest vessels, 4.26.



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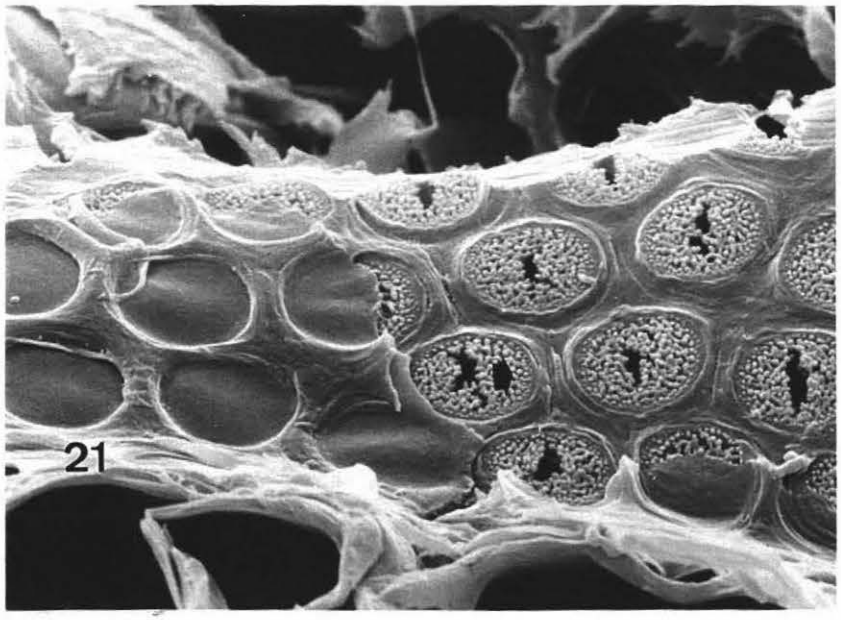

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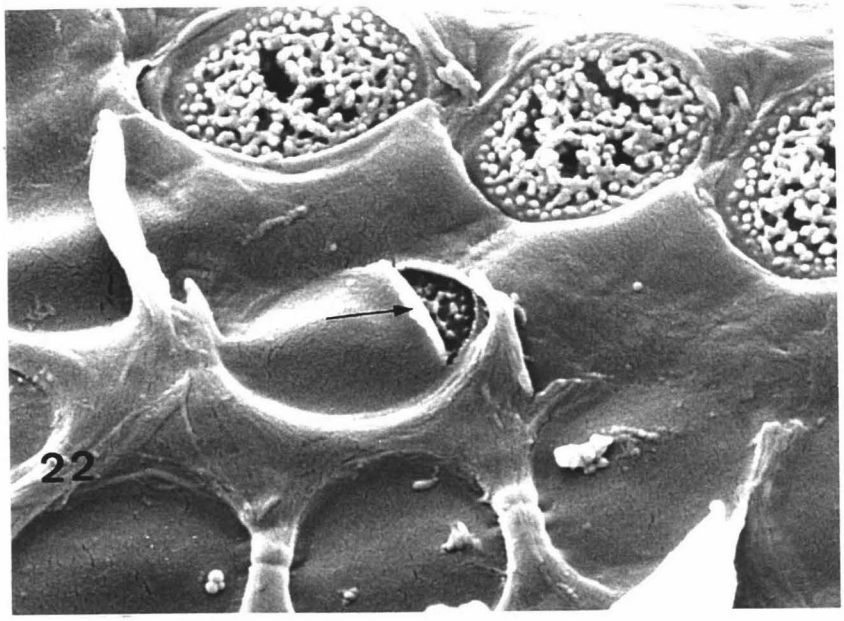
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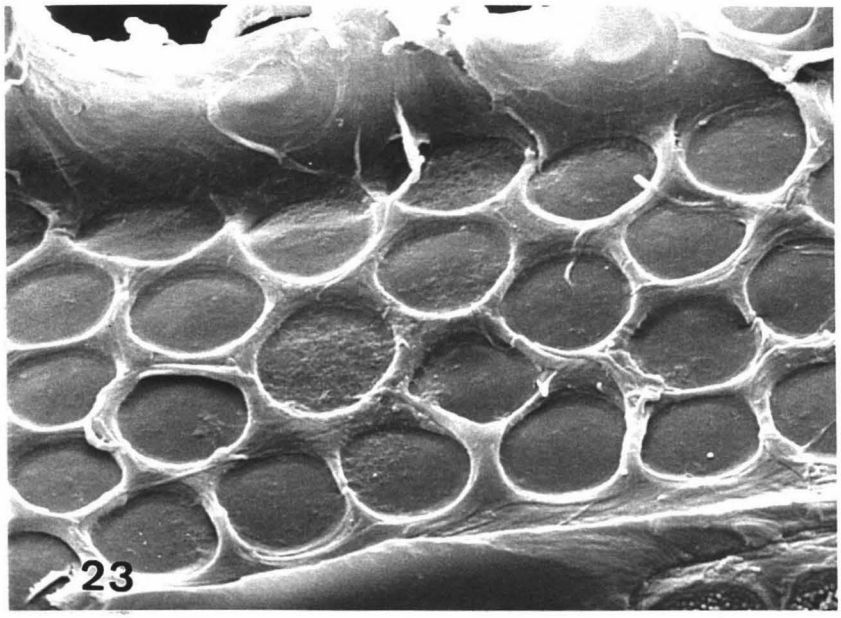
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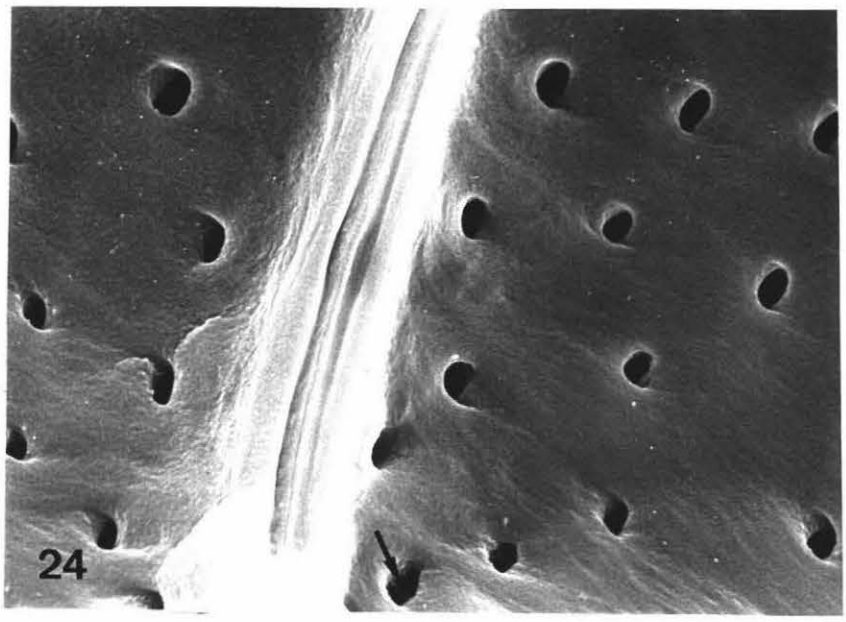
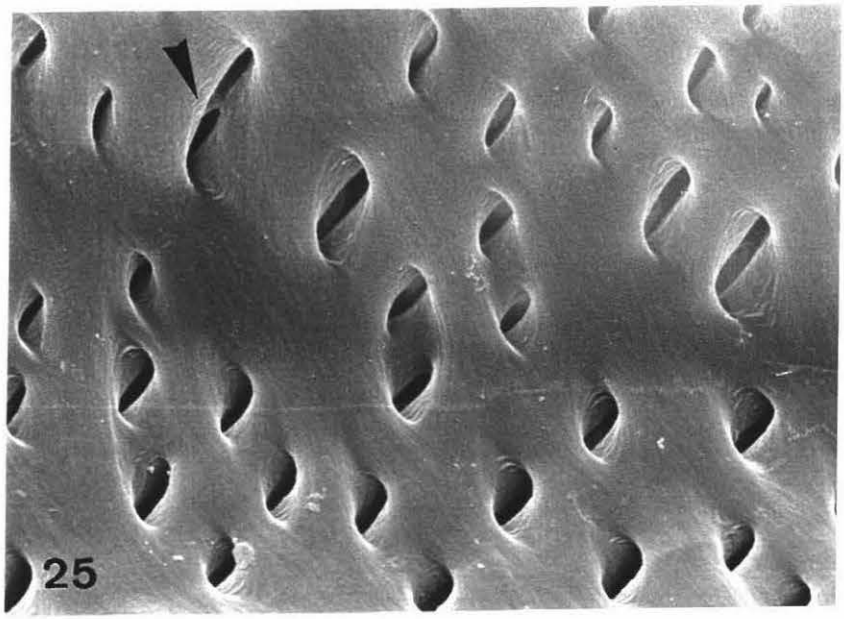


Figure 4.20 – 4.24 SEM micrographs of lowland forest vessels showing vestures in their pits. 20,21 show dense branched vestures spreading over apertures (arrow heads). 22 shows a small portion of membrane peeled exposing vestures below the membrane (arrow). 23 shows pits with intact membranes. 24 shows vestures located deep inside pit chambers (arrow) and smooth to lightly warty walls. 20 and 22 at magnification of X8000. The rest at X4000.



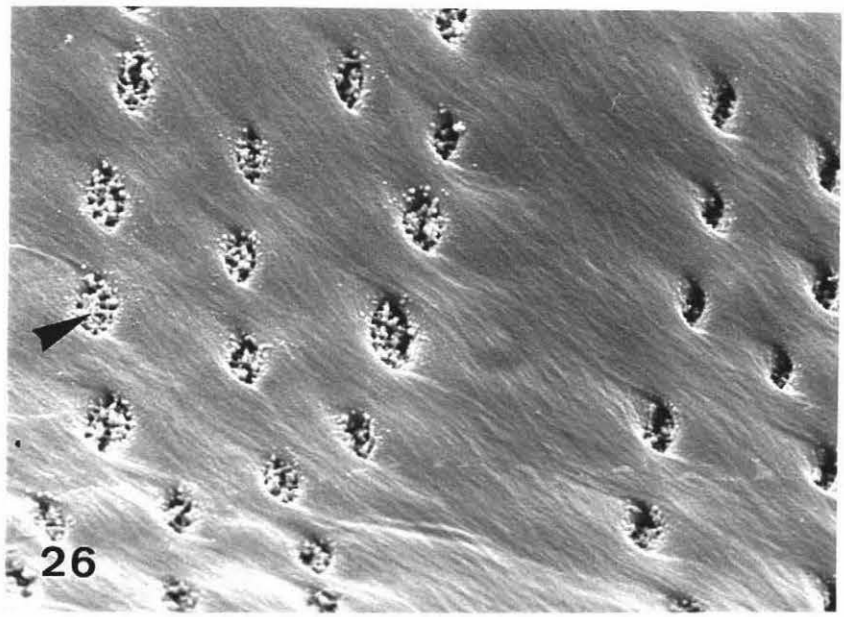


Figure 4.25 – 4.26 SEM micrographs showing branched vestures inside each pit of wide vessels of plants from hot thermal soils habitat. 25 elongated pits with short grooves interconnecting paired pits (arrow head) 26 shows branched vestures confined to each pit apertures (arrow head) X4000

4.2.5 3 Sand dune

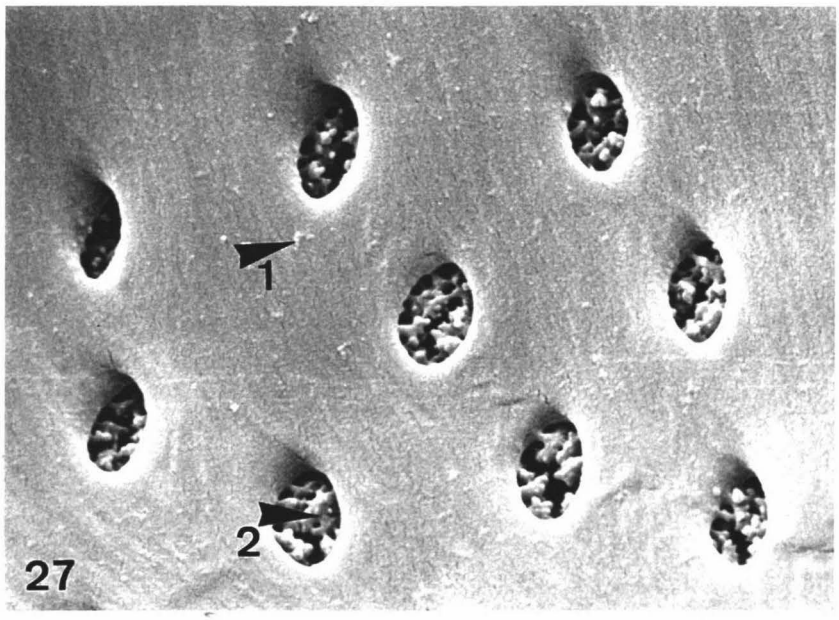
Some of the inner walls of these vessel elements appeared slightly granular or warty as shown in fig.4.27 (arrow head 1) and some smooth, fig. 4.28. Some of the pits probably those of the vessel to ray parenchyma type were roundish in shape while others (intervessel pits) appeared to be ellipse and polygonal in shape with curved walls at the ends, fig. 4.28. Fig. 4.29 (arrows) shows vestures deep inside the pit chambers. Figs. 4.27 with more circular shaped pits, showed a network of vestures covering pit apertures (arrow head 2). The vestures here are confined to the pit cavity but are a little bit to the inside of the surface of the pit cavity.

4.2.5.4 Subalpine

The inside walls of the vessel elements were more warty as compared to those of the above habitats figs.4.30 and 4.31. Both the intervessel and vessel to ray parenchyma pits had vestures, figs 4.30 (arrow head) and 4.33 (arrow). Some of the pits were connected by short grooves as it was the case in hot thermal soils habitat, see figures 4.31 (arrow head). Simple vestures on the polygonal or elongated pits were confined to the rim of the pit cavity while branched ones were confined to pit chambers, figs. 4.30 and 4.31. Some of the less elongated pits showed no signs of vestures (fig.4.32). The walls bearing the more rounded pits appeared more smooth, figs 4.34.

4.2.5.5 Swamp habitat

The inner walls of vessels here were covered with more warts as compared to those of sand dune and subalpine habitats. This is shown in figures 4.35, and 4.36. Some of the pit apertures were more circular, figs.4.37 while some were more elongated, 4.35 and some curved too. The vestures were distributed like those of vessels in above habitats in that they appear to be confined to the inside of the pit cavity. They also appeared to be branched and covered the pit aperture like those of sand dune and hot thermal soils, 4.37, 4.38.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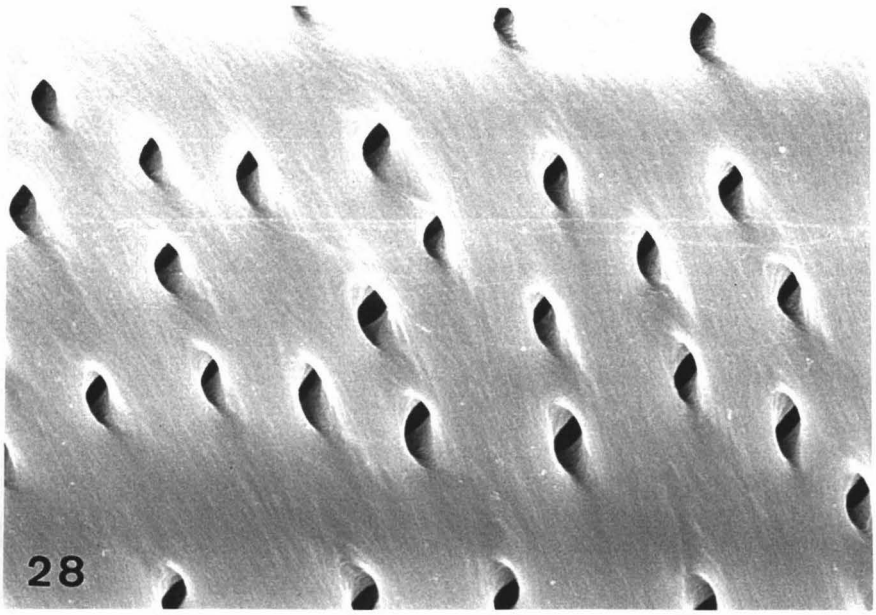
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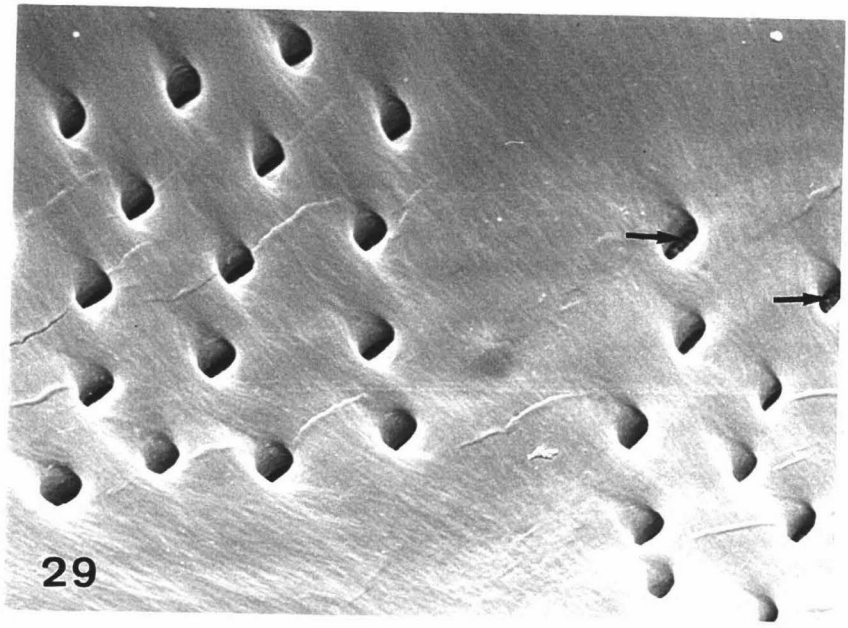
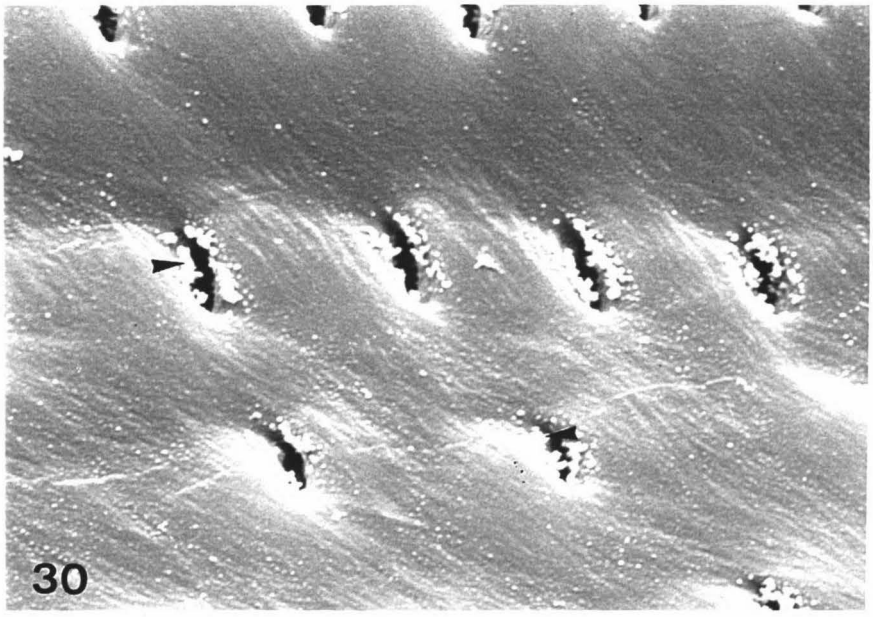


Figure 4.27 – 4.29 SEM micrographs showing vestures in pits of wide vessels from sand dune habitat. 27 shows vessel wall covered slightly with warts (arrow head1) and branched vestures confined to the pit aperture (arrow head 2) X8000. 28 shows curved pits without any sign of vestures. 29 shows vestures deep inside the pit chambers (arrows) X4000.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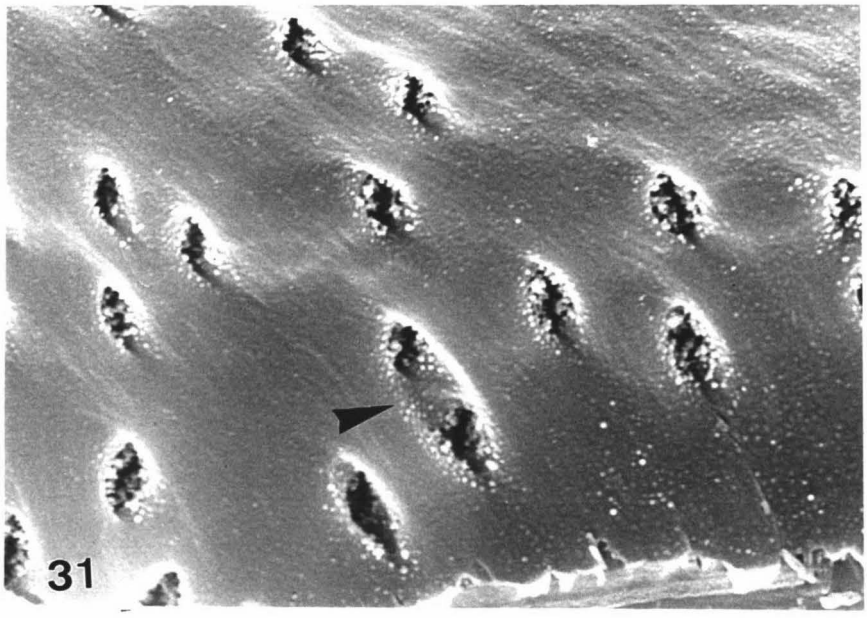
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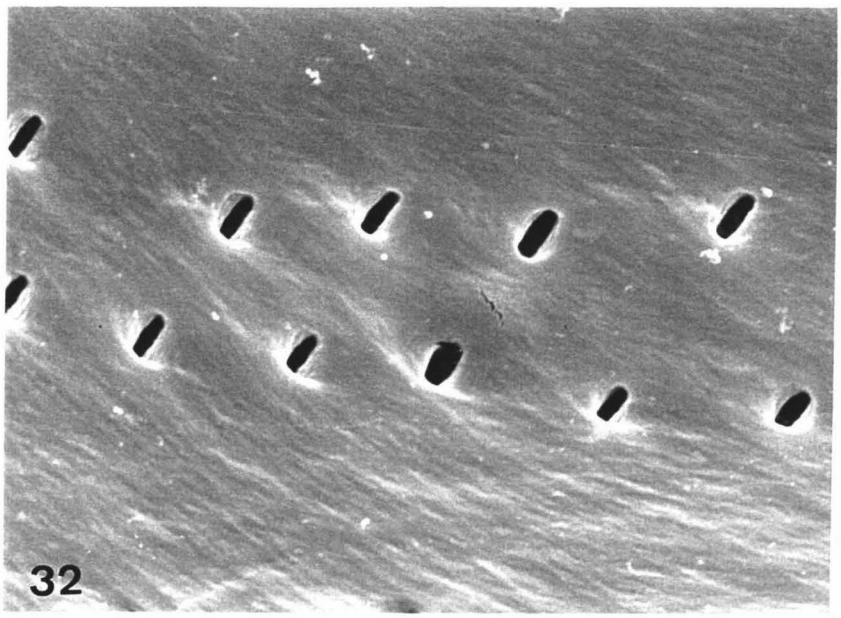
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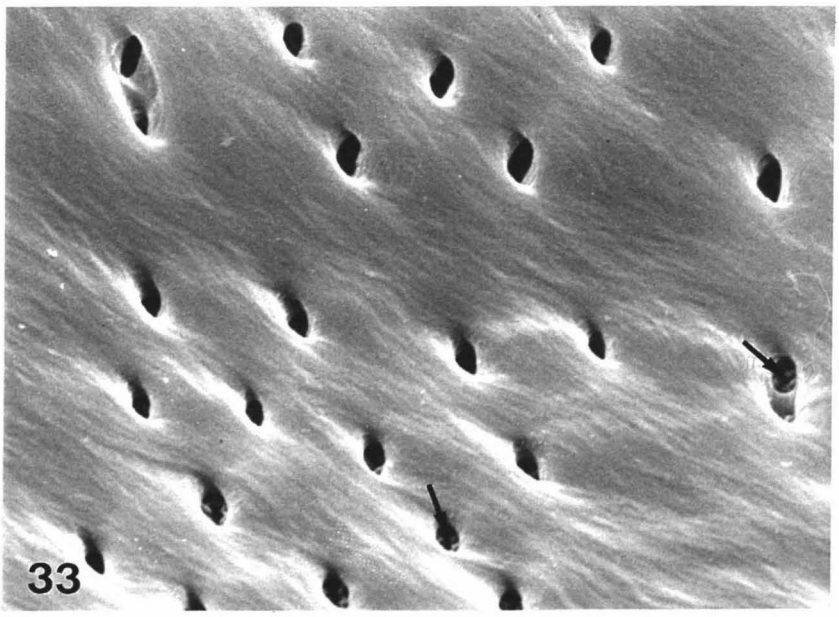
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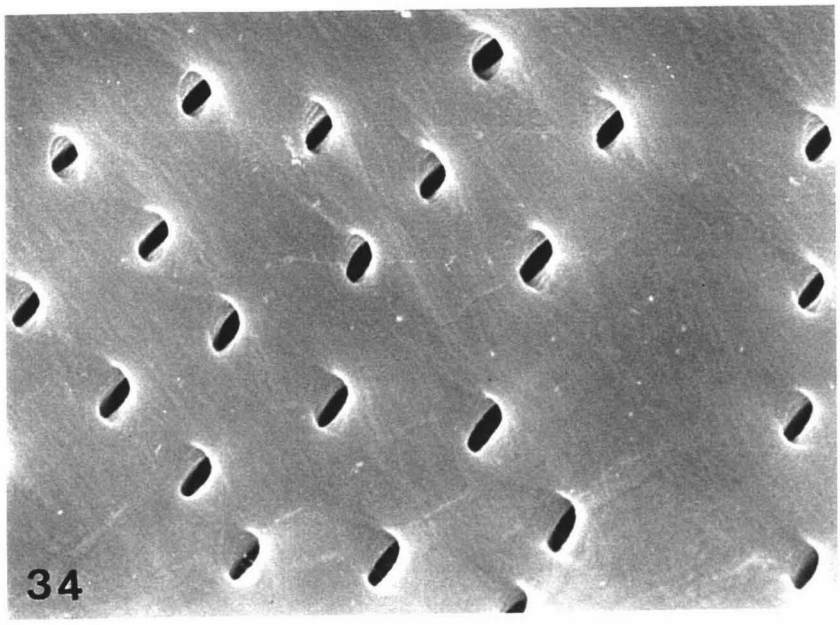
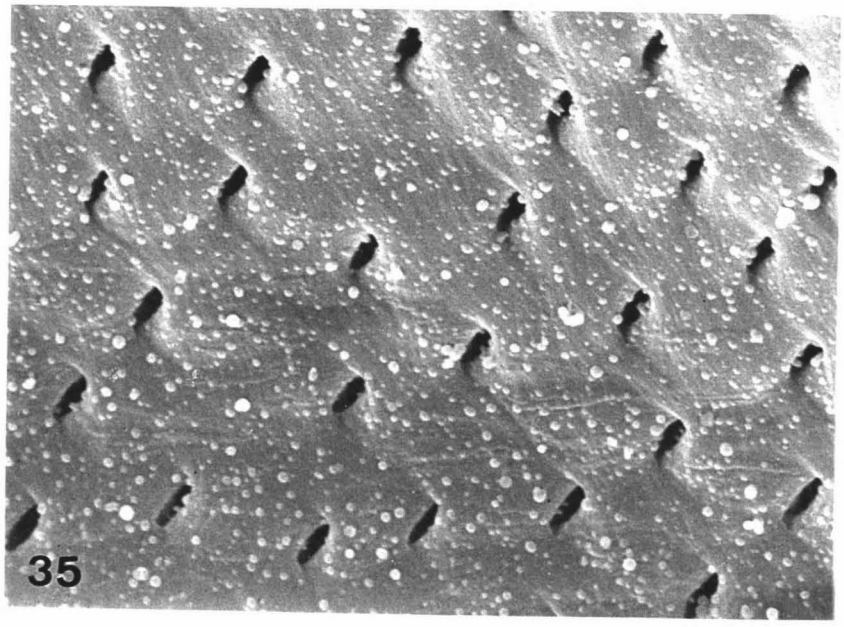


Figure 4.30-4.34 SEM micrographs showing vestures in the pits of wide vessels from subalpine habitat. 30 shows walls covered lightly with warts and vestures confined to the rim of pit apertures (arrow heads) 31 shows pit pairs connected by short grooves (arrow head) and the pits with branched vestures. 32 shows smooth walls and less elongated pits with no sign of vestures. 33 shows vestures confined deep in the pit chambers (arrows). 34 shows smooth walls bearing curved pits.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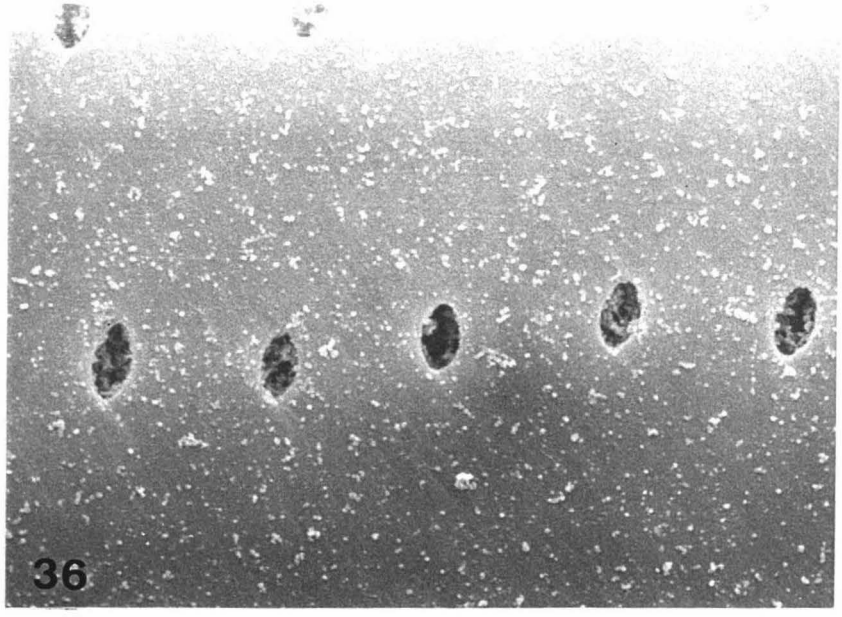
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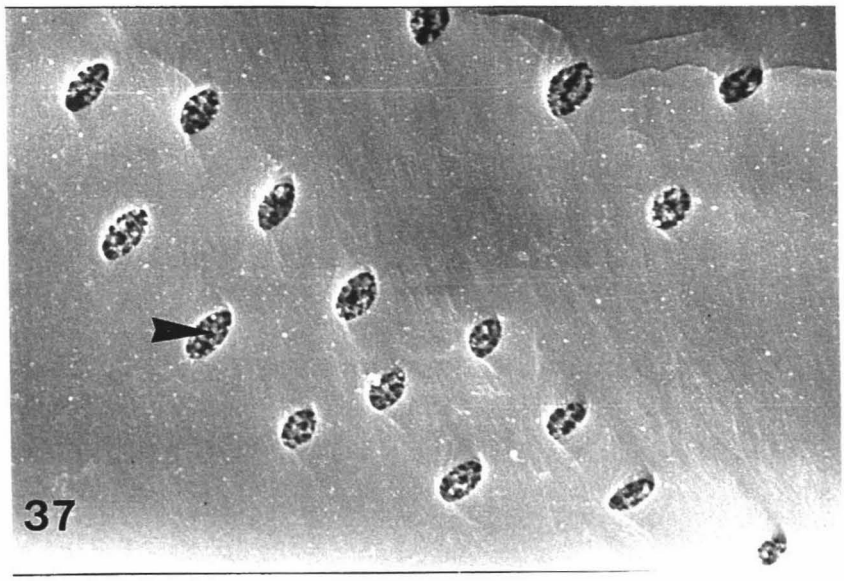


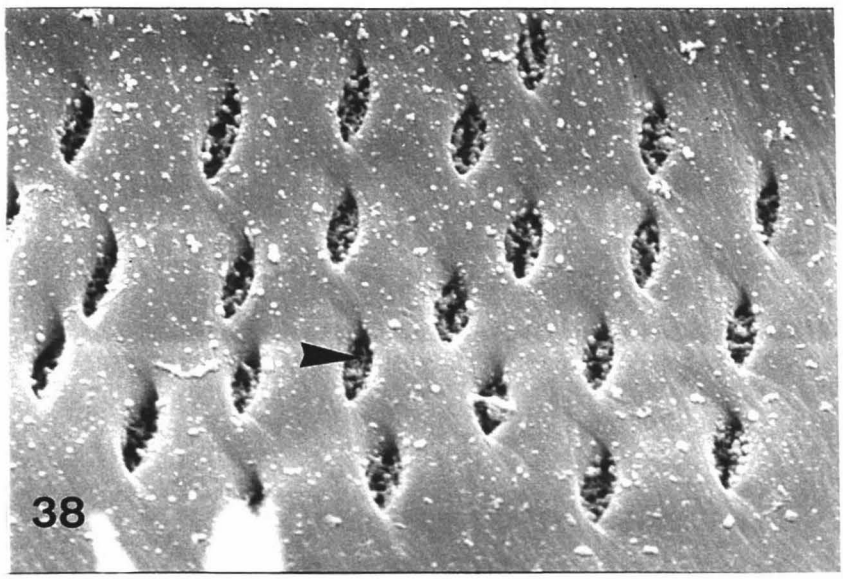


Figure 4.35 – 4.38 SEM micrographs showing vestures in pits of wide vessels from swamp habitat. 35 and 36 shows inner walls of wide vessels covered densely with warts of different sizes.37- 38 shows circular and elongated pits all with vestures confined to pit cavity and covering the apertures (arrows). X4000.

4.3 Analysis of cell types within a habitat

4.3.1 Wide vessels

The ANOVA table in appendix 1 showed that there were significant differences in cell length, width, wall thickness and abundance between trees of the same habitat ANOVA tables in app.1, 2, 3 and 4. The differences between trees within a habitat were significant either compared to the differences between samples or between individual cells.

In habitat A the majority of the trees had long and narrow cells (4). These were trees 9, 6, 4 and 7. The rest had short and wide (3), long and wide (2) and short and narrow (1) cells. For habitat B four trees 2, 1, 8 and 10 had long and wide cells while 4 trees, 3, 7,4 and 9 had short and narrow cells. Habitat C majority of cells (4) had long and wide cells and these were trees 10, 3, 1 and 4. In habitat D, the majority of trees (5) had short and wide cells and these were trees 4, 6, 8, 5 and 9. Habitat E majority of trees (4) had long and wide cells and these were 5, 4, 7 and 6. These relationships are shown from figures 4.7 and 4.8 above.

Habitat A trees 8, 1, 3 and 2 had wide and thick walled cells and 9, 7, 10 and 4 had narrow and thick walled cell. Habitat B, trees 8, 1, 2 and 5 had wide and thick walled cells and these made the majority of 40%. Habitat C trees 1, 9,7 and 3 had wide and thin walled cells making 40%, and this was the majority of trees. In habitat D the same percentage of trees as in C had wide and thick walled cells. These were trees 6, 8, 10 and 5. Habitat E had trees 6, 7, 5 and10 having wide and thick walled cells. All these trends are shown in figures 4.8 and 4.9 above.

As for the relationship between widths of cell and their abundance, habitat A had 4 trees with wide and high abundance of cells (trees 3, 2, 1 and 5) and an equal number with narrow and low abundance (trees 9, 10, 7 and 6). In habitat B there were four trees with wide and low abundance of cells (8, 1, 10 and 2) and also 4 had narrow and high abundance of cells (9, 4, 6 and 7). In habitat C the majority (4) had wide and high abundance of cells and these were trees 7, 10, 6 and 9. In E the same trend, trees

6, 7, 5 and 1 had wide and high abundance of cells. These are shown in figures 4.8 and 4.10 above.

Table 4.18 Mean, standard deviation and vessel group type of trees in each habitat

Habitats	A	B	C	D	E	F
Tree number	Mean, std, GroupType.	Mean, std, GroupType	Mean, std, GroupType	Mean, std, GroupType	Mean, std, GroupType	Mean, std, GroupType
1	1.443 0.167 S	1.387 0.063 S	1.701 0.21 CL&OCH	1.876 0.191 CL	1.227 0.063 S	1.288 0.121 S
2	1.931 0.136 OCH	1.994 0.324 CL	1.165 0.114 S	1.646 0.11 CL	1.222 0.106 S	1.194 0.031 S
3	1.695 0.341 OCH	1.404 0.208 S	1.308 0.022 S	2.323 0.257 CL&OCH	1.151 0.032 S	1.068 0.033 S
4	1.514 0.331 S&CL	1.626 0.144 OCH	1.323 0.148 S	1.26 .0017 S	1.36 0.289 S	1.267 0.062 S
5	1.712 0.311 CL	1.492 0.388 S	1.22 0.067 S	2.967 0.058 OCH	1.282 0.106 S	
6	1.553 0.153 S&CL	1.104 0.077 S	1.506 0.019 S&CH&CL	1.443 0.389 S&CL	1.333 0.106 S	
7	1.626 0.092 CL	1.416 0.109 S	1.3 0.185 S	1.933 0.777 S&CL	1.169 0.095 S	
8	1.936 0.473 CL	1.52 0.15 S	1.189 0.058 S	2.466 0.291 CL	1.585 0.2 S&CL	
9	1.148 0.093 S	1.70 0.155 CH	1.276 0.2	1.794 0.182 CL	1.259 0.082 S	
10	1.452 0.499 S	2.059 0.295 CL&OCH	1.243 0.078 S	1.973 0.525 CL	1.552 0.1 S&CL	

Legend:

CL = vessels mostly in clusters (vessels in groups of more than 2)

CH = vessels in chains running perpendicular to the wood rays

S = mostly solitary vessels

OCH = oblique chains of vessels

Table 4.18 above shows the differences of vessels groupings in the different trees within each habitat. In habitat A most trees have clusters and chains and oblique chains. Only trees 1,9,10 had mostly solitary vessels. In habitat B 6 trees have solitary group of vessels and only trees 2, 4, 9, and 10 have clusters, chains and oblique chains. Habitat C had a high number of trees with solitary groups and only trees 1 and 6 had clusters, chains and oblique chains. Habitat D has the all of its trees with vessels in clusters and chains and oblique chains. Tree five had the highest mean value group of about 3 as shown in the above table. Habitat E consists of trees with mostly solitary groups of vessels and only trees 8 and 9 had clusters.

4.3.2 Fibriform vessels

In habitats B, C, D and E there was a relationship between length and width of cells. Cells with great length had great width. Habitat B had 4 of its trees having long and wide cells and these were trees 2,1,8, and 10 while the rest of the trees either had long/narrow or short/wide and short/narrow cells. Habitat C had the same number. Trees showing this relationship were 5, 8, 4 and 7. Habitat D had 5 trees 10, 7, 8, 6 and 5. In habitat E, it was 5 of the trees with the same trend and these were trees were 9, 5, 1, 6 and 10, which made 50% of the trees in this habitat. See figures 4.5 and 4.6. Habitat A showed all sorts of relationship and it appeared that there was no positive relationship of length and width. From figures 4.11 and 4.12 there is a relationship between tree width and wall thickness. For instance trees 4,3, 6, 7 and 10 in A had narrow thick walled cells on average. In habitat B there was no clear trend shown by the trees because there were equal combinations of wide and thin walled (3) and narrow and thick walls (3) or wide and thick walled (2) and narrow and thin walled (2) cells. In habitat C most of the trees showed wide and thick walled vessels. In habitat D, 6 of the trees had wide and thick walled cells, and these were trees 6, 5, 4,

7, 2 and 8. In habitat E trees 10,4,9,2 and 9 (5) had wide and thin walled cells on average.

4.3.3 Libriform Fibres

Figures.4.14 and 4.15 show that there was a relationship between the length and width of cells in the trees. In habitat A, there was no significant trend because 3 trees had long and wide cells, 3 had long and narrow while the rest had short/narrow cells and short/wide cells (2 each). Habitat B majority (4) had short and wide cells and these were trees 9, 6, 7 and 3. Habitat C trees 7, 10, 2 and 9 had short and wide cells while the rest shared the other combinations. Habitats D and E there was no outstanding relationship. As for the relationship between the width and thickness of walls, habitat A, D and E showed no significant trend. Habitat B had majority of trees (5) with wide and thick walled cells and habitat C the majority of trees (4) had the same trend. See figures 4.15 and 4.16.

4.3.4 Fibre-tracheids

In habitat A, the majority of trees (4) had long and narrow cells. These were trees 4, 3, 2 and 7. Habitat B showed no trend in the relationship between the cells lengths and widths. Habitats C, D and E had same trend as A. In C 4 trees, 1,10,6 and 3 had wide and long cells, in D the same number of trees, (4,8,1 and 2) had long and wide cells. In habitat E 5 trees had long and wide cells. These were trees 5, 1, 6, 9 and 8. See figures 4.17 and 4.18.

As for the relationship between the widths and wall thickness of cells, habitat A showed no clear relationship. The rest showed some relationships. For example, B had 4 trees with wide and thick walled cells and these were trees 1, 10, 3 and 8. Habitat C the same number of trees (4) as in A, had the same relationship. These were trees 7, 1, 10 and 6. In habitat D trees 4, 6, 5 and 2 had the same type of relationship as in B and C. Habitat E it were trees 7, 6, 9, 5 and 8 with wide and thick walled trees. See figures 4.18 and 4.19 above.

4.4 Cell types correlation

There was a significant correlation between the average wide vessel's length and average libriform fibres and also with fibre-tracheids' length for samples as a whole. There were marginal differences between the slopes of the relationship in the different habitats. See figures 4.39 and 4.40 below. From the scatter plots in figure 4.39 below it is quite clear that there was a positive correlation between the vessel length and the libriform fibre length. This was much obvious for habitats B, C, D and E. Scatter plot for habitat A had no discrete relationship. The same trend applied to the relationship between the length of wide vessels and that of the fibre-tracheids, fig. 4.40.

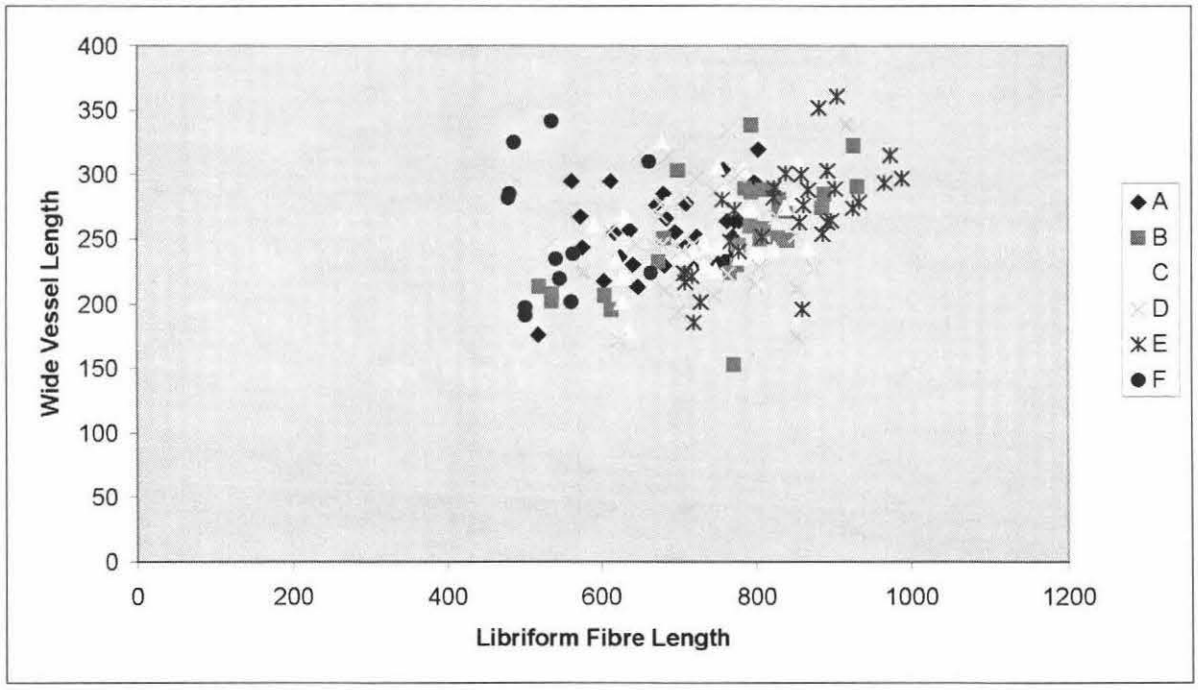


Fig. 4.39 Mean vessel length as a function of mean libriform fibres length in each tree within each habitat. Each point represents the mean value for a single tree. Data used is as in appendix. All measurements were in micrometers.

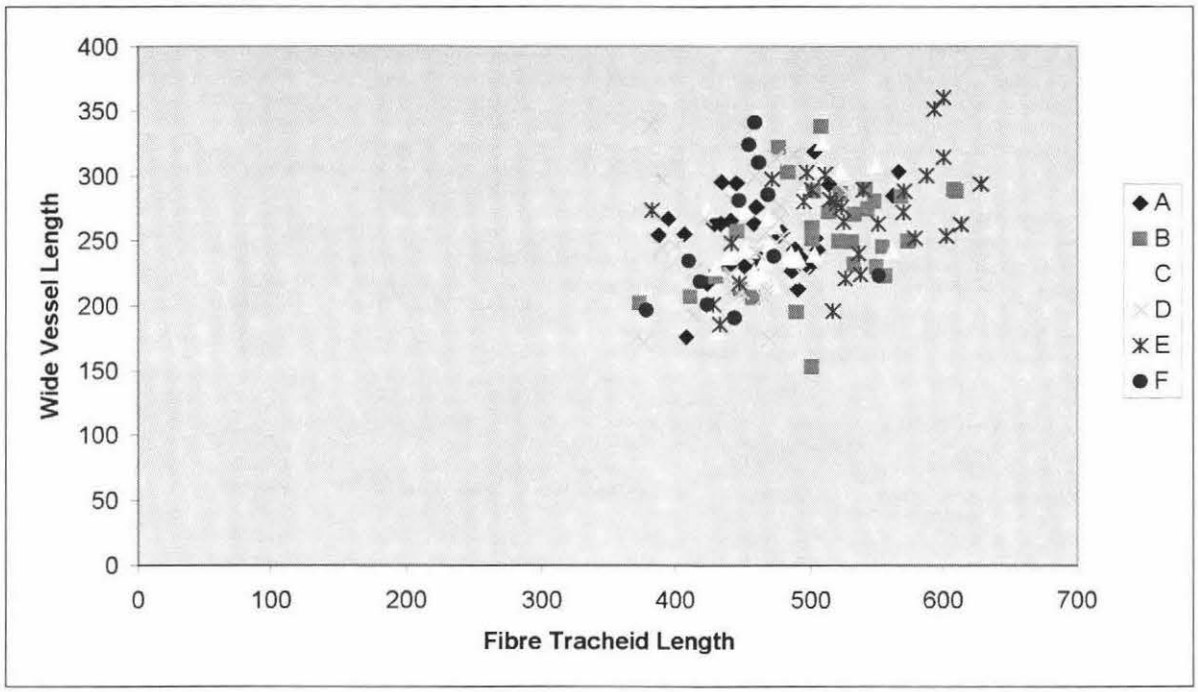


Fig. 4.40 Mean vessel length as a function of mean fibre-tracheids length in each tree within each habitat. Each point represents the mean value for a single tree. Data used is as in appendix. All measurements were in micrometers.

4.5 Prostrate Manuka (Habitat F)

4.5.1 Wide vessels and fibriform vessels

When the analysis of variance was performed on data of prostrate manuka, the following results were found:
The lengths of the wide vessels and fibriform vessels do not differ significantly from those of the upright plants in the five habitats. This is shown in fig. 4.7, 4.11 and Table 4.2 and 4.8. Fig. 4.8 and Table 4.3 showed that the prostrate manuka had narrow wide vessels when compared to the upright plants. The same was true for the fibriform vessels as shown in fig. 4.12 and Table 4.9. Generally the wide vessels here had thinner walled cells as compared to upright plants (except for plants in habitat A). This is shown in fig. 4.9 and Table 4.4. The same applies to the fibriform vessels as shown in fig. 4.13 and table 4.10.

The wall thickness here was not significantly different from that of habitats A and B. As for abundance wide vessels table 4.5 showed that F had significantly higher number of vessels per millimetre squared. As for the vessel grouping there was no significant difference from C and E.(see table 4.7). The vessels were mostly in solitary form (table 4.18). The wood had both distinct growth rings and diffuse wood.

4.5.2 Libriform fibres and Fibre-tracheids

Observations from the light microscope showed that prostrate manuka had fewer libriform fibres as compared to upright plants of the above habitats. The prostrate manuka had significantly shorter cells than any of the upright plants, this is shown in fig. 4.14 and Table 4.12 above. The widths of these fibres were comparatively smaller as shown in table 4.13 and fig. 4.15 and fig. 4.18 and table 4.16. The same applied to the wall thickness of libriform fibres, which were quite thin walled as compared to the fibres of the upright plants. This is shown in fig. 4.16 and table 4.14.

The fibre-tracheids length were not significantly different from those of the upright plants especially those of habitats A and D, see fig 4.17 and Table 4.15. There was no significant difference between the wall thickness of the prostrate manuka and that of the upright plants except for those in habitat D had thick walled fibre-tracheids, see table 4.17 and fig.4.19.

4.5.3 Presence of vestures

These pits appeared more elongated in shape than circular. The less elongated pits were curved at the ends like those of the hot thermal soils, swamp and subalpine habitats, fig4.42. There was an occurrence of short grooves joining a pair of pits too, fig 4.43 (arrow head). Figures 4.44 and 4.45 showed a very distinct phenomenon of prominent round and branched protuberances in their inner walls. Some of the walls showed webby like appearance, fig. 4.43. The vestures in these pits were very small as compared to those found in vessels of upright plants. They were more confined to the pit cavities, fig. 4.42 (arrows).

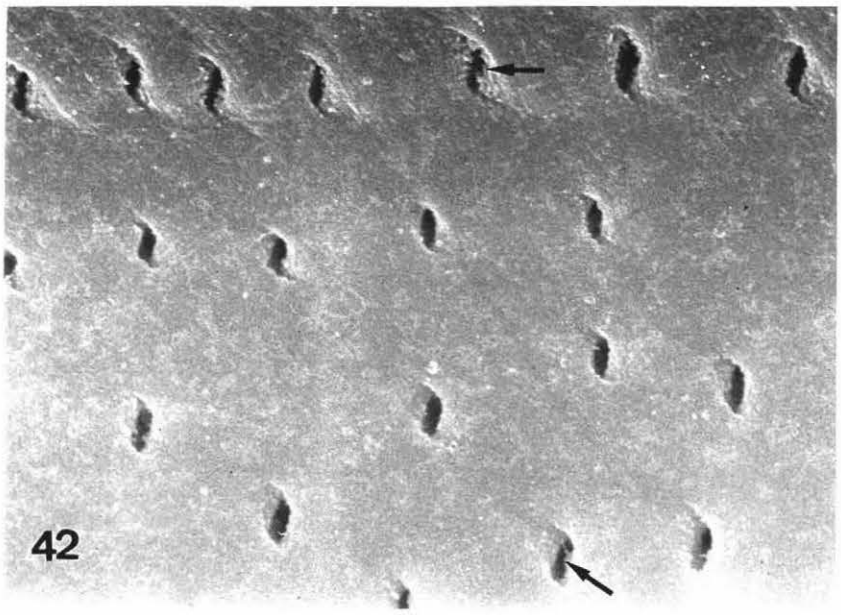
4.5.4 Differences between trees of Prostrate Manuka

For wide vessels, tree 1 had the longest, widest and thick walled cells. The others do not show a particular relationship worth noting. For fibriform vessels the relationship was as follows, tree 1, 3, 4 and 2 had long/wide to short/narrow cells respectively. Tree 1 still had wide and thick walled cells while the rest do not show a particular trend. For fibre-tracheids trees 4 and 1 had long and wide cells and trees 3 and 2 had the short and narrow cells. Tree 2 and 3 had thick walled cells while 4 and 1 had thin walled cells. For libriform fibres tree, 4 had long, wide and thick walled cells. Tree 1 had narrow thin walled cells.

A

B

Figure 4.41 Photographs showing prostrate manuka from which samples were obtained.



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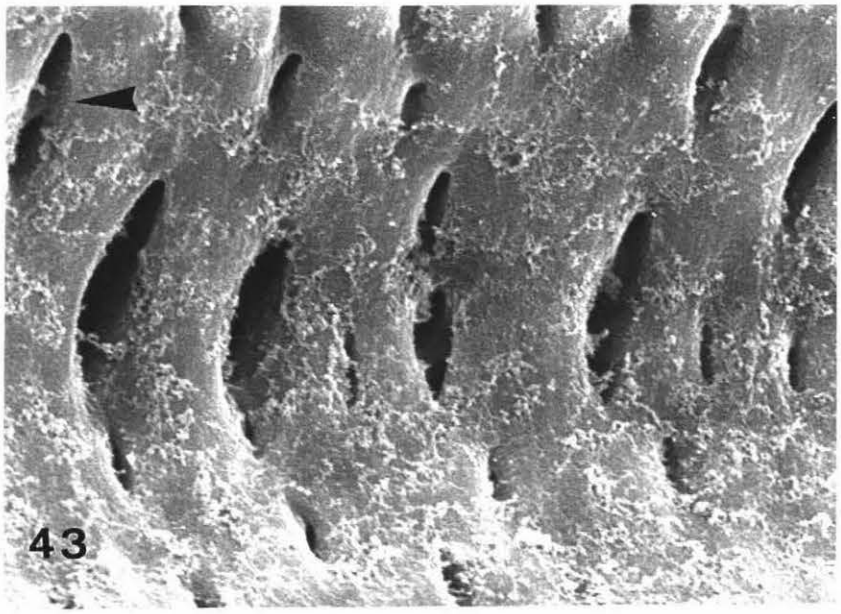

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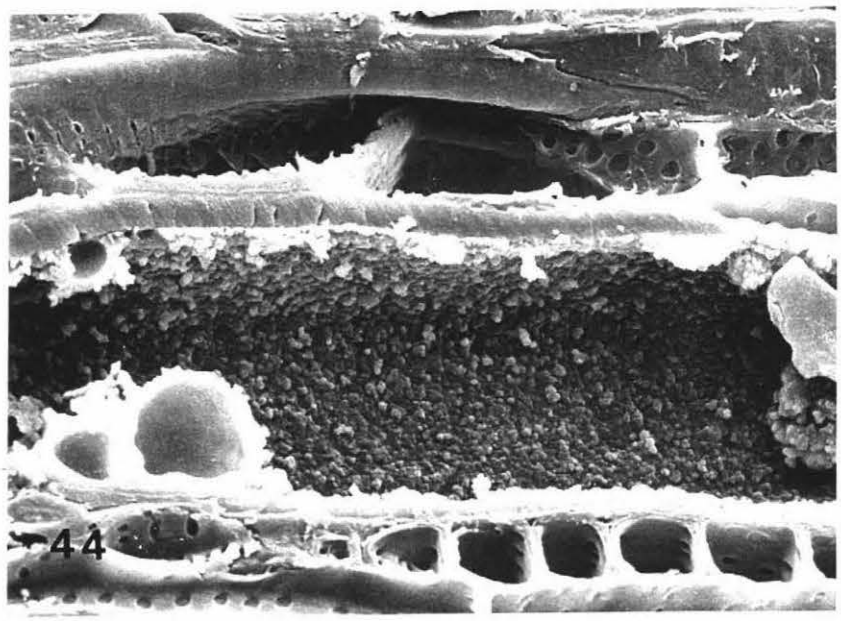

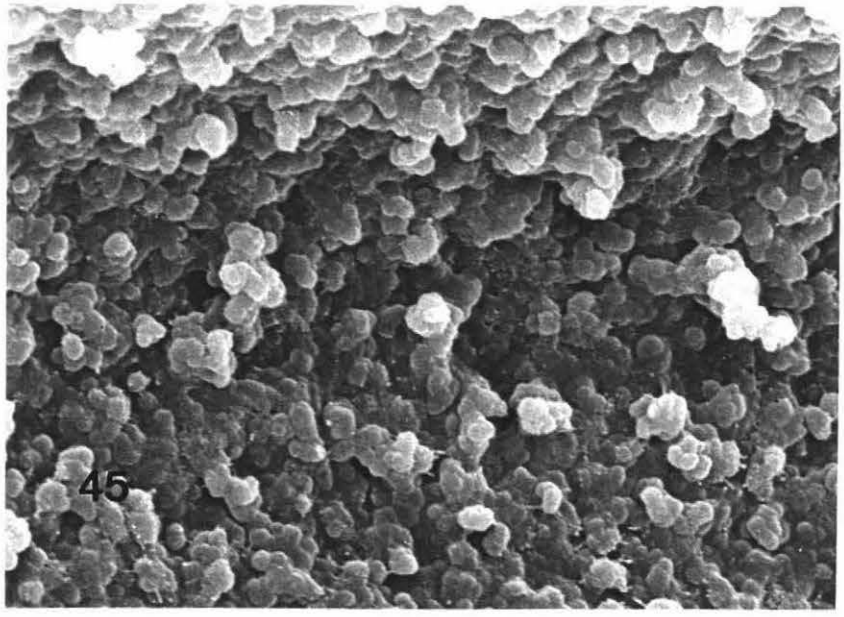

Figure 4.42 – 4.45 SEM micrographs showing vestures in pits of wide vessels from prostrate manuka plants. 42 shows curved pits with less pronounced vestures (arrows) X4000. 43 shows occurrence of pit pairs joined by short grooves (arrow head) It also shows web like structures in the cell walls. 44 shows prominent branched warts covering cell walls X830. 45 shows the warts at a greater mgnification X4000.

4.5.5 Correlation between length of wide vessels and that of fibres

From scatter plots in figures 4.39 and 4.40 there seemed to be no discrete correlation between the length of the wide vessels and that of the libriform fibres and that of the fibre-tracheids.

5.0 DISCUSSION

5.1 Variation between populations

The main objectives of this study were to determine any wood anatomical variation within a population and between populations of manuka growing in diverse habitats. From the results it is evident that there are variations both within and between the populations of the five habitats. The most important question is whether these results show any correlation with ecology and whether they conform to the general trends found in previous research or whether there are departures from the general trends. Can the departures from the general trend be explained or not? It should be mentioned that generally there are few studies dealing with wood anatomy variation within a species except a few that correlated wood anatomy with altitude. Therefore it might be difficult to make generalizations as to how these findings compare to the general trends, which were drawn from studies on genera and families. However comparisons are attempted where appropriate. Before these questions can be addressed, it is appropriate first to stipulate the assumptions that were made regarding ecological conditions of the different habitats.

The sand dune habitat had a stand with a low number of trees growing on elevated areas and the trees showed signs of being blown by winds from one direction (fig.4.1), which might cause them to have high transpiration rates. These trees were growing on sandy soils and sandy soils have generally low water retention capacity. Therefore we could make an assumption that they had more water stress and high negative pressures in their conductive system.

In the subalpine habitat trees were exposed to a physiological drought due to mild and severe frost weather in winter times (fig. 4.3). At least once a year the vessels will be freezing and thawing, a process that is thought to cause air embolisms. Like the sand dune habitat water stress would be expected in vessels of these trees. High negative

pressures leads to more risks of embolisms and therefore these two habitats would be regarded as less mesic.

The hot thermal soils habitat's trees were growing on soils saturated with soil moisture but the difference would be the high temperatures that their roots were exposed to as shown in table 4.1 and fig.4.2. It is not known whether the high soil temperatures would cause any water stress in the vessels of these trees. It would be interesting if this could be investigated.

The margins of lowland forests habitat was situated within an area at the foothills of the Tararua Range (fig.4.4) and also on the margins of a river and therefore the soil moisture is expected to be high. Therefore the trees might not be experiencing water stress in their vessels. Probably the transpiration rates would be lower too. This habitat is then classified as a more mesic habitat.

The swamp habitat's trees grow on a swamp that is comparatively more mesic than all the other habitats (see fig. 4.5). The habitat was characterized by trees with great heights.

5.1.1 Variation in the wide vessels dimensions

Wide vessel lengths

There was no significant variation in the length of vessel elements between the habitats (table 4.2 and fig.4.7). These results conform to those of Noshiro and Suzuki (1995) in which they found that intraspecific variation (variation between the members of one species) was less pronounced or in some cases totally absent. But they are contrary to that of a study on *Alnus nepalensis* in which it was found that vessel element length decreased as altitude increased (high altitudes had low temperatures and were more dry) (Noshiro et al., 1994). Carlquist (1988) in his review on wood anatomy and ecology has shown that vessel element length always show a correlation with ecology. The lack of variation in the length of wide vessels is a unique feature of the results in this current study. There were however, variations

between the different populations in terms of vessel element diameter, wall thickness, abundance, grouping and area of perforation plates.

Vessel element diameter

In this study the margins of lowland forests habitat had the widest cells, followed by swampy habitats. The other three habitats, sand dune, hot thermal soils and subalpine had narrow vessels and were not significant from each other (table 4.3). Considering the fact that the swamp and margins of lowland forest are more mesic and the other three habitats less mesic, these results do conform to the general trend that mesic habitats have wider cells and less mesic have narrow vessels. Wide vessels tend to provide more efficient water conduction while narrow ones, though they may seem to be less efficient, provide conductive safety. In water stressed conditions there are risks of embolisms in the conductive systems and it is believed that wide vessels are more prone to embolisms than narrow ones. There is also evidence that larger volume conduits are more susceptible to embolism induced by freezing and once embolism has occurred larger conduits are probably more difficult to refill than smaller ones (Ewers et al., 1990). Mauseth et al. (1998)'s view that vessel diameter correlate well with plant height, does not hold here because the short trees of subalpine habitat did not differ in their vessel diameters from those of the sand dune and hot thermal soils which had taller trees. Even though other researchers have provided conclusive evidence that long vessels are usually wide and short vessels narrow in diameter, in this research there is a departure from this trend because there was no difference in the length of vessels with large diameters and those with small diameters.

Vessel Wall Thickness

Vessel wall thickness has been considered functionally significant in offering sufficient mechanical strength to withstand strong negative pressures (Carlquist, 1975). Therefore the general trend for wall thickness is that greater vessel wall thickness is an expression of xeromorphy, that is, vessels of arid flora have thick walled cells compared to those of the mesic habitats. To the contrary, results in this research show that the margins of lowland forests, swamp, and subalpine habitats have thick walled cells (table 4.4) and the sand dune and the hot thermal soils habitats have thin walled cells. This trend was also displayed by Baas et al. (1983)'s study in which they found that tropical plants in less xeric regions had wide and thick walled

cells as compared to the shrubs of arid regions that had narrow and thin walled cells. Even though these results seem to contradict general trends, Carlquist (1975) had pointed out that wall thickness should be viewed with the diameter of vessels. He said that for similar mechanical strength narrow vessels need much thinner walls than thicker ones.

Vessel density or abundance

Previous researchers have established that vessel density increases with dryness of habitat and decreases with wetness of a habitat (Carlquist, 1988). This is because numerous vessels per mm squared provide conductive safety by ensuring that embolisms formed under water stressed vessels do not seriously impair the conductive efficiency of a plant (Carlquist, 1988) The sand dune and hot thermal soils habitats had significantly greater density of vessels than the margins of low land forests, swamp and subalpine habitats (see table 4.5). The results here seem to conform to the general trends obtained in studies on families and genera, *Alnus nepalensis* (Noshiro et al., 1994), and Noshiro and Suzuki's (1995) study on four *Rhododendron* species. The results also showed a very close relationship between diameter and density of vessels. It appears that those habitats with narrow cells also had a high level of density and vice versa. Sand dune and hot thermal soils with narrow diameters had high levels of vessel density followed by margins of lowland forests, swampy and subalpine habitats (these latter two did not differ significantly). The results for manuka seem to follow the general trend that where vessels are wider in diameter there are fewer per unit of a transactional area (Carlquist, 1980). The high density compensates for the narrowness of the vessels and this combination makes the narrow vessels even more efficient in water conduction in water stressed vessels.

Lindorf (1994) classified vessel density into two categories: very numerous and extremely numerous. Vessel densities of 40 to 150 vessels per mm^2 are very numerous and those above 150 are extremely numerous. According to this classification, manuka had very numerous vessels since the mean range was from 52-66. Comparing the density of manuka with Carlquist (1977)'s data of arctic flora which had average density of 599, southern California alpine shrubs with average density of 442, (Carlquist and Hoekman, 1985), *Berberis* with 552 (Carlquist 1995b) and Heenan (1997)'s results of *Carmichaelia* with vessels densities of up to 735,

manuka's densities are comparatively low and as thus could be considered as a more mesic species. However, the density of vessels in this study might not be comparable to that of other researchers because only wide vessels were counted where as in most studies narrow vessels are also counted. It would have been difficult to include fibriform vessels since from the cross section they could not be differentiated from vasicentric and vascular tracheids and probably from parenchyma cells too.

Area of perforation plates

Area of perforation plates was larger in swamp habitat followed by hot thermal soils, subalpine, sand dune and margins of lowland forests (table 4.6). These results are quite interesting since they seem not to correspond with the diameters of vessels in these habitats. The expectation would be that margins of lowland forests habitat should have a higher area of perforation plates since it had wider vessels than all the other habitats. As to why they show this awkward trend is not apparent now.

Vessel Grouping

Vessels in margins of lowland forests had highest mean group followed by sand dune, hot thermal soils, subalpine and swamp habitats (table 4.7). It is quite interesting for the margins of lowland forest to have more grouped vessels despite its more mesic conditions. The expected trend would be high mean group in sand dune, the subalpine and hot thermal soils and low mean group in margins of low land forests and swamp habitats. The average groupings showed that margins of lowland forests (1.979), sand dune (1.601) and hot thermal soils (1.57) on average had grouped vessels if the average values are rounded to 2 (table 4.7). The groups were either clusters or oblique chains. The other two, swamp and subalpine had more solitary vessels. On average these habitats had groupings of mesic habitats when compared to some studies on xeric flora where the average group was 7.55 for coastal sage species and 4.76 of chaparral vegetation species studied by Carlquist and Hoekman (1987), 15.6 species of *Carmichelia* studied by Heenan (1997) and 3.6 in Lindorf (1994) studies.

Grouping of vessels is regarded as a way of providing alternative conduits whereby water can be conducted in the same pathways in case one or several vessels in a group are incapacitated by air embolisms (Carlquist, 1984a). Which means that they provide conductive safety especially where there are negative pressures caused by either low

soil moisture availability, high transpiration rates (sand dune) freezing and thawing process in cold conditions (subalpine). But it should be remembered that the general trends were drawn from investigations on members of a genera and families which might not be applicable to members of a species. The other explanation for the vague trends could be the presence of vascular tracheids and vasicentric tracheid in the wood of manuka. The presence of these cells is thought to associate with smaller degree of vessel groupings since they form a subsidiary conductive system in case the vessels are embolized (Carlquist 1984a). It should be noted that in this current research on manuka only wide vessels were counted to determine the grouping. In most research fibriform vessels are counted. This might explain why there seem to be low number of groupings. As already mentioned above regarding density of vessels, it would have been difficult to include fibriform vessels since from the cross section they could not be differentiated from vasicentric and vascular tracheids and probably from parenchyma cells too.

Table 5.1 Summary of the differences in wide vessel characters between the habitats. The habitats are listed according to their degree of variation for each cellular feature. Those in the same box are not significantly different.

	Greatest variation	to	least variation
Length	**There was no variation in all the habitats**		
Diameter	Margins of lowland forests	Swamp	Sand dune, subalpine and hot thermal soils
Wall thickness	Margins of lowland forests, swamp and subalpine	Hot thermal soils	Sand dune
Abundance	Sand dune and hot thermal soils	Margins of lowland forests	Swamp and subalpine habitats
Grouping	Margins of lowland forests	Sand dune and hot thermal soils	Subalpine and swamp habitats.
Area of Perforation plate	Swamp	Hot thermal soils, subalpine, sand dune	Margins of lowland forests

Past research has shown that the length, width and abundance of vessels are three most effective characters that depict variation in wood anatomy between xeromorphic and mesomorphic habitats. In this study, multivariate analysis showed that abundance was the most obvious wide vessel feature that varied between habitats, followed by the diameter, wall thickness and the least distinguishing feature is length.

Vestures

Vestures are said to be adaptive to increase wall surface area, which then increase bonding of water and tensile strength of water column in the vessels and thus reduce the risks of embolisms. This appealing function of vestures might lead one to believe that vestures would be a common phenomenon in plants growing in xeric environments or colder areas where there is water stress on vessels. But in Baas et al. (1983)'s research, they found that vestures were instead common to plants growing in mesic conditions rather than xeric ones. Even though some research found them more in xeric plants, Carlquist (1988) in his review of wood anatomy and ecology suggested that vestures tend to characterize an entire family irrespective of the habitat.

The current research has found that all the habitats were characterized by the presence of vestures just as Meylan and Butterfield (1978), Johnson (1984) and Patel (1994) reported it in previous studies. But there were some differences in the density, appearances and distribution of vestures. Vestures within each pit from the margin of lowland forests habitat (fig. 4.20) were quite dense and more distinct and these could be classified as small and hemispherical as in Heady, Cunningham, Donnelly and Evan (1994). A spectacular feature of the pits of hot thermal soils and subalpine habitats were the occurrence of grooves that interconnected pit pairs (4.25, 4.31). The hot thermal soils, sand dune and swamp vestures were less dense and less branched but covered the pit apertures as seen in those from margins of lowland forests (figs. 4.26, 4.27 and 4.37). Vestures in subalpine elongated pits were minute and only confined to the rim of the pit cavity fig. 4.30 and 4.31.

Swamp vessel walls were more covered with warts, fig. 4.35, 4.36. These warts were more prominent than those of sand dune and subalpine habitats (fig. 4.27, 4.30). The prostrate manuka vessels were comparatively more warty as compared to the vessels of the upright manuka plants in the five habitats. The prostrate manuka had more prominent nodule like warts that spread over the lumen; a phenomenon similar to that found in *Kunzea ericoides* by Patel (1994), see fig. 4.44and 4.45. Since this warty feature occurs even in swamp habitat, it is difficult to speculate that the presence of warts is a form of adaptation to dryness. It should be mentioned that the samples studied for each habitat were quite few (two per habitat) and therefore they might not have given a good representative picture.

5.1.2 Fibriform vessels

There was no significant variation in the length of fibriform vessels between the populations except for margins of lowland forests, which had significantly short vessels (table 4.8). Margins of lowland forests had the widest fibriform vessels followed by sand dune. Sand dune fibriform vessel diameters though larger, were not significantly different from those of hot thermal soils and swamp habitats statistically. Subalpine had small diameters of fibriform vessels, but were not significantly different from those of swamp and hot thermal soils habitats (table 4.9).

Margins of lowland forests had the thickest cell walls followed by subalpine and swamp habitats (the latter two were not significantly different from each other), see table 4.10. The rest had thin walled cells. This trend is quite similar to that of the wide vessels above. Margins of lowland forests had the greatest area of perforation plates, followed by sand dune and swamp and subalpine (these three were not significantly different from each other) and the least was subalpine (table 4.11). See table 5.2 for summary of these.

The biological significance of fibriform vessel differences with habitat is not easily interpreted. There appear to be conflicting observations. For example margins of lowland forests and swamp habitats show the greatest differences, which is difficult to reconcile in terms of water relations. The results remain an enigma.

Table 5.2 Summary of the differences in libriform vessel characters between the habitats. The habitats are listed according to their degree of variation for each cellular feature. Those in the same box are not significantly different.

Greatest variation to least variation

Characters	Habitats		
Length	No variation between four habitats	Margins of lowland forests	
Diameter	Margins of lowland forests	Sand dune swamp, hot thermal soils,	Swamp, Hot thermal soils, Subalpine
Wall thickness	Margins of lowland forests	Subalpine Swamp	Sand dune, Hot thermal soils,
Area of perf. Plate	Margins of lowland forests	Swamp, Hot thermal soils, Sand dune	Subalpine

5.1.3 Libriform fibres

Not much is mentioned about the correlation of libriform fibres with habitat in previous research. From the current study, it seems that there were no correlations between the dimensions of fibres and habitat. For example, margins of lowland forests fibre length (727.68 um), was not significantly different in fibre length from the hot thermal soils (762.22 um) and the subalpine (740.68 um) habitats. The diameter of libriform fibres from margins of lowland forest (19.6um) was not significantly different from that of sand dune habitat (19.2 um). The same trend applied to their wall thicknesses. Length of fibriform fibres correlates more with the size of the organ or plant bearing them (Carlquist, 1975). Greater length of fibres conveys much strength to neighbouring vessels. From this current study swamp habitat had the longest libriform fibres(table 4.12). But the diameter of its libriform fibres was smaller than of margins of lowland forests and sand dune though significantly not different from that of all other habitats (table 4.13). It should be mentioned that this

habitat had trees with the greatest heights and as such the results tend to conform to the general trend mentioned above.

However, these results should be viewed with caution because subalpine habitat, which had comparatively short trees, did not differ significantly in the length of its fibres (740.68 um) with margins of lowland forests (727.68 um), which is a more mesic habitat. (Note the above quoted averages are the untransformed means in the appendix 16) These results are comparable to those of Heenan (1997) in that the fibres of more mesic habitats were not that different from those of xeric habitats. For example, *Carmichaelia australis* and *C. odorata* (mesic species) had mean lengths of 1010 um and 940 um respectively where as *C. compacta* and *C. nana* (xeric species) had fibre length of 700 um and 1078 um respectively.

It appears here that there is a correlation between the cell width and the cell wall thickness. Those habitats with wide cells had also thick walled cells. These were sand dune, margins of lowland forest and swamp habitats. Hot thermal soils and subalpine had narrow and thin walled cells on average.

Table 5.3 Summary of the differences in libriform fibre characters between the habitats. The habitats are listed according to their degree of variation for each cellular feature. Those in the same box are not significantly different.

Greatest variation to least variation

Characters	**Habitats**		
Length	Swamp	Hot thermal soils, Subalpine, Margins of lowland forests	Sand dune
Diameter	Margins of lowland forests, Sand dune, Swamp	Swamp, Hot thermal soils, Subalpine	
Wall thickness	Sand dune, Margins of lowland forests, Swamp	Hot thermal soils, Subalpine	

5.1.4 Fibre-tracheids

There was a variation between the habitats in all the dimensions of the fibre-tracheids. Swamp habitat had the longest fibres (529.73 um) but the length was not significantly different from that of hot thermal soils (511.16 um). Subalpine and sand dune had median lengths of fibre-tracheids and were not significantly different from hot thermal soils, though smaller than those of hot thermal soils. Margins of lowland forests had the shortest cells (table 4.15). As for the diameter, margins of lowland forests and sand dune had the widest cells followed by swamp and hot thermal soils (the latter two were not significantly different). Subalpine had much narrow cells (table 4.16). For the cell wall thickness, all the habitats did not vary significantly except margins of lowland forests habitat, which had significantly thicker walls (table 4.17). But there was no distinct correlation with habitat. Instead, there was much overlap between the habitats. These results are contrary to those of Noshiro et al. (1994), whose study on *Alnus nepalensis* showed that fibre-tracheid length decreased with increasing drought.

As already mentioned for libriform fibres, length of fibres correlates with the size of organ or plant bearing them. This means that the greater the height of the organ or plant the greater the length of the fibres. In this study the swamp habitat showed greater length than all the other habitats, a similar trend to that of its libriform fibres. It was then followed by hot thermal soils, sand dune, subalpine and the least was margins of lowland forests (table 4.15). For the swamp habitat the correlation is quite positive because its trees had greater heights, but as for the other habitats it is not clear whether this trend holds. For instance, subalpine with short trees would be expected to have shorter vessels than margins of lowland forests but the opposite is true. Margins of lowland forests seem to have wider and thick walled cells, a trend similar to that of the other cell types.

Table 5.4 Summary of the differences in fibre-tracheid characters between the habitats. The habitats are listed according to their degree of variation for each cellular feature. Those in the same box are not significantly different.

Greatest variation to least variation

Characters	Habitats		
Length	Swamp, Hot thermal soils	Hot thermal soils, Sand dune, Subalpine	Margins of lowland forests
Diameter	Margins of lowland forests, Sand dune	Swamp, Hot thermal soils	Subalpine
Wall thickness	Margins of lowland forests	Swamp, Sand dune, Hot thermal soils, Subalpine	

A significant feature about these results was that margins of lowland forests had the widest and greatest cell wall thickness for all the cell types. Swampy habitat possessed the longest fibres.

5.2 Variation within a population

The second part of the aim of this study was to establish whether or not there are variations of wood anatomy within each population of manuka. Variation was evident within a sample, between samples in a tree and between trees in each habitat across all the habitats. Within each population there was variation in all cell types in all dimensions, i.e., length, diameter, wall thickness, abundance, area of perforation plates and groupings.

There were some peculiar relationships between dimensions of cells. Most trees showed a positive correlation between cell length and width, cell width and wall thickness. But the relationship between the diameter and abundance of vessels was different from the expected. For example most trees with wide cells had high abundance of cells, a trend that departs from the general trend that wide cells are

usually low in density. In swamp, hot thermal soils and subalpine habitats, most trees had solitary vessels hence the low cell group averages. But for sand dune and margins of lowland forests, most trees had clustered cells or chains of cells either running perpendicular to the wood rays or across in an oblique pattern (see table 4.18).

5.3 Correlation between length of wide vessels and that of fibres

According to Carlquist (1975) length of fibres parallels that of vessel elements in any given species. From these results at least in four habitats, hot thermal soils, subalpine, margins of lowland forests and swamp, there was correlation between fibre length and vessel length. This is shown in figure 4.42 and 4.43. Trees with long vessels had long fibres. The accepted reason for identical length is attributed to origin: long fibres along side long vessels are thought to be a product of the same fusiform initials.

5.4 Prostrate manuka

While investigations were in progress some prostrate manuka (a one-off sample provided by Landcare Research NZ Ltd) was investigated too. Prostrate manuka had comparatively small cells except for the length of wide vessels, the length of fibriform vessels and wall thickness of fibre-tracheids in which it was not significantly different from upright plants. As for the abundance it had the highest levels as shown in table 4.5. This trend conforms to the known general trend that wood characters correlate well with the habit of the plant. From Ewers et al. (1990) it was found that prostrate plants or scramblers tend to have narrow vessels than their upright counter parts. Because of the nature of their growth they do not need much mechanical support from their fibres, for the greater the length of fibres the greater their strength (Carlquist, 1975). The prostrate manuka had quite short fibres, a trend that agrees with that of Carlquist's observations. Compared to the upright plants this manuka was growing on acidic and most infertile sandstone soils. The minimum temperatures were reported to be much lower (12.8 in January to 4 degrees Celsius in July, while that of Wellington

(location of swamp habitat) were 16.4 and 8.2 degrees Celsius. Therefore this could also be a contributory factor to the small cells these plants had.

5.5 Influence of other plant features

Previous research has always shown inconsistencies in plant anatomy and morphology with respect to ecological trends. Sometimes there are less pronounced trends or the results do not conform to general trends. Some of these inconsistencies have been attributed to the presence of factors that Carlquist (1988) calls overriding factors. These could be the presence of xeromorphic leaves, i.e., leaves with a small surface area and heavily cuticled, or the nature of the root system like extensive, deep or superficial root systems. Lindorf (1990) hinted that xylem and leaves have evolved together as a unit and show correlated adaptations to the environmental extremes. He said leaves could buffer xylem tissue against prevailing environmental conditions resulting in xylem showing low levels of specialization.

Manuka is reported to have a xeromorphic nature (Cook, Mark and Shore, 1980; Johnson, 1984), probably due to its small heavily cuticled leaves, its extensive superficial root system and the presence of mycorrhiza in its roots. Manuka tends to tolerate boggy soils since its phellogen readily forms aerenchyma tissue (Cook, Mark and Shore, 1980) These authors also found that manuka has greater root oxidising activity, which can significantly exclude iron. They say the xeromorphic nature of its leaves decreases the rate of water movement to the root surface and this increases the time available for oxidation of toxins in soils with iron and sulphide levels. This feature might explain why manuka can tolerate the hot thermal soils that have sulphur deposits and might probably weaken any wood adaptations in this habitat. Therefore the less pronounced wood variation in manuka might be attributed at least in part to the above factors.

Other factors that were compromised in this research were the age of the plants and their genetic variations. The age of plants has been reported to contribute to differences in the dimensions of cells. For instance Zimmerman (1983) found that

tracheids become longer and wider with increasing age and also Bailey and Tupper (1918) (in Carlquist 1975) reported that vessel element length increases with age. It was not possible to determine age of trees in each habitat. A stand of trees of similar height and size were assumed to be of the same approximate age. But it is obvious that there might have been age differences between trees of different habitats and probably those of the same habitat. The same might be true with their genetic differences. That is why age and genetic variation might have been contributing factors to the trends established in this study.

Baas et al. (1983)'s study showed that genera, *Rhus pisticia*, *Capparis*, *Lycium*, *Rhamnus*, *Ficus* and the member of the woody Papilionoideae desert species had the same wood anatomy as the Mediterrenean or of even more mesic cool temperate species. Among the four species of *Rhododendron* studied by Noshiro and Suzuki (1995), only two had outstanding variation with altitude. Therefore as in Baas et al. (1983), it appears that the environment seems not to induce well-defined structural adaptation to such an extend that wood of less xeric species will be different from those of more xeric species. It could be a question of evolution that these characters had evolved in their mesic ancestors and they happen to function equally well in arid conditions. Perhaps the lack of variation in some of the dimensions of cells as in the length of wide vessels and fibriform vessels could be attributed to the above reasons. From the above results one is bound to accept Carlquist's (1977) suggestion that each species has its own series of anatomical solutions in coping with water relations. Therefore departures from the general trends should always be expected and probably appreciated.

5.0 CONCLUSIONS

The primary aim of this study was to establish whether or not wood anatomical variation exists in manuka both between and within populations in a wide variety of habitats. Between populations the research has established that there are no variations in the length of wide vessels and fibriform vessels and also in the wall thickness of fibre-tracheids. According to the null hypothesis there are no differences in the wood anatomy of manuka between populations growing in distinctly different habitats. These results support this null hypothesis since there were no significant variations between populations in the vessel length of wide vessels between the habitats. As for the length of fibriform vessels, there was no variation between the populations except for margins of lowland forests, which had significantly shorter cells. The same trend occurred in the wall thickness of fibre-tracheids where all the habitats were not significantly different except margins of lowland forests, which had thicker walls. The homogeneity of the length of wide vessels, length of fibriform vessels and wall thickness of fibre-tracheids is a unique feature of these results, which significantly departs from the general trends.

On the contrary the research has established variations between populations in the rest of wood anatomy characters. Among all the habitats, margins of lowland forests had significantly larger cell diameter and wall thickness in all cell types. It had the shortest fibre tracheids and median libriform fibre length, though the latter was not significantly different from that of hot thermal soils and subalpine habitats. As for the area of perforation plates, margins of lowland forests had the smallest for wide vessels and the greatest for fibriform vessels. It had the greatest mean group of vessels and also median density of wide vessels.

The swamp habitat had significantly long fibre-tracheids and libriform fibres. The area of perforation plates of wide vessels was significantly greater than that of the other habitats. Its wide vessels had the smallest mean density and mean group. The swamp habitat's wide vessels had median diameters and thick walls, though the latter was not significantly different from that of margins of lowland forests and sand dune

habitats. The swamp habitat had median diameters, median wall thickness and also median area of perforation plates of fibriform vessels. The diameter and wall thickness of libriform fibres were not significantly different from that of margins of lowland forests and sand dune habitats even though smaller than of both habitats. The fibre-tracheids of the swamp habitat had median diameters and were not significantly different from that of hot thermal soils habitat.

Sand dune habitat had comparatively short libriform fibres, median fibre-tracheids length (though the latter was not significantly different from that of hot thermal soils and subalpine habitats). It had the smallest diameters of wide vessels, second largest diameter of fibriform vessels and large diameters of both fibres. But the mean diameters of fibres were not significantly different from those of margins of lowland forests. Sand dune plants also had thin cell wall thickness in both types of vessels and thick cell walls of libriform fibres. These plants possessed median area of perforation plates and median grouping of wide vessels. Sand dune habitat was one of the habitats with high levels of cell density.

Median fibre lengths, median fibriform vessel diameters and median fibre-tracheid diameters characterize manuka plants growing in the hot thermal soils habitat. These plants had narrow wide vessels and narrow libriform fibres. The plants had thin cell walls of libriform fibres and fibriform vessels, but median cell wall thickness of wide vessels. The hot thermal soils habitat also had median area of perforation plates for both types of vessels. It had also median grouping of wide vessels and like sand dune, it had the highest levels of wide vessel density.

Like the hot thermal soils habitat, subalpine habitat had median fibre lengths and was marked with narrow diameters of all cell types. Even though the wall thickness of wide vessels of plants in this habitat was smaller than that of margins of lowland forests and swamp habitats, it was not significantly different from them. The subalpine habitat plants had median thick cell walls of fibriform vessels and thin libriform fibre cell walls. These plants also had median area of perforation plates for wide vessels and small area of the fibriform vessel perforation plates. They had small density and small mean group of wide vessels.

This study has also established variations within each population in all the cell types and in all their dimensions or characters. The study showed that plants in each population anatomically differ in the sizes of their lengths, widths, wall thickness, abundance of wide vessels, average group of wide vessels and area of perforation plates of wide vessels and fibriform vessels.

Though variations were established within and between populations in most of the cell characters, the correlation of wood anatomy with habitat seemed to be less pronounced as compared to that in previous studies. General trends were manifest in diameter, wall thickness and abundance of wide vessels. More mesic habitats, that is, margins of lowland forests and swamp, were characterised by the greatest diameters and wall thicknesses and also much lower abundance of wide vessels. The less mesic habitats, sand dune, subalpine and hot thermal soils had the highest density of wide vessels with narrow diameters and thin walls.

These results support the well-established theory that selective forces for evolution of different wood features in different habitats exert an adaptation for conductive safety and efficiency (Carlquist, 1988). In mesic habitats the major selective force is for conductive efficiency and therefore the vessels have a tendency towards phylogenetic widening. Whereas in less mesic habitat the major selective force is for conductive safety and thus the vessels tend to develop narrow diameters. The results also follow the general trend that where vessels are wider in diameter there are fewer per unit of a transactional area. The high density of vessels is for selective advantage for it compensates for narrowness of vessels resulting in conductive efficiency. The high density of vessels is also a conductive safety mechanism (Bass et al., 1983).

6.1 Further study

This research has established that there are variations in the wood of manuka within a population and between populations of manuka growing in different habitats. However the effect of different ecological factors in different habitats was less pronounced as compared to that of studies on families and genera. It is acknowledged that this study has overlooked the possible effects of age and genetic variations

between plants within a habitat and between habitats. Because of this limitation it is apparent that these variations cannot be attributed to ecology only. Therefore it would be more appropriate if further research to improve experimental control is conducted using the same genetic stock or clone grown in different environments. This will eliminate genetic variations between individuals and it will also eliminate age differences between plants. The variations obtained then will be attributed to differences in ecological factors. To this end ten cuttings were taken from the swamp habitat and successfully struck in the glasshouse with the long-term aim of growing these plants in different environments.

Another investigation that would be of interest is that of finding what effect heat has on the growth of plants. It is not clear whether the high soil temperatures of hot thermal soils habitat contributed to the small dimensions in the hot thermal soils habitat. It would be of interest to find if the hot temperatures cause any water stress in the vessels of plants.

APPENDICES

Table A1 ANOVA table for length of wide vessel

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	0.839	0.168	0.45	0.8102
Tree within Site	48	17.86	0.372		
Tree within Site	48	17.86	0.372	3.97 2.19	0.0001 a 0.0006 b
Sample	2	0.16	0.080	0.85 0.47	0.4272 a 0.6263 b
Sample within Site	10	1.96	0.196	2.09 1.16	0.0223 a 0.3303 b
Sample within Tree within Site	96	15.60	0.170	1.81	0.0001 a
Error (Cell within sample within...)	1458	136.62	0.094		

a: compared to Error (Cell within Sample within Tree within Site)
b: compared to Sample within Tree within Site

Table A2 ANOVA table for width of wide vessels

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	15.87	3.175	7.86	0.0001
Tree within Site	48	19.40	0.404		
Tree within Site	48	19.40	0.404	6.51 3.03	0.0001 a 0.0001 b
Sample	2	1.03	0.514	8.29 3.85	0.0003 a 0.0248 b
Sample within Site	10	2.35	0.235	3.79 1.76	0.0001 a 0.0792 b
Sample within Tree within Site	96	12.29	0.134	2.15	0.0001 a
Error (Cell within sample within...)	1462	90.78	0.062		

Table A3 ANOVA table for wall thickness of wide vessels

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	12.92	2.584	8.50	0.0001
Tree within Site	48	14.59	0.304		
Tree within Site	48	14.59	0.304	3.70 1.74	0.0001 a 0.0119 b
Sample	2	0.05	0.023	0.28 0.13	0.7548 a 0.8765 b
Sample within Site	10	2.35	0.235	2.86 1.34	0.0015 a 0.2205 b
Sample within Tree within Site	96	16.11	0.175	2.13	0.0001 a
Error (Cell within sample within...)	1462	120.05	0.082		

Table A4 ANOVA table for abundance of wide vessels

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	81.97	16.395	6.54	0.0001
Tree within Site	48	120.35	2.507		
Tree within Site	48	120.35	2.507	83.11 7.35	0.0001 a 0.0001 b
Sample	2	0.51	0.255	8.47 0.75	0.0002 a 0.4755 b
Sample within Site	10	2.73	0.273	9.04 0.80	0.0001 a 0.6295 b
Sample within Tree within Site	96	31.03	0.341	11.30	0.0001 a
Error (Cell within sample within...)	1452	43.80	0.030		

Table A4(i) Mean, minimum and maximum length, upper and lower quartiles of width, wall thickness (um) and abundance of wide vessels for all the habitats and prostrate manuka.

TREE	LMEAN	LMAX	LQ3	LQ1	LMIN	WMEAN	WMAX	WQ3	WQ1	WMIN	WTMEAN	WTMAX	WTQ3
1	239.23	360.00	288.00	192.00	138.00	65.93	95.38	76.10	53.66	34.15	4.21	7.69	4.88
2	219.33	348.00	246.00	180.00	132.00	65.23	98.46	76.10	54.63	35.12	3.93	8.78	4.62
3	248.50	360.00	282.00	210.00	144.00	60.77	90.77	68.29	50.77	38.46	4.51	7.69	4.88
4	274.60	450.00	318.00	216.00	174.00	59.30	106.15	73.85	43.08	18.54	3.62	4.88	4.62
5	275.80	426.00	330.00	228.00	120.00	71.03	121.95	84.62	60.00	33.85	3.74	7.80	3.90
6	253.42	390.00	312.00	210.00	120.00	56.08	85.85	68.29	45.85	29.27	3.84	8.78	4.62
7	252.86	354.00	306.00	216.00	4.80	57.15	84.88	61.46	48.78	35.12	4.34	6.15	4.88
8	280.80	468.00	348.00	222.00	72.00	77.06	120.00	89.23	63.41	37.07	4.95	7.80	6.15
9	264.33	438.00	340.00	186.00	150.00	47.89	96.59	60.00	36.92	25.34	4.33	6.15	4.88
10	242.08	480.00	300.00	192.00	120.00	55.40	138.46	69.23	35.38	20.49	3.89	6.92	4.62
1	288.62	438.00	342.00	216.00	162.00	69.96	89.23	79.02	61.54	36.92	4.54	7.69	4.88
2	311.07	468.00	390.00	240.00	180.00	67.50	93.86	72.31	61.54	43.08	4.50	7.69	5.85
3	207.37	312.00	252.00	150.00	90.00	56.76	87.69	69.23	47.69	24.62	3.92	6.15	4.62
4	237.85	348.00	276.00	186.00	132.00	60.75	104.62	69.27	47.80	38.46	4.92	9.23	6.15
5	241.72	540.00	294.00	167.50	22.50	64.48	115.00	70.77	50.77	29.23	4.51	7.69	4.88
6	261.58	378.00	300.00	210.00	140.00	62.70	93.85	72.20	53.85	32.20	4.83	7.80	6.15
7	230.05	384.00	252.00	198.00	90.00	52.15	86.15	63.41	40.00	32.31	4.44	9.23	4.88
8	273.52	456.00	318.00	225.00	107.60	70.33	96.92	78.46	58.46	41.54	4.61	6.15	5.85
9	236.72	378.00	280.00	192.00	150.00	62.72	81.54	67.69	58.46	21.54	4.00	6.15	4.62
10	257.08	414.00	294.00	216.00	132.50	68.09	95.38	78.46	50.77	44.62	4.08	7.69	4.62
1	250.47	378.00	300.00	198.00	120.00	62.57	93.85	75.38	47.69	30.77	4.51	7.69	4.62
2	215.82	318.00	246.00	174.00	90.00	54.04	104.62	63.08	43.08	29.27	4.73	7.69	6.15
3	275.00	426.00	312.00	252.00	120.00	59.82	81.54	67.69	50.77	38.46	4.65	6.15	4.62
4	249.23	390.00	300.00	192.00	126.00	62.37	104.62	72.31	49.23	23.08	4.77	7.69	4.88
5	258.52	486.00	300.00	204.00	120.00	57.94	83.08	67.69	49.23	36.10	5.43	9.23	6.15
6	240.80	342.00	294.00	192.00	150.00	62.98	93.85	75.12	52.68	26.34	5.42	7.80	6.15

7	232.75	372.00	270.00	192.00	138.00	70.91	100.00	76.92	61.54	46.83	4.64	7.69	5.85
8	261.35	384.00	312.00	210.00	120.00	53.39	73.85	63.08	43.08	35.38	4.73	7.69	6.15
9	227.45	408.00	258.00	174.00	108.00	59.35	88.78	66.15	53.68	26.15	4.36	6.83	4.88
10	292.00	486.00	348.00	222.00	150.00	67.60	92.31	76.92	58.46	47.69	4.91	7.69	6.15
1	270.18	390.00	325.00	216.00	135.00	64.37	95.00	70.00	55.00	48.78	4.74	10.73	5.00
2	291.00	555.00	335.00	230.00	175.00	56.17	80.00	65.00	50.00	35.00	4.13	5.00	5.00
3	256.50	430.00	345.00	180.00	100.00	61.00	85.00	75.00	50.00	20.00	4.83	7.50	5.00
4	250.50	395.00	300.00	210.00	40.00	77.67	110.00	95.00	65.00	40.00	4.92	7.50	5.00
5	242.17	425.00	275.00	200.00	80.00	69.75	100.00	80.00	60.00	45.00	5.25	7.50	5.00
6	218.25	366.00	246.00	168.00	22.00	78.25	120.00	90.00	62.50	42.50	5.29	7.50	5.00
7	271.20	438.00	324.00	204.00	138.00	62.88	87.50	80.00	47.50	32.50	5.54	11.25	7.50
8	213.17	390.00	252.00	156.00	107.50	75.46	120.00	90.00	60.00	42.50	4.98	7.50	5.00
9	222.47	372.00	270.00	174.00	100.00	67.97	87.80	78.05	60.00	41.95	4.70	7.81	5.00
10	282.13	462.00	318.00	228.00	138.00	75.23	119.02	88.78	64.62	33.17	5.28	10.73	6.15
1	293.80	412.00	318.00	258.00	198.00	71.45	81.54	76.92	68.29	44.88	4.15	6.15	4.62
2	253.34	432.00	288.00	198.00	84.00	68.34	95.38	76.92	58.46	29.27	4.59	7.69	4.62
3	194.02	324.00	228.00	144.00	102.00	51.68	80.00	60.00	38.46	31.12	4.98	7.69	6.15
4	272.12	444.00	318.00	216.00	108.00	62.32	81.54	72.31	55.38	41.54	4.26	7.69	4.62
5	322.00	528.00	378.00	252.00	168.00	71.21	104.62	78.46	59.51	43.90	5.87	7.80	6.15
6	287.18	408.00	340.00	240.00	92.50	83.45	135.00	97.50	70.77	40.00	6.56	10.00	7.50
7	295.00	504.00	372.00	222.00	162.00	71.79	124.62	78.46	55.38	38.46	4.85	9.23	6.15
8	273.30	438.00	330.00	216.00	132.00	63.10	92.31	73.85	52.31	35.38	4.82	7.69	6.15
9	263.70	456.00	288.00	222.00	138.00	63.51	80.76	75.38	52.31	30.77	4.18	6.15	4.62
10	267.27	468.00	336.00	204.00	96.00	66.21	93.85	76.92	61.15	27.69	5.23	10.77	6.15
1	341.25	474.00	384.00	288.00	232.50	53.00	64.62	60.00	44.62	33.85	5.08	7.69	6.15
2	248.30	468.00	318.00	180.00	90.00	42.20	75.38	48.62	32.31	20.00	4.00	7.69	4.62
3	267.20	408.00	318.00	216.00	168.00	46.55	56.59	52.31	41.54	30.77	3.49	6.83	4.62
4	220.80	324.00	264.00	192.00	72.00	50.23	83.08	58.46	38.05	27.69	3.57	4.88	4.62

WTQ1	WTMIN	AMEAN	AMAX	AQ3	AQ1	AMIN
2.93	1.95	78.30	100.00	84.00	72.00	60.00
2.93	1.95	92.70	102.00	99.00	88.00	78.00
3.90	1.95	122.67	157.00	133.00	113.00	94.00
2.93	1.54	76.67	103.00	91.00	66.00	55.00
2.93	1.95	66.73	97.00	79.00	59.00	28.00
2.93	1.95	62.00	86.00	69.00	52.00	41.00
3.90	2.44	46.67	64.00	53.00	41.00	31.00
3.90	1.95	44.80	60.00	49.00	40.00	30.00
3.08	2.31	36.37	52.00	41.00	32.00	25.00
3.08	1.95	39.07	57.00	45.00	33.00	24.00
3.08	2.93	43.87	58.00	49.00	39.00	27.00
3.08	3.08	47.10	64.00	53.00	41.00	36.00
3.08	1.54	53.40	94.00	65.00	41.00	29.00
3.90	2.93	71.95	120.00	77.50	61.00	50.00
3.08	3.08	54.50	75.00	64.00	42.00	36.00
3.90	3.08	75.20	94.00	81.00	69.00	57.00
3.08	1.95	96.70	155.00	123.00	63.00	41.00
3.90	2.93	51.63	65.00	58.00	45.00	39.00
3.08	1.54	93.40	160.00	102.00	81.00	67.00
3.08	1.54	50.43	70.00	56.00	45.00	35.00
3.41	2.93	42.57	57.00	46.00	40.00	24.00
4.62	1.54	41.53	63.00	49.00	33.00	28.00
4.62	2.93	51.13	72.00	59.00	45.00	35.00
3.90	2.93	50.40	233.00	50.00	39.00	33.00
4.62	3.92	57.83	96.00	62.00	49.00	37.00
4.62	3.08	56.50	73.00	62.00	49.00	42.00
3.90	2.93	52.57	96.00	66.00	34.00	25.00
3.08	2.93	59.83	113.00	64.00	43.00	28.00

3.90	2.93	57.00	84.00	62.00	50.00	37.00
4.62	1.54	55.40	76.00	60.00	51.00	42.00
4.39	1.25	102.73	129.00	116.00	91.00	68.00
2.50	2.50	66.20	80.00	73.00	60.00	54.00
5.00	2.50	44.03	65.00	52.00	34.00	28.00
5.00	2.50	46.83	87.00	68.00	32.00	25.00
5.00	5.00	87.23	129.00	93.00	78.00	64.00
5.00	2.50	48.77	67.00	58.00	38.00	30.00
5.00	2.50	55.00	79.00	59.00	48.00	40.00
5.00	2.50	62.60	83.00	76.00	53.00	41.00
3.90	2.93	40.47	60.00	47.00	35.00	21.00
3.90	1.95	46.47	62.00	55.00	41.00	25.00
2.93	1.95	50.90	69.00	52.00	47.00	44.00
3.90	2.93	45.22	85.00	52.00	37.00	19.00
4.62	3.08	69.80	116.00	81.00	52.00	41.00
3.08	3.08	45.63	59.00	50.00	42.00	35.00
4.88	3.08	68.97	85.00	76.00	64.00	52.00
5.00	3.08	76.90	106.00	85.00	68.00	57.00
3.08	3.08	72.27	97.00	88.00	60.00	37.00
3.08	3.08	47.03	77.00	63.00	35.00	20.00
3.08	3.08	43.00	61.00	48.00	38.00	32.00
4.62	3.08	32.87	47.00	38.00	29.00	24.00
3.08	3.08	126.50	154.00	142.00	111.00	101.00
3.08	1.95	120.06	190.00	150.00	86.00	53.00
2.93	1.54	165.13	228.00	187.00	147.00	84.00
3.08	1.54	112.37	143.00	121.00	100.00	87.00

Table A6 ANOVA table of `fibriform vessels' lengths`

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	8.16	1.632	7.87	0.0001
Tree within Site	48	9.95	0.207		
Tree within Site	48	9.95	0.207	4.01 1.94	0.0001 a 0.0030 b
Sample	2	0.60	0.298	5.78 2.79	0.0032 a 0.0663 b
Sample within Site	10	1.28	0.128	2.48 1.20	0.0061 a 0.3020 b
Sample within Tree within Site	96	10.26	0.107	2.07	0.0001 a
Error (Cell within sample within...)	1278	66.03	0.052		

Table A7 ANOVA table of fibriform vessel widths

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	12.44	2.488	24.35	0.0001
Tree within Site	48	4.90	0.102		
Tree within Site	48	4.90	0.102	2.31 1.73	0.0001 a 0.0118 b
Sample	2	0.09	0.043	0.98 0.73	0.3762 a 0.4830 b
Sample within Site	10	0.48	0.048	1.08 0.81	0.3743 a 0.6200 b
Sample within Tree within Site	96	5.67	0.059	1.33	0.0202 a
Error (Cell within sample within...)	1278	56.61	0.044		

Table A8 .ANOVA table for wall thickness of fibriform vessels

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	13.07	2.613	10.52	0.0001
Tree within Site	48	11.92	0.248		
Tree within Site	48	11.92	0.248	2.72 1.56	0.0001 a 0.0328 b
Sample	2	0.01	0.004	0.04 0.02	0.9582 a 0.9758 b
Sample within Site	10	1.38	0.138	1.51 0.87	0.1284 a 0.5644 b
Sample within Tree within Site	96	15.27	0.159	1.74	0.0001 a
Error (Cell within sample within...)	1278	116.68	0.091		

Table A8(i)The mean, minimum and maximum, upper and lower quartiles fibriform vessels length, width, and wall thickness. (um)

SITES	TREE	LMEAN	LMAX	LQ3	LQ1	LMIN	WMEAN	WMAX	WQ3	WQ1	W
A	1	406.60	588.00	456.00	372.00	234.00	26.78	38.46	30.77	23.41	
A	2	359.23	510.00	420.00	300.00	222.00	26.06	41.95	30.24	23.08	
A	3	411.66	588.00	456.00	342.00	310.00	24.37	39.02	27.32	21.46	
A	4	418.57	582.00	496.00	324.00	212.00	24.68	38.05	27.32	21.46	
A	5	412.82	612.00	474.00	336.00	246.00	26.91	37.50	30.24	24.39	
A	6	399.08	670.00	441.00	322.50	240.00	24.47	36.92	27.69	21.54	
A	7	414.57	600.00	474.00	366.00	290.00	24.52	35.12	27.50	21.54	
A	8	441.07	850.00	480.00	354.00	255.00	25.52	41.95	29.27	21.46	
A	9	397.80	600.00	438.00	335.00	258.00	25.73	36.10	29.23	23.41	
A	10	390.12	735.00	408.00	330.00	235.00	23.48	41.95	26.15	18.46	

B	1	486.15	910.00	540.00	414.00	294.00	25.58	41.54	29.27	21.54
B	2	475.35	708.00	534.00	396.00	234.00	24.76	35.38	29.23	23.08
B	3	349.58	516.00	402.00	294.00	234.00	22.51	35.00	26.15	18.46
B	4	406.71	522.00	492.00	346.00	247.50	23.20	29.23	26.15	20.00
B	5	392.05	636.00	435.00	320.75	249.00	23.21	34.15	26.25	19.76
B	6	461.12	780.00	528.00	360.00	264.00	22.51	29.23	25.37	21.46
B	7	417.85	660.00	450.00	357.00	270.00	24.07	33.17	27.32	21.46
B	8	457.04	702.50	528.00	392.00	230.00	24.60	46.15	26.15	21.54
B	9	411.64	570.00	480.00	330.00	276.00	24.36	40.00	27.69	20.00
B	10	419.82	600.00	486.00	342.00	264.00	22.81	27.69	23.08	21.54
C	1	366.50	510.00	432.00	302.50	282.00	24.19	33.85	27.69	20.00
C	2	349.87	485.00	380.00	300.00	222.50	22.39	41.95	24.62	18.46
C	3	383.58	510.00	450.00	318.00	252.00	24.06	35.38	26.15	21.54
C	4	394.73	480.00	432.00	342.50	318.00	23.50	32.20	27.32	20.00
C	5	410.05	552.00	450.00	348.00	234.00	24.41	44.62	27.69	21.51
C	6	367.65	522.00	426.00	300.00	240.00	23.29	30.77	24.62	21.46
C	7	391.30	579.00	423.00	330.00	240.00	22.41	30.77	23.74	20.00
C	8	398.06	564.00	474.00	330.00	252.00	22.11	33.17	23.08	19.23
C	9	364.44	477.50	417.00	318.75	222.00	20.81	30.77	21.54	18.00
C	10	434.92	646.00	492.00	363.00	324.00	20.51	26.15	23.08	19.23
D	1	337.73	480.00	385.00	270.00	220.00	26.37	42.00	30.00	20.00
D	2	330.17	525.00	400.00	255.00	135.00	27.00	45.00	30.00	20.00
D	3	337.70	510.00	408.00	270.00	160.00	23.21	35.00	25.00	20.00
D	4	339.30	555.00	410.00	275.00	210.00	28.42	50.00	30.00	20.00
D	5	344.67	490.00	390.00	300.00	175.00	27.83	40.00	35.00	25.00
D	6	348.98	522.00	414.00	264.00	210.00	30.71	60.00	32.50	26.25
D	7	391.53	534.00	468.00	318.00	177.50	28.17	40.00	30.00	25.00
D	8	367.78	504.00	438.00	300.00	222.50	30.38	45.00	35.00	27.50
D	9	333.33	522.00	372.00	276.00	172.50	30.74	53.85	37.50	23.08
D	10	392.50	700.00	456.00	312.00	235.00	28.03	48.78	30.24	23.45
E	1	462.93	672.00	558.00	366.00	312.00	26.13	38.46	27.69	23.08
E	2	411.02	630.00	462.00	366.00	240.00	23.14	35.38	24.62	20.00

E	3	333.55	492.00	380.00	288.00	180.00	19.56	29.23	21.54	16.92
E	4	412.09	572.50	432.00	347.70	270.00	23.79	33.85	26.15	21.54
E	5	470.28	700.00	534.00	408.00	264.00	23.68	33.85	26.15	20.00
E	6	451.96	820.00	504.00	370.00	234.00	23.73	36.92	24.62	20.00
E	7	419.38	558.00	462.00	390.00	307.50	23.09	35.38	26.15	20.00
E	8	390.75	612.00	450.75	318.00	246.00	23.62	30.77	27.69	20.00
E	9	513.56	820.00	600.00	432.00	312.00	23.16	48.46	24.62	18.46
E	10	430.32	654.00	516.00	318.00	258.00	24.11	33.85	27.50	21.54
F	1	473.48	612.00	546.00	390.00	270.00	20.00	33.85	21.54	18.46
F	2	330.03	504.00	378.00	282.00	186.00	17.83	24.62	20.00	16.92
F	3	404.97	576.00	498.00	318.00	227.50	19.75	26.15	21.46	18.46
F	4	403.36	700.00	456.00	348.00	235.00	19.16	24.62	20.49	16.92

WTQ1	WTMIN
3.08	1.95
2.93	0.98
2.93	1.54
3.08	1.54
2.93	1.54
2.93	1.54
2.93	1.46
2.93	1.54
2.93	1.95
3.08	1.95
3.08	1.54
3.08	1.54
3.08	1.54
3.08	1.54
3.08	1.54
3.08	2.31
2.93	2.93
3.08	1.54

3.08	1.54
1.54	1.54
3.08	1.54
3.08	3.08
3.08	1.54
3.08	1.95
3.08	3.08
3.90	2.93
3.08	2.31
3.08	1.54
3.08	1.54
3.08	1.54
2.50	1.25
2.50	2.50
5.00	2.50
3.00	2.50
5.00	2.50
3.75	2.50
3.25	2.50
3.25	2.50
3.08	2.50
3.90	2.93
3.08	3.08
3.08	1.54
3.08	1.54
3.08	1.54
3.08	2.93
3.08	2.93
3.08	1.54
3.08	1.54
3.08	1.54
3.08	1.54

3.08	3.08
1.95	1.54
1.54	0.98
2.93	1.54

Table A9 ANOVA table for length of libriform fibres

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	18.57	3.715	11.74	0.0001
Tree within Site	48	15.19	0.316		
Tree within Site	48	15.19	0.316	8.19 4.14	0.0001 a 0.0001 b
Sample	2	0.26	0.131	3.38 1.71	0.0345 a 0.1869 b
Sample within Site	10	1.08	0.108	2.79 1.41	0.0020 a 0.1882 b
Sample within Tree within Site	96	7.34	0.076	1.8	0.0001 a
Error (Cell within sample within…)	1454	56.21	0.039		

Table A10 ANOVA table for width of libriform cells

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	9.41	1.882	19.82	0.0001
Tree within Site	48	4.56	0.095		
Tree within Site	48	4.56	0.095	3.06 1.38	0.0001 a 0.0916 b
Sample	2	0.27	0.133	4.28 1.93	0.0141 a 0.1511 b
Sample within Site	10	0.61	0.061	1.97 0.89	0.0328 a 0.5465 b
Sample within Tree within Site	96	6.61	0.661	2.22	0.0001 a
Error (Cell within sample within...)	1454	45.10	0.031		

Table A11 ANOVA table for wall thickness of libriform fibres

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	330.79	66.16	5.74	0.0001
Tree within Site	48	553.5	11.53		
Tree within Site	48	553.5	11.53	4.51 2.17	0.0001 a 0.0006 b
Sample	2	5.24	2.62	1.02 0.49	0.3596 a 0.6122 b
Sample within Site	10	31.47	3.15	1.23 0.59	0.2667 a 0.8164 b
Sample within Tree within Site	96	509.85	5.31	2.08	0.0001 a
Error (Cell within sample within...)	1454	3720.99	2.56		

Table A12 ANOVA table for fibre-tracheids length

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	6.271	1.254	7.40	0.0001
Tree within Site	48	8.140	0.170		
Tree within Site	48	8.138	0.170	4.43 2.56	0.0001 a 0.0001 b
Sample	2	0.085	0.043	1.11 0.64	0.3289 a 0.5285 b
Sample within Site	10	0.653	0.065	1.71 0.98	0.739 a 0.4618 b
Sample within Tree within Site	96	6.363	0.066	1.73	0.0001 a
Error (Cell within sample within...)	1441	55.102	0.038		

Table A13 ANOVA table for fibre-tracheids width

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	11.517	2.303	19.92	0.0001
Tree within Site	48	5.549	0.116		
Tree within Site	48	5.549	0.116	3.48 2.31	0.0001 a 0.0002 b
Sample	2	0.058	0.029	0.88 0.58	0.4157 a 0.5601 b
Sample within Site	10	0.387	0.039	1.17 0.77	0.3099 a 0.6536 b
Sample within Tree within Site	96	4.800	0.050	1.51	0.0015 a
Error (Cell within sample within…)	1441	47.839	0.033		

Table A14 ANOVA table for fibre-tracheids wall thickness

Source	DF	Type 1 SS	Mean Square	F Value	Pr > F
Site	5	10.56	2.11	8.29	0.0001
Tree within Site	48	12.22	0.255		
Tree within Site	48	12.22	0.255	3.06 2.12	0.0001 a 0.0009 b
Sample	2	0.30	0.150	1.80 1.24	0.1660 a 0.2930 b
Sample within Site	10	1.36	0.136	1.63 1.13	0.0931 a 0.3502 b
Sample within Tree within Site	96	11.55	0.121	1.44	0.0041 a
Error (Cell within sample within...)	1441	120.00	0.083		

Table A11(i) Libriform fibres mean, minimum and maximum, upper and lower quartile values of length, width and wall thickness (um)

SITES	TREE	LMEAN	LMAX	LQ3	LQ1	LMIN	WMEAN	WMAX	WQ3	WQ1	WMIN
A	1	691.33	1040.00	780.00	588.00	342.00	19.28	26.15	21.54	16.59	10.24
A	2	656.30	870.00	750.00	564.00	468.00	21.05	40.00	23.08	16.92	12.50
A	3	718.70	910.00	820.00	590.00	460.00	18.48	23.08	20.00	16.92	15.38
A	4	717.77	1040.00	820.00	594.00	384.00	21.55	32.20	24.39	18.46	13.66
A	5	760.27	1020.00	860.00	606.00	522.00	19.68	26.34	21.46	16.92	14.63
A	6	663.40	940.00	830.00	528.00	390.00	18.30	32.31	20.49	15.38	13.85
A	7	713.83	1038.00	834.00	610.00	354.00	17.28	24.62	18.54	15.38	11.71
A	8	749.47	1008.00	850.00	640.00	384.00	18.70	31.22	20.49	15.61	13.60
A	9	601.57	860.00	695.00	474.00	396.00	18.24	27.32	21.46	15.60	7.69

A	10	591.88	920.00	710.00	486.00	258.00	19.73	31.22	22.50	16.92	12.31
B	1	801.37	1104.00	950.00	678.00	504.00	17.07	24.62	19.92	13.85	12.31
B	2	850.17	1330.00	1003.00	700.00	456.00	15.92	25.38	16.92	13.85	8.78
B	3	531.67	750.00	594.00	468.00	343.00	17.47	27.69	19.51	15.38	13.85
B	4	693.67	1130.00	798.00	570.00	462.00	15.47	21.46	16.92	13.85	7.69
B	5	821.77	1012.00	960.00	710.00	498.00	16.69	24.62	18.46	15.38	9.23
B	6	747.60	1026.00	860.00	636.00	456.00	17.59	23.08	20.00	15.38	13.66
B	7	720.13	1290.00	840.00	552.00	444.00	16.99	26.15	18.46	15.38	11.71
B	8	855.20	1090.00	980.00	760.00	522.00	16.66	23.08	16.92	15.38	12.31
B	9	765.00	1000.00	830.00	670.00	606.00	17.27	30.76	18.46	15.38	10.77
B	10	835.60	1000.00	880.00	790.00	708.00	17.02	21.54	18.46	15.38	12.68
C	1	679.73	980.00	770.00	570.00	396.00	15.84	18.46	16.92	13.85	10.72
C	2	667.00	870.00	750.00	588.00	444.00	16.45	21.54	16.92	15.38	13.66
C	3	822.70	1090.00	910.00	750.00	474.00	17.33	23.08	20.00	15.38	12.31
C	4	774.67	1002.00	870.00	690.00	564.00	16.23	21.54	18.46	13.85	12.31
C	5	785.63	990.00	840.00	710.00	600.00	17.08	23.08	18.54	15.38	12.31
C	6	783.53	1001.00	900.00	640.00	438.00	16.17	19.51	17.56	15.38	11.71
C	7	742.18	1002.00	870.00	643.00	522.00	18.25	23.41	20.00	16.10	12.68
C	8	804.07	1002.00	890.00	720.00	564.00	15.72	21.54	16.92	13.85	12.31
C	9	627.40	800.00	720.00	546.00	462.00	16.43	21.54	18.46	13.85	13.85
C	10	719.97	1080.00	820.00	603.00	450.00	17.22	24.62	18.46	15.38	13.85
D	1	610.63	900.00	670.00	525.00	410.00	19.56	30.00	20.00	17.50	12.50
D	2	689.67	900.00	780.00	645.00	275.00	20.33	30.00	30.00	15.00	12.50
D	3	706.83	1050.00	870.00	575.00	380.00	18.25	40.00	20.00	15.00	7.50
D	4	736.83	1110.00	860.00	600.00	515.00	22.58	30.00	25.00	20.00	15.00
D	5	623.00	840.00	700.00	525.00	370.00	18.42	27.50	20.00	15.00	12.50
D	6	739.10	1010.00	870.00	624.00	444.00	20.00	25.00	22.50	17.50	15.00
D	7	779.37	1110.00	860.00	700.00	516.00	19.13	25.00	20.00	17.50	15.00
D	8	852.33	1120.00	955.00	768.00	510.00	20.71	25.00	22.50	17.50	15.00

D	9	787.00	1080.00	920.00	705.00	366.00	19.01	27.32	21.46	16.58	13.66
D	10	752.00	1140.00	810.00	670.00	468.00	18.06	24.39	20.00	15.61	11.71
E	1	921.00	1164.00	1003.00	820.00	600.00	19.66	29.23	21.54	16.92	15.38
E	2	709.90	1000.00	810.00	610.00	459.00	17.95	23.08	20.00	15.38	10.76
E	3	768.50	1110.00	960.00	650.00	390.00	17.70	24.62	20.00	15.38	13.85
E	4	866.87	1230.00	990.00	760.00	408.00	17.01	23.08	18.46	15.38	12.31
E	5	889.57	1150.00	1002.00	790.00	564.00	18.61	33.41	20.00	16.92	11.71
E	6	831.87	1080.00	890.00	760.00	480.00	20.54	27.50	22.50	18.46	15.00
E	7	828.33	1160.00	950.00	670.00	480.00	18.00	21.54	20.00	16.92	12.31
E	8	862.77	1180.00	990.00	750.00	534.00	17.96	27.69	20.00	15.38	10.77
E	9	840.90	1100.00	960.00	770.00	510.00	19.33	30.77	21.54	16.92	13.85
E	10	904.63	1170.00	1002.00	805.00	660.00	18.90	45.38	20.00	15.38	10.76
F	1	554.18	1060.00	603.00	468.00	396.00	14.23	18.46	15.38	12.31	10.31
F	2	517.23	750.00	580.00	444.00	378.00	15.19	20.00	16.92	12.68	10.76
F	3	501.00	690.00	546.00	450.00	330.00	15.16	20.00	16.59	12.68	10.73
F	4	597.00	880.00	684.00	525.00	282.00	15.96	20.49	16.92	14.63	9.23

WTMEAN	WTMAX	WTQ3	WTQ1	WTMIN
6.54	10.77	7.80	4.88	1.95
6.36	10.77	7.69	4.88	2.50
7.63	12.31	8.78	6.53	3.90
6.88	13.66	7.69	4.88	2.93
7.44	10.73	8.78	6.15	4.88
5.41	7.80	6.15	4.62	2.31
6.76	11.71	7.69	5.85	3.90
6.27	8.78	6.83	5.85	3.90
4.86	7.80	5.85	3.90	1.54
5.63	9.23	7.50	4.62	3.08

6.01	9.23	6.15	4.62	4.62
5.75	7.69	6.15	4.62	3.08
6.03	7.69	7.69	4.62	3.08
5.68	7.80	6.15	4.62	3.08
5.84	9.23	7.69	4.62	3.08
6.99	9.23	7.69	6.15	4.62
5.61	7.69	6.15	4.88	3.90
6.05	9.23	7.69	4.62	3.08
5.51	7.69	6.15	4.62	3.08
6.32	9.23	7.69	6.15	3.08
5.67	7.69	6.15	4.62	3.08
5.92	7.69	7.69	4.62	3.85
5.54	7.69	6.15	4.62	1.54
6.75	13.85	7.69	6.15	4.62
5.79	9.23	6.83	4.62	3.08
5.20	9.23	6.15	3.90	2.93
5.96	9.76	6.83	4.62	3.85
5.85	7.80	6.15	4.62	3.08
5.28	7.80	6.15	4.62	1.54
4.93	7.69	6.15	4.62	2.93
5.92	10.00	7.50	5.00	2.50
5.17	10.00	5.00	5.00	2.50
5.92	10.00	7.50	5.00	2.50
7.00	10.00	10.00	5.00	2.50
6.42	10.00	7.50	5.00	2.50
6.50	8.75	7.50	5.00	3.75
7.00	10.00	7.50	5.00	2.50
7.04	10.00	7.50	6.25	2.50
6.57	9.76	7.69	5.39	3.08
6.32	10.73	7.69	4.88	3.08

5.15	7.69	6.83	3.08	1.54
6.37	9.23	7.69	5.85	3.08
6.20	9.23	7.69	4.62	3.08
5.57	9.23	6.15	4.62	1.54
5.46	8.78	7.69	3.90	2.31
7.02	12.50	8.75	5.85	1.54
6.99	9.23	7.69	6.15	4.62
6.31	9.23	7.69	4.62	1.54
6.07	9.23	7.69	4.62	3.08
6.86	10.00	7.69	6.15	4.62
4.20	7.69	4.62	3.08	1.54
4.51	6.15	6.15	3.08	1.54
4.77	6.83	5.85	3.90	1.95
5.24	9.23	6.15	4.62	1.54

Table A14(i) The mean, minimum and maximum, upper and lower quartile values of fibre-tracheids length, width, and wall thickness. (um)

SITES	TREE	LMEAN	LMAX	LQ3	LQ1	LMIN	WMEAN	WMAX	W
A		1	475.70	690.00	540.00	408.00	309.00	24.21	40.00
A		2	466.97	654.00	510.00	440.00	270.00	20.69	31.22
A		3	474.27	570.00	528.00	414.00	294.00	19.88	29.27
A		4	501.40	750.00	558.00	432.00	336.00	20.70	26.15
A		5	505.73	850.00	570.00	420.00	294.00	24.01	39.02
A		6	423.30	660.00	474.00	360.00	288.00	21.71	36.34
A		7	462.48	704.00	498.00	420.00	257.00	19.15	26.34
A		8	501.73	750.00	570.00	414.00	306.00	21.61	27.32
A		9	442.60	665.00	520.00	396.00	252.00	20.26	32.20
A		10	420.40	570.00	462.00	384.00	306.00	20.85	30.77

B	1	509.33	738.00	552.00	450.00	336.00	20.02	35.38
B	2	499.23	750.00	576.00	426.00	305.00	20.00	26.15
B	3	409.78	660.00	462.00	330.00	282.00	19.37	24.62
B	4	514.93	700.00	594.00	438.00	287.50	17.78	21.54
B	5	559.70	780.00	606.00	497.50	345.00	17.92	24.62
B	6	561.28	800.00	594.00	492.00	414.00	18.00	28.29
B	7	505.33	910.00	528.00	462.00	288.00	18.73	24.67
B	8	554.53	740.00	630.00	480.00	288.00	19.13	26.15
B	9	475.57	680.00	522.00	414.00	330.00	17.79	23.08
B	10	521.67	740.00	570.00	459.00	360.00	19.27	33.85
C	1	501.77	750.00	540.00	456.00	390.00	19.41	26.15
C	2	448.13	558.00	520.00	393.00	336.00	19.01	29.23
C	3	472.90	790.00	540.00	405.00	322.00	17.97	24.62
C	4	445.37	660.00	516.00	390.00	306.00	17.07	23.08
C	5	500.47	750.00	540.00	449.00	372.00	17.29	23.08
C	6	481.43	660.00	540.00	426.00	342.00	18.70	23.08
C	7	462.30	670.00	531.00	392.25	342.00	19.79	26.15
C	8	487.53	660.00	540.00	438.00	384.00	16.32	22.44
C	9	455.37	740.00	516.00	396.00	300.00	17.42	23.41
C	10	495.87	670.00	582.00	432.00	301.00	18.64	23.08
D	1	468.40	610.00	515.00	435.00	325.00	22.17	35.00
D	2	465.00	680.00	535.00	405.00	305.00	22.00	40.00
D	3	408.58	590.00	452.50	350.00	255.00	20.92	32.50
D	4	494.50	675.00	580.00	425.00	260.00	24.67	35.00
D	5	432.67	670.00	475.00	355.00	280.00	22.00	30.00
D	6	419.47	680.00	474.00	354.00	264.00	24.17	32.50
D	7	422.93	770.00	450.00	342.00	252.00	20.79	28.75
D	8	472.07	660.00	528.00	414.00	312.00	21.92	30.00
D	9	418.95	690.00	474.00	330.00	240.00	20.32	29.23

D	10	441.12	710.00	496.00	372.00	264.00	21.80	31.22
E	1	589.35	1000.00	684.00	486.00	366.00	20.36	31.22
E	2	502.07	700.00	558.00	412.00	354.00	19.41	24.62
E	3	459.40	870.00	527.50	366.00	276.00	17.33	29.23
E	4	490.73	700.00	555.00	426.00	312.00	19.53	27.69
E	5	598.97	820.00	690.00	498.00	420.00	19.81	24.62
E	6	576.33	830.00	618.00	504.00	415.00	20.62	30.00
E	7	500.77	680.00	570.00	426.00	354.00	21.14	38.46
E	8	514.12	700.00	552.00	474.00	342.00	19.85	26.15
E	9	550.88	840.00	618.00	468.00	384.00	20.10	24.62
E	10	503.20	890.00	570.00	402.00	318.00	19.45	24.62
F	1	458.97	624.00	496.00	420.00	318.00	16.63	27.69
F	2	413.93	564.00	444.00	378.00	300.00	15.63	22.50
F	3	442.23	594.00	510.00	372.00	306.00	15.73	23.01
F	4	482.77	710.00	530.00	438.00	348.00	18.18	30.77

WTMEAN	WTMAX	WTQ3	WTQ1	WTMIN
4.38	7.80	4.88	3.08	1.95
3.33	6.15	3.90	2.31	1.54
4.71	7.69	4.88	3.90	2.93
3.79	8.78	4.62	2.93	1.95
4.07	6.83	4.88	3.08	2.93
3.27	5.85	3.90	2.93	1.95
3.61	4.88	4.62	2.93	1.95
4.14	6.15	4.62	3.08	1.54
3.68	7.50	4.62	2.93	1.54
3.71	4.62	4.62	3.08	2.93

3.84	5.00	4.62	3.08	2.31
3.51	6.15	4.62	3.08	1.54
3.92	6.15	4.62	3.08	2.31
3.56	4.88	4.62	3.08	1.95
3.52	6.15	4.62	3.08	1.54
4.20	7.69	4.88	3.08	3.08
3.61	6.15	4.62	3.08	1.95
3.96	6.15	4.62	3.08	1.54
3.40	6.15	3.85	3.08	1.54
3.61	6.15	4.62	3.08	1.54
4.45	7.69	4.62	3.85	2.93
3.98	7.69	4.62	3.08	1.54
3.48	6.15	3.08	3.08	2.93
3.99	6.15	4.62	3.08	2.93
4.04	7.69	4.62	3.08	3.08
4.39	7.50	4.88	3.08	1.54
4.06	6.83	4.75	3.08	1.95
3.64	4.88	4.62	3.08	1.54
3.52	6.15	4.62	3.08	1.54
4.06	6.15	4.62	3.08	3.08
4.25	5.00	5.00	2.50	2.50
4.67	7.50	5.00	5.00	2.50
4.75	7.50	5.00	5.00	2.50
5.00	7.50	5.00	5.00	2.50
4.67	7.50	5.00	5.00	2.50
5.00	7.50	6.25	5.00	2.50
5.33	7.50	6.25	5.00	2.50
4.42	7.50	5.00	3.25	2.50
4.03	9.23	4.62	3.08	2.50
4.97	9.23	6.15	3.90	2.50

3.41	5.00	4.62	3.08	1.54
3.94	6.15	4.62	3.08	2.04
3.98	7.69	4.62	3.08	1.54
3.74	6.15	4.62	3.08	2.50
4.00	6.15	4.62	3.08	3.08
4.93	7.50	5.38	4.62	1.95
4.46	6.15	4.62	3.85	3.08
4.15	6.15	4.62	3.08	3.08
4.01	6.15	4.62	3.08	1.54
4.15	6.15	4.62	3.08	2.31
3.53	4.62	4.62	3.08	1.54
3.83	5.00	4.62	3.08	1.54
3.81	6.15	4.88	2.93	1.95
3.62	6.83	4.62	3.08	1.95

Table A15 Correlation of vessel length and libriform fibre length and fibre tracheids length
ANOVA Table and data

	Wide Vessel Length						
	Overall	Site A	Site B	Site C	Site D	Site E	Site F
	n=162	n=30	n=30	n=30	n=30	n=30	n=12
Libriform Length	0.34296	0.33448	0.63636	0.30473	0.05872	0.65131	-0.05412
	p=0.0001	p=0.0708	p=0.0002	p=0.1016	p=0.7579	p=0.0001	p=0.8673
Fibre Tracheid Length	0.36114	32477	0.39749	0.54815	0.13213	0.46343	0.26876
	p=0.0001	p=0.0799	p=0.0296	p=0.0017	p=0.4864	p=0.0099	p=0.3983

Analysis of Covariance

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SITES	5	7086.53353	1417.30671	1.08	0.3711
LFLENGTH	1	33077.8152	33077.8152	25.32	0.0001
LFLENGTH * SITES	5	13762.1557	2752.43114	2.11	0.0676
Error	150	195957.185	1306.38123		

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SITES	5	7086.53353	1417.30671	1.02	0.4096
FTLENGTH	1	30559.9201	30559.9201	21.93	0.0001
FTLENGTH * SITES	5	3246.69827	649.339653	0.47	0.8011
Error	150	208990.537	1393.27025		

SITES	TREE	PART	_TYPE_	_FREQ_	WVLENGTH	LFLENGTH	FTLENGTH
A		1S	0	10	252	768.4	503.4
A		1T	0	10	229.3	681.9	460.8
A		1U	0	10	236.4	623.7	462.9
A		2S	0	10	213	646.7	490.5
A		2T	0	10	227.4	719.3	486.2
A		2U	0	10	217.6	602.9	424.2
A		3S	0	10	236.4	764	493.2
A		3T	0	10	265.6	684.2	441.2
A		3U	0	10	243.5	707.9	488.4
A		4S	0	10	303.6	755.8	567
A		4T	0	10	263.4	760.6	458.4
A		4U	0	10	256.8	636.9	478.8
A		5S	0	10	277.8	708.4	515.8
A		5T	0	10	230.4	770.4	498.4
A		5U	0	10	319.2	802	503
A		6S	0	10	229.8	640.6	440.7
A		6T	0	10	263.4	776.6	434.4
A		6U	0	10	267.05	573	394.8
A		7S	0	10	276	670.2	460.2
A		7T	0	10	230.88	749.4	451.7
A		7U	0	10	251.7	721.9	475.55
A		8S	0	10	285	679.8	562.8
A		8T	0	10	294	797.1	513.4
A		8U	0	10	263.4	771.5	429
A		9S	0	10	254.5	616.4	387.5
A		9T	0	10	243.3	576	505.1
A		9U	0	10	295.2	612.3	435.2
A		10S	0	10	294.6	562	445.8
A		10T	0	10	255.6	695.05	406.8
A		10U	0	10	176.05	518.6	408.6
B		1S	0	10	288.6	820.4	501.6

B	1T	0	10	303	698.3	483.4
B	1U	0	10	274.25	885.4	543
B	2S	0	10	322.2	926.7	476.9
B	2T	0	10	338.4	793.4	507.4
B	2U	0	10	272.6	830.4	513.4
B	3S	0	9	213.333333	519.666667	448.666667
B	3T	0	10	202.2	536.2	373.2
B	3U	0	11	207.181818	537.363636	411.227273
B	4S	0	10	286.2	793.4	522.4
B	4T	0	10	195.15	613.6	490
B	4U	0	10	232.2	674	532.4
B	5S	0	10	284.4	888	569
B	5T	0	10	287.9	806.8	609.8
B	5U	0	10	152.85	770.5	500.3
B	6S	0	10	250.1	681.4	520.4
B	6T	0	10	245.4	776.6	554.85
B	6U	0	10	289.25	784.8	608.6
B	7S	0	10	260.3	792	501.166667
B	7T	0	10	223.3	764.6	556.6
B	7U	0	10	206.55	603.8	457.8
B	8S	0	10	290.2	931.8	541.8
B	8T	0	10	280.6	829.1	548
B	8U	0	10	249.76	804.7	573.8
B	9S	0	10	257.4	809.2	446.2
B	9T	0	10	230.2	774.2	549.7
B	9U	0	10	222.55	711.6	430.8
B	10S	0	10	251.35	828	501.2
B	10T	0	10	270.85	838	532.9
B	10U	0	10	249.05	840.8	530.9
C	1S	0	10	248	731.4	469.55
C	1T	0	10	261	590.8	474.2
C	1U	0	10	242.4	717	561.55
C	2S	0	10	220.4	628.4	459.4
C	2T	0	10	201.45	627	426.6

C	2U	0	10	225.6	745.6	458.4
C	3S	0	10	308.4	853.4	548.6
C	3T	0	10	242.4	823.1	445.6
C	3U	0	10	274.2	791.6	424.5
C	4S	0	10	243.95	754	453.2
C	4T	0	10	229.55	732.8	430.5
C	4U	0	10	274.2	837.2	452.4
C	5S	0	10	303.6	782	521.9
C	5T	0	10	235.4	779	489.2
C	5U	0	10	236.55	795.9	490.3
C	6S	0	10	243	865.6	456
C	6T	0	10	240	777	485.3
C	6U	0	10	239.4	708	503
C	7S	0	10	236.6	699.6	485.4
C	7T	0	10	237.65	803.5	438.25
C	7U	0	10	224	718.75	463.5
C	8S	0	10	282	851.4	495
C	8T	0	10	286.8	757.6	494.2
C	8U	0	10	215.25	803.2	473.4
C	9S	0	10	179.75	634	431.1
C	9T	0	10	268	629	468.8
C	9U	0	10	234.6	619.2	466.2
C	10S	0	10	306	749.1	506.3
C	10T	0	10	244.2	733.1	473.1
C	10U	0	10	325.8	677.7	508.2
D	1S	0	10	246.55	644	477
D	1T	0	10	317	651.4	486.7
D	1U	0	10	247	536.5	441.5
D	2S	0	10	282	706.5	442.5
D	2T	0	10	277	676	478
D	2U	0	10	314	686.5	474.5
D	3S	0	10	172	623.5	376.75
D	3T	0	10	297.5	721	389.5
D	3U	0	10	300	776	459.5

D	4S	0	10	223	762.5	495
D	4T	0	10	287.5	744.5	527.5
D	4U	0	10	241	703.5	461
D	5S	0	10	246	679.5	389
D	5T	0	10	256	612	467.5
D	5U	0	10	224.5	577.5	441.5
D	6S	0	10	214.7	798.8	444
D	6T	0	10	193.7	699.3	414.2
D	6U	0	10	246.35	719.2	400.2
D	7S	0	10	206.4	744.9	466
D	7T	0	10	339	917	381
D	7U	0	10	268.2	676.2	421.8
D	8S	0	10	253.25	851.7	478.6
D	8T	0	10	174.55	852.5	469.6
D	8U	0	10	211.7	852.8	468
D	9S	0	10	228.6	803.5	393.65
D	9T	0	10	210.8	683	449.1
D	9U	0	10	228	874.5	414.1
D	10S	0	10	267.4	825.5	477.3
D	10T	0	10	244.2	668.5	390.6
D	10U	0	10	334.8	762	455.45
E	1S	0	10	293.8	966.1	628.15
E	2T	0	10	315	974.1	600.3
E	2U	0	10	289.4	822.8	539.6
E	2S	0	10	217.1	707.7	447.8
E	2T	0	10	223.8	706.2	537.4
E	2U	0	10	221.4	715.8	525.75
E	3S	0	10	185.65	719.1	433.45
E	3T	0	10	195.6	859.4	516.35
E	3U	0	10	200.8	727	428.4
E	4S	0	10	289.2	902	500.55
E	4T	0	10	248.4	764.3	442.5
E	4U	0	10	278.75	934.3	519.5
E	5S	0	10	360.6	903.5	600.4

E	5T	0	10	351.6	880.2	593.5
E	5U	0	10	253.8	885	603
E	6S	0	10	300.55	858	587.8
E	6T	0	10	288.6	866.5	570.8
E	6U	0	10	272.4	771.1	570.4
E	7S	0	10	280.8	754.4	494.6
E	7T	0	10	301.2	838.6	510.9
E	7U	0	10	303	892	496.8
E	8S	0	10	240.6	777	535.6
E	8T	0	10	297.3	989	471.6
E	8U	0	10	282	822.3	513.9
E	9S	0	10	263.1	855.1	550.8
E	9T	0	10	276	860	522.9
E	9U	0	10	252	807.6	578.95
E	10S	0	10	264.6	896.2	524.4
E	10T	0	10	274.2	925.5	382.2
E	10U	0	10	263	892.2	613.6
F	1S	0	10	341.25	535.8	459.4
F	2T	0	10	324.6	486.9	455.1
F	2U	0	10	310.2	661.25	462.4
F	2S	0	10	219	547.1	419.4
F	2T	0	10	190.9	502.3	444.6
F	2U	0	10	196.8	502.3	377.8
F	3S	0	10	281.4	479.4	447.6
F	3T	0	10	285.6	481.2	468.7
F	3U	0	10	234.6	542.4	410.4
F	4S	0	10	223.2	663.8	551.6
F	4T	0	10	201	562.6	423.9
F	4U	0	10	238.2	564.6	472.8

Table A16 Mean and standard deviations of untransformed data

FIBRI_FORM VESSELS Mean and standard deviations (untransformed Data)

Habitat	Length		Diameter		Wall thick.	
	Mean	std.	Mean	std	Mean	std
A	404.975	97.1357	25.25803	5.434206	3.580878	1.087773
B	428.6184	110.3824	23.81125	5.116098	3.490833	1.094523
C	383.5135	79.61388	23.03323	4.75049	3.783678	1.015471
D	352.37	89.87605	28.08537	6.981039	4.407947	1.346586
E	433.3048	109.973	23.5052	5.200161	3.7129	1.103701

Prostrate Manuka Fibriform Vessels

(Untransformed Data : Means and standard deviations)

	Length	Diameter	Wall thick.
Mean	397.4684	19.04884	3.118632
Std.	105.5525	3.375623	0.426703

Means and standard deviations of untransformed Data of Libriform fibres

Habitat	Length		Width	
	Mean	std.	mean	
A	686.4517	157.9588	19.20988	
B	762.2167	172.4525	16.81877	
C	740.6779	142.2145	16.66191	
D	727.6767	158.0629	19.60416	
E	842.4333	164.2664	18.56663	
F	542.1525	116.6227	15.16265	

Habitat	Diameter	Wall. Thick.	
	std	mean	std
A	4.093696	6.379066	1.942798
B	3.051549	5.978282	1.446289
C	2.472242	5.769919	1.837353
D	4.305981	6.384653	1.904955
E	3.695022	6.201384	1.882831
F	2.482968	4.689593	1.441895

Mean and standard deviations of untransformed data of manuka for Fibre-tracheids

Habitat	Length		Diameter		Wall thick.	
	mean	std	Mean	std	mean	std
A	467.4583	97.4288	21.33727	4.356179	3.865519	1.192372
B	511.1555	109.0228	18.80241	3.505097	3.714209	1.0679
C	475.1997	86.52998	18.15138	3.011378	3.957247	1.168955
D	444.3683	99.58437	22.07443	4.195796	4.708457	1.368576
E	529.729	121.4992	19.76783	3.71688	4.079814	1.160917

Prostrate manuka fibre-tracheids

length		Diameter		Wall thick.	
mean	std	mean	std	Mean	std
449.475	78.05352	16.5415	3.239619	3.936201	2.071442

Area of perforation plate of wide vessels

Habitat	Area	
	Mean	Std.
A	870.1931	422.0706
B	1081.154	992.7976
C	975.5727	613.8837
D	846.5355	514.949
E	1136.176	428.3617

WIDE VESSELS

Habitat	length		Diameter		Wall.thick		Abund.	
	mean	std.	mean	std.	Mean	Std.	Mean	Std.
A	255.096	74.96697	61.58297	19.07657	4.137387	1.369406	66.59667	27.94477
B	254.557	80.33123	63.5445	15.15822	4.436134	1.337653	65.61667	32.20715
C	250.3383	73.35368	61.09777	14.82175	4.814853	1.261838	52.47667	17.28289
D	251.7567	84.20349	68.87443	18.15663	4.966401	1.461143	60.03333	23.28647
E	269.475	88.04441	67.0984	17.47453	4.977416	1.5623	54.88	19.49888

Prostrate Manuka. Wide vessels (untransformed data)

	Length	Diameter	Wall thick.	Abund.
Mean	253.8958	46.19908	3.853955	129.9417
Std.	85.07443	12.23559	1.27153	36.09704

Note: Symbols used in the Tables

DF = degree of freedom, SS = sum of squares

LMEAN = mean length, LMAX = length maximum, LQ3 = length upper quartile, LQ1 = Length lower quartile, LMEAN = Length mean, WMEAN = Width MEAN, WMAX = Width maximum value, WQ3= width upper quartile, WQ1 = width lower quartile, Wmin = width mean, WtMEAn =wall thickness mean, WTMAX = Wall thickness maximum, WTQ3 = wall thickness upper quartile, WTQ1= Wall thickness lower quartile, WTMIN = wall thickness minimum, AMEAN = Abundance mean, AMAX= Abundance maximum, AQ3 = Abundance upper quartile, AQ1 = Abundance lower quartile, AMIN = Abundance minimum value

FREQ = Frequency, WV = wide vessels, FV= fibriform vessels, LF = Libriform fibres, FT= Fibre-tracheids

Wall thick. = Wall thickness

Abund. = Abundance

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