STUDIES ON THE CONSERVATION OF WATERLOGGED WOOD IN NEW ZEALAND

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So many highly interesting and well preserved wooden artefacts have been found in swamps that it is slowly dawning on us that our swamps are the best museums we have on this island and that *Hine-i-te-Hutu*, the swamp maid, is a more efficient curator than some upper world museums possess.
(Elsdon Best, 1925:26)

ABSTRACT

This thesis is a study of properties of certain New Zealand woods recovered from waterlogged environments. The woods are those which were commonly used by the pre-european Maori to make artefacts, and the properties are those which affect the way these artefacts can be conserved after they have been removed from wet archaeological sites.

The properties studied were (a) the species of wood used (b) the forms and shapes of the timbers (c) the densities (d) directional shrinkages, and (e) directional penetrabilities of each wood. The results of this research are intended to aid conservators to correctly treat the artefacts.

The research began with studies of (a) New Zealand wet site archaeology, (b) the structure and properties of wood in general, and (c) the techniques used to conserve waterlogged wood worldwide.

This was followed by a survey of circa. 1000 wooden Maori artefacts from Museums involving the identification, by thin section microscopy, of wood species. 30 wood types from 22 tree species were found to have been widely used. A collection was made of samples of each type in different states of decay.

Each sample was tested for density, directional shrinkage and directional penetrability.

The penetrability was measured by vacuum impregnation of water into wood blocks. Results were compared to those from sound oak (Quercus robur), a wood which has been studied intensively by conservators in Europe.

Detailed summaries of the conservation properties of 26 wood types are given. This reveals that while some New Zealand woods are easy to conserve others provide considerable problems. The latter woods are all highly durable in wet sites, extremely dense, have high shrinkages and are highly impenetrable. These will require special types of treatment to avoid damage during conservation.

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CHAPTER ONE

AIMS AND OBJECTIVES

PREAMBLE

The last twenty years have seen a remarkable expansion in the number and sizes of the art galleries, museums, archives, etc. in this country. Despite the valuable work these institutions were doing, professional people employed there had, by the late 1970's, concluded that there was one serious deficiency in the field. This was the serious lack of conservation work. It was felt that it was wrong to collect and store cultural property without being able to prevent, control or reverse its deterioration.

This problem was presented to central government since the financial resources needed to solve it were beyond the capacities of the institutions concerned. Through the offices of the then Minister of Arts (Mr Alan Highet) a major effort was begun to recruit and train local people in this field, to establish proper facilities in the institutions concerned, and to provide salaried positions for conservators.

In 1978 the Minister for the Arts, through his Advisory Committee on Art Galleries and Museums,

called for applications for the funding of projects in the conservation field. At that time the Waikato Art Museum had a serious problem involving very large quantities of waterlogged wooden Maori artefacts that had recently been excavated from a local swamp by a staff member, Mr Steve Edson. The Museum Director, Mr Ken Gorbey, along with Edson, drafted a proposal to the committee for someone to do some work on their problem. This proposal was agreed to and in November of that year Gorbey and Edson, along with Professor Roger Green and Mr Karel Peters of the Anthropology Department, Auckland University, met Mr R. Cator of the Department of Internal Affairs to draft a detailed proposal.

The proposal that resulted from the above meeting was that a student would be located at the Chemistry Department, Waikato University, to work on a doctoral dissertation on the topic of waterlogged wood conservation problems of New Zealand with the financial support of Internal Affairs.

The broad objectives of the work were formulated as follows:

The basic aim is to determine what properties are peculiar to New Zealand woods recovered from anaerobic environments. This will lead to recommendations as to the use or adaptation of known conservation methods or perhaps the evolution of new methods for the preservation of wooden artefacts recovered from swamps.
(Correspondence from Waikato University, 1979).

Within this broad framework it was suggested;

Among the detailed problems for study are:

(i) wood recognition and identification procedures

(ii) a survey of Maori-utilised woods and their preservation properties

(iii) for at least the main timber types, to examine the change in properties as a function of time and location of burial, including an extended time scale to pre-Maori sub-fossil samples

(iv) the behaviour of different classes of wood on removal from the swamp environment, both sound and degraded samples (this may include a survey of museum and other specimens from earlier excavations and finds)

(v) the examination of reported preservation techniques from simple drying to in situ polymerization to reinforce degraded timber

(vi) the adaptation of the most suitable methods to New Zealand specimens

(vii) possibly the evolution of new or strongly modified methods (ibid.).

The joint supervisors of the project were to be: Dr K. Mackay, Chemistry Department, Waikato University; Dr J. Harris, Deputy Director, Forest Products Division, Forest Research Institute, Rotorua and Prof. R. Green of the Anthropology Department, Auckland University. The above people were also members of an advisory committee that included Mr K. Gorbey of the Waikato Art Museum, Mr K. Peters of the Anthropology Department, Auckland University and Mr J. Fry, Conservator at the National Museum, Wellington. This committee was formed to advise the research worker on ethical and museological issues involved in the preservation of artefacts and to generally advise and support the scholar.

The topic was further characterized as an interdisciplinary one involving aspects of wood biology, chemistry and archaeology with the exact line to be followed depending on the scholar's previous experience and training.

The scholarship was advertised in 1978 and this writer was the successful applicant, taking up the position in July 1979. In preliminary discussions it was acknowledged that the scholar would concentrate on a sub set of the problems described in the brief. The author's background made it appropriate to focus on archaeology and wood biology aspects and to leave more chemical studies for future consideration.

DEFINING THE TOPIC

After an initial survey of the wood conservation literature to provide familiarization with the field, discussions were held between the writer and Mr Karel Peters who was then the only person in New Zealand with wet wood conservation experience. It was agreed that although the techniques of conservation used here are similar to those used overseas, our woods are very different. Mr Peters had many experiences of artefacts which inexplicably 'failed' when being conserved by methods which he had used with great success previously. He felt that certain New Zealand woods might be difficult to conserve and that until more was known of their properties, attempts at conservation might damage valuable artefacts.

It was decided, therefore, to study selected properties of relevant New Zealand woods to discover which of the latter might cause problems during conservation and to define each wood type in terms useful to the conservator.

PAST RESEARCH

In making its central concern a study of the properties of wet wood, this research has few direct parallels with studies done overseas. Until very recently research in wet wood conservation has concentrated on largely empirical studies of methods and materials.

A variety of approaches have been taken. Individual techniques have been studied (e.g. Bryce et. al., 1975; Jespersen, 1982; or Ambrose, 1976). Conservation histories of specific artefacts have been given (e.g. Biek et. al., 1958; Blackshaw, 1974; or Bright, 1979). Studies have been made comparing the results of different techniques on the same woods (e.g. Gratton, 1982; Schweingruber, 1982). The actual materials used have been examined (e.g. Brownstein, 1982). Equipment used has been described (e.g. Alagna, 1977, or Murdock, 1978). Storage, handling and labelling of artefacts has been studied (e.g. Dawson et. al., 1982; Powell and Wilkie, 1976).

The amount of research on the actual properties of wood has been limited. Microscopic and chemical investigations have been made (e.g. Florian, 1977 and 1981; Hoffman, 1982). These studies indirectly relate to how woods behave during different conservation treatments.

Closer to our problem is the work of Young and Wainwright (1982) who studied conservation processes at the cellular and intracell wall level.

The past research which has come closest to resembling the present research approach is that of Christensen (1970). During a major conservation project he struck problems caused by the properties of one particular wood, oak heart wood. This timber, when sound, seemed to resist penetration by the consolidants being used. He then initiated a research effort to determine the cause by studying the wood's properties.

A similar, if somewhat more superficial, piece of research was undertaken in Canada (Grosso, 1976) for similar reasons, though in this case the cause of conservation failure was oil impregnation before burial.

RESEARCH AIMS

The aim of this research was to produce a classification of New Zealand woods using the properties that affect conservation. It is intended that this will be used by conservators as an aid to selection of conservation treatments.

The strategy was to elaborate Christensen's research methods and to apply them to all New Zealand woods commonly used by the pre-European Maori. These woods came from a flora that is isolated and endemic. It is related, in part, to archaic southern hemisphere floras in Australia, South America and South Africa and, in part, to more recent (angiosperm) floras of tropical areas to the north, in Melanesia and South East Asia. The woods bear little or no resemblance to those of Northern Hemisphere temperate latitudes where most previous work has been done.

THE NATURE OF WATERLOGGED WOOD

When we discuss waterlogged wood we are dealing with, not one, but a whole series of quite different materials. When wood decays it is converted from one substance into another, from wood as we use it in our daily lives to a form of peat. As wood decays it also progressively loses those properties that once characterized its species and type. It is generally true that highly degraded wet wood is much the same material everywhere with variation mostly being due to different conditions existing during burial. There is, therefore, nothing unique about the properties of highly degraded New Zealand swamp wood except the species it originally derived from.

Overseas experience has shown that it is the sound wood in waterlogged artefacts that is the most difficult to conserve not the degraded wood (e.g. Barkman, 1976:50). This is because some woods have properties, usually their impenetrability to consolidants, which inhibit conservation and these are lost during degradation.

RELEVANT WOOD PROPERTIES

Wood has two types of properties which are relevant to this research. The first are those which led to their use by the pre-European Maori for artefact manufacture. The second are those which affect how we can conserve those artefacts today.

Usage properties included the species of tree involved and the form and nature of wood that was obtained from it. This research must supply a list of the wood species commonly used by the pre-European Maori, the form of the wood used and the type of artefact made from each.

This information can only be collected by conducting a survey of museum collections of wooden artefacts, identifying the species of wood used, and recording the size, shape and anatomical origin (e.g. branchwood, whole stems, planks cut from trunks etc.) of each.

Conservation properties involve such things as the durability of the wood in wet sites, the penetrability of wood in various states of decay, the woods density

and natural shrinkage. An examination of overseas literature on wood conservation suggests that it is the penetrability of sound wood which most affects conservation. Where highly impenetrable wood occurs in artefacts severe conservation difficulties arise due to the failure of consolidants to enter (e.g. Christensen, 1970:49). Identifying such New Zealand woods is obviously a main concern of this research.

Decay rapidly increases penetrability in wood and identifying which New Zealand timbers are durable in wet sites and, therefore, will occur in a sound state is important. This research can be done by examining the state of decay of wood of artefacts in museum collections.

Conservation treatments usually involve controlling or halting the dimensional changes which occur when wood dries. In sound wood these changes are reversible and are called shrinkage. Shrinkage in wood increases with increasing wood density. Measuring the normal density and shrinkage of timbers would, therefore, aid the conservator to anticipate the behaviour of wood to be treated and is a property this research will document.

Density of swamp wood can be related to the degree of decay. Given the average density of sound wood one can estimate the amount the swamp wood has lost to degradation (Barkman, 1976:50).

To summarise, durability, density, shrinkage and penetrability are the relevant conservation properties of wood. When conserving an artefact, comparisons between these values for sound and artefact wood can be used to (a) judge the likelihood that sound wood is present; (b) estimate the degree of decay that may have occurred; (c) predict the dimensional changes the wood will undergo on drying; and (d) predict what materials may be introduced to the wood to control those changes.

DATA COLLECTION STRATEGIES

When studying the properties of woods used by the pre-European Maori, two approaches might be adopted. The first could be called the intensive approach and is typical in wood industry research. The second is a more general and wide one and is, it is felt, more appropriate here.

The intensive approach involves the selection of a few of the relevant wood types and the collection of a large number of samples of each. These would be subjected to numerous measurements of their properties designed to produce highly accurate, reproduceable and statistically valid results. This would produce a large body of highly accurate data concerning a small number of wood types.

The second approach would be to collect a small number of samples of wood from all species and types of wood used by the pre-European Maori and perform a limited number of tests on each. One would expect to produce broad (if less accurate and precise) generalizations that would describe the peculiarities of all relevant woods.

In choosing between the detailed but narrow, and the less precise but broad approach, it is necessary to consider the nature of the problem faced. Wood is highly variable in its structure and properties. It can have a complex grain that twists, curls around knots and follows other irregularities in the tree. The density, shrinkage and penetrability of timber can change drastically over short distances within pieces of timber. In the timber industry wood is used in a regular and rather limited way. Sawn timber is cut only from straight grained large diameter trunks with roots, stumps and branches being discarded. Efforts are made to exclude unusual or a typical wood and to produce as uniform a product as possible.

For the above reasons research in the forest industry tends to follow the first approach as their product possesses sufficient homogeneity to make this possible.

The pre-European Maori used wood in a quite different manner. Small amounts of wood were used and each piece was selected individually. While straight grained trunk wood might have been selected for some

purposes (e.g. canoes, carved panels or building timbers) the majority of small and medium sized artefacts would have been made from stems, branches or forked pieces selected to suit a specific purpose. Where a dense wood was required, a piece might have been selected that was the heaviest to be found and, thus, atypical of the species as a whole. The result of Maori selection practices was that large numbers of species were used but in only small amounts and atypical wood was selected for.

Another major cause of variability in wood of artefacts is decay processes that occur during burial. These processes will have occurred in response to environmental conditions undergone and will differ considerably between otherwise similar artefacts and, thus, cannot be predicted in advance.

These considerations suggest that the broader approach is more appropriate in this case. It was felt better to produce general conclusions regarding all the relevant woods than to aim at higher accuracy based on large samples.

The time available would have limited the other approach to only a few wood types and it was not clear if highly accurate measurements have any practical value to conservators of real artefacts.

THESIS OUTLINE

The research done in this project is described in seven chapters whose contents are outlined below.

Chapter Two describes wet site archaeology in New Zealand. A short account of the origins and material culture of the prehistoric Maori is followed by descriptions of the types of sites where wooden artefacts and other organic remains can be preserved. The contents of representative examples of these sites are then discussed and the chapter concludes with an account of the general conservation needs that wet site archaeology will generate in the forseeable future in New Zealand.

Chapter Three concerns the properties of wood. It describes wood from the point of view of both composition and structure. It covers the dynamics of wood behaviour particularly its reactions to water and describes the processes of decay which can occur, especially in wet environments.

Chapter Four concerns waterlogged wood conservation. The ethics of the subject are discussed, followed by

an account of various pre-treatment processes that have been tried. A short history of the subject is given followed by detailed descriptions of methods and techniques developed to date.

Chapter Five concerns research designed to discover how the pre-European Maori selected wood to make artefacts, which woods were used and the collection of samples of each of these woods for use in other parts of this study. It describes a survey of wooden artefacts held in Museum collections which involved the identification of wood species and type of over a thousand items. The species and types of wood and their frequency is then listed. An account will then be provided of the collection of examples of each wood type.

Chapter Six concerns the measurement of the density and directional shrinkage of each of the wood samples mentioned above followed by an analysis of the results.

Chapter Seven concerns the measurement of the directional penetrability of the wood samples and an analysis of the results.

Chapter Eight is a synthesis of the results of the research dealing with each wood type in turn. The chapter concludes with a grouping of New Zealand woods into classes on the basis of their conservation properties and suggests approaches conservators might take to them.

The text of this thesis will be concluded with a short conclusion and recommendation section which will assess the work done in this study and point to possible future work in this field.

CHAPTER TWO

WET SITE ARCHAEOLOGY IN NEW ZEALAND

INTRODUCTION

This chapter will attempt to place the conservation of waterlogged wood within the framework of New Zealand archaeology. It will begin by describing Polynesian material culture with particular reference to the role played by wood and other normally biodegradable materials. This will be followed by a discussion of the nature of the New Zealand archaeological record and the extent to which these materials have figured in it up to the present time. The types of sites where objects of wood and fibre can be expected to be found intact will then be described and attention will be drawn to selected sites that have yielded wooden artefacts as a result of excavation or collection. Current and future archaeological work involving wet sites will then be considered together with the conservation needs this activity will generate. The chapter will be concluded with a consideration of the extraordinarily valuable resource that these wet sites represent and the critical role that conservation will play if their

contents are to be recovered and preserved for study and display in museums. More than any other type of artefact, wooden carvings have the capacity to enrich the museum collection of this country and to attract maximum public interest.

POLYNESIAN MATERIAL CULTURE

The arrival of the ancestors of the modern Maori in New Zealand over one thousand years ago was a culmination of a process of discovery and settlement of the islands that are scattered over the face of the world's largest ocean, the Pacific. Oceania, as these islands are known, had previously shared with Antarctica the dubious distinction of being the last major sector of the earths' surface to be occupied by the human race. *Homo erectus* had occupied the Java region during the Pleistocene era and some of the earliest examples of modern man had made their way to New Guinea and Australia by at least 50,000 years ago (White and Allen 1980:730). Despite this, the islands of the open Pacific remained out of the reach of man until a much later date. This situation continued until the arrival, or local development, of an elaborate maritime technology that allowed people to live off, and cross, open seas, and horticultural

systems to intensify food production on the limited areas of land available on the small islands of this area.

While there is some evidence that the early inhabitants of the New Guinea region had developed their own horticultural systems at an early date (Bellwood 1979:11) it was the emergence of a new cultural complex in Northern Melanesia, clearly owing much in its language, its plant foods and animal domesticates, its technology and its sea voyaging abilities to eastern Island South East Asia, which allowed human settlement to spread across the Pacific to New Zealand (Green, 1979:45). The people involved are often named 'Austronesian'(Bellwood 1979:24) and their initial spread outward involved a culture named 'Lapita' whose sites date to 1600-500 B.C. (Green 1979:34), indicating that Maori culture has had behind it at least 3600 years of cultural development within the environment of the islands of the open Pacific.

One of the many distinctive features of the prehistoric Oceanic cultures was the complete absence of metals. Their tools were of stone, shell, wood and fibre. This Neolithic technology was, however, no barrier to the development of highly complex

material cultures, with houses, canoes, fortifications and religious structures being some of the most spectacular found anywhere in the world, not the least because of their highly developed and elaborate ornamentation.

Though few in numbers, compared to other peoples met by the European explorers during the age of European expansion, the Polynesians have had a great impact on the minds of Westerners. They were often described in heroic or utopian terms, perhaps due to their locations on remote and often beautiful islands scattered over the great ocean and to the attractiveness of the people and their material cultures (Jennings 1979:1). Portable items of their culture are familiar sights in museums all over the world, often overshadowing those from more populous cultures.

When viewing Polynesian manufactured items, one is struck by the fact that it is dominated by items made of wood; stone being mostly used for very small objects except on a few atypical islands such as Easter Island. The skill of Polynesian wood working, as shown in their houses, canoes and statues, is justly world famous. To study their material culture

without considering wooden objects would result in an entirely unsatisfactory appreciation of their achievements. Unfortunately, for most prehistoric Polynesian cultures this is precisely what we are forced to do since items made from wood or other readily biodegradable materials rarely survive in archaeological sites.

THE NEW ZEALAND ARCHAEOLOGICAL RECORD

To Polynesians accustomed to their small tropical islands, New Zealand's large, temperate landmass must have been a strikingly different environment. One of the most notable features of this new land must have been its vast forests of huge trees. It is scarcely surprising then that Maori material culture is dominated by the use of wood almost to the exclusion of other available materials. Stone, for example, was only very rarely used as a building material, a few stone buttressed banks being the exception. As a medium for free standing statues it was used even less often and in house building it was avoided altogether. In short, wood was the primary raw material for prehistoric Maori culture.

Maori wood working was characterised by a degree of skill and artistry for which it is world famous. Their canoes, house and store house panels, weapons and storage containers are rightly regarded as works of art. The Maori wood working tradition that we are most familiar with is that of the recent past, first observed by the early explorers and still practised, to some extent, even today. This tradition has clearly had a long history of development inside the country since the styles used now are very different from those of other Polynesian cultures.

To a great extent, our knowledge of prehistoric Maori culture is based on archaeology. The archaeological record is made up of the material remains of past cultures that have survived the natural forces of decay. Up to the present time these remains have only rarely produced substantial amounts of wooden artefacts. As a consequence, our knowledge of prehistoric Maori culture has been peculiarly slanted in favour of stone, bone and shell artefacts. These latter materials had, quite probably, a rather lesser place in Maori technology and disappeared rapidly on the arrival of European trade goods. The odd situation has arisen whereby we know a great deal about prehistoric stone, bone and shell working

from archaeological studies yet there have been few, if any, observations of craftsmen actually making items of these materials. Conversely, little is known about prehistoric wood working yet we can observe modern craftsmen reproducing the styles and methods that have direct roots in the prehistoric era. There may be little we can do about the absence of modern shell, stone and bone working techniques but we can do a great deal about our lack of knowledge of prehistoric wood working if the appropriate archaeological strategies are adopted.

While artefacts of biodegradable materials are rarely found they do occasionally turn up from dry caves, waterlogged soils and peats, and from lakes, rivers and estuaries. Many museums have collections of wooden artefacts obtained from these sources, though most are undated and have few cultural associations. Systematic archaeology in wet sites in this country since 1968 has brought about the realisation that these sites represent an enormously rich source of information about the prehistoric past.

New Zealand is fortunate in that its moist, temperate climate allows the development of abundant waterlogged deposits where artefacts made from wood,

fibre etc. would survive if they had entered. Dry caves are less numerous and most have already been discovered, though in some remote areas, e.g., Fiordland, finds are still to be made.

Wet sites have not attracted their due attention in the past for a number of reasons. One is that they can be very difficult to locate, being buried in often featureless boggy deposits. An example of this difficulty is shown by the Kauri Point site on Tauranga Harbour. Here, during the excavation of a small Pa site, the small boggy stream bed alongside was systematically searched for sites by probing with a kauri gum spear (Shawcross, 1962). The survey revealed the existence of a cultural deposit which will be described, in detail, below. Such small areas of wet ground are common near dry archaeological sites but have only rarely been examined for the existence of cultural material by archaeologists.

There are at least two reasons for the above lack of interest, apart from simple ignorance of their possible existence or value. The first is that they are difficult and uncomfortable to excavate. Artefacts that may be found are often highly degraded and will virtually self destruct if dried

without the application of expensive and time consuming conservation treatments. Such treatments have only recently become available and in the past the wood was either dried without treatment or subjected to various (often destructive) processes fondly thought to have preservative attributes. Many collections of wooden artefacts in museums consist of those items that are rugged enough to have survived these events.

Two approaches to the above problem seem to have been adopted by professional archaeologists in the last twenty years. The first has been to proceed with wet site excavation in the hope that the material recovered would be able to be conserved in the future when trained staff and adequate facilities became available. In the meantime, the material was placed in plastic bags or water storage tanks until it could be dealt with adequately. The theory seems to have been that the staff and facilities would only be made available when it was demonstrated that an immediate need for them existed. This was the approach taken during the first systematic excavation of wet sites in New Zealand, at Kauri Point (Shawcross 1976) and at Lake Mangakaware (Bellwood 1978b). The result of

this approach has, indeed, been the training of a staff member of Auckland University, Anthropology Department and the provision of some facilities for conservation.

The 'dig first and conserve later' approach inevitably accompanies salvage archaeology in wet sites. These excavations occur when the material in the sites is in immediate danger of destruction. Recent examples of this type of an archaeological activity were at Kohika (Irwin 1975) and Te Miro (Edson 1979).

A second approach has been to establish conservation facilities and to train staff in the field before embarking on any wet site archaeology. This approach can occur where salvage digs are not imminent and where research archaeology is the primary objective. This has been the strategy of the Anthropology Department at Otago University, Dunedin.

The emergence of salvage archaeology in the last ten years has been the result of an increasing awareness of the value of our cultural resources. Another consequence of this awareness has been the establishment of public archaeology in the development

of an Archaeology Section of the New Zealand Historic Places Trust. Wet site archaeology may now become a regular feature of the field in New Zealand due to the high status certain to be given to these sites ensuring that the recovery of their contents is likely if they are under threat of damage or destruction.

A consequence of the above developments in local archaeology is that the facilities available for the conservation of waterlogged wooden finds have been greatly overtaxed. Furthermore, conservation work that has been completed to date has brought about the realisation that the success or failure of a particular method in a particular circumstance is controlled by the type and condition of the wood involved and that until some basic research is done on local woods and conditions conservation will remain an unscientific and uncertain affair. This realisation led directly to the establishment of this research project in 1978.

NEW ZEALAND WET SITES

It would be unusual to find an archaeological site in this country further than 100 metres from a body of water or a patch of waterlogged ground. Wet

sites can be found in many different types of waterlogged deposits. These include lakes, slow flowing streams, the margins of rivers, tidal mud flats, springs, the sea bed and various types of waterlogged soil and peat.

One reason for the proximity of the sites to water was the strong part played by aquatic activities in the subsistence and settlement patterns of the prehistoric Maori. Above all, they were boatmen and fishermen who rarely lived from from a navigible body of water. Where defense was not a factor, their habitations were often located at the waters edge and their daily activities would have included working on or around water. Sites were often located on islands in the sea, in rivers, in lakes and in swamps. Some of these were even man-made.

Another very important factor in the creation of wet sites in this country was the habit of the prehistoric Maori of storing wooden artefacts in water. They were well aware of the preservative properties of waterlogging to judge from the numbers of apparently deliberate caches of objects that have been found (eg., Duff, 1961). The swelling and softening effects of waterlogging on wood may also have been appreciated and used where this

improved the properties of the artefacts. Waterlogging increases the weight of dry wood by 50 - 70%, an important feature in such artefacts as digging sticks, mauls and mallets etc. where weight is an advantage. Lastly, burial in wet ground was a very effective means of hiding valuable items since they were safe from all except those who knew precisely where they had been put.

Many artefact types were used wet and never dried out during their useful life. Examples of these could be bowls and other hollow artefacts that had to be watertight. Drying tends to cause cracks thus making the object unsuitable for holding liquids. Canoes were kept damp for the same reasons, either being stored in shady places on land or being sunk in shallow water. Canoe sheds were constructed for larger vessels, their purpose being to keep the sun off, not the rain!

Canoes sunk in rivers and lakes are quite common in many parts of the country, sometimes in remarkable numbers. They often occur in bodies of water where the only access for them would have been overland. Canoes would have been constructed on the spot, used, and sunk in an identifiable place for later recovery and use. Any new group, wishing to use the lake,

for birding, eeling etc., would have to construct their own canoe which would also be added to the lake's contents. Such canoes have accumulated in certain lakes, for example, in the central Waikato basin. These tend to be small bodies of water formed at the edges of the peat domes common in that area. At least three canoes are known from Lake Mangakaware, which covers only about 6 ha. (Bellwood 1978b), and four have recently been reported from the nearby Lake Maratoto (S. Edson, pers. comm.). Even the tiny man-made pond behind the causeway at the Te Miro site (see below) contained one canoe (Edson 1976). Lakes all over the country contain canoes and several a year are found, only to be reported in local newspapers and then forgotten. They represent a problem that can be temporarily shelved since the best current advice one could give is to 'push them in deeper and record the spot'.

Horticultural implements, *ko* (digging sticks), *ketu* (paddle shaped weeders), *hoko* (spade-like implements) and *kaheru* (composite shovel-like tools) were often stored by thrusting them down into boggy ground. Caches of these tools have often been found in the northern part of the North Island, mostly in small patches of wet ground near good garden

soils. These caches were probably the main source of the horticultural implements held in museums.

Several of the above caches have been found and investigated archaeologically. These include a series of small ones located during the Waitara swamp search (Duff 1961). A more recent discovery was made in a Hamilton suburb and has given us a good picture of such sites. It was located in a narrow strip of boggy soil that ran alongside a small stream which was deeply cut into the terraces of the Waikato river. It was within the built up area of the city, on a section comprising the house on the bank above the stream and the vegetable garden at the bottom, on the stream margin. The owner had discovered the cache while preparing his potato patch. The artefacts were all found within a few square metres, at the end of a buried fallen tree trunk. This trunk would have spanned the stream and is thought to have formed a bridge on a track from a small *pa* on a nearby spur to the horticultural soils on the lower river terraces (S. Edson, pers. comm.). The cache held: one *kaheru* blade; three *kaheru* shafts; one *ko* ; two *teka* (*ko* footrests); nine *ketu*; one *hoko* as well as a *hinaki* (eel trap); an adze; a house door slab; many bundles of lashing

vine and, finally, a fine carved *pataka paepae* (S. Edson, ms.).

The above horticultural implements had been thrust down into the peaty soil close together with the other artefacts nearby. Although it was primarily a cache of gardening tools, its status and location must have been reasonably well established for it to have been used to store the more valuable items. Another notable point is that it was not in what would normally be described as a swamp; the area of wet ground being too small to appear on any map.

At Lake Mangakaware, in the Waikato, an entirely different type of waterlogged site was discovered and excavated (Bellwood, 1978b). A small fortified village had been built on a small promontory on the edge of the lake. On the lake side the palisades were set out into the water, and on the inland side into boggy ground. As a consequence, the post butts have been preserved and are still visible today. Occupation debris from the village accumulated in the shallows of the lake, including many wooden artefacts and discarded building timbers. Many of these were recovered by divers who groped around in the soft lake bed mud. The cultural

deposit had accumulated in the unplanned and casual way that middens do, containing broken and lost items. Its contents have provided an important view of the types and forms of timbers used in normal prehistoric domestic architecture.

The building of man-made islands in swamps as village and *pa* sites was a feature of many low-lying areas of the North Island in the later prehistoric period (Bellwood 1978a:410). With the draining of these areas for agricultural purposes in recent times many of these sites have either been destroyed or dried out so that the wooden and other biodegradable artefacts have been destroyed. Those sites that remain intact are often under threat from continuing drainage works. One such site was at Kohika in the Bay of Plenty.

The Kohika site was excavated in a salvage operation, producing many wooden artefacts and huge quantities of worked timber that had been used as part of the foundations of the island. The site contained all the items that would be associated with a village community including a full range of domestic artefacts (Irwin 1975, Moore 1975).

Estuarine environments offer good possibilities for the discovery of waterlogged artefacts or sites. The mangrove flats of Whangarei Harbour have yielded a rich assemblage of wooden artefacts to a local resident who made periodic searches of the eroding edges of the small islands that are numerous there (Barry Keene, pers. comm.). Such islands were popular places for the prehistoric inhabitants to judge from the surface scatters of cooking and other occupation debris (G. Nevin, pers. comm.). The people who had lived there had lost, or deliberately stored, wooden artefacts in the estuarine muds where they can be found today.

Some sites are of an unexpected or unique nature. At Kauri Point on the Tauranga Harbour a search of a swampy stream margin beside a *pa* site that was under excavation revealed just such an unusual site. It consisted of a small platform, made from discarded horticultural implements, carvings, palisade posts and brushwood, extending out into the wet ground. It had been used as the repository for ritually damaged and discarded items, primarily wooden hair combs and obsidian chips. A wide range of other small valuable items were also present though in low numbers (Shawcross 1976). This site yielded an

extraordinarily rich assemblage of artefacts of types not normally seen even in wet sites. It included over one hundred wooden hair combs, which increased the number of such items in museum collections by a factor of at least ten.

Sites containing very valuable house panel carvings have turned up in Taranaki where a whole series have been found over the last thirty years (Duff 1961). The deliberate burial of the house and *pataka* panels may have been done as a response to threats of war, the swamps being a place of safekeeping. These items turn up from time to time as the result of ditch digging and other agricultural activities.

Complex, multi-purpose sites have been found. An example of this type is the Te Miro site near Cambridge in the Waikato. Here, in the mid 1800's, the Ngati Haua, under the leadership of Wiremu Tamahana, established model agricultural settlements in response to missionary influence. During this time, the first feature of the wet site, a causeway to carry a trackway across a small stream, was built. The causeway created a small pond behind it which was then used in the following period for eeling and perhaps, fowling. Later, during the late 1890's, the local

settlement became the focus for the King Movement and a Maori 'Parliament House' was built, called the *Kahunganui*. The village was later abandoned and the parliament house damaged in a European settler's scrub fire. The owners then returned, collected the remains of the building, and buried them in a nearby swamp. This swamp turned out to be the now sediment infilled causeway pond (Edson, 1979).

The excavations at Te Miro, started in response to a farmer's drainage operations that threatened to destroy the site, revealed three stages of occupation. The first included a causeway, as well as the tools used in its construction and the remains of the vegetation cleared to make way for it. The second stage involved eeling and was represented by eel clubs and a canoe. The third stage involved the deliberate burial of the timbers of the *Kahunganui* as well as a wide range of domestic artefacts such as household utensils, toys etc. that showed a curious mixture of traditional Maori and European forms.

The Te Miro site proved to be very rich in a variety of, often unique, artefact types as well as the remains of a meeting house that was of some

considerable historical importance in this country. There were successors to the first *Kahunganui*, and, in fact, the present one was being restored at the time of the excavations. The excavation was also of some relevance to this research project since the material recovered so overtaxed the conservation resources of the country that it was decided that some basic research needed to be done to establish wood conservation on a sounder basis.

A common location for wet sites in this country is the swamps in coastal dunes. One such site was at Waitore in southern Taranaki. This site is a deposit of peaty clays at the back of a coastal dune that is being eroded by a small stream. Artefacts from what had been a 15th century A.D. fishing camp have been eroding out and have been collected by local residents and also recovered by formal archaeological excavation (Cassels 1979). Artefacts include what appears to be parts of an outrigger canoe as well as other more mundane items associated with the camp. The Waitore assemblage is currently the earliest securely dated collection of wooden artefacts in the country (Lawler 1979:109).

A similar site type has been located at Jacksons Bay in South Westland. It was discovered by road workers during bulldozing. The material was passed to the West Coast Historical Museum at Hokitika then sent to the Otago University, Anthropology Department where this writer was involved in its conservation. The collection includes parts of what appears to be an outrigger canoe of some structural complexity as well as a variety of other domestic artefacts and fishing gear.

The final site type is the European era shipwreck. There are many shipwrecks on our coasts and even in our lakes that may be of some historical interest. An example of this might be the remains of two whale boats that are in Lake Waikaremoana. These were built by European settlers at the time of Te Kooti's insurrection and have attracted the interest of the Waiouru Military Museum.

FUTURE NEEDS IN WET SITE WOOD CONSERVATION

Artefacts from wet sites in New Zealand can be classified into several classes in terms of their origin. Artefacts that require the most urgent attention are those that constantly trickle into local museums. These items have usually been

discovered by members of the general public and pose an insoluble problem to museum staff who have neither the training nor the facilities to adequately deal with the material. All that they can do is place the artefacts in tanks to await someone who can take the problem off their hands though the artefacts are of sound wood it is often possible for museum staff to undertake slow drying techniques.

In the past some museum staff have attempted to conserve waterlogged wooden artefacts with rather mixed results. At Taranaki Museum it had been the custom to treat artefacts with a mixture of linseed oil and a solvent. This treatment has had the ultimate effect, on sound items, of slightly increasing shrinkage compared to what it would have been if no treatment had been performed. In the case of degraded artefacts, destruction occurred.

The great disadvantage of the linseed oil method is that oil leaks out of the artefacts after drying and polymerizes on the surfaces creating an unsightly mess. In these cases, fortunately, reconservation is possible whereby the oil is extracted with solvents, the wood rehydrated and conservation begun again.

Local museums may be forced to undertake salvage archaeology where wet sites are under immediate threat of destruction, the Te Miro excavation being a case in point. This activity will inevitably produce material that is beyond the capacities of the museums to conserve.

The New Zealand Historic Places Trust is responsible for public archaeology and may have to organise a wet site rescue excavation in the future. The Trust Archaeology Section has no facilities for conserving waterlogged finds at the present.

The canoes, boats and ships that lie on the beds of our rivers, lakes and coastal seas are another problem that await conservation solutions. At the present it is often possible to defer any action and hope that they will survive in their present environments. Ultimately, however, some of them will need to be raised and conserved, a task far beyond the conservation resources available at present.

Another problem area concerns research archaeology in waterlogged sites. In field archaeology, this is

perhaps the activity that promises the greatest yield of information per unit of energy invested due to the richness of the material in these sites. Unfortunately, the problem of preserving the material that gives these sites their value is so difficult that a policy has arisen of avoiding them until conservation facilities are available. In the recent past the only wet sites that have been dealt with are those in immediate danger of destruction.

To meet the needs in the conservation field that are described above certain facilities are required. Waterlogged wooden artefacts come in all shapes and sizes, from small hair combs and toys, to medium sized horticultural tools, to large items such as palisade posts, canoes and ships. In practical terms it is possible to classify them into three categories.

Firstly, small portable items that can be picked up by one person and carried easily, can be transported by car, taken through normal doorways, up lifts and stairs etc. In numbers, these artefacts would make up the majority of those requiring conservation.

Secondly, large portable artefacts. These can be transported, perhaps by truck, from the sites to the conservation laboratory. The laboratory would need to be on the ground floor, with double door access from the outside and have floor loading capacities that could accommodate the huge weights of the storage tanks for the artefacts. In terms of bulk, the large portable artefacts would supply most of the material requiring conservation in New Zealand.

The third category involves super large items such as house beams, large canoes and boats. These would be too large or fragile to transport over long distances and require special cradles and lifting gear to move. These must be conserved at or near their findspots which would involve temporary field laboratories.

The facilities available in New Zealand at present include the laboratories of the two university departments that teach archaeology; the Anthropology Departments of Auckland and Otago Universities. A limited amount of work has also been performed at the Waikato Art Museum, Hamilton, and Taranaki Museum, New Plymouth. The Auckland laboratory has

been involved in the field for some time and the man in charge, Mr Karel Peters, has built up considerable expertise in the subject. A small freeze drier is in operation there. Unfortunately, the Auckland laboratory is not large and is located on the seventh floor of a building. It can only handle the small portable artefacts.

The Otago laboratory has a very large area available, including extensive ground floor space with double door access to road ways. It also has a large (4 by 1 metre chamber) freeze drier and heated impregnation tanks. This laboratory has only recently been established and no trained staff are available to operate the facility. This laboratory has the capacity to handle all the sizes of artefacts requiring laboratory conservation.

Conservation at the museums mentioned has involved simpler types of treatment but with varied degrees of success. With expert guidance there is no reason why these institutions should not continue to conserve a considerable amount of carefully selected types of material with great success in the future.

In summary, the basic facilities for waterlogged wood conservation do exist in New Zealand. The critical task at present is to provide a trained, professional conservator to turn the facilities available into a working laboratory capable of dealing with the whole waterlogged wood conservation problem on a national scale. Such a person must be fully trained as an archaeological conservator and not only run a laboratory but be able to assist with excavation of wet sites, undertake on-site conservation, lifting, packing and transport to a laboratory. The conservator should then have the facilities to store and then conserve the artefacts.

Clearly the conservator must have the financial backing to carry out this work. This, however, is a subject which poses some problems. In other fields of conservation the objects concerned are already owned by institutions both public and private who, with some assistance from the state may establish their own conservation facilities. The wet wood artefacts, requiring conservation are, however, those currently underground awaiting discovery. They are, by law, the property of the Crown by virtue of the Antiquities Act of 1965 and private ownership and sale is illegal. As owners, the Crown should meet the conservation costs. This situation was not foreseen and a funding policy to meet this obligation has yet to be formulated.

CHAPTER THREE

THE PROPERTIES OF WOOD

INTRODUCTION

This chapter will describe the basic composition, structure and dynamics of wood and the processes of decay and waterlogging it can undergo. It will begin with a description of the basic building blocks of wood material followed by coverage of how these materials are built up into cell walls, the walls into cells, cells into tissues and the tissues into whole trees. This will be followed by an account of the dynamic processes that normal wood undergoes with particular reference to its reactions with water. The processes of wood degradation and waterlogging will then be described along with an explanation for the drastic effects of dehydration on degraded waterlogged wood.

THE BASIC WOOD COMPONENTS

Wood is built up from a limited number of organic polymers that show a remarkable uniformity in their composition across the whole plant kingdom. Though there are numerous minor constituents of wood, often called extractives, the three dominant materials are

cellulose, hemicellulose and *lignin.*

Cellulose accounts for approximately 50% of all wood material and comprises about one third of the total material produced by all plants (Panshin and de Zeeuw 1970:69). Chemically it can be described as B-D-glucopyranose residues linked by glucosidic bonds between the 1 and 4 carbons of the adjacent residues to form a continuous linear chain (ibid.). The basic repeating unit is the *cellobiose unit*, a disaccharide composed of two glucose molecules. Cellulose exists in wood as a macromolecule of molecular weight 300,000 to 500,000, i.e., 900 - 1500 cellobiose units. The long linear molecule is about 2.5 to 5 microns long (ibid.).

Hemicellulose makes up five to thirty per cent of wood. It is a less well defined material than cellulose, involving a number of closely related compounds. Two of these constitute the bulk of hemicelluloses found in wood. They are *xylans* and *glucomannans*. Xylans are polymers of anhydro forms of pentose sugars and glucomannans polymers of anhydro forms of hexose sugars, especially glucose and mannose (ibid.:72).

Eighteen to thirty per cent of wood is made up of lignin (Stamm 1964:3-4), the characteristic material of wood (though also found in some grasses and ferns). There is no known non-modifying solvent for native lignin; it is not hydrolysable into monomeric units and appears to lack the orderly repeating structure of the wood polysaccharides. As a consequence, this material is the least well known of all wood components at the molecular level even today (Hoffman 1982:74). What is generally agreed is that it consists of large molecules, linked in three dimensions with a skeleton involving phenolic compounds (Meier 1962:38, Panshin and de Zeeuw 1970:71).

ORGANISATION OF WOOD MATERIALS

In the wood cell wall, cellulose molecules are organised into bundles in an orderly, partially crystalline, manner. These bundles are called the *elementary fibrils*, each of which is made up of approximately forty cellulose molecules (ibid.:79, Hoffman 1982:74). These elementary fibrils are oblong in cross section and are very long. They contain regions where the cellulose molecules are arranged in a crystalline manner (called *crystallites*), alternating with areas where the molecules are in a disorderly arrangement (called the *amorphous regions*). Groups of

four elementary fibrils are cemented together, by hemicellulose and lignin, to form *microfibrils* (ibid.:74). Bundles of microfibrils are themselves cemented together to form *macrofibrils*. These can be organised into sheets, one macrofibril thick, that are layered in such a way, in the secondary cell wall, that the macrofibrils in each adjacent sheet are at a slight angle to each other (Esau 1960:53, Panshin and de Zeeuw 1970:79).

ORGANISATION AT THE CELLULAR LEVEL

The *primary wall* is the first structure formed during cell growth. It consists of macrofibrils with random orientations set in a lignin rich matrix. It is initially flexible and can expand as the cell grows and elongates. When the cell reaches its final shape this primary wall may become secondarily thickened by the addition of layers towards the inside of the cell. In normal wood cell walls three such layers are present; the *S1* layer; the *S2* layer and the *S3* layer. These layers, along with the cement that holds each cell to its neighbours, the *middle lamella*, are illustrated in Figure One.

The bulk of the cell wall is composed of the S2

layer. The macrofibrils in this layer run along the axis of the cell at a slight angle to it. They are held in place by the S1 layer on the outside and the S3 layer on the inside. The macrofibrils in these latter two layers run at right angle to those in the S2 layer, i.e., around the axis of the cell. The centre of the cell is hollow and is called the *Lumen*.

The distribution of basic wood materials varies across the cell wall, this distribution being illustrated in Figure Two. The *Compound Middle Lamella*, as the middle lamella and the primary wall together are called, is thin compared to the S layers but contains a substantial proportion of the lignin. Due to their greater width, the S layers possess over fifty per cent of the lignin in the cell wall (contrary to some earlier reports, e.g., Meier 1962:40) even though it is present in low proportions.

The S layers are very variable in thickness. In New Zealand species this variation can be very wide with the *fiber cells* of lace bark (*Hoheria sexstylosa*) having a cell wall so thick that there is virtually no cell lumen left, while, at the other extreme, whau (*Entelea arborescens*) has a cell lumen at least ten times wider than the cell wall (Meylan and Butterfield

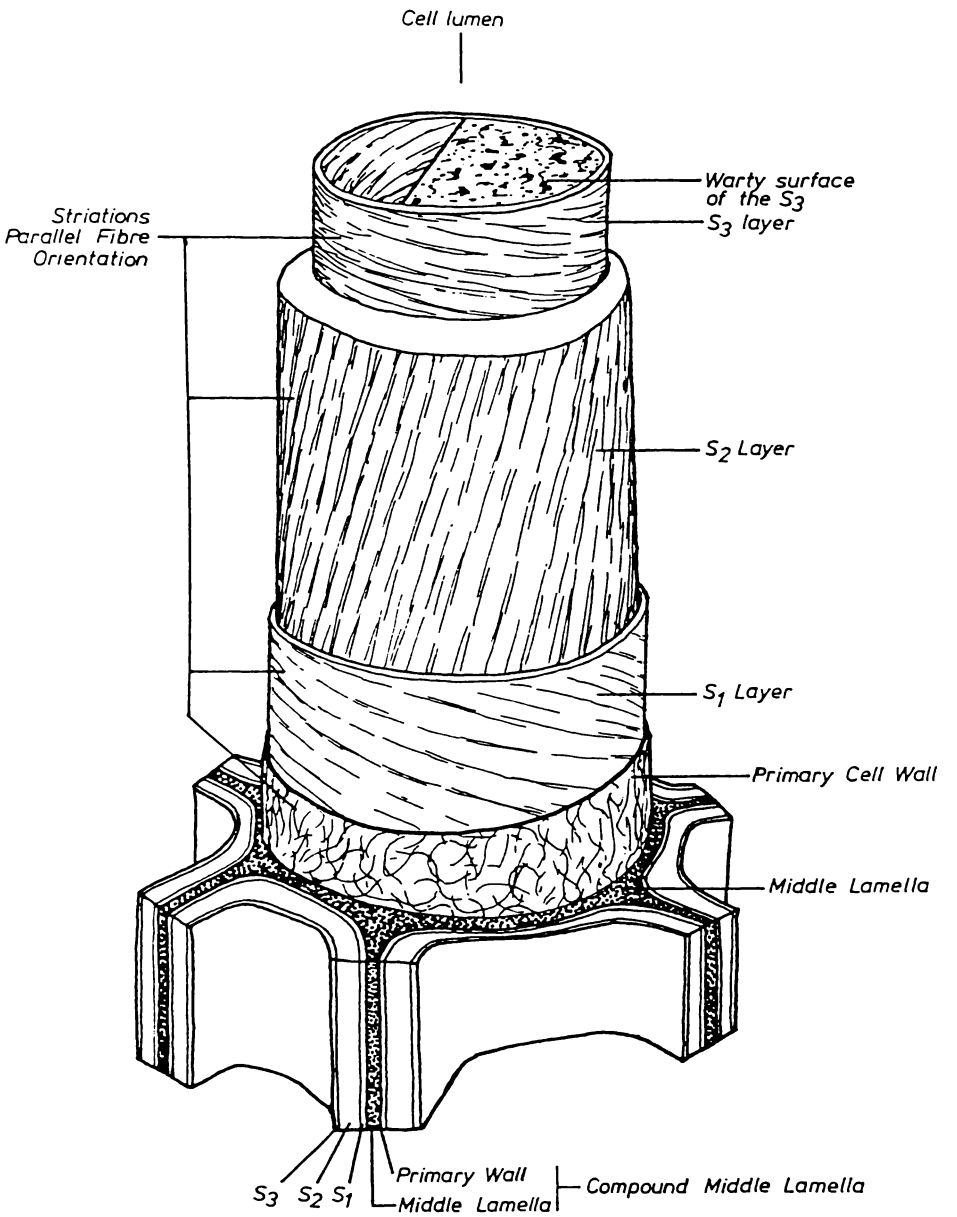


FIGURE ONE: Cell wall structure of wood
(After Panshin and de Zeeuw 1970:Fig.3-6)

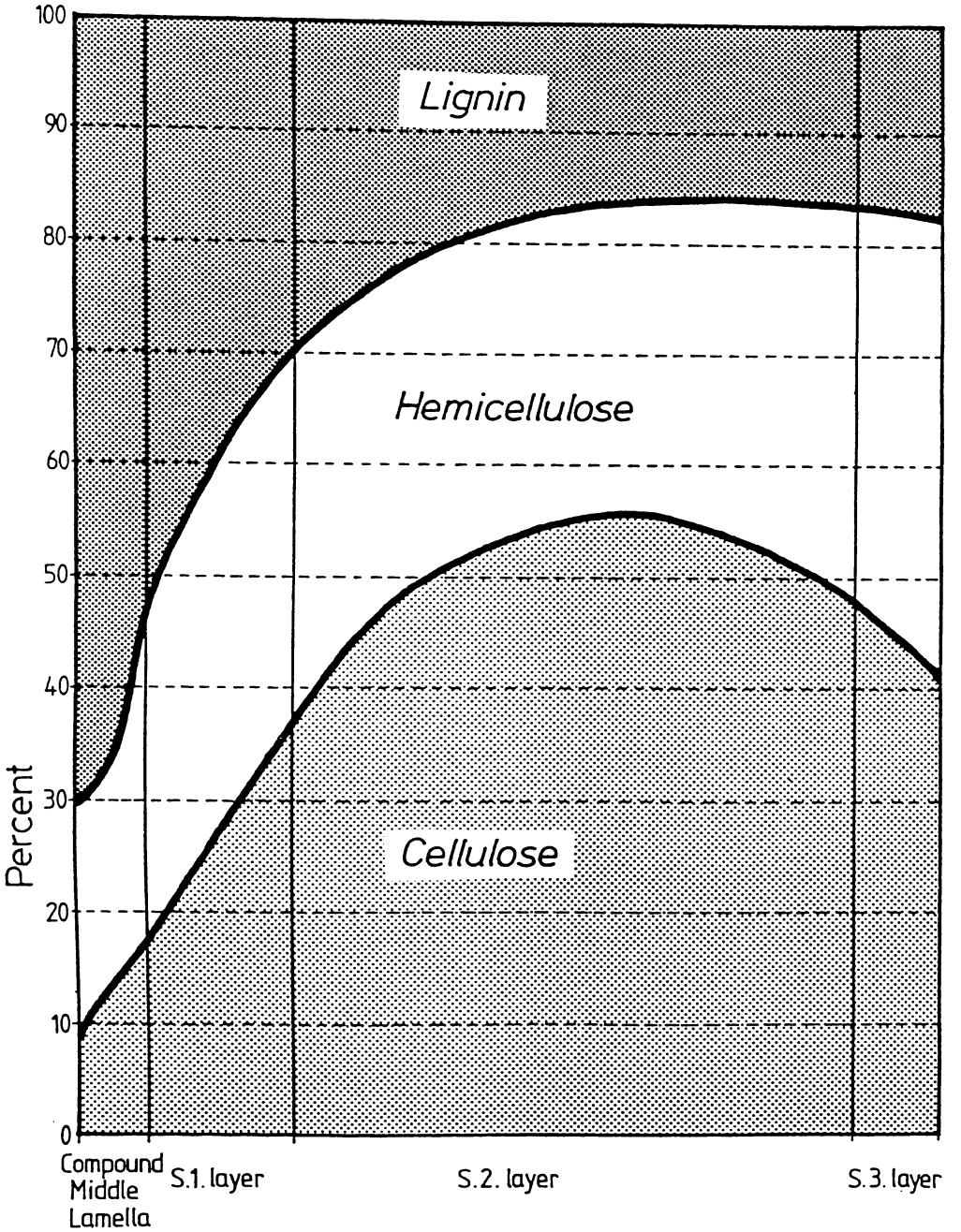


FIGURE TWO: Proportions of different components across the cell wall (After Panshin and de Zeeuw 1970: Fig. 3-10)

1978:108-111). The distribution of the basic wood materials across these walls is of importance since, during degradation, the polysaccharides tend to be preferentially removed leaving a lignin skeleton behind.

WOOD STRUCTURE

From the point of view of plant anatomy, wood can be defined as *secondary xylem* (Esau 1960:76). Xylem is the water conducting tissue of plants and becomes the agency of mechanical support when its cell walls become secondarily thickened, i.e., the S layers are added. When the process of secondary thickening has been completed, the cell loses its cytoplasmic contents and dies, becoming a passive conduit for water that is transmitted from the roots of the plant to the leaves and a mechanical support for the crown of leaves.

Wood growth begins at the growing tips of the twigs but this task is soon taken over by the *vascular cambium*, a layer of meristematic cells forming a single sheath around the growing trunk and branches. This cambial layer buds off xylem cells towards the centre of the trunk and *phloem* cells towards the outside. Phloem is the tissue that transports food

material from the leaves to the rest of the plant. When phloem dies, as it is replaced by new cells, it forms the *inner bark*. The *outer bark* is formed by a separate layer of meristematic tissue outside the inner bark, called the *cork cambium*. Since the trunk of the tree expands during growth, the bark layers are forced to split into separate segments (Panshin and de Zeeuw 1970:61).

Occasionally species do not follow the above pattern of growth. The New Zealand species parapara (*Hoimerliodendron brunonianum*) and mangrove (*Avicennia resinifera*) both bud off their phloem cells towards the centre of the trunk forming bands of *included phloem* (Meylan and Butterfield 1978 72-3, 244-5).

There are a variety of different cell types in secondary xylem and these are summarised in Table One.

The axial system consists of cells elongated along the axis of the trunk, branches and roots of the tree. In gymnosperms this tissue is usually made up of a single cell type, the tracheid, although in some New Zealand species there are a small number of parenchyma cells present also. The tracheids perform both water transport and mechanical support functions at the same

time. The axial parenchyma cells appear to function as conduits for resin.

TABLE ONE: Main Cell Types in Wood
(Adapted from Esau 1960:78)

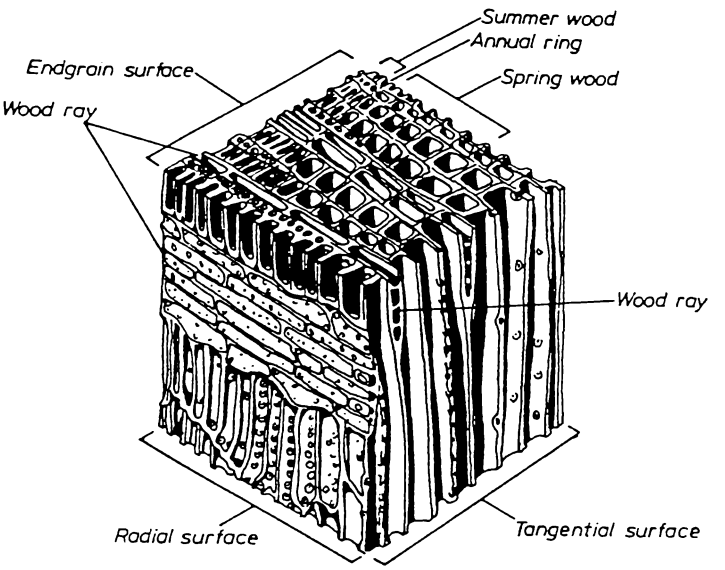
CELL TYPES	FUNCTIONS
(A) AXIAL SYSTEM	
i. Tracheary Elements	
Tracheids	both water transport and support
Vessels (angiosperms only)	water transport only
ii. Fiber cells	
Fibers (angiosperms only)	support, sometimes storage
iii. Parenchyma	
Parenchyma (in both)	storage and translocation of substances
(B) RADIAL SYSTEM	
i. Parenchyma	
Parenchyma (in both)	storage and translocation of substances

Angiosperm axial systems are more complex with different cell types for each function. Water is carried by *vessel elements* that are very wide, open

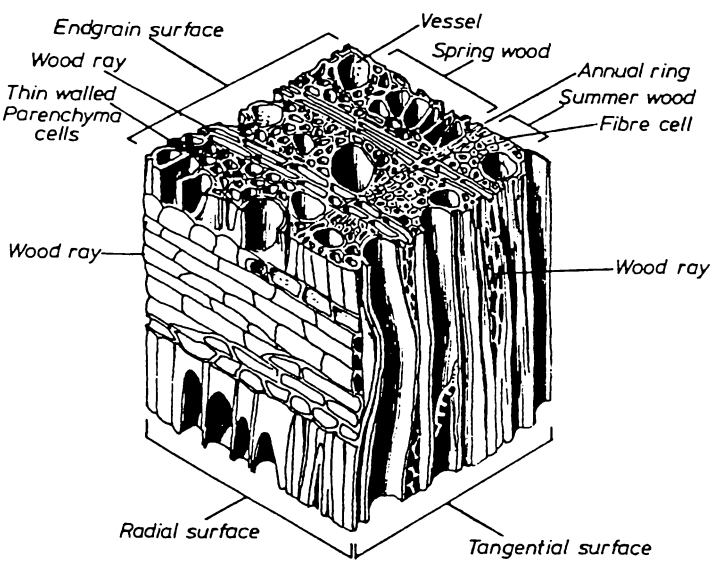
ended cells stacked end on end forming tubes that extend from the tips of the roots to the twigs that bear the leaves. Mechanical support is provided by the narrow, thick walled *fiber* cells. The thin walled *parenchyma* cells perform metabolic functions, translocate substances and also store them.

The *radial* system runs from the centre of the trunks, branches etc. out to the bark. *Rays* are bundles of cells, each bundle being lensoid in cross section with the long axis being vertical (see Figure Three). Gymnosperm rays are simple, being only one to two cells wide, but in angiosperms there is a huge variation between species with some being up to thirty cells wide as in the case of the local seven finger (*Schefflera digitata*).

Gymnosperm wood is simpler and more uniform between species than angiosperm wood. In the latter the patterns of association of the different cell type can vary dramatically between species. The density of the wood can also vary enormously, producing both the lightest (e.g. balsa) and the densest (e.g. *Lignum vitae*) types of wood.



Gymnosperm Wood



Angiosperm Wood

FIGURE THREE: An illustration of the cell anatomy of a Gymnosperm and Angiosperm wood

WOOD DYNAMICS

Though in many respects a remarkably stable material, wood will shrink and swell to a significant degree. This is caused by the uptake and release of water from the cell walls.

In dry wood, cell walls contain only 2% void space (Stamm 1964:132) yet when fully saturated they contain approximately 40% water by volume. In these circumstances it is obvious that the voids in the wall must have opened up as the water entered, i.e., a wood to wood interface was replaced by a water to wood one. This special process is referred to as *adsorption* to distinguish it from normal capillary absorption where the wood/air interface is replaced by a wood/water one.

When sound, fully saturated wood is slowly dried the water in the cell lumena is lost first. This causes no dimensional change whatsoever. Shrinkage only begins when water is removed from the cell walls. The point where the cell walls are fully saturated but there is no water in the cell lumena is called the *fibre saturation point*. This has been found to be a relatively standard 30%, by weight, of water (ibid.).

Water is adsorbed into the cell wall and is lodged between the cellulose molecules in the amorphous regions of the elementary fibrils and in voids between the higher order structural elements. As water enters it forces apart the cellulose strands opening up new voids. It is this forcing apart of the strands that causes the swelling of wood. When wood is dried the water is withdrawn and the forces of surface tension draw the strands together again causing shrinkage of the wood.

As described above, cellulose strands are between 500 and 2000 times as long as they are wide, therefore, when water is deposited between them swelling only occurs at right angles to their length. The elementary fibrils are arranged into microfibrils which join to form macrofibrils. These make up the cell walls where, in the thickest layer (the S2), they are all oriented along the length of the cell. Since the axial system of wood has the bulk of the cells and as these are elongated along the axis of the trunk, swelling mostly occurs at right angles to this axis. This is *radial* and *tangential* swelling. *Longitudinal* swelling rarely exceeds 1% whereas changes in the other two dimensions can reach 20%.

In the case of a simple, non-stressed hydroscopic gel (e.g., gelatin) the amount of shrinkage or swelling is a function of the properties of the gel itself and has nothing to do with the shape the gel happens to be formed into. If wood were of this nature then the dimensional changes would be independent of the density and would also be isometric, i.e., the wood cells would retain their relative dimensions. This is very far from being the case and two features of wood behaviour require explanation.

The first property is that swelling and shrinkage in wood increases with increasing density.

The second property is that the cross sectional shapes of the cells change during swelling. Both these facts are a consequence of cell walls being highly stressed systems.

The secondary cell wall is formed under conditions of full saturation (Stamm 1964:224). The outer S1 layer, formed then, will prevent any subsequent swelling from exceeding the cells' original outside diameter. The S3 layer, lining the cell lumen, will keep the lumen from shrinking in diameter at all times. As the cell wall material is laid down in a relatively

standard density, i.e., 30% of its weight water; 70% wood material, it can lose and gain only the former percentage during wetting and drying. As the cell lumen diameter remains the same, it is only the external diameter that can increase during swelling. The magnitude of the increase in diameter will, therefore, depend on the thickness of the cell wall which, in turn, determines the density of the wood. Therefore, the denser the wood, the greater the swelling and shrinkage of the wood.

Another feature of wood dynamics that is important here, is differential shrinkage. Wood will shrink between 1.5 and 2.5 times as much in the tangential dimension as the radial one. The causes have long been debated (Stamm 1964:231) but more recent ideas link it to greater lignification of radial cell walls (Barbour and Leney 1982:210). The causes are, however, of less significance than the consequences which depend on the shape and anatomical origin of the piece of wood. For example, if a shaft of wood is cut from one side of a tree trunk, its shrinkage, on drying, will cause the cross section to change from circular to oval (see Figure Four), but if the shaft is made from a single stem, it will reduce its diameter and form a radial split. In the latter case

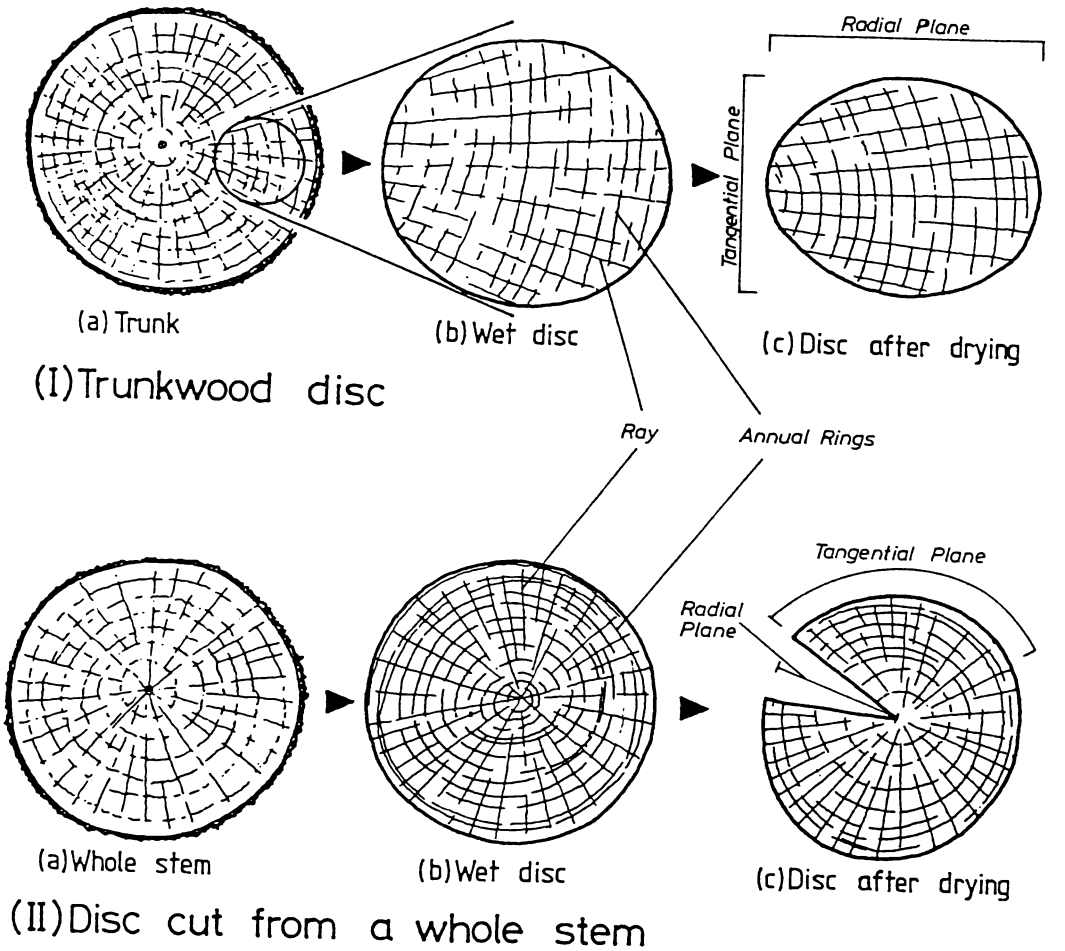


FIGURE FOUR: The effects of differential shrinkage on wood discs from different parts of a tree. assuming approximately 10% radial and 20% tangential shrinkage

the actual nature of splitting will vary with the wood species, wood density and the rate and conditions of drying.

WOOD DEGRADATION

All basic wood materials are biodegradable by various micro-organisms when moisture and oxygen availability suit their individual growth requirements. The main agencies of wood deterioration are fungal infections, though in waterlogged conditions this role is taken over by bacteria.

Decay occurs most rapidly where there is abundant moisture and free oxygen available in the wood. In these conditions *basidiomycete* fungi can attack and digest the wood. *Brown rots* attack mainly gymnosperms, degrading the cellulose and hemicellulose, leaving a brown lignin residue behind. In advanced cases, brown rots leave wood with a spongy texture giving drastic shrinkage and cubical checking when the specimen is dried (Panshin and de Zeeuw 1970:342-3).

White rots seem to primarily affect angiosperms, digesting all basic wood components, leaving behind a stringy, spongy, whitish material that does not suffer

drastic shrinkage on drying. Both brown and white rot hyphae travel along the cell lumena crossing to adjacent cells via existing intercellular pits or via bore holes made by the fungi itself (Ibid.).

Dry rot and *pocket dry rots* occur in wood that has a low water content. Moisture is provided either by wood breakdown or is transported to the site of decay by special vessels from damper areas nearby.

Ascomycetes and *Fungi imperfecta* may also attack wood. The most important type of decay these organisms cause is *soft rot*. This can occur in wood where the water content is near saturation but where some oxygen is available. Unlike the situation in basidiomycete attack, the fungal hyphae penetrate inside the cell walls, following the fibre orientation in the S2 layer, i.e., spiralling around the cell lumen at a steep angle. This type of decay is of great importance in wood conservation as it can occur in waterlogged conditions if the water is aerated. The S layers are attacked but the middle lamella is often left untouched.

Ascomycetes and *Fungi imperfecta* also include moulds which attack stored food in the ray and axial parenchyma cells. This often causes no loss of

strength in the wood though sometimes the thin walls of the ray cells may be damaged causing great loss of tangential strength in the wood and consequent splitting in the radial plane.

Bacteria may play a part in wood deterioration especially in waterlogged anaerobic conditions. Bateria of the *Clostridium* group can ferment cellulose (Bock 1970:552), though the rate of cellulose loss is much lower than with fungal attack. Insects will also attack wood which they digest by culturing bacteria or protozoa in their gut that possess the enzymes to break down cellulose. Insect attack can occur in almost completely dry wood.

One of the most important aspects of microbial attack on wood is the severe reduction in decay rate that occurs on waterlogging (Jagels 1982:70) especially where conditions are anaerobic. Under the latter conditions lignin is highly resistant to attack and studies have shown (eg. Hoffman, 1982,76) that the carbohydrate fraction of wood is preferentially removed by decay leaving lignin enriched material. This resistance of lignin to anaerobic decay is the main reason for the formation of peat and coal deposits.

WATERLOGGED WOOD

When wood is waterlogged and sufficient sediments are deposited around it to ensure the creation of anaerobic conditions, bacteria cause decay by slowly removing the cellulose. The lignin, however, will remain and, since it is concentrated in the compound middle lamella, a skeletal structure retaining the shape and form of the object will remain so long as water fills the voids previously occupied by the cellulose.

The removal of cellulose and hemicellulose by the micro-organisms will increase the size of the voids in the cell wall. Since swelling in wood is mainly caused by cellulose, its absence will ensure that closure of these voids during drying will be permanent. This is partly due to the presence of reactive hydroxyl groups on the walls of the voids that will form permanent bonds across them if the water is removed. The water acts as a bulking agent holding up a fragile and physically unstable framework of residual lignin (Hoffman 1982:82). Unfortunately, though the object may be in a stable state, it is one which is inconvenient for museum curators.

When sound wood dries it does not begin to shrink until the fibre saturation point is reached as the cells are strong enough to resist the forces of surface tension generated by the removal of water from the cell lumena. In degraded waterlogged wood the cell walls are not strong enough and the whole cell implodes as water is withdrawn and thus it begins to shrink as soon as drying commences. Since the cell walls tend to be lignified more on their radial walls this collapse is very much greater in the tangential plane than the radial one.

After all the water is removed from the cell lumena during drying, it starts to be removed from the cell walls themselves. They, in turn, collapse and the wood dries out to a compressed, twisted, checked lump of almost pure lignin that has little resemblance, in shape, to its original saturated form. Subsequent rewetting will have no effect on the wood since this form of shrinkage is irreversible.

Dimensional change in drying degraded wood is a different process to that in sound wood and is better referred to as *cell collapse* (Barbour and Leney 1982:210). On the microscopic level these two processes are mutually exclusive since shrinkage is caused by the

desorption of water from cellulose strands and if sufficient cellulose is present to allow this there will usually be sufficient strength in the cell wall to prevent cell collapse. The converse of this is equally true. At the macroscopic level both processes can occur in the same piece of wood, typically by the collapse of a degraded surface layer leaving the sound core covered by cubes of drastically altered wood residue. Another common occurrence is the collapse of the ray parenchyma cells which are thin walled and do not resist decay to the same extent as other cell types. This results in multiple radial cracks.

SUMMARY

The above coverage of the properties of wood usefully introduces the subject of waterlogged wood conservation since it describes the details of the processes that must be manipulated, controlled or halted in order to stabilise the dimensions of wooden objects, both sound and degraded.

CHAPTER FOUR

TECHNIQUES OF WATERLOGGED WOOD CONSERVATION

INTRODUCTION

This chapter will describe most of the principles of wet wood conservation and include a detailed coverage of the different techniques that have been tried up to the present time. An account will first be given of the 'ethics' of wood conservation, i.e., what the conservator should be attempting to achieve. This will be followed by descriptions of some of the pretreatment processes that have been applied to wood to prepare it for the actual conservation process. The bulk of the chapter will be taken up by descriptions of the different conservation techniques that have been tried up to the present time. This will begin with an account of the methods used prior to 1950 when the subject began to expand into a separate discipline . Modern conservation methods will be considered under five headings:

1. bulking with dissolved solids
2. bulking by polymerization of low molecular weight monomers
3. mineralization techniques
4. sublimation drying techniques
5. combination bulking/sublimation drying techniques.

The chapter will be concluded with a summary of the methods that are now preferred along with a discussion of the practical, financial and ethical merits of each as they relate to New Zealand.

ETHICAL CONSIDERATIONS

There has been an unstated principle behind the preparation of many wooden objects on display in museums. They have been carefully cleaned, oiled, varnished and polished and have been artistically placed in display cases. In this situation they rarely look as they did when in use. It has even been suggested that museum curators prefer their artefacts to not only show signs of having had a lot of work put into their preparation, but smell, not discretely, but strongly of naphthalenic acid (Christensen 1970:96).

In New Zealand museums it has been the habit of some curators in the past to coat their valuable Maori wooden artefacts with kauri gum-based varnishes which were then polished to a high gloss. Similarly, it has been a tradition that carved panels of meeting houses etc. should be given regular coats of new paint. At the Auckland Museum the carved panels on display received their latest coat of paint in response to an impending royal visit as it was thought that they looked shabby (D. Simmons, pers. comm.).

Before a conservator undertakes the task of restoring a waterlogged wooden artefact, therefore, he must have some idea as to the state that it should, ideally, be brought to. The most important points he must establish concern the appearance of the object at various times in its history. These include its appearance when manufactured, when in use, when discarded and when discovered in recent times. The object might have had quite different appearances at each of these times and each of these are potential visual aims for the conservator. However, it is often not up to the conservator to make this decision but rather the owner or custodian of the object. Potential alternatives include the appearance when in use, when lost or discarded and, a less likely possibility,

when discovered.

The artefacts are usually found in their water swollen state. The conservator must decide whether this was its condition when in use or whether the artefact was used in the dry state. Many prehistoric Maori artefact types were, in fact, used wet, e.g., digging sticks, mauls, pounders etc. as has been described in Chapter One. Theoretically one should retain the artefact in this waterlogged state as it is the most authentic condition for it. This, however, is hardly a convenient state for an artefact in a museum collection. Ideally, then, the conservator might wish to produce an object that appeared wet and swollen. By coincidence, many conservation techniques have been criticised for yielding a wet, dull look yet this may be the most desirable appearance for this category of artefact even though it is not 'pretty'.

Many conservation treatments aim at a light brown, 'natural wood' appearance. In some cases, however, the artefacts may never have had such a surface look except when newly manufactured and, in fact, have been stained and darkened by long handling and use. An

example of this might be a wooden food bowl that has become blackened and worn.

The conservator must also know the mechanical requirements the curator might have for the artefact on its return from treatment. Artefacts that are to be kept in a bed of cotton wool in a museum drawer may need little mechanical strength built into them by the conservation process. In contrast, others may need to withstand considerable handling or even be reused for their original purpose. Examples of the latter could be the carved panels of meeting houses etc. Another example could involve the 'naturally' preserved canoes in lakes and rivers that could be put back into use after simply being bailed out. An actual example of this has happened in the recent past when a canoe of prehistoric age was paddled across the path of a speed boat race on Lake Horowhenua as a protest against the use of the lake for that purpose. This incident was shown on national television.

The conservator must always establish whether an artefact actually needs to be conserved at all. Conservation techniques are expensive and time-consuming and all alternatives must be considered

before embarking on them. An object could be drawn, photographed or a mould taken from it instead of preserving it. Examinations of the object, to determine the species of wood etc., could be made and then it could be discarded. Many objects might simply be returned to their resting places in the waterlogged environment, instead of conserving them in the laboratory.

Making casts of the artefacts may often be a more satisfactory approach than conservation. When the object is first discovered in its waterlogged state it may possess surface detail that could be lost during the conservation treatment. This is particularly true of the detail that exists on the outermost one or two millimetres, detail that is normally highly degraded and can be lost in the slight drying that accompanies excavation and transport of the item to the laboratory. Furthermore, many conservation processes result in the noticeable smoothing and rounding off of the fine surface detail that a mould taken at the time of discovery would pick up (Christensen 1970: 55). An example of a successful casting operation involved the Graveney Boat found in Kent in southern England (van Geersdaele 1975).

A plaster of paris mould was taken of the boat at the time of excavation and, though the actual boat has subsequently been conserved, it is the cast taken from this mould that is on display at the National Maritime Museum at Greenwich while the original is kept in a back room (Howard Murray, pers. comm. 1981).

An important ethical concern in conservation involves the need of the conservator to take samples from an artefact for the purposes of wood identification, determination of state of decay, mineral content and C^{14} dating etc. This may interfere with the integrity of the item unless it is done with great care and skill. In some circumstances it may be possible to remove quite a large piece of the item and fill the gap left to disguise this operation. In other cases it may be necessary to avoid sampling the object on the grounds that it may cause irrepairable damage. In this issue it is up to the conservator to balance the factors involved and reach a reasonable compromise taking into account the general principle that the less alteration the artefact is subjected to the better.

The last point concerning ethics is one made

by the Danish conservator, Christensen (1970:96), who states that if conservation is truly successful then it should be impossible to see that anything at all had been done to the artefact except to dry it out. He goes on to state that this may cause considerable difficulties when the conservator later requests payment for the cost of the work done on the item. What is causing the problem here is that some museum curators and archaeologists have little idea of what to expect of conservation and may make criticisms of the appearance of the completed job which are not well informed. What, to the conservator, is a very successful piece of work in view of the difficulties, may appear to the curator as a rather unexciting looking piece of wood which he would not feel able to put on display as it did not look 'nice'. The better informed curator might feel obliged to view the object through his public's eyes and express some disappointment on their behalf. Obviously, the conservator must have detailed discussions with the owners prior to the work being carried out to avoid misunderstandings arising and to provide them with some realistic expectations as to the final appearance of the objects in question. In turn the curator should give some thought to displaying the object with a label that explains its appearance.

PRETREATMENT PROCESSES

Waterlogged wooden artefacts normally require some pretreatment processes prior to being subjected to conservation. These can all be loosely described as 'washing' activities as they involve the removal of material from the wood. Anaerobic environments produce some rather unpleasant properties in wood especially in its smell. Bacterial activity can lead to the release of quite surprising amounts of hydrogen sulphide and other gases. Soluble salts must be washed out of the wood, particularly if it has come from saline or brackish environments. Wood from swamps often contain large amounts of brown dissolved organic material, especially tannates and humates. The pH of the wood is usually very low and it must be brought to near neutral conditions before treatment. All of the above contaminants can be removed by prolonged storage in fresh water that is changed frequently.

A common category of cleaning involves the removal of foreign solid material from the surface of the wood. This can include silts and clays which are not difficult to remove but also may include organic material such as plant roots that penetrate

the artefact itself. The removal of these roots and other embedded material may require much time and skill.

A more complex type of pretreatment involves the removal of material in the wood that is insoluble in water. Waterlogged wood may have an ash content as high as 15 - 20% (compared to fresh wood that has less than 1%) (Blackshaw 1976:29). These impurities often include iron salts (particularly sulphides), other sulphur compounds and calcium salts (ibid. Christensen 1970). Where iron nails have been used in the artefacts, patches of corrosion products are built up. These consolidate the wood preventing any dimensional change. As few conservation processes avoid small dimensional changes, these patches of corrosion products will cause rupturing and splitting when the artefact finally dries out. Consequently, iron compounds must sometimes be removed from the wood.

Pretreatments may also be used to improve the permeability of the wood to the consolidants that are later to be used to stabilise the artefact. Removal of materials in the wood that are blocking the pores is an integral part of some conservation techniques.

Finally, there is often felt to be a need to improve the surface colour of the conserved artefact by various bleaching processes.

Wood has been treated with 5% acetic acid to remove normally insoluble materials, particularly inorganic salts and acid soluble humus fractions (Christensen 1970:50). Another treatment involves soaking the artefact in 5% EDTA (ethylenediamine-tetraacetic acid, bisodium salt) plus ultrasonic vibration for 24 hours. This treatment is for the removal of iron corrosion products, to improve the surface appearances of the objects and to improve permeability (Murray 1982:14). A 5% solution of oxalic acid (ibid.:17) has also been used to remove iron, and a 1% solution to remove surface iron stains (Barkman et. al., 1976:18).

Attempts to improve permeability have involved soaking the object in 10% sodium hydroxide solution (Christensen 1970:50). Another method is to use the acid bath followed by solvent extraction with acetone (McKerrel et. al., 1972:111-125). Ammonia and hydrogen peroxide have also

been used to improve the wood's appearance (Mühlethaler et. al., 1973).

An investigation of the effects of some of the above chemicals on both the wood and the material used during subsequent consolidation suggests that hydrogen peroxide, hydrochloric acid and sodium hydroxide may improve the wood's appearance but have other effects that make their use inadvisable (Blackshaw 1976:27-35). However, EDTA and Detarol (N-hydroxylethylethylenediaminetriacetic acid, trisodium salt) appeared to be suitable surface treating agents (ibid.).

A final subject to be included under the heading of pretreatment is storage of waterlogged wood. Ideally, this should occur under passive conditions but, in practice, this is never achieved. On the removal of the wood from anaerobic, acid sediments and its placement in a bath in fresh aerated water, many processes are initiated. The wood never really comes to equilibrium with its storage environment but continues to change. The aerated water of the storage container allows quite rapid changes to take place, especially those caused by microbial action.

Various methods have been tried to create a suitable environment for wet wood storage (Dawson, et. al., 1982) including the use of biocides (ibid., Pearson et. al., 1982:267-9, Dawson 1982:267-77). Recently, however, there has been a move to avoid the use of these biocides altogether and to try to create stable conditions using either temperature control, filtering or water replacement (Dawson et. al., 1982). Another approach is to use biological controls, e.g., fish and aquatic snails in the storage tanks. These animals tend to keep the water in a stable and clean state, ensuring that no buildup of slime etc. occurs on the artefacts thus removing much of the need for cleaning when the artefacts come to be finally conserved (ibid.).

HISTORICAL METHODS OF WATERLOGGED WOOD CONSERVATION

Prior to World War II the conservation of waterlogged wood was carried out by museum curators and archaeologists who operated outside the confines of any established discipline. They dealt as best they could with the items as they turned up. One institution that has had a long history of dealing with waterlogged finds is the National Museum of

Denmark whose archaeological collections grew out of the private collections of the kings of Denmark. The earliest developments in the field of waterlogged wood conservation are agreed to have come from the work of an employee of King Frederick VII, named Jørgensen, who records the use of alum (potassium aluminium sulphate, $KAl(SO_4)_2.12H_20$) in 1859 (Christensen 1970:13). It would appear that this method was developed shortly after 1850. The method was in continuous use from then until 1958 (ibid.). The best description of the technique is given by one of the last conservators to have been involved in its use, B. Brorson Christensen. The wood was immersed in a hot (90°C) super-saturated solution of alum for about two hours and then removed, washed and allowed to cool. The principle was that alum would penetrate the pores of the wood displacing the water and crystallise on cooling, preventing collapse of the wood during drying. The process was completed by the application of many coats of linseed oil during drying followed by a varnish coating (ibid.).

The success rate of this method varied a great deal. One of the greatest drawbacks of the technique was that alum is hygroscopic and will absorb water, repeatedly dissolving and recrystallising where humidity is high and fluctuating. This causes

swelling and disruption of the artefact (ibid.).

Other methods used in museum basements around the world are less well documented. In New Zealand linseed oil was soaked into slowly drying artefacts (Ken Gorbey, pers. comm.). This may have a slight consolidating effect on small, highly degraded artefacts though it produces an unsightly mess when the oil seeps out later. On sound artefacts (where it was mostly used) the results are rather debatable but there is good reason to believe that slow drying without any treatment at all would have yielded superior results in these cases.

No doubt, a great many other methods were used from time to time around the world but few records were kept and there was little communication between workers.

The beginnings of modern waterlogged wood conservation can probably be traced to the work of the American wood technologist A.J. Stamm in 1956 when he introduced the use of 'PEGs' as agents for dimensional stabilisation of wood (Stamm 1956). These materials are polymers of ethylene oxide with the general formula $HOCH_2\ (CH_2OCH_2)n\ CH_2OH$

where n equals the average number of oxyethylene groups. Polyethylene glycols, hereafter referred to as PEGs, are designated by a number that approximates the average molecular weight of that particular grade. Grades in use in conservation are PEG 400 (M.W. 380 to M.W. 420), PEG 1500 (now 540 blend, a 50/50 mixture of M.W.300 and M.W.1430), PEG 4000 (M.W.3000 to M.W.3700) and, less often used, PEG 6000 (M.W.7000 to 9000).

Starting with the work of Christensen in Denmark in the 1950's and 1960's a whole series of methods have been developed to conserve waterlogged wood. Since that time the subject has developed into a separate discipline, within the general field of art conservation, with its own literature and with frequent conferences where most of the workers in the field meet on a regular basis and exchange views.

MODERN TECHNIQUES

The first group of techniques can be described as bulking methods and can be divided into those which involve the diffusion of a dissolved solid into the wood followed by its freezing or crystalisation and those which involve diffusion of a low molecular

weight monomer into the wood followed by polymerization. Simple bulking methods will be described first.

SIMPLE BULKING

1. Hard wax embedding

This method was developed by Christensen (1970:27) as a modification of standard microscopic embedding techniques. The water in the wood is exchanged for ethanol by immersion in a series of ethanol baths of increasing concentration. The ethanol is replaced by xylene or toluene in a similar manner followed by further replacement by paraffin wax at 60°C. Up to this point the technique follows standard microscopic embedding methods. The final step is to replace the paraffin wax with a hard wax mixture at 80°C. The hard wax used by Christensen was as follows; one part Damar resin: one part crude Carnauba wax: one part paraffin wax: three parts bees wax. The artefact is removed from the 80°C bath of wax, cleaned of surplus wax with a mixture of benzene and chloroform and allowed to set hard. The method works well and yields an artefact that is strong and has a good final appearance. Obviously

the method can only be employed with small artefacts due to the dangers associated with the volatile solvents employed.

2. The acetone/rosin method (McKerrel, et. al., 1972).

This method was developed to conserve smaller items of European oak heartwood that had resisted impregnation with PEGs. The wood is first pretreated in a 10% hydrochloric acid bath followed by solvent extraction with acetone. Rosin is added to the acetone until a saturated solution is formed. This is then heated to 60°C to drive off the remaining acetone and to keep the pure rosin residue molten. The artefact is then withdrawn from the bath, washed free of surplus rosin and allowed to set. This method is very effective and is used to treat sound, highly impermeable woods e.g., as in ships' tackle blocks made from *Lignum vitae*. The method is used only on small artefacts due to the danger from the solvent and the necessity for vapour tight ovens.

3. Ethanol/ether/resin method (McCawley, 1977:21).

This technique is similar to method No.1. Water in the wood is replaced with ethanol, then diethyl ether. Dammar resin is added until a saturated solution is reached and then the artefact is taken

from the bath and dried. The low surface tension of the ether reduces drying stresses. This method also works well, producing an artefact of good final appearance and imparts considerable mechanical strength. The dangers of using ether need hardly be dwelt upon here; needless to say, small artefacts only can be conserved with this method.

4. The PEG 4000 hot bath method

This was the first method developed to use PEG and remains the most popular one for large objects. The literature relating to this process is extensive. A good description is given by Christensen (1970:36). The artefacts are placed in a water bath heated to 60°C and small quantities of PEG 4000 are added daily. Normally the amounts are such that the PEG concentration is raised by less than one per cent per day. When the concentration of PEG reaches 60-80 per cent the artefacts are removed from the bath, washed free of excess wax with hot water or other solvents and allowed to cool.

The principle in this method is that the water soluble wax will diffuse (slowly, since it is a large molecule) into the wood, replacing the water. When the PEG sets it forms a waxy solid thereby

bulking the wood and preventing it collapsing.

This method, when first developed, was hailed as the solution to many of the problems besetting the field. PEG was relatively cheap, non-toxic, non-corrosive to suitable tank linings, non-volatile and soluble in the cheapest and safest liquid of all - water. The size of objects to be treated was limited only by the size of the tank.

The method has now been in use for the last twenty years and most of its deficiencies are now apparent. PEG 4000, even in its pure form, has only the strength of candle wax, i.e., not strong enough to resist any but the most gentle handling. PEG 4000 is a very large molecule that diffuses very slowly and, in its hydrated form, is too large to penetrate quite a number of woods when in their sound state. For example, white oak (*Quercus robur*), so popular for ship building, and general construction, often contains a sound undegraded core. PEG 4000 will not penetrate this core and as the concentration of PEG increases around it, it loses water due to osmotic forces and shrinks drastically. A large proportion of the literature on waterlogged wood conservation that has come from northern Europe in

the last twenty years has focussed on this problem.

Another serious problem with the PEG 4000/hot bath technique is that PEGs will oxidize quite rapidly if temperatures are raised to 60°C and abundant oxygen is present in solution. In the heated baths oxygen levels are normally low but over the long periods of time required to complete impregnation oxidative degradation occurs. Furthermore, oxidation may be catalysed by metals such as iron, copper etc.. PEG breaks down to a host of products, the most important being formic acid (Brownstein 1982:280-1). This explains the persistent tendency for PEG baths to suffer a sharp drop in pH followed by a massive release of dark coloured materials from the wood (Christensen 1970:58). The effects of degradation on the physical properties of the PEG do not seem to be great as far as the mechanical strength of the wax is concerned, but they do seem to increase its hygroscopicity rather noticeably (ibid.). The acids not only release dark material from the wood resulting in a poor final appearance in the artefacts but give rise to corrosion problems in tanks and pipelines.

The final appearance of the PEG 4000 treated artefacts is not good, being black or dark brown, dull and dampish looking with a heavy, soft feel. There are some advantages with this treatment not found in many others. The treated artefacts can be heated to 80°C and bent and twisted into a different shape; an important feature where such things as strakes from boats are concerned as it allows them to be returned to their original shape (ibid.:55). Due to the advantages of the method mentioned at the beginning of this account, the PEG 4000 hot bath method remains popular for very large finds though there is no doubt that the search for more effective alternatives is continuing vigorously.

5. The PEG 1500 spray method

This method was chosen for the conservation of the hull of the warship, Vasa, the largest single conservation project ever attempted (Barkman 1975:65-105). This ship was far too large to be placed in a tank and was treated with a spray of PEG 1500. The 1500 grade (a 50/50 blend of MW.300 and MW.1430) was chosen as it was felt that the relatively sound wood of the hull, made from the impervious heartwood of oak, would not take up a higher molecular weight so easily.

6. The PEG 1500 hot bath treatment

This was chosen for the treatment of waterlogged oak timbers from a 17th century Dutch East Indiaman, wrecked on the Houtman Abrolhos off the coast of Western Australia (Pang 1981). The details of the treatment are given by Pang but do not vary greatly from that used in the PEG 4000 hot bath treatment.

7. PEG 1000 hot bath technique

This is being used for the conservation of the Bremen Cog, a 14th century A.D. Hanseatic merchant vessel. This ship is being impregnated in a huge tank (Hoffman 1981:41-4), with the unusual feature of a window in the side to permit museum visitors, i.e., the general public, to view the ship while conservation is in progress. This has been done because the impregnation time was calculated to be up to twenty years (ibid.:42). This project has yet to be completed.

8. The PEG 4000 cold bath method

This method was developed by Christensen (1970:51) to avoid the difficulties he was having with the PEG 4000 hot bath treatment of large oak heartwood timbers with sound cores. The wood was placed in a bath containing 25% PEG 4000 that was raised to 50% over 12 months. The wood was then

removed from the bath and slowly dried out while being given a once daily quick immersion in the 50% PEG solution (ibid.). The method avoids the collapse of the central core that occurred in the hot bath treatment.

9. Slow drying/daily painting of PEG 540 blend

This method is used for artefacts that are relatively sound. They are dried very slowly while being painted daily with 540 blend PEG (formerly called PEG 1500, in fact a blend of PEG 300 and 1430 grades). This method is at present being used at the Canadian Conservation Institute, Ottawa.

10. PEG 4000/methanol treatment (Albright 1966)

In this method small items are impregnated with PEG using methanol. At 40°C PEG diffuses quite rapidly in methanol and concentration of up to 90% PEG can be achieved (Christensen 1970:90). The artefact is allowed to dry out after impregnation.

11. Sucrose or table salt bulking (Barkman et. al., 1976)

This method involves placing the object in a heated (60°C) water bath while daily small increments of sugar or NaCl are added. This is continued until either 30%, by weight, of sugar or 27% NaCl is

achieved. The artefacts are then removed from the bath and dried very slowly. The method operates on much the same principle as the alum method since these materials will crystallise in the cells of the wood preventing cell collapse. The method has been tested in field conditions and has been found to be a practical one (Grosso 1981). The use of biocides, in the case of sucrose, will produce a relatively non-biodegradable item.

12. Impregnation by various water soluble organic materials (McCawley 1977:21)

Included under this heading are the various experiments using methyl cellulose, polyvinyl acetate and polybutyl methacrylate. These methods have not been a great success with only poor penetration of the consolidant and little resulting protection from shrinkage and cracking.

in situ Polymerization bulking

The second general type of bulking technique involves the impregnation of low molecular weight monomers into the wood followed by their polymerisation *in situ*.

13. The Arigal C method (Muller-Beck and Haus 1960, Muhlethaler et. al., 1973, Blackshaw 1976)

This method was developed in Switzerland and has been widely used in central and eastern Europe. Arigal C was a widely used trade name for a brand of water soluble melamine formaldehyde resins. The artefact is placed in a bath of 25% Arigal C for an extended period. An initiator, usually 100 volume hydrogen peroxide, is then stirred into the bath which is left to stand for a further five days. The artefact is then removed and washed free of surface resin with hot water, wrapped in tissue paper, placed inside several plastic bags, and then heated to 60°C for four days to cure the resin. The method works reasonably well but unfortunately tends to result in shrinkage in the six months after the consolidation.

Other materials that have been tried include styrene/divinyl benzene; vinyl chloride; vinyl acetate/styrene; methyl methacrylate, butyl methacrylate; 2 hydroxyethyl methacrylate; various oligomers of methyl methacrylate; and dimethyl siloxane (McCawley 1977:23-4, Mavroyannakis 1982, de Tassigny 1981, Munnikendam 1967, 1972a, 1972b, 1973).

As a general rule these methods have lost favour in wet wood conservation. The wood must be subjected to complex solvent replacement techniques in most cases, the monomers are often volatile and highly toxic, and finally, the polymerized materials are almost impossible to remove once the treatment has been completed. Reversibility is a very important feature of any treatment as it is often critical in achieving a good surface appearance. The greatest problems with these methods, apart from the expense of the commonly used gamma radiation polymerization treatments, is in obtaining this good surface appearance. The fluid monomer constantly leaks from the artefacts when the impregnation is complete and consequently polymerization results in poor surfaces on the upper side and excess plastic on the under side. The strength of the artefacts is far in excess of the requirements of conservation unless one wishes to reuse the object for its original purpose. In general, these methods can only be used on small items for which there are a number of equally good if not superior methods that are much simpler, cheaper and safer.

MINERALIZATION METHODS

The next group of conservation techniques can be referred to as mineralization methods. In these inorganic materials are deposited on the internal surfaces of the cells of the wood, strengthening them so that they can resist drying forces without collapse.

14. Electrokinesis processes (McCawley 1977:21)

These methods were experimented with in Poland in the early 1950's but do not appear to have been used successfully elsewhere. Wood is suspended between two electrodes across which a current is passed. The potential drop between these electrodes encouraged liquids to migrate towards the negative pole allowing the impregnation of various inorganic materials into the wood. These included water glass ($Na_2O.\ SiO_3$), calcium chloride ($CaCl_2$), acetic acid (CH_3COOH), phosphoric acid (H_3PO_4) and others (ibid.:21, and Muhlethaler, Barkman and Noack, 1973:50).

15. The chromate method (Bouis 1973, McCawley 1977)

This involves the diffusion of sodium chromate ($Na_2Cr_2O_7$) and chromium trioxide (CrO_3) into the wood which are then modified and deposited as chromium

chromate $(Cr_2CrO_4)_3$ and calcium chromate (Ca_2CrO_4) precipitates.

16. The TEOS method (Irwin and Wesson 1976, Jespersen 1982:203-9)

This has been a more recent development. It involves the use of an organic silicon chemical, tetraethoxysilane. This reacts with water in the following way:

$$Si(OC_2H_5)_4 + 2H_2O \longrightarrow SiO_2 + 4\ CH_3CH_2OH.$$

The method is carried out as follows; the artefact is dehydrated by solvent replacement using acetone, ethanol, tertiary butanol or some other suitable solvent, in such a way that a small quantity of water remains intimately associated with the wood material. The object is then placed in a bath of TEOS for sufficient time to allow it to replace the solvent in the wood. The theory is that a thin layer of SiO_2 will be deposited over all internal surfaces consolidating the item and preventing cell collapse on drying. This method has now been thoroughly evaluated and the conclusions are that the method is quite unsatisfactory for wood (ibid.), but highly promising for fibre, rope, textiles etc. if a plasticizer is introduced to reduce the inevitable

brittleness of the end product. An important disadvantage of the method is that SiO_2 is soluble only in hydrofluoric acid.

SUBLIMATION DRYING TECHNIQUES

As was mentioned in Chapter Two, cell collapse in highly degraded wood is caused by drying stresses, primarily surface tension forces. One way to prevent cell collapse, therefore is to reduce the surface tension forces either by drying from a liquid with a low surface tension or by sublimation drying.

17. Drying from diethyl ether

In this method the water in the artefact is replaced by another solvent which is then replaced by ethyl ether. This liquid has a very low surface tension and evaporates without causing high drying stresses. The ethyl ether is evaporated off under a low vacuum (Christensen 1970:28). An advantage of this method is that no preliminary cleaning of the artefact is necessary as the dirt falls off after drying with gentle brushing. The artefact usually will require subsequent consolidating and this is done with an initial quick dip in a dilute solution of Sandarac resin in diethyl ether followed by

vacuum drying. Further coating may be applied using solvents that do not dissolve the sandarac resin. Small, moderately degraded artefacts can be conserved in this way.

18. Freeze drying from water

This method has been tried but is unsatisfactory without considerable modifications. The principle is that surface tension causes most drying stresses and is a property of liquids, thus by freezing an item and placing it in a vacuum the water will pass from a solid to the gaseous state and by-pass the problem. Three factors make this approach unattractive in its unmodified form. Firstly,water can expand by 12.5% (by volume) on freezing thus causing internal rupturing in the wood (Ambrose, 1976:8). The second is that the freeze dried wood is hydroscopic and on removal from vacuum will absorb moisture in a way that sets up intense stresses and thus causes post-drying rupturing (ibid., and Rosenquist, 1959:66). Despite these observations I have had some success with this method on small, highly (and evenly) degraded samples as has Till (1980).

The third factor is the behaviour of water inside, intact cell walls. In the case of relatively intact or sound cell walls, freeze drying actually can increase shrinkage (Eriksen, Schmidt and Laing, 1968) compared

to shrinkage during oven drying. This is due to the fact that water will supercool in the ultrafine capillaries in the cell walls and will boil off under vacuum causing excessive shrinkage (ibid., and Grattan and McCawley, 1982:261).

The modifications to the freeze drying method introduced to avoid the excessive shrinkage problem come under the heading of combination bulking/sublimation techniques and are considered below.

19. Sublimation from t-butanol (Christensen 1970:29)

Tertiary butanol is a liquid with some interesting properties in the field of conservation. It freezes at approximately 25°C, boils at 80°C, is miscible with water in all proportions and does not expand on freezing. If the water in the artefact is replaced with t-butanol, one can freeze the object at nearly room temperature and remove the t-butanol by sublimation with only a very modest vacuum. Attempts to use this method have not been very successful

(Rosenqvist 1959), perhaps due to post drying distortion and cracking mentioned above.

20. 'Autosublimation' of camphor (Christensen 1970:90)

In this method water is replaced by methanol and then synthetic camphor is added slowly, the temperature being raised to 40°C towards the end of the process. A concentration of 75 to 80% camphor can be reached. The artefact is then removed from its bath and the methanol is allowed to evaporate and the camphor to slowly sublime (as it will do at room temperatures and normal atmospheric pressures).

COMBINATION BULKING/FREEZE DRYING METHODS

Freeze drying directly from water has been shown above to be unsuitable as a conservation technique. The same applies to t-butanol. Drying from ethyl ether and sublimation from camphor are successful methods but impractical except for very small items. The principles of the above methods, however, are clearly good ones and the methods described below combine them with various forms of bulking techniques to produce some of the most satisfactory methods that have been developed to date for conserving waterlogged wood.

21. Tertiary butanol/PEG 4000/sublimation method

This method was specifically developed to deal with difficult cases of conservation (Christensen 1970:91) and has come to be regarded as the surest and most effective way of treating smaller objects (Sawada 1981). The artefact is slowly dehydrated in tertiary butanol until all the water is replaced. PEG 4000 is added to the bath until up to 60% concentration is reached. Warming the solution to approximately 54°C will allow rapid assimilation of the PEG. The artefact is then removed from the bath and the excess PEG is washed off. The artefact is then frozen, either in a freezing chamber or using liquid nitrogen (ibid.). The tertiary butanol is then drawn off as a vapour under vacuum. Surplus PEG is then either heated with an infra-red lamp making it melt and able to be absorbed into the wood, or sponged off with a cloth soaked in tertiary butanol (if a lighter colour is required).

The t-butanol method has some very attractive features. Penetration of the PEG 4000 is much faster than when it is dissolved in water. This is because at 55 - 60°C t-butanol is less viscous than water and, more importantly, the t-butanol/PEG complex

appears to be smaller than the water/PEG complex since considerable bulk is added by water molecules attached by hydrogen bonds to form a large solvent shell (Brownstein 1982:279). Studies on the bonding of cations to PEGs show that reactivity is much greater in methanol than in aqueous solutions, suggesting that fewer bound molecules are present. The steric bulk of the t-butyl groups would severely limit the number of bound t-butanol molecules ensuring a small size for the complex. Discolouration of the PEG that is so common in heated aqueous solutions is not a problem in tertiary butanol.

The t-butanol/PEG 4000 method gives good dimensional stabilisation with almost no changes occurring during treatment or during subsequent storage. Colour and surface detail retention are also very good. Due to the use of the moderately volatile t-butanol, considerable safety precautions are necessary and only the smaller items can be dealt with by this method though one facility for the treatment of larger objects has been set up in Denmark. A variation of this method is to replace the PEG with a hard wax mixture (Christensen 1970:94).

22. Freeze drying from a dilute PEG400 solution

This method was developed by Ambrose who felt that freeze drying from water was the most direct and satisfactory approach to wet wood conservation on ethical grounds (Ambrose 1971, 1972, 1975, 1976). In this method the expansion of water on freezing is modified by the diffusion of a quantity of PEG 400 into the artefact in a heated bath. As PEG 400 is a small molecule it diffuses readily into wood. After impregnation with PEG the artefact is frozen and placed in a vacuum chamber and the water vapour is drawn off. Ambrose's initial results were good and subsequent tests showed that this was indeed a very attractive method (Rosenqvist 1975). The materials involved (i.e. water and PEG 400) are both non-toxic and non-volatile allowing their use on a large scale. The only size restriction is with the size of the vacuum chamber.

Subsequent work on freeze drying has clarified the nature of the process (Grattan and McCawley 1982:261). Inside the wood, the liquid (for example, a 25% PEG/ water by weight mixture) will behave in the following way below 0°C. Crystals of pure water will form in the cell lumen yielding a slurry of ice crystals in

a liquid composed of supercooled water and PEG 400. This occurs only in the cell lumena as the cell wall voids are too small to allow any freezing. When the artefact is placed in a vacuum the ice will sublime from the cell lumena and the water/PEG mixture is left behind. After the water is removed (by boiling) from the cell walls, the PEG 400 is deposited in them replacing the bound water and preventing cross bonding of OH^- groups (Ambrose 1973). In Ambrose's original method, between 5 - 15% by weight PEG was used in the impregnation bath but subsequent research (McCawley 1982) has shown that between 25 - 30% PEG will achieve much greater shrinkage restraint. A modification of this method for highly degraded wood has recently been reported (Murray 1982:14) involving PEG 4000 instead of PEG 400.

With the above method reliable and good quality conservation can be achieved in small to medium sized artefacts, the maximum size being restricted only by the size of the vacuum chamber. This restriction can be avoided by the use of non-vacuum freeze drying. Ambrose experimented with non-vacuum freeze drying but abandoned it since the rate of drying is slower than vacuum drying by a factor of four (Ambrose 1975:10).

This time difference is not as critical as it might seem since the impregnation time for the PEG can be as long as 12 to 18 months (ibid.). Furthermore, it has been noted that in the central Canadian winter climatic conditions are suitable for 'natural'freeze drying for at least three months of the year (Grattan and McCawley 1978) and subsequent experiments have shown that this is feasible for artefacts (Grattan, et. al., 1980). Further developments have included a simple and cheap way to modify domestic chest freezers to perform non-vacuum freeze drying and the use of commercial freezing units (e.g. refrigerated truck containers) for the same purpose (ibid., Murray 1982).

ASSESSMENT OF METHODS

The following section will give an assessment of the conservation techniques that are currently preferred by conservators, in terms of their aesthetic, practical and financial attributes. From the practical point of view the choice of a method for a particular operation is determined by a very large list of factors. There is no possible book of remedies which

can tell you which is the best but, rather, treatments are prescribed as a doctor would do so for a patient, taking all factors into consideration.

The main points to be taken account of are

1. the size of the object
2. the state of decay of the wood
3. the type or species of wood (for sound wood only)
4. the appearance and handling properties that are desirable in the finished work.

Secondary considerations include

1. the cost of the process
2. the time it will take
3. facilities, materials and trained staff available at the time
4. the intrinsic value of the artefact
5. storage space available for the object prior to conservation.

If one assumes that it is desirable to conserve the artefact by the best method with no expense spared, that the staff and facilities are available

and time is not a factor, then it is possible to consider the possibilities in terms of size of the artefact.

Small items

These can be defined as those that are small enough to be treated inside a fume cupboard, i.e., roughly a maximum of one metre long and perhaps .25 metres in diameter. Some of the possible techniques are listed below.

(a) Hard wax embedding

(b) Acetone/rosin

(c) Alcohol/ether/resin

(d) T-butanol/resin/sublimation

(e) T-butanol/PEG 4000/sublimation

(f) Water/PEG 4000/sublimation

(g) Water/PEG 400/sublimation

The first five all involve baths of volatile solvents, some of them, e.g., diethyl ether, quite dangerous. The hard wax or resin techniques produce a good hard, dry, finish but retain surface detail less well than the sublimation techniques and also involve a lesser degree of control over shrinkage during treatment. The sublimation techniques give excellent

shrinkage restraint and are the best for highly degraded objects especially where retention of fine surface detail is essential. The resin impregnating methods might be more suitable for sound wood of simple surface shape where ruggedness is required after conservation.

Medium Sized Objects

These could be roughly defined as larger than one metre in length but small enough to be placed into the largest freeze drying chamber available in the New Zealand situation, i.e., less than four metres long and perhaps half a metre in diameter. The methods available are much more limited for such objects. Although large scale facilities have been developed to handle t-butanol it is unlikely that these would be available in New Zealand in the immediate future. In the absence the following methods would be suitable.

(a) PEG 4000/hot bath treatment

(b) PEG 4000/water/sublimation

(c) PEG 400/water/sublimation

(d) Slow drying/PEG 540 blend painting

For sound wood, slow drying/painting PEG 540 blend is suitable. For artefacts that contain both degraded and sound wood, the PEG 400/freeze drying would be best, while for uniformly well degraded items the PEG 4000/freeze drying technique might be applicable as the higher molecular weight grade would be able to enter the wood in that state of decay. For artefacts of medium size the PEG 4000 hot bath technique is possible but less attractive due to the disadvantages of this method listed previously.

Large items

These could be defined as those that are too big to enter a freeze drying chamber but small enough to be transported to a laboratory for treatment. For these items the same methods are suitable as for the medium sized items except that non-vacuum freeze drying would have to be employed using commercial size freezers. Due to the difficulties in obtaining access to such freezers the PEG 4000 hot bath treatment becomes a more attractive alternative for highly degraded items where the quality of surface detail is not absolutely vital.

Super Large Items

These include ships or very large canoes that cannot be readily transported nor easily placed in a tank. For these objects slow drying with PEG 540 blend painting is an acceptable technique but only if the artefacts are made of wood that is relatively sound. For more difficult jobs, such as wooden plank boats held together with iron nails, the problems increase to a point where solving them is a task for a well funded institution specifically set up for the purpose, e.g., the Mary Rose Trust which is engaged in raising and conserving King Henry VIII's flagship in Portsmouth, England.

CONCLUSIONS

From the detailed review of the techniques of conservation that has been presented above it should now be possible to set out precisely what the local conservator needs to know about New Zealand woods and conditions before he can prescribe a suitable treatment for a particular artefact.

CHAPTER FIVE

THE UTILISATION OF WOOD BY THE PRE-EUROPEAN MAORI

INTRODUCTION

Though New Zealand possesses about 550 species of woody plants it is reasonable to suppose that the pre-European Maori would have been very selective in choosing woods for most of their artefact types. The following chapter describes the work done to identify which species were chosen and the specific uses for each. The general characteristics of New Zealand native timbers are discussed in comparison to those of Northern Hemisphere temperate latitudes where most previous wood conservation work has been done. This is followed by a description of wood identification techniques and the way in which this author handled them. The results of a survey of pre-European Maori wood use involving over one thousand wooden artefacts from museum collections in this country are then presented along with a discussion for each artefact type. A short list of the woods commonly utilised by the pre-European Maori is presented, followed by a description of the collection of samples of each wood type in a variety of states of decay. These samples were used in detailed studies of wood properties.

WOOD TYPES IN NEW ZEALAND

As a general rule gymnosperms produce low to medium density woods for the following reasons. Their wood is primarily composed of tracheid cells whose function is to provide both mechanical support and water transport in the tree trunk. The need to ensure water flow down the centre of the cell limits the thickness of the cell walls which, in turn, limits the wood's density. In temperate northern latitudes, gymnosperms are referred to as softwoods, an appellation not always logical elsewhere. For example, there are at least two New Zealand native gymnosperm species (matai and miro) that produce wood denser than white oak, a wood referred to in Europe as a hard, dense timber.

Angiosperms are often referred to as hardwoods, as all very dense woods come from that group. However, angiosperms also produce a complete range of possible types in terms of density. For example, balsa is a 'hardwood'. The reason why oak is regarded as a dense wood in Europe, is because there are very few timbers native to that region that produce truly dense timbers.

New Zealand angiosperms have a very wide range of different wood types including an important group that yields very dense woods. These were important to the prehistoric Maori who used them in situations where we would use metal. Consequently, we can expect to find woods of a type that are not often found in temperate Northern Hemisphere sites occurring in large numbers in New Zealand.

WOOD IDENTIFICATION

The only reliable way to identify swamp wood is by thin section microscopy. Each wood species usually has characteristics of its cell anatomy that can be used to distinguish it from all others. Wood samples are softened with hot water and thin sections cut with either a hard backed razor blade, a scalpel or a wood microtome. The sections can be cut from each of the three anatomical planes of the wood. The sections can then be cleared of intra-cellular debris by leaching with 3% sodium hypochlorite in water, washed, stained with Johansen's saffranin and examined under a microscope at magnifications of between 60 and 600 diameters. Often wood species can, however, be determined simply by examining untreated sections mounted in water.

The author learnt wood identification techniques at the Forest Research Institute at Rotorua under the guidance of Dr J. Harris, Deputy Director, Forest Products Division. This involved learning the techniques and preparing a comparative collection of permanently mounted thin sections that included about 50 of the commonest New Zealand native species. The gymnosperms were learnt at Rotorua but the angiosperms were mastered later with the aid of the comparative collection.

Recognition of wood species varies in difficulty but, fortunately, recent work on local wood anatomy (Patel 1973a, 1973b, 1973c, 1974a, 1974b, 1974c, 1974d, 1975a, 1975b, 1975c, 1978, Patel and Bowles 1978, Meylan and Butterfield 1980) has made identification of the commoner species relatively simple. For practical purposes, Patel's papers on the gymnosperm cell anatomy and Meylan and Butterfield's scanning electron micrographs of the angiosperms were used to identify the wood.

The difficulties encountered are mostly of two types. Firstly, wood from the surface of artefacts taken from anaerobic environments is often highly

degraded and has often suffered cell collapse. This can make wood recognition hazardous particularly where one is attempting to separate woods that have very similar cell anatomies. The two species that presented the most difficulty in this respect were rimu and totara. As a consequence much artefact wood was only identifiable to the rimu/totara level. The second problem concerned species whose cell anatomy is identical within a genus. An example of this is some of the members of the genus *Myrsine*, where *M. australis* is not distinguishable from *M. salicina*. The former is, however, a much commoner species than the latter and the identification is given as '*Myrsine* sp. (probably *M. australis*)'.

Samples to be used for the preparation of thin sections were taken from the selected artefacts by inserting the tip of a 6 mm chisel in a surface fissure and levering out a small block of wood. This task was made easy by the fact that swampwood artefacts normally have a chequered and split surface. These samples were taken at the museums where the artefacts are held and then taken to the laboratory at Waikato University for identification.

RESULTS

About one thousand pre-European Maori wooden artefacts from five separate museum collections were subjected to wood identification procedures. The museums were: Auckland War Memorial Museum, Auckland; Waikato Art Museum, Hamilton; Te Awamutu and District Historical Society Museum, Te Awamutu; Taranaki Museum, New Plymouth and Otago Museum, Dunedin.

A summary of the results is given in Table Two. Some of the names of the artefact types listed require explanation. 'Canoe gear' refers to everything involved with canoes except the hulls and the paddles, i.e., thwarts, bailers, bow and stern pieces, masts, outriggers, etc.

Mallets are small clubs used for hammering chisels. Adze sockets are wooden sleeves that fit over the butts of the adzes and are lashed to adze hafts. 'Shovels' have been various described as shovels, push hoes and kumara mounding implements (Best 1976:49). Ketu are weeding tools shaped like miniature paddles. Ko are digging sticks and teka are their foot rests. Hoko is a loose generic term for spade-like implements. Wakahuia are small boxes for storing valuables. Firemaking gear involves a flat slab of wood with grooves in it and a

pencil shaped piece of wood that is rubbed up and down in the groove to create an ember. The Te Miro causeway timbers are a single collection of items that buttressed the earthwork construction concerned.

The wood terminology in Table Two also requires some refinement and explanation. The term kauri refers to two completely different types of wood produced by the same tree species. Normal trunk wood kauri is a soft, straight grained timber but most of the artefacts made from kauri in Table Two are of branch heartwood. This latter wood is considerably denser than the trunk wood and, furthermore, is almost totally impregnated with a hard brittle resin. The resulting material bears little resemblance to the commercial kauri timber we are familiar with today. The branch wood was used for fernroot beaters, bark beaters, mauls, and weapons, while the horticultural implements, house timbers, carved house panels and palisade posts were made from the trunk wood.

A similar situation applies to a type of kahikatea called 'mapara' (Best 1977:154-7). This is resin impregnated timber that can be found by cutting open rotten kahikatea logs found in the bush. This form of kahikatea was used for the spinning tops.

TABLE TWO: Prehistoric Maori Utilization of Timbers

SCIENTIFIC NAMES	COMMON NAMES	HOUSE TIMBERS	CARVED PANELS	PALISADE POSTS	BOWLS, CONTAINERS	CANOES	CANOE GEAR	FERN ROOT BEATERS	MALLETS	TAPA BEATERS	MAULS	PADDLES	ADZE HAFTS	ADZE SOCKETS	WEAPONS	EEL CLUBS	KAHERU SHAFTS	KAHERU BLADES	KETU	KO	TEKA	HOKO	SPINNING TOPS	WAKA HUIA	BONE BOXES	COMBS	FIRE MAKING GEAR	TE MIRO CAUSEWAY TIMBERS	MISCELLANEOUS ITEMS	TOTALS
Agathis australis	Kauri	16	1	1				72		5	4				3				1	1		2								106
Podocarpus spicatus	Matai	5	1	5	40	2	3	10			4		5				10			1			2					1		89
	Rimu/Totara or Kahikatea	14	9	1	9	1	4	12		1	1		12				1			2	1	4	1	3	3			1	2	82
Podocarpus totara	Totara	24	12	7	13	2	22					2	5			1	1		1	1		4		2	7				10	114
Dacrydium expressinum	Rimu	15		1	3	3	1				1		8													10			1	43
Phyllocladus sp.	Tanekaha or Toatoa	3		4	2			4			2		3			1					1								1	21
Dacrydium Kirkii	Monoao				2								2							1				1	1					7
Libocedrus sp.	Pahautea or Kawaka							1			2										1									4
Podocarpus dacrydioides	Kahikatea				1																		4							5
Podocarpus hallii	Hall's Totara	1			2	1	1					1	5											1						12
Podocarpus colensoi	Silver pine	1																		1										2
Unidentifiable woods			2										1								7									10
Leptospermum scoparium	Manuka				1		1	4	2		3	7			5	2	1		20	54	1	8							2	111
Leptospermum ericoides	Kanuka							5				17		1	3	1		2	22	30	2	4	1						1	89
Nestegis sp.	Maire				2			19	2		6				7	3		14	7	7	1	5							1	74
Metrosideros sp.	Rata & Pohutukawa		1					3			13	2			3	1			2	6	1		1						5	38
Myrsine sp.	Mapou (probably)							3			1		1	8	1					21	6									41
Beilschmiedia tawa	Tawa	4		4			1						1			3			3						4			6	1	27
Laurelia novae-zelandice	Pukatea	10		4	5						2					1						1								23
Vitex lucens	Puriri			3	1			2				4	1	1				1		1		2								16
Hedycarya arborea	Porokaiwhiria	6															1			4	1							1		13
Dodonaea viscosa	Akeake														4					1		1								6
Myrtus bullata	Ramarama												2	1							2									5
Knightia excelsa	Rewarewa				1						1																	1		3
Sophora microphylla	Kowhai				4							1			1															6
Brachyglottis repanda	Rangiora							1													1									2
Weinmannia racemosa	Kamahi							2																						2
Carpodetus serratus	Putaputaweta																			1										1
Hebe sp.																				1										1
Schefflera digitata	Pate, sevenfinger													1																1
Coprosma sp.																					1									1
Melicytus ramiflorus	Mahoe			1																										1
Ascarina lucida	Hutu							1																						1
Olearia sp.											1																			1
Beilschmiedia tarairi	Tarairi														1						1								1	3
Pseudopanax crassifolium	Lancewood																				1									1
Planchonella novo-zelandica	Ironwood										1																			1
Dracophyllum sp.																													1	1
Griselinia littoralis	Kapuka																									4				4
Hoheria sp.	Lacebark																												1	1
	TOTALS	99	26	31	86	9	33	139	4	6	42	34	46	12	28	13	14	17	56	133	28	31	9	7	15	10	4	10	27	969

Another distinction could be made between wood from the trunk of the tree and branch wood. Some artefact types are exclusively made from one or the other whereas others can be made from both. An example of the latter is the 'shovel' shafts. The ones made from matai or totara were made from trunkwood while the one made from manuka and the one made from porokaiwhiria (*Hedycarya arborea*) were made from whole natural stems.

WOODS USED IN ARTEFACTS

House timbers are mostly made from sections of gymnosperm trunks with a few smaller timbers being made from angiosperm woods. Wood use can vary enormously between different sites even when they are in the same geographical area. An example of this feature is the collections from three sites that are within 80 km of each other in the central North Island. These are Mangakaware, Te Miro and Patetonga whose building timber identifications are shown below in Table Three. This shows that while it may be possible to make general statements about wood preferences, each individual site may have its own pattern.

TABLE THREE: Woods used for house timbers at three archaeological sites

SPECIES	SITES		
	Mangakaware	Te Miro	Patetonga
Agathis australis	1	-	14
rimu/totara	8	3	-
Podocarpus totara	2	10	3
P. spicatus	2	2	-
Dacrydium cupressinum	1	12	-
Phyllocladus trichomanoides	-	3	-
Laurelia novae-zelandiae	6	1	-
Beilschmiedia tawa	1	2	-
TOTALS	21	33	17

Carved house panels are made predominantly from totara, though matai and kauri were also occasionally used and sometimes an odd timber like the one example of rata as well.

Palisade posts appear to have been made from all the suitably sized timbers available on the spot. For example, the posts from Te Miro and Mangakaware, as shown below on Table Four, reflect the lowland forest environment where these sites were located.

TABLE FOUR: Woods used for palisade posts at Mangakaware and Te Miro

SPECIES	SITES	
	Mangakaware	Te Miro
Podocarpus totara	1	2
rimu/totara	-	1
Dacrydium cupressinum	-	1
P. Spicatus	4	1
Phyllocladus trichomanoides	1	-
Laurelia novae-zelandiae	4	-
Beilschmiedia tawa	-	4
Melicytus ramiflorus	1	-

Bowls, troughs and other wooden containers are predominantly matai with totara as a less popular option. Gymnosperms make up 71 of the 85 containers identified with pukatea, in the Waikato, and kowhai, in Otago, being the only popular angiosperms.

The river canoes sampled were made from a variety of large diameter gymnosperm logs; rimu, matai, totara and Hall's totara in particular. The miscellaneous canoe gear was mostly of totara with only the two canoe thwarts being made from angiosperms.

Fern root beaters were made from the twisted, knotty branch heartwood of kauri where this species was available. In Northland, Auckland, Thames and Coromandel, where kauri were abundant, only two of the 48 beaters sampled were made from other woods. Where kauri was not available it was replaced with a variety of the harder gymnosperms and the denser angiosperms. This pattern was found in Taranaki while in the Waikato there was the mixing of the two traditions as kauri was available only in some areas. The pattern of wood use in fern root beaters is shown below in Table Five.

Mallets were made from tough, dense angiosperms such as manuka and maire while bark beaters were made from kauri branchwood (in Northland) and rimu in Taranaki.

Mauls were made from a variety of woods, most of which were the toughest and heaviest ones available. Thirteen species were found to have been used, with rata, manuka and maire being the most popular.

Paddles were mostly made from kanuka or manuka with puriri, rata and kowhai being used less often.

TABLE FIVE: Regional wood use in fern root beaters

SPECIES	SITES			
	Northland/ Auckland	Thames/ Coromandel	Waikato	Taranaki
Agathis australis	29	17	26	-
Phyllocladus trichomanoides	-	-	4	-
Podocarpus spicatus	-	-	7	2
rimu/totara	-	-	8	3
Dacrydium cupressinum	-	-	-	1
Nestegis cunninghamii	-	-	13	6
Leptospermum scoparium	-	-	4	-
Vitex lucens	-	-	-	2
Metrosideros robusta	-	-	3	-
Leptospermum ericoides	-	-	5	-
Weinmannia silvicola	-	-	2	-
Ascarina lucida	-	-	1	-
Brachyglottis repanda	-	1	-	-
Myrsine sp.	1	-	-	-
TOTALS	30	18	73	14

Adze hafts were primarily made from gymnosperm branchwood while the adze sockets were made from the heavier angiosperm woods (see Wallace 1982). Weapons were made from the heaviest woods available in contrast to the eel clubs which were made from scrap wood and seemed to have no particular pattern of species preference.

Kaheru (the shovel/push hoe/kumara mounding implement) showed a very clear pattern of wood selection. Ten of the 14 shafts were of matai while 14 of the 17 blades were made from maire. In a similar fashion, the weeders (ketu) were almost all made from manuka or kanuka. Ko, the digging sticks, showed some interesting patterns of regional variation as can be seen in Table Six. Some of the variations can be accounted for by reference to the way in which the different museum collections were accumulated. The Auckland collection had derived, mostly, from private collections, while the Taranaki one had come mainly from archaeological sites. Certain woods, such as *Myrsine* sp. (probably *M. australis*, the commonest one), do not survive the rigors of burial so well as others and suffer disfiguring splitting when they are dried out so, consequently, they are unlikely to have reached

the Auckland collection. On the other hand there are species present in the Waikato and Taranaki that are absent from the Auckland collection that would have survived perfectly well. After considerable reflection, the author feels that the pattern of wood use illustrated in Table Six is mainly a result of ecological variation whereby a dominance of regrowth scrub species used in the north and the east, with an increase of forest species, such as rata, along the west coast as one proceeds south reflects the prehistoric vegetation patterns. The effects of selection practices of the different museums is felt to have been of less importance in creating the patterns shown in Table Six.

The teka (ko footrests) include at least 14 wood species out of a total of 28 artefacts indicating that there were no preferences for any particular species in operation. One would suspect that it was the shape of the wood that was important and when a suitable piece was found it was used no matter what the wood species was.

Ten out of the 31 hoko (spade like implements) were made of gymnosperms, though there was a general preference for dense woods.

TABLE SIX: Regional Patterns of Wood Use in Ko (Digging Sticks)

SPECIES	SITES		
	Northland to Coromandel	Waikato	Taranaki
Leptospermum scoparium	34	11	8
L. ericoides	15	6	9
Myrsine sp.	-	6	15
Nestegis sp.	1	2	4
Metrosideros sp.	1	2	3
Vitex lucens	-	-	1
Dodonaea viscosa	1	-	-
Carpodetus serratus	-	1	-
Hedycarya arborea	-	-	4
Hebe sp.	-	-	1
rimu/totara	-	2	-
Podocarpus spicatus	-	1	-
P. totara	1	-	-
Dacrydium kirkii	1	-	-
D. colensoi	-	1	-
Agathis australis	1	-	-
TOTALS	55	32	45

Tops were made of the harder, denser gymnosperm woods, matai and 'kapara'. Kapara, as mentioned earlier is resin impregnated kahikatea. Wakahuia were mostly made from totara, but monoao and Hall's totara were also used. Totara was also popular for bone boxes, though tawa (an unusual choice for carving) was used as well.

The combs, which were all from the Kauri Point swamp site mentioned in Chapter One, were all made from rimu. The fire making gear, all from Otago, was made from kapuka *(Griselinia littoralis)*.

WOOD SPECIES AND TYPES COMMONLY USED BY THE PRE-EUROPEAN MAORI

A list of the wood species that were important to the pre-European Maori can be derived from the right hand side of Table Two. When the information concerning the anatomical part of the tree used in each instance is included, one can provide a list of the important wood types. This list is given in Table Seven.

As can be seen from Table Seven, it was common for the same tree species to provide more than one wood type (e.g., trunk wood and branch wood). Some of the woods, however, escape the classifications

provided. For example, some of the ko were made from rata (*Metrosideros robusta*) in the form of the aerial roots that later coalesce to form the trunk of the tree. This, however, cannot always be confirmed in the artefacts examined in the wood utilisation survey as there was often no surface evidence as to the anatomical origin of the wood used.

COLLECTING SAMPES OF EACH WOOD TYPE

Ideally one would like to collect several samples of each type of wood in a range of states of decay, from sound, modern wood through to highly degraded swamp wood. In practice it would be impossible to find all these different types and, furthermore, there being so many it would be difficult to complete tests on density, shrinkage and directional penetrability for all of them. In the event it was decided to collect as many as was possible in the time available. Approximately 164 samples were finally assembled from a variety of sources, mainly timber merchants, friends and from the author's own collecting efforts. Other material was donated from museum collections.

These samples are listed and described in Appendix One. They cover most of the types listed in

Table Seven with a suitable number of samples of the more important species. A reasonable range of samples in various states of decay were collected for some species. The results of tests on density and shrinkage are reported in the following chapter.

TABLE SEVEN: List of woods that were important to the prehistoric Maori

WOOD TYPES	SPECIES NAME
1. Kauri branch heartwood	*Agathis australis*
2. Kauri trunk heartwood	" " "
3. Matai trunk heartwood	*Podocarpus spicatus*
4. Matai branchwood	" " "
5. Totara trunk heartwood	*P. totara*
6. Totara branchwood	" "
7. Rimu trunk heartwood	*Dacrydium cupressinum*
8. Rimu branchwood	" " " "
9. Tanekaha trunkwood	*Phyllocladus trichomonoides*
10. Tanekaha branchwood	" " " "
11. Monoao trunkwood	*D. kirkii*
12. Kawaka trunkwood	*Libocedrus plumosa*
13. 'kapara' (resinous kahikatea)	*P. dacrydioides*
14. Hall's totara trunkwood	*P. hallii*
15. Hall's totara branchwood	" "
16. Manuka stems	*Leptospermum scoparium*
17. Kanuka stems	*L. ericoides*
18. Kanuka trunkwood	" "
19. Maire branchwood	*Nestegis* sp. (prob. *N. cunninghamii*)
20. Rata or pohutukawa branchwood	*Metrosideros* sp.
21. Mapou stems	*Myrsine* sp. (prob. *M. australis*)
22. Tawa trunkwood	*Beilschmiedia tawa*
23. Tawa branchwood	" " "
24. Pukatea trunkwood	*Laurelia novae-zelandiae*
25. Puriri branchwood	*Vitex lucens*
26. Porokaiwhiria stems	*Hedycarya arborea*
27. Akeake stems	*Dodonaea viscosa*
28. Ramarama stems	*Myrtus bullata*
29. Rewarewa trunkwood	*Knightia excelsa*
30 Kowhai trunkwood	*Sophora microphylla*

CHAPTER SIX

THE DENSITY AND DIRECTIONAL SHRINKAGE OF NEW ZEALAND WOODS

INTRODUCTION

The reasons for measuring the density and shrinkage of the woods important to the pre-European Maori have been given in Chapter One and will not be repeated here. The first matters covered are the techniques used in this study to measure density and directional shrinkage. A description of each sample tested and a list of the results obtained is contained in Appendix Two. These results are analysed and discussed under the following topics: resin content of the wood and other sources of error; average timber densities; average total timber shrinkages; the relationship between density and shrinkage in samples; the effects of partial degradation on the density and shrinkage; the different types of progress of decay; the ratios of tangential to radial shrinkage; and lastly, the changes in this relationship resulting from partial degradation.

TECHNIQUES

Wood density can be measured in a variety of ways. In the timber industry weight per cubic foot air or kiln dried is often used (Entrican et. al., 1951:29). Many methods can be used to measure degradation in waterlogged wood ranging from inserting a pin to plot the distribution of highly degraded wood in an artefact through to very objective measurements such as X.R.D. analyses which measure the crystalinity of cellulose (Head 1979:85-92).

The standard technique in wood conservation is to express density as water content by weight of saturated wood (ibid., and Barkman, 1976:50). This can be either expressed as a percentage of dry or wet weight. In the former case values of over 100% are often found and for ease of comprehension, the latter form is used throughout this study.

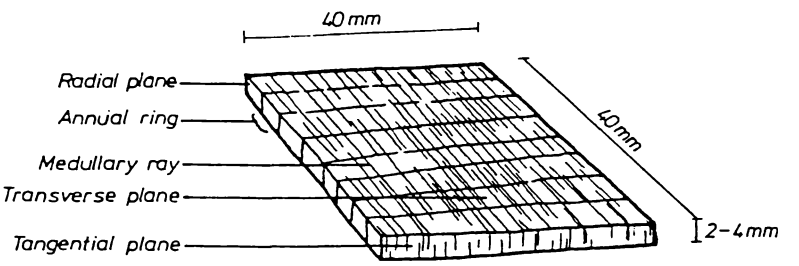
In some cases the above values are converted to pore volume percentages using the fact that the density of water and wood substance are known. The latter has a specific gravity of circa 1.56 in all states of decay and thus P = 156 x u/u x 1.56 + 100

where P = % pore volume and u = maximum water content (Barkman 1976:50). Such calculations are of value when estimating the amount of consolidant required to achieve bulking in the wood.

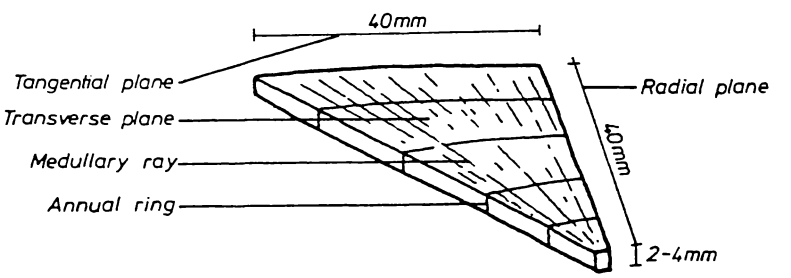
In this research density and directional shrinkage was measured in a single operation. In density determination the main problem is obtaining a fully saturated sample. As water penetrates wood along the grain many times faster than across it, samples were prepared by cutting them into slices 2-3mm thick across the grain so that water had to travel only 1.5mm to reach the centre.

The samples were from 30-50mm wide and trimmed so that their edges followed the radial and tangential planes of the cell anatomy. This meant that the samples were square or rectangular when they were made from trunk wood (where these planes are approximately at right angles) but are triangular where small diameter branch and stem wood was involved. This is illustrated in Figure Five.

The samples were sanded down with very fine sand paper so that water could be blotted off their surfaces completely. They were saturated with water in the



(A) Trunkwood sample



(B) Branchwood or stem wood sample

FIGURE FIVE: Sample preparation for density and shrinkage determination

following way. To give accurate results complete saturation is necessary. A variety of methods were experimented with including prolonged soaking, however, this proved slow for many wood types and two methods were used to speed up water penetration.

The first of these involved soaking the samples in ethyl ether for several days, washing them in water and dropping them in boiling water. Ethyl ether has a very low surface tension and penetrates the wood rapidly and thoroughly. The boiling dries off the remaining ether and air. The process was completed by soaking the samples overnight in water.

This method gives rapid and complete saturation of the wood samples but has a drawback, however, in that when the ether used was evaporated it was found that significant amounts of resin had been extracted from a few gymnosperm woods. This led to the use of a second method for those woods involving cycles of alternate boiling and vacuum extraction to remove air. This was much more laborious but constant weight was achieved for all samples in 20 cycles.

When the samples were completely waterlogged they were removed from the water, blotted, weighed on an analytic balance and measured with a pair of calipers along their radial and tangential planes. In this latter process the measurements were between two marked points as trials using metal pins as measuring points resulted in unacceptable cracking when the samples were dried. The samples were then dried in an oven at 105°C for two days. They were then re-weighed and re-measured. The results were represented in the following ways. Density was represented as per cent,

by weight, water content at full saturation. Shrinkage was represented firstly, as per cent shrinkage from the saturated to oven dried condition for both tangential and radial dimensions and, secondly, an estimate of the volumetric shrinkage calculated by using the above two values. The latter figure was calculated by taking a theoretical cube of wood with no longitudinal shrinkage on drying, (a situation close to reality with sound wood) and assuming perfectly symmetrical shrinkage. Using the radial and tangential shrinkage values a volumetric shrinkage value can be obtained by simple arithmetic. This figure was calculated because it is inconvenient to present the results in plots of shrinkage against density where two separate shrinkage values are present. The experimental errors generated are discussed in Appendix Four (pages 279-284).

Several samples were taken from each of the types of wood listed on Table Eight. The raw results are listed in Appendix Two.

ANALYSIS

The first factor to be considered in relation to wood density is the presence of resins and other wood 'extractives'. These materials can contribute a substantial proportion of the weight of some timbers

and thus affect the calculated density values. The importance of this is greatest where shrinkage is considered, as this factor is related to the amount of basic wood components present whereas the resin does not react with water and either plays no part in shrinkage, or reduces it by mechanically restraining the wood.

In Appendix Two it can be seen that kauri branch wood is the most dense wood studied. This wood, however, is also the one with the most resin. To find out how much was present in one particular sample (No. 119), it was leached with acetone to remove the resin. This was done by soaking the dry sample in acetone and then placing it in boiling water which caused the acetone to be driven off rapidly. Repeated cycles of this treatment yielded declining amounts of resin until no more floated to the surface of the water. The water content, at saturation, of the leached sample was still approximately 25% less than average trunkwood samples. Examination of thin sections of kauri wood indicated that the figure of 25% is reasonable as the branchwood cell walls were visibly thicker than those of the trunk wood. In summary, the kauri branch wood was found to be significantly denser than the trunk wood in terms of

basic wood components, and that the variable amounts of resin present add further weight.

Shrinkage in Sound Woods

As shrinkage is related to the density, in Figure Six the average density of each wood species or type is plotted against its average total shrinkage value. The averages were calculated by taking the average value for the several samples that were tested from each of the woods listed in Table Eight. Where several different examples of each wood type were present a combined average was calculated. Only the woods that were important to the pre-European Maori and only those that were in a sound condition are included in Figure Six.

Figure Six provides the conservator with several important pieces of information. The most critical of these concerns the likely value for density and shrinkage expected for the sound wood, present in an artefact, of known species and type.

It can be seen from Figure Six that all the dense woods are angiosperms and that all the softer woods, with the exception of pukatea *(Laurelia novae-zelandiae)* are gymnosperms. It is not that angiosperms do not

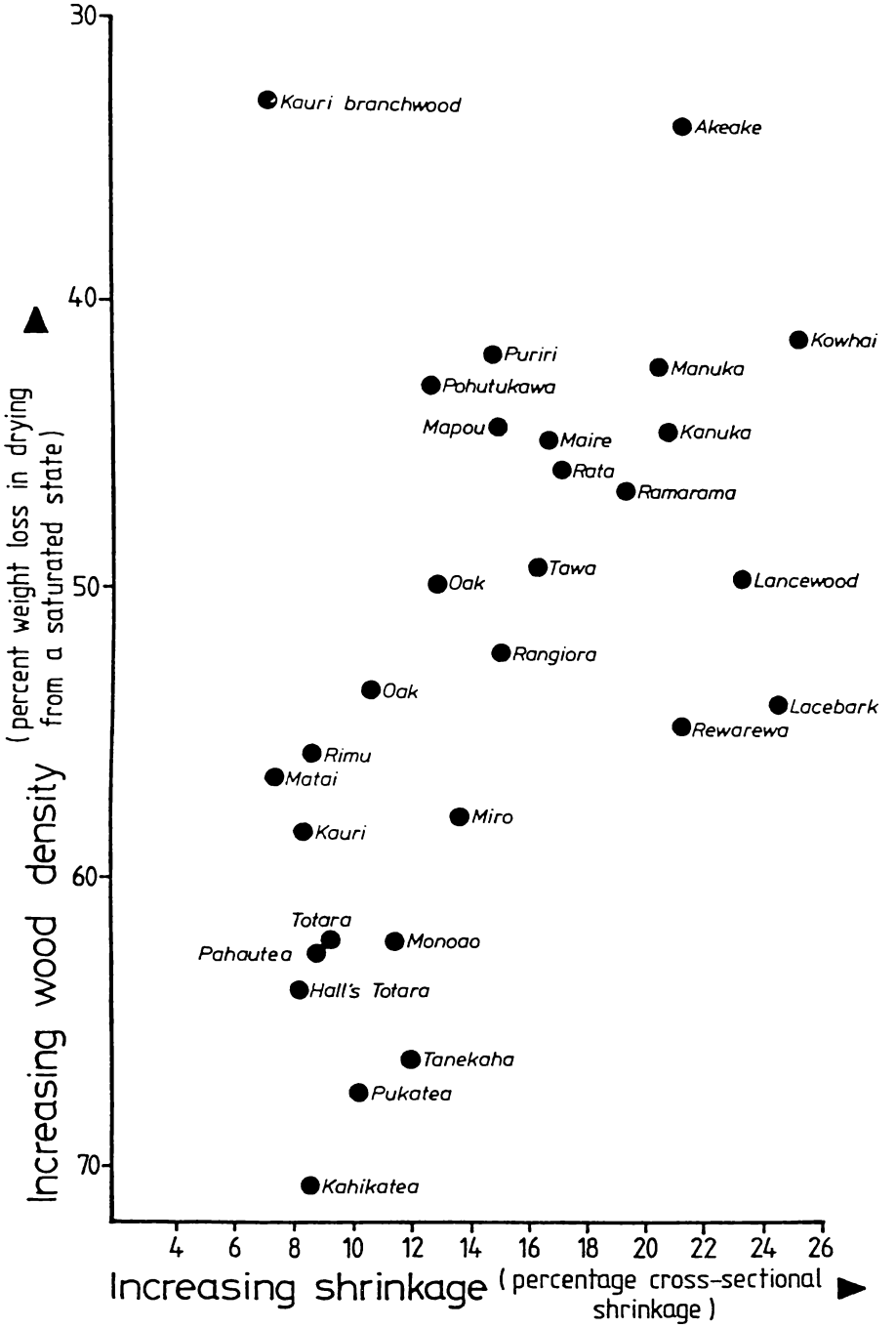


FIGURE SIX: A plot of density against shrinkage for 29 woods. Density is measured as weight loss when oven dried from a saturated state. Shrinkage is the estimated cross section shrinkage occurring during the same drying.

produce soft woods (in fact the softest woods known belong to this group) but rather that the prehistoric Maori rarely used them for their artefacts. The angiosperm woods, being dense, have high, to very high, shrinkages on drying. These range from 10-30% (total) shrinkage. As tangential shrinkage is much greater than radial shrinkage, the wood changes its relative proportions when it is dried. At the higher levels of shrinkage shown on Figure Six, these changes assume major proportions and if an artefact was used by the prehistoric Maori in a water swollen form, any conservation treatment which fails to prevent normal shrinkage will also fail to preserve the artefact in its original shape. In the woods with lower rates of shrinkage, these changes are not so dramatic and artefacts will retain their proportions relatively well.

If the artefacts were in the dry state when they were used, the conservation treatment will have to involve some deliberate shrinkage of similar magnitudes to those shown in Figure Six to restore them to their correct proportions.

The gymnosperm woods shown in Figure Six have values of density and shrinkage that are substantially

lower than those of the angiosperms. The lightest of these, kahikatea and tanekaha, could be regarded as light woods, but the others, particularly rimu and matai, could be regarded as relatively dense woods. In Europe the white oak (*Quercus robur*) is considered to be the producer of a hard, high shrinkage wood, yet in these respects it only marginally exceeds the denser New Zealand native 'soft woods'.

In Figure Six it can be seen that kauri branch wood is the heaviest wood recorded but that its shrinkage values are quite low. This is due to the very high resin content of that wood. Resin adds weight but effects the shrinkage values negatively as it has a partial bulking effect on the wood, restraining shrinkage.

The relationship between density and shrinkage is demonstrated in Figure Six. In general it shows that shrinkage increases with increasing density, but this relationship is rather loose. Some woods appear to shrink more than their density would suggest. Examples of this are rewarewa, kowhai (*Sophora microphylla*), ramarama (*Myrtus bullata*), lancewood (*Pseudopanax crassifolius*), tanekaha (*Phyllocladus trichomanoides*) and pukatea. Others, such as akeake,

puriri, pohutukawa, oak, matai and rimu have a lower rate of shrinkage than their density would suggest. It might be suggested that this characteristic has some relevance to the uses to which these woods were put as excessive shrinkage on drying would greatly complicate the seasoning of smaller diameter timber prior to artefact manufacture.

Variation in Shrinkage

An important thing to point out about Figure Six is that the points on the graph are the result of averaging a set of figures. The number of measurements used in each case is too small to warrant representation in the form of ranges or standard deviations, but to give the reader an idea of what these figures were,a selected series of woods have been plotted in Figure Seven, showing all the individual measurements in each case. It can be seen that for each particular sample, density and shrinkage does vary and that, furthermore, there is often an appreciable difference between examples of the same wood species. Another point is that there is greater variation within samples of swamp wood compared to those of sound modern timber. The magnitude of experimental errors in the figures shown is discussed in Appendix Four on pages 279-284.

The sound swamp wood is represented by manuka (sample No. 68) and matai (sample No. 66). This is possible due to the swamp wood having lost the degree of cohesiveness found

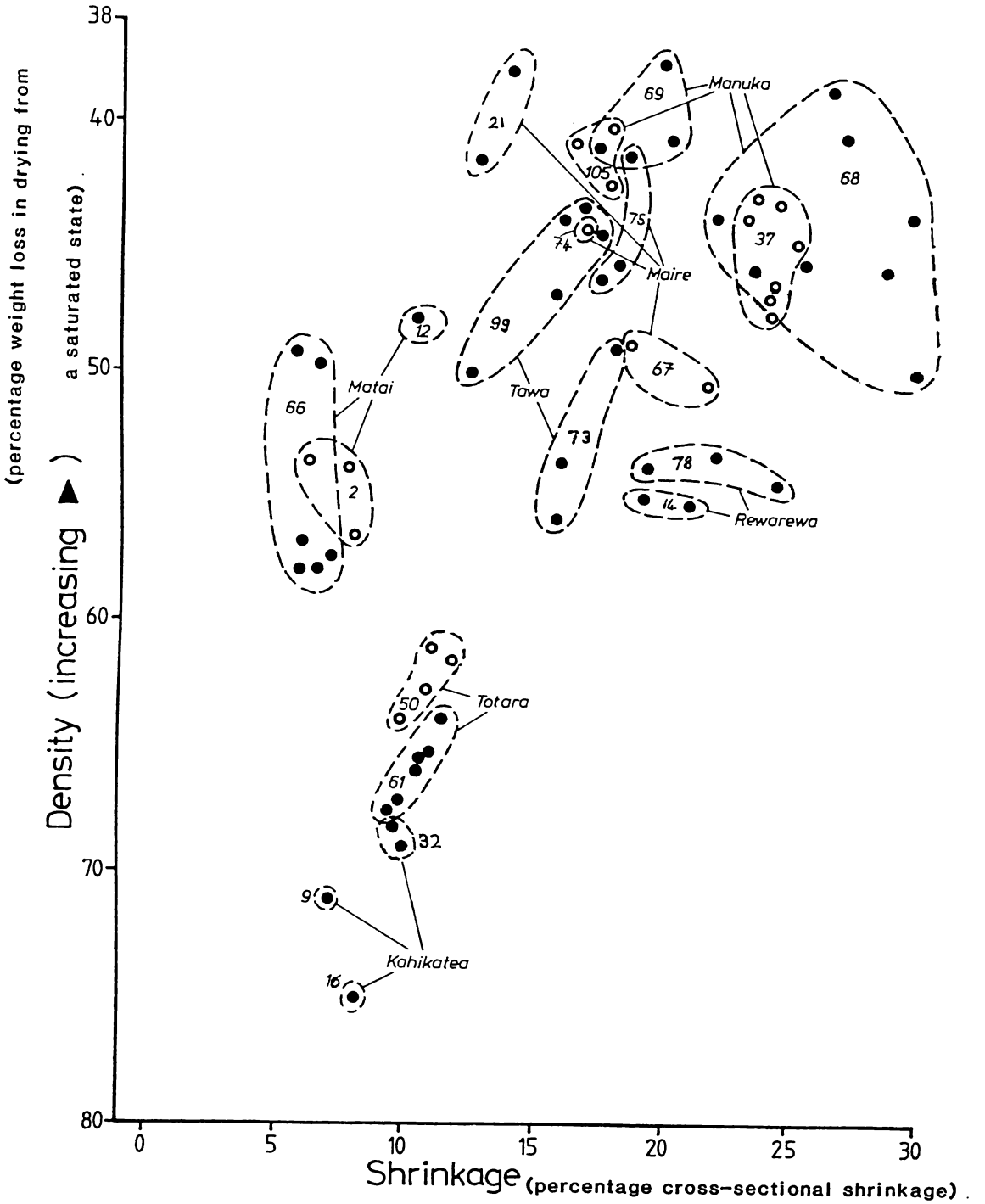


FIGURE SEVEN: Variation in density and shrinkage between samples cut from the same pieces of wood. Values for each piece are circled. Numbers given are reference numbers of each piece of wood and are listed in Appendix One.

in modern timber even though its density values suggest that actual loss of wood material during burial has been minimal.

Shrinkage in Degraded Woods

As many pre-European Maori swamp wood artefacts contain sound wood, the above date is important; however, one must also consider the behaviour of partially degraded timber. As mentioned in Chapter Four, partially degraded wood is defined as wood which has lost a measurable amount of its basic wood material, but is not degraded enough to suffer cell collapse when dried from a saturated state.

The first matter to be discussed concerning partially degraded wood is the manner in which decay progresses. This occurs, in waterlogged conditions, in one of two ways in most cases. In those woods which are readily penetrated by organisms that cause decay, degradation occurs simultaneously throughout the object. In those woods which are impervious to decay-causing organisms, decay proceeds as a zone of highly degraded wood that slowly penetrates the artefact from the outside inwards.

In wood having the first type of decay progress, three possible states of decay could, theoretically

be present. The first is where the wood is totally sound. This would only occur for the first few years after burial and would be rarely, if ever, found in a prehistoric swamp wood artefact. The second possible state is where the wood is partially degraded throughout, a very common situation in New Zealand swamp wood. The third state is where the wood is highly degraded throughout and this is also common.

In woods which are resistant to the entry of decay causing organisms three states of decay are also found. The first is where the wood is completely sound throughout, a common occurrence in swamp wood. The second state is where the artefact has a highly degraded surface covering a completely sound core. Again this is a common state in which to find swamp wood of this type. The third state is the same as occurs in the other wood type, i.e., the wood is completely degraded throughout.

During the course of this research it became apparent that both of the above modes of decay progression occurred in the various New Zealand native woods that were important to the prehistoric Maori. Species where decay occurs throughout the

wood include mahoe, mapou, tawa, pukatea, rewarewa and kahikatea. Those where decay occurs slowly, from the outside inwards, include manuka, kanuka, rata, totara and kauri. The woods listed above include only those for which swamp wood samples were available to the author. The status of the other commonly utilised species is unknown at present.

Figures Eight and Nine illustrate the water content and shrinkage patterns of wood in different states of decay. The magnitude of errors in the calculation of these values is discussed in Appendix Four on pages 279-284. The decayed wood samples have been attacked by a variety of micro-organisms depending on their histories of burial. Their condition is discussed below.

In Figure Eight six samples of manuka are shown, three of them (samples Nos 37, 69 and 105) sound modern timber, one (sample No. 68) sound swamp wood and two (sample Nos 135 and 136) of partially degraded swamp wood. The latter two were composed of completely sound wood with small patches of highly degraded wood in them. The latter samples have substantially reduced density values and increased shrinkages due to the patches of highly degraded wood suffering cell

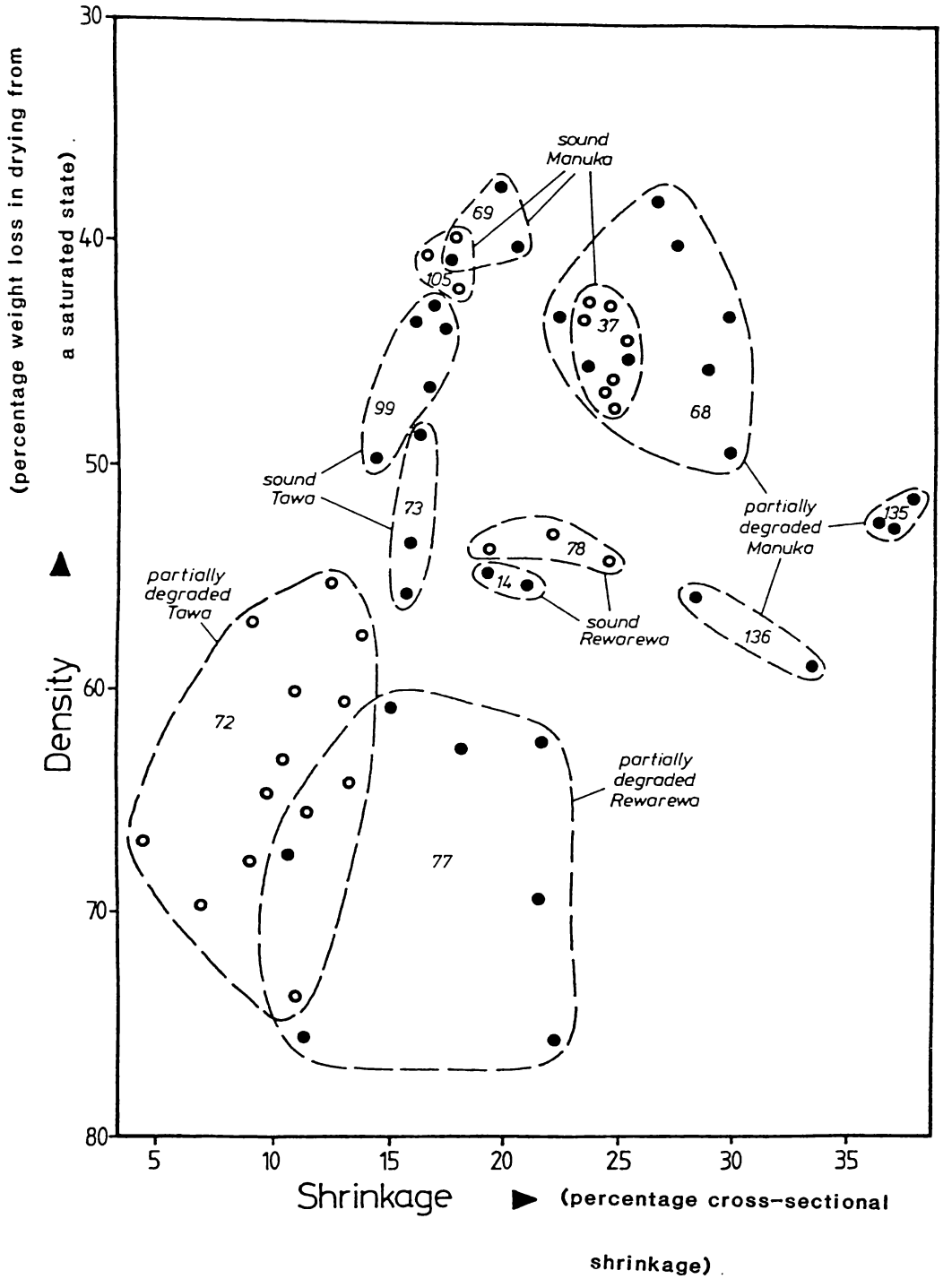


FIGURE EIGHT: Changes in the shrinkage and density of tawa, rewarewa and manuka wood due to partial degradation

collapse during drying. The effects of prolonged immersion in the swamp on samples of No.68, the old, sound swamp wood, are minimal, the only changes evident being a greater variability in density and shrinkage values.

The above pattern of swamp wood either having the same or greater shrinkage than sound wood is characteristic of woods that degrade from the outside inward. Woods that degrade simultaneously throughout show an entirely different pattern. In Figure Eight the tangential and radial shrinkages of two samples of sound tawa and of rewarewa, along with a sample of each that has suffered partial degradation are shown. What is notable in these examples is that the density values show there has been a substantial loss of wood material in the partially degraded sample (20 - 30%) and that the result of this is that the shrinkage has been reduced. This reduction in shrinkage is perhaps a little unexpected but might be logical if degradation had acted to erode the cell walls evenly, thinning them so that they became like the walls of lighter, and thus, lower shrinkage timbers.

The above pattern of reduced shrinkage in partially degraded woods is repeated for the woods shown in

Figure Nine where samples of mapou and rangiora, that have lost approximately 52% and 47% of their wood material respectively, are shown. The latter figures were obtained by taking the average densities of the sound and partially degraded samples and calculating the difference in wood material content.

As the woods that decay simultaneously throughout are almost never found in the sound state in waterlogged conditions, the relevant data on shrinkage values for these timbers are those for partially degraded timbers, not those for sound ones. The density values for those woods when sound can, however, be used to calculate the degree of degradation of the partially degraded wood.

Proportional Shrinkage

As was mentioned in Chapter Two, tangential shrinkage is substantially greater than radial shrinkage. The figure quoted was between 1.5 and 2.5 times greater. While this may be generally true for commercial timber internationally, the range of variation within the timber types studied in this research was much wider. This is illustrated in Figure Ten where the average values of tangential shrinkage are plotted against those for radial shrinkage. As can be seen, the proportions range from 0.75 : 1 to 4 : 1. Precisely why kahikatea

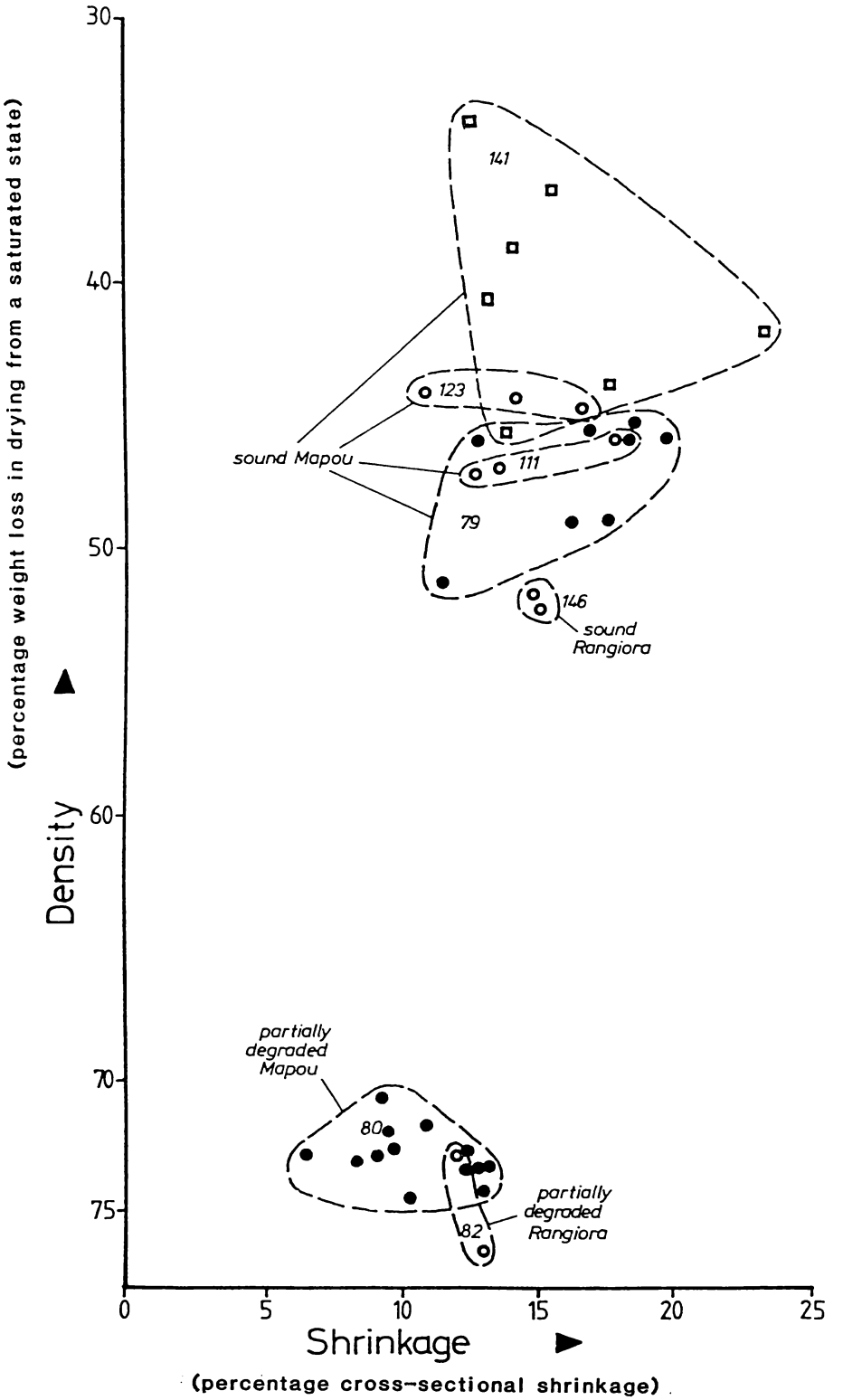


FIGURE NINE: Changes in shrinkage and density of mapou and rangiora due to partial degradation

has an average tangential shrinkage that is less than the radial one is not known. The other low proportional value for tangential shrinkage is the one for kauri branchwood. It is felt that the resin that impregnates this wood may possibly be the cause of this low value. This might occur if the resin was concentrated in the medullary ray cells of the wood where it would help in reducing tangential shrinkage. In this respect it is notable that most resinous New Zealand native gymnosperms do tend to accumulate their resin in ray cells.

The woods which had the highest ratio of tangential to radial shrinkage were mapou and rewarewa (where it was 4:1). In the case of mapou, this factor is of considerable importance as this was a species commonly used by the prehistoric Maori and, furthermore, always used in the form of whole stems. One could expect the development of radial cracks during drying of such stems would be quite dramatic. A test of this was made on a modern 50 mm diameter stem of mapou. On air drying it developed a 6 - 7 mm wide crack that ran the full length of the sample. Obviously this wood must normally have been used either in the green state or kept artificially waterlogged as the

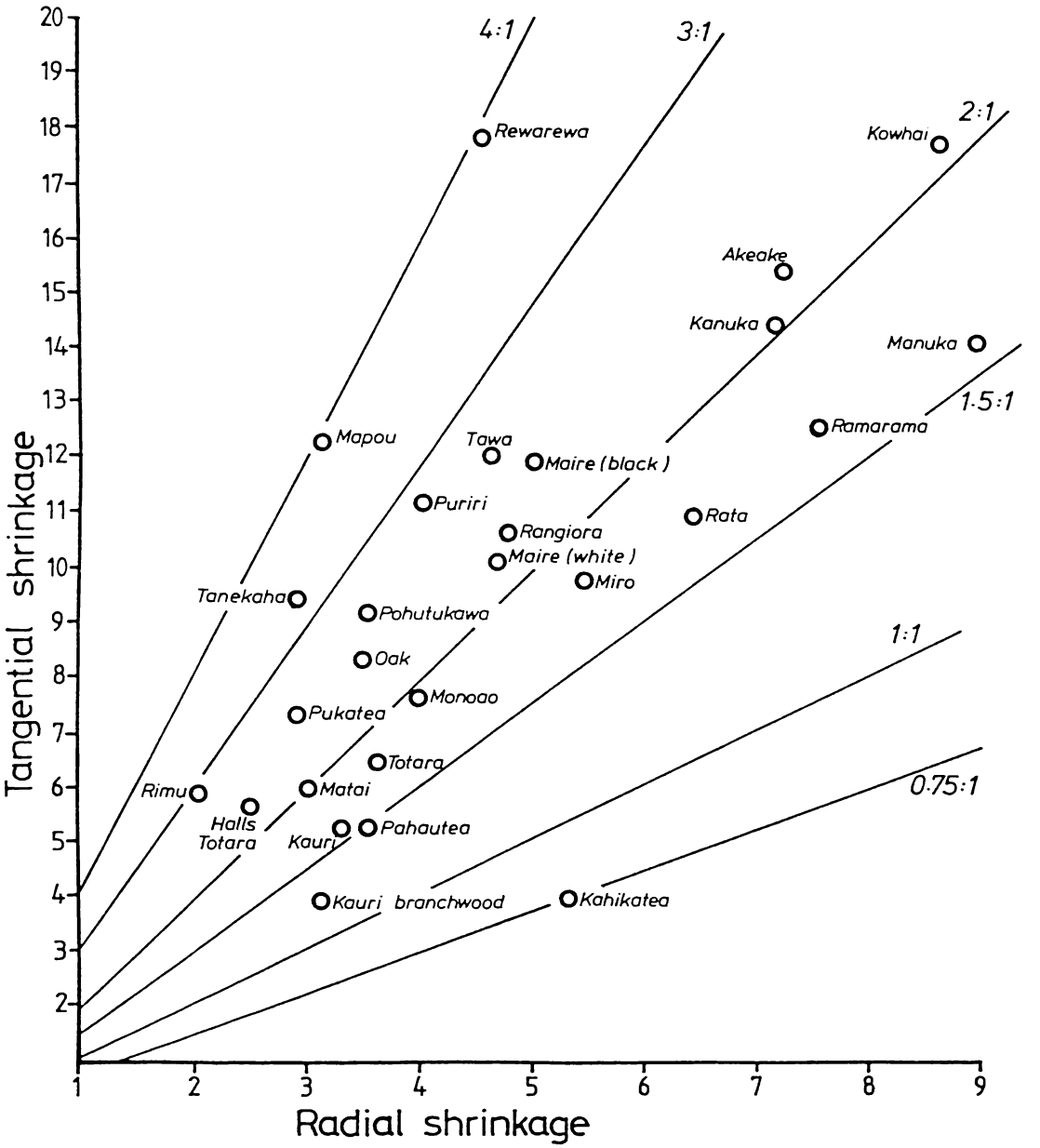


FIGURE TEN: The magnitude and ratio of tangential to radial shrinkage in 26 sound woods

cracking is of such a magnitude that artefacts would have become unservicable if dried out. As digging sticks made from mapou have often been found in caches in swamps it is suspected that they were always used in the waterlogged state.

If the mapou values are compared to those of manuka and kauri branchwood, species also used by the prehistoric Maori in the form of whole stems, it can be seen that the latter two would have behaved quite differently when dried. There is little doubt that manuka, kauri branch wood and, no doubt, many other species, would have been able to have been dried out without severe cracking.

As was pointed out in an earlier section, many woods are never found in a sound state in swamps, and since Figure Ten only includes sound woods, some of its information is only marginally relevant to wood conservation. For this reason the tangential to radial shrinkage ratio of partially degraded timbers was studied. In Figures Eleven and Twelve the tangential and radial shrinkage values of partially degraded mapou (Figure Eleven) and rewarewa (Figure Twelve) samples are plotted. As can be seen in Figure Eleven, partial degradation has reduced the

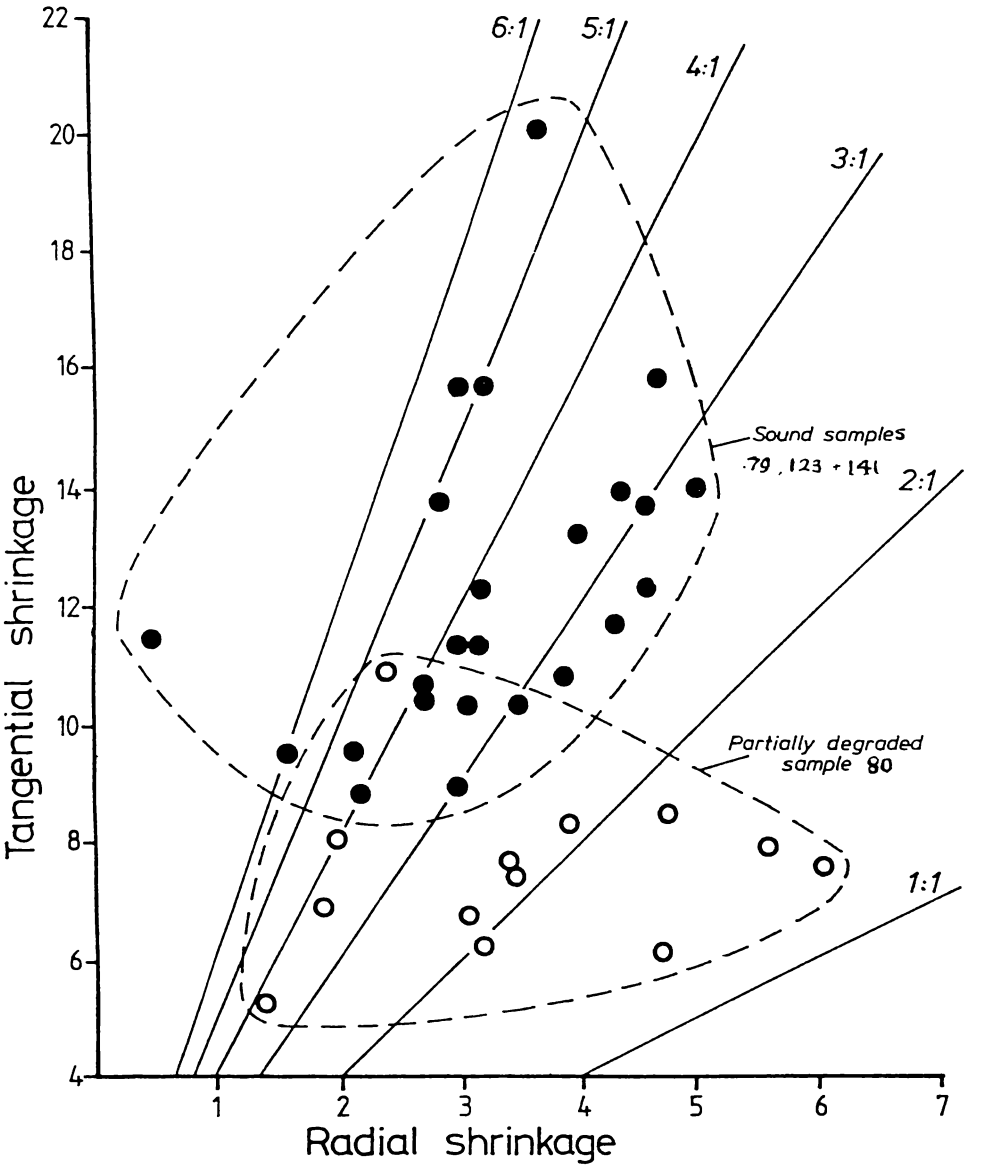


FIGURE ELEVEN: Radial and tangential shrinkage within samples of sound and partially degraded *Myrsine australis*

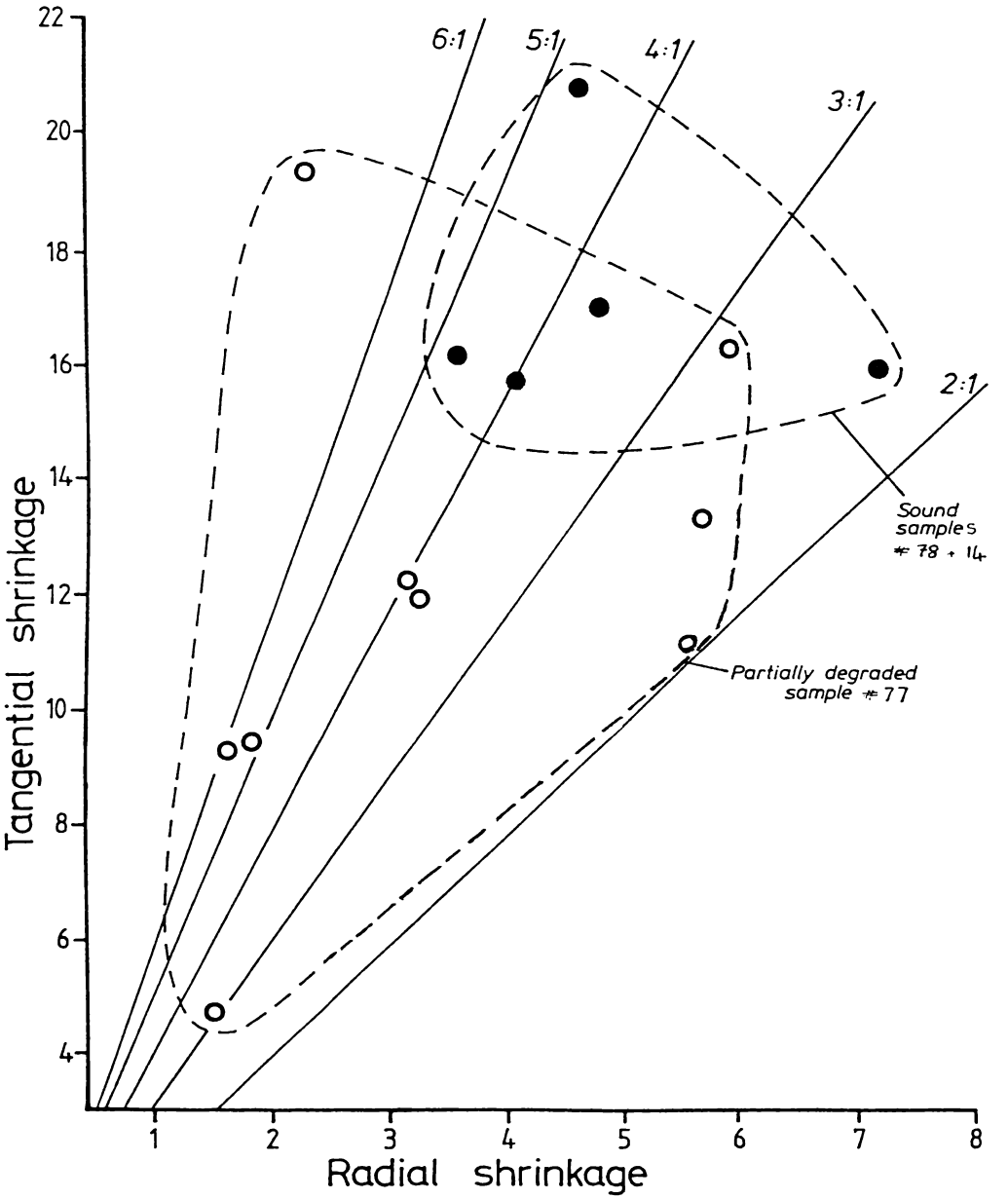


FIGURE TWELVE: The magnitude and ratios of tangential to radial shrinkages within a sound and a partially degraded sample of rewarewa (*Knightia excelsa*)

ratio from 4:1 to under 2.5:1. Many artefacts examined during this research were made from mapou and were found in the partially degraded state. These artefacts were in museum collections and had been dried out without effective treatment to control shrinkage. They did develop disfiguring radial cracks, though these were, as the above data would suggest, of noticeably smaller size than occurred in the test sample of modern mapou.

That a reduction in the ratio of tangential to radial shrinkage is not the inevitable result of partial degradation is shown by the results for rewarewa shown in Figure Twelve. They show that the average ratio is the same for both sound and partially degraded wood though the range and variation of values is much greater in the latter samples.

CONCLUSIONS

The purpose of the above chapter was to define, for most of the relevant wood types, what are the types and magnitudes of the changes that waterlogged wood can be expected to undergo when dried out. It is these changes that the conservator must be able to predict and to control, by various treatments, if he

is to be able to adequately conserve waterlogged wooden artefacts. The above account of shrinkages and densities of selected New Zealand native timbers has given a sketch of precisely what the conservator is up against.

CHAPTER SEVEN

DIRECTIONAL PENETRABILITY OF NEW ZEALAND WOODS

INTRODUCTION

Perhaps the most important piece of information the conservator can possess about a swamp wood artefact is its penetrability with respect to various materials that might be introduced to control dimensional changes during drying. Many of these consolidants have high molecular weights and overseas experience has shown that it is the failure of these to enter the wood that is the prime cause of failure of conservation processes. Oak heartwood has given the most problems and the literature has been dominated by accounts of attempts to overcome them. One important thing this research needs to determine is whether our local timbers include ones that behave in the same way as oak.

The first section of this chapter will describe the technique that was used to measure the penetrability of wood. This is followed by a discussion of the results of the penetrability tests on 42 samples of local gymnosperms, 57 of local angiosperms and 13 of

white oak heartwood. This discussion will include the placing of each wood type in a penetrability class with respect to oak.

THE PENETRABILITY TESTS

The test developed was designed to place each wood type in a penetrability class relative to the penetrability of oak heartwood rather than to measure more technical data such as the rate of diffusion of different molecular weight solids through the wood. Instead of studying diffusion directly it was decided to measure the porosity of the wood, i.e., the rate of penetration of water through dry wood samples. Since the word porosity is used in wood technology to refer to the pattern of distribution of pores (i.e., vessels) in the wood (e.g., oak is a ring porous wood), the word penetrability will be used henceforth.

A method for determining the penetrability of wood devised by Christensen (1970:62-5) involved sealing the sides (but not the ends) of cubes of wood then placing them end grain down in a shallow pool of water. The time taken for moisture to penetrate to the upper end of the cube was measured and, by comparing results for different wood types, a set of wood penetrability classes was developed.

The above method was applied to some New Zealand timbers, both modern wood and swamp wood. When a 40 mm cube of sample No. 80 (partially degraded mapou) was tested, it took between one and three seconds for moisture to penetrate to the other end. On the other hand, when a similar sized block of modern kauri was tested, only 5 mm penetration was achieved in two days. The difference in rate of penetration here involved a factor of 345,000. It was later discovered that kauri was, in fact, a comparatively penetrable wood by New Zealand standards.

A disadvantage of the above method was that water tended to creep up the sides of the wood blocks if penetration was slow. Clearly this method would not yield much information about the more impenetrable local timbers, a critical defect as these were precisely the ones of most interest to the conservator.

After discussions with several people at the Forest Research Institute at Rotorua, a suitable method of penetrability testing was devised. At the Forest Research Institute a method was in use to test the ability of the Bethel (vacuum/pressure) treatment to impregnate various timbers with water-borne preservatives.

It involved cutting wood samples into small blocks and sealing five of their sides. The blocks were then placed in a vacuum chamber and the air pumped off. The chamber was then flooded with water and a positive air pressure was applied for a set length of time. The samples were then removed from the chamber and weighed. The results were presented as the percentage weight increase as a percentage of the pre-calculated maximum possible weight increase.

The above method was modified for use in the present research by the omission of the positive pressure step thus greatly simplifying the equipment required. This equipment is illustrated in Figure Thirteen.

The samples were prepared in the following way. Blocks, approximately 20 mm on an edge were cut and sanded so that each face followed one plane of the cell anatomy of the wood, i.e., each block had two transverse, two radial, and two tangential sides. For each wood type three blocks were prepared. These were sealed on five sides with nitrocellulose in amyl acetate. Several layers of the sealant were applied to ensure watertight faces. For each wood type, the samples were sealed so as to expose a transverse

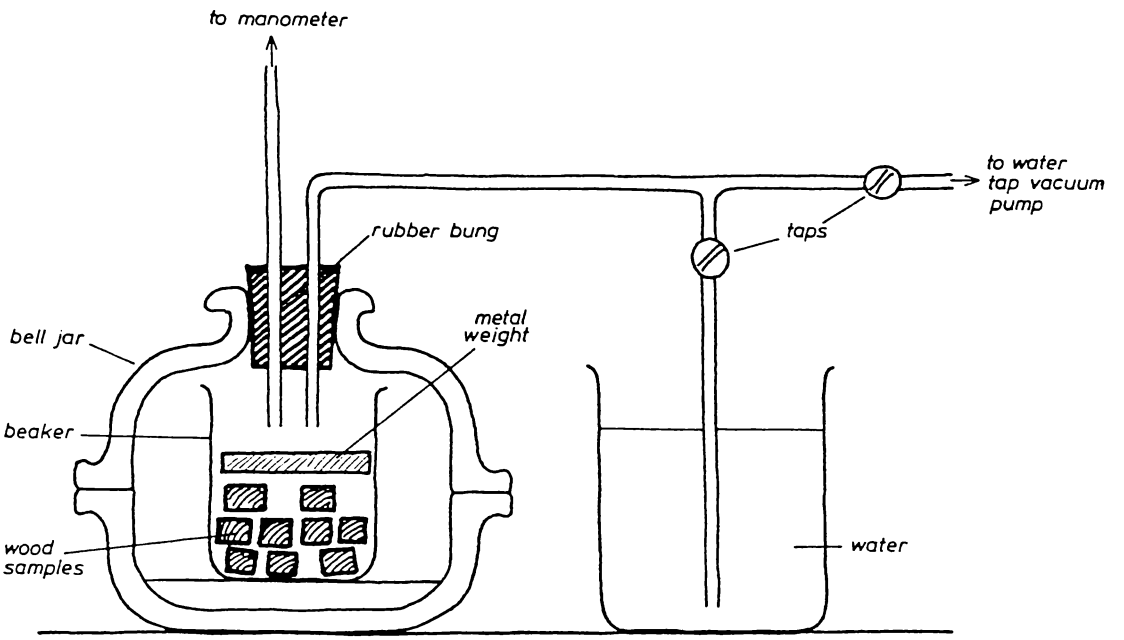


FIGURE THIRTEEN: Apparatus for testing the penetrability of wood samples

face, one a radial face and one a tangential face.

Impregnation was performed in the following way. The samples were placed under a metal weight in a beaker to ensure they remained submerged during impregnation. The beaker was placed in the vacuum chamber and the air was withdrawn using a water tap vacuum pump achieving a vacuum of about 90 kilopascals. The samples remained under vacuum for four hours and then the beaker was flooded with enough water to cover the blocks. The vacuum was then released and the samples were allowed to take up water for exactly one hour. At the end of this time they were removed from the beaker, their surface water was removed with a towel and they were weighed.

The information used to calculate the percentage saturation achieved was as follows. The maximum possible weight increase figures were derived from the density figures listed in Appendix Two, i.e., the per cent weight loss on drying figures listed can be converted to per cent weight increase on saturation values by simple arithmetic. The samples were weighed before they were sealed (when in the oven dry state), after sealing and, finally, after impregnation.

The results of tests on samples of the New Zealand native timbers that were important to the prehistoric Maori are listed in Appendix Three. A discussion of the errors inherent in these results is given in Appendix Four (pages 279-284).

DISCUSSION OF THE RESULTS

The results listed in Appendix Three can be used to construct a preliminary classification of the penetrability of the woods tested. These classes are defined below.

Class I: Ultra-impenetrable woods. Defined as those that achieved less than 5% saturation in the tests. Given the small size of the sample blocks, this amount represents little more than surface wetting i.e., almost zero penetration.

Class II: Highly impenetrable woods. Those which achieved between 5 and 20% saturation when impregnated along the grain but which achieved little more than surface wetting across it.

Class III: Moderately impenetrable woods. Those that achieved 20% - 50% saturation along the grain but, again, little across it.

Class IV: Partially penetrable woods. Those which achieved 50 - 100% saturation along the grain in the tests but little across it, i.e., highly penetrable in one direction and highly impenetrable in another.

The above four classes all might be referred to as impenetrable, however, where actual artefacts are concerned, it would depend, in some instances, on the shape as to whether penetration could occur. For example, if the object's surface included a large area of end grain, Class III and IV wood might be penetrable, whereas, in the case of shafts made from natural stems, all penetration would have to be across the grain so that the wood might be highly resistant.

Class V: Moderately penetrable woods. Those where there was 50 - 100 % saturation when tested along the grain and, on average, 10 - 50% across it.

Class VI: Ultra-penetrable woods. Those where there was above 50% saturation in all directions through the wood when tested.

In order to relate the results of the penetrability tests to actual conservation problems, oak heartwood samples were included in the above

tests since their properties, in relation to actual treatment processes, are known. The 13 oak samples tested yielded two distinct sets of results (see Figure Fourteen). These were strongly correlated with the manner of growth of the wood. The first group included New Zealand grown oak only. This wood was notable for its rapidity of growth, i.e., its annual rings were very wide. The other group included all the oak samples that had been grown in the Northern Hemisphere plus one sample of locally grown wood. All samples in this group, without exception, were slow grown with, on average, 6.6 annual rings per centimeter compared to the 3.8 of the local oak. The one slow grown local sample was from a shelter belt where the trees are very crowded and of rather scrubby form.

The speed of growth has a strong effect on the cell anatomy since oak is a ring porous wood. It produces a band of large vessels in the early spring but only small diameter vessels (and other cell types) for the rest of the growing season. It would appear that the large vessels are the ones that determine a significant amount of the penetration of liquids into the wood. There are, proportionally, more large vessels in slow grown wood since the band of spring

wood vessels is rather constant in width with variation in annual ring widths being due to the late wood.

As a consequence of the above, slow grown oak was used as the reference point when classifying New Zealand timbers with respect to their ability to be penetrated by consolidants since the work in Europe on conserving oak would have been done on wood of this growth form.

Penetrability of Sound Woods

In Figures Fourteen and Fifteen the results for sound examples of the woods that were commonly utilised by the pre-European Maori are given along with those for the two types of oak heartwood. The first wood to be discussed will be the oak. As can be seen in Figure Fourteen, the slow grown, i.e., European type, falls into class III. This means that it has moderate penetration along the grain but almost none across it. The rapidly grown wood is more impenetrable, falling into class II.

In considering the results for New Zealand timbers, it was not surprising that the heart of branchwood kauri was found to be ultra-impenetrable since it was almost completely saturated with resin. The results for totara, Hall's totara, and pahautea *(Libocedrus bidwillii)* are somewhat of a shock,

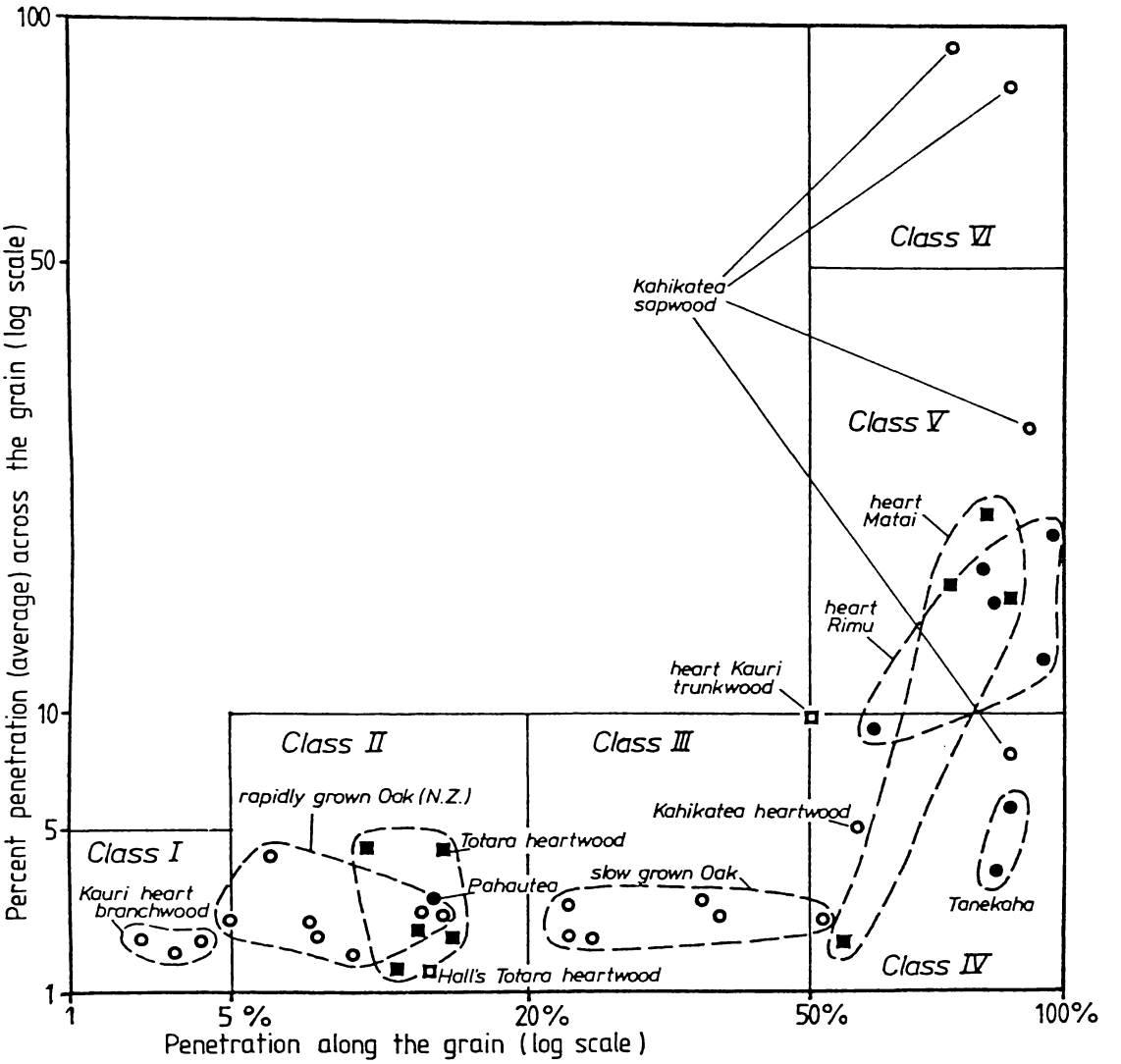


FIGURE FOURTEEN: The directional penetrability of ten types of sound gymnosperm woods and two growth types of white oak heartwood. A plot of penetration along the grain against average penetration across it in the tests.

however, being distinctly more impenetrable than European grown oak. This is rather alarming given that these are woods that often occur in a sound state in sites and must, therefore, be expected to give rise to considerable problems for the conservator. The other results are rather self explanatory, but show that the other New Zealand gymnosperms are likely to give fewer problems to the conservator.

Figure Fifteen gives the results for the sound angiosperm wood. There is an important group that falls into classes I and II. These involve heartwood of puriri, pohutukawa, black maire, akeake and kowhai. These are all woods that are quite likely to be found in archaeological wet sites in a sound state. The ones in class I are very much more impenetrable than heartwood oak and it is to be expected that they will be extremely difficult to impregnate with any consolidant, no matter how small its molecular weight might be.

Manuka and kanuka were the most commonly used angiosperm woods of the prehistoric Maori and are ones that are often found in a completely sound state in anaerobic environments. They are shown on Figure Fifteen to be only slightly more penetrable than

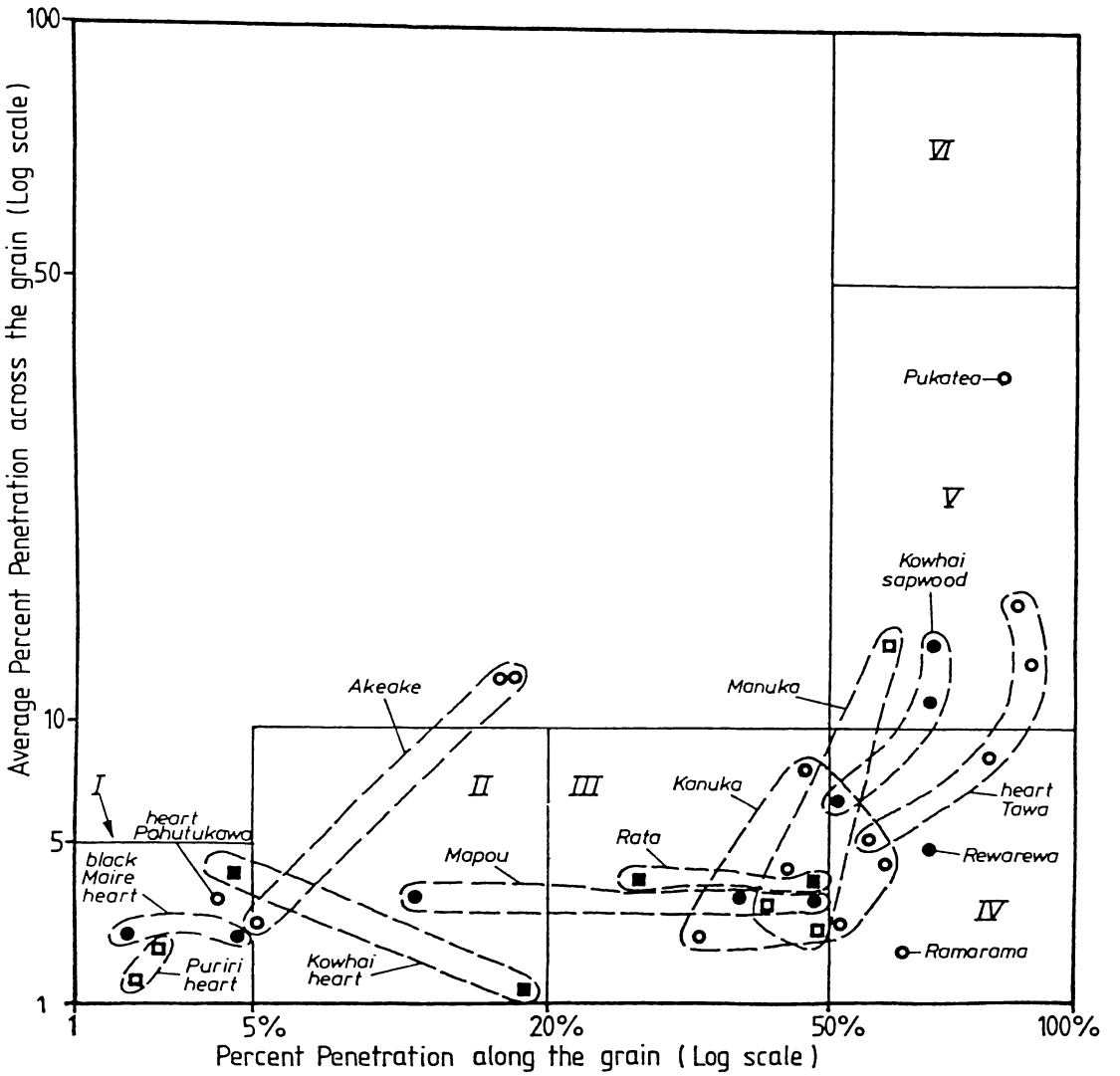


FIGURE FIFTEEN: The directional penetrability of 15 sound Angiosperm woods measured by percentage saturation in the Penetrability Tests. Penetration along the grain plotted against the average penetration across it.

heartwood oak which bodes ill for the conservator who must deal with them.

Penetrability of Sapwood

The results mentioned above are for heartwood only. To examine the differences between heartwood and sapwood, examples of both were selected from species that have highly impenetrable heartwood. Six pairs of samples, each from the same tree, were tested and the results shown on Table Sixteen. In each case the differences are spectacular with most sapwood being moderately to highly penetrable. Except in the case of kauri where resin contents are different, there is no great difference in density between the two forms of wood underlining the lack of correlation between penetrability and this property.

Penetrability of Degraded Wood

The above results are all for sound wood. Some species, however, rarely occur in wet sites in a sound condition. Examples of these, both sound and partially degraded were tested. These results are shown on Figure Seventeen and Eighteen.

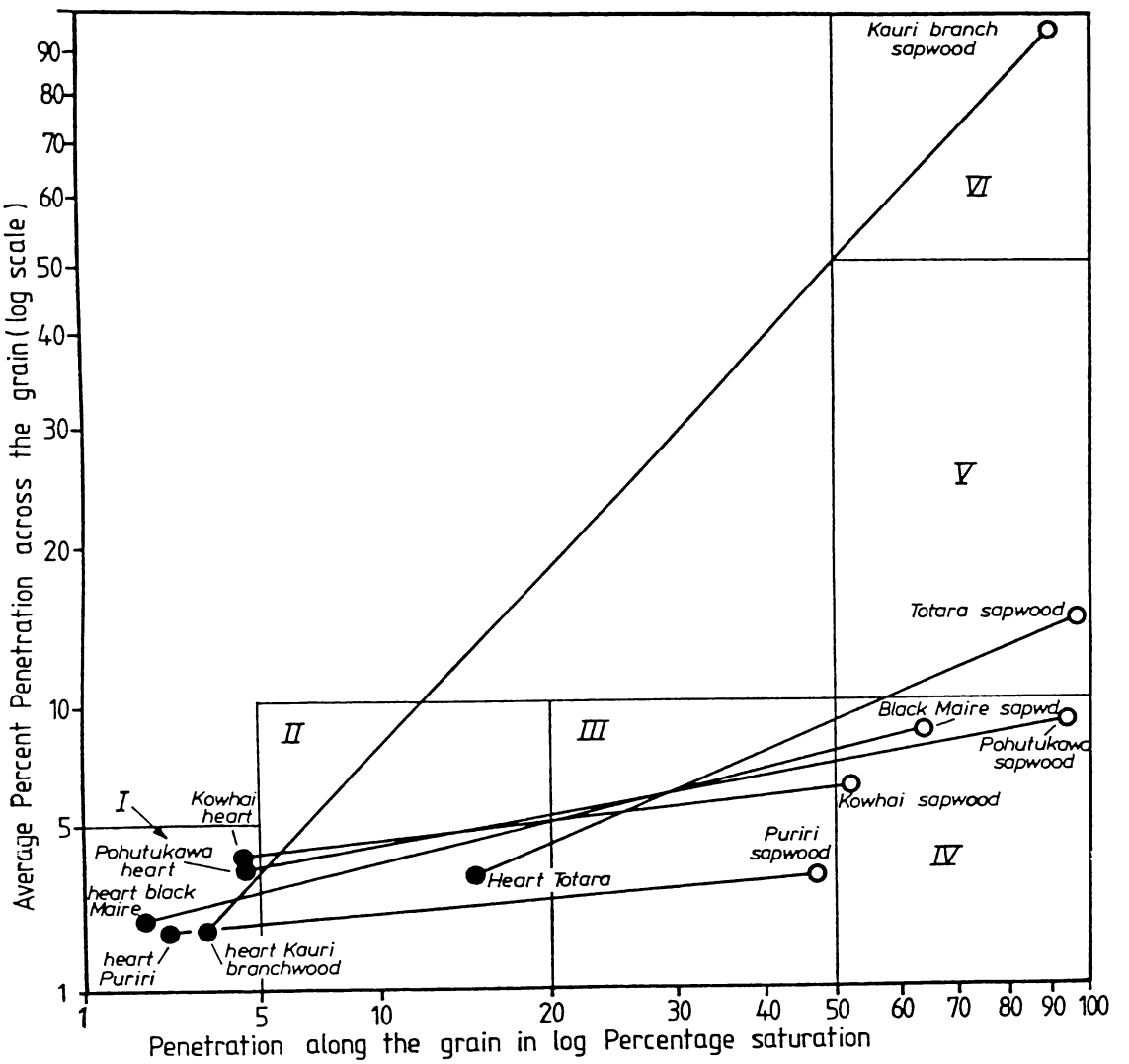


FIGURE SIXTEEN: The differences in penetrability between samples of heart and sap wood from the same tree in six species of sound wood

The results of the tests on gymnosperm woods that were partially degraded are shown in Figure Seventeen along with those for sound wood of the same species for comparison. It illustrates that totara heartwood can be found in swamps in all states of soundness and decay. Not surprisingly, penetrability increases dramatically with increasing decay. The other woods illustrated here were much more penetrable to begin with and show increases in penetrability mainly across the grain. As a general rule then, woods that have been partially degraded will be highly penetrable and will present few problems to the conservator in this respect.

The above generalisation applies to the angiosperms as well, as is shown in Figure Eighteen. The results for mapou and tawa are the most dramatic in this respect. Mapou changes from being a moderately impenetrable wood to being an ultra-penetrable one. In fact, it is highly likely that these results under-estimate the penetrability of partially degraded mapou since the sealing compound tended to soak into this highly absorbent wood, reducing the amount of water it could take up. Furthermore, it is suspected that all the water it was going to absorb during the tests was taken up during the first few seconds of the impregnation time.

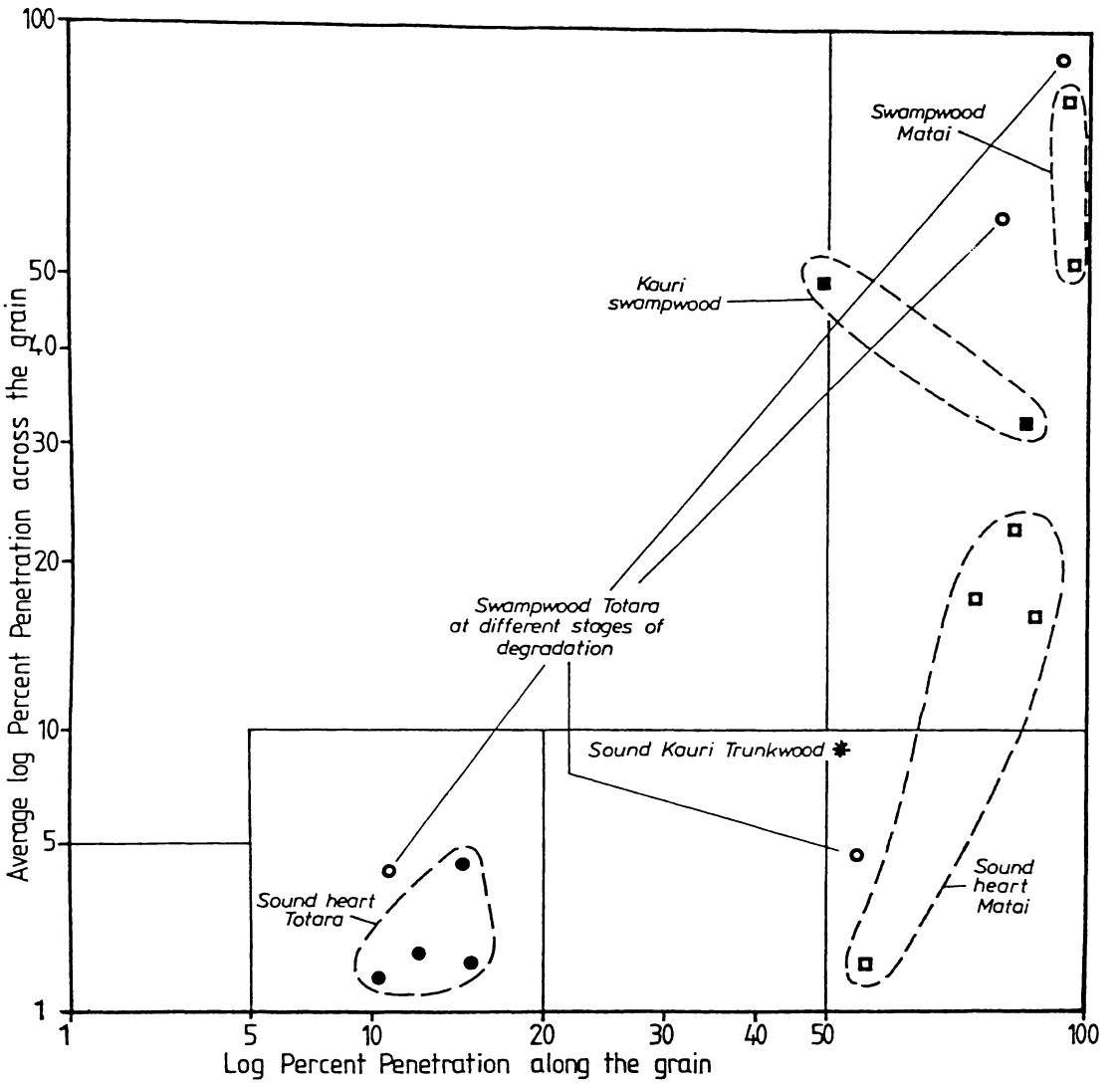


FIGURE SEVENTEEN: Comparison between the penetrability of sound and partially degraded samples of three Gymnosperm woods

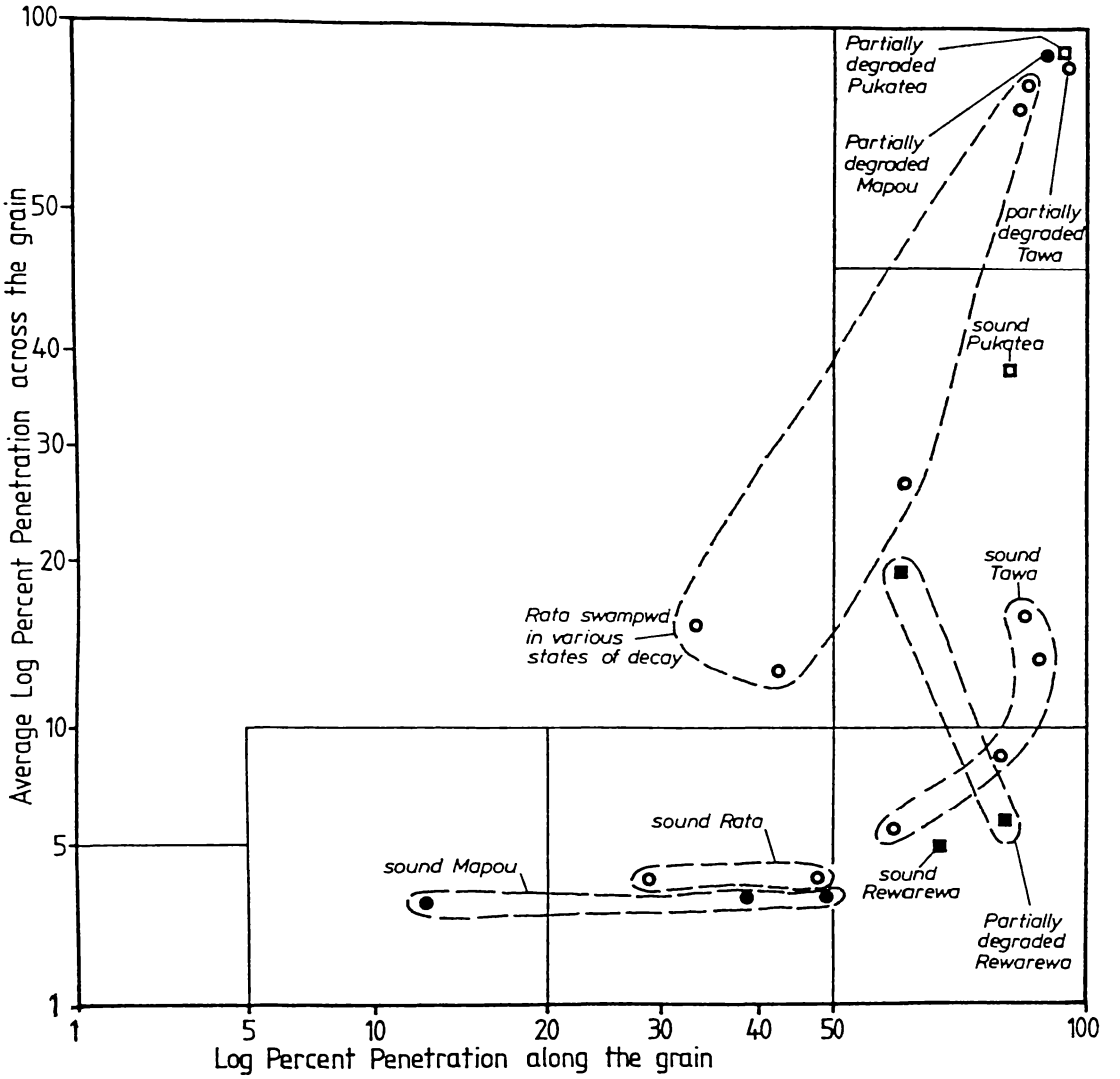


FIGURE EIGHTEEN: Comparison between the penetrability of sound and partially degraded samples of five angiosperm woods

CONCLUSIONS

The results of the penetrability tests reported above are thought to be adequate to allow the woods involved to be separated into classes with respect to their penetrability to consolidants used in various conservation processes. In the next chapter these results will be combined with the others to give a characterisation of each wood in terms of its 'conservability'.

CHAPTER EIGHT

SYNTHESIS OF RESULTS

INTRODUCTION

This chapter summarises the data collected on each wood type and draws conclusions on their conservation. Each type will be discussed in turn under the following headings:

The tree

Uses

Durability

Density

Shrinkage

Penetrability

Conservation

At the end of the chapter wood types are listed in groups sharing similar properties and general comments are made summarising suitable conservation approaches.

Conservation Advice

During the initial stages of this research the author discussed aims and objectives with the people

appointed to advise him on conservation and museological matters. What emerged from these discussions was that any tendency to produce a 'cookbook' of conservation 'recipes' was to be strenuously avoided. It was suggested that museum people might desire such an approach but that good conservation ethics dictated that conservation processes should only ever be prescribed for individual artefacts and never be arbitrarily determined beforehand.

In this chapter we are dealing with wet wood types, not artefacts, and thus specific conservation proposals cannot be given. When artefacts are examined, factors such as size, shape, value and finish, degree of decay in different parts of the item, the resources and money available for conservation, the future storage conditions and many other pertinent facts need to be taken into consideration in deciding an appropriate conservation procedure.

What can be done here is to suggest which conservation techniques cannot be used with specific wood types and outline a few approaches that may be appropriate. This is particularly true for the wood types that present great difficulties for the conservator since it is the identification and discussion of these that is the main subject of this research.

Another potent argument against compiling a 'cookbook' for New Zealand wet wood conservation is the high rate of progress in development of new or modified methods would make such a 'cookbook' soon out of date. In contrast, the properties of New Zealand woods which relate to conservation will not vary with time and an account of them will always remain useful.

THE WOOD PROPERTIES

Kauri trunkwood *(Agathis australis)*

This species can form a very large tree, 30m or more in height and over 3m in diameter. It grows from North Cape in the north to Maketu and Kawhia in the south though subfossil wood can be found in swamps in certain places south of this, for example, in Waikato swamps where it is abundant.

It produces two distinct woods, trunkwood and branchwood and these will be considered separately, trunkwood first.

Uses: The heart trunkwood was used for planks, palisades and carved panels (see Tables Two, p.124;

Three, p.127; Five, p.130; and Seven, p.137).

Durability: Kauri has a reputation for durability in water which is partly responsible for its demand as a shipbuilding timber (Entrican et. al., 1951:54). Examination of museum artefacts of this wood suggests that this property also affects prehistoric artefacts as they are often found in a sound state. This property may be due to the high resin content of the wood.

Density: This wood has low to moderate density compared to other New Zealand woods (ibid:52, and Figure Six, p.146).

Shrinkage: is low (Figure Six, p.146; Entrican et. al., 1951:Table Three) and is even with a ratio of tangetial to radial shrinkage close to 1.5:1 (see Figure Ten, p.159).

Penetrability: Kauri, even when sound heartwood is tested, appears to be reasonably penetrable both along and across the grain (see Figure 14, p.175).

Conservation: Kauri trunkwood contains substantial amounts of resin that ought to be retained as it is an integral part of the wood. This fact makes the

use of organic solvents that might leach this material out undesirable. Aside from this kauri trunk wood does not possess properties that make it a difficult wood to conserve. Consequently conservation decisions can be made on the assumption that commonly used conservation materials should penetrate this wood given time.

A warning should be given about this wood type. As the same species also produces a very different type of wood, one should be careful to ensure that it is the lighter, straight grained, lower resin content trunkwood that is being considered and that no knots of branch wood or patches of ultra resinous wood are present before applying the conclusions given above.

Kauri Branch wood *(Agathis australis)*

The tree: Is the same one as for the previous wood type.

Use: This timber was used as whole stems of heart branch wood probably collected from under kauri trees with the sapwood already rotted off. It was used for fern root beaters, bark pounders, mauls, weapons and horticultural implements (see Tables Two, p.124 and Five, p.130).

Durability: This wood is one of the most durable forms found. It can be collected from under stands of kauri where branches have fallen and the sap wood (which is not so resinous) has rotted away. It persists on the ground surface for very long periods of time and has been collected from the surfaces of swamps and other wet ground where kauri trees have not grown for up to a hundred years. It is almost always found in artefacts in a sound condition except for a very thin layer on the surface which is sometimes highly degraded.

Density: This wood includes examples that are the densest found in New Zealand (see Figure 6, p.146). This density is due to the very high resin content. The examples tested showed highly variable resin content (see Appendix 2), however, observations on artefacts suggests that the densest wood available was chosen and therefore would have been closest to sample No. 36 (ibid.) which had approximately 26.5% water (by weight) at full saturation. Given that a test conducted on one sample (sample 119, p.144) showed that the actual wood material is denser than trunk kauri and given that cell walls will absorb up to 30% by weight water, one can calculate that most of the water in this sample was inside the cell walls.

This indicates that the resin almost completely fills the cell lumena of the wood, producing a situation similar to the results of some conservation processes, e.g. the acetone-rosin method (Method 2, p.90) where the wood cells are embedded in a hard material.

Shrinkage: Despite its high resin content, this wood does not shrink or swell any less than normal kauri (see Figure 6), however, as this species produces low shrinkage wood, dimensional changes on drying will always be small. This indicates that the resin does not penetrate the cell walls to prevent water swelling them, nor is so distributed in the wood to prevent normal shrinkage and swelling.

Penetrability of this wood is the lowest among the gymnosperms tested with less than two percent penetration of water under vacuum (see Figure 14, p.175 and Appendix Three, p.274) in most cases. These figures represent no more than surface wetting and indicate that the wood is too impenetrable to register in the tests conducted. Clearly the resin content almost totally blocks entry of liquids over the times used.

Conservation: As with other kauri wood, organic solvents must be avoided as they would leach out the resin. Removing the resin would not only affect the integrity of the artefact but be pointless as the resin virtually 'pre-conserves' the object. Given the extreme impenetrability of the sound wood one could not guarantee that any dissolved material would penetrate this wood. Consequently, the artefacts should never be frozen as damage may occur. Fortunately, artefacts made from this wood are usually completely sound and due to their low shrinkage can be controlled dried with good likelihood of success.

Where there is surface decay of artefacts this surface material must be consolidated prior to drying. This dictates a water born consolidant such as P.E.G. 4000. When using this material, however, a heated bath must not be used as the interior of the artefact will not take up the wax and osmotic forces may cause the internal water to be lost causing "caved in" surfaces. The P.E.G. 4000 cold bath treatment could be used in this instance (Method 8, p.95) as it appears to be the one that suits the specific requirements of this

wood, though the daily painting on of P.E.G. 540 blend (Method 9, p.96) could also be used if the outer surface is only partially degraded, utilizing the fact that the later material has greater penetration.

Matai trunkwood *(Podocarpus spicatus)*

The tree is large reaching 30m in height and is distributed throughout New Zealand.

Uses: The pre-European Maori used the trunkwood for planks, posts, bowls, canoes, implement shafts and spinning tops (see Tables Two, p.124, Three, p.127, Four, p.128, Five, p.130, Six, p.133 and Seven, p.137). The canoes and perhaps the bowls may have been used in a permanently wet state to avoid leaking due to shrinkage cracks.

Durability: Examination of artefacts in museum collections suggests that this timber is only moderately durable in wet sites.

Density of matai is moderate, being one of the denser of the gymnosperms (see Figure Six, p.146) and it normally has a low resin content though some

heartwood might contain appreciable amounts in patches which will make the wood heavier.

Shrinkage in this species is low and even with an average tangential to radial ratio in the samples tested of close to 2:1 (see Figures Six, p.146, and Ten, p.159).

Penetrability of this wood is excellent along all planes even with sound heartwood (see Figure 14). This wood does not possess inherent properties that prevent the use of any specific treatment. A conservation method can be selected on the basis of the artefacts attributes alone.

Matai branchwood *(Podocarpus spicatus)*

The tree is the same as for the previous wood.

Uses of the wood were fernroot beaters (for areas outside the distribution of kauri), mauls and adze hafts (see Table Two, p.124 and Seven, p.137).

Samples of this wood were not collected and examined therefore cannot be commented on directly.

Observations made on artefacts of this wood suggest that unlike kauri, the branchwood does not appear to differ markedly from the trunkwood and thus one might apply, with caution, the results of work on the latter timber to it.

Totara trunkwood *(Podocarpus totara)*

The tree is large, reaching 30m. It is distributed throughout the country but is rare or absent in the far South.

Uses made of the timber were; planks, shafts of tools, canoes, house timbers, posts, bowls and carved panels (See Table Two, p.124, Three, p.127, and Four, p.128). It was a multi-purpose wood and is likely to be found, in sites, in numerous forms.

Durability of this timber is good in wet conditions and sound wood will commonly be found as artefacts as shown by the condition of many in Museum collections.

Density of totara trunkwood is rather low (see Figure Six, p.146 and Appendix Two, p.259).

Shrinkage in this wood is also low (ibid) and even, the average ratio of tangential to radial shrinkage being between 1.5:1 and 2:1 (see Figure 10).

Penetrability of this wood, when sound heartwood is concerned, is poor being less than Northern Hemisphere oak (see Figure Fourteen).

Conservation of sound heart trunk totara (the commonest form likely to be found) faces a significant problem; the impenetrability of the wood. Comparison with Northern Hemisphere oak suggests that it is of comparable penetrability. Experience with sound oak heart wood suggests (for example christensen, 1970:79) that molecules of P.E.G. of molecular weights 1500 and 4000 will not enter this wood.

The above situation suggests that no attempt should be made to impregnate sound totara heart with high molecular weight consolidants e.g., P.E.Gs 1500 or 4000. Conservation should either aim at treating degraded portions of the artefact with cold baths of high molecular weight consolidants, so that the sound core of the artefact is unaffected, followed by controlled drying (e.g. methods 8 or 9, p.95), or should use very low molecular weight impregnants, e.g. P.E.G. 400 and very long soak times to ensure adequate penetration.

In short, whatever technique is chosen to suit the particular circumstances, it should avoid the dangers of penetration failure.

Totara branchwood *(Podocarpus totara)*

The tree is the same as the above.

Uses were for adze halfs (see Table Two, p.124).

Examples of this wood were not collected and their properties cannot be commented on here though, unlike kauri, this wood does not appear to vary dramatically from trunkwood and the assumption should be made that any heartwood present will be equally impenetrable to high molecular weight consolidants.

Halls Totara *(Podocarpus hallii)*

The tree reaches 20m in height and is closely allied to *Podocarpus totara*. The species tends to be rarer than its relative and to occupy higher altitudes except in the deep south where it replaces *P. totara* entirely and is abundant.

Uses include house timbers, bowls, canoes, canoe gear paddles and adze hafts (Table Two, p.124). One would

expect its use to be restricted outside the south of the South Island (where it would replace *P. totara*).

The properties relating to conservation of *P.hallii* are so similar to those of *P. totara* that they need not be repeated (see preceding section for this and for conservation suggestions).

Pahautea *(Libocedrus bidwillii)*

The tree, also known as Kaikawaka, is small, up to 16m, and generally occurs at higher altitudes. It occurs from the central North Island southwards but a closely allied species, Kawaka, *(L. plumosa)* occurs further north.

Uses include fern root beaters, mauls and ko footrests (see Table Two) but its rarity prevents an adequate account of its utilization.

The properties of this wood and its conservation are so similar to *P. totara* and *P. hallii* that the data on the former can be used for *L. bidwillii*, i.e., it should be conserved in the same way.

Rimu trunkwood *(Dacrydium cupressinum)*

The tree reaches 50m in height and 1.5m in diameter. It occurs throughout New Zealand and is abundant in most lowland forests.

Uses of the wood include houses, planks, posts, canoes, mauls and combs (see Table Two, p.124). As a common and multi-purpose timber it can be expected to occur in sites in numerous artefacts.

Durability in wet sites is not easy to judge but artefacts will be found in wet sites in a sound state where preservation conditions are good.

Density of rimu is high for a gymnosperm though only moderate compared to New Zealand timbers generally (see Figure Six, p.146 and Appendix Two p.260).

Shrinkage of sound wood is quite low (ibid) but is somewhat uneven anatomically on average, i.e. it has an average tangential to radial shrinkage ratio of circa. 3:1 (see Figure Ten, p.159).

Penetrability of rimu is high along all planes (see Figure 14, p.175) even for sound heartwood though patches of very resinous wood may exist where this is not the case.

Conservation With its low shrinkage and high penetrability rimu does not appear to possess properties that specifically exclude any conservation technique. The only problem with this timber is that it can be very difficult to distinguish, microscopically, from totara, which does possess such properties. If it can be definitely identified as rimu, the conservation technique may be selected on criteria other than that of wood type. Given that rimu may have been used to make artefacts as different as hair combs and canoes the actual choice cannot be dictated by the wood type alone.

Kahikatea Sapwood *(P. dacrydioides)*

The tree is the tallest in New Zealand reaching 40m. It grows in wet conditions throughout the country and is common.

Uses of this wood were somewhat limited due to its softness and lack of durability. This latter property is caused by the very small amount of heartwood formed.

In this study only one artefact, a bowl (see Table Two, p.124), was found made of this species. Ethnographical information records weapons, spears, posts, canoes and torches as having been made from kahikatea (Boileau, 1978, p.56.).

Durability is low for the reason given above.

Density of the wood is the lowest of all recorded in this research (see Figure Six, p.146).

Shrinkage is also low being, similar to other gymnosperm woods in this respect (ibid). Shrinkage is remarkably even and is unique in that, on average, the radial shrinkage is greater than tangential (see Figure Ten, p.159).

Penetrability of kahikatea sapwood is high to very high, being, on average, the most penetrable gymnosperm wood tested (see Figure Fourteen, p.175).

Conservation of kahikatea trunk sapwood does not face any problems due to wood properties. The wood is light, has low shrinkage and is readily penetrable even when in a sound state. Since this wood was used for a a variety of sizes and shapes of artefacts, different

conservation techniques will be applicable depending on the individual circumstances but none should be excluded by virtue of wood properties alone.

Kahikatea heartwood *(P. dacrydioides)*

The tree is as above. It produces small amounts of resinous heartwood some of which is similar in properties to kauri heart branchwood in that it is almost completely impregnated with resin. In this form it may have been called 'Mapara' by the pre-European Maori (see p.122).

Uses include spinning tops (see Table Two, p.124) and, perhaps, combs and weapons (Boileau, 1978, 56).

Durability would be good for this wood increasing with increasing resin content.

Density of this wood will vary depending on resin content but might be high (e.g. sample No. 58, Appendix Two, p.261).

shrinkage does not appear to be different from sapwood as the actual cell walls are no thicker in heartwood (ibid).

Penetrability was tested in only one sample, a relatively low resin content piece, and this was found to be moderately penetrable (see Figure Fourteen, p.175). With highly resinous pieces, however, one would expect penetrability to be very low.

Conservation of this wood presents some difficulties. Techniques involving organic solvents must be avoided to protect the resin content which is an integral part of the artefact. Secondly, penetrability is likely to vary from moderate to extremely low. This wood should be treated in the same way as heartwood branch kauri, i.e., no attempt should be made to impregnate the sound core of the object. Possible treatments would be techniques 8 and 9, pp.95-6).

Monoao *(Dacrydium kirkii)*

The tree is quite large, up to 25m in height and 1m in diameter, but has a limited modern distribution occurring only between Hokianga and Manukau harbours in northern New Zealand. Sub-fossil wood in sound condition is, however, found further south, e.g. in Waikato swamps.

Use of this timber appears to have been quite common in areas where it was available as five artefact types

were present in the seven artefacts whose wood is identified in Table Two (p.124). These uses include bowls, adze hafts, ko, wakahuia and a bone box (ibid.).

Durability of this wood is high as it is used as fence posts in the Waikato (where it is found in swamps) for this reason. It has a high resin content which may be the factor conferring this property.

Density of the wood is low judging from the one sample of sound heart swampwood tested (see Figure Six, p.146).

Shrinkage is also low (ibid) and reasonably even with a ratio of tangential to radial shrinkage measured at circa 2:1 (see Figure 10, p.159).

Penetrability of the sound wood was tested only for one sample (sample no. 86) and appears to be rather low (see Appendix Three, p.261).

Conservation of this timber where it is found in a sound state does present some problems. The high resin content rules out most use of organic solvents, and the low penetrability, the high molecular weight consolidants used with a hot bath system. Low molecular weight impregnants, e.g. P.E.G. 400, are suitable if a

long soak time is allowed for, however, the shape and size of the specific artefact must be taken into account (i.e., the distance along and across the grain the impregnant must travel to reach the centre of the artefact). Clearly this wood must be treated with caution and precautions taken to ensure that method chosen is appropriate.

Manuka *(Leptospermum scoparium)*

Tree or shrub reaching 8m in height. It is abundant throughout New Zealand being dominant on burnt over or recently cleared land. In densely settled areas of the country this species may have been one of the most common wood available.

Uses of this wood were dictated by its small diameter. It was used for fern root beaters (where kauri was not available), mallets, mauls, weapons, paddles, horticultural implements and a host of other smaller items (see Table Two, p.124). It was also used as poles for fences, palisades, houses and numerous other rough use.

The wood is durable in water, and as it commonly grows on swamps, its sub-fossil remains are an important

component of peat deposits where it is often found in a sound condition despite being hundreds or thousands of years old.

Density of this timber is very high (see Figure Six, p.146) and it is reputed to be very strong.

Shrinkage in this wood is high, averaging about 20% cross-sectional reduction on drying (see Figure Six, p.146). Shrinkage is, however, rather even with an average tangential to radial ratio of just above 1.5:1 (see Figure Ten, p.159). Due to this factor, and to its tangential strength, whole sound stems form only minor radial splits on drying.

Penetrability is rather low, overlapping in range with that of northern hemisphere oak heartwood (see Figure Fifteen, p.177). Penetration is quite low across the grain in this species (ibid.). As most manuka artefacts are long and narrow, due to the small diameter timber used, most impregnants used in conservation will have to penetrate in this direction making the wood, in practice, much more difficult to conserve than the figures at first suggested.

Conservation of this wood presents some difficulties. Consolidants such as PEG 4000 and PEG 1500 will not penetrate the sound wood and hot baths of these materials

should never be used. On the other hand this wood possesses some properties aiding conservation processes. Firstly, it is a small timber and small molecules such as PEG 400 should diffuse across the short distances involved if sufficient soak time is allowed. Secondly, the wood may have high shrinkage rates but these are very even and stems when sound seem to resist radial cracking on drying suffesting that great tangential strength is present. These facts, combined with the durability of the timber means that sound artefacts can simply be slowly dried to effect good conservation results. This method, consciously employed or not, has no doubt been applied to artefacts contained in the large collections of agricultural implements made from manuka that are held in museums in New Zealand.

As the PEG 400/Freeze drying method is applicable to sound manuka and as the PEG 4000 cold bath (see Figure Fifteen, p.177) or PEG 540 blend methods (Methods 8 and 9, pp.95-6) are applicable to partially degraded wood, no real difficulty should be found in selecting a suitable conservation technique for manuka artefacts.

Kanuka *(L. ericoides)*

This tree is closely allied to the previous species

though it is rather larger, reaching 16m in height. It is widespread throughout New Zealand.

Uses of kanuka show an almost identical pattern to that of manuka with variation due only to the greater size of the former. For example, in artefacts which require a broader piece of wood, such as paddles, the use of kanuka dominates; where long narrow shafts are required, e.g. ko, manuka dominates; finally, where the object is small enough to be made equally well from either wood, e.g. ketu, usage is about equal (see Table Two, p.124).

Durability of kanuka in swamps, as far as can be estimated from museum specimens, appears similar to manuka, i.e., it is high.

Density of kanuka is slightly lower than manuka but overlaps in range (see Figure Six, p.146).

Shrinkage of kanuka is also slightly lower (ibid.) and is slightly less even (see Figure Ten, p.159).

Penetrability of kanuka is almost identical to manuka with almost complete overlap in range (see Figure Fifteen, p.177).

Conservation: Kanuka has almost identical properties and uses to manuka and conservation should take into account the same facts and proceed as described for that species.

Black Maire *(Nestegis cunninghamin)*

The tree is large, reaching 23m and occurs only in the North Island and Marlborough in the South Island. An allied species White Maire *(N. lanceolata)* is present over the same range and is in distinguishable anatomically in swampwood.

Uses: The wood is heavy, tough, hard and rigid (Entrican, Ward and Reid, 1951:51) and was used where these properties were important, i.e., for fern root beaters, mallets, mauls, weapons, eel clubs, kaheru blades, ketu, ko, teka and hoko (see Table Two, p.124, Table Five, p.130, Table Six, p.133).

Density of the wood is high (see Figure Six, p.146).

Shrinkage is also high (ibid.) and reasonably even on average (see Figure Ten, p.159)

Penetrability of sound heart Maire is extremely low falling in the lowest range in the tests (see Figure Fifteen, p.177). The amount of water penetrating the

wood in these tests was so low that it can be regarded as little more than surface wetting and is regarded as on or below the range measurable with the technique used.

Conservation: of this wood presents many problems. It is durable and therefore is likely to be found in a sound state. Its natural shrinkage is high. It is possible that it will resist penetration by all but the smallest molecular impregnants. Artefacts made from this wood are mostly either small or long and thin thus distances on impregnant will have to travel to reach the centre of the object will be short but mostly across the grain.

Conservation techniques involving impregnation with high molecular weight substances should be avoided e.g., the PEG 4000 hot bath technique. The PEG 400/ Freeze drying method would be possible but only if very long soak times are employed, i.e., up to two years. Some of the techniques involving organic solvents and resin (e.g. method no. 2, the acetone Rosin method) might be suitable. At the conservation laboratory of Parks Canada the writer saw the results of the latter method when applied to sound ships tackle blocks made from *Lignum vitae*, a wood renowned for its density and durability. For smaller items this technique might be applicable.

Where the wood is partially or highly degraded the problems lessen as penetrability increases, however, care should be taken to ensure that no sound wood is present before applying methods that involve PEG 4000 or similar sized molecules.

Rata and Pohutukawa *(Metrosideros robusta, M. umbellata* and *M. excelsa)*

These trees are closely related. Northern rata *(M. robusta)* forms large trees up to 30m in height and grows from North Cape to mid-South Island. It tends to form from coalesced aerial roots of an epiphytic seeding. Southern rata *(M. umbellata)* forms a shrub or small tree up to 20m in height and occurs from Whangarei southwards becoming more common in the deep south. Pohutukawa *(M. excelsa)* occurs as far south as the mid-North Island as a seashore or coastal tree. It forms massive spreading crowns on little or no trunk.

Uses of this wood were very similar to Maire, i.e., fern root beaters, mauls, paddles, weapons, eel clubs, ketu, ko, teka and spinning tops (see Table Two, p.124).

The durability of the wood appears to be high as it is common in a sound form in stream beds running off Pirongia Mountain (see Appendix One, p.252).

The density of these woods is high (see Figure Six, p.146) to very high (see Entrican, Ward and Webb 1951:53) and they are extremely strong and tough (ibid.).

Shrinkage in these woods is moderately high (see Figure Six, p.146) and quite variable (see Figure 10, p.159).

Penetrability of northern rata *(M. robusta)* is low and within the range of northern European heart oak for both sound modern and wood collected from streams (see figure Fifteen, p.177 , and Appendix Three, p.276). Penetrability of sound pohutukawa heartwood is extremely low (ibid.). Southern rata was not tested.

Conservation of this wood presents the same problems as that of Maire. Due to the anatomical similarities it is often not possible to distinguish between the three species of *Metrosideros* and therefore one must be cautious and assume that if sound heartwood is present, then the wood may resist penetration by all but the smallest molecules. Conservation should proceed as for Maire (see above).

Puriri *(Vitex lucens)*

The tree reaches 20m and occurs abundantly in coastal and lowland forest in the northern half of the North Island.

Uses of Puriri include palisade posts, bowls, fern root beaters, paddles, adze hafts, adze sockets, kaheru blades, ko and hoko (see Table Two, p.124). In many respects these uses are identical to those of the other hard tough dense woods Manuka, Kanuka, Rata, Maire and Pohutukawa.

Durability of this wood is high to judge from museum specimens.

Density of this wood is also high (see Figure Six, p.146).

Shrinkage: in this timber is high to moderate (ibid.) and rather uneven (see Figure Ten, p.159).

Penetrability: of sound heart Puriri is extremely low, little above surface wetting in the results of the tests shown in Figure Fifteen, p.177).

Conservation of this wood should follow the same suggestions as that for Maire as the essential properties of both woods are so similar.

Akeake *(Dodonaea viscosa)*

A tree or shrub up to 10m in height, it is common on

coasts and in coastal forest in the North Island and down to the middle of the South Island.

Use of the wood was mainly for weapons (four out of the six examples found) but a ko and a hoko was also found to be made from it (see Table Two, p.124).

Durability: Little evidence of its durability is available but as an ultra dense, ultra impenetrable wood (see below) it is likely to be very durable in wet sites.

Density: This wood is, on average, the densest known for New Zealand (see Figure Six, p.146).

Shrinkage is high but relatively even (ibid. and Figure Ten, p.159).

Penetrability of this wood is low to ultra-low (see Figure Fifteen, p.177).

Conservation of this wood must follow the same pattern as for Maire, Pohutukawa, Rata and Puriri as they all share similar properties (see Maire, above).

Kowhai *(Sophora microphylla* and *S. tetraptera)*

The tree is small being up to 10m for *S. microphylla* and 14m for *S. tetraptera*. The former species occurs

as far south as Southland and the latter only in central-south North Island. This tree produces virtually equal amounts of sap and heartwood.

Uses of the wood include bowls, paddles, and weapons (see Table Two, p.124).

Durability of the wood is not known but, as with Akeake, its heartwood is dense and impenetrable (see below) and thus should survive unaltered in swamps if conditions are suitable. The sapwood, however, is readily penetrable and may degrade much more rapidly (see Figure Sixteen, p.179).

Density of this wood is very high (see Figure Six, p.146) and does not appear to be greater in heartwood as compared to sapwood (see Appendix Two, p.269).

Shrinkage in this species is very high, the highest recorded in this research (see Figure Six, p.146) but is reasonably even compared to other woods (see Figure Ten, p.159).

Penetrability of heartwood Kowhai is low to ultra-low (see Figure Fifteen, p.177) but the sapwood is moderately penetrable (see Figure Sixteen, p.179).

Conservation of wood of this species will be much the same as for Maire, Rata, Puriri, Pohutukawa and Akeake as their properties are similar. The only likely difference will occur when Kowhai sapwood is present as it is unlikely to be present as sound wood and will be quite penetrable. As conservation tends to be determined by the most difficult aspect of an artefact's wood, the sapwood's properties may not be relevant if some sound heart is also present, therefore, the approach taken should follow that given above.

Mapou *(Myrsine australis)*

A small tree reaching 7m in height very common in scrub and regenerating forest throughout New Zealand.

Uses include fern root beaters, mauls, adze hafts and their detachable sockets and ko. In many cases this wood appears to have been used either green or wet as many artefacts, especially ko, have their bark still attached, and as stems of this wood develop spectacular radial splitting when seasoned.

Durability of this wood appears very low and no sound wood from swamps or in the form of artefacts

was encountered. Fresh wood when placed in water gives off large amounts of dissolved material of a pink colour. This may explain why modern wood has low penetrability (see below) but swamp wood seems to be rapidly entered by decay organisms and degrades evenly throughout, i.e., the materials preventing penetration are water soluble and are rapidly leached from the wood.

Density of sound wood is high (see Figure Six, p.146) but as sound wood is never encountered in wet sites this factor does not affect conservation practices.

Shrinkage of this wood is moderately high (ibid.) and is extremely uneven with a ratio of tangential to radial shrinkage averaging 4:1 in sound wood. This ratio is very variable and declines when partial degradation occurs as does total shrinkage (see Figure Nine, p.157; Figure Ten, p.159; and Figure Eleven, p.161).

Penetrability of this wood is low when sound (see Figure Fifteen, p.177) but as sound wood does not occur in sites this is not relevant to conservation. Partially degraded Mapou is ultra penetrable (see Figure Eighteen, p.182) and, when dry, acts like

blotting paper taking up water extremely rapidly.

Conservation of this wood does not face any serious barriers as it is highly penetrable when degraded. In the past, partially degraded artefacts were dried out slowly either with no other treatment or with coatings of linseed oil (see p.87). Due to the extremely uneven shrinkage of this wood, i.e., its high tangential shrinkage, this method produced massive radial cracking in the artefacts. Slow drying of this species should never be undertaken for this reason. Suitable techniques are ones which prevents most or all dimensional change, e.g. PEG 400/Freeze drying, since artefacts used in the green or wet state originally should be maintained in their water swollen dimensions. Furthermore, the fact that this wood has uneven shrinkage when partially degraded or sound and was used usually in the form of whole stems makes radial cracking a likelihood unless no significant dimensional change occurs during conservation.

Tawa *(Beilschmiedia tawa)*

A large tree, up to 25m high and 1m in diameter, it is common throughout the North Island and the northern tip of the South Island.

Uses of the trunkwood include planks, battens, posts, bowls, horticultural implements and sometimes carved items, e.g. bones (see Table Two, p.124).

Durability of this wood appears to be low in wet sites to judge from the condition of artefacts in museum collections and totally sound wood is unlikely to be found in wet sites.

Density of the wood is moderate (see Figure Six, p.146, and Entrican, et. al., 1951:56).

Shrinkage in this wood is high to medium (ibid.) and is, on average, rather uneven with a tangential to radial shrinkage ratio of circa 3:1 (see Figure Ten, p.159).

Penetrability of this wood is high (see Figure Fifteen, p.177) even in sound heartwood and considering sound wood is not likely to be encountered by conservators, this wood will present no problem in this regard.

Conservation of tawa swamp wood will not provide the conservator with many problems as far as wood properties are concerned. The most serious problem to be overcome is the uneven shrinkage and the

cracking this may entail. Controlled drying is clearly not an acceptable method, however, this timber poses no serious obstacles to other methods and these can be used where they are appropriate.

Tawa branchwood was used for adze helves (see Table Two, p.124). As this wood behaves in a similar fashion to trunkwood it should be treated in the same way.

Pukatea *(Laurelea novae-zelandiae)*

This is a large tree up to 23m high and 2m in diameter in wet forest south to the northern tip of the South Island.

Uses of the wood included small house timbers, posts, bowls and even mauls (see Table Two, p.124). In the case of mauls the wood would have been used wet as this timber is very light.

Durability of Pukatea is low in wet conditions to judge from museum specimens.

Density of this wood is very low and, in fact, was the only really light angiosperm wood commonly used (see Figure Six, p.146).

Shrinkage in this wood is very low though not, on average, very even with a tangential to radial shrinkage ratio of circa 2.5:1 (see Figure Ten, p.159).

Penetrability of this wood is the highest found for sound wood in this research and materials will penetrate well across all planes of the wood (see Figure Fifteen, p.177).

Conservation of this wood is not inhibited by any aspect of its properties except perhaps its uneven shrinkage. This latter property would make slow drying a little hazardous but as this technique is only used where the wood is completely sound and since Pukatea is unlikely to be found in this condition in wet sites, this situation need never arise. Conservation techniques can be chosen on criteria other than wood properties on the assumption that these properties will not cause the failure of the method.

Porokaiwhiria *(Hedycarya arborea)*

A tree reaching 15m, abundant in lowland and wetter areas through the North Island and the northern tip

of the South Island.

Uses of the wood include smaller house timbers, shafts of horticultural implements and ko (see Table Two, p.124).

Durability of this wood appears low as no sound wood from sites was found, only partially degraded material being present.

Density, shrinkage and penetrability of this wood was not tested on sound timber but in its partially degraded state it is light, with medium shrinkage (see Appendix Two, p.268) and is ultra penetrable when dry, being like blotting paper absorbing water in seconds (see Appendix Three, p.278).

Conservation should be the same as for Mapou as the artefacts and wood properties of Porokaiwhiria are very similar to this species. Slow drying should never be attempted and, with whole stems, one should ensure maximum dimentional control to avoid radial cracking. Due to its high penetrability in the degraded state, most methods are possible and the one most appropriate should be chosen for each instance.

Ramarama *(Myrtus bullata)*

A shrub reaching 8m, present throughout the North Island and the northern tip of the South Island.

Uses found were for adze hafts and their detachable sockets and ko foot-rests (see Table Two, p.124).

Durability of this wood appears to be moderate judging from the few artefacts examined though since whole stems were normally used much sapwood is likely to be present ensuring that extremely sound artefacts will rarely be found.

Density is in the medium to high range for N.Z. woods (see Figure Six, p.146).

Shrinkage is high for sound heartwood but very even (see Figure Ten, p.159).

Penetrability for sound heartwood was only tested on one sample and proved to be very high along the grain. Artefacts that are short should be readily penetrable along the grain but if long shafts are found problems may be met.

Conservation: This is not a particularly difficult wood but as the number of samples tested is small, it is hard to be precise. If completely sound heart wood is present in the form of long shafts of wood, only small molecular weight impregnants should be used, i.e., PEG 400. On the other hand if artefacts are small and short along the grain, little difficulty should be faced introducing consolidants.

Rewarewa *(Knightia excelsa)*

A large tree 30m high, occurring in the North Island and the northern tip of the South Island.

Uses of this wood recorded in this study were for bowls and mauls (see Table Two, p.124).

Durability of this wood appears, from examination of museum artefacts, to be only moderate, partially degraded wood being typically found.

Density of this wood is moderate (see Figure Six, p.146).

Shrinkage in this wood is both high and extremely uneven (see Figures Six, p.146; Ten, p.159; and Twelve, p.162).

Penetrability of sound wood is high along the grain but low across it (see Figure Fifteen, p.177) but in partially degraded wood it is ultra-high (see Appendix Three, p.277).

Conservation of this wood should never involve simple drying due to the very uneven ratio of tangential to radial shrinkage which would cause massive radial cracking. As this wood forms large diameter trunks it is less likely to be used for long narrow shafts than smaller species. The low penetrability of the wood across the grain is not, therefore, a major problem, e.g. bowls have a lot of end grain exposed and penetration along this is high. For artefacts with genuinely sound heartwood present and low amounts of end grain exposed, very long soak times should be employed and small molecular weight impregnants used.

Conservation Groups of Woods

Highly resinous heartwood of some gymosperm species form a special class of wood for the conservator. These woods include heart Kauri branchwood, 'Mapara' or resinous Kahikatea heartwood and, perhaps, unusually resinous pieces of other gymnosperms such as Totara,

Rimu or Matai. The amount of resin in these woods can be determined by taking a small sample of sound wood from the artefact, thin sectioning it and examining it under a microscope. The resin will be visible in the cells of the wood.

These woods are always used to make small artefacts due to the size of the timber available. Conservation treatments using organic solvents are unacceptable as they would remove the resin. The woods are ultra impenetrable and cannot be impregnated with most conservation materials.

Fortunately these woods are highly durable in wet sites. Consequently, slow drying is a good method if no surface decay has occurred. If the latter situation prevails, the most suitable method might be the PEG 4000 cold bath treatment. This method (see Method 8, p.95) will impregnate the degraded surface but have no effect on the sound interior. The artefact is slow then dried which allows the interior to dry out without any further treatment while the surface is protected by its consolidant.

Ultra impenetrable woods from the second group to be discussed. These include the heartwood of Maire,

Puriri, Kowhai, Pohutukawa and Akeake (see Figures 14, p.175, and 15, p.177). Most of the artefacts made from these woods will be small to medium in size. They are very durable timbers and may commonly be found in a sound state in wet sites. They are all very dense and show high natural shrinkage.

If these artefacts are completely sound, slow drying may be appropriate but this must be done with great care due to their high shrinkages. If the artefacts are partially degraded the PEG 400 Freeze drying method might be applicable but extremely long soak times would be necessary. If the artefacts are small, some of the techniques involving organic solvents and resin or wax bulking might also be suitable but due to the range in shape and form these artefacts have, it is not possible to give any precise instructions about when to use these methods.

What is clear is that artefacts made from the above woods should never be conserved using high molecular weight consolidants as the chances are high that these will fail to penetrate.

Moderate to highly impenetrable wood from a group that includes three gymnosperms Totara, Hall's Totara

and Pahautea and three angiosperms, Rata, Manuka and Kanuka (see Figures 14, p.175 and 15, p.177). The first three are light woods with low shrinkages and the latter three are dense, with high shrinkage. These woods are moderately durable and can often be found in wet sites in a sound state though they equally can be found partially or highly degraded if preservation conditions are poor.

When the above woods are found in a sound state, they cannot be conserved using high molecular weight consolidants as these will not penetrate. They are as impenetrable as sound oak heartwood and experience has shown that this timber will not take up these materials.

Artefacts made from these woods are so variable in size, shape and other factors that it is difficult to offer definite suggestions concerning their conservation. However, it may be possible to use smaller molecules such as PEG 400 if the artefacts are small and if very long soak times are used.

Where it can be determined that these woods are partially or highly degraded the conservation options increase and choices should be made on factors other than wood type.

Moderately penetrable woods form a group characterised by good penetration along the grain even in sound heartwood (see Figures 14, p.175 and 15, p. 177) but poor penetration across it. This group includes heart wood of Kauri, Kahikatea, Tanekaka and resinous Matai (see Figure 14, p.175) and heart of Tawa, Rewarewa, Ramarama, and perhaps, Kowhai sapwood (see Figure 15, p.177).

Due, no doubt, to their penetrability along the grain, these wood are not highly durable in sites but this varies with conditions of burial and with the shape of the artefact. If an artefact has a high proportion of its surface consisting of end grain (e.g. a bowl), it would be much less durable than a long narrow shaft which has very little end grain exposed.

The penetrability of artefacts will also vary for the same reason as given above for durability. Obviously, sound wood in the form of shafts will have to be soaked for a longer period than bowls in order to impregnate them during conservation. Given sufficient soak times most artefacts made from these woods will be penetrated by impregnants of higher molecular weight.

Due to the extreme range of types of artefacts made from these woods, specific conservation proposals

cannot be made but it can be stated that these woods do not have properties that make conservation inordinately difficult.

Highly penetrable woods include: sound Kahikatea (sapwood), Rimu, Matai and Pukatea (see Figures 14, p.175 and 15, p.177); the sapwood of most of the species examined in this research (see Figure 16, p.179), and; all wood which has suffered partial (see Figure 17, p.181) or heavy decay.

The above woods can be impregnated with consolidants of all molecular weights. In conserving these woods the conservator chooses his method on the basis of factors other than wood properties.

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Having reviewed the state and potential of wet site archaeology in New Zealand, the properties and structure of wood and the field of waterlogged wood conservation processes worldwide, a research strategy that fulfilled the stated objectives of this project and suited the situation in this country and the facilities available to the research worker was developed. The research began with the identification of the timber types that were used by the prehistoric Maori and what each was used for. This was followed by the collection of samples of each wood type in different states of decay and by the testing of each for density, directional shrinkage and directional penetrability. These studies allowed the characterisation of each wood sample with respect to their likely behaviour when treated by the conservator.

CONCLUSIONS

The research project, reported in this thesis, has approached the subject of waterlogged wood conservation from an angle that is different to most work done overseas. There, research has been typically

of an applied type, i.e., it has been done by practising conservators as a sideline to their normal work and has been designed to solve immediate problems that they face in their day to day work. Other research has been more theoretical but has tended to concentrate on either a single aspect of a technique, a material used in conservation or has been designed to develop a new (or modified) technique of treatment.

The present research project was of a much more theoretical and general type and was undertaken in circumstances rather divorced from the everyday problems of a conservation laboratory. This was an inevitable consequence of the structure and design dictated by the research funding. Another factor which led to the application of such a theoretical and general approach was that New Zealand trees are mostly endemic and their timbers are, from the point of view of wood conservation, almost entirely unknown. This factor led to the research project taking as its starting point the most basic considerations possible.

In Europe and North America the type of studies that this thesis reports have never been undertaken on a systematic basis but, rather, have been accomplished

in a piecemeal fashion during the course of practical conservation activities over a long period of time. It has not been necessary, in those regions, to systematically catalogue the properties of the different woods and only in Christensen's early studies (Christensen 1970:61-74) does one find an approach similar to that adopted in the present work.

The advantage inherent in the approach taken in this research is that the conservator is, at the end, provided with a coherent set of information concerning the relevant properties of the woods involved in his artefacts that has been collected at the same time using a standard set of materials and techniques. These results are satisfactory as far as they go but they apply to actual conservation practice only indirectly. In practice, each artefact found in a wet site is a special problem in itself and its particular properties are a result, not only of the type of wood and its properties, but the peculiarities of the shape of the artefact and its particular history of use. It is impossible to predict these properties accurately using the results of theoretical studies done beforehand since these only provide a

set of parameters which delimit the range of possibilities for each wood. As useful as these parameters are, they are only a first step in establishing the properties of the artefact in question.

RECOMMENDATIONS FOR THE FUTURE

The basic recommendation that must be made here is that since the theoretical background studies have been completed, further progress can only be made in the context of actual practical conservation activities. In New Zealand our wet sites and the organic artefacts that they contain represent an enormously valuable cultural resource which is, at present, available for study only to a limited degree. The greatest obstruction to our access to this resource is the lack of conservation facilities and trained staff to deal with the material once it has been removed from the ground. Until these facilities and, at least, one full time professional conservator are available this cultural resource will remain mostly beyond our reach and we will be limited to studying the material that is uncovered accidently and from salvage excavations of sites where it is in the process of being destroyed.

In short, the field of wet site archaeology is, to

a great extent, in a state of suspended animation due to the conservation problem. Even if no deliberate research archaeology in wet sites in undertaken in the future, the volume of material that is being accidently uncovered dictates that some effort be put into the conservation field. It is felt that in these sites is a greater potential than anywhere else for the illumination of our prehistoric past. They contain material that is unique to this country and is, at present, being destroyed by neglect and apathy.

In conclusion, this research project must be a lead up to the establishment of adequate conservation facilities or it will have been a waste of time and money. It is to be hoped that this does not occur and that this field will come to fulfil its great potential.

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APPENDIX ONE: A list of the wood samples collected for this research

Abbreviations:

E&B = Ellis and Burnand Co. Ltd, Hamilton
W = collected by the present author
W.U. = Waikato University swamp wood collection
S.F. = State Forest
W.T. = Whitecliffs Timber Co., Auckland
M.U. = Modern Upholstery Ltd, Dunedin

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	KAURI (*Agathis australis*)		
47	Modern, sound, heart trunk wood	Salvage lumber	W
52	Very old, sound resinous heart trunk wood	lower Waikato	W.U.
56	Very old, partially degraded trunk sap wood	lower Waikato	W.U.
36	Modern sound heart branch wood	Moehau Range	D. Nevin
119	Modern sound heart branch wood	Waipouia S.F.	J. Coster
120	Modern sound sap branch wood	Waipouia S.F.	J. Coster
55	Very old, sound resinous heart trunk swamp wood	East Kaipara	W.U.
4	Modern sound heart branch wood	Coromandel	W.
	MATAI (*Podocarpus spicatus*)		
126	Modern sound heart trunk wood	Commercial lumber	W.T.
12	Modern sound heart trunk wood	Commercial lumber	W.T.
128	Modern sound heart trunk wood	Minginui S.F.	D. Nevin
2	Modern sound heart trunk wood	Commercial lumber	W
66	Very old partially decayed heart trunk swamp wood	Waikato	A. Brennan
45	Very old partially decayed heart trunk swamp wood	Whatawhata swamp, Hamilton	W

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	TOTARA (*Podocarpus totara*)		
59	Very old partially decayed heart trunk swamp wood	Whatawhata swamp	W
63	Very old partially decayed heart trunk swamp wood	Te Miro	S. Edson
50	Very old sound heart trunk swamp wood	Huntly	Mrs Engebretsen
37	Modern sound heart trunk wood	Moehau Range	D. Nevin
138	Highly degraded heart trunk swamp wood	Waitore	R. Fyfe
17	Sound modern heart trunk wood	Commercial lumber	E&B
60	Very old partially degraded heart trunk swamp wood	Waikato	W.U.
28	Modern sound sap trunk wood	Commercial lumber	E&B
96	Partially degraded heart trunk wood	Moehau Range	D. Nevin
26	Sound modern heart trunk wood	Commercial lumber	E&B
62	Sound modern sap trunk wood	Ohakune	D. Nevin
61	Sound modern heart trunk wood	Commercial lumber	W
	RIMU (*Dacrydium cupressinum*)		
1	Modern sound heart trunk wood	Commercial lumber	W
15	Modern sound heart trunk wood	Commercial lumber	E&B
27	Modern sound sap trunk wood	Commercial lumber	E&B
139	Very old sound heart trunk swamp wood	Te Miro	S. Edson
38	Modern sound branch wood	Pirongia S.F.	W
42	Very old, partially degraded heart trunk swamp wood	Waikato	W.U.
	TANEKAHA (*Phyllocladus trichomanoides*)		
19	Sound modern trunk wood	Commercial lumber	E&B
7	Sound modern trunk wood	Commercial lumber	W.T.
97	Sound modern branch wood	Mangakawa	W

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	MONOAO (*Dacrydium kirkii*)		
86	Sound, very old, resinous heart trunk swamp wood	Waikato area	W.U.
127	Sound, very old, resinous heart trunk swamp wood	Waikato area	Hugh Oliver
	KAWAKA (*Libocedrus plumosa* and *bidwillii*)		
30	Modern sound heart trunk wood (*L. plumosa*)	Commercial lumber	E&B
5	Modern sound heart trunk wood (*L. bidwillii*)	Ohakune	D. Nevin
	KAHIKATEA (*Podocarpus dacrydioides*)		
16	Modern sound trunk sap wood	Commercial lumber	E&B
32	Modern sound trunk sap wood	Commercial lumber	E&B
9	Modern sound trunk sap wood	Commercial lumber	W.T.
8	Modern sound trunk heart wood	Commercial lumber	W.T.
57	Old partially degraded trunk sap wood	Te Miro	S. Edson
125	Modern sound branch wood	Claudelands bush	W
58	'Kapara' sound resin filled patch of heart wood	Wanganui R.	H. Oliver
	HALL'S TOTARA (*Podocarpus totara*)		
64	Sound modern heart trunk wood	Ohakune	D. Nevin
10	Sound modern heart trunk wood	Commercial lumber	W.T.
	MIRO (*Podocarpus ferrugineus*)		
49	Modern sound branch wood	Ohakune	W
20	Modern sound trunk sap wood	Commercial lumber	E&B
140	Modern sound trunk sap wood	Commercial lumber	Forest Research Institute
	MANUKA (*Leptospermum scoparium*)		
135	100mm diameter stem, partially degraded swamp wood	Rukuhia swamp	W

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	Manuka Cont.		
136	50mm diam. stem partially degraded swamp wood	Rukuhia swamp	W
67	30mm diam. stem partially degraded swamp wood	Te Miro	S. Edson
68	50mm diam. stem sound swamp wood	Whatawhata swamp	W
105	70mm diam. stem sound modern live wood	Ngaruwhahia S.F.	W
37	30mm diam. stem sound modern live wood	S. Pirongia S.F.	W
116	50mm diam. stem sound modern seasoned wood	Pirongia	W
69	120mm diam. stem sound modern seasoned wood	Taupiri mnt	Mrs Engebretsen
	KANUKA (*Leptospermum ericoides*)		
114	100mm diam. trunk green sound modern wood	Pirongia	W
115	200mm diam. trunk green sound modern wood	Pirongia	W
70	250mm diam. trunk seasoned sound modern wood	Aotea area	W
124	160mm diam. trunk sound old swamp wood	Huntly area	Mrs Engebretsen
	BLACK MAIRE (*Nestegis cunninghamii*)		
67	Modern sound heart trunk wood	sample	Forest Research Institute
21	Modern sound heart trunk wood	Pirongia area	H. Oliver
75	Modern sound heart trunk wood	Ohakune	D. Nevin
75	Modern sound sap trunk wood	Ohakune	D. Nevin
24	Modern sound heart branch wood	Pirongia	H. Oliver
	WHITE MAIRE (*N. lanceolata*)		
112	Modern sound heart trunk wood	Whatawhata	H. Oliver

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	RATA (Northern) *Metrosideros robusta*)		
130	Modern sound heart trunk wood	Minginui S.F.	K. Tawhio
103	Modern sound heart trunk wood	Sample	Forest Research Institute
131	Modern sound heart trunk wood	Ohakune	D. Nevin
101	Very old degraded heart trunk wood	Hinuera Formation	W.U.
22	Modern sound heart trunk stream wood	Pirongia	H. Oliver
102	Modern sound heart trunk stream wood	Pirongia	W
107	Modern sound heart branch stream wood	Pirongia	W
23	Modern sound heart branch wood	Raglan	H. Oliver
	POHUTAKAWA (*Metrosideros excelsa*)		
95	Modern sound trunk sap wood	Coromandel	D. Nevin
93	Modern sound trunk heart wood	Coromandel	D. Nevin
91	Modern sound trunk heart wood	Coromandel	D. Nevin
	MAPOU (*Myrsine australis*)		
111	Modern sound 150mm green stem	Te Miro	W
79	Modern sound 200mm seasoned stem	Waikato	H. Oliver
123	Modern sound 80mm seasoned stem	Claudelands	W
141	Modern sound 80mm green stem	Pirongia mnt.	W
80	Old partially degraded 200mm stem of swamp wood	Hamilton	S. Edson
48	Very old highly degraded 80mm stem of swamp wood	Waitore	R. Fyfe

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	TAWA (*Beilschmiedia tawa*)		
18	Modern sound heart trunk wood	Commercial lumber	E&B
29	Modern sound heart trunk wood	Commercial lumber	E&B
99	Modern sound heart trunk wood	Pirongia mnt.	W
129	Modern sound heart trunk wood	Te Kuiti	T. Bell
72	Old slightly degraded heart trunk wood	Te Miro	S. Edson
100	Modern sound branch wood	Waikato	W
73	Modern sound branch wood	Ohakune	W
71	Modern slightly degraded branch swamp wood	Hamilton	W
43	Old highly degraded branch swamp wood	Waitore	R. Fyfe
	PUKATEA (*Laurelea novae-zelandiae*)		
46	Old partially degraded trunk sap swamp wood	Te Miro	S. Edson
33	Modern sound trunk sap wood	Commercial lumber	E&B
51	Modern sound 'buttress' sap wood	Ngaruawahia S.F.	W
142	Modern sound trunk sap wood	Sample	Forest Research Institute
	PURIRI (*Vitex lucens*)		
121	Sound modern heart trunk wood	Aupouri S.F.	J. Coster
104	Sound modern heart trunk wood	Aupouri S.F.	J. Coster
106	Sound modern heart trunk wood	Aupouri S.F.	J. Coster
94	Sound modern sap trunk wood	Moehau Range	D. Nevin
117	Sound modern heart branch wood	Raglan	W
92	Sound modern heart branch wood	Moehau Range	D. Nevin
90	Sound modern sap branch wood	Moehau Range	D. Nevin
143	Sound modern heart trunk wood	Sample	Forest Research Institute

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	POROKAIWHIRIA (*Hedycarya arborea*)		
83	Old partially degraded 80mm stem swamp wood	Te Miro	S. Edson
	AKEAKE (*Dodonaea viscosa*)		
133	Modern sound seasoned stem wood	Huntly area	W
134	Modern sound seasoned stem wood	Huntly area	W
118	Modern sound green stem wood	Raglan	W
25	Modern sound green stem wood	Hamilton	H. Oliver
144	Modern sound seasoned stem wood	Sample	Forest Research Institute
	RAMARAMA (*Myrtus bullata*)		
85	Modern sound seasoned stem wood	Hamilton	W
	REWAREWA (*Knightia excelsa*)		
14	Modern sound trunk wood	Commercial lumber	E&B
78	Modern sound trunk wood	Commercial lumber	W
77	Old partially degraded trunk swamp wood	Te Miro	S. Edson
	KOWHAI (*Sophora microphylla* and *tetraptera*)		
110	Modern seasoned sound heart trunk wood	Pirongia	W
109	Modern seasoned sound sap trunk wood	Pirongia	W
108	Modern green sound sap trunk wood	Pirongia	W
144	Modern seasoned sound heart trunk wood	Sample	Forest Research Institute
113a	Modern seasoned sound heart trunk wood	Pirongia	W
113b	Modern seasoned sound sap trunk wood	Pirongia	W
44	Modern seasoned sound heart trunk wood	Whatawhata	H. Oliver
145	Modern seasoned sound sap trunk wood (*S. tetraptera*)	Sample	Forest Research Institute

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	RANGIORA (*Brachyglottis repanda*)		
82	Old partially degraded stem of swamp wood	Te Miro	S. Edson
146	Modern sound stem sap wood	Pirongia mnt.	W
	KAMAHI (*Weinmannia racemosa*)		
39	Modern sound branch sap wood	Ohakune	W
147	Very old highly degraded swamp wood	Waitore	R. Fyfe
	MAHOE (*Melicytus ramiflorus*)		
148	Old partially degraded trunk swamp wood	Te Miro	S. Edson
3	Modern sound sap trunk wood	S. Pirongia S.F.	W
84	Modern partially degraded sap branch wood	Hamilton	W
149	Modern sound sap branch wood	Pirongia mnt.	W
	(*Olearia avicenniaefolia*)		
41	Sound modern heart stem wood	Waiau R.	H. Oliver
	TARAIRI (*Beilschmiedia tarairi*)		
88	Modern sound branch sap wood	Ngaruawahia S.F.	W
	LANCEWOOD (*Pseudopanax crassifolius*)		
81	Modern sound 200m stem wood	Ohakune	W
	LACEBARK (*Hoheria sexstylosa*)		
76	Modern sound trunk wood	Raetihi	D. Nevin
	MANGAEO (*Litsea calicaris*)		
35	Modern sound trunk wood	Commercial lumber	E&B

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
	HINAU (*Elaeocarpus dentatus*)		
34	Modern sound trunk wood	Commercial lumber	E&B
	MANGROVE (*Avicennia resinifera*)		
89	Modern sound branch wood	Coromandel	D. Nevin
137	Modern sound trunk heart wood	Whangarei Harbour.	W
	POKAKA (*Elaeocarpus hookerianus*)		
132	Sound modern trunk timber	Minginui S.F.	K. Tawhio
	PUTAPUTAWETA (*Carpodetus serratus*)		
150	Old partially degraded stem wood	Te Miro	S. Edson
151	Modern sound branch sap wood	Hamilton	W
	WHITE OAK (*Quercus robur*)		
6	Modern rapidly grown N.Z. heart trunk wood	Cambridge	W
153	Modern rapidly grown N.Z. heart trunk wood	N.Z.	M.U.
155	Modern rapidly grown N.Z. heart trunk wood	N.Z.	M.U.
156	Modern rapidly grown N.Z. heart trunk wood	N.Z.	M.U.
157	Modern rapidly grown N.Z. heart trunk wood	N.Z.	M.U.
158	Modern rapidly grown N.Z. heart trunk wood	N.Z.	M.U.
159	Modern rapidly grown N.Z. heart trunk wood	N.Z.	M.U.
160	Modern rapidly grown N.Z. heart trunk wood	N.Z.	M.U.
161	Modern slow grown heart trunk wood	N. Europe	M.U.
162	Modern slow grown heart trunk wood	Japanese	M.U.

REF. NO.	DESCRIPTION OF SAMPLE	ORIGIN	COLLECTOR
163	Modern slow grown heart trunk wood	N. Europe	M.U.
164	Modern slow grown heart trunk wood	Japanese	M.U.
154	Modern slow grown heart trunk wood	N. Europe	M.U.
98	Modern slow grown heart trunk wood	Temuka, N.Z.	W

APPENDIX TWO: Shrinkage and Density Data

Density = per cent weight of water at full saturation

Shrinkages = per cent shrinkage from saturated to oven dry dimensions

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE ESTIMATED CROSS-SECTIONAL
	KAURI (*Agathis australis*)				
47	Sound, heart trunk wood	61.4	3.7	1.4	5.1
		57.7	7.5	1.6	9.0
		62.5	6.5	4.6	10.8
		58.2	6.3	3.2	9.3
		58.8	4.1	5.1	8.9
		57.3	3.2	1.5	4.7
		56.9	3.1	2.5	5.5
		56.6	6.8	6.5	12.8
		57.5	6.5	5.6	11.7
		58.6	3.2	1.4	4.6
		59.0	5.5	4.6	9.9
		56.4	3.1	2.4	5.4
55	Sound, heart swamp wood	57.0	4.6	1.7	6.2
		65.9	5.7	1.6	7.5
		57.3	6.5	3.8	10.1
		56.2	4.5	3.3	7.7
		63.6	6.1	5.9	9.5
56	Partially degraded sap swamp wood	67.2 65.4	2.6	2.7	4.6
36	Sound branch heart wood	24.1 28.9	5.1	3.4	8.1
119	Sound branch heart wood	43.2	3.6	3.1	6.6
		44.6	4.1	2.6	6.6
		44.5			
		46.0			
120	Sound, sap branch wood	50.0	3.7	3.4	7.0
		50.0	3.3	2.7	6.0
		49.7	4.2	2.8	6.9
4	Recent sound heart branch wood	38.6 36.8	3.0 3.3	1.9 4.9	4.8 8.1

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	RADIAL	EST. CROSS SECTIONAL
	MATAI (*Podocarpus spicatus*)				
126	Sound modern trunk heart wood	51.1			
		51.6			
		45.9			
128	Sound modern trunk heart wood	47.4			
		48.2			
2	Sound modern trunk heart wood	55.3	5.5	0.6	6.1
		53.8	3.5	2.5	7.6
		56.4	6.3	1.9	7.9
12	Sound modern trunk heart wood	47.7	6.7	3.7	10.2
66	Very old partially decayed heart trunk swamp wood	49.5	3.2	2.3	6.4
		57.3	5.6	1.5	7.1
		57.7	5.2	1.2	6.4
		57.7	5.4	0.6	5.9
		56.6	4.7	1.2	5.8
		49.0	3.3	2.4	5.7
45	Very old partially decayed heart trunk swamp wood	53.2	7.4	4.6	11.6
		57.5	7.1	5.3	11.9
	TOTARA (*Podocarpus totara*)				
61	Modern sound heart trunk wood	65.1	6.8	4.4	10.8
		63.7	7.6	4.0	11.3
		65.9	6.6	4.0	10.4
		65.2	7.1	3.9	10.7
		67.0	6.9	3.1	9.8
		67.4	6.6	3.1	9.5
26	Sound trunk heart wood	65.0	4.7	3.5	8.1
17	Sound trunk heart wood	55.2			
6	Sound trunk heart wood	56.6	6.5	3.8	10.1
		59.9	7.9	3.8	11.4
62	Sound trunk sap wood	61.4	5.5	2.4	7.7
		61.5	5.5	0.6	6.1

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
60	Partially degraded trunk heart wood	74.7	9.3	0.6	9.9
		74.5	5.0	1.8	6.7
		77.9	5.9	2.9	8.7
		74.6			
50	Sound trunk heart swamp wood	62.6	7.3	3.8	10.9
		61.4	8.3	4.7	11.8
		63.9	7.4	4.4	9.9
		60.9	7.5	4.4	11.0
63	Partially degraded heart trunk wood	61.3	4.4	5.9	10.0
		63.3	5.1	2.8	7.9
		61.5	8.5	4.3	12.4
		64.4	9.5	5.4	14.4
138	Highly degraded charred trunk heart wood	82.3	22.9	15.3	34.7
		83.9	27.4	14.4	37.9
	RIMU (*Dacrydium cupressinum*)				
1	Modern commercial heart trunk wood	50.2	4.5	2.1	6.4
		48.7	4.8	1.4	6.9
		47.5	4.6	2.9	8.4
		52.5	8.7	3.4	11.8
15	Modern commercial heart trunk wood	58.5	5.3	2.4	8.9
27	Sound trunk sap wood	63.6			
42	Very old partially degraded trunk wood	60.8	5.1	1.3	6.3
		68.4	9.5	4.4	13.5
139	Very old sound trunk heart wood	55.6	6.7	1.1	9.7
	TANEKAHA (*Phyllocladus trichomanoides*)				
19	Modern commercial trunk wood	66.3	9.4	2.9	11.9
7	Modern commercial trunk wood	56.9			
97	Modern sound branch wood	48.7			

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
	MONOAO (*Dacrydium kirkii*)				
86	Sound heart trunk swamp wood	61.1	6.6	4.3	10.8
		61.37	7.1	3.9	10.7
		63.5	8.3	3.8	11.8
		63.0	8.5	3.7	11.9
127	Partially degraded heart trunk swamp wood	70.5			
	CEDAR (*Libocedrus bidwillii*)				
5	Modern heart trunk wood	62.3	4.8	3.6	8.3
		63.35	4.6	3.8	8.3
		60.85	6.2	3.0	9.8
	KAHIKATEA (*Podocarpus dacrydioides*)				
16	Modern trunk sap wood	75.4	5.2	4.9	8.1
32	Modern trunk sap wood	67.9	4.4	5.3	9.5
		69.4	3.4	6.7	9.8
9	Modern trunk sap wood	71.0	2.8	4.9	7.5
8	Modern trunk heart wood	56.0	7.6	5.2	12.4
58	Modern 'kapara' resinous wood	19.7	8.7	0.9	9.5
		19.2	4.9	2.8	7.6
57	Partially degraded sap trunk swamp wood	70.3	5.7	2.8	8.3
		68.0	6.0	3.9	9.7
		68.1	6.9	3.3	10.0
		70.3	7.5	3.9	11.1
		68.9	6.4	4.6	10.7
		68.4	7.1	3.9	10.8
		70.0	8.1	2.6	10.5
125	Partially degraded branch wood	52.7	2.5	3.7	6.1
		49.4	2.5	2.8	5.2
		61.5	4.4	3.8	8.1
		58.6	2.3	1.9	4.1
		61.2	2.9	5.4	8.2
		64.7	5.5	4.2	9.4
		61.0	5.2	4.4	9.4

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
	HALL'S TOTARA (*Podocarpus hallii*)				
64	Sound modern heart trunk wood	62.8	5.7	2.0	7.6
10	Sound modern heart trunk wood	65.1	5.7	3.1	8.6
	MIRO (*Podocarpus ferrugineus*)				
20	Modern sound trunk sap wood	61.2	6.7	2.4	9.0
140	Modern sound trunk sap wood	54.5	11.6	7.5	18.3
49	Modern sound branch sap wood	56.0	11.2	6.4	17.0
	MANUKA (*Leptospermum scoparium*)				
68	Very old sound swamp wood stem	45.4	15.7	11.4	25.3
		45.7	13.7	11.5	23.6
		43.5	14.3	9.2	22.2
		45.8	18.6	12.4	28.7
		49.6	18.3	13.9	29.7
		43.4	21.2	10.9	29.8
		38.2	18.4	10.1	26.5
		40.2	19.0	10.4	27.4
67	Very old degraded swamp wood stem	63.7	15.0	12.4	25.
135	Old, very degraded swamp wood stem	52.6	24.7	15.3	36.2
		52.8	23.2	17.7	36.3
		51.4	27.2	15.8	37.3
136	Old, very degraded swamp wood stem	56.0	17.1	13.5	28.2
		59.0	20.1	16.1	33.3
105	Sound modern stem wood	40.7	9.5	7.8	16.5
		40.0	10.8	7.9	17.9
		42.3	11.4	7.3	17.9
69	Sound modern stem wood	40.4	12.9	8.3	20.2
		37.5	12.6	8.3	19.9
		41.1	11.5	6.8	17.5

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	RADIAL	EST. CROSS SECTIONAL
37	Sound modern stem wood	-	16.8	9.5	24.7
		-	16.1	8.8	23.4
		-	14.4	9.7	22.6
		-	15.7	9.7	23.9
		42.7	16.2	8.8	23.6
		46.2	17.1	8.6	24.3
		43.6	16.1	8.4	23.2
		47.5	17.6	8.0	24.3
		44.5	17.9	9.0	25.2
		43.0	16.9	9.1	24.5
		46.8	16.4	9.3	24.2
	KANUKA (*Leptospermum ericoides*)				
70	Sound modern trunk wood	45.9	11.0	6.0	16.3
		44.2	14.3	5.5	19.0
		45.0	13.0	7.1	19.2
		44.4	13.8	4.8	17.9
		44.1	15.2	6.4	20.6
114	Sound modern trunk wood	45.6	13.2	6.4	18.8
		41.2	17.0	6.8	22.7
115	Sound modern trunk wood	45.4	17.7	5.3	22.1
		45.2	18.4	7.6	24.6
		44.2	17.7	3.5	20.5
124	Sound old trunk swamp wood	47.1	14.3	6.2	19.6
		45.6	12.2	7.7	19.0
		47.6	13.3	3.9	16.7
		48.5	13.5	9.1	21.3
		46.5	15.1	8.2	22.1
		45.8	15.0	7.0	20.1
		46.0	14.1	6.4	19.6
	BLACK MAIRE (*Nestegis cunninghamii*)				
67	Sound trunk heart wood	50.2	16.4	6.2	21.7
		48.7	13.1	6.1	18.4
74	Sound trunk sap wood	44.8	13.0	4.8	17.2

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
75	Sound trunk heart wood	45.5	13.5	5.3	18.1
		41.1	13.3	5.9	18.5
		46.0	13.1	5.2	17.6
21	Sound trunk heart wood	37.7	10.2	4.2	13.9
		41.3	9.5	3.5	12.7
	WHITE MAIRE (*Nestegis lanceolata*)				
112	Sound heart trunk wood	44.8	9.9	4.6	14.0
		44.9	10.2	5.7	15.3
		46.3	10.3	3.8	13.7
	NORTHERN RATA (*Metrosideros robusta*)				
102	Sound branch heart waterlogged wood	46.2	7.5	5.3	12.4
		42.7	10.1	4.6	14.2
		45.7	8.4	4.6	12.6
107	Sound branch heart waterlogged wood	46.9	14.8	9.8	23.1
		45.5	14.6	9.3	22.6
		45.9	17.6	7.2	23.6
		47.2	8.6	7.5	15.4
		46.4	8.9	8.7	16.8
		46.1	18.5	7.6	24.3
22	Dense, waterlogged heart trunk wood	31.1	-	-	-
23	Sound modern branch wood	40.8	11.0	5.9	16.2
131	Sound modern heart trunk	41.3			
		41.4	10.3	6.7	16.3
		41.2	11.1	7.0	17.3
130	Sound modern heart trunk	44.0	-	-	-
101	40,000 year old heart trunk wood, well degraded	67.1	16.5	9.8	24.7
		67.8	13.2	10.1	22.0
		68.2	15.0	9.2	23.0

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
	POHUTUKAWA (*Metrosideros excelsa*)				
91	Sound heart branch wood	37.9	11.0	4.0	14.6
93	Sound heart branch wood	43.1	8.5	3.7	12.0
95	Sound sap branch wood	47.0 42.7	8.2	2.9	10.9
	MAPOU (*Myrsine australis*)				
80	Partially degraded swamp wood stem	72.8 73.4 72.9 73.4 72.3 70.6 71.7 74.4 73.1 72.0 74.1 74.3 72.6	5.1 7.5 6.8 7.8 8.4 6.4 7.5 8.4 10.8 6.6 6.8 5.9 8.0	1.4 6.1 2.4 5.7 3.9 3.2 3.4 4.7 2.4 3.1 1.9 4.7 2.0	6.4 13.1 9.1 12.5 12.0 9.4 10.7 12.7 12.9 9.5 8.6 10.3 9.9
79	Sound modern stem wood	51.7 45.5 45.9 49.0 45.8 45.2 45.9 49.0	9.5 12.3 10.4 13.8 15.9 15.7 14.0 13.7	2.1 4.6 2.7 2.9 4.7 3.4 5.0 4.6	11.4 16.9 12.8 16.3 19.9 18.6 18.3 17.6
123	Sound modern branch wood	44.1 44.6 44.4	9.4 13.3 10.8	1.6 4.0 3.9	10.9 16.7 14.3
141	Sound modern stem	36.4 38.6 33.8 41.7 43.8 40.5 45.3	11.7 11.3 10.3 20.1 13.9 10.3 11.3	4.3 3.1 2.6 3.7 4.4 3.5 3.0	15.6 14.1 12.6 23.4 17.7 13.2 14.0

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
111	Sound modern stem	45.9	15.7	3.0	18.2
		47.1	11.3	0.5	11.8
		46.9	8.8	3.0	11.6
			8.7	2.2	10.7
			10.5	2.7	13.0
48	Highly degraded swamp wood (cell collapse, not shrinkage, being measured)	87.2	74.1	15.0	78.0
		87.7	71.6	25.7	81.1
		86.1	60.6	32.8	73.6
		83.0	55.2	25.7	66.7
	TAWA (*Beilschmiedia tawa*)				
99	Sound modern trunk wood	46.7	10.5	7.0	16.7
		49.9	8.6	4.1	12.3
		43.7	13.2	3.3	16.0
		44.1	12.6	5.0	17.4
		43.1	11.2	6.3	16.8
29	Sound modern trunk wood	49.9	-	-	-
18	Sound modern trunk wood	55.5	-	-	-
129	Sound modern trunk wood	48.8	-	-	-
72	Partially degraded trunk swamp wood	60.2	7.4	4.8	12.9
		66.3	3.6	0.7	4.3
		65.2	8.4	2.9	11.1
		55.0	8.6	4.1	12.4
		69.4	5.8	8.8	6.6
		64.3	5.3	4.3	9.5
		56.7	5.6	3.5	8.9
		67.4	6.6	2.3	8.8
		62.8	4.8	5.5	10.1
		63.9	6.4	5.7	13.0
		73.5	7.0	3.9	10.6
		59.9	8.0	3.1	10.8
		57.6	8.9	5.0	13.5
73	Sound modern branch wood	48.9	14.4	4.3	18.1
		53.5	12.6	3.8	15.9
		55.8	11.7	4.5	15.7
71	Slightly degraded modern branch wood	61.2	5.4	3.1	8.3
		56.1	10.5	4.7	14.7
		59.5	7.6	3.2	10.6
		60.0	7.1	2.5	9.4
		57.0	7.4	2.9	10.0

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
43	Highly degraded branch swamp wood (cell collapse not shrinkage is occurring in this sample)	90.3 90.5	84.4 76.9	29.0 47.4	88.9 87.8
	PUKATEA (*Laurelia novae-zelandiae*)				
33	Sound commercial sap trunk wood	67.9 68.6 66.6 67.4	7.3 6.5	1.0 1.0	8.3 7.9
142	Sound commercial sap trunk wood	66.3 68.0	6.5 9.0	5.9 3.4	12.0 12.2
51	Sound buttress wood	58.6 58.5 58.7 58.1	8.9 13.0 9.9 9.9	5.9 4.8 3.9 3.7	14.3 17.2 13.4 13.1
	PURIRI (*Vitex lucens*)				
143	Modern heart trunk wood	40.9	14.6	5.1	19.0
90	Modern sap branch wood	45.0 48.2	16.1 10.1	2.8 3.2	18.4 13.0
92	Modern heart branch wood	38.6 40.1	11.2 10.7	4.3 5.0	15.0 15.2
94	Modern sap branch wood	46.9 46.8 45.3 47.1	8.4 7.5 8.7 11.3	3.2 2.9 3.6 2.1	11.3 11.2 12.0 13.2
106	Modern sap branch wood	40.3	7.3	4.1	11.1
104	Modern heart trunk wood	36.6 37.9	10.0 8.4	2.8 4.9	12.5 13.3
121	Modern heart trunk wood	39.2	12.4	8.4	19.8
117	Modern heart branch wood	46.1 46.2 43.1 42.9 44.5	9.4 8.5 11.3 8.2 8.0	4.5 4.7 3.1 4.9 4.2	13.6 12.8 14.0 12.7 11.9

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
	POROKAIWHIRIA (*Hedycarya arborea*)				
83	Partially degraded swamp wood stem	62.0	10.9	3.7	16.2
		70.1	5.7	5.6	11.0
		62.8	8.5	4.6	12.7
		61.9	8.4	4.1	12.2
		61.1	6.4	6.6	12.7
		58.4	7.3	4.5	11.5
	AKEAKE (*Dodonaea viscosa*)				
144	Modern sound stem	30.6	14.4	8.8	22.6
		31.5	18.2	7.8	24.6
25	Modern sound stem	36.2	14.4	6.8	19.8
		36.8	15.0	5.6	20.2
133	Modern sound stem	35.0	-	-	-
		34.2	-	-	-
134	Modern sound stem	35.8	-	-	-
		33.8	-	-	-
	RAMARAMA (*Myrtus bullata*)				
85	Sound seasoned trunk	45.9	16.9	8.6	24.1
		46.2	9.3	6.2	15.0
		47.2	11.6	6.9	17.7
		46.2	11.2	7.5	17.5
		46.6	14.2	8.3	21.3
	REWAREWA (*Knightia excelca*)				
78	Sound modern trunk wood	53.1	16.1	7.1	22.1
		53.7	16.3	3.5	19.2
		54.3	21.0	4.5	24.5
14	Sound modern trunk wood	55.2	17.1	4.7	21.0
		54.9	15.8	4.0	19.2
77	Partially degraded modern trunk wood	75.6	9.5	1.8	11.0
		69.4	19.7	2.2	21.4
		62.6	13.1	5.6	18.0

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	RADIAL	EST. CROSS SECTIONAL
77	Cont.	67.3	9.3	1.6	10.7
		62.3	16.5	5.8	21.4
		62.1	4.7	1.5	6.2
		60.8	12.0	3.2	14.8
	KOWHAI (*Sophora microphylla & S. tetraptera*)				
145	Modern sound sap wood	42.4	20.7	10.1	28.7
144	Modern sound sap wood	37.3	17.5	9.5	25.4
		37.8	19.5	9.2	26.9
		43.6	19.0	7.7	25.3
44	Modern sound heart wood	44.2	12.1	5.3	16.8
		43.8	16.2	5.8	21.1
		44.1	16.7	10.1	25.1
108	Modern green sap wood	44.8	18.3	10.3	26.7
		45.6	19.9	10.6	29.2
109	Modern seasoned sap wood	41.6	15.3	6.9	21.1
		45.7	15.5	7.5	21.8
110	Sound seasonsed heart wood	36.1	15.0	9.1	22.7
		37.5	15.7	7.9	22.1
113	Sound green heart wood	35.4	18.8	6.9	24.4
		33.7	18.6	11.2	27.7
		34.5	25.7	7.9	31.6
		46.5	20.4	9.6	28.0
		48.1	21.1	9.7	28.7
	RANGIORA (*Brachyglottis repanda*)				
146	Sound modern stem	52.3	11.6	3.9	15.1
		51.7	9.7	5.6	14.8
82	Degraded swamp wood stem	76.4	15.7	3.1	13.0
		72.9	7.9	4.4	12.0

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
	KAMAHI (*Weinmannia racemosa*)				
39	Sound modern branch wood	54.7	18.5	11.5	27.9
		55.2	21.4	8.8	28.4
147	Very degraded swamp wood	85.0	50.9	24.2	62.8
		88.5	69.4	16.8	74.6
		85.5	63.5	17.3	69.8
	MAHOE (*Melicytus ramiflorus*)				
149	Sound trunk sap wood	59.6	25.9	7.0	31.1
		60.0	22.5	7.8	28.6
		56.0	21.6	5.4	25.8
		60.0	7.8	3.8	11.3
		61.8	7.2	2.1	9.1
3	Sound modern sap wood	64.2	18.1	4.7	22.0
		61.7	17.5	9.1	25.0
148	Sound sap swamp wood	66.6	14.0	7.4	20.4
		63.5	9.3	4.4	12.0
84	Sound modern branch wood	66.4	7.4	2.4	9.7
		65.5	10.4	1.5	11.7
		68.3	8.4	3.0	10.9
		66.4	9.1	2.3	11.3
		68.1	9.6	3.0	12.3
	PUTAPUTAWETA (*Carpodetus serratus*)				
150	Partially degraded stem	68.5	5.3	1.5	6.8
		68.6	3.6	1.7	5.3
		73.0	6.8	3.2	9.8
		79.5	12.0	-1.7	10.5
	TARAIRI (*Beilschmiedia tarairi*)				
88	Sound modern branch wood	56.5	6.3	3.6	9.7
		56.2	8.3	4.5	12.4
		57.4	7.6	4.0	11.3

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	RADIAL	EST. CROSS SECTIONAL
	LANCEWOOD (*Pseudopanax crassifolium*)				
81	Sound modern stem	50.0	17.9	7.7	24.2
		49.4	15.3	7.9	22.0
	LACEBARK (*Hoheria sexstylosa*)				
76	Sound modern trunk wood	53.5	18.7	6.2	22.8
		54.5	20.8	6.4	25.8
	TITOKI (*Alectryon excelsus*)				
150	Sound modern branch wood	47.8	14.3	6.1	19.5
		48.7	15.6	9.2	28.4
		57.5	8.8	3.9	11.0
	OAK (*Quercus robur*)				
6	Sound modern trunk wood	49.3	9.0	2.8	11.5
		50.2	9.5	4.8	13.9
98	Sound modern trunk wood	53.2	7.6	3.9	11.2
		53.9	7.7	3.1	10.6
		53.1	7.1	2.7	9.6
153	Sound modern NZ grown trunk wood	51.8			
155	Sound modern NZ grown trunk wood	52.4			
156	Sound modern NZ grown trunk wood	54.2			
157	Sound modern NZ grown trunk wood	54.6			
158	Sound modern NZ grown trunk wood	53.7			
159	Sound modern NZ grown trunk wood	45.5			

REF NO.	DESCRIPTION	DENSITY	SHRINKAGE TANGENTIAL	SHRINKAGE RADIAL	SHRINKAGE EST. CROSS SECTIONAL
160	Sound modern NZ grown trunk wood	53.9			
161	Sound modern Yugoslav grown trunk wood	48.7			
162	Sound modern Japanese grown trunk wood	58.9			
163	Sound modern N. European grown trunk wood	55.7			
164	Sound modern Japanese grown trunk wood	55.2			
154	Sound modern N. European grown trunk wood	60.2			

APPENDIX THREE: Impregnation test results

A = % weight increase after impregnation
B = % weight increase as a percentage of the maximum possible weight increase, i.e. percent saturation
L = longitudinal penetration
R = radial penetration
T = tangential penetration

REF NO.	DESCRIPTION	L		R		T	
		A	B	A	B	A	B
	TOTARA (*Podocarpus totara*)						
61	Modern heart trunk wood	28.0	15.8	3.1	1.8	1.6	0.9
65b	Modern heart trunk wood	21.0	15.1	8.4	6.0	3.6	2.6
65a	Modern sap trunk wood	158.6	99.3	8.1	5.1	38.6	24.2
50	Sound swamp heart wood	17.6	10.7	9.3	5.7	5.0	3.0
59	Degraded heart swamp swamp wood	116.5	77.3	62.5	41.4	118.8	78.8
26	Sound heart trunk wood	19.8	10.7	0.8	0.4	1.7	0.9
63	Partially degraded heart trunk wood	81.7	54.1	8.4	5.6	6.2	4.1
17	Modern heart trunk wood	15.1	12.3	2.5	2.0	1.4	1.2
60	Partially degraded heart trunk wood	288.8	92.2	314.9	100.5	256.4	81.8
	MATAI (*Podocarpus spicatus*)						
2	Modern heart trunk wood	108.7	88.2	22.0	17.8	19.1	15.4
31	Modern heart trunk wood	75.3	82.6	22.2	24.3	17.1	18.7
12	Modern heart trunk wood	78.5	73.3	25.5	23.8	12.4	11.6
128	Modern heart trunk wood	50.3	55.0	1.2	1.3	1.2	1.3
66	Slightly degraded heart trunk wood	129.2	96.3	22.0	16.4	129.9	96.8
45	Partially degraded heart trunk wood	113.0	90.9	106.8	86.0	-	-
	KAURI (*Agathis australis*)						
47	Modern heart trunk wood	70.8	50.6	10.3	7.3	15.4	11.0
47	Slightly degraded heart trunk wood	118.3	84.2	77.6	55.2	7.5	5.4
55	Sound heart trunk swamp wood	70.5	47.6	80.8	54.6	64.9	43.8
56	Partially degraded sap swamp wood	212.7	109.2	223.5	114.7	179.1	91.7

REF. NO.	DESCRIPTION	L A	L B	R A	R B	T A	T B
	Kauri Cont.						
4	Sound branch heart wood	2.4	4.0	0.4	0.6	1.1	1.9
36	Sound branch heart wood	0.8	2.1	0.6	1.4	0.6	1.4
119	Sound branch heart wood	2.6	3.2	1.3	1.6	0.8	1.0
120	Sound branch sap wood	90.5	90.9	96.1	96.5	-	-
	RIMU (*Dacrydium cupressinum*)						
15a	Sound heart trunk wood	116.3	82.3	13.1	9.3	21.4	15.2
15b	Sound heart trunk wood	119.3	84.5	24.8	17.6	21.1	15.0
27	Sound heart trunk wood	105.1	60.1	18.0	10.3	14.7	8.4
42	Sound heart swamp trunk wood	180.0	98.4	32.1	17.5	45.5	24.9
38	Sound heart branch wood	136.4	81.8	25.8	15.6	34.2	20.5
1	Sound heart trunk wood	114.2	96.5	12.9	10.9	17.9	15.1
	KAWAKA (*Libocedrus bidwillii*)						
5	Sound modern heart wood	22.1	13.4	4.6	2.8	3.7	2.2
	MONOAO (*Dacrydium kirkii*)						
86	Sound heart trunk swamp wood	51.5	32.6	4.3	2.7	12.3	7.8
127	Partially degraded trunk swamp wood	268.5	112.4	86.5	36.2	85.8	35.9
	KAHIKATEA (*Podocarpus dacrydioides*)						
16	Sound trunk sap wood	228.6	74.6	308.6	100.7	288.9	94.3
9	Sound trunk sap wood	136.0	86.8	9.0	5.7	14.9	10.2
32	Sound trunk sap wood	204.2	93.2	90.3	41.2	63.7	21.1
57	Partially degraded trunk sap wood	192.4	85.9	193.6	86.4	185.6	82.8
8	Sound trunk heart wood	74.5	58.4	4.7	3.7	8.5	6.7
	TANEKAHA (*Phyllocladus trichomanoides*)						
19	Sound trunk wood	161.9	82.3	4.4	2.3	10.2	5.2
7	Sound trunk wood	114.5	86.6	4.4	3.3	11.1	8.4
97	Sound branch wood	101.9	107.1	21.5	22.6	25.7	27.0

REF. NO.	DESCRIPTION	L A	L B	R A	R B	T A	T B
	HALL'S TOTARA (*Podocarpus hallii*)						
64	Sound modern heart wood	22.6	12.1	1.1	0.6	2.3	1.2
10	Sound modern sap wood	142.3	84.4	117.4	69.7	42.5	25.2
	MIRO (*Podocarpus ferruginous*)						
20	Sound modern sap wood	136.6	86.7	10.6	6.6	39.6	25.1
	MANUKA (*Leptospermum scoparium*)						
68	Sound swamp wood	5.5	7.0	4.9	6.6	8.1	10.8
40	Sound modern wood	43.8	49.7	1.7	1.9	1.7	1.9
105	Sound modern wood	30.1	42.0	1.2	1.6	2.9	4.0
116	Sound modern wood	39.9	61.0	1.9	3.0	9.4	14.4
	KANUKA (*L. ericoides*)						
69	Sound heart swamp wood	41.4	47.5	9.1	10.4	5.4	6.2
70	Sound heart wood	42.6	52.4	1.8	2.2	-	-
114a	Sound sap wood	46.1	60.2	2.9	3.7	2.6	4.7
114b	Sound heart wood	34.8	45.2	4.7	6.1	1.6	2.1
115	Sound heart wood	36.3	44.5	1.0	1.3	2.2	2.7
	BLACK MAIRE (*Nestegis cunninghamii*)						
75	Sound heart trunk wood	1.1	1.4	0.7	0.9	2.1	2.7
74	Sound sap trunk wood	41.7	63.6	4.8	5.9	9.2	11.3
21	Sound heart branch wood	2.9	4.8	1.3	2.1	1.0	1.6
	WHITE MAIRE (*N. lanceolatum*)						
112	Sound sap trunk wood	52.1	62.9	2.3	2.7	3.7	4.5
	MAPOU (*Myrsine australis*)						
79	Sound heart wood	11.3	12.6	3.0	3.9	1.7	1.9
123	Sound heart wood	-	-	5.9	7.4	16.4	20.6
111	Sound heart wood	38.9	38.7	3.5	4.1	1.7	2.0
111	Sound heart wood	42.8	48.9	-	-	-	-
80	Partially degraded heart wood	250.0	92.9	247.4	92.0	239.8	89.1

REF. NO.	DESCRIPTION	L		R		T	
		A	B	A	B	A	B
	AKEAKE (*Dodonaea viscosa*)						
25	Sound heart wood	10.4	18.1	6.7	11.7	5.1	8.9
118	Sound sap wood	32.2	60.8	2.3	4.4	1.0	1.8
133	Sound heart wood	9.2	17.4	1.1	2.7	7.0	13.2
134	Sound heart wood	2.9	5.5	1.3	2.4	1.1	2.0
	PUKATEA (*Laurelia novae-zelandiae*)						
46	Partially degraded trunk wood	236.7	92.5	235.3	91.9	226.7	88.5
33	Sound trunk wood	168.8	80.9	107.5	51.4	45.0	21.5
51	Sound buttress wood	101.8	77.8	5.3	3.8	4.6	3.5
	PURIRI (*Vitex lucens*)						
90	Sound sap branch wood	38.3	46.6	1.5	1.8	3.8	4.6
92	Sound heart branch wood	1.3	2.1	1.6	2.5	0.4	0.6
94	Sound sap branch wood	42.0	47.7	2.1	2.4	2.9	3.4
104	Sound heart branch wood	9.92	1.5	1.0	1.6	0	0
117	Sound sap branch wood	41.9	52.1	4.0	4.9	5.95	7.4
	POHUTUKAWA (*Metrosideros excelsa*)						
95	Sound sap branch wood	75.0	84.3	1.9	2.1	13.5	15.2
91	Sound sap branch wood	57.6	94.4	9.5	15.5	1.9	3.1
93	Sound heart branch wood	3.4	4.4	2.6	3.4	2.7	3.5
	RATA (*M. robusta*)						
23	Sound branch wood	45.1	65.4	11.3	16.4	10.9	15.8
22	Sound waterlogged 'river' wood	14.3	31.6	8.0	17.5	6.0	13.3
102	Sound waterlogged 'river' wood	50.0	61.4	24.0	29.5	16.9	20.8
103	Sound trunk wood	38.5	28.3	5.6	4.1	2.1	1.6
107	Sound waterlogged 'river' wood	36.8	42.5	6.4	7.4	15.4	17.8
131a	Partially degraded trunk wood	61.4	87.2	63.0	89.5	56.5	80.3
131b	Partially degraded trunk wood	47.9	83.2	45.1	78.4	45.5	78.9
130	Sound trunk wood	37.8	48.1	3.5	4.4	2.5	3.2

REF. NO.	DESCRIPTION	L A	L B	R A	R B	T A	T B
	TAWA (*Beilschmiedia tawa*)						
71	Sound branch wood	120.7	84.7	19.6	13.8	25.3	17.8
72	Partially degraded heart trunk wood	198.6	117.3	159.2	94.1	140.9	83.3
99	Sound heart trunk wood	6.4	7.6	11.4	13.7	20.3	24.2
100	Sound branch wood	6.9	4.3	10.9	6.8	6.6	4.6
29	Sound heart trunk wood	57.9	58.1	4.9	4.9	5.1	5.1
18	Sound heart trunk wood	110.1	88.2	11.5	8.9	22.1	17.7
129	Sound heart trunk wood	75.8	79.6	8.0	8.4	8.1	8.5
	REWAREWA (*Knightia excelsa*)						
77	Partially degraded heart trunk wood	112.5	63.0	36.1			25.7
14	Sound heart trunk wood	85.9	70.1	9.7			5.2
78	Sound heart trunk wood	77.8	67.1	67.1			4.3
	KOWHAI (*Sophora microphylla*)						
108	Sound sap wood	56.4	68.3	6.4	7.8	16.9	20.4
119	Sound sap wood	40.1	51.7	4.1	5.3	5.8	7.5
110	Sound heart wood	2.6	4.5	24.9	4.7	1.6	2.7
113a	Sound sap wood	56.9	66.8	1.7	1.9	18.5	20.6
113b	Sound heart wood	10.2	19.3	0.6	1.0	0.04	0.07
	RAMARAMA (*Myrtus bullata*)						
85	Sound stem wood	53.7	61.9	1.1	1.3	1.7	2.0
	RANGIORA (*Brachyglottis repanda*)						
82	Partially degraded wood	99.5	33.8	27.0	9.2	10.2	3.5
	LANCEWOOD (*Pseudopanax crassifolius*)						
81	Sound stem wood	72.7	71.3	12.5	12.3	20.0	19.6
	MAHOE (*Melicytus ramiflorus*)						
75	Sound sap wood	82.2	48.4	7.2	4.2	13.3	7.8

REF. NO.	DESCRIPTION	L		R		T	
		A	B	A	B	A	B
	RIBBON WOOD (*Hoheria sexstylosa*)						
76	Sound trunk wood	74.8	63.7	3.7	3.2	3.7	3.2
	TARAIRI (*Beilschmiedia tarairi*)						
88	Sound branch wood	14.9	11.3	1.6	1.2	0.9	0.7
	POROKAIWHIRIA (*Hedycarya arborea*)						
83	Partially degraded swamp wood	147.8	84.7	146.5	83.9	147.8	84.6
	POKAKA (*Elaeocarpus hookerianus*)						
132	Sound trunk heart wood	15.6	13.5	1.1	1.0	7.0	6.0
	OAK (*Quercus robur*)						
6	Sound heart trunk wood	13.5	13.6	2.4	2.4	2.6	2.6
153	Sound heart trunk wood	6.2	5.8	1.3	1.2	7.4	6.9
155	Sound heart trunk wood	8.6	7.8	2.8	2.5	1.7	1.5
156	Sound heart trunk wood	11.2	9.5	2.0	1.7	8.7	7.3
157	Sound heart trunk wood	5.5	4.6	1.9	1.6	2.6	2.2
158	Sound heart trunk wood	9.6	8.3	2.1	1.8	1.9	1.6
159	Sound heart trunk wood	14.1	14.8	2.8	2.9	1.4	1.5
160	Sound heart trunk wood	11.4	9.7	1.4	1.2	1.3	1.1
98	Sound heart trunk wood	26.7	23.3	2.1	1.9	1.8	1.6
154	Sound heart trunk wood	20.6	21.7	3.0	3.2	1.6	1.7
161	Sound heart trunk wood	51.7	36.1	3.0	2.1	4.3	3.0
162	Sound heart trunk wood	64.5	51.2	3.0	2.4	1.9	1.5
163	Sound heart trunk wood	48.2	39.1	3.0	2.4	2.4	1.9
164	Sound heart trunk wood	38.5	25.4	2.2	1.4	2.1	1.4

Appendix Four:
Experimental Error Estimation

This can be discussed under three headings, shrinkage measurement error, water content measurement error and penetrability measurement error.

Shrinkage Measurement Error

The method for measuring shrinkage used in this study is described on pages 140-142. In order to illustrate the magnitude of purely experimental errors in values obtained by the method a separate experiment was carried out. In it a sub-sample of wood was cut from sample #80 (partially degraded *Myrsine australis*) and prepared as described on pages 140-142. Radial shrinkage was measured when the sample was saturated and when it was oven dry. In this experiment the sample was measured 20 times when wet and then 20 times when oven dried. These values could be used to calculate 400 separate shrinkage values from the one shrinkage event with all variation in the results being due to purely experimental error.

A sample of 20 of these shrinkage values were calculated and analysed to yield a mean and a standard error of the mean. The latter value is calculated as follows

standard error of the mean at the 95% confidence interval

$$= 1.96 \times \frac{s}{(n)^{\frac{1}{2}}}$$

Where n = 20 and S = the estimated standard deviation of the sample calculated by the formula

$$s = \left[\frac{\sum_{1}^{n} (x_i - \bar{x})^2}{n - 1} \right]^{\frac{1}{2}}$$

The figure obtained for mean shrinkage of sample #80 was 5.1 ± 0.14%. This can be taken as the magnitude of the experimental error for individual shrinkage values reported in Appendix Two assuming that the same method was applied.

Where shrinkage values were calculated on several sub samples from the same piece of wood variation in these values will be due to two factors, experimental error plus actual variation in this property across this piece of wood. In the case of Sample #80

13 values of radial shrinkage are listed in Appendix Two on page 265. The standard error of the mean of these values is ± 0.808. As this figure is the sum of experimental error and actual variation (Sebor, Pers. Comm.) experimental error contributes only approximately one sixth of variation around this mean. Purely experimental error, in this case, is much smaller in magnitude than actual variation in the property being measured throughout the sample. Though experimental error may be the same for all samples, variation in shrinkage may not be. For example, Sample #72 has 13 reported values of radial shrinkage with a mean of 4.2 ± 1.058%. In this case, purely experimental error contributes a smaller amount to the total variation calculated.

Water Content Calculation Error.

The method used to calculate water content values is given on pages 140-142. In order to calculate the purely experimental errors inherent in this technique the same method used as for shrinkage values, i.e. a piece of #80 was weighed 20 times wet and 20 times dry and 20 of the possible 400 values were calculated. This gave a mean value for this single drying event of 73.42 ± 0.084%. Again this can be compared to the 13 values of water content reported in Appendix

Two (page 265) which give a mean value of 72.89 ± 0.59 indicating that experimental error is less than a sixth of the magnitude of actual variation of water content throughout sample #80.

The figure for Sample #80 can be compared with those for Sample #72 which gave a mean of 63.25 ± 2.9% indicating that purely experimental error contributes very little to the variance in values of water content across this particular sample.

Estimation of Experimental Error in Penetration Tests

The method used to measure wood sample penetrability is described on pages 166-171. In short, a block of wood, sealed on five sides, was impregnated with water under vacuum for one hour after which its percent weight increase was measured. This value was then taken as a percentage of the maximum possible weight increase, the latter value having been determined by the work on water content described in the previous section.

The purely experimental errors generated in measuring weight increase on impregnation can be calculated without much difficulty. The blocks of wood that were impregnated were much larger than those used to measure water content and had a much

lower surface to volume ratio. This means that the weighing errors will be close to the accuracy of the balance. This weighed to three decimal places of a gram and was accurate to at least 0.005 gms. Given this error and a dry weight of the block of two grams (an average weight for the blocks) sample #80 would have had a weight increase on impregnation of 250 ± 0.72%. The error value is small and clearly would not contribute greatly to the error of the final value of percent saturation.

In order to calculate the full errors of the final results it would have been necessary to impregnate a number of blocks, along each plane in the wood, from each sample in order to calculate variation in penetrability throughout this sample. This would give a mean weight increase (with an error estimate) to be taken as a percentage of the mean maximum possible weight increase (with its error estimate). An error for the mean penetrability of the wood of each sample would then have been able to be calculated with its associated error estimate. As only single values for weight increase were calculated, this true error is not able to be calculated.

What can be done is to calculate the errors in the final results due only to uncertainty in the value of maximum possible weight increase. For

Sample #80, 13 values of water content at saturation were measured. If each one is used individually to calculate the percent saturation of the cube of Sample #80 that was pressure impregnated, thirteen final values can be obtained. A mean value of 92.9 ± 2.8% can be calculated where the error is the standard error of the mean at the 95% confidence limit.

Using the above approach, Sample #72 gives a value of 114 ± 14.4%; Sample #47, 50.6 ± 2.2%; Sample #68, 7.0 ± 0.72%; and Sample #79, 12.6 ± 0.8%. Most of these error values, though representing only part of the inherent uncertainty involved, are very small considering what they were used for. They were used to place samples into penetrability categories as shown on Figures Fourteen to Eighteen, where longitudinal penetrability values were divided into four classes; 1% - 5%, 5% - 20%, 20% - 50% and 50% - 100%. Even if the true error values were two or three times greater they would not seriously affect allocations into such broad categories.