ENVIRONMENTAL ARBORICULTURE, TREE ECOLOGY AND VETERAN TREE MANAGEMENT

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Summary

The appreciation and management of veteran trees has been transformed in recent years by the activity of the Ancient Tree Forum (ATF). This is a UK initiative, which has brought attention to the quality and condition of the living heritage reflected in the great number of ancient tree sites found in the British Isles, which are among the finest in Northern Europe. Such developments have been influenced by a multidisciplinary approach, which regards the tree as inherently linked to its ecological context. This approach is now beginning to inform mainstream arboricultural thinking and practice. The paper attempts to synthesize the various trends in current thinking that have led to new approaches in veteran tree management. These include the importance of improving the understanding of the ageing process in trees to clarify the terminology that can be applied to define different states of tree development. This draws on morphology and an appreciation that ageing is not a one-way process in trees, while also stressing the significance of reiterative and 'phoenix' growth for tree longevity. The paper also considers the tree as a co-evolutionary organism and refers to the work of MATTHECK, RAYNER and SHIGO, together with environmental-philosophical views of trees to suggest a natural meeting point in the consideration and understanding of veteran trees. The incorporation of such concepts into management considerations is important when surveying and specifying works for veteran trees, and as a result, management schedules are now being projected over thirty to one hundred year periods for veteran tree populations. Management practices include promotion of 'phoenix' regeneration, restoration pruning, recording of tree habitat, integrated tree viability assessments, deadwood management and the importance of fungi for tree health and recycling processes.

Keywords: ageing process* ancient trees* ecology* deadwood * morphology * tree management * veteran trees

Introduction

The pollarding of trees has a deep resonance in the European cultural landscape. The presence of old pollards can be seen extending from the uplands of Scotland (QUELCH, 2000), the Islands of Greece (RACKHAM & MOODY, 1996) to the silvopastoral systems of southern Spain known as 'La Dehesa' (MONTERO, SAN MIGUEL & CANELLAS, 1998). The continued presence of these trees in the landscape is, in part, due to the method of tree husbandry. The process of cutting the crowns of trees above grazing level has ensured that they were retained for their produce value as 'working trees' (GREEN, 1996) while the method of cutting served to ensure that these trees, when open grown, developed trunks supporting relatively small crowns. Managed pollards tend to be mechanically stable and long-lived. Since the practice of cutting pollards for produce ceased on most sites in the UK between 100 and 220 years ago (READ, 1996), the majority of pollards are now vulnerable to crown collapse (LONSDALE, 1999).

Considerable interest has developed over the last decade in the value of old pollard and heritage trees (READ, 1991 & 1996) and the importance of their associated habitat. The work of the Ancient Tree Forum (ATF) has stimulated a growing appreciation of the need to conserve the ancient tree heritage, to improve knowledge and understanding and communicate about the ecological context associated with trees (READ, 2000). The ATF drew together individuals from many disciplines including arborists, biologists and tree managers, to work collectively for the benefit and continuity of the existing population of old trees. Since 2000 the ATF has formed a partnership with the Woodland Trust to work together for their common aims.

In the UK, the work of major influences in modern arboriculture such as SHIGO (1991), MATTHECK (1991) and RAYNER (1993) has not only served to clarify thinking and influence techniques but has also resulted in confusion and debate. There are parallels in the ecological field, with the encyclopaedic work of writers such as RACKHAM (1993), PETERKEN (1996) and VERA (2000). The emerging debate might be expected to bring together some of these threads and reveal new and interesting connections to inform the science and practice of arboriculture.

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The majority of practicing arborists and consultants either operate in urban situations or gain their livelihood from trees in non-rural locations. This circumstance is likely to influence, and possibly limit, the direction and dynamics of the discipline and the resources available for the technical application of knowledge. Trees have evolved within a changing landscape down through history. However, the majority of considerations regarding tree management today are associated with constraints imposed upon their growth and biology linked to pressures inflicted on their natural state by built-up and polluted environments. A synthesis is suggested between the various strands and influences in modern arboriculture, implied through a vision of the tree as a co-evolutionary organism that has developed through intricate and interdependent processes. This draws attention to the possibility that, if today a great many trees are growing in environments that are limiting their development and biodiversity, then this will impact on the future evolutionary potential of trees and their ecology.

The ability of trees, following natural collapse, to layer and go through cycles of rejuvenation (FORTANIER & JONKERS, 1976), offers evidence that some tree species may have a tendency to immortality and therefore the means to carry diverse assemblages of flora and fauna over millennia. An improved understanding of the ageing process in trees (including the way that different associate species colonise and influences growth and wood condition), should lead to the development of management approaches and techniques that imitate natural processes and support improved longevity.

The Problems of Definition

The term 'veteran tree' began to be widely used following the inception of the Veteran Trees Initiative, which was a four-year partnership led by English Nature. The initiative was inspired by the ATF and aimed to raise awareness, provide training, clarify best practice and harmonise survey methodology. Naturally, the ability to recognise a veteran tree is crucial to sharing common ideas on the subject and throughout the project, which ended in 2000, there was considerable debate about the criteria for defining the 'veteran' state and appropriate descriptive terms for recognising veteran features.

The definition of a veteran tree, developed by the ATF, is a tree "that is of interest biologically, aesthetically or culturally because of its age, size or condition" (READ, 1999). An alternative definition is offered by Lonsdale (1999), as a tree that is "an old and valued specimen, which may have survived beyond the typical age range for the species". This latter definition takes into consideration that different tree species have different life expectancies and the point at which they enter old age will vary between species.

John White (WHITE, 1998) in his reflections of patterns of growth (in describing his system for age estimation with reference to tree girth for a range of species) refers to a period in the ageing process when the current annual increment (CAI) begins to be spread evermore thinly and the cross-sectional area of annual rings begins to decline. It may be argued that when this state persists the tree has entered the ancient stage.

In general, the terms 'old', 'veteran' and 'ancient' tend to be used interchangeably in the literature without any significant distinction. This will be the case in this article. However these terms and concepts are a constant subject of discussion. The term 'old' tends to refer to the chronological age of the tree (even though the time of germination may not be known). A current view is developing that 'veteran' describes a tree that has been through hard times and is a survivor. In other words, it is a tree that may have had an accelerated passage through the ageing process through abiotically induced, physiological stress and wounding. It is a term that has borrowed from the human experience of war, where soldiers may mature rapidly under duress and through physical suffering. This term was given common currency through the Veteran Trees Initiative.

The term 'ancient' implies inherent stature and relates to a tree that has passed more gradually through the various stages of the ageing process. The ancient stage has been divided into three further phases (READ, 2000): 'early ancient' with the onset of crown retrenchment, 'late ancient' where annual rings become discontinuous and 'senescent' with the onset of terminal decline. It is worth noting that there are examples of trees that to date appear never to reach the senescent stage, such as the Fortingall yew (MORTON, 1998) and the Tortwoth chestnut (PAKENHAM, 1996), which further confuses the picture.

Despite these problems of definition there does appear to be sufficient understanding of these terms for most practical purposes. Trees may be considered old by virtue of their chronological age, appearance and the level of damage and dysfunction expressed in their form. The reason for the ambiguity lies in the nature of the subject matter. Veteran trees are organisms that have a high level of complexity and carry a record of their past in their growth patterns that have responded to wounding (SHIGO & MARX, 1977) and mechanical stresses (MATTHECK, 1991) over long periods of time. These resulting deformations are expressions of their 'body language' (MATTHECK, 1995). One way for the observer to decode the signs carried from the past is through an interpretation of their form.

Interpreting Tree Form and Understanding Ageing

Johann Goethe, the German philosopher, poet and botanist who spanned the turn of the 19th century, (renowned as the author of the tragedy *Faust*), developed a curious view of the plant. He considered nature as a living unity where mind, matter and the observer and object are inextricably linked. He argued that the developmental process and life history of individual plants could be read by their form if the observer has sufficient training and insight.

Goethe took the example of a leaf sequence on a branch. Taking the oldest (most basal) leaves to the newest (apical) in sequence, observation shows that each leaf is individually different in form. However, each is an expression of the tree species and the sequence is an expression of the growth of that shoot over time. By shuffling the sequence, the observer can see that the pattern and order of growth appears strange. By sharpening our perception of order and form, we can deepen our understanding of plant development. In reverse, Goethe's admiration for nature's 'dynamic order' led him to perceive the form of the plant as a 'memory' of its entire development and life history – i.e. the concept of morphology (CAPRA, 1996). Goethe took this further to the extent of interpreting the morphology of plants as an expression of internal physiological process (ARBER, 1950).

A concept of plant morphology was presented at the second European Congress of Arboriculture. This explored the connection between the effects of the physical environment on tree structure and described the ageing process (from seed to senescence) as an expression of the relationship between morphology and the physiological state of the tree (RAIMBAULT, 1995). This model identified a morphological progression for a 'standard' tree. Raimbault applies this as a diagnostic procedure to identify and interpret variations from the standard progression in order to indicate physiological disturbances in the state of the tree.

Raimbault refers to the concept of 'plant memory'. He divides the lifespan of the tree from seed to death into ten stages. The first stages, (*stages 1 to 5*), follow the development from seedling to early maturity where increasing ramification and complexity occur in the branch and twig structure. During these stages, apical dominance is exerted. The root system also ramifies, producing a tiered formation, developing at different levels to optimise its capacity to serve the above ground crown exploration.

During the next period of development (*stages 6 to 8*), the crown is increasingly rounded with some loss of peripheral vitality, gradual loss of under-branch (abaxial) growth and the initiation of reiteration. Some branch loss occurs with associated dysfunction of conductive tissue. As the inner crown begins to express new growth with vascular channels to the root system, the outer crown begins to die back (basifugal mortality). During stage 8, incipient root death occurs with increased fungal colonisation leading to internal trunk decay from below.

In the later stages (*stages 9 and 10*), the living crown condenses and lows. The translocation of resources between root system and canopy is deployed to lower regions of the trunk and crown. Further outer-crown mortality occurs while foliar function is maintained through generation of new shoots from dormant or adventitious buds on the trunk and main branch system. At the latter stage, the bark circumference becomes discontinuous as vascular dysfunction progresses on the main trunk. However, the longevity of the tree now depends largely on mechanical stability of the crown and root anchorage and the effectiveness of the vascular columns on the trunk, directly plumbed to the root system, that serve independent and multiple mini-trees within the body of the parent tree. Where cambial columns provide discreet but complete units in the face of the disintegration of the parent tree, the parts that remain have the capacity to rejuvenate and progress through a cycle of some or all of stages 1 to 10.

While trees may be categorised in terms of age class from juvenile to mature and senescent, as described above, the ageing process of the tree is in fact far more complex. However, it is worth persisting with the various models provided, so that the arborist has an improved ability to interpret and make judgements about the morphology of trees.

A further method for exploring the ageing process is outlined by Fortanier and Jonkers (1976), who categorise three primary types of ageing. These are chronological ageing, ontogenetical ageing and physiological ageing and are summarised below.

Chronological ageing is the duration since germination and may refer to the entire tree or a part of the tree. It is described solely in temporal terms.

Ontogenetical ageing refers to the genetic potential of the individual tree. This is described in terms of development phases from germination to senescence. This view of ageing is influenced primarily by the activity of the meristematic tissue.

Physiological ageing reflects primarily the senescence that is induced in the tree or part of the tree through abiotic and other stresses.

This way of understanding ageing in trees is important as it focuses attention on the cambial layer, thus introducing a link between the influence of external events on physiological function, growth of anatomical structures and tree morphology.

Ontogenetic ageing has been further divided into four developmental phases (DEL TREDICI, 2000). These are the 'seedling phase', from germination to the end of the first season; 'juvenile phase' is from the second season to sexual maturity (which equates to Raimbault's stages 2 to 4/5). The 'adult phase' is 'major part of the trees life span' (equating to Raimbault's stages 5 to 8), and the 'senescent phase', which is identified with deterioration and disease. This latter phase equates to Raimbault's 9th and 10th stages. As has been noted above, the survival of the tree depends on the circumstances and availability of resources favourable to support and stimulate tissue that has remained dormant. Del Tredici argues that in the physiological ageing process, rejuvenation is controlled by differentiated tissue (comparable with the concept of veteranisation referred to above). However, ontogenetic rejuvenation is controlled by meristematic tissue (comparable with the processes leading to 'ancient' status). Del Tredici explores the nature of rejuvenation, which is the link between the physiological and ontogenetical aspects of ageing and demonstrates that the ageing process may not apply uniformly to the tree organism as a whole. So that rejuvenation may be occurring at localised points and organs of the tree at different rates. Therefore implications of this knowledge are significant for tree management for longevity.

The Pitfalls of Interpreting Morphology

When reiterative growth 'breaks free' from the rest of the system and the surviving residual column of the tree has the potential to pass through another cycle, the tree may then succeed in transferring the colonised assemblages of fungi, flora and fauna from the parent. These 'phoenix' stems then carry the paradox of being both parent and progeny.

While Raimbault's model appears to terminate at the senescent stage of the tree, it is in fact unclear whether, for him, this is the end for the tree or merely a stage in a new cycle. However, Raimbault succinctly identifies that the diagnostic use of his system is a tool for clarification of management options with regard to longevity. As such, this currently unappreciated approach has considerable potential for the management of trees and, to date has been largely unexplored.

Goethe, apart from a few followers, fell out of fashion at the turn of the 20th century, however there are aspects of his philosophy that are once again receiving attention. His method of observation and engagement with natural history has some resonance with the thinking and experience of quantum mechanics, modern evolutionary theorists and observers of veteran trees.

Although not obviously derived from Goethe's concept of plant morphology, the concepts involved in the field of biomechanics (MATTHECK, 1991; MATTHECK & BRELOER, 1995) frequently touch upon the form of the tree, while focusing on the tree's response to mechanical stress through adaptive growth. Significantly, whilst this is underpinned by the application of hard science, (using mathematical models and the use of diagnostic devices), Mattheck's success is largely attributable to the way he has integrated science with the common experiences of tree observation which are universally accessible. With his cartoons involving Stupsi the hedgehog (1996), Mattheck appeals to a common engagement of people with trees and their environment, thus crossing the boundary between science and artistic perception, thereby adding value to the experience of the arborist (MATTHECK & BETHGE, 1995).

Mattheck also refers to Raimbault's model (MATTHECK & BETHGE, 1998), using his talent for communication and cartoon illustration, where he describes the emergence of reiterative management in the tree as the loss of 'monarchic organisation' of stems and branches (i.e. loss of apical dominance) where, the subjugated 'law abiding, submissive vassals' (the emergent side branches) vie with one another to achieve dominance.

FIGURE 1. *Fraxinus excelsior* at The Nest wood pasture in Scottish borders showing reiterative growth from upper branch surfaces, after loss of main stem from crown ('monarch without head' [after MATTHECK & BETHGE, 1998)]

Theoretical models eventually extrapolate into practical implications. With respect to tree failure, the possibility of misinterpretation and poor diagnosis may have serious consequences for liability and management solutions. This is a fundamental issue for arborists who, while having concern for habitat and amenity, have a duty to take into consideration the management of trees for reasonable safety (LONSDALE, 1999). Arborists are constantly confronted with the body language of the tree, when assessing mechanical integrity and physiological condition. Shigo, Mattheck and Rayner, at a scientific level, have influenced much of current interpretation of arboricultural knowledge and practice by translating their own experience for the practical benefit of others.

Many biologists and arborists who have participated in ATF site visits, have been perplexed by the apparent contradictions of seeing trees that are evidently young or pre-mature and which are in fact found to be vegetative regeneration from ancient parent trees. In other words, such 'young' trees may be hundreds or thousands of years old, having survived in ancient wood pasture and pasture woodland sites in the face of extreme pressures.

The interpretation of 'defects', 'viability', and even the 'value' of trees, may vary according to our cultural heritage and is influenced by economic considerations of utility and function. Mattheck and Bethge (1998) advocate that 'trees which are tired of life should be respected and be felled for the sake of their dignity', to ensure their rapid replacement. Such views are constantly changing and are subject to many influences. There is a fundamental contradiction in a society that bases its economy on the rapid turnover of consumer goods and tends to provide short-term management budgets for trees with long life expectancies. The prognosis and management proposals for old trees that are under stress (and their rejuvenated successors), often depend on the time scale that we bring to the formulation of future management. As a result of the experiences of the ATF, increasingly, management plans for veteran trees populations are being developed over periods as long as 100 years.

The Veteran Tree as an Expression of Co-evolution

The world of science was turned upside down in 1927 in the field of subatomic particle physics, when Werner Heisenberg presented his 'Uncertainty Principle' (MCFADDEN, 2000). This concept led to the paradox of Bohr's statement that 'no elementary phenomenon is a phenomenon until it is a registered [observed] phenomenon'; so that, at the quantum level, 'there is no such thing as an electron or photon in the absence of measurement'. At the most basic level of physical reality, the units of existence are not subatomic particles but phenomena. These limits of subatomic scientific certainty became known as the 'Copenhagen Interpretation of Quantum Mechanics', and pose the paradoxical conclusion that 'electron plus measuring device collapses into a single classical reality' (ZUKAV, 1999). These questions of perception and reality have parallels in the field of environmental ethics and philosophy, where events and issues are available to multiple interpretations (ROZZI, 1998).

While these conclusions regarding the nature of reality have caused particle physicists perplexity and discomfort, their science has developed and evolved to accommodate these paradoxes. In arboriculture we have, whether we appreciate it or not, been influenced by such developments but have yet to confront their implications, particularly with regard to the integration of various schools of thought. The question arises how to bring together Shigo's concept of compartmentalisation, boundary setting and barrier zones (SHIGO, 1991), Mattheck's axiom of uniform stress, self-optimisation and biomechanics (MATTHECK, 1995) and Rayner's concepts of indeterminate, hydrodynamic systems and dynamic boundaries (RAYNER, 1997).

Rayner (1993) argues that, in contrast to those members of the animal kingdom (where organisms originate at conception, are fully differentiated by the sexual stage and, while possibly increasing in size, continue in this form until senescence and death), fungi and trees show a potential for growth and differentiation throughout their lives. This he terms 'indeterminate'. He also brings attention to the intimate relationship between the hydrological systems of trees and fungi ('self-plumbing' systems), where the interaction appears to be so strongly connected that it is hard to determine which organism is causing the barriers between them and at which point resources are redistributed to the disadvantage of one or the other organism (RAYNER, 1997). Rayner further brought to the arboricultural world the clarification of the various functions of fungi in relation to trees. This provided a deeper understanding of wood decomposition processes, bark and leaf colonisation, nutrient recycling and various strategies of fungal colonisation, including the role of endophytes and the dynamics whereby fungi may switch from saprotrophic decomposition to a pathogenic mode.

As a consequence of Rayner's work, and the tireless efforts of Ted Green (1991 et al) to interpret the ecological implications of Rayner's concepts of tree management for the benefit of arborists, a deeper understanding of the role of fungi has developed. This has opened the door to seeing the tree as a far more complex organism than is required by an understanding of tree biology alone. Furthermore, the imagination has been taken into the invisible realm of the internal topography of the ageing woody structure, conveying images of a network of fungal hyphae that are present throughout the vascular system. Thus the microcosm of succession becomes inhabited with an array of invertebrates, when the woody tissue has been prepared sufficiently for them to express their own specialist lifestyle and to find their place in the web of life that becomes the ancient tree.

In order to understand the ancient tree, we need to move from the concept of a unitary organism to a perception of a complex of interdependent organisms that have evolved through competition and mutualism. Many of the fungi that are known for their wood degrading properties operate differently, at different times within the same species and between different species, affecting the wood structure at different rates and in different ways. For example, *Inonotus hispidus* expresses versatility in the way it switches rot modes within ash (*Fraxinus excelsior)* depending on hydration and its locality. Additionally, it may cause more rapid embrittlement in ash than in London plane (*Platanus x hispanica)* (SCHWARZE, LONSDALE & FINK, 1997.)

Arborists have to struggle with these complexities in diagnosing the risks posed when ash trees are colonised by *I. hispidus* and in doing so make decisions to manage risks. What arborists may not take into consideration is that the *Inonotus* fungal bracket may itself be colonised by a range of invertebrates. These may include the false darkling beetle, such as the Nationally Scarce *Orchesia micans* (ALEXANDER, pers. comm.). Without taking this into consideration, arboricultural management may be unknowingly detrimental to endangered wildlife.

With some species of fungi, there may be a whole array of dependent invertebrate species that use the fruit body at some time in their life cycle. For example, the birch polypore (*Piptoporus betulinus*) plays host to at least 36 known beetles in the UK (102 worldwide). Dryad saddle (*Polyporus squamosus)* has 246 species worldwide (ANDERSON, 2001).

All arborists have to consider the implications of honey fungus (*Armillaria sp.)* in relation to tree health and stability. It is instructive to explore its ecological context to illustrate the implications of the genus for environmental arboriculture. The presence of honey fungus is ubiquitous in natural forests. In temperate zones, this fungus is found wherever trees are found. A known single colony of *Armillaria bulbosa* has been estimated to occupy an area of 15ha and weigh 100 tonnes with a calculated age of over 1,500 years (RAYNER, 1993). However, the presence of this species is often confused with the more aggressive *A. mellea*. While addressing issues relating to risks of mechanical tree failure, arborists should moderate their response when called to inspect trees suspected of colonisation by honey fungus. The much feared and denigrated honey fungus runs third in the above mentioned species table, with 90 species dependent on the fruiting body, worldwide (ANDERSON, 2001).

It is important to find contexts where natural processes can be observed in order to better understand the dynamics of colonisation between host and fungus. La Tallaie, an area of pasture woodland of some 34ha in Fontainebleau Forest a minimal intervention area for a period of some six hundred years. The Ancient Tree Forum has organised a number of study visits to the area and has noted examples of natural collapse and glade creation in this old-growth system. After several return-visits a discovery was made when observing lines of medium sized beech trees. It became apparent that, in certain areas that natural collapse of maiden trees onto already decaying trunks on the forest floor had occurred. The fallen trees were rooting and their laterals were forming the trunks of the successive generation. A key component for the engine of this process appeared to be honey fungus, which was producing accelerated wood decomposition of fallen trunks in saprotrophic mode. The environmental arborist is drawn into longer time scales of perception from such experiences and into considerations of the co-evolutionary possibilities and strategies that may be implicated by such timescales. Although these observations are by no means unique, the experience conveys a perspective on the evolutionary process and this may be a clue to the role of honey fungus in the evolution of beech.

In the fallen beech trees described above, it is noted that different parts of the tree are in different growth phases so that, as long as the root system is adequate and in contact with sufficient nutrients and water resources in its fallen state, the tree's longevity will depend upon its capacity to generate localised growth from available meristems. As mentioned earlier, this capacity to retain embryonic tissue throughout the tree's life, is the key to longevity and is inherently related to its indeterminate nature (RAYNER, 1993).

A further exploration of co-evolutionary processes can be found in the interaction between oak *(Quercus robur)* and hawthorn (*Crataegus monogyna*) on wood pasture systems. A recent survey of 884 old pollards at Hatfield Forest revealed a significant number of veteran hawthorn trees. These represented 42% of all recorded veterans at the site. As many as one third of the hawthorns were phoenix trees. In fact many of these phoenix hawthorn were 'on the move', having collapsed and layered repeatedly over long periods (termed 'serial phoenix' trees) (FAY & FAY, 2000). The complexity and long history of Hatfield Forest has been celebrated and well documented as an example of a medieval forest of wood pasture that has remained significantly unchanged over the last thousand years (RACKHAM, 1998). The veteran tree population dynamics, at a site with this history of grazing ecology, highlight the relationship between hawthorn and oak. There is now considerable evidence that hawthorn serves to protect oak seedlings in the face of grazing pressure. Both the hawthorn and the jay *(Garrulus glandarius)* are major collaborators in the success of oak. Vera reports that 35 – 40 jays were recorded to have moved 63,000 acorns in 10 days, which extrapolated to a population of 65 birds in 4 weeks moving 500,000 acorns. Additionally the jay is known to bury acorns at the foot of hawthorn in wood pasture thorny mantle, where the seed may be left till the following June, when the jay may return to train its young to 'raid the larder' (VERA, F.W.M. 2000). This picture suggests a significant co-evolutionary relationship between species.

While these relationships may be intriguing when revealed in the context of important sites such as Hatfield Forest, they should also raise questions for the arborist when choosing species and formulating management in the urban context or in estate management. In Hatfield Forest the oak provides habitat and food source for the jay. Both oak and hawthorn are colonised by the polypore 'chicken-of-the-wood' *(Laetiporus sulphureus).* Both tree species have some wood boring beetles of the same genus (e.g. the jewel beetle *Agrilus sinuatus* (colonising hawthorn) *& A. pannonicus* (colonising oak). Hawthorn has the added role of providing a nectar source for these beetles. The beetles are part of the food chain for other insects and birds. These dynamics further illustrate the complex relationships between the tree and associated organisms. The discipline of arboriculture and the interests of mycologists, ornithologists and entomologists are all served by the interaction between disciplines for benefit of tree ecology and go some way to defining one of the special roles for environmental arboriculture.

Rayner (1996) implies that the co-evolution of fungi and trees is so intimately linked that their mutual interaction may be far broader than commonly perceived. He suggests that communication between tree and fungus constantly occurs via chemically communicated feedback systems and dynamic interaction between boundaries. He notes that ectomycorrhizae sheath tree roots, protect the tree against toxins and forage essential minerals for the tree in exchange for photosynthate supplied by the tree. Rayner further describes how ectomycorrhizae also provide contact between the tree and adjacent roots of the same species and, via other mycorrhizal species, make contact between the tree and other plants. Rayner refers to work that implies that parent trees are involved in 'nursing' their seedlings through such processes. Rackham (1993) observes the poor success of naturally regenerating oak seedling in wood pasture this century, compared with records from the last. This he attributes to oak mildew (*Microsphaera alphitoides)*. However, this connection may be influenced by the below-ground circumstances suggested by Rayner that affect mycorrhizal conditions for parent seed nursing.

Rayner (1997) takes these concepts still further in his exploration of the phylogenetic evolutionary tree, (which represents the evolutionary order of species). He considers the possibility of 'horizontal gene transfer', where genetic information may be transferred *between* species through the intermediary of viruses and bacteria – a phenomenon that is exploited in the laboratory by genetic engineering. He speculates that in the light of this, such mechanisms may have influenced the symbiotic arrangements that have evolved to forge the close relationship between trees and fungi.

Keeping the Cambium in Mind

Shigo (1986) notes that every tree cell once originated as a cambial cell. He describes the under-bark sheath of undifferentiated, meristematic cambium as a 'tissue generator', producing a hierarchy of compartments that include cells, rings and rays. In response to injury and dysfunction, cells are predisposed to become chemically altered with the cambium effectively growing a 'new tree' around the zone of dysfunction. Rayner (1993) proposed that, following wounding, the effected wood tissue is hydro-dynamically controlled (i.e. alterations in the microenvironment associated with cell hydration serve to influence gaseous exchange and control fungal growth). According to Pearse (2000), xylem water content can increase in reaction zones by up to 1.7 times that of normal content, causing gas normally present in functional sapwood, to be displaced, thereby restricting the oxygen supply and consequently fungal growth.

The meristematic embryonic web, that is the cambial sheath, and the array of dormant buds distributed about the surface of the tree provide the means of prolonging the trees life. These organs have the potential to generate shoots or roots when appropriately stimulated. The question arises, what stimulates and controls this growth?

Mattheck describes how the cambium responds to physical stresses and compensates for excess loading by deploying wood to regulate and thereby optimise the mechanical design of the tree (the Axiom of Uniform Stress). In his book *Trees: The Mechanical Design* (1991), he shows a wide range of deformations and adaptations to stresses imposed upon the tree. The cambium can therefore be seen as a sensory organ, capable of stress perception and of actively responds to such stimuli. The cambium grows around dysfunctional tissue, interacting with endophytic fungi, pumping water into and between cells and regulating conditions around wounds.

The many and contradictory ways that the cambium operates have parallels with the paradox of quantum physics, where subatomic phenomena may behave both as particle and wave events. It is said that in the quantum world the best we can hope for is a set of delusions that agree with one another. To illustrate how our expectations influence our perceptions Eddington, in the 1930s, tells the story of a man who tells a disbelieving person that, inside a block of marble, is hidden a human head and then proceeds with nothing more than a hammer and chisel to chip away and reveal the head. Hopefully, the generative mystery of the cambium will similarly continue to be revealed. How we understand the tree in relation to its broader ecology (its growth context and the habitats that it supports) will inevitably determine the direction of future management. Perhaps, by chiselling away at these concepts and paradoxes, a quantum theory of the tree will be revealed.

FIGURE 2.
Carpinus betulus trunk at Hatfield Forest showing
adventitious root development at early stage of trunk regeneration

FIGURE 3.
Trunk remnant rejuvenation: *Carpinus betulus* at Hatch Park showing Rejuvenation resulting in two trees from a discontinuous parent trunk (perhaps not for the first time for this specimen)

Some Veteran Tree Management Issues

'Phoenix' Regeneration
In Fontainebleau, storm damaged veteran beech trees were observed where evidence suggested that dormant meristems were stimulated by increased light from natural clearance with reiterative growth and the development of new crowns. On the basis of these observations and the many examples of phoenix-like growth elsewhere, restoration programmes to mature trees are now being developed, which involve experiments that imitate natural processes. One such method involves the introduction of a natural fracture effect to selected crown limbs combined with localised weight reduction. Current treatment that are now being introduced, attempt to mimic ontogenetic rejuvenation (FORTANIER & JONKERS, 1976). As these techniques mimic observed 'survival strategies' for trees (reflecting conditions that occurred in their natural state), improved recording of these processes is important as well as understanding in what circumstances replication treatments may be successful.

Tree survival strategies that reflect phoenix-type regeneration include:

- *Trunk layering* where, following total trunk collapse existing laterals change mode to function as trunks (seen in beech, birch, hornbeam and hawthorn)
- *Trunk regeneration* arising from development of internal adventitious rooting forming a succession trunk within a gradually disintegration of parent trunk (most broadleaved species).
- *Trunk remnant rejuvenation* where the retention of isolated columns on the trunk following early reiteration and advanced decomposition results in callus / wound wood reforming an entire or near-entire small diameter trunk that supports a rejuvenated crown, [following stage 10 of Raimbault's model], (ash, oak, beech, hornbeam and hawthorn).
- *Lateral layering* arising from limbs which subside to ground level resulting in layered rooting and reiterative growth that develops to form a new trunk (this has been seen in beech, yew, hawthorn, hornbeam, oak, sweet chestnut)
- *Basal rejuvenation* where total trunk collapse results in basal regeneration to form new trunks (beech, hawthorn, hornbeam, lime, oak,)
- *Phoenix crown regeneration* following collapse of crown stems that develop rooting, reiterate and form new radiating trunks (yew, sweet chestnut, lime and oak)
- *Natural crown restoration* arising from canopy fragmentation resulting in rejuvenated trunk and crown growth (ash, beech, field maple, hornbeam, yew, most species)

Often, arborists are engaged in preventing limb subsidence by propping or removal. There are many cases now where treatments might include the promotion of layering. Where layering is actively occurring, this may be supported by the addition of topsoil to encourage rooting. On occasional sites with old trees methods are being explored to introduce targeted cuts that provide gradual further limb subsidence. All such operations are usually phased over many years and are being undertaken at a number of key veteran tree sites in the UK.

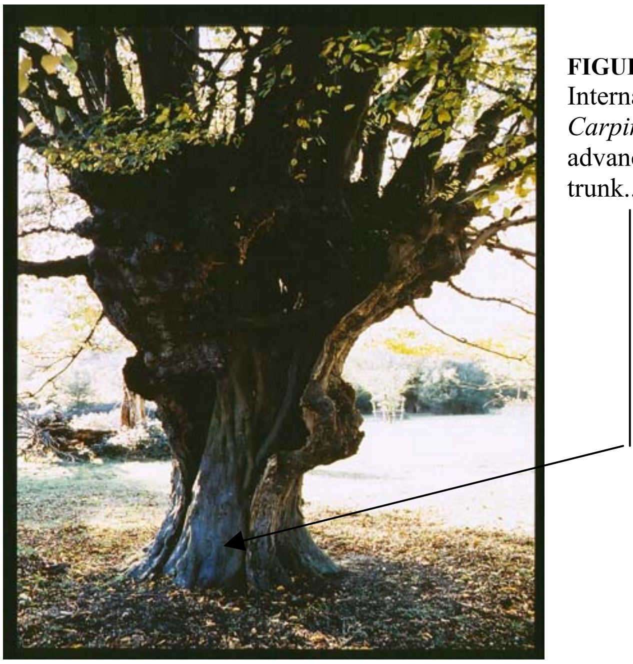

FIGURE 4.
Internal trunk regeneration:
Carpinus betulus trunk at Hatfield Forest showing advanced transformation of adventitious to succession trunk..

FIGURE 5.
Trunk layering of *Fagus sylvatica* at La Tallaie, Fontainebleau, France.

Intervention Approaches and Restoration Pruning

Methods of intervention will usually be prompted by the fact that many old trees are lapsed pollards with boles bearing the weight of pollard crowns often of between 100 to 250 years growth. On a number of key sites the rate of loss from mechanical failure ranges between 5% and 10% per annum, at the point of inspection. Management therefore has been to focus on a prioritised programme of crown stabilization, employing crown restoration practices.

Since Shigo (1991), crown reduction has generally been frowned upon in modern arboriculture. However, there has been considerable success in promoting recovery in many species, where crown or root stability has been compromised using the technique of restoration pruning. This method is intended to introduce increased light to regions of the crown by targeted pruning. This does not necessarily take the form of the 'drop-crotching' cutting method but involves systematic pruning about the periphery with return periods dependent on response. This involves a sensitive phased reduction, often using turbo saws in the initial stages to provide minimum diameter cuts. These operations are gradual with ultimate treatment times of several decades duration. All such treatments tend to be monitored. Such programmes will usually have three, five or ten year return periods and are responsive to patterns of crown growth. Where important trees are assessed to show signs of low vitality, systems of end-growth pruning may be employed, similar to renewal pruning of fruit trees. On limbs where vital signs appear low, attempts to stimulate cambial activity to promote adventitious bud formation by scoring branches with a timber scribe are being explored. Target pruning is not uniformly favoured. Other techniques include the creation of a number of live stubs in the crown, leaving lengths of three to five times the diameter from the point of attachment, with the intention of imitating the process of natural fracture (e.g. equivalent to random breakage from approx. force 9 winds, Beaufort Scale). These techniques are now beginning to be considered in some urban tree management programmes to enhance the dynamics of street tree wildlife corridors. They are also actively being introduced to owners of trees by environmental arborists who are in contact with the ATF.

Dead wood Management

Environmental arboriculture and tree ecology regards dead wood and the species that depend on dead wood, at some stage of their life-cycle (saproxylic habitat) as vital components of the ecosystem. Therefore management should be designed to promote and enhance the sustainability and condition of dead wood in tree populations (ALEXANDER GREEN. & KEY 1998). At Windsor Great Park, probably the key site for dead wood insects in Britain (FOWLES, ALEXANDER & KEY 1999), Ted Green has explored the importance of this saproxylic resource and carried out innovative experiments that are designed to improve dead wood status. (GREEN, 1995a, 1995a, 1996a, 1997). These include the re-erection of felled trunks to improve quantities of standing dead wood, the introduction of simple compartments with apertures for birds and bats in resurrected timber and tying cut branches with cavities back onto crown limbs for nesting sites.

The introduction of 'coronet cutting' was trialed at Ashtead Common National Nature Reserve, Surrey. Following a major fire a significant proportion of the 2000 oak pollards and many maiden trees were seriously scorched and damaged. Trials took place between 1997 and 1999. There was a need to retain as much of the standing dead oak whilst providing reasonable management with respect to the safe condition of the trees. To meet these objectives many trees were truncated and experiments were undertaken to mimic the effects of natural breakage. One of the results of this was the development of the technique of coronet cutting, which replicates the shattered end of storm-damaged limbs through skilful chainsaw use. This was unexpectedly well received by the public and has the benefit of increasing woody surface area for colonisation.

As a result of this and current guidelines for risk management aerial dead wood is now frequently required to be retained in a stable form with reduced lever arm and end-weight, using natural fracture techniques. These techniques that have evolved from the management of veteran trees are also now considered in the pruning of amenity trees.

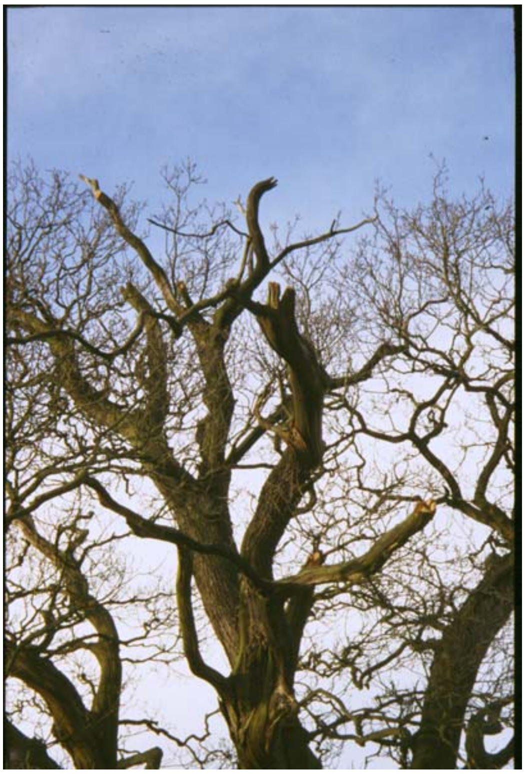

FIGURE 6.
Crown restoration showing coronet cuts and natural fracture technique on *Quercus robur* at Knepp Park, Sussex.

Natural fracture techniques are now being introduced to create live stubs in crown restoration treatments, to promote specialist habitats and enhance colonisation rates of niche species.

Recording of Tree Habitat

An important aspect of veteran tree management involves the recording of tree habitat. The Specialist Survey Method (SSM) (FAY & DE BERKER, 1997) was designed to provide the national standard for surveying veteran trees. This is a means of recording old trees from the point of view of their habitat. The SSM identifies a range of tree features that are colonised by fungi, flora and fauna. It also broadly records the presence of dependent species. Detailed veteran tree surveys have now been carried out at Hatfield Forest, Richmond Park, Slindon Estate and Ashton Court, in addition to a number of surveys undertaken by Wildlife Trusts and other organisations. Many records are now stored at regional environmental record centres.

The application of this system provides the means to collate data at a national level and evaluate population trends that may eventually influence policy. One of the benefits for arborists of using the system is that it focuses entirely on the woody substrate of the tree and contributes to training in this aspect of environmental arboriculture.

The SSM has now been further enhanced to provide a quantified habitat and tree viability evaluation to inform management. Management programmes generated by the system incorporates current best practice with model work schemes for thirty to one hundred year schedules.

Current Wildlife Legislation

The Wildlife and Countryside Act 1981 made it an enforceable offence to 'intentionally' damage, destroy or obstruct access to any structure or place, which any species scheduled under the Act, uses for protection or shelter. The recent Countryside and Rights of Way Act 2000, introduces increased penalties and includes the notion of 'reckless' harm to protected species. This has a similar connotation in ecological terms to the requirement for reasonable safety under occupier's liability for duty of care. Both cases hinge on the issue of foreseeability, requiring that reasonable measures are taken to avoid causing harm. Bearing in mind that some bats require less than 2cm entry, it is possible to imagine circumstances where a risk assessment to evaluate foreseeable harm to protected species may be required on all trees prior to implementing works (whether or not on development sites).

FIGURE 7.
Trunk remnant rejuvenation of *Tilia cordata* at Turville Heath, nr Henley-on-Thames showing internal adventitious root that is now broken free to form a secondary buttress trunk.

Choosing Appropriate Intervention

The interpretation of deformations (variations from a perceived standard) does not automatically imply the structure of the tree is defective. Given sufficient time and adaptive growth, associated with a wound site or site of mechanical stress, the optimisation of the architecture of the tree may be re-established, with increased wood strength in the vicinity of a previously weakened site (MATTHECK & BETHGE, 1998). Over-reaction to perceived defects in old trees has led to the loss of many veteran trees (and their associated habitat) in the interests of meeting duty of care. In order to address this issue, the Veteran Trees Initiative published 'The Guide to Risk and Responsibility' (DAVIS, FAY & MYNORS, 2000) to assist with the decision making process involved in balancing concerns relating to hazard and habitat. The guide therefore points out that, with respect to risk, veteran trees are simply a class of tree and need to be inspected without prejudice and with the same level of diligence as for any other tree. In recognition of the possible high value of a tree's habitat, management policy needs to take such factors into consideration. In some instances this may result in increased costs. Options should always be explored first for feasible ways whereby risks may be reduced to acceptable levels by non-tree management (such as moving the target beyond the falling distance of the hazard, before considering measures that may reduce the habitat value).

Conclusion

The British Isles contain a high proportion of Northern Europe's ancient trees. Through the work of the ATF, knowledge and understanding about their biological and cultural significance is being constantly improved. While there are a number of important veteran tree sites, there is a developing awareness that veteran tree populations are vulnerable to pressures of pollution and inappropriate management. To meet these challenges, there is considerable emphasis now placed on improving our understanding of the ageing process itself. This may have the potential benefit of drawing from knowledge of the strategies that trees appear to demonstrate for maintaining their living system. While knowledge is based on observation, interpretation and the scientific method, the major contributors to the field of arboriculture and ecology discussed in this article, have had expansive vision and ability to communicate complex ideas. Such ideas articulate both certainty and ambiguity, and convey the possibility that, through combining the spheres of science and art, the paradoxes that are inherent in the ecological process may lead to new paradigms and fresh approaches. As ancient trees carry assemblages of species over considerable periods of time, the approach of environmental arboriculture has been to consider that, not only does the tree have a function in longevity, but the associated species may also contribute to this process. Environmental arboriculture takes into consideration the possibility that the tree, fungi, flora and fauna all combine in an interdependent co-evolutionary process and should aim to support the eternal possibilities of the tree. This being the case, the choices made when managing trees will potentially impact on future tree evolution.

Acknowledgement

I am indebted to Ted Green who set me on this path and now there is no turning back. He is the founder and inspiration of the ATF and through tireless energy, articles and lectures, he has managed to communicate to a wide range of professional and lay conservationists about many of the emerging ideas that relate to ancient trees and environmental arboriculture

I also thank Nigel de Berker, who has brought so many interesting ideas to our enjoyment of old trees and Gerald Dawes, Mike Ellison, Ellen Fay and Kevin Frediani for their helpful comments and suggestions.

The Ancient Tree Forum may be contacted on their website www.woodland-trust.org.uk/ancient-tree-forum

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