# Rethinking the tree from the ground up

## *Inspired by living with ancient trees*

## PART 1:
## Developing a philosophical model from life and professional observations

"*The limits of my language mean the limits of my world*" Ludwig Wittgenstein

**Introduction**

The way we think about trees influences how they are managed. Perceiving the tree as a discrete organism with strict boundaries limits the imagination and constrains our curiosity.

What do the following definitions have in common?

- "Woody perennial plant of 6m or more on a single stem, which may divide low down…above ground level" (Mitchell, A. 1986. Trees of Britain and Northern Europe Collins)

- "A highly compartmented perennial, woody, shedding plant that is usually tall, single-stemmed and long-lived…the variations are almost endless." (Shigo, A. 1986. A new tree biology dictionary. Shigo and Trees, Associates)

These define the tree as a discrete object but not in terms of ecology, microbiology, rhizosphere or the environment.

This individualistic paradigm considers the visible above-ground parts, the phyllosphere. It overlooks life within the leaves, branches, trunk (the endosphere) and ignores the roots and soil ecosystem (the rhizosphere).

**Fig 1: Rethinking the tree from the ground up**
Inspired by ancients

Evolutionary theory emphasises the role of competition between individuals for environmental fitness. Complementary to this model is one of symbiosis, where organisms adapt and survive through mutualism. Symbiosis is ubiquitous, hidden in life as we know it today. Margulis (1981) describes how, antagonistic microorganisms gained a transformative evolutionary advantage when they combined to become a novel organism. This occurred when ancestral bacteria were incorporated into the larger nucleated cell, forming the organelles that we now call mitochondria and chloroplasts. These processes changed species complexity and drove cellular evolution causing an exponential transformation in the development of the living cell and the green plant in particular. Then life really took off.

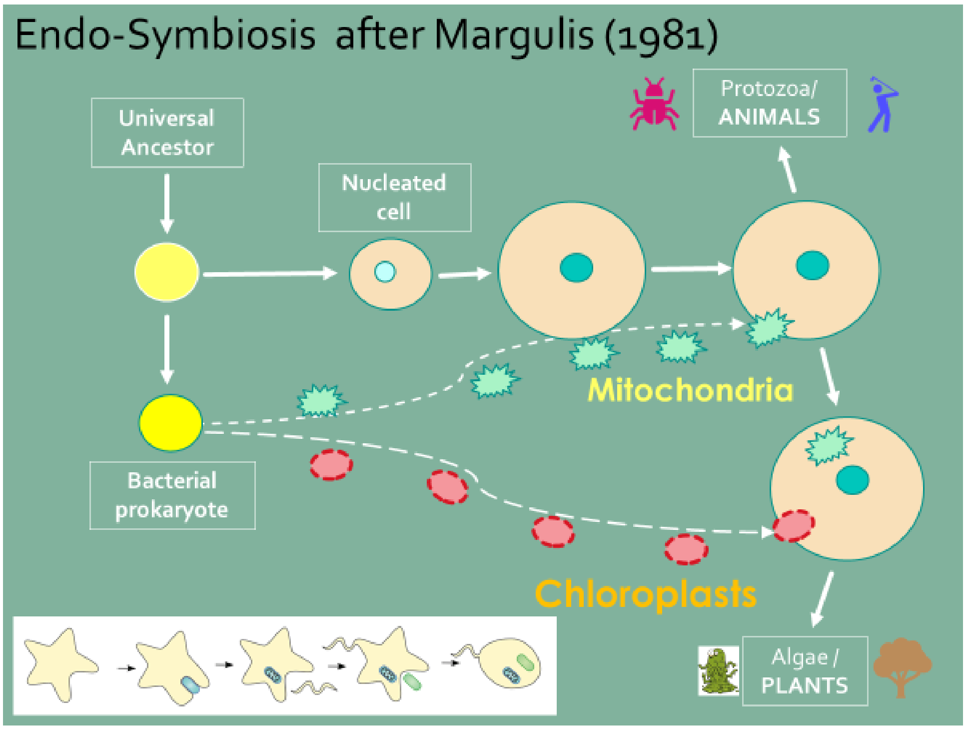


**Fig 2: Endosymbiosis after Margulis( 1981)**

**The microscopic theatre**

The symbiotic model is challenging. It shifts the spotlight from the theatre of readily visible individual actors who have clearly determined roles to a vast cast of players each performing multiple parts on a microscopic stage. Viewed in this way the concept of the *unitary tree* as host and the microorganism as invader and/or coloniser needs rethinking, as it generates a *binary model* that implies a simple hierarchical order contrary to the relationships that characterise symbiosis, which are reciprocal and variable. As with the human alimentary biome, the tree is infused with symbiotic microbial communities, which, while potentially antagonistic, largely operate as functional partners within the rhizosphere and phyllosphere. When mutually beneficial, these complex relationships and scales of organised interdependency confer advantage and resilience and arguably constitute a tree-microbiome that functions as a superorganism.

**The emergence of the integrated model and rhizosphere arboriculture**

Alex Shigo was arguably the main potent force in communicating twentieth century knowledge about amenity trees (trees outside woodlands) and was instrumental in the generational development of tree care theory and good management. His guiding texts New Tree Biology and Modern Arboriculture (Shigo 1989, 1991) helped shape the development of arboriculture as a discipline based on knowledge of tree biology and laid the foundation for a generation of practitioners. While, we do not criticise on the basis of knowledge at the time, it is important to understand context – the emphasis is on the tree as an entity, particularly in relation to decay and compartmentalisation. In the 49 chapters of Modern Arboriculture, there is a single chapter that considers roots, 12 pages out of 600 pages, with a passing brief mention of mycorrhizae and of soil compaction.

The lack of awareness of the tree's below-ground and endogenous context has created a vacuum that influenced modern arboriculture. The tree as an insular discrete organism tends to frame a paradigm based on above ground observations that drives practitioners to focus management on utilitarian concerns about amenity and safety. An integrated model of tree biology, one that extends the paradigm to takes account of the co-evolved influences of allied organisms within and around the tree, would signal the foundation of a twenty first century arboriculture

Over recent decades concern for loss of dependant species and habitat has stimulated interest in conservation and the study of ancient trees (Fay 2015) leading to a lifespan approach (Dujesiefken et al 2016). Behind these emerging disciplines is the inherent respect the practitioner has for the tree. However, we await the scientific vocabulary, upon which to build professional discourse, training and development. The integrated approach extends the scope of arboriculture and offers commercial opportunities with benefits for sustainability and the public good. For example, the UK Ancient Tree Forum has co-initiated European innovations such as the Veteran Tree Network (VETree and VETcert projects) to develop knowledge and standards for good management creating new arboricultural sub-disciplines and expertise relating to the lifespan approach in:

- Evaluation and conservation of natural heritage
- Tree habitat surveying, dead wood assessment
- Management techniques for longevity, habitat conservation, succession and creation
- Risk management psychology
- Planning and development in the built environment
- Population dynamics
- Trees in relation to natural capital
- Tree pathology and resilience management

Without taking account of soil bacteria and mycorrhizal relations, tree management will be deficient. Trees have adapted to nutrient- and water-deficient soils through mycorrhization; the process whereby fungal-root partnerships develop supported by bacterial communities, conferring evolutionary benefit on all parties. The extent of the value of mycorrhizae is reflected in the amount of energy that the tree expends on maintaining the rhizosphere – allocating up to 20% of photosynthetic assimilates to rhizosphere management in the form of exudates and other deposition (4).

Once established, the mycorrhizal-tree together with beneficial bacterial communities constitute an organism that is greater than the sum of its parts (5). These, along with non-beneficial microbes, are in constant 'communication' driving the ecology of the rhizosphere through chemical signalling with one another and the tree. Roots are neither static nor passive. Beneath an old oak, for example, generations of roots have been in intimate contact with microorganisms and the soil – constantly tip-exploring and sensing their environment, secreting sugars and proteins, while shedding cells and depositing other chemicals, interacting within the soil-space and with microbial populations.

The plant is involved in controlling the soil environment through root secretions (including sugars, hormones, amino acids and gases) that attract and regulate microbial communities for growth and defence (6, 7). As microbes are consumed, digested and excreted by other soil food web organisms, this unlocks nutrients made available for recycling. Carbohydrate-rich root exudates that are bound with cast-off root cells within the fine, slime layer stimulate bacteria to forage around the zone surrounding the root surface. Exudates are also involved in mycorrhization through attracting helper-bacteria, which modify the soil environment and provide a 'dating agency' for root-fungus compatibility and assist with propagule germination (8). Once established, along with foraging for essential nutrients for the tree, mycorrhizae are fundamental to tree health, influencing water relations between the tree and the soil, evapotranspiration and photosynthesis.

**The host-coloniser conundrum**

So to return to our definition of the tree, we start with the concept of a unitary organism. The more we investigate, the more the model needs to account for complexity. Conventionally, the literature considers the tree as *host* and all organisms that are housed within the tree as *colonisers*, and in some cases as *invaders*. But the more we learn about the microbiome as a congregation of co-drivers, the more opaque our definition becomes.

Behind terms such as 'host' and 'coloniser' there lies an implied bias, perhaps not surprising as it seems illogical that the small might be host to the large. Conventionally, the host-coloniser concept is characterised by assumption of the superior size of the host as a single, unitary organism and that there are defined boundaries between host and colonising individuals. However, this fails to account for the various levels of aggregation between microbial communities and that the relationships and boundaries between tree and microbes, and likewise between microbes themselves, are both variable and dynamic. 'Hosting' is ambivalent, and, like Schrödinger's cat paradoxical, appearances may be deceptive – fungal-bacterial communities might reasonably be considered to be host to the tree. This is more than mere philosophy; our understanding of these matters determines the scientific paradigms by which we operate and in turn how trees are managed. While arboriculture is beginning to consider these complexities, we await the development of a coherent language to overcome the boundaries of our inherited frames of reference.

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## PART 2:

## Rethinking tree health: Developing an integrated model of tree disease and management

Tree populations in decline may be the 'canary in mine' alerting us to underlying disorders in the natural environment. A shift is taking place in the approach to tree disease research that conventionally has concentrated study on target pathogens. Today, increasing account is being taken of the complex environmental factors that predispose trees to disease, including recent interest in the rhizosphere and its communities.

While the search for pathogens is a necessary part of understanding disease management, when oversimplified the disease-victim model channels investment away from understanding predisposing factors.

These issues are explored with respect to oak declines. Pathogens may directly cause decline or be indirectly involved along with other stress-inducing influences (1). Decline symptoms of UK native oak (*Quercus robur* and *Quercus petraea*) include crown die back, bark lesions and stem bleeds. The aetiology often involves set-back and recovery. Prolonged declines are referred to as 'chronic oak decline' (COD), and rapid severe declines as 'Acute Oak Decline' (AOD). Oak declines in Britain have been associated with drought, defoliation, root pathogens, frost and powdery mildew (*Eresyphe alphitoides*) (2,3). Severe declines have been recorded periodically during the 20$^{th}$ century . Recent outbreaks have been attributed to pathogen hypotheses.

In 2009 AOD was hypothesised as a distinct disease (4) involving novel bacterial species isolated from trunk bleeds, often associated with oak jewel beetle galleries (*Agrilus biguttatus*). Bacterial strains (with canonical virulence genes) from necrotic lesions were hypothesised to constitute a polymicrobial pathogen-complex (5). Recently tree pathologists have also considered predisposing biotic and abiotic factors (6,7,8).

**Environmental triggers**

The rhizosphere surrounding oak trees is home to a species-rich polymicrobial biome. Studies of oak associated species have identified 47,000 operational bacterial taxanomic units (OTUs) and 18,500 fungal OTUs, along with 1,178 insect species, 716 lichen species and 229 moss and liverwort species (9). This is highly significant for AOD and tree disease in general.

There is an awakening to environmental factors and new multidisciplinary studies are focusing on the role of the below ground ecosystem in tree health and disease (10). Pathogens can even remain dormant and form transient commensal communities, transitioning into pathogenicity under certain triggers (11).

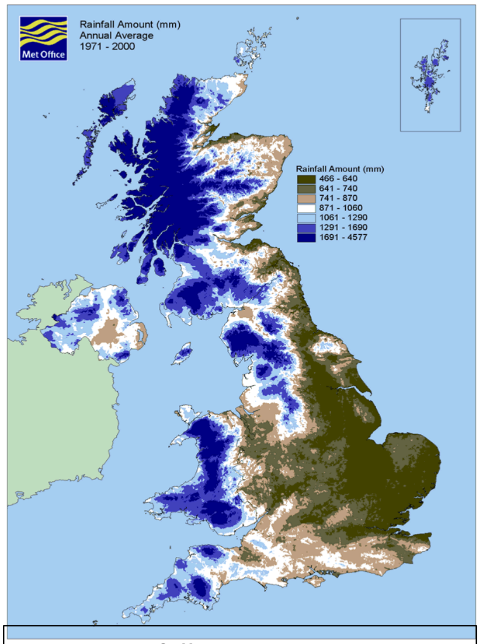


**Fig. 1: Rainfall map 1971-2000**
(source: Met Office data)

The controversial role of the oak jewel beetle illustrates the problems of siloed knowledge. AOD studies identify the beetle as a disease vector, through transmission of infective propagules. According to Alexander (12) there is no reliable evidence that the jewel beetle is causally, rather than casually involved. The species is oak co-evolved and naturally attracted to necrotic tissue and has been found on many, but not all symptomatic AOD trees. On this basis, defining AOD by the presence of the beetle is misleadingly circular.

Poor soil and rooting function that impairs hydraulic conductivity within the plant leads to photosynthetic inefficiency and carbon starvation (10). These, together with declining rainfall and droughting effects such as oak mildew (13) are predisposing factors. Combined they compound pathways to decline.

Disrupted hydrology influences plant water availability and disease susceptibility. UK average rainfall between 1971-2000 (Fig. 1) and AOD distribution records (2008 – 2017) (Fig. 2) indicate an inverse correlation between rainfall and AOD and suggest that drought stress is a key factor in AOD susceptibility (14).

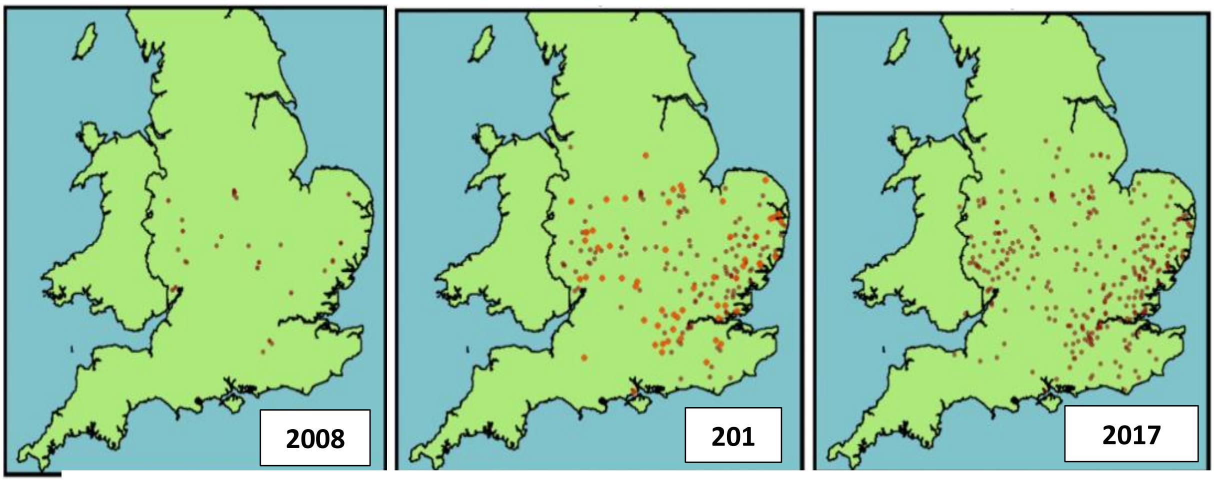




**Fig. 2: UK Sites affected by AOD (2008-17)**

**Tree declines – ground-up solutions**

Treework veteran tree population studies indicate declining tree condition is often accompanied by rhizosphere damage. Various factors that are common to high use public areas affect the rhizosphere (e.g. compaction, disrupted drainage, animal impacts and removal of leaf-litter and woody-debris). Such factors disorder soil chemistry, alter pH, deplete soil organic matter (SOM), and upset fungal/bacterial and carbon/nitrogen ratios. Conventionally livestock and dog fouling impacts are seldom considered. A negative correlation is indicated between high visitor pressure and both soil carbon:nitrogen (C:N) ratio and micro-organism activity (Fig 3) (15). High visitor pressure negatively impacts crown condition and mycorrhizal colonisation (Fig 4).

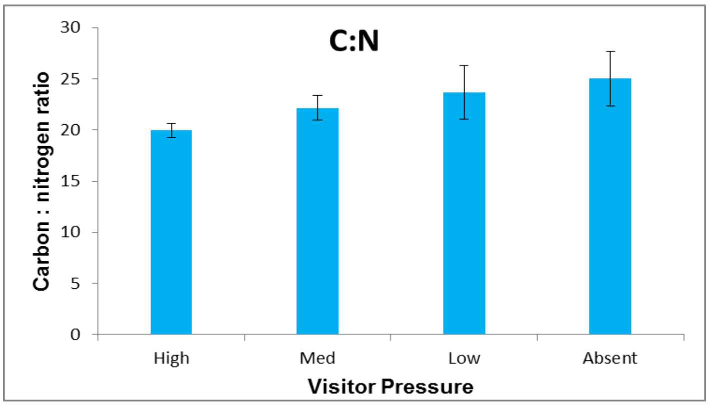


**Figure 3**
C:N ratio as a function of high visitor pressure at a site near London

**Compost teas**

Treeworks soils department have designed study trials of treatment applications to the rhizosphere and crown, innovating aerated compost tea use (ACTs) on trees in decline. This is a departure from conventional pharmaceutical plant management. Ongoing studies involve investigation of different treatments and monitoring above and below ground indicators.

Bulky composts recycle organic matter to the soil but do so slowly and the availability and quantities of associated microbiology is variable, is frequently anaerobically dominated and limited by attachment to the parent material with biological glues.

Compost tea, is a brewed water extract of compost, used for centuries in traditional agriculture and viticulture. It is aerated and applied as a fine spray as a root and foliar drench. Oxygenation together with a bio-accelerator increase microbial activity. Foliar ACT, appropriately applied, increases leaf-surface biological activity, duration of stomatal opening and photosynthetic efficiency. ACT leaf coating inhibits bacterial and fungal colonisation. Depending on the porosity of the soil, ACT percolates through the rhizosphere and enhances the soil food web processes.

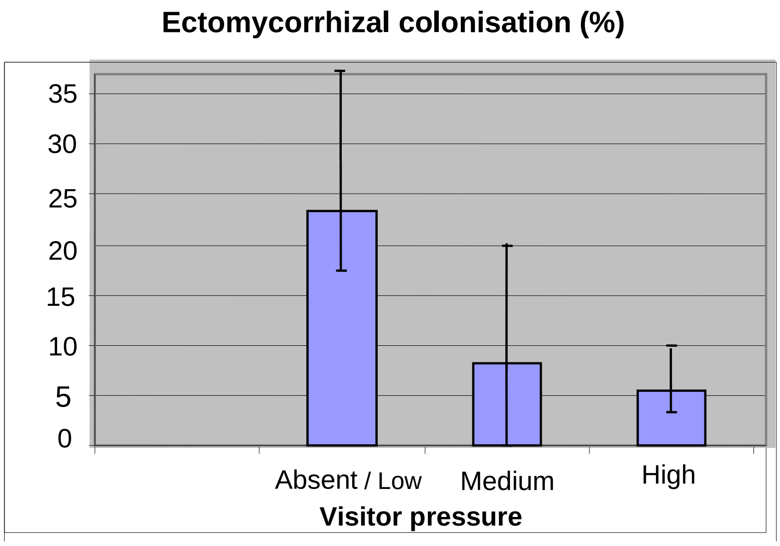


**Figure 4: Nature conservation UK site with 400+ veteran trees: 600,000 visitors p.a.**
Ectomycorrhizal colonisation on veteran beech reduces with visitor pressure.

**Treework study methodology**

At sites with mature oak in decline and sweet chestnut (*Castanea sativa*) with ink disease different amendments were applied to study groups. Study groups include – Controls, ground treatment (GACT), crown treatment (CACT), Woodchip mulch and biochar. A database of soil microbiology and chemistry has been maintained together with crown health indicators, mildew infestation and stem bleeds.

Intermediate findings on mature declining oaks indicate improved rhizosphere and crown condition following ACT applications. Foliar ACT showed crown not only showed crown recovery but also improved soil quality. Woodchip application also showed soil and crown benefits (Figs 5 and 6).

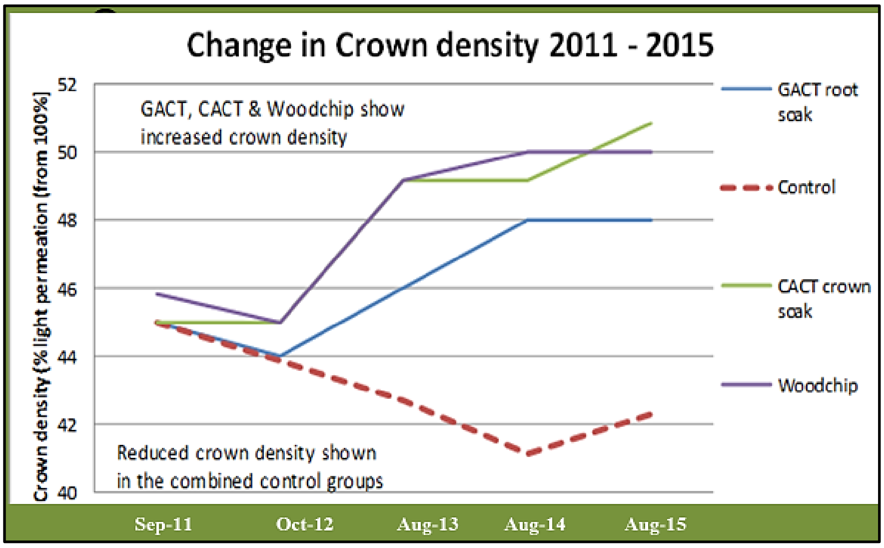


**Fig 5: Crown density change 2011-2015**
Mean change in crown density (%) for treatment groups 2011 - 2015

**CACT Foliar treatment**

2011 (< 60% ) 2014 (<45%)

**Wood chip**

2011 (< 40% ) 2014 (<30%)

**Fig 6 : AOD trees performance with ACT & woodchip**
Crown condition improvement following application of ACT to crown (LHS) and woodchip mulch applied to rhizosphere (RHS).

**Conclusion**

Reimagining the tree from the ground up inspired by observations of ancient trees, should create a curiosity about the conditions that favour exceptional longevity. A model of the tree as a superorganism, rather than as a discrete entity suggests a shift in philosophy is needed. Arboricultural therapeutic treatments should engage with ground-up biological processes that favour resilience and ecological diversity. To resolve this research deficiency, we need to step up research investment based on the integrated model of the tree as ecosystem.

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