Crown reduction, from one unknown load to another.

HARTILL
TRÄDEXPERT

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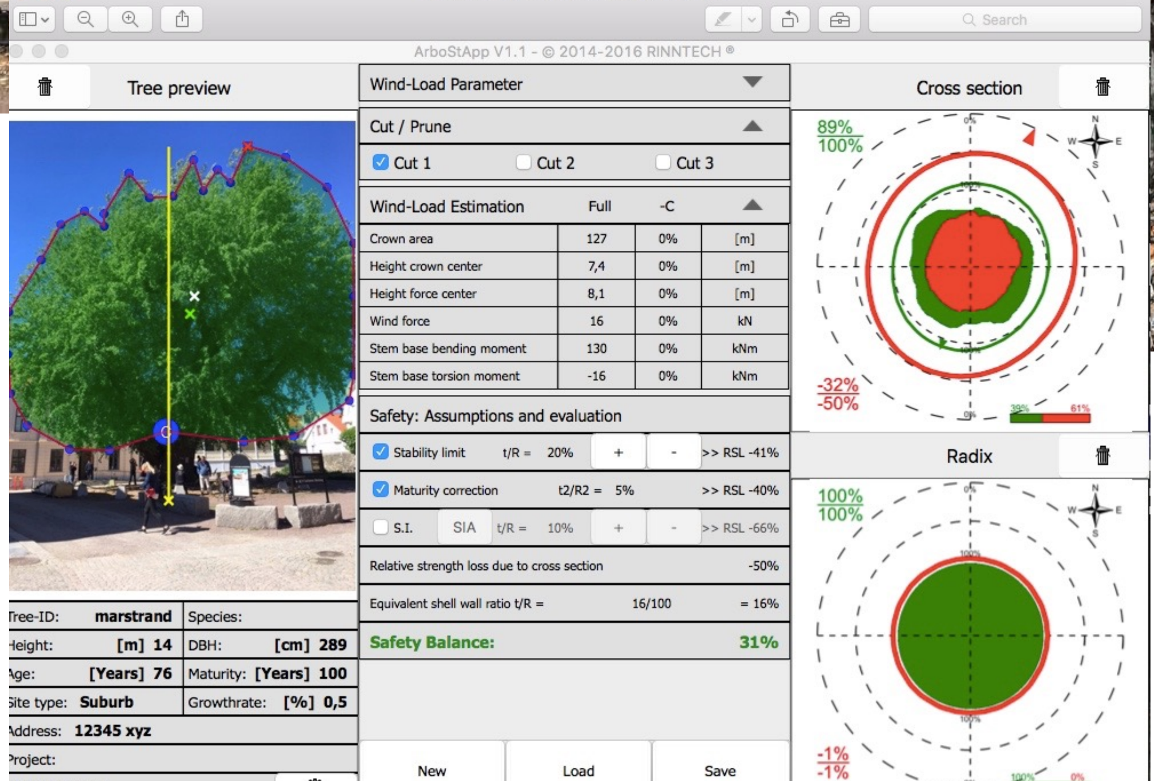
- Tree Climber since 1987
- Company established in 1995
- Clients include City councils
- Private estates/homeowners
- Woodland and conservation management organisations

- Housing companies
- Architects
- Landscape designers
- Railway and Utility companies
- Other arboricultural companies.

I am not a consultant, but we are consulted for advice.



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ArboStApp V1.1 - © 2014-2016 RINNTECH ®

Wind-Load Parameter

Cut / Prune

☑ Cut 1 ☐ Cut 2 ☐ Cut 3

Wind-Load Estimation	Full	-C	
Crown area	127	0%	[m]
Height crown center	7,4	0%	[m]
Height force center	8,1	0%	[m]
Wind force	16	0%	kN
Stem base bending moment	130	0%	kNm
Stem base torsion moment	-16	0%	kNm

Safety: Assumptions and evaluation

☑ Stability limit t/R = 20% + - >> RSL -41%

☑ Maturity correction t2/R2 = 5% >> RSL -40%

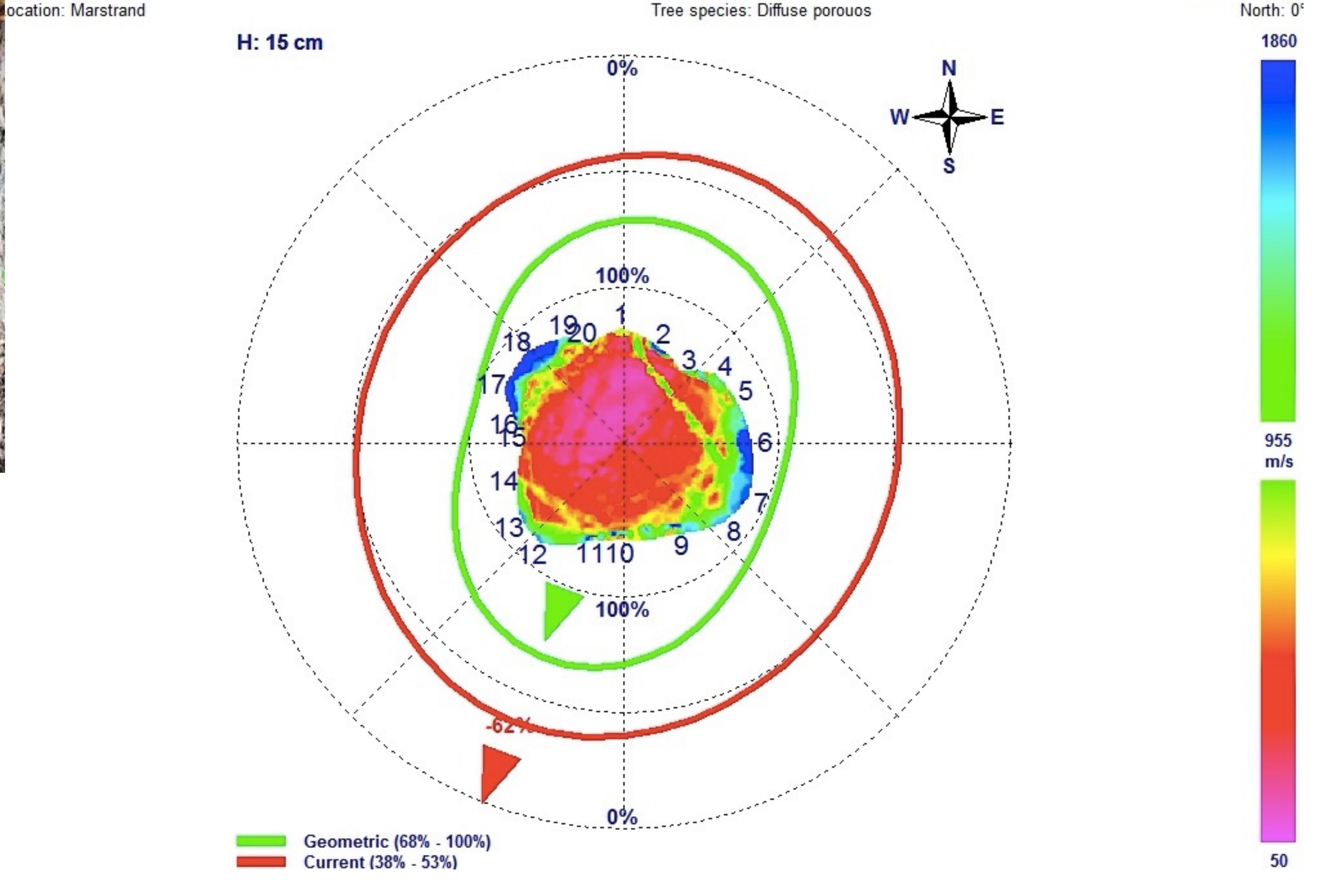
☐ S.I. SIA t/R = 10% + - >> RSL -66%

Relative strength loss due to cross section -50%

Equivalent shell wall ratio t/R = 16/100 = 16%

Safety Balance: 31%

Tree-ID:	**marstrand**	Species:	
Height:	**[m] 14**	DBH:	**[cm] 289**
Age:	**[Years] 76**	Maturity:	**[Years] 100**
Site type:	**Suburb**	Growthrate:	**[%] 0,5**
Address:	**12345 xyz**		
Project:			



roject:

ocation: Marstrand

Tree: Poppeln

Tree species: Diffuse porouos

Date: 2017060

North: 0

"Among the <u>inumerable</u>
modifications which waylay
human arrogance on every side
may well
be reckoned our ignorance of the
most common objects and effects,
a defect of which we become more
sensible by every attempt to
supply it.

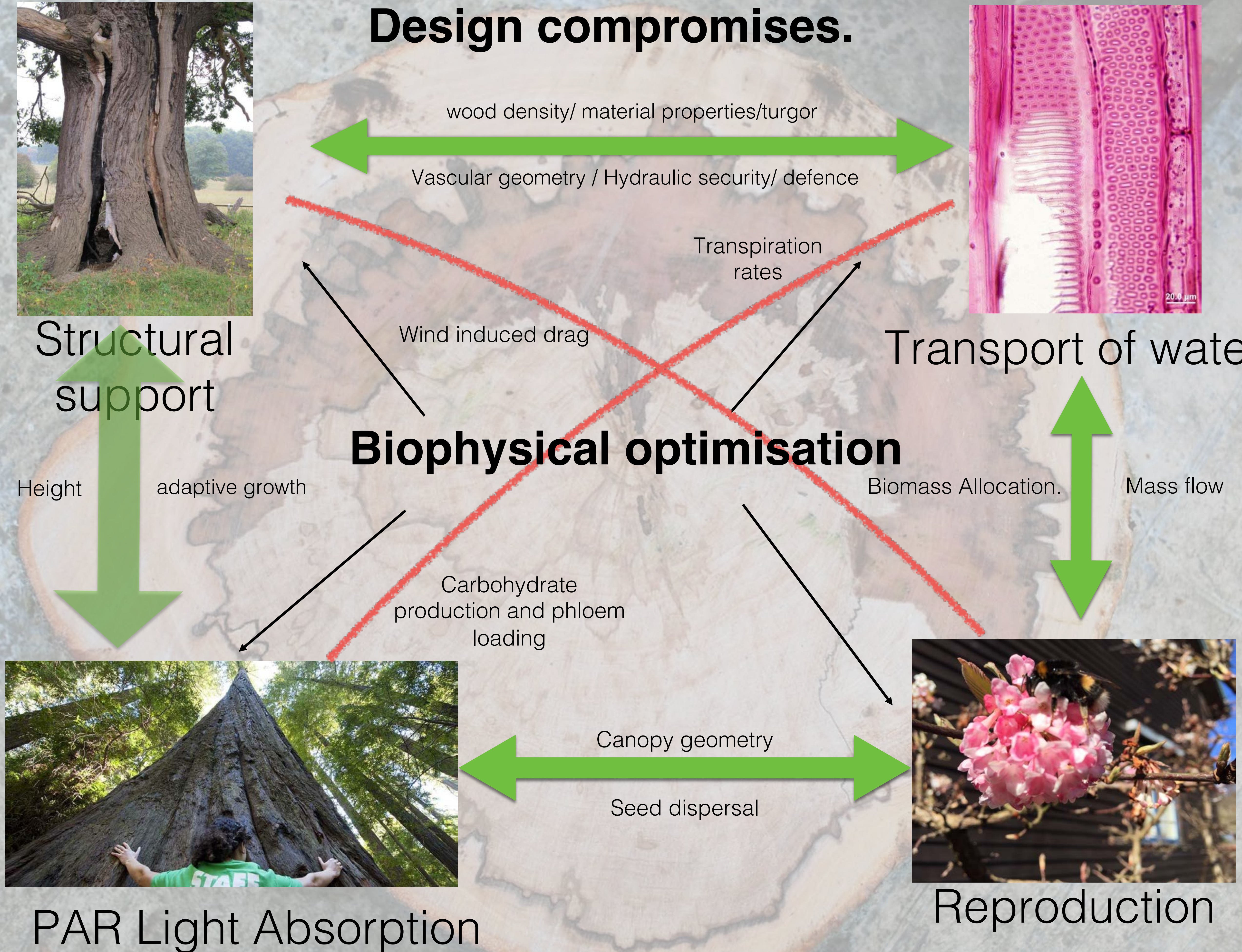
Vulgar and inactive minds
confounded familiarity with
knowledge and conceive
themselves
informed of the whole nature of
things when they are shown their
form or told their use;

but the <u>speculist</u>, who is not
content with superficial views,
harasses himself with fruitless
curiosity, and still, as he inquires
more, perceives only that he
knows less".

Samuel Johnson, The Idler
(Saturday 25th November 1758.)

Wind is a fluid.

Design compromises.



Structural support

Transport of water

wood density/ material properties/turgor

Vascular geometry / Hydraulic security/ defence

Transpiration rates

Wind induced drag

Biophysical optimisation

Height

adaptive growth

Biomass Allocation.

Mass flow

Carbohydrate production and phloem loading

Canopy geometry

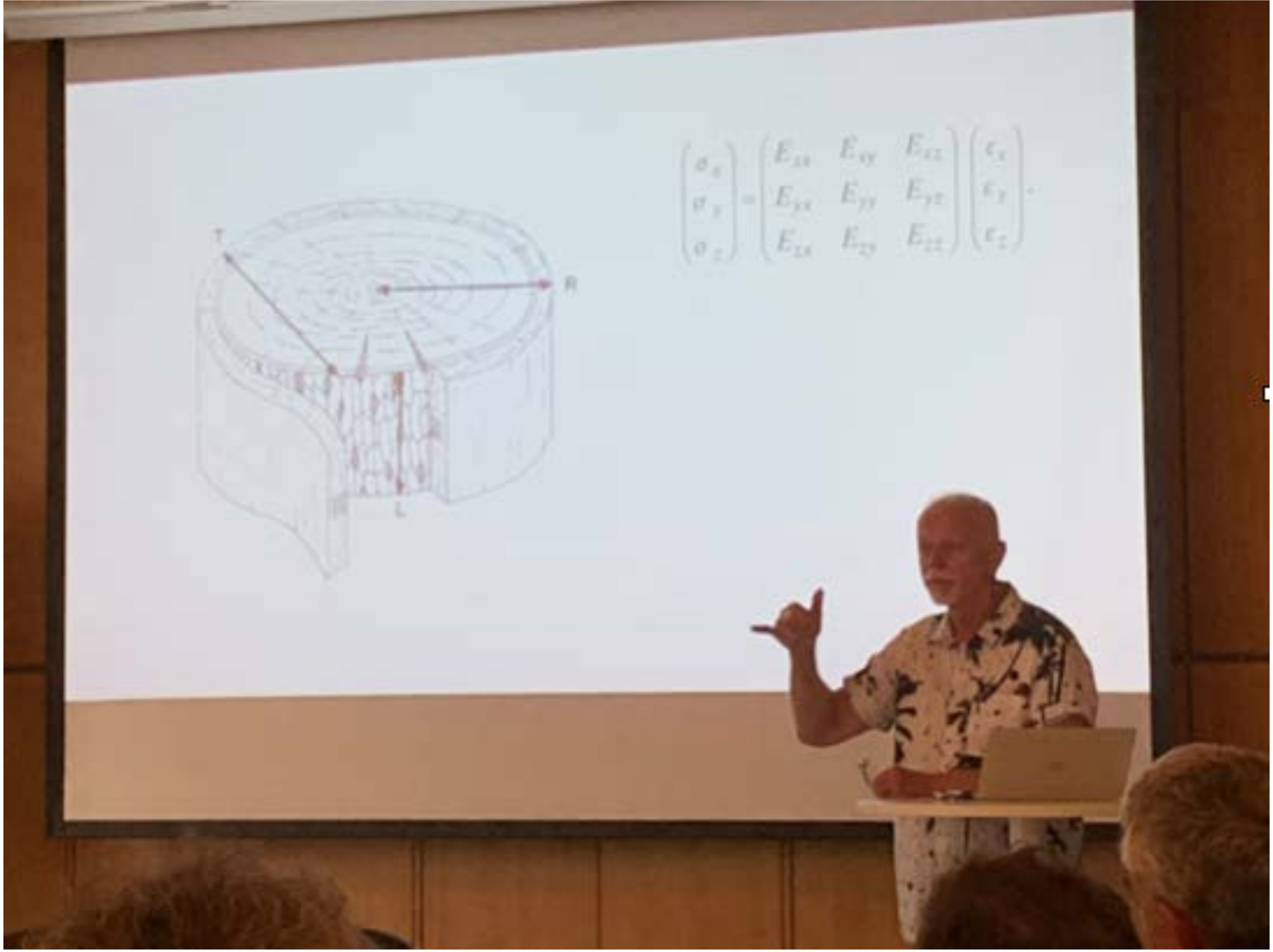
Seed dispersal

PAR Light Absorption

Reproduction

Refences and essential reading, before undertaking crown reduction work.

- Plant Physics Karl Niklas and Hanns-Christof Spatz 2012
- Niklas, K. J. *Plant Allometry: The Scaling of Form and Process* (University of Chicago Press, 1994).
- Plant Biomechanics and engineering approach to plant form and function KJ Niklas 1992 Chicago press
- Wood Decay Communities in Angiosperm Wood . Lynne Boddy, Jennifer Hiscox, Emma C. Gilmartin, Sarah R. Johnston, and Jacob Heilmann-Clausen 2017.
- The origins of decay in living deciduous trees: the role of moisture content and a re-appraisal of the expanded concept of tree decay. Lynne Boddy and Alan Rayner 1983.
- Interactive effects of water supply and defoliation on photosynthesis, plant water status and growth of Eucalyptus globulus A. G. Quentin, A. P. O'Grady, C. L. Beadle, C. Mohammed, E. A. Pinkard 2012
- The Parenchyma of Secondary Xylem and Its Critical Role in Tree Defense against Fungal Decay in Relation to the CODIT Model Hugh Morris ,Craig R Brodersen ,Francis Willis Matthew Robert Schwarze
- Steven Jansen 2016
- Vessel diameter is related to amount and spatial arrangement of axial parenchyma in woody angiosperms Hugh Morris, Mark Alan Frank Gillingham Lenka Plavcova Steven Jansen 2018
- Mechanosensitive control of plant growth: bearing the load,sensing, transducing,and responding. Bruno Moulia, Catherine Coutand, and Jean-Louis Julien. 2015
- To respond or not to respond,the recurring question in plant mechanosensitivity. Nathalie Leblanc-Fournier, Ludovic Martin , Catherine Lenne, and Mélanie Decourteix.
- Invariant scaling relationships for interspecific plant biomass production rates and body size.
- Karl J. Niklas and Brian J. Enquist. 2000
- Transverse stresses and modes of failure in tree branches and other beams.
- A. R. Ennos and A. van Casteren 2010.
- Mechanical properties of wood disproportionately increase with increasing density, Karl J Niklas and Hanns-Christof Spatz 2012.
- CANONICAL RULES FOR PLANT ORGAN BIOMASS PARTITIONING AND ANNUAL ALLOCATION
- KARL J. NIKLAS AND BRIAN J. ENQUIST. 2002
- ALLOMETRIC THEORY AND THE MECHANICAL STABILITY OF LARGE TREES: PROOF AND CONJECTURE
- KARL J. NIKLAS AND HANNS-CHRISTOF SPATZ 2006.
- Growth and hydraulic (not mechanical) constraints govern the scaling of tree height and mass
- Karl J. Niklas and Hanns-Christof Spatz 2004
- A general review of the biomechanics of root anchorage Christopher J. Stubbs , Douglas D. Cook and Karl J. Niklas, 2019
- WORLDWIDE CORRELATIONS OF MECHANICAL PROPERTIES AND GREEN WOOD DENSITY
- Karl J. Niklas, and Hanns-Christof Spatz . 2010
- Relationships of density, microfibril angle and sound velocity, with stiffness and strength in mature wood of Douglas fir. Lachenbruch, Johnson, Downes, Evans, 2009.
- Non-destructive evaluation of wood stiffness and fibre coarseness, derived from SilviScan data, via near infrared hyperspectral imaging Te Ma, Tetsuya Inagaki, Satoru Tsuchikawa 2019
- Rapid prediction of wood stiffness from microfibril angle and density, R, Evans and Jugo Ilic. 2001
- Experimental evidence for a mechanical function of the cellulose microfibril angle in wood cell walls, A reiterer, H,Lichtenegger, S, Tschegg and P.Fratzl 1998.
- Mechanical Properties of Green Wood and Their Relevance for Tree Risk Assessment Hanns Christof Spatz and Jochen Pfisterer 2013
- Drag co -efficients for British forest trees derived from wind tunnel studies. G.J Mayhead 1973
- Wind induced stresses in cherry trees, Evidence against the hypothesis of constant stress. K J Niklas and Hanns Christof Spatz 2000
- Basic Biomechanics of self supporting plants Windlass and gravitasional loads on Norway spruce Spatz and Bruchert 2000
- Dynamic loading of trees. Ken R James 2006 Arboricultural Journal
- Xylem function and the ascent of sap. Zimmerman 1983
- Safety and efficiency conflicts in hydraulic architecture. scaling from tissues to trees 2008 Sperry/ McCulloh
- The Limits to tree height, Koch, Sillet, Jennings, Davis 2004.
- Response to Klaus Mattheck’s letter 2000 K,J Niklas H.C Spatz (Critique of axism of uniform stress)
- Modes of failure in tubular plant organs H,C Spatz , K,J Niklas 2013
- Defoliation constrains xylem and phloem functionality RACHEL M HILEBRAND,Uwe G Hacke,Victor J Leiffers 2019.
- Niklas KJ, Spatz H-C. 2000. Wind-induced stresses in cherry trees:evidence against the hypothesis of constant stress levels.



$$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\end{pmatrix}=\begin{pmatrix}E_{xx} & E_{xy} & E_{xz}\\ E_{yx} & E_{yy} & E_{yz}\\ E_{zx} & E_{zy} & E_{zz}\end{pmatrix}\begin{pmatrix}\epsilon_x\\ \epsilon_y\\ \epsilon_z\end{pmatrix}.$$

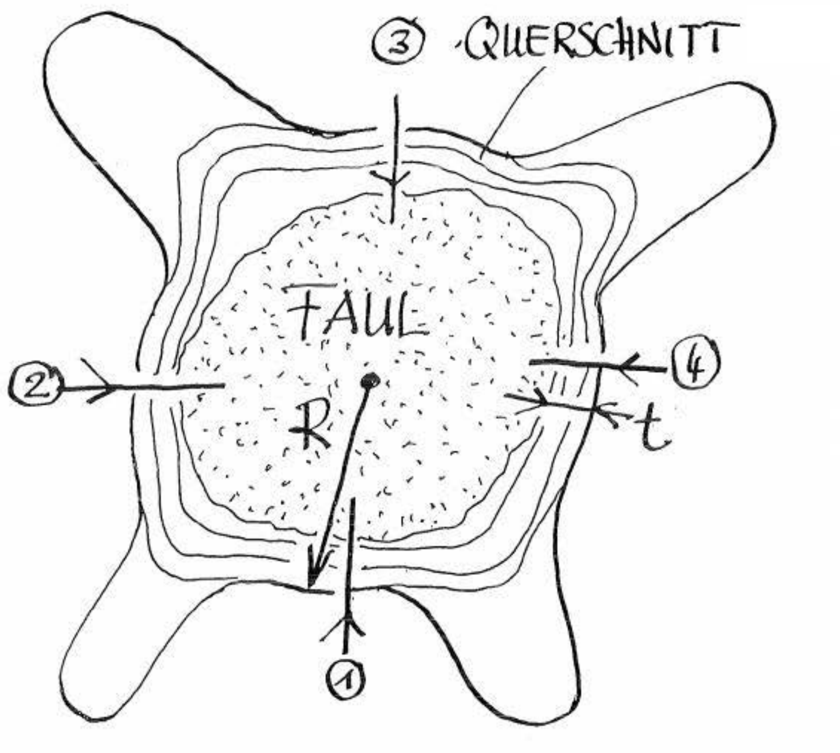
30 delegates from 10 countries.
Link Freely available at:
Hartill träd expert on Vimeo

Sweden's oldest street tree(600 yrs)
The Radio Oak Stockholm.

Visual Tree Assessment (VTA)

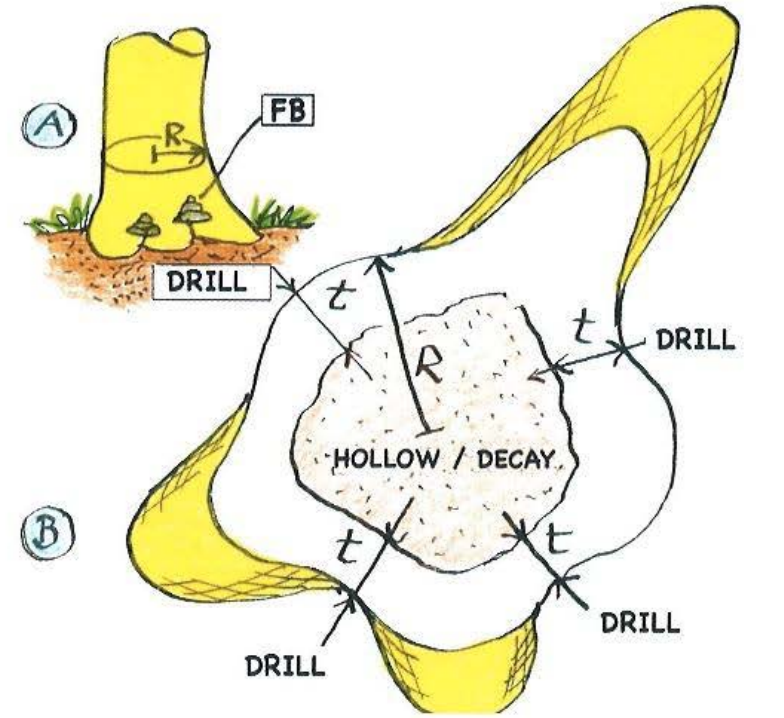
„1/3-rule“ for evaluating breaking safety

Practical application: drill between the buttresses“



UM $t/R \geq 0.3$ ABZUFRAGEN, BOHRE MAN ZWISCHEN DIE WURZELANLÄUFE, WO IN DER REGEL DIE WANDSTÄRKE AM DÜNNSTEN IST. MIT $t/R = 0.3$ BEWERTEN WIR DAS STAMMBRUCH-RISIKO DES VOLL BEKRONTEN BAUMES.

The residual wall thicknesses at the stem base



"For assessing $t/R>0.3$, it is necessary to drill between the buttresses, where the shell wall commonly is the thinnest. With $t/R=0.3$ we evaluate the stem breaking probability of the fully crowned tree."

C. Mattheck, 1995 / 2012

Visual Tree Assessment (VTA)

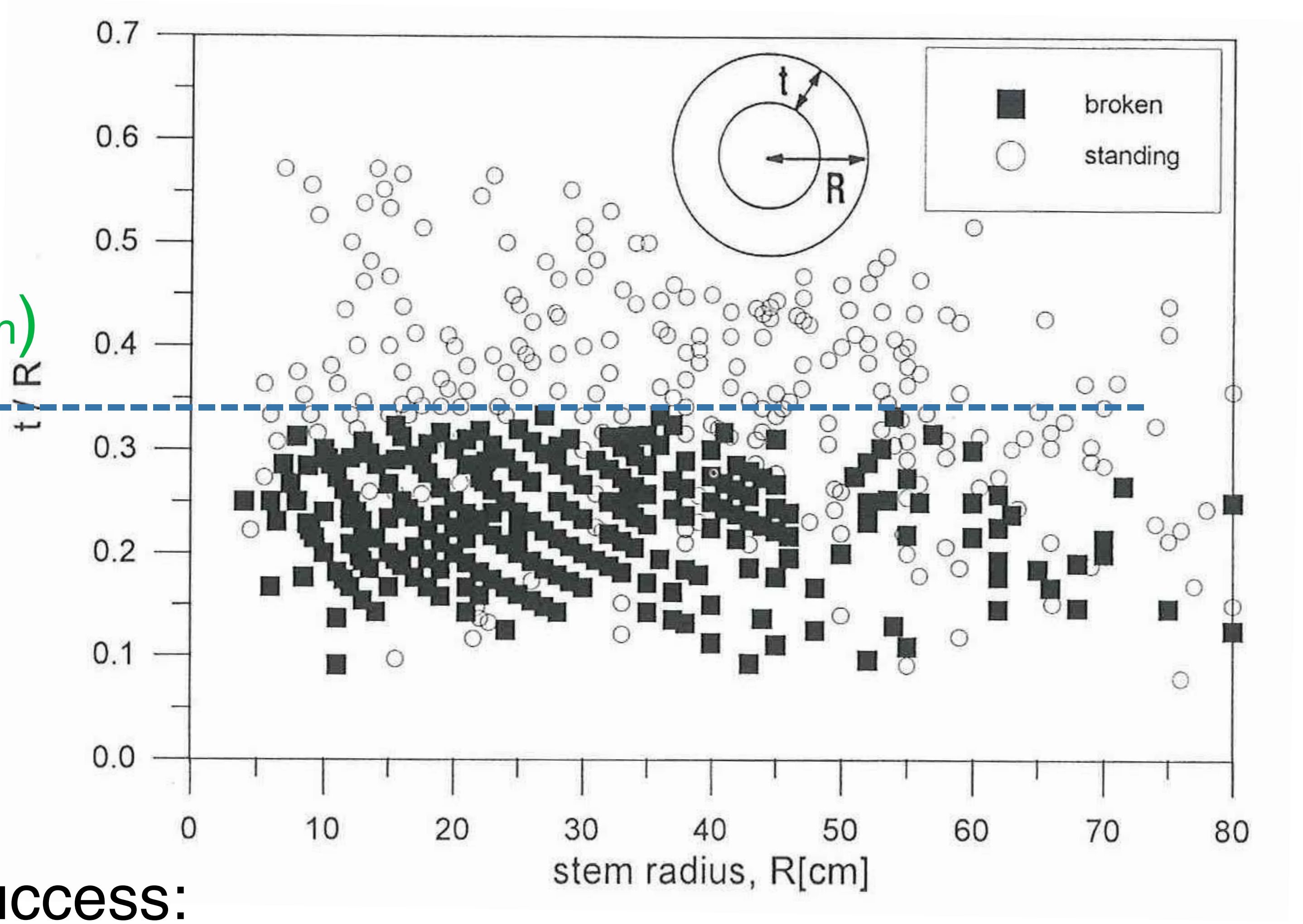
“1/3-rule” for evaluating breaking safety

The quick world wide success of this safety-criterion was largely a consequence of the fact that there are no black squares above t/R=1/3, suggesting a clear and simple distinction between safe and (potentially) unsafe trees.
Especially judges, lawyers and insurance companies liked this because it suddenly seemed simple to evaluate tree safety by just drilling between the buttresses.

SAFE

(no ■ broken tree in the graph)

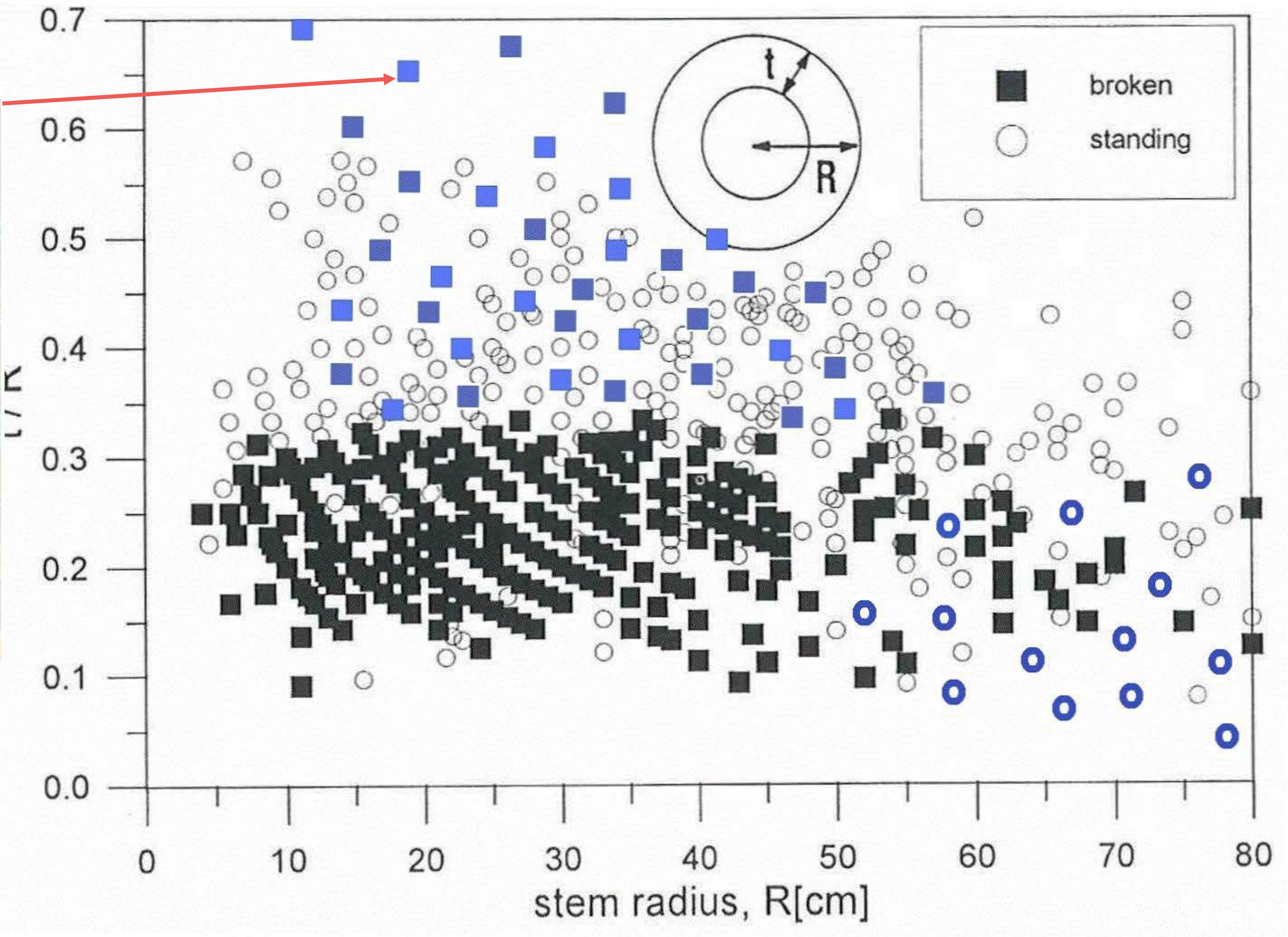
(POTENTIALLY)
UNSAFE



One reason for its success:
(alleged) simplicity and clarity

Slide Frank Rinn.

► The VTA - t/R-graph has to be “completed” by common natural observations, leading to a less clear first impression:



►there is no clear distinction any more between SAFE and UNSAFE.

slide F. Rinn

Visual Tree Assessment (VTA)

„1/3-rule“ for evaluating breaking safety

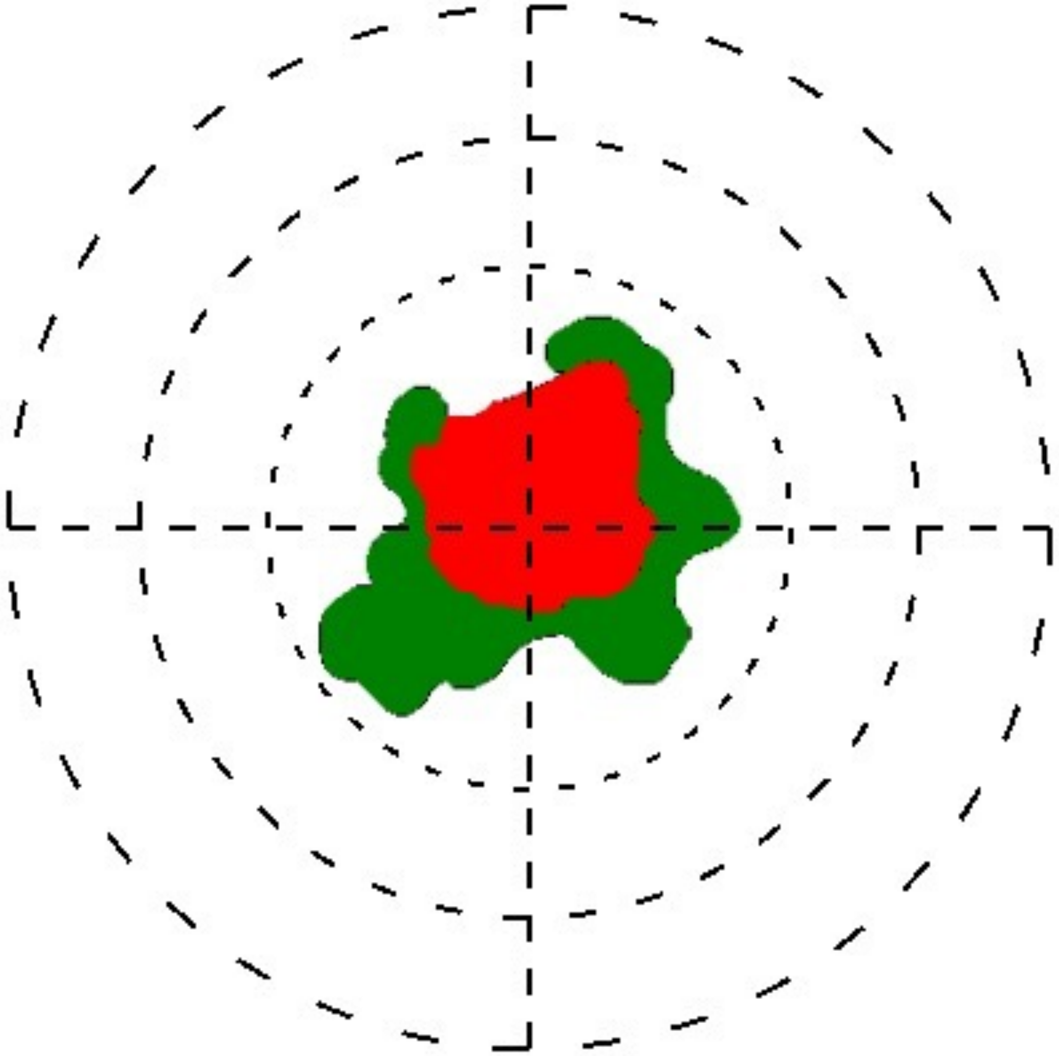
Drilling between
the buttresses?

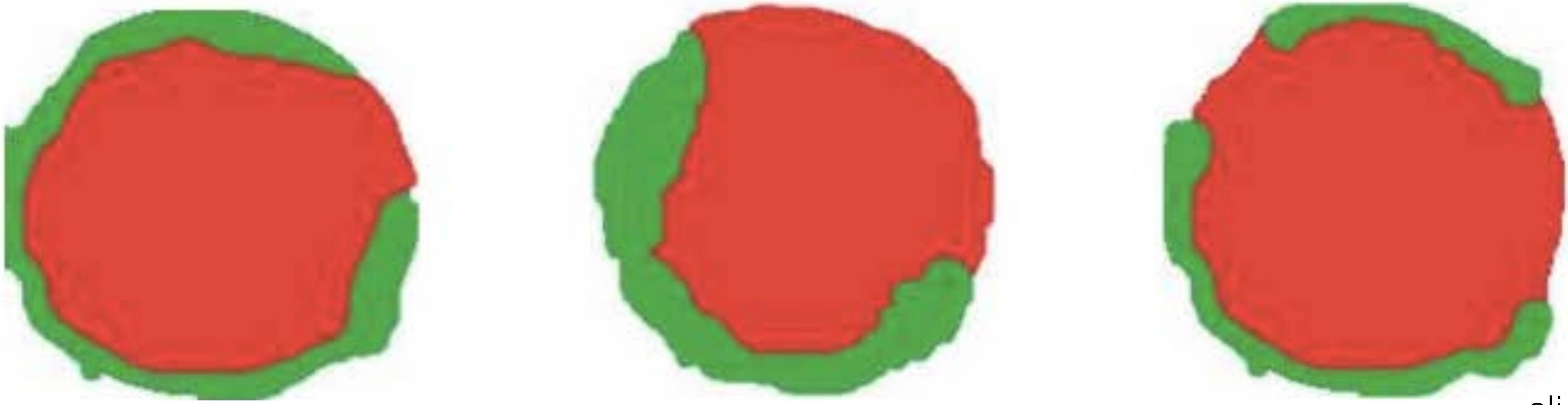
F Rinn

Fagus sylvatica, Denmark.

Ustilina deusta present.

- **Where to drill?**
- **What is the strength loss?**
- **What is the strength of the remaining wood?**
- **What is the load bering capacity of the stem**
- **What are the maximum loads the tree experiences?**
- **Will crown reduction improve stability long term?**
- **Should the tree be removed for safety?**
- **Do nothing?**

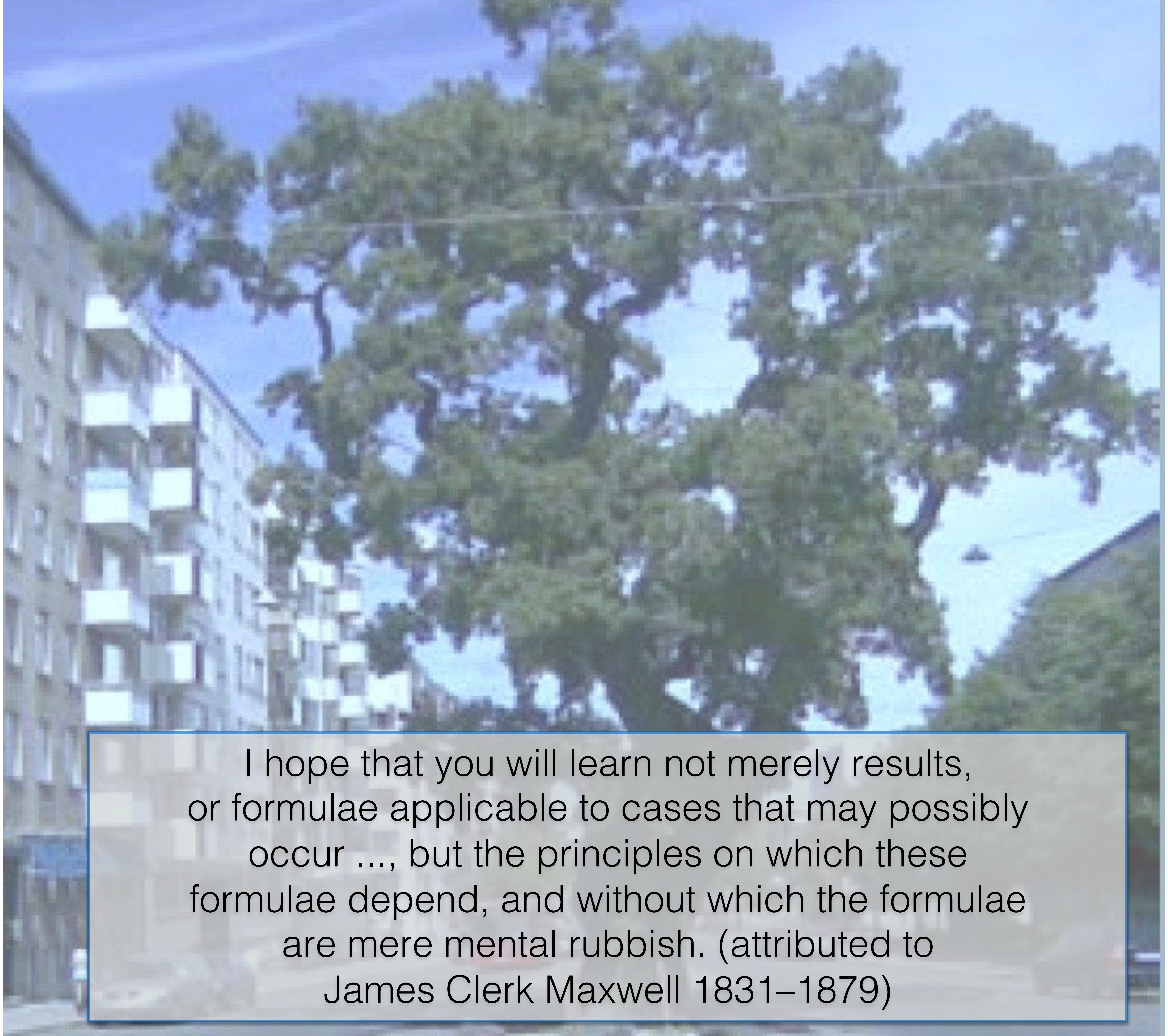




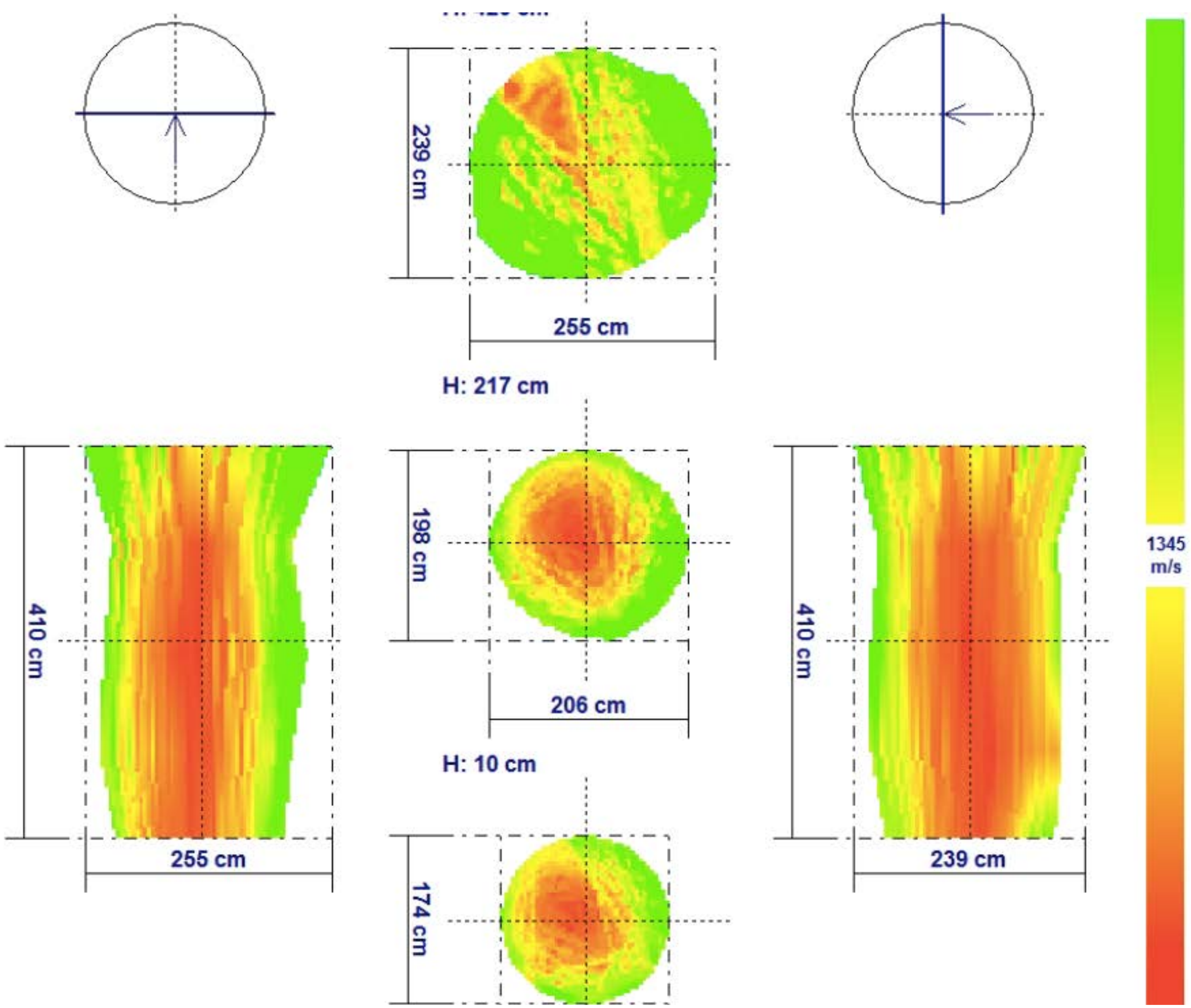
slide: F.Rinn

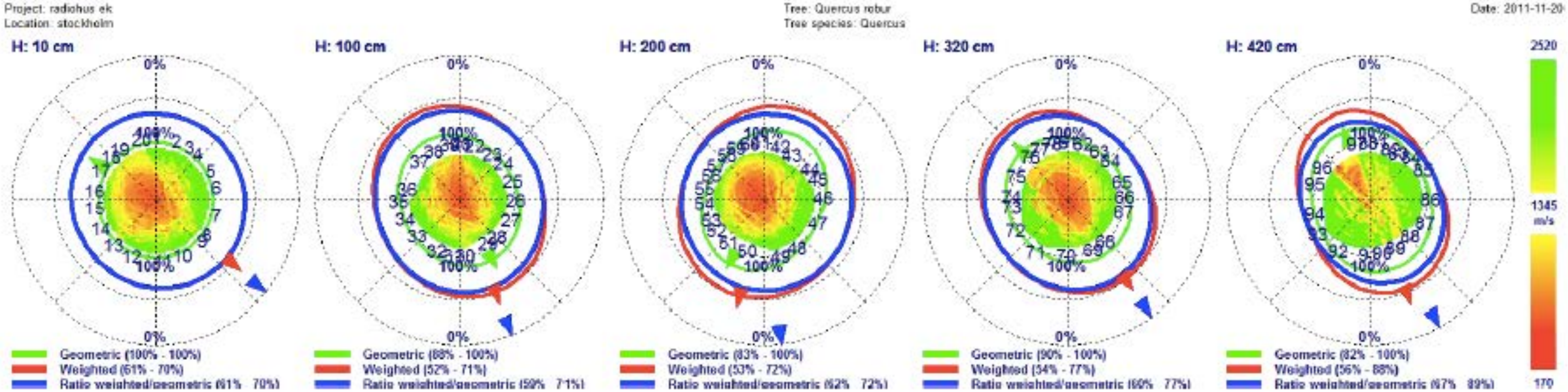
$$\text{Breaking Safety} = \frac{\text{Load carrying capacity}}{\text{(max) Load}}$$

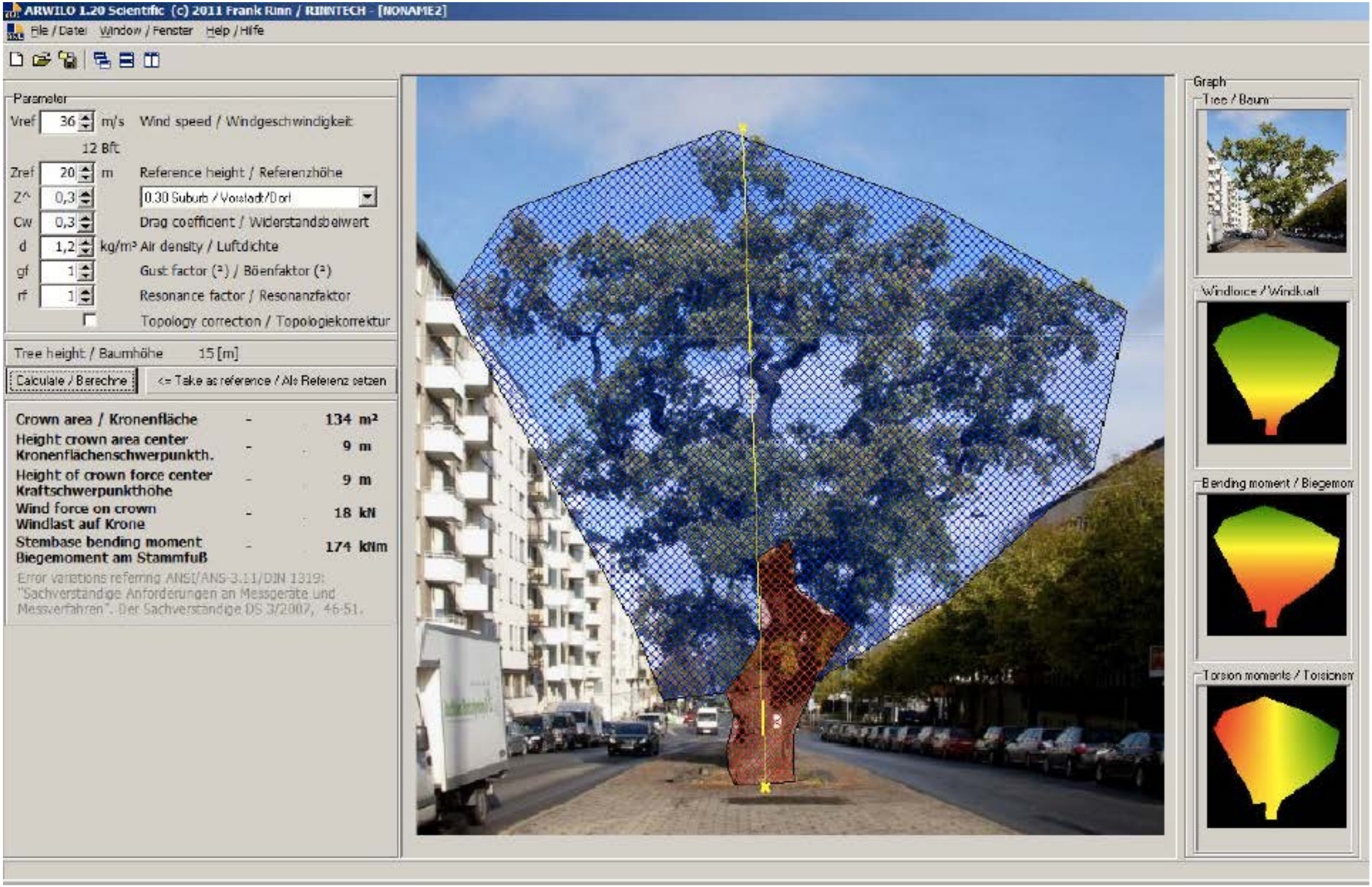
But what of the principles?



I hope that you will learn not merely results,
or formulae applicable to cases that may possibly
occur ..., but the principles on which these
formulae depend, and without which the formulae
are mere mental rubbish. (attributed to
James Clerk Maxwell 1831–1879)


239 cm
255 cm
H: 217 cm
198 cm
206 cm
410 cm
255 cm
410 cm
239 cm
H: 10 cm
174 cm
1345 m/s


Project: radiohus ek
Location: stockholm
Tree: Quercus robur
Tree species: Quercus
Date: 2011-11-20
H: 10 cm
H: 100 cm
H: 200 cm
H: 320 cm
H: 420 cm
0%
100%
2520
1345 m/s
170
Geometric (100% - 100%)
Weighted (61% - 70%)
Ratio weighted/geometric (61% 70%)
Geometric (88% - 100%)
Weighted (52% - 71%)
Ratio weighted/geometric (59% 71%)
Geometric (83% - 100%)
Weighted (53% - 72%)
Ratio weighted/geometric (62% 72%)
Geometric (90% - 100%)
Weighted (34% - 77%)
Ratio weighted/geometric (60% 77%)
Geometric (82% - 100%)
Weighted (56% - 88%)
Ratio weighted/geometric (67% 89%)



Vref 36 m/s Wind speed / Windgeschwindigkeit

12 Bft

Zref 20 m Reference height / Referenzhöhe

Z^ 0,3 0.30 Suburb / Vorstadt/Dorf

Cw 0,3 Drag coefficient / Widerstandsbeiwert

d 1,2 kg/m^3 Air density / Luftdichte

gf 1 Gust factor $(^2)$ / Böenfaktor $(^2)$

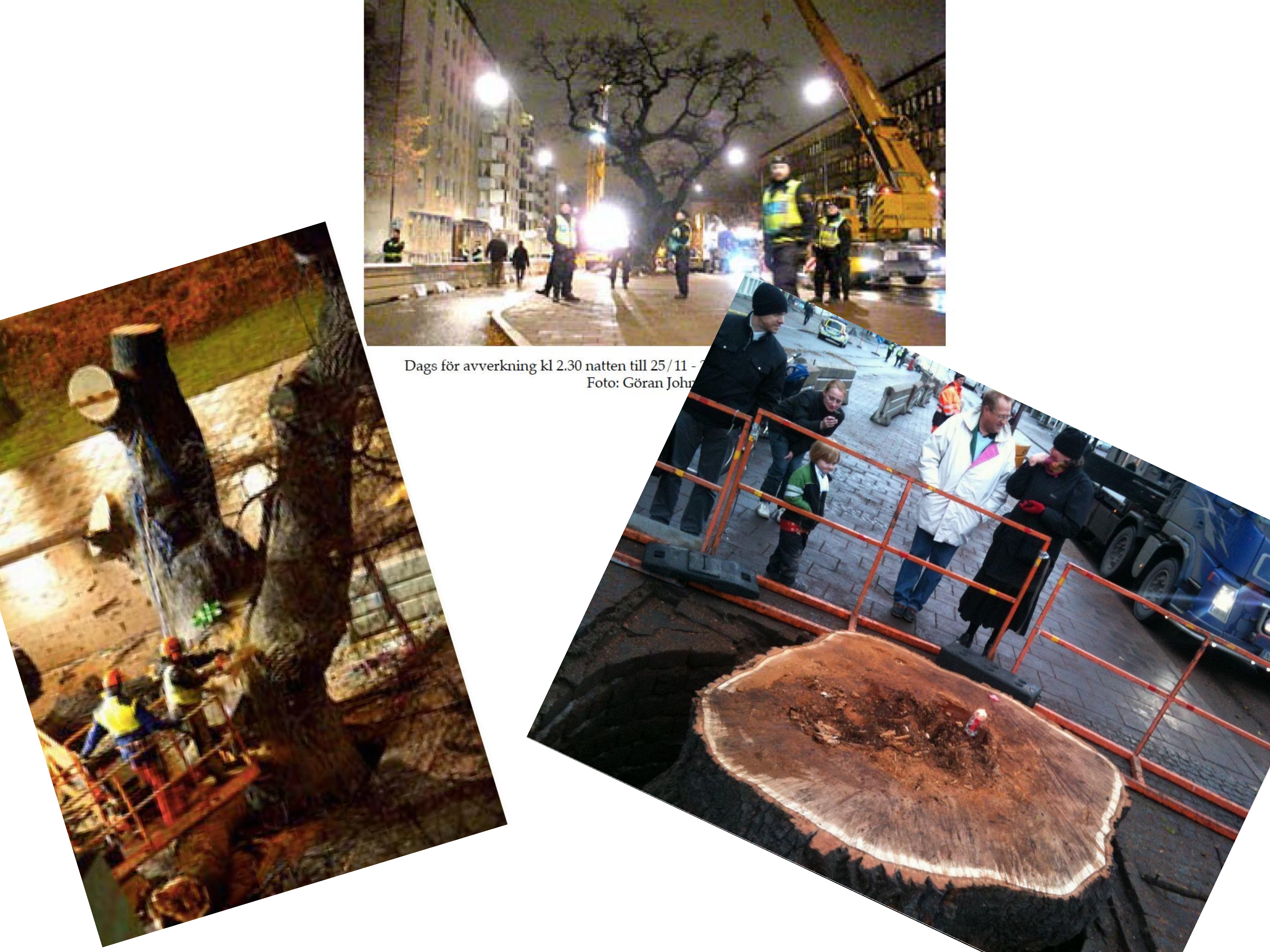
rf 1 Resonance factor / Resonanzfaktor

☐ Topology correction / Topologiekorrektur

Tree height / Baumhöhe 15 [m]

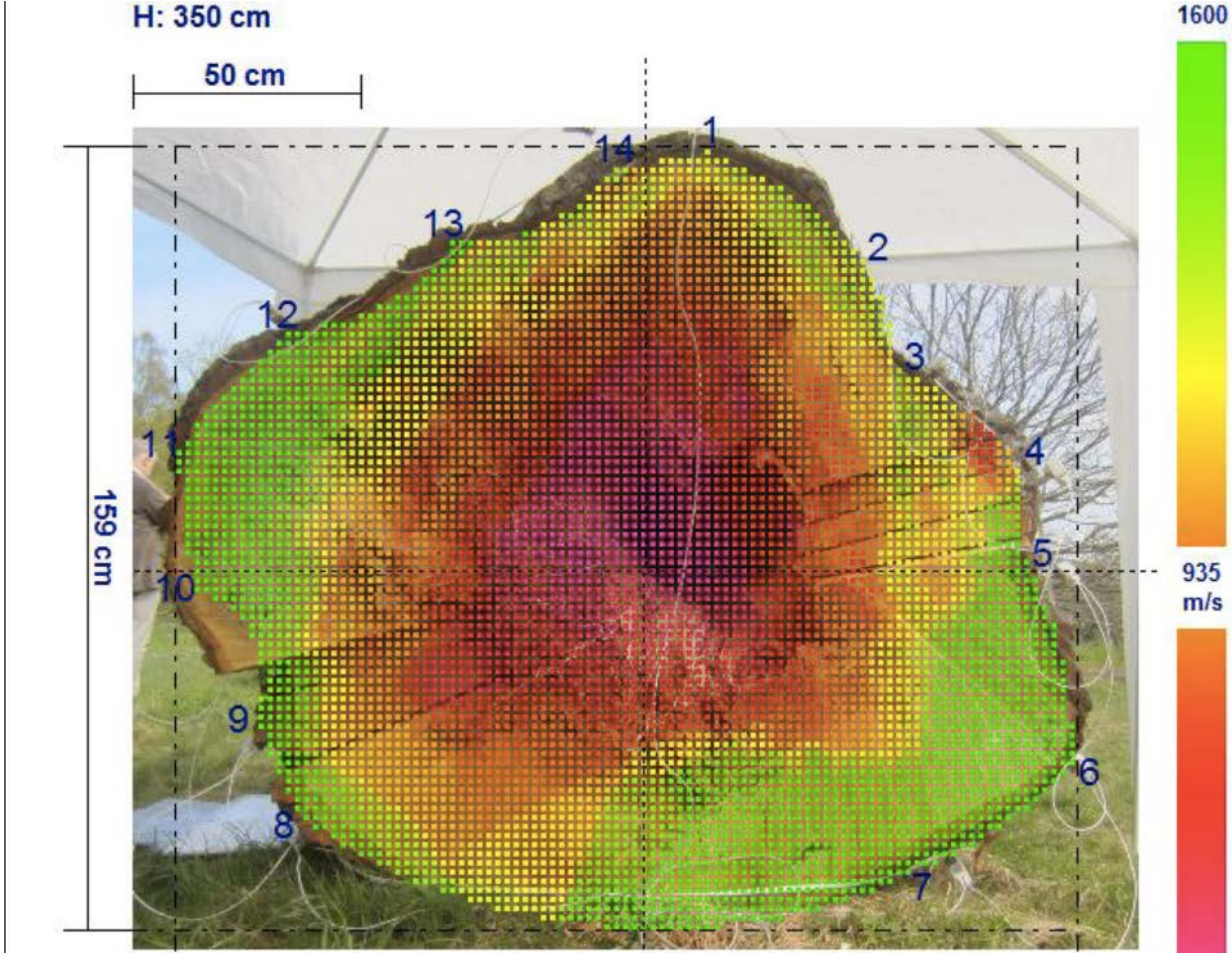
Crown area / Kronenfläche	-	**134 m^2**
Height crown area center **Kronenflächenschwerpunkth.**	-	**9 m**
Height of crown force center **Kraftschwerpunkthöhe**	-	**9 m**
Wind force on crown **Windlast auf Krone**	-	**18 kN**
Stembase bending moment **Biegemoment am Stammfuß**	-	**174 kNm**

Error variations referring ANSI/ANS-3.11/DIN 1319: "Sachverständige Anforderungen an Messgeräte und Messverfahren". Der Sachverständige DS 3/2007, 46-51.



Dags för avverkning kl 2.30 natten till 25/11 -
Foto: Göran John

The real picture, stem analysis, same tree, International Veteran tree conference Stockholm 2012.



Assuming a relatively low modulus of elasticity of 10’000 N/mm² (typical for oak is ~13’000 N/mm²), a bending strength of 90 N/mm² (typical for oak is 96 N/mm²), a wind load center in 10m height above ground, and the smallest measured diameter of the stem (~1.7m), in case of intact cross section this oak would be able to withstand a wind load of 20 Mega Newton Meter (20 MNm).

The worst case scenario of the wind load assessment estimated ~175 kNm. Thus the theoretical safety factor would be in the range of more than 100.

As the maximum reduction of cross sectional load carrying capacity was about ~32%, the safety factor of the actual tree would be still in the range of higher than 50, thus far away from the natural safety factor of young trees (between 4 and 5).

In actual fact, in this sheltered urban situation, the real wind load is much smaller than estimated by the worst case scenario, most probably by about 50% (or even more), this brings the safety factor to a correspondingly higher level.

Based on this safety factor approach, the probability of failure of the oak due to wind loading even with this amount of decay (~32% strength loss) would be much lower than that of young intact trees.

Thus there is no indication of any dangerously higher probability of failure of the stem.

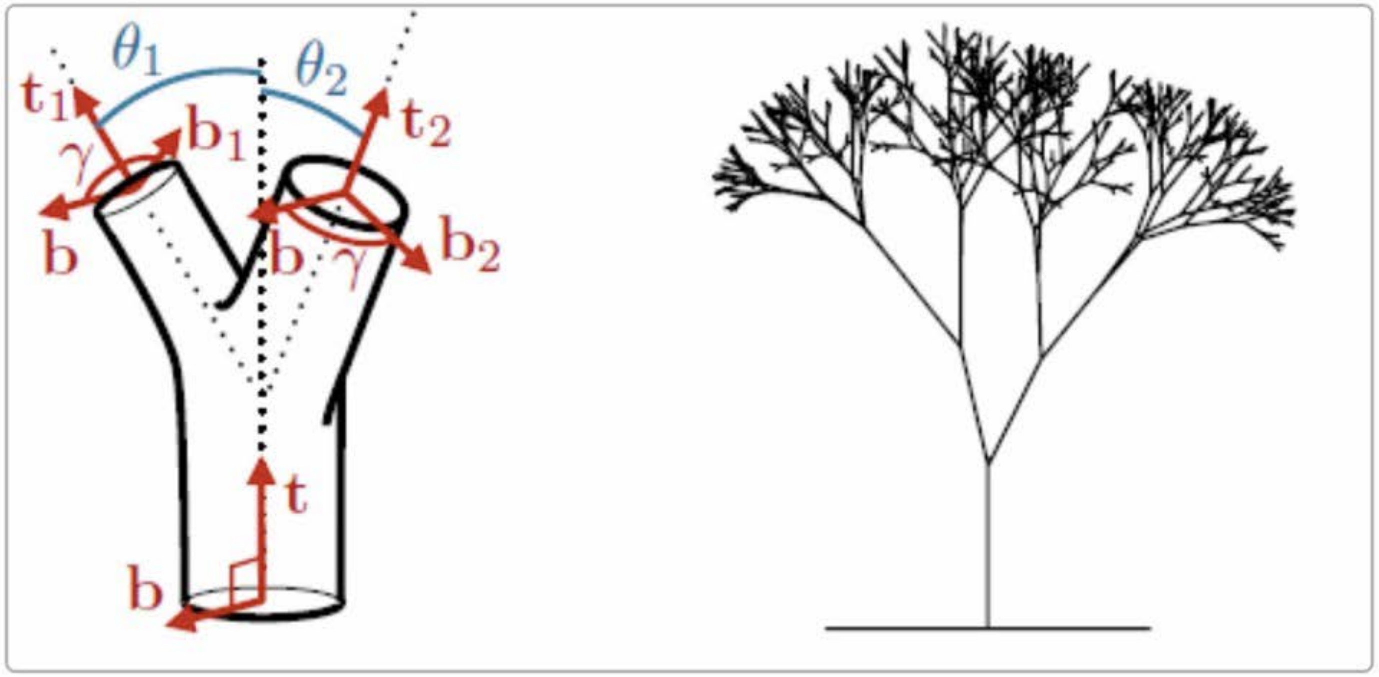
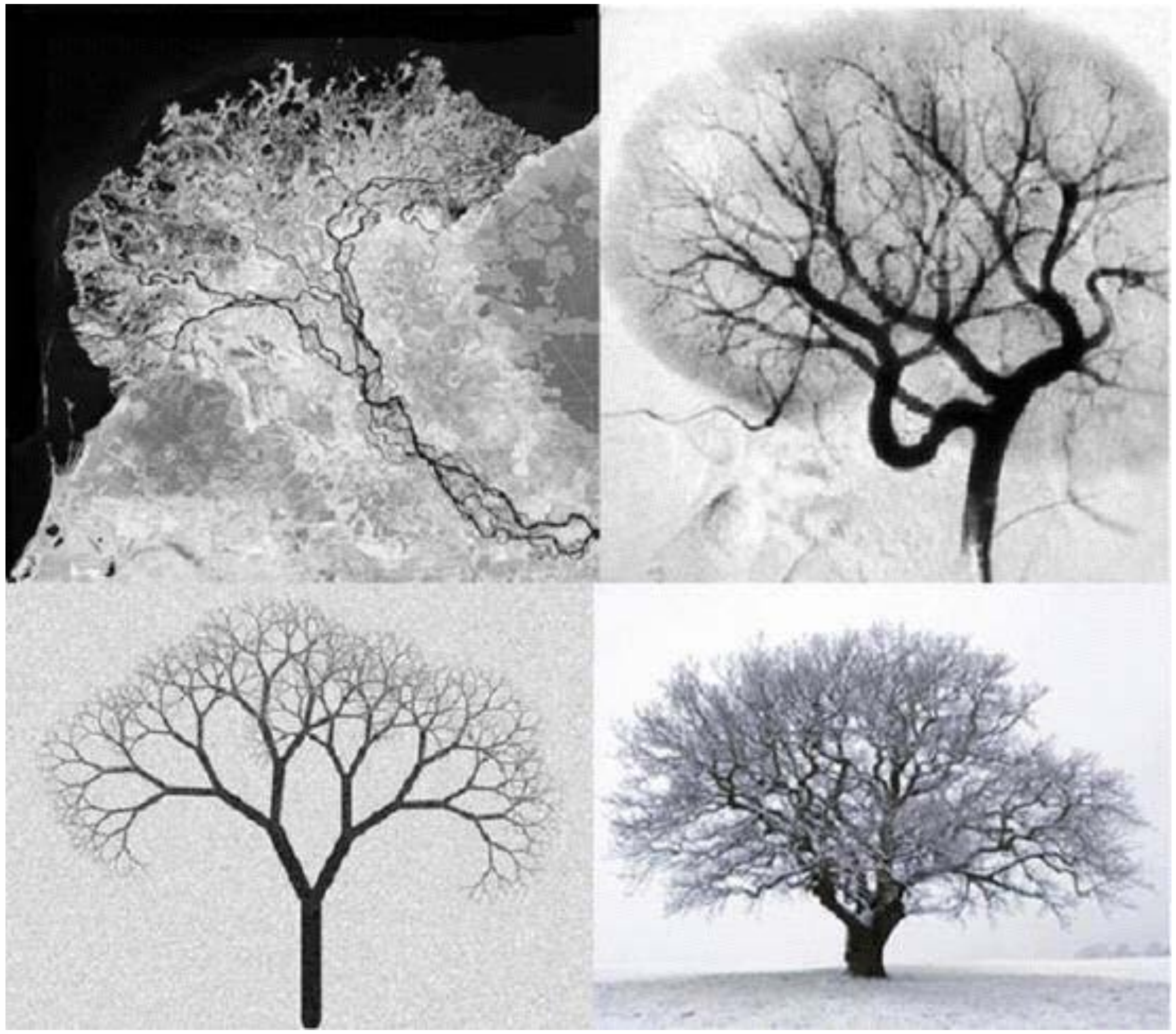
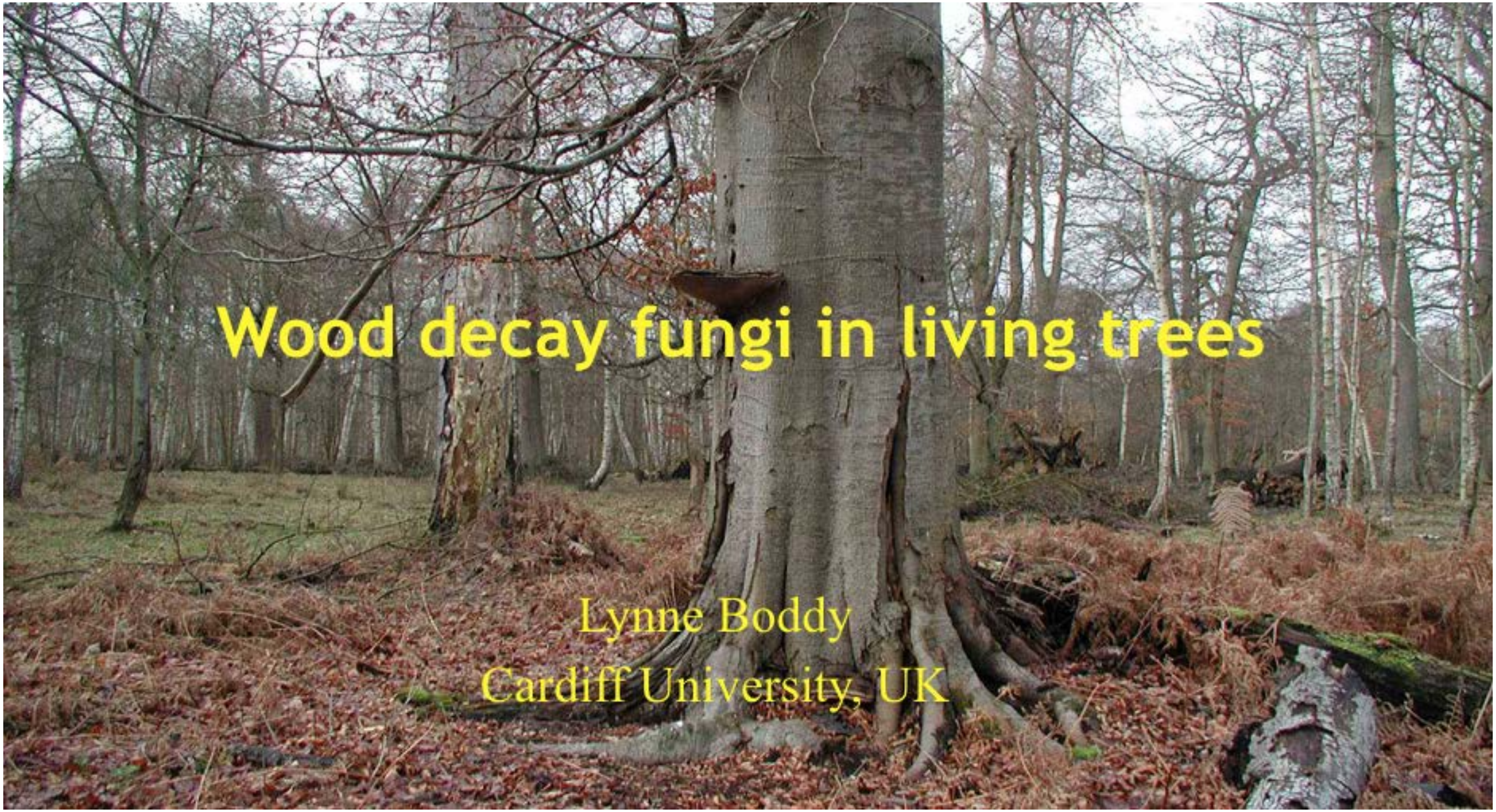


Image Courtesy Christophe Eloy | University of Provence



Hydraulic scaling theory

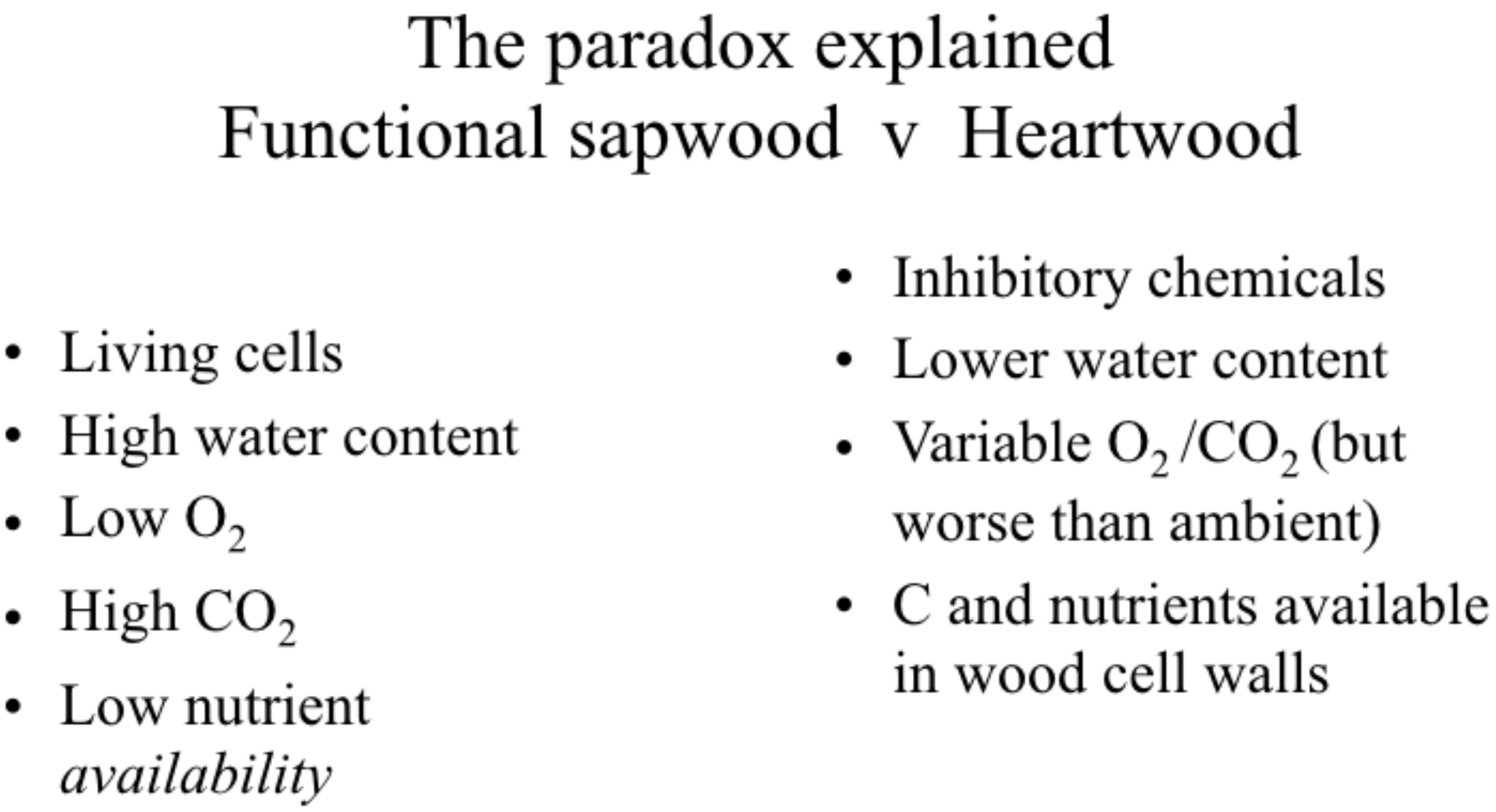
Growth and hydraulic (not mechanical) constraints govern the scaling of tree height and mass. Spatz & Niklas



Wood decay fungi in living trees

Lynne Boddy

Cardiff University, UK



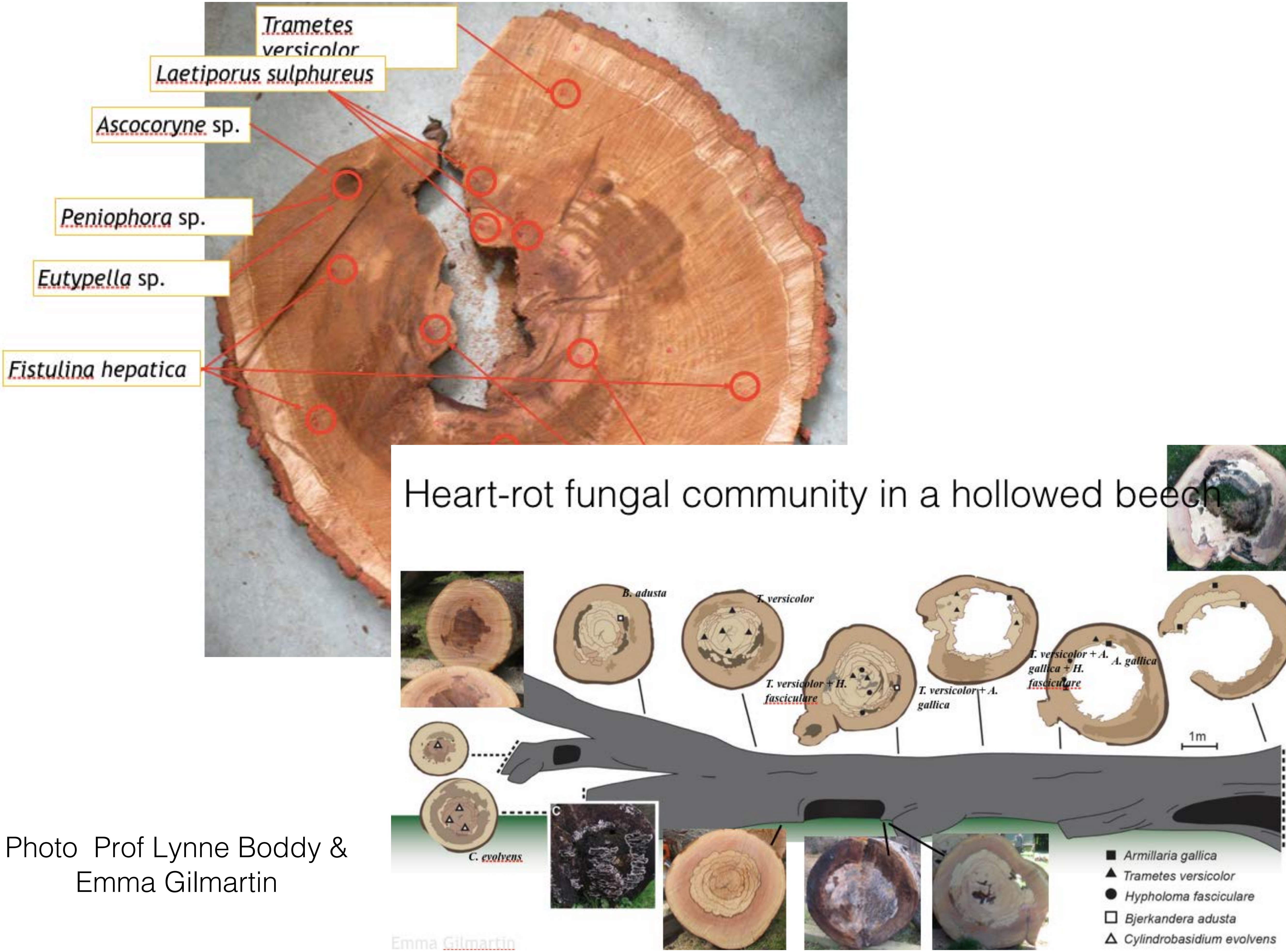
The paradox explained
Functional sapwood v Heartwood

- Living cells
- High water content
- Low O_2
- High CO_2
- Low nutrient *availability*

- Inhibitory chemicals
- Lower water content
- Variable O_2 /CO_2 (but worse than ambient)
- C and nutrients available in wood cell walls

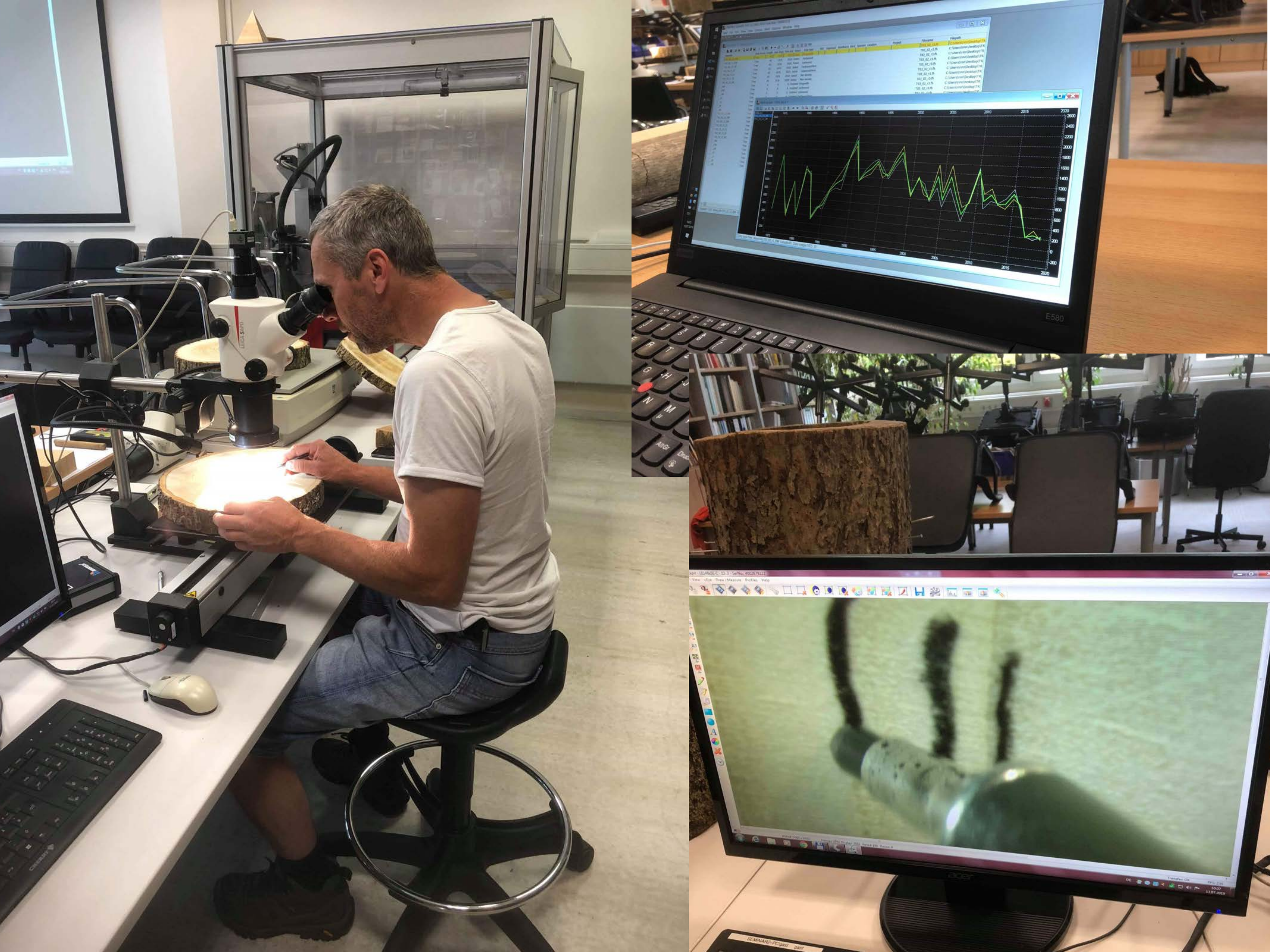
Slide Prof. Lynne Boddy

Photo Prof Lynne Boddy



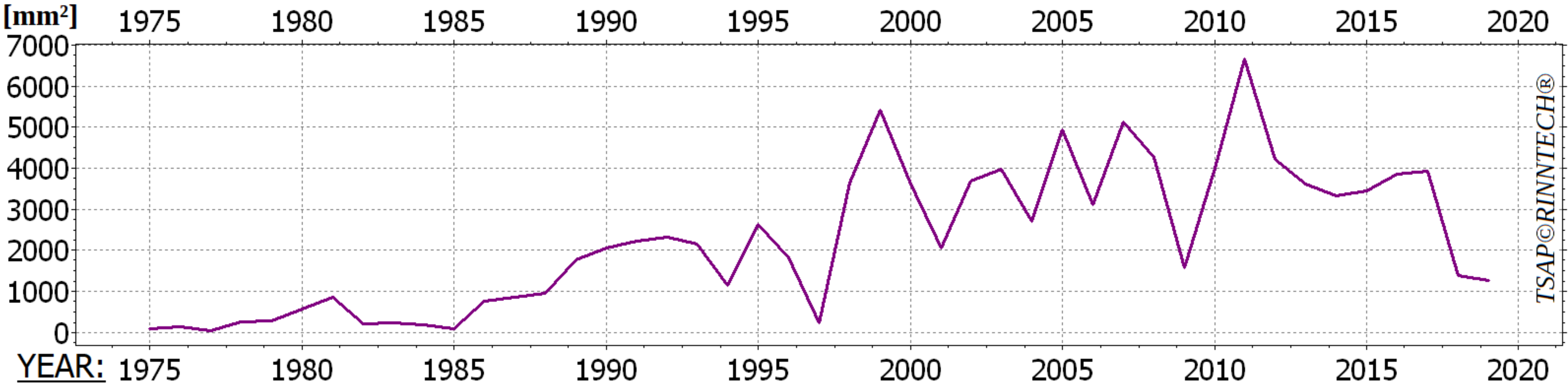
Heart-rot fungal community in a hollowed beech

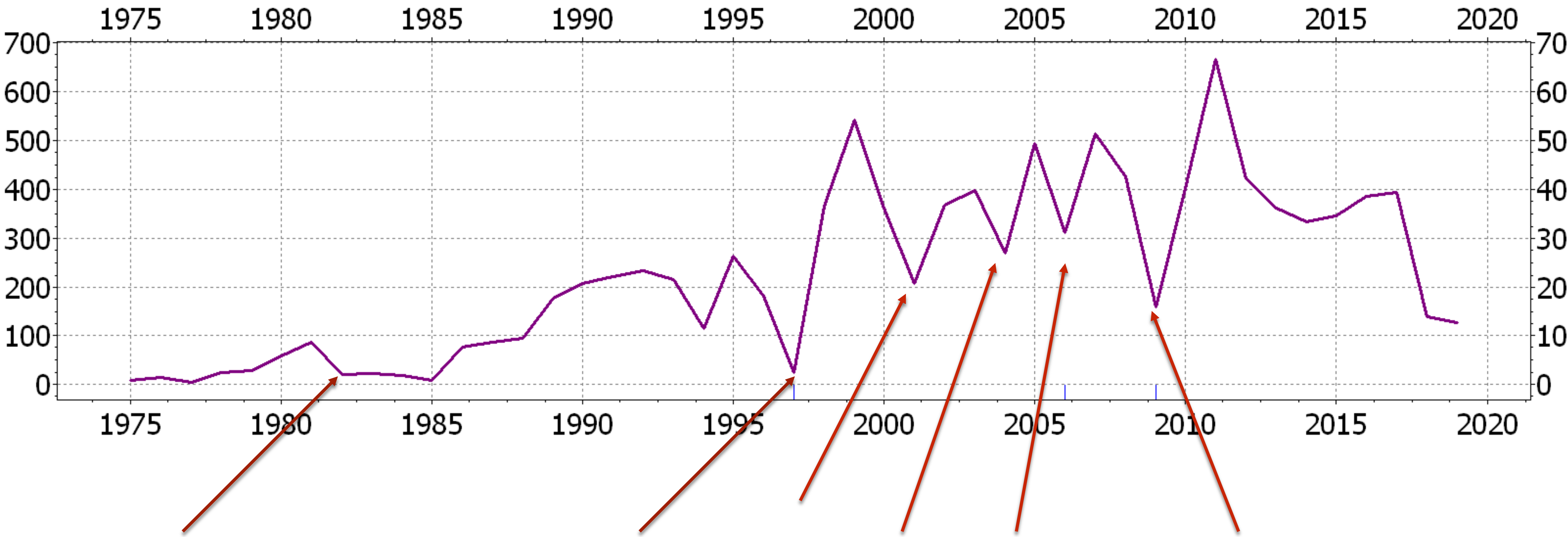
Photo Prof Lynne Boddy &
Emma Gilmartin

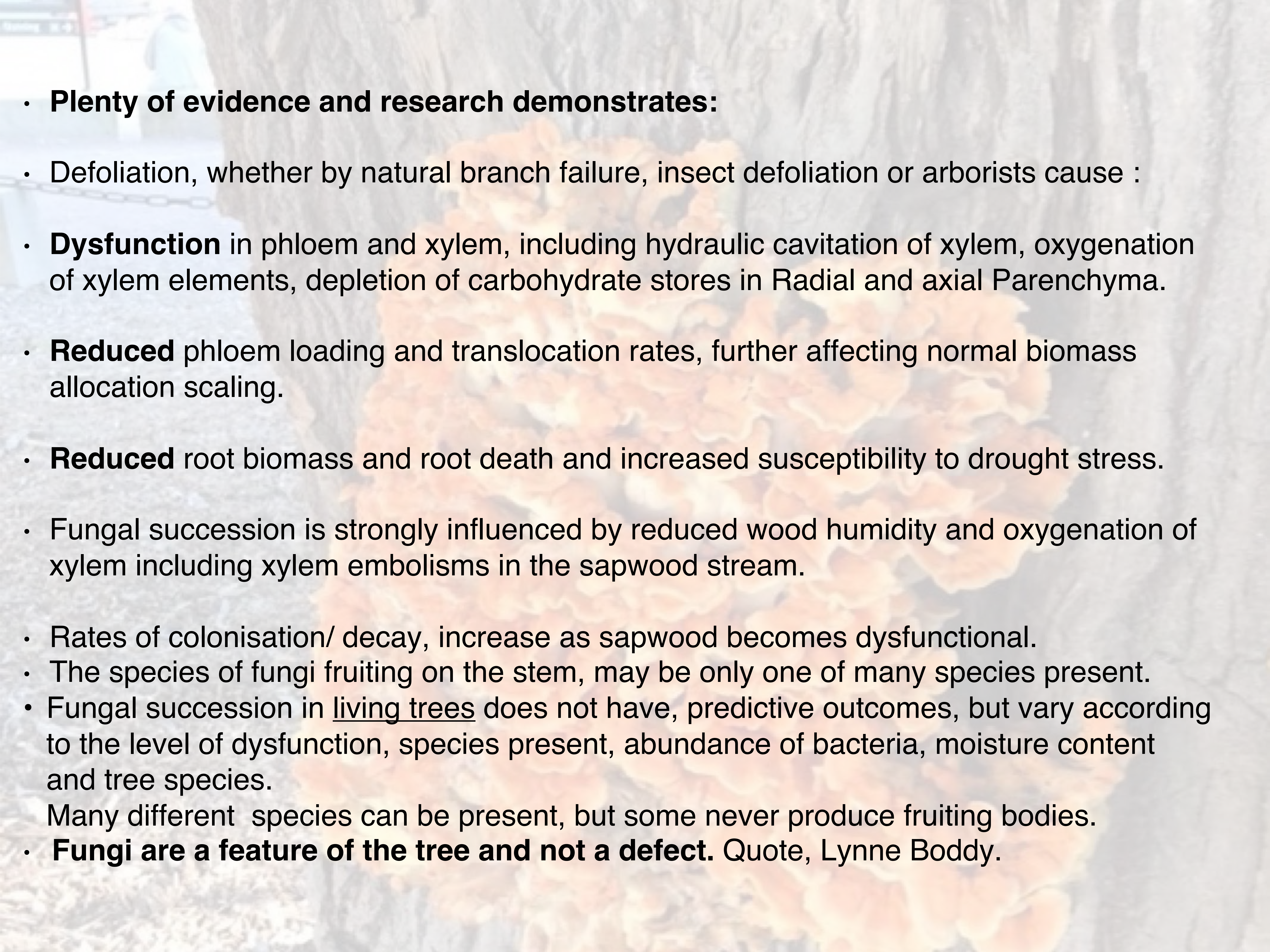


Annual (incremental) growth of basal stem cross sectional area

Tilia cordata, street tree, Gothenburg, Sweden, felled in Summer 2019







- **Plenty of evidence and research demonstrates:**

- Defoliation, whether by natural branch failure, insect defoliation or arborists cause :

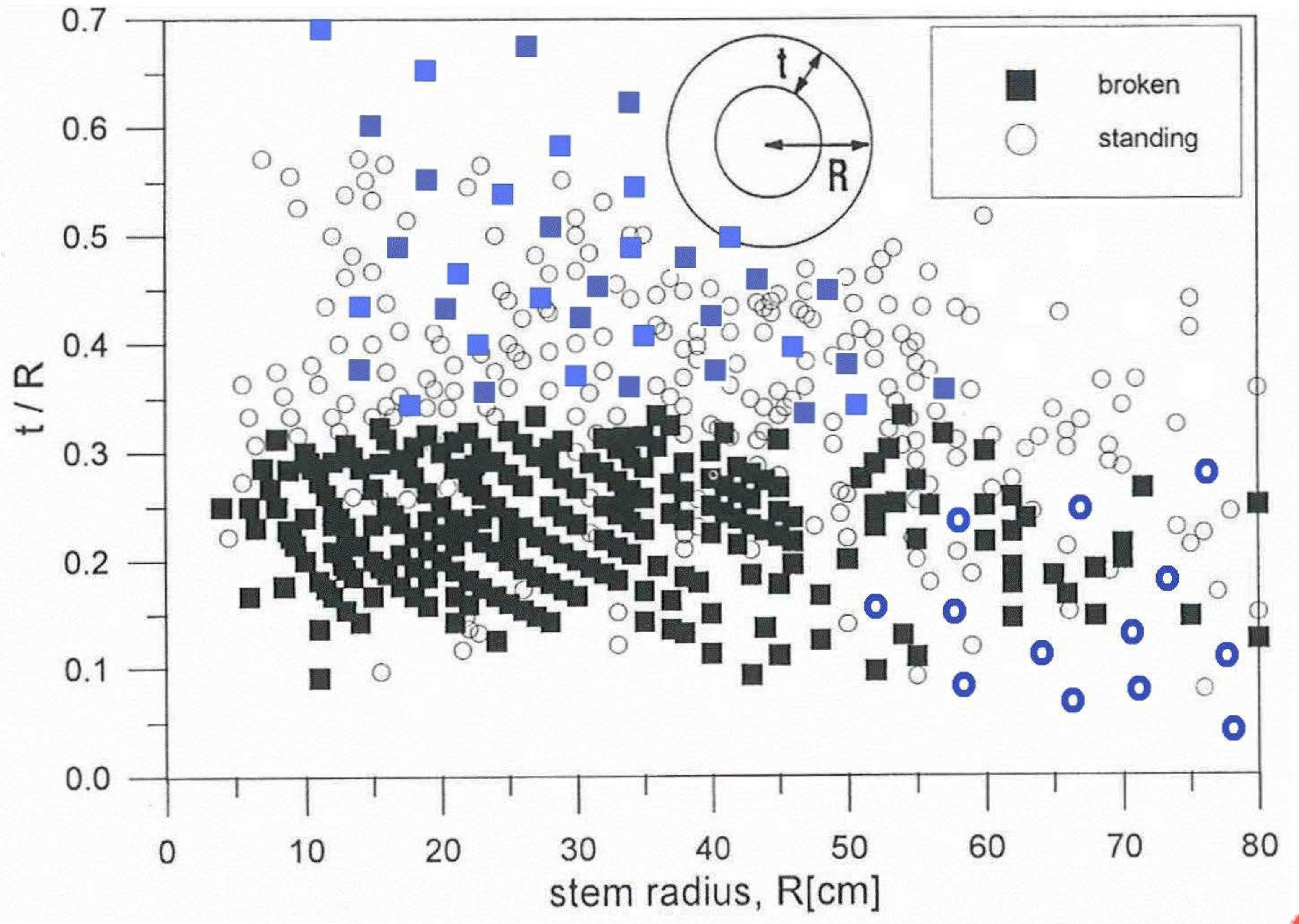
- **Dysfunction** in phloem and xylem, including hydraulic cavitation of xylem, oxygenation of xylem elements, depletion of carbohydrate stores in Radial and axial Parenchyma.

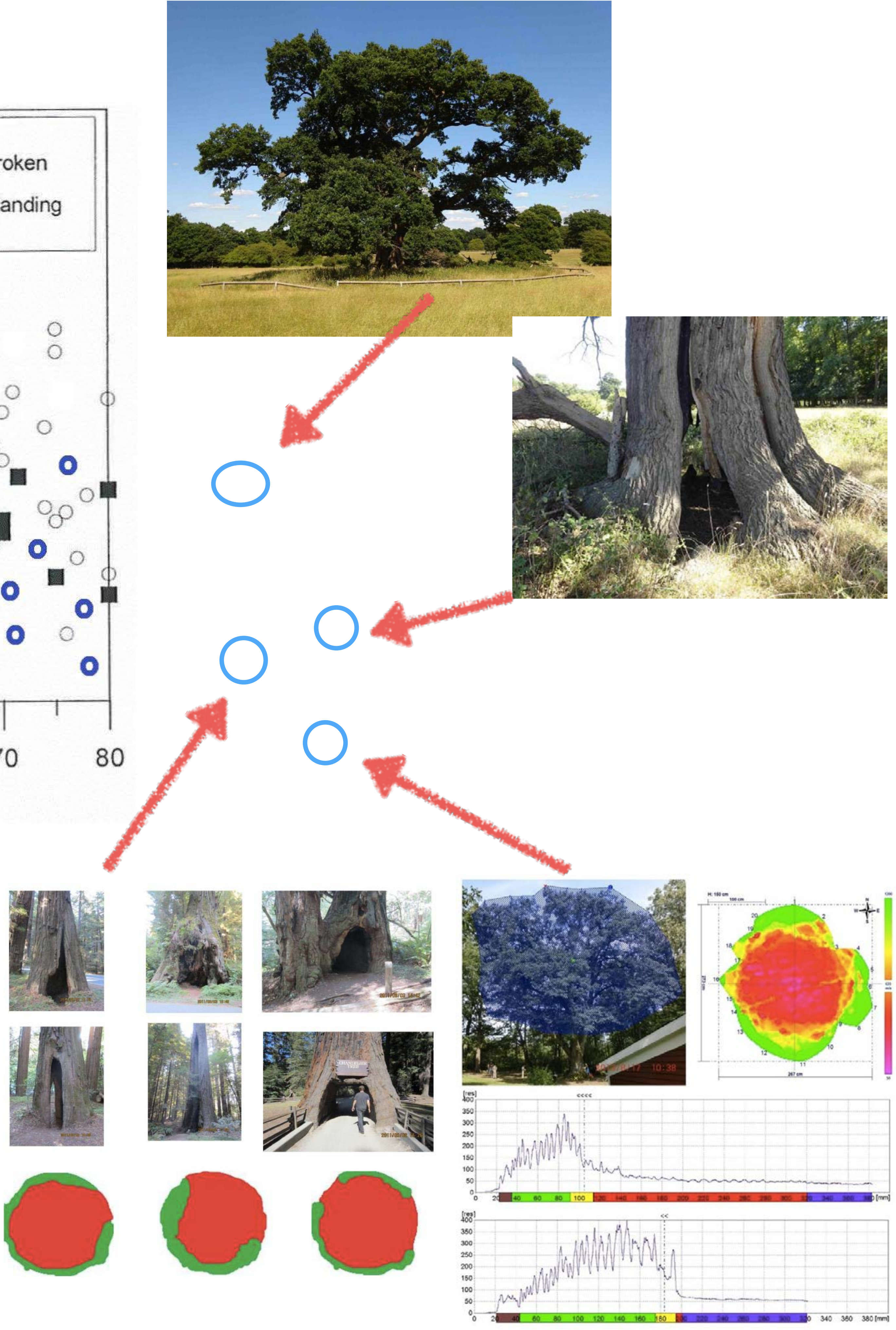
- **Reduced** phloem loading and translocation rates, further affecting normal biomass allocation scaling.

- **Reduced** root biomass and root death and increased susceptibility to drought stress.

- Fungal succession is strongly influenced by reduced wood humidity and oxygenation of xylem including xylem embolisms in the sapwood stream.

- Rates of colonisation/ decay, increase as sapwood becomes dysfunctional.
- The species of fungi fruiting on the stem, may be only one of many species present.
- Fungal succession in living trees does not have, predictive outcomes, but vary according to the level of dysfunction, species present, abundance of bacteria, moisture content and tree species.
  Many different species can be present, but some never produce fruiting bodies.
- **Fungi are a feature of the tree and not a defect.** Quote, Lynne Boddy.





➡ the VTA-t/R-rule graph has to be extended by circles for the many old and heavily decayed / hollow trees, still standing even in high winds, indicating that there seems to be ‚hidden‘ safety in the system ...

Lets examine the biomechanics.

- The original t/R=1/3 - rule graph
  - is not showing the whole story and
  - gets less clear when completed with further real natural observations

- The VTA 1/3 rule is not applicable to the common mature urban tree to be inspected in

terms of safety because these trees have;
  - irregularly shaped / non-circular cross-sections
  - non-central (off centre) defects

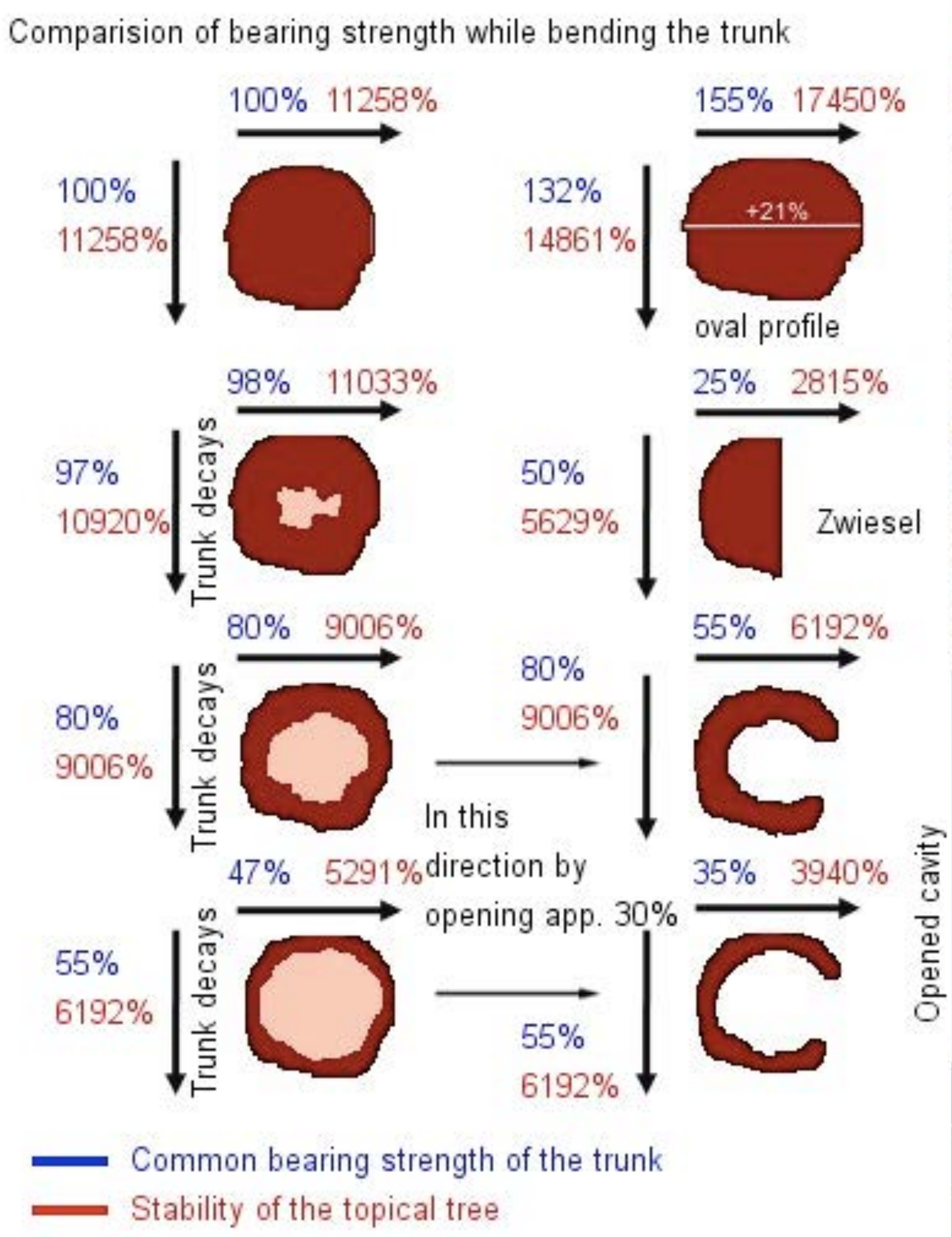
- The VTA 1/3 rule is obviously totally inappropriate for mature, old and veteran trees!

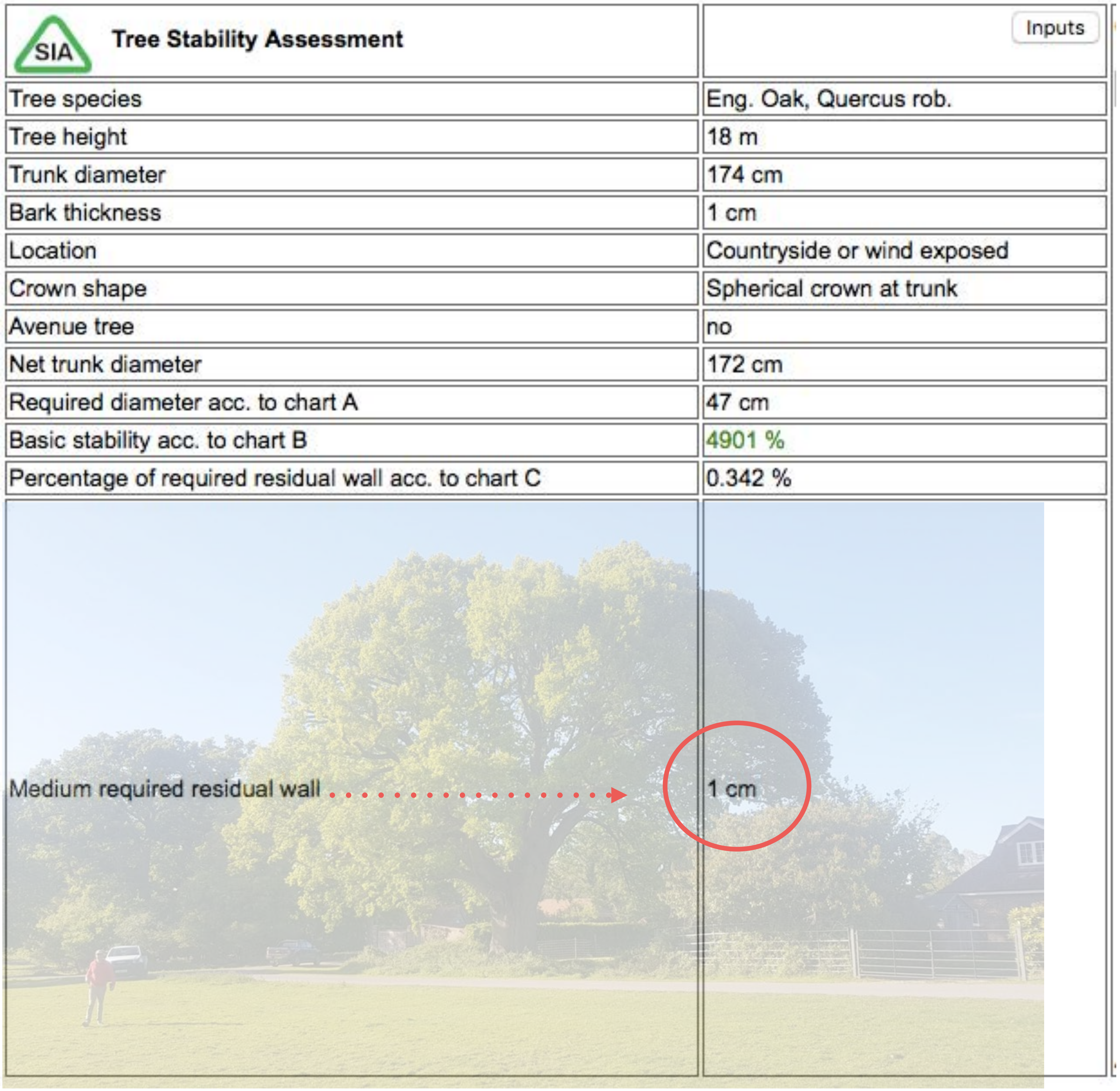
The VTA t/R>1/3 rule is

- an appropriate breakage safety measure for young (still growing in height) slender forest trees with circular stems and centrally located decay/voids (often found in forests stands);


Frank Rinn

Tree statistics and alternative to VTA?


Comparision of bearing strength while bending the trunk



Tree Stability Assessment	
Tree species	Eng. Oak, Quercus rob.
Tree height	18 m
Trunk diameter	174 cm
Bark thickness	1 cm
Location	Countryside or wind exposed
Crown shape	Spherical crown at trunk
Avenue tree	no
Net trunk diameter	172 cm
Required diameter acc. to chart A	47 cm
Basic stability acc. to chart B	4901 %
Percentage of required residual wall acc. to chart C	0.342 %
Medium required residual wall	1 cm

SIA practically calculates this for stem breaking safety:

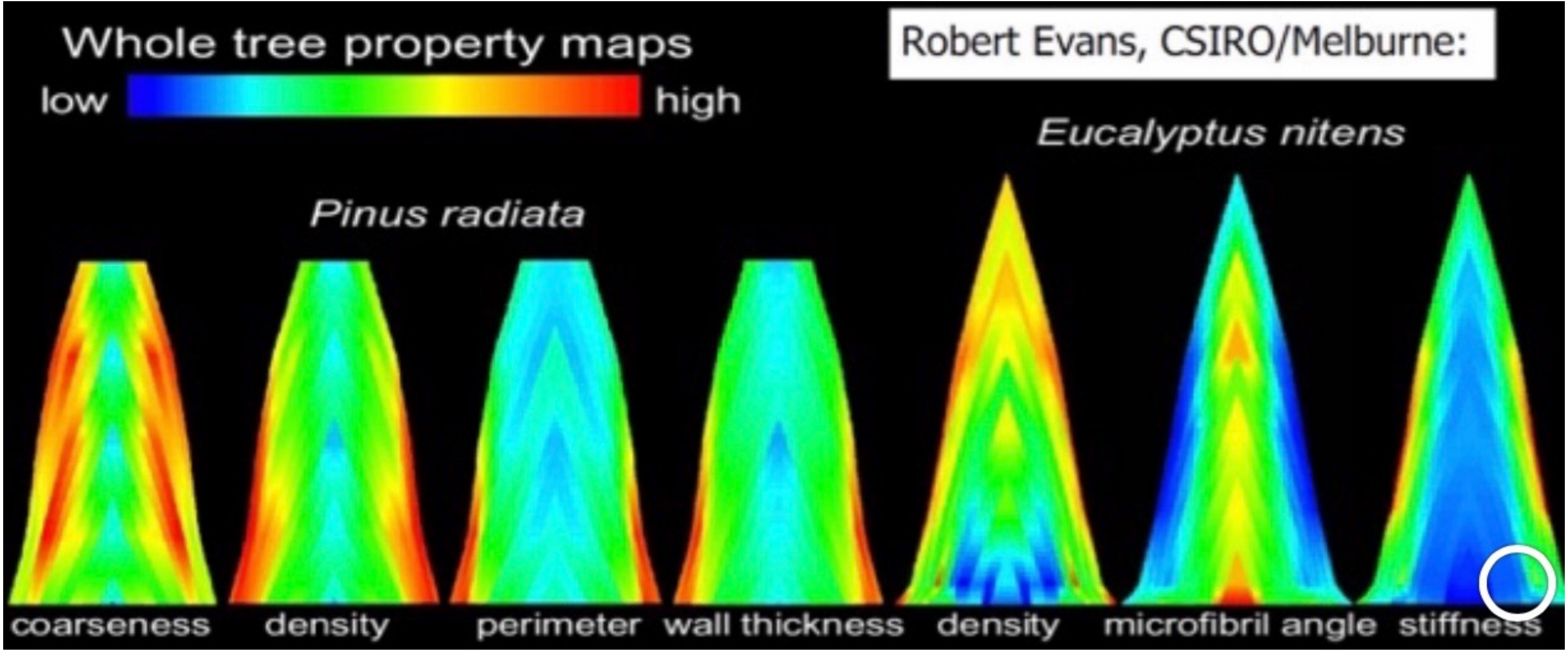
$$S \sim \frac{E * \varepsilon crit * D}{(q * A * cw * v. * H)}$$

where:

Safety is approximately equal to **E**(elastic modulus) x **εcrit** critical strain x/ **D** cross sectional stem area / **q** air density x **A**(crown area x Cw (drag coefficient) x V (wind speed) x **H Height**

Values given is red are Highly variable and very difficult to quantify.
H/D is the most important factor in this formula!

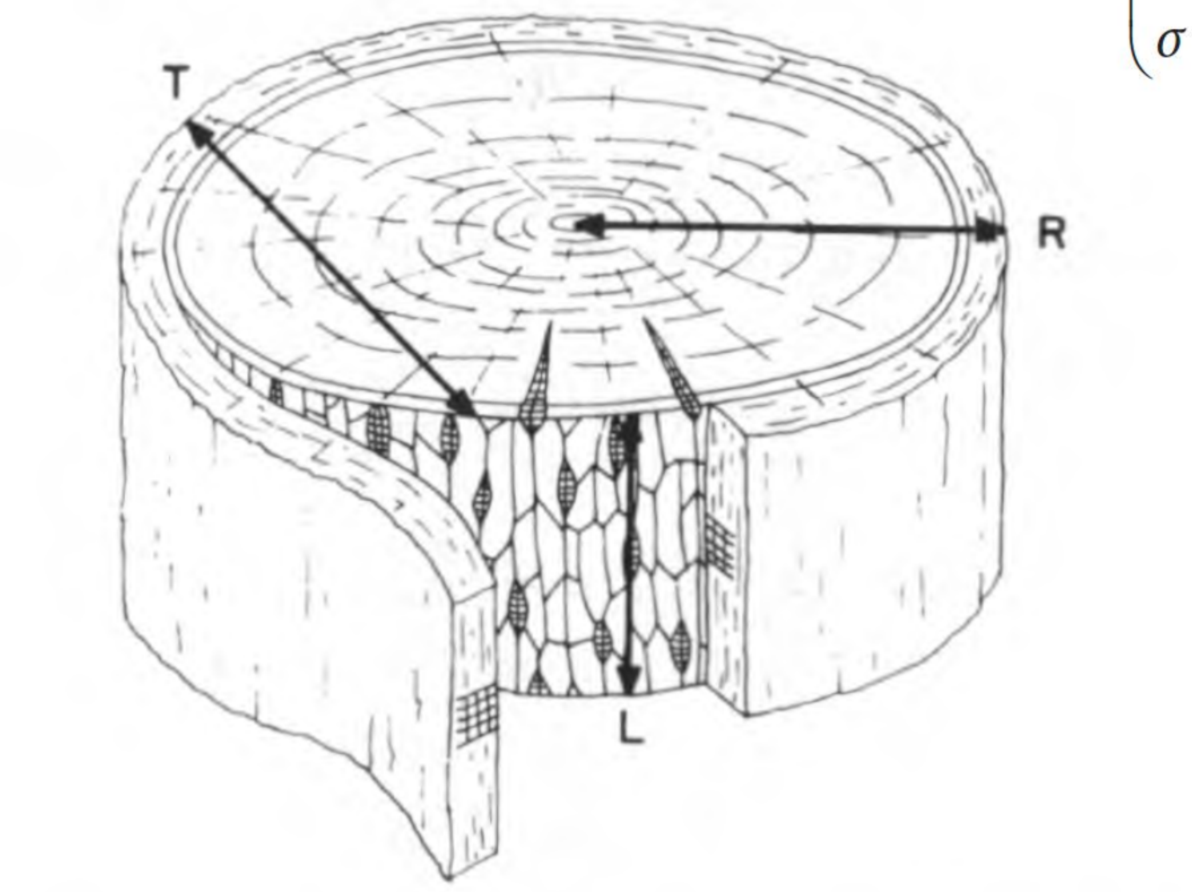
But:
-**SIA uses the wrong math (Spatz & Niklas) εcrit values are for isotropic material not anisotropic green wood.**
-SIA ignores the huge impact of wood anatomical variances within a tree and between trees affecting flexural stiffness (R, Evans, P, Fratzl).
Rapid prediction of wood stiffness from microfibril angle and density, R, Evans and Jugo Ilic. 2001

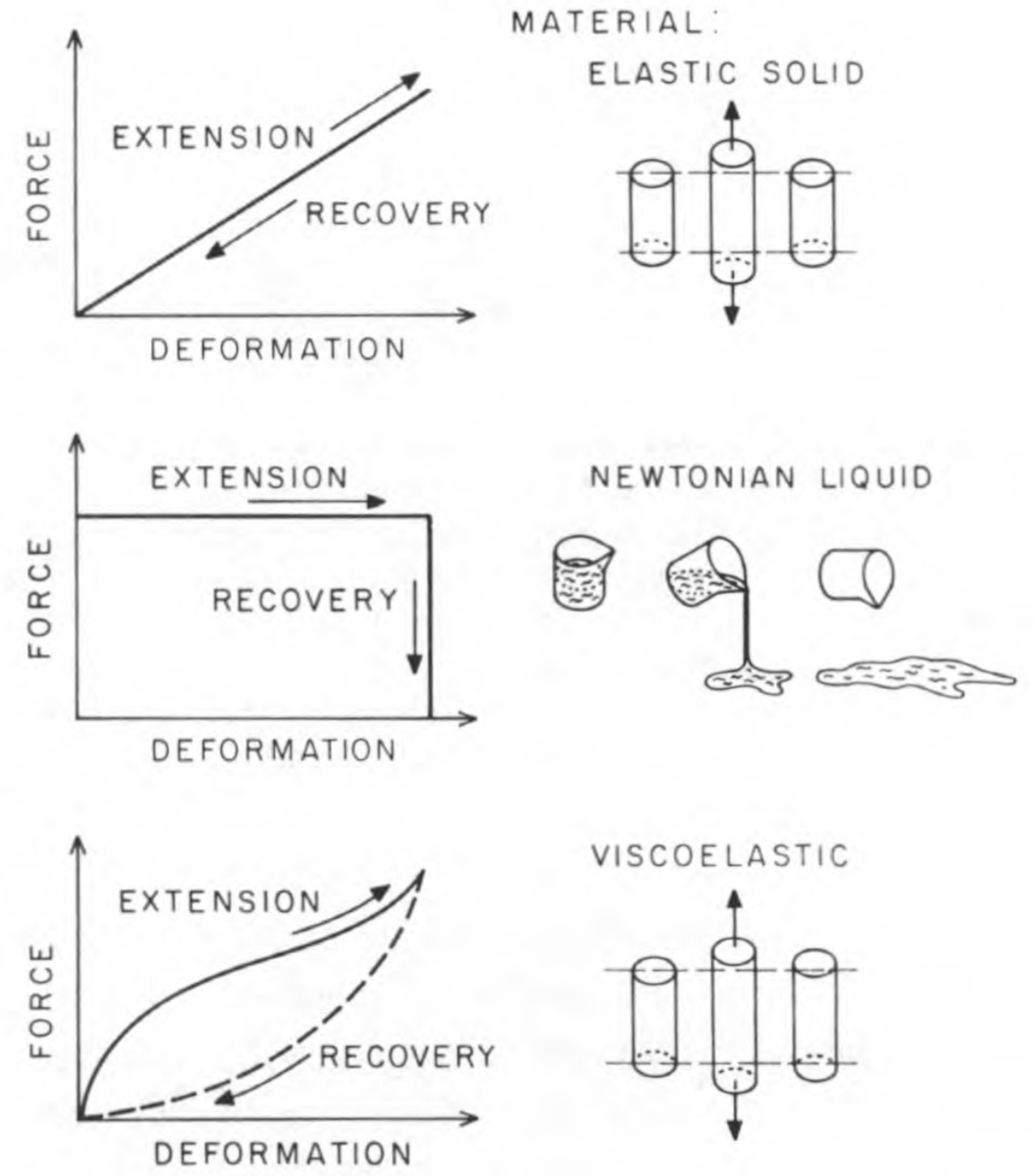


Papers worth reviewing:
Rapid prediction of wood stiffness from microfibril angle and density, R, Evans and Jugo Ilic. 200
Relationships of density, microfibril angle and sound velocity, with stiffness and strength in mat
Experimental evidence for a mechanical function of the cellulose microfibril angle in wood cell w
– SIA reference values are either incorrect and inappropriate (Spatz, Niklas, Pfisterer).
WORLDWIDE CORRELATIONS OF MECHANICAL PROPERTIES AND GREEN WOOD DENSITY
Karl J. Niklas, and Hanns-Christof Spatz . 2010
Mechanical Properties of Green Wood and Their Relevance for Tree Risk Assessment Hanns Chr

Wood is a cellular solid

$$\begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \end{pmatrix} = \begin{pmatrix} E_{xx} & E_{xy} & E_{xz} \\ E_{yx} & E_{yy} & E_{yz} \\ E_{zx} & E_{zy} & E_{zz} \end{pmatrix} \begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \end{pmatrix}.$$



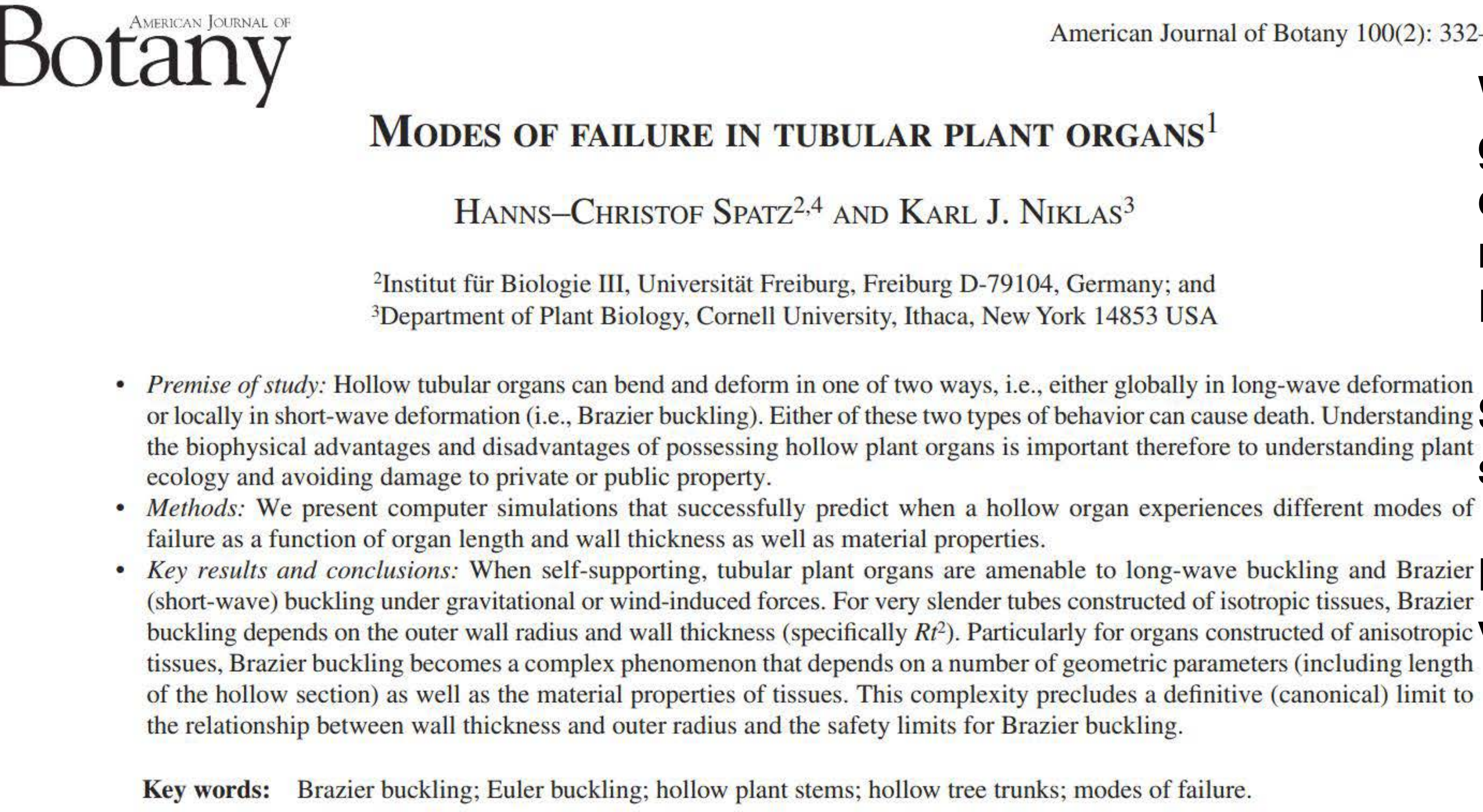


Wood does not behave isotropically

Wood is an anisotropic material and exhibits complex viscoelastic deformations.

Non compressive liquids (water will affect material properties)

Trees will not conform to bending curves associated with an isotropic material such as aluminium tubes.



American Journal of Botany 100(2): 332–336. 2013.

MODES OF FAILURE IN TUBULAR PLANT ORGANS[1]

HANNS–CHRISTOF SPATZ[2,4] AND KARL J. NIKLAS[3]

[2]Institut für Biologie III, Universität Freiburg, Freiburg D-79104, Germany; and
[3]Department of Plant Biology, Cornell University, Ithaca, New York 14853 USA

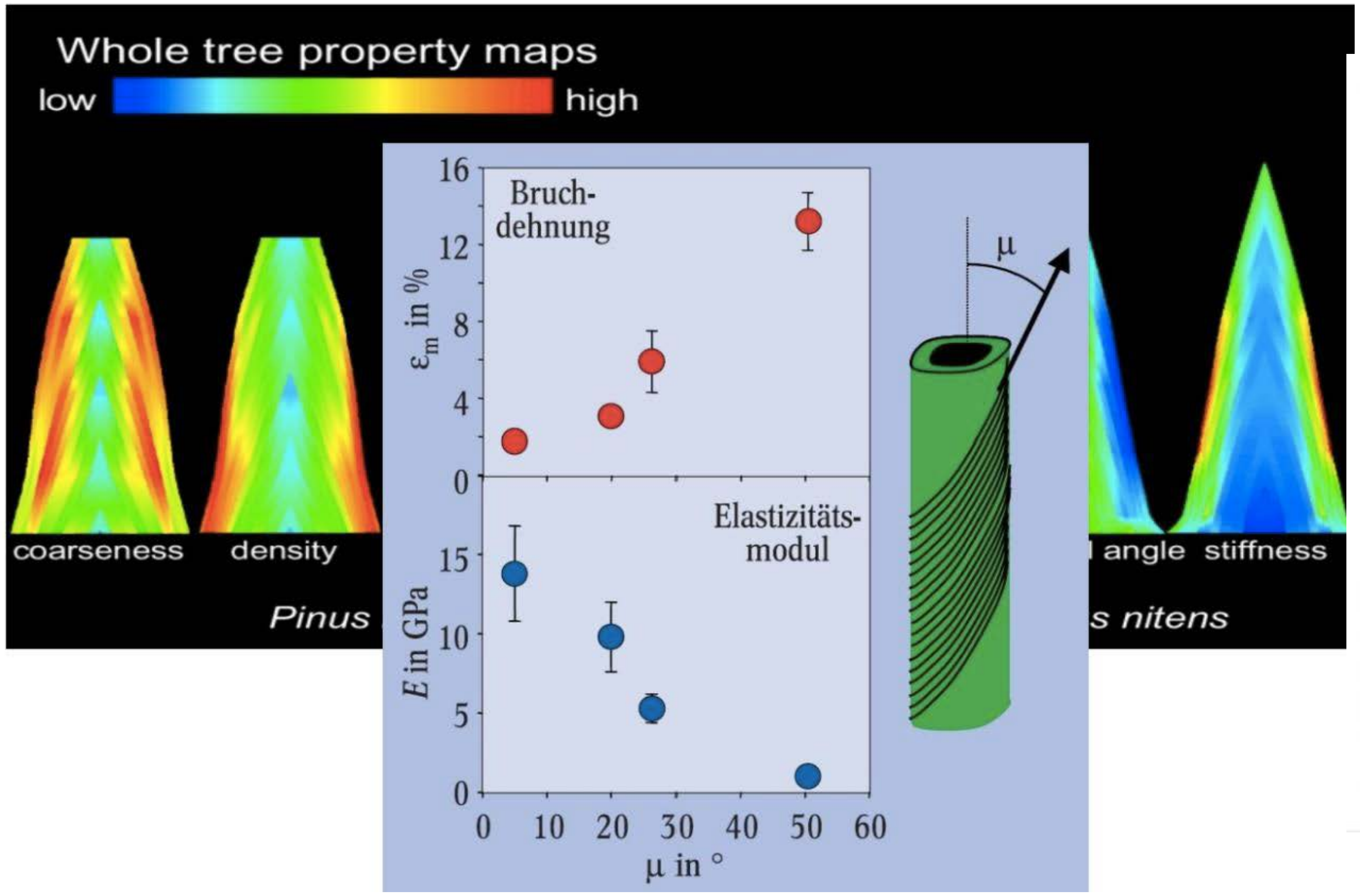
- *Premise of study:* Hollow tubular organs can bend and deform in one of two ways, i.e., either globally in long-wave deformation or locally in short-wave deformation (i.e., Brazier buckling). Either of these two types of behavior can cause death. Understanding the biophysical advantages and disadvantages of possessing hollow plant organs is important therefore to understanding plant ecology and avoiding damage to private or public property.
- *Methods:* We present computer simulations that successfully predict when a hollow organ experiences different modes of failure as a function of organ length and wall thickness as well as material properties.
- *Key results and conclusions:* When self-supporting, tubular plant organs are amenable to long-wave buckling and Brazier (short-wave) buckling under gravitational or wind-induced forces. For very slender tubes constructed of isotropic tissues, Brazier buckling depends on the outer wall radius and wall thickness (specifically Rt^2). Particularly for organs constructed of anisotropic tissues, Brazier buckling becomes a complex phenomenon that depends on a number of geometric parameters (including length of the hollow section) as well as the material properties of tissues. This complexity precludes a definitive (canonical) limit to the relationship between wall thickness and outer radius and the safety limits for Brazier buckling.

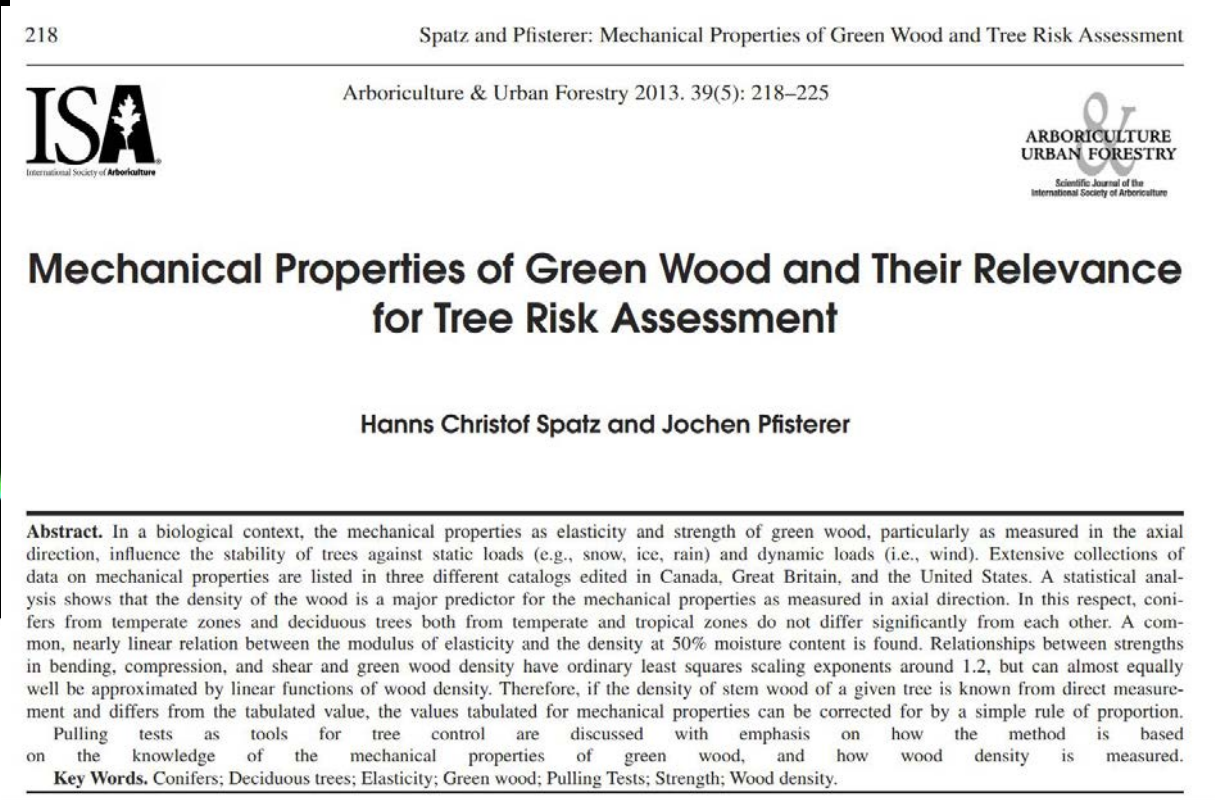
Key words: Brazier buckling; Euler buckling; hollow plant stems; hollow tree trunks; modes of failure.

Whole tree, green wood density values vary greatly along with stem flexural stiffness and cell microfibril angles as result of mechanosensing and tree ring allometry. Evans & Fratzl.

So what are the correct values for flexural stiffness in sound wood in any particular tree?

How does the pull test and subsequent SIA values account for this?





Arboriculture & Urban Forestry 2013. 39(5): 218–225

ARBORICULTURE & URBAN FORESTRY
Scientific Journal of the International Society of Arboriculture

Mechanical Properties of Green Wood and Their Relevance for Tree Risk Assessment

Hanns Christof Spatz and Jochen Pfisterer

Abstract. In a biological context, the mechanical properties as elasticity and strength of green wood, particularly as measured in the axial direction, influence the stability of trees against static loads (e.g., snow, ice, rain) and dynamic loads (i.e., wind). Extensive collections of data on mechanical properties are listed in three different catalogs edited in Canada, Great Britain, and the United States. A statistical analysis shows that the density of the wood is a major predictor for the mechanical properties as measured in axial direction. In this respect, conifers from temperate zones and deciduous trees both from temperate and tropical zones do not differ significantly from each other. A common, nearly linear relation between the modulus of elasticity and the density at 50% moisture content is found. Relationships between strengths in bending, compression, and shear and green wood density have ordinary least squares scaling exponents around 1.2, but can almost equally well be approximated by linear functions of wood density. Therefore, if the density of stem wood of a given tree is known from direct measurement and differs from the tabulated value, the values tabulated for mechanical properties can be corrected for by a simple rule of proportion.

Pulling tests as tools for tree control are discussed with emphasis on how the method is based on the knowledge of the mechanical properties of green wood, and how wood density is measured.

Key Words. Conifers; Deciduous trees; Elasticity; Green wood; Pulling Tests; Strength; Wood density.

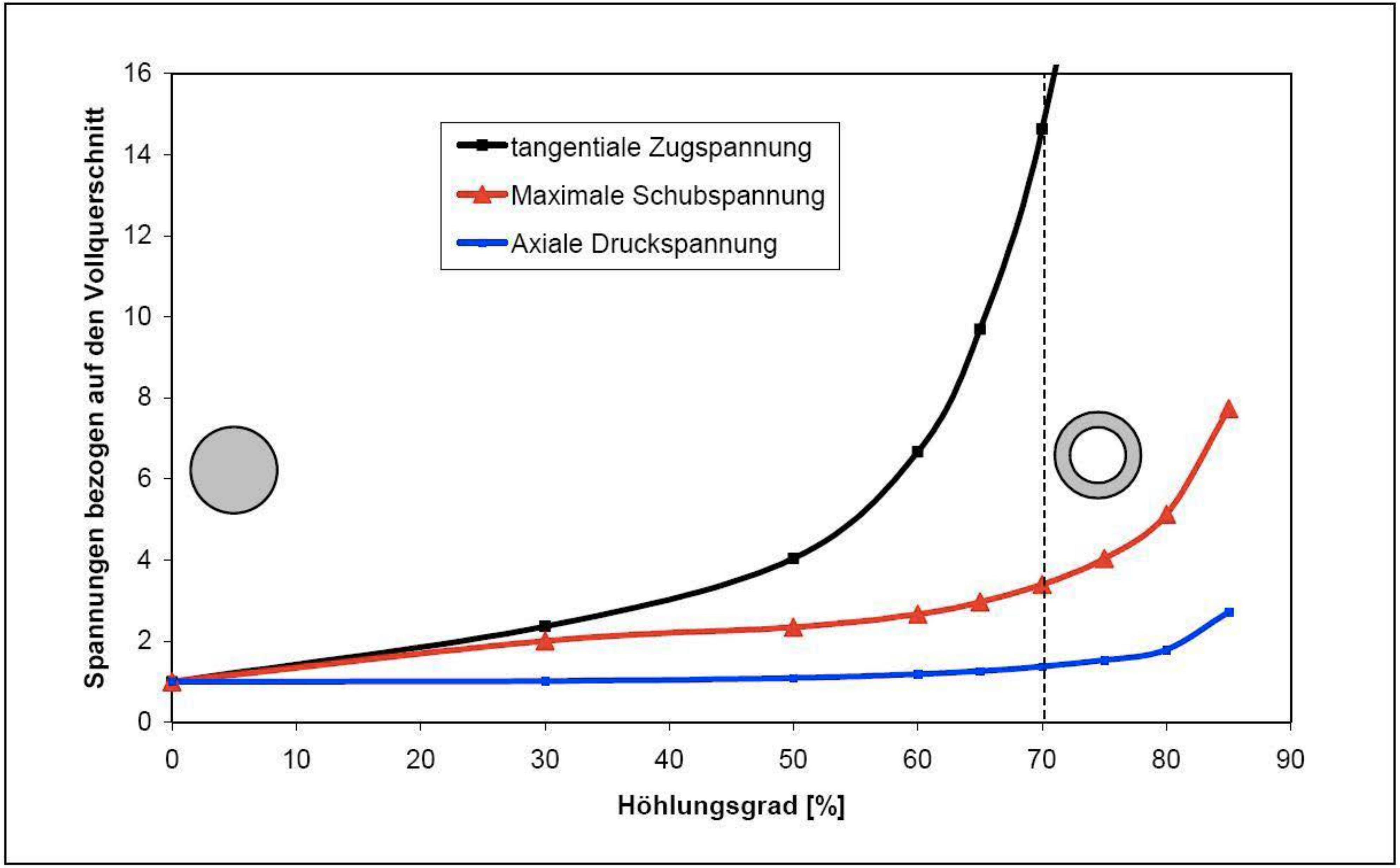
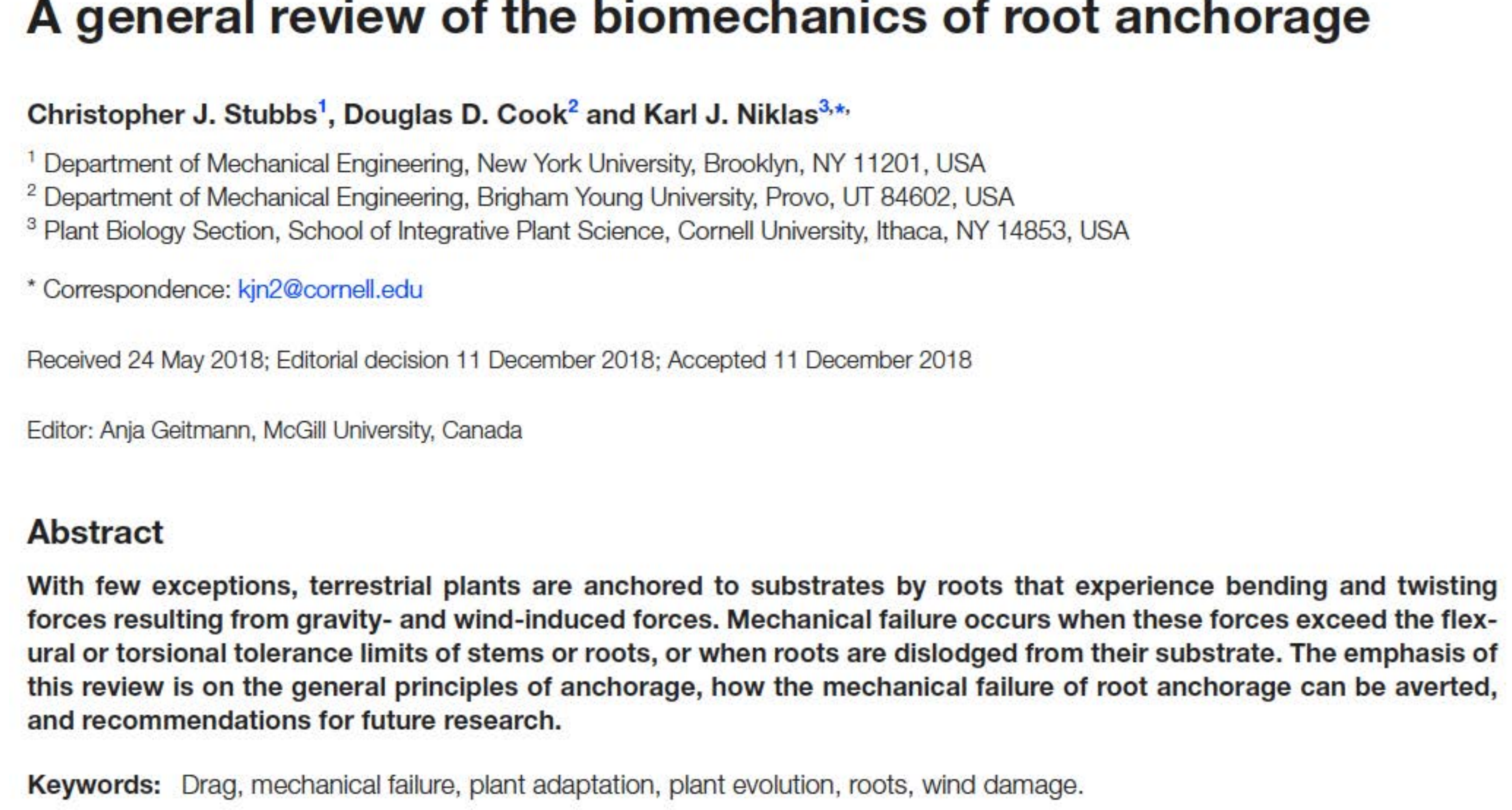


Abbildung 3.12: Anstieg versagensrelevanter Spannungen im Baum infolge steigender Ausmorschung

Tangential stresses increase more than shear and compression, explaining the more frequent torsional failures of mature trees.

Q. Which wind load forces should we be most concerned with?

Modes of failure in tubular plant organs H,C Spatz , K,J Niklas 2013
Mechanical Properties of Green Wood and Their Relevance for Tree Risk Assessment
Hanns Christof Spatz and Jochen Pfisterer 2013.



A general review of the biomechanics of root anchorage

Christopher J. Stubbs[1], **Douglas D. Cook**[2] **and Karl J. Niklas**[3,*]

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Editor: Anja Geitmann, McGill University, Canada

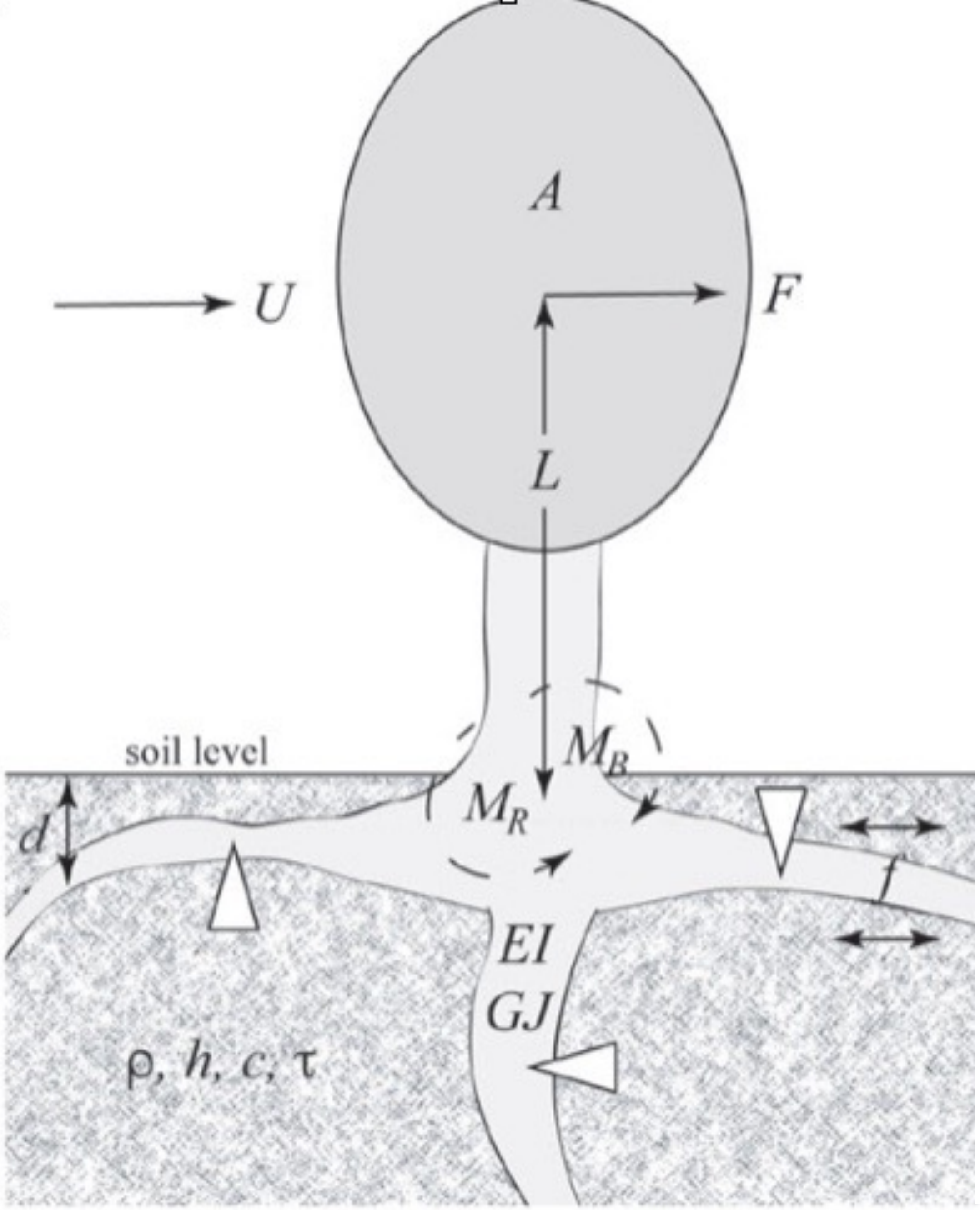
Abstract

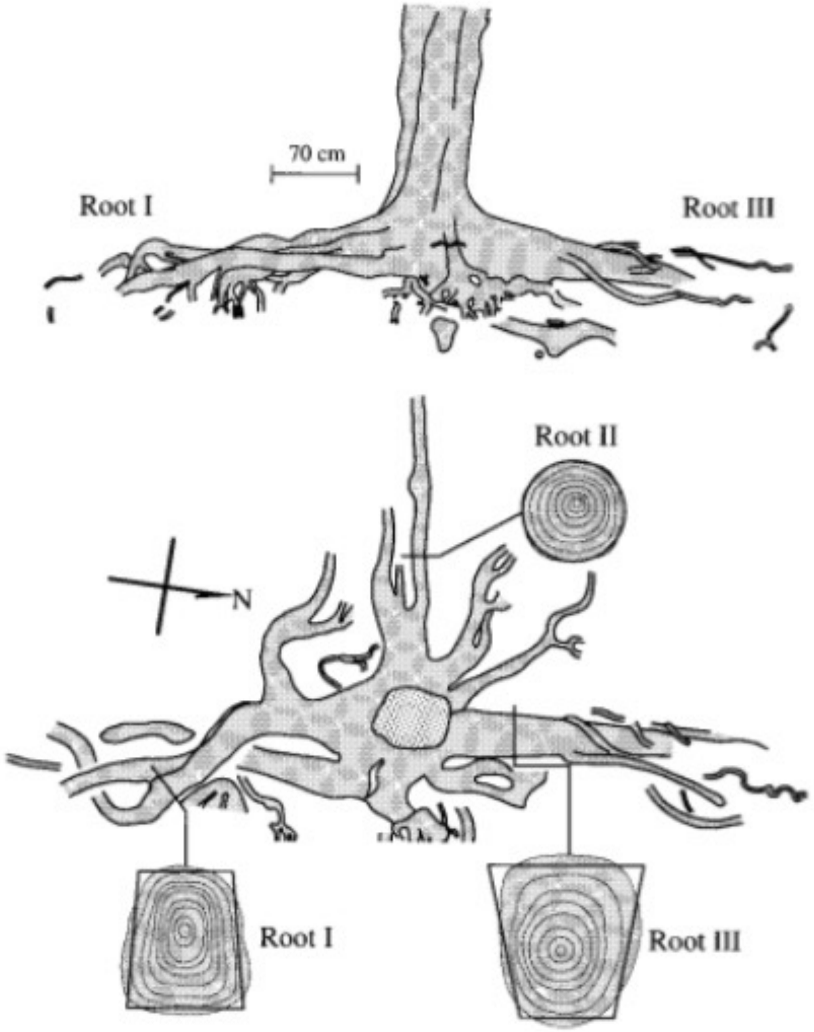
With few exceptions, terrestrial plants are anchored to substrates by roots that experience bending and twisting forces resulting from gravity- and wind-induced forces. Mechanical failure occurs when these forces exceed the flexural or torsional tolerance limits of stems or roots, or when roots are dislodged from their substrate. The emphasis of this review is on the general principles of anchorage, how the mechanical failure of root anchorage can be averted, and recommendations for future research.

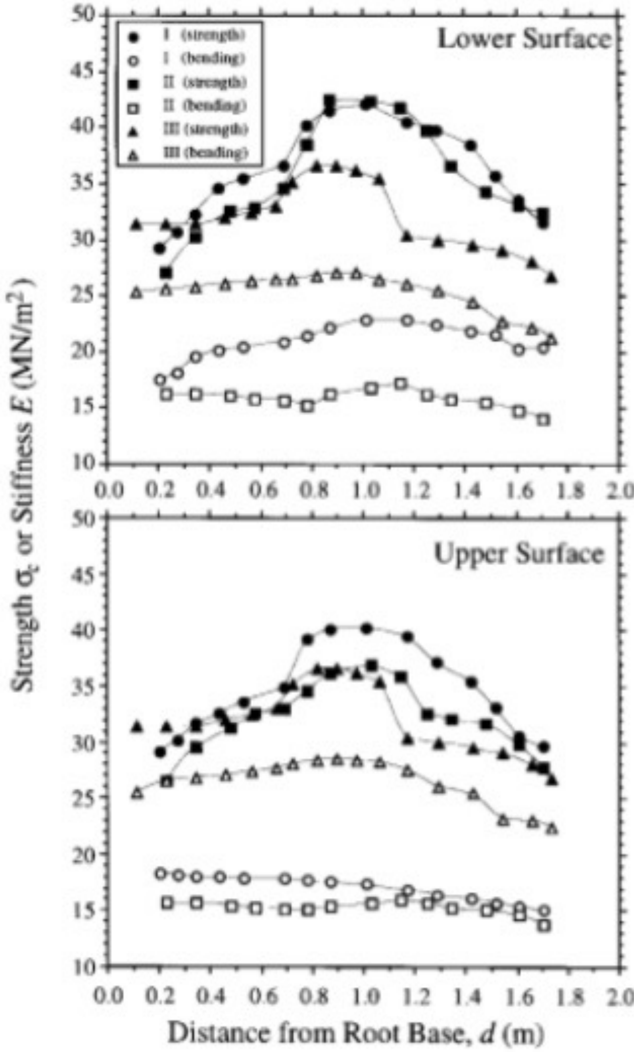
Keywords: Drag, mechanical failure, plant adaptation, plant evolution, roots, wind damage.

How do tilting curves take into account changes in soil moisture?
How do Tilting curves take not account variations in stem flexural stiffness due to adapt
How do tilting curve account for differing root geometries and that the root plate does n

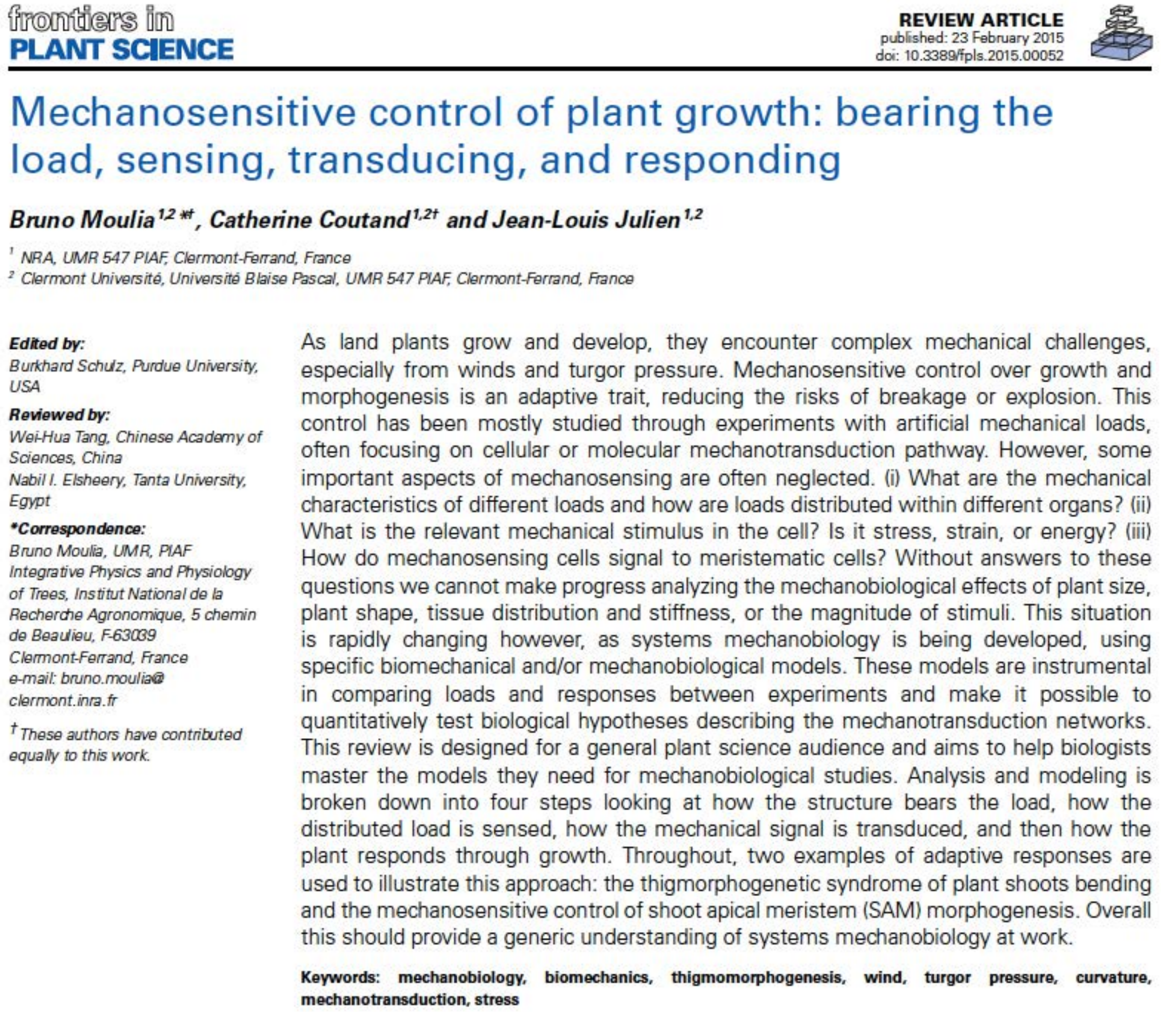
– The University of Stuttgart stated in 1994:
“We did not measure any reference data for [SIA] pulling tests because the planned
research project was not funded; Wessolly & the SIA group have
to give evidence of the method and claimed reliability –this cannot be replaced by any referenc
http://download.rinntech.com/2017_RINN_PullTestPrinciples_WesternArborist_Winter.pdf







Karl.J.Niklas



frontiers in
PLANT SCIENCE

REVIEW ARTICLE
published: 23 February 2015
doi: 10.3389/fpls.2015.00052

Mechanosensitive control of plant growth: bearing the load, sensing, transducing, and responding

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[2] Clermont Université, Université Blaise Pascal, UMR 547 PIAF, Clermont-Ferrand, France

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† These authors have contributed equally to this work.

As land plants grow and develop, they encounter complex mechanical challenges, especially from winds and turgor pressure. Mechanosensitive control over growth and morphogenesis is an adaptive trait, reducing the risks of breakage or explosion. This control has been mostly studied through experiments with artificial mechanical loads, often focusing on cellular or molecular mechanotransduction pathway. However, some important aspects of mechanosensing are often neglected. (i) What are the mechanical characteristics of different loads and how are loads distributed within different organs? (ii) What is the relevant mechanical stimulus in the cell? Is it stress, strain, or energy? (iii) How do mechanosensing cells signal to meristematic cells? Without answers to these questions we cannot make progress analyzing the mechanobiological effects of plant size, plant shape, tissue distribution and stiffness, or the magnitude of stimuli. This situation is rapidly changing however, as systems mechanobiology is being developed, using specific biomechanical and/or mechanobiological models. These models are instrumental in comparing loads and responses between experiments and make it possible to quantitatively test biological hypotheses describing the mechanotransduction networks. This review is designed for a general plant science audience and aims to help biologists master the models they need for mechanobiological studies. Analysis and modeling is broken down into four steps looking at how the structure bears the load, how the distributed load is sensed, how the mechanical signal is transduced, and then how the plant responds through growth. Throughout, two examples of adaptive responses are used to illustrate this approach: the thigmorphogenetic syndrome of plant shoots bending and the mechanosensitive control of shoot apical meristem (SAM) morphogenesis. Overall this should provide a generic understanding of systems mechanobiology at work.

Keywords: mechanobiology, biomechanics, thigmomorphogenesis, wind, turgor pressure, curvature, mechanotransduction, stress

frontiers in
PLANT SCIENCE

MINI REVIEW ARTICLE
published: 14 August 2014
doi: 10.3389/fpls.2014.00401

To respond or not to respond, the recurring question in plant mechanosensitivity

Nathalie Leblanc-Fournier[1,2]*, **Ludovic Martin**[3], **Catherine Lenne**[1,2] **and Mélanie Decourteix**[1,2]

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In nature, terrestrial plants experience many kinds of external mechanical stimulation and respond by triggering a network of signaling events to acclimate their growth and development. Some environmental cues, especially wind, recur on time scales varying from seconds to days. Plants thus have to adapt their sensitivity to such stimulations to avoid constitutive activation of stress responses. The study of plant mechanosensing has been attracting more interest in the last two decades, but plant responses to repetitive mechanical stimulation have yet to be described in detail. In this mini review, alongside classic experiments we survey recent descriptions of the kinetics of plant responses

If evidence from research by Frank Telewski, Bruno Moulia, Catharin Lenne and Nathalie Leblanc -Fournier and others on Mechanosensing is of any interest the tree is highly sensitive and adaptive to external loads,

Quote Telewski " mechanical stimulations result in a thigmomorphogenetic syndrome generally characterised by reduction in stem height, modification of the mechanical properties of the stem, increase in root biomass and local increases in stem radial growth depending on the species".

But when we reduce trees..or make weight reduction on trees, how will the tree respond and how will this affect wind induced drag?
Instead of reducing weight, should we be adding load to stimulate adaptive response?
What happens when we reduce weight? Reduced response, followed by regrowth and greater load?

Some thoughts about VTA and SIA.

The VTA-t/R-1/3-rule does not apply to the mature urban tree but shows that breakage is getting significantly more probable when more than 20% of LCC is lost in Young trees with circular stems

● SIA does not allow to you to determine breakage safety due to inappropriate maths and wrong reference values.
The method seems to underestimate the LCC of young still growing trees and overestimate the LCC of mature trees.

Interestingly what we are finding is that the first initial failure in roots occurs approximately at the same strain as the first tangential failure at the stem base.

►so, how to evaluate stability and load by assessing

1) loss in LCC (cross-sectional load carrying capacity)

2) wind load (for real local wind speed)

The tree already knows the load.

The suggestion is Self -referencing

Based on the evidence that the trees know best how much wood of what

Practically applied this means:

- <u>For young trees, still growing in height:</u>

Evaluation of defected cross sections by direct comparison with intact cro

- <u>For mature trees, taking into account:</u>

Past height reductions due to reaching the hydraulic limit for growth.
The number of Years of maturity (since height growth stopped and diame
Relative loss of cross-sectional load carrying capacity as a result of wood

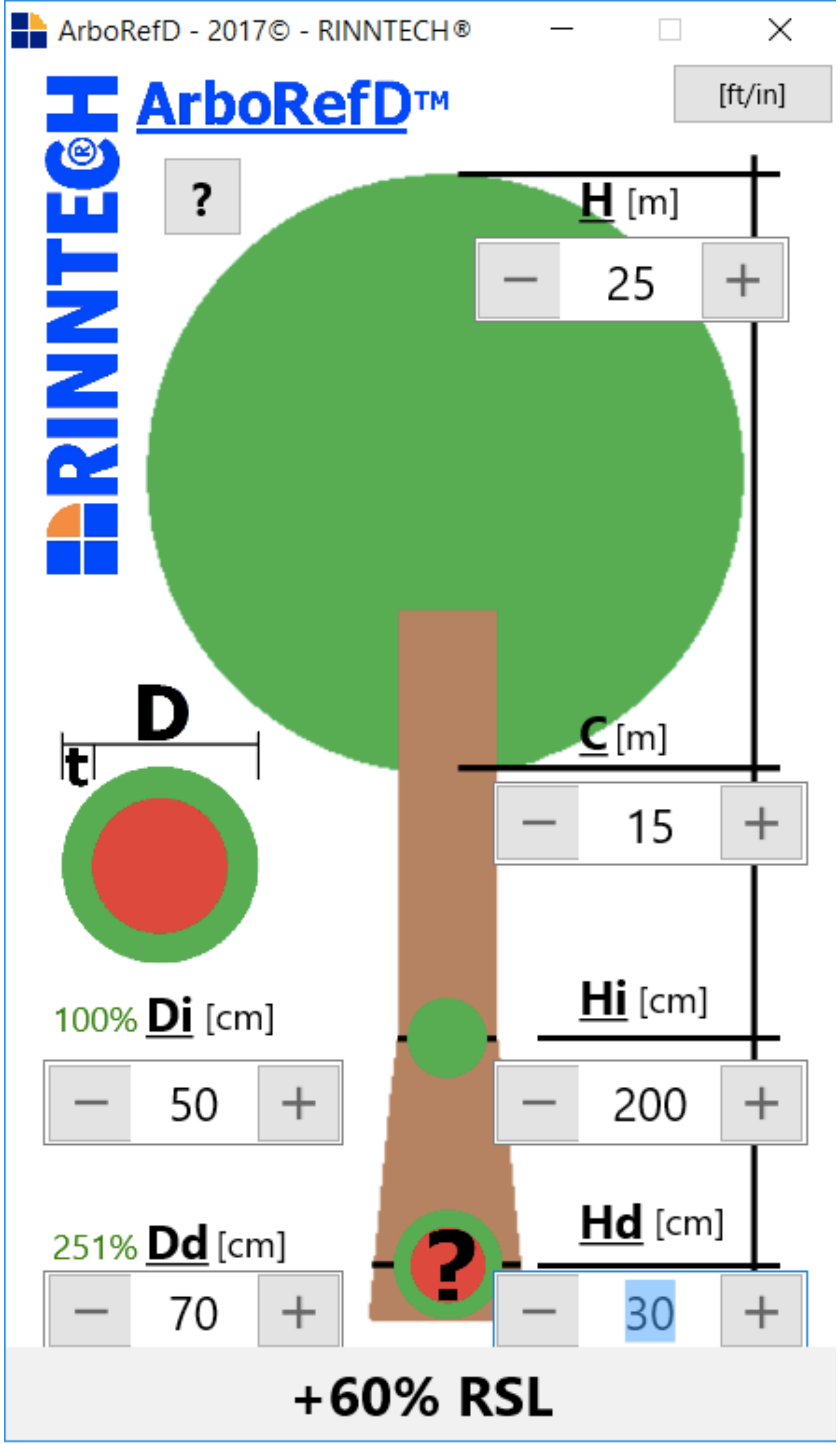
So we can only assume, that at the point the tree is 100% intact, it is already

- Once we have calculated the stem diameter and area of decay at the weakest p
- As we already mentioned, water and hydraulic capacity restricts growth, in partic
- A 3% increase in girth of a tree no longer growing in height represents a 10% inc
- This means that we must include the subsequent increase in stability as a result

Once we know the growth rate diameter increase annually, typically, 0,5cm per year we can estimate how many years and subsequently how much diameter has increased since reaching maximum height.

What we are finding, with mature decayed trees, because of the greater increase in stem diameter, in relation to height, most have a far greater stability than much younger trees with no decay.

In addition, due to mechanosensing trees are not only growing where load is experienced, but also changing the flexural stiffness of the sapwood every year, in relation to the load they experience in a very localised way.



H [m] 25

C [m] 15

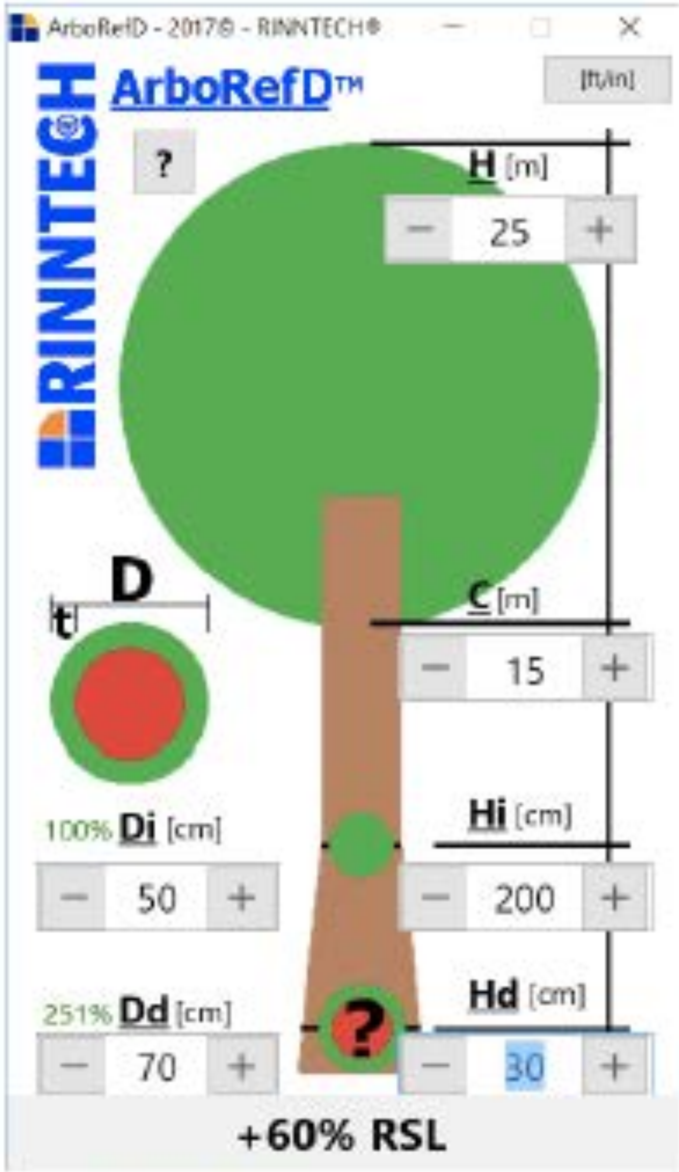
100% Di [cm] 50

Hi [cm] 200

251% Dd [cm] 70

Hd [cm] 30

+60% RSL



H [m] 25

C [m] 15

100% Di [cm] 50

Hi [cm] 200

251% Dd [cm] 70

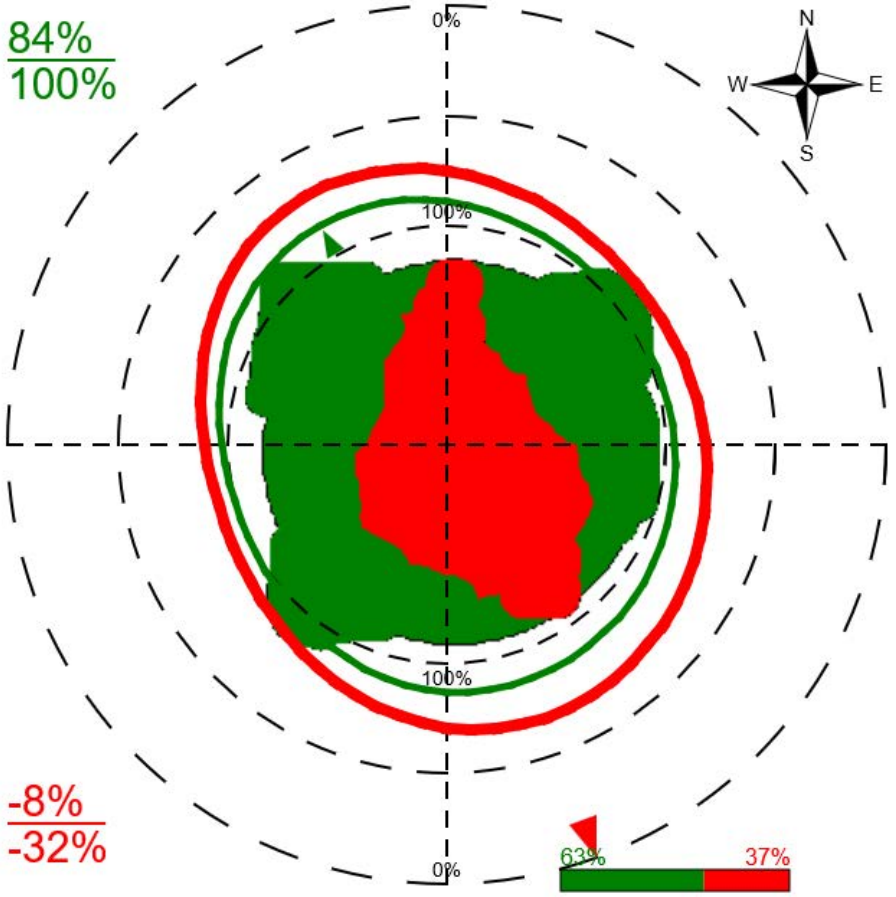
Hd [cm] 30

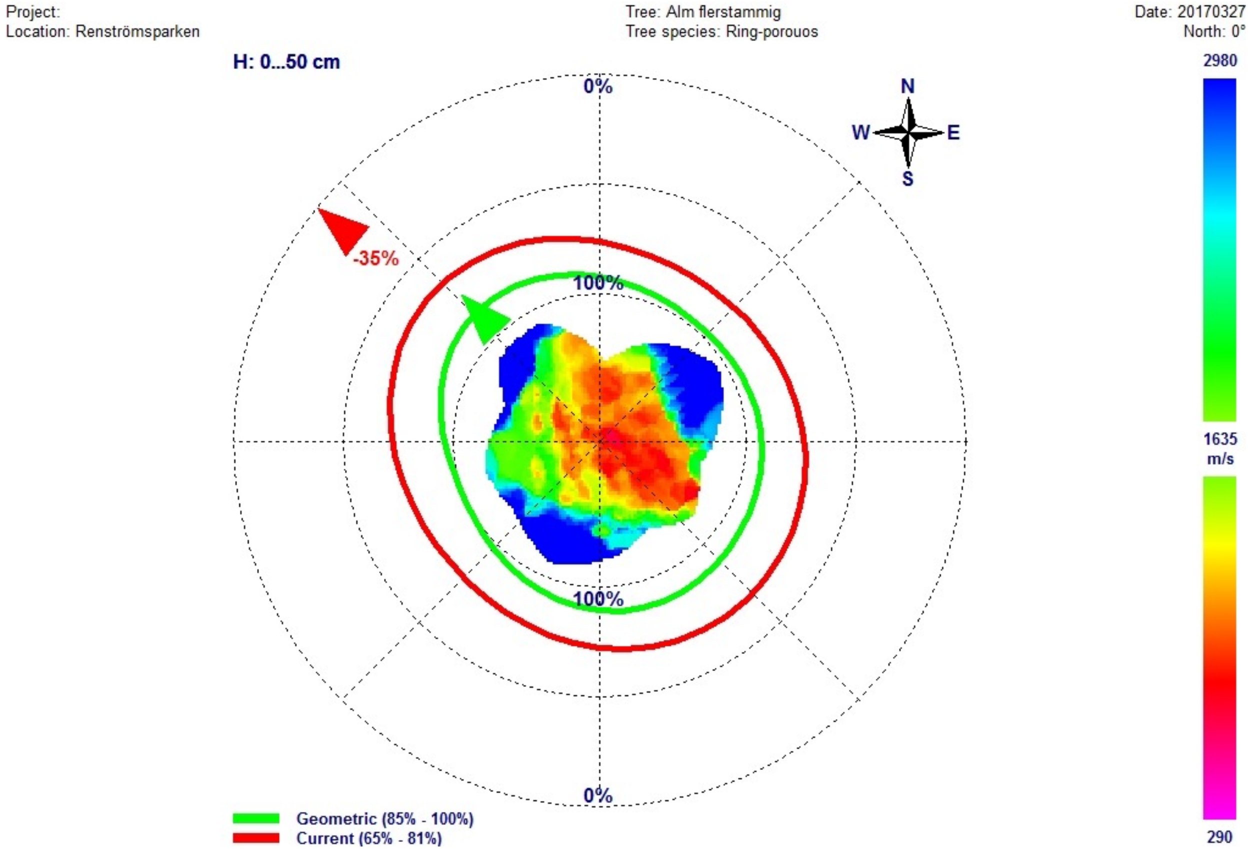
+60% RSL

1.6 * 0.7 ≈ 1.1

≡ 110%

Basic safety of the hollow cross-section ~160%.
Fungal colonisation takes away ~30%.
Leading to a resulting safety of: 0.7*1,6 ≈ 1.1 ≡ 110%.
The decayed cross section is still approx. 10% safer when compared to the intact cross-section above. No need for pruning.



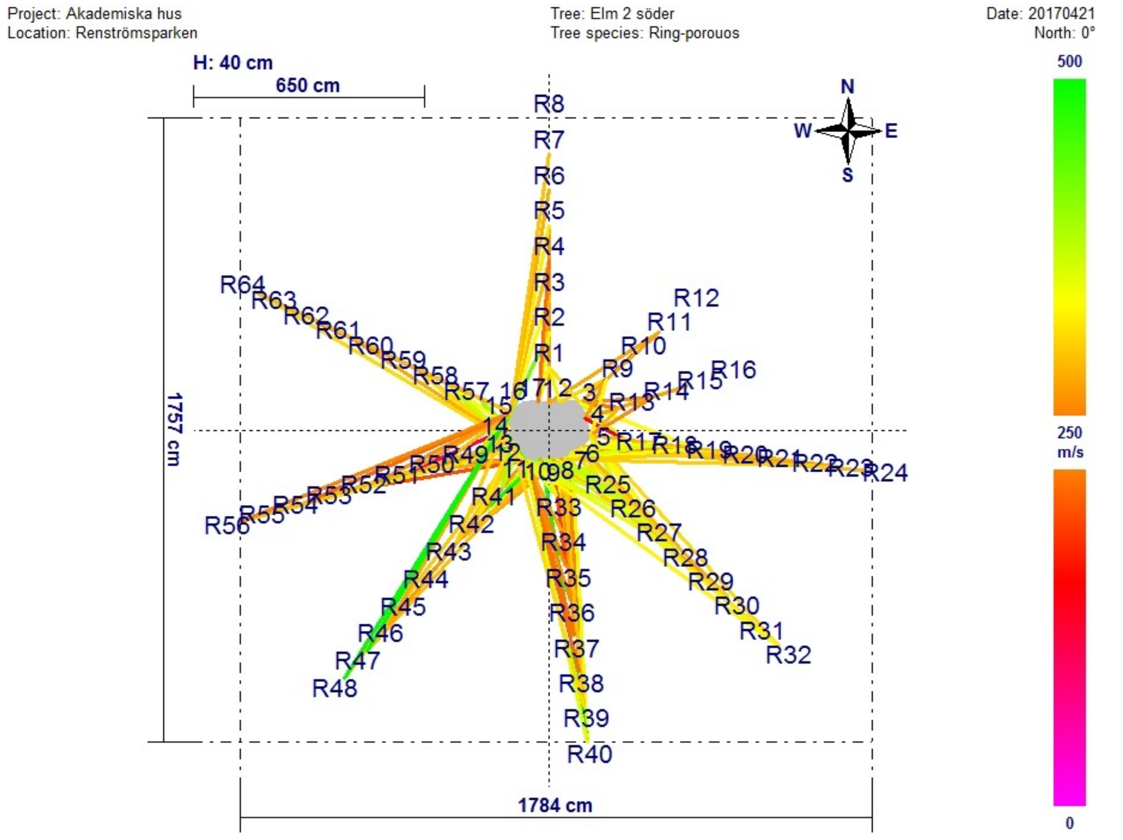

Project:
Location: Renströmsparken

Tree: Alm flerstammig
Tree species: Ring-porouos

Date: 20170327
North: 0°

H: 0...50 cm

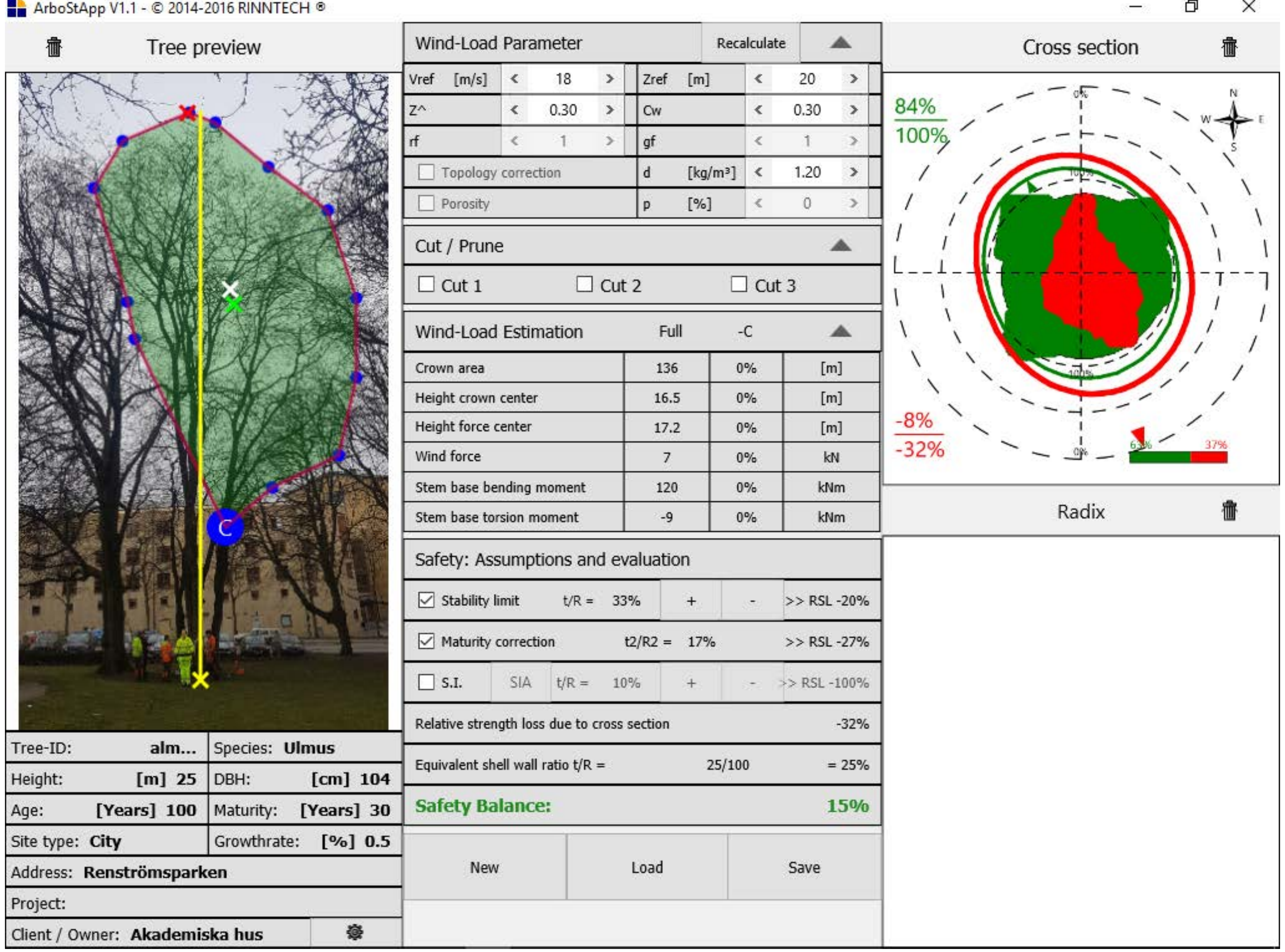
🟩 Geometric (85% - 100%)
🟥 Current (65% - 81%)


Project: Akademiska hus
Location: Renströmsparken

Tree: Elm 2 söder
Tree species: Ring-porouos

Date: 20170421
North: 0°

H: 40 cm



Wind-Load Parameter

Vref [m/s] 18
Zref [m] 20
Z^ 0.30
Cw 0.30
rf 1
gf 1
☐ Topology correction
d [kg/m³] 1.20
☐ Porosity
p [%] 0

Cut / Prune

☐ Cut 1 ☐ Cut 2 ☐ Cut 3

Wind-Load Estimation

	Full	-C	
Crown area	136	0%	[m]
Height crown center	16.5	0%	[m]
Height force center	17.2	0%	[m]
Wind force	7	0%	kN
Stem base bending moment	120	0%	kNm
Stem base torsion moment	-9	0%	kNm

Safety: Assumptions and evaluation

☑ Stability limit t/R = 33% + - >> RSL -20%
☑ Maturity correction t2/R2 = 17% >> RSL -27%
☐ S.I. SIA t/R = 10% + - >> RSL -100%

Relative strength loss due to cross section -32%

Equivalent shell wall ratio t/R = 25/100 = 25%

Safety Balance: 15%

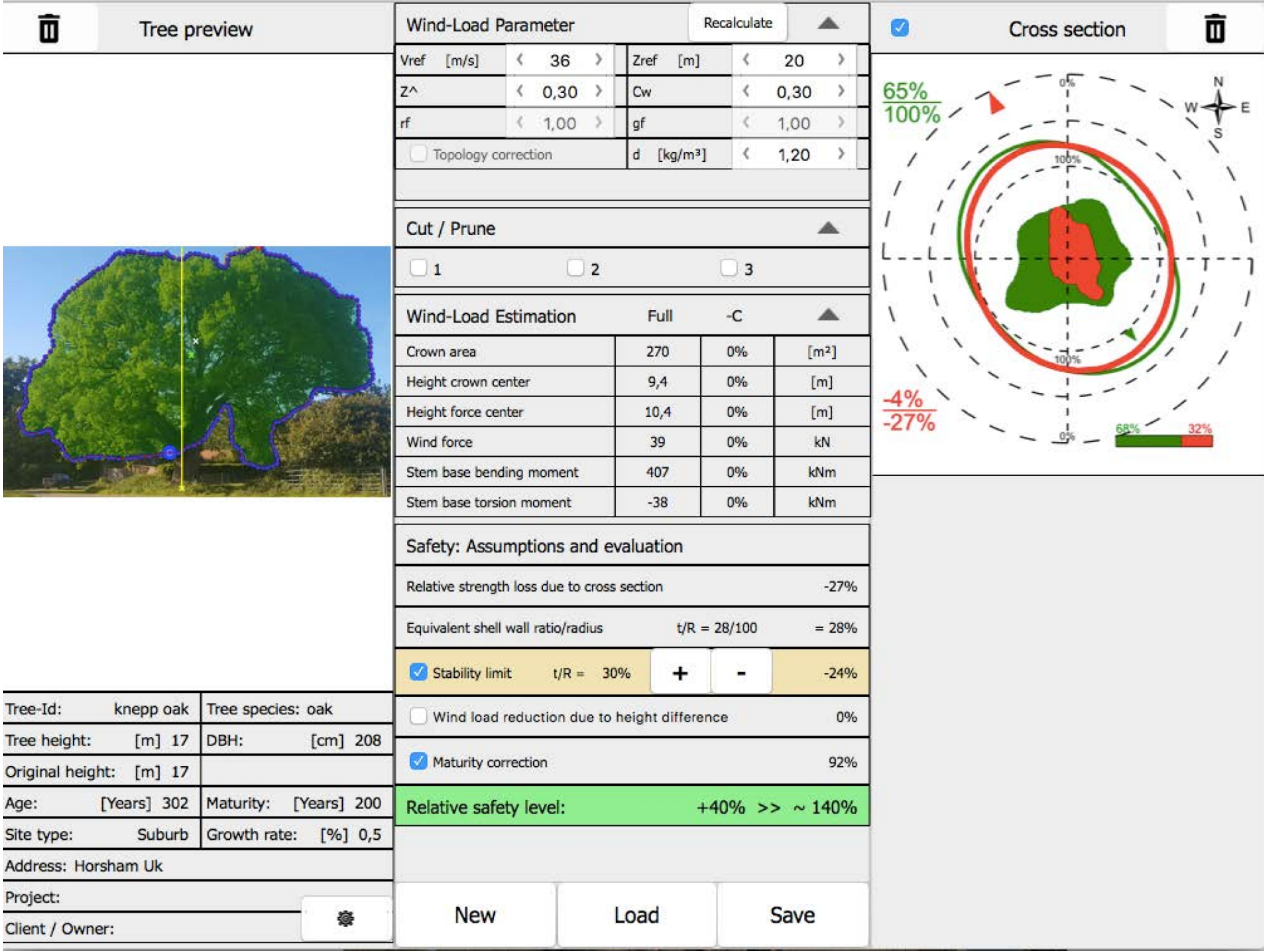
New Load Save

Tree-ID: **alm...**	Species: **Ulmus**
Height: **[m] 25**	DBH: **[cm] 104**
Age: **[Years] 100**	Maturity: **[Years] 30**
Site type: **City**	Growthrate: **[%] 0.5**

Address: **Renströmsparken**

Project:

Client / Owner: **Akademiska hus**



Wind-Load Parameter

Vref [m/s]	36	Zref [m]	20
Z^	0,30	Cw	0,30
rf	1,00	gf	1,00
☐ Topology correction		d [kg/m³]	1,20

Cut / Prune

☐ 1 ☐ 2 ☐ 3

Wind-Load Estimation

	Full	-C	
Crown area	270	0%	[m²]
Height crown center	9,4	0%	[m]
Height force center	10,4	0%	[m]
Wind force	39	0%	kN
Stem base bending moment	407	0%	kNm
Stem base torsion moment	-38	0%	kNm

Safety: Assumptions and evaluation

Relative strength loss due to cross section		-27%
Equivalent shell wall ratio/radius	t/R = 28/100	= 28%
☑ Stability limit	t/R = 30% + -	-24%
☐ Wind load reduction due to height difference		0%
☑ Maturity correction		92%
Relative safety level:		+40% >> ~ 140%

Tree-Id: knepp oak	Tree species: oak
Tree height: [m] 17	DBH: [cm] 208
Original height: [m] 17	
Age: [Years] 302	Maturity: [Years] 200
Site type: Suburb	Growth rate: [%] 0,5

Address: Horsham Uk

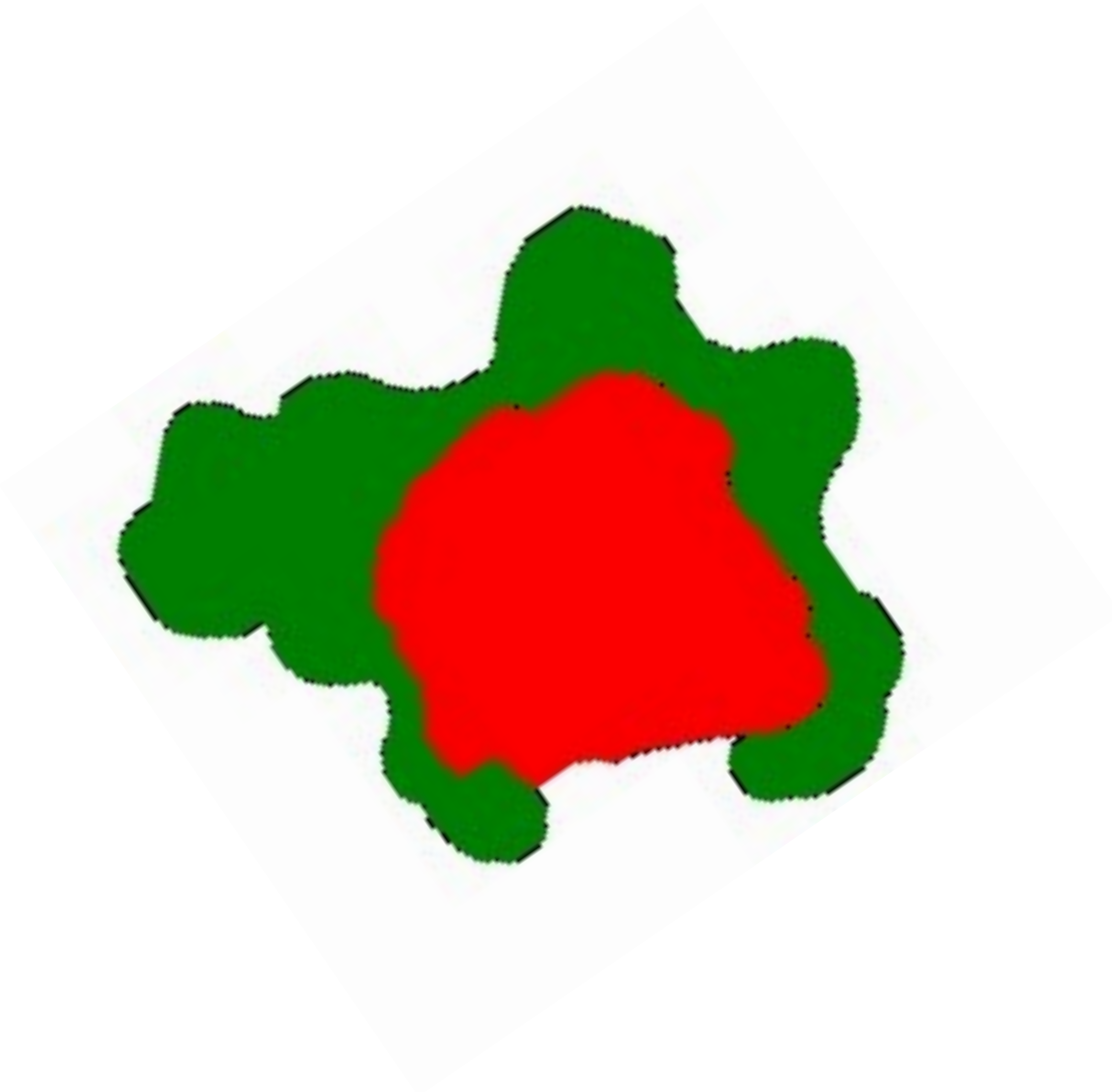
Project:

Client / Owner:

Summary.

- Most trees, even with fungal decay associations, actually have very good stability.
They do not require any additional input from arborists.
- Trees may require pruning to prevent torsional loading, green wood is roughly 10 times weaker under torsional loading than than in tension and so small changes to symmetry will make large changes to stability.
- Pruning trees with fungal colonisation seems to increase the rate of decay and ultimately the tree has reduced stability with increased canopy load as the canopy regrows. This is because the tree reallocates biomass to replace leaf lost by defoliation, the result seems to be a larger, denser canopy on a weaker stem, with more decay.
- Crown reduction, in association with drought stress may cause root death.
- Very small changes in tree height afford very large decrease in bending load.

diameter-280 Height-27m

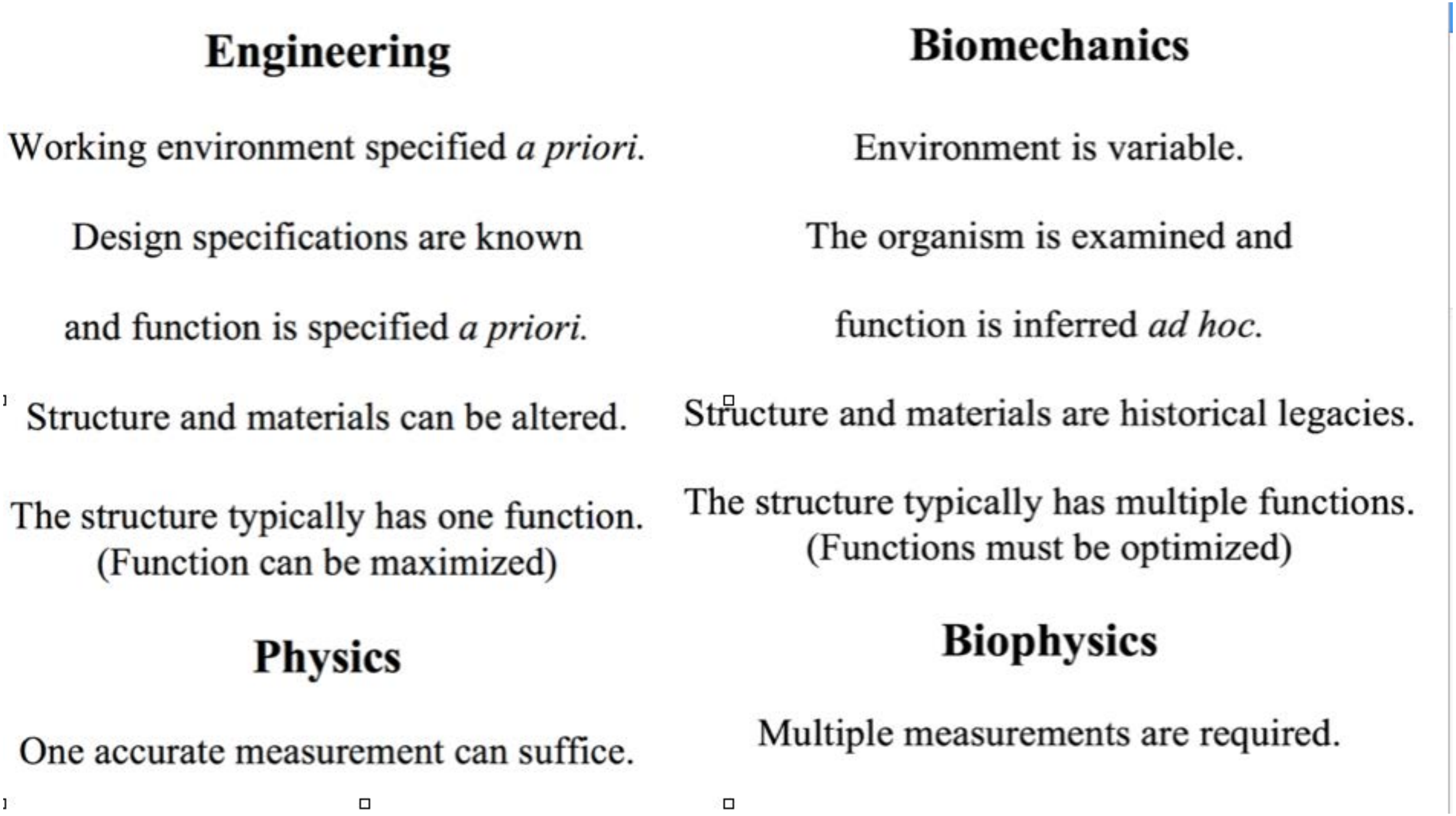


HARTILL
TRÄDEXPERT

Thank you!

Special thanks should go to:
Professor Lynne Boddy,
Emeritus Professor Karl J Niklas,
Frank Rinn and Mike Ellison.

Questions!

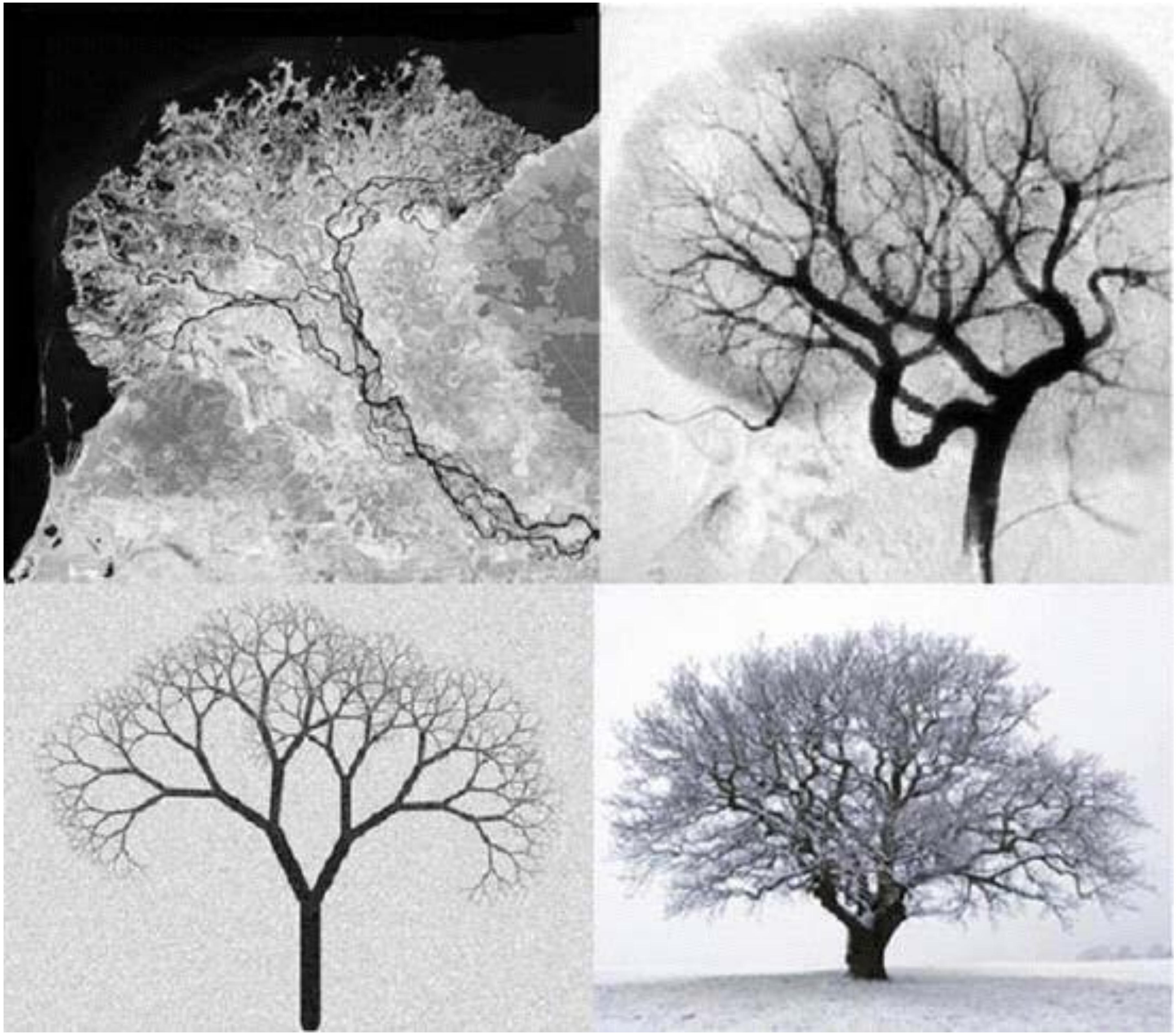


Engineering	Biomechanics
Working environment specified *a priori.*	Environment is variable.
Design specifications are known and function is specified *a priori.*	The organism is examined and function is inferred *ad hoc.*
Structure and materials can be altered.	Structure and materials are historical legacies.
The structure typically has one function. (Function can be maximized)	The structure typically has multiple functions. (Functions must be optimized)

Physics	Biophysics
One accurate measurement can suffice.	Multiple measurements are required.

Karl Niklas

What do you observe in wood with pre existing decay?



Fluid mechanics principles also replicate in all biological systems

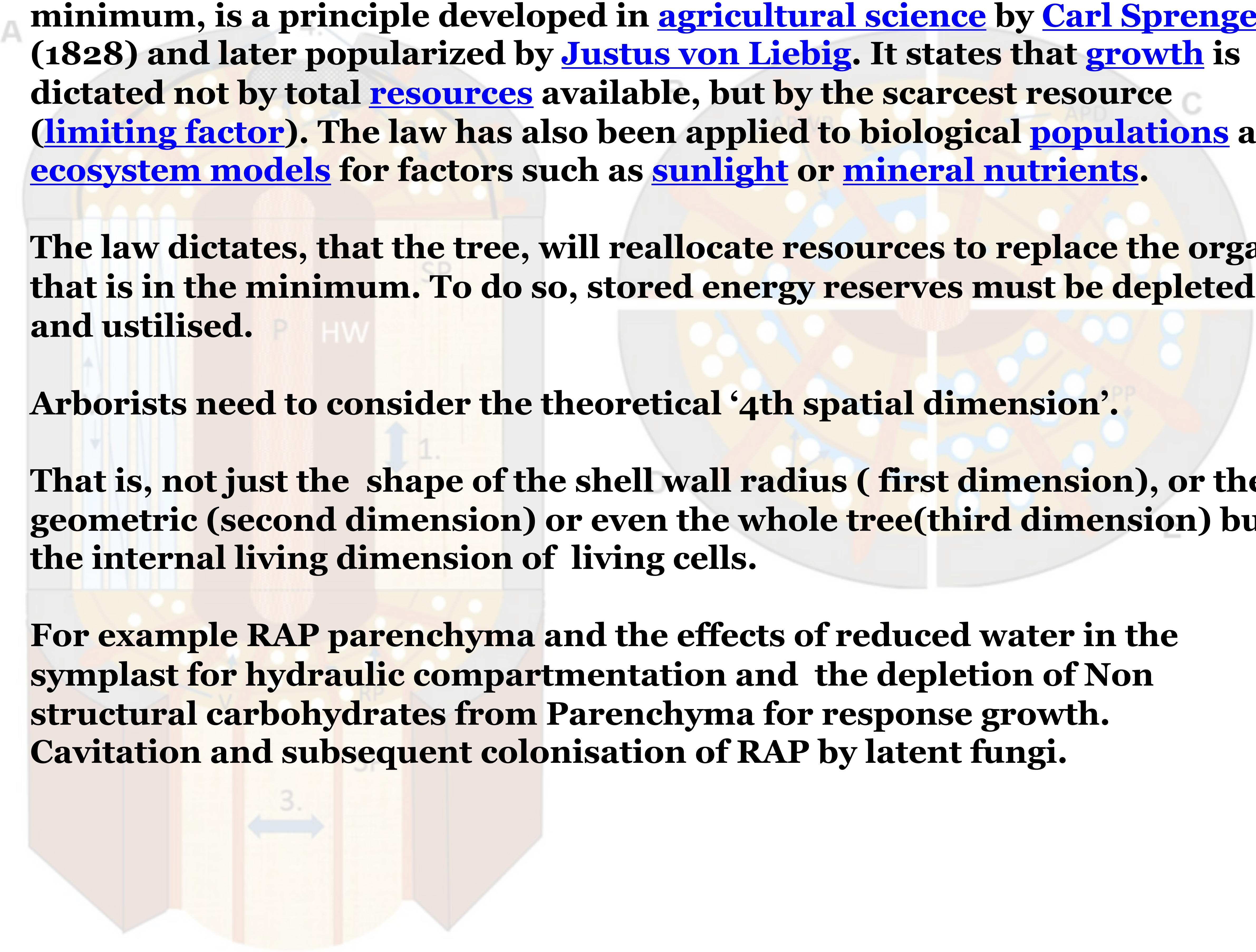
Liebig law of the minimum, often simply called Liebig's law or the law of the minimum, is a principle developed in agricultural science by Carl Sprengel (1828) and later popularized by Justus von Liebig. It states that growth is dictated not by total resources available, but by the scarcest resource (limiting factor). The law has also been applied to biological populations and ecosystem models for factors such as sunlight or mineral nutrients.

The law dictates, that the tree, will reallocate resources to replace the organ that is in the minimum. To do so, stored energy reserves must be depleted and ustilised.

Arborists need to consider the theoretical ‘4th spatial dimension’.

That is, not just the shape of the shell wall radius (first dimension), or the geometric (second dimension) or even the whole tree(third dimension) but the internal living dimension of living cells.

For example RAP parenchyma and the effects of reduced water in the symplast for hydraulic compartmentation and the depletion of Non structural carbohydrates from Parenchyma for response growth. Cavitation and subsequent colonisation of RAP by latent fungi.



The tree is essentially assimilating biomass annually, by fixing carbon and forming wood fibres for growth and support. To do this, and to grow so large, it must be able to photosynthesise and compete for light amongst its neighbouring plants.

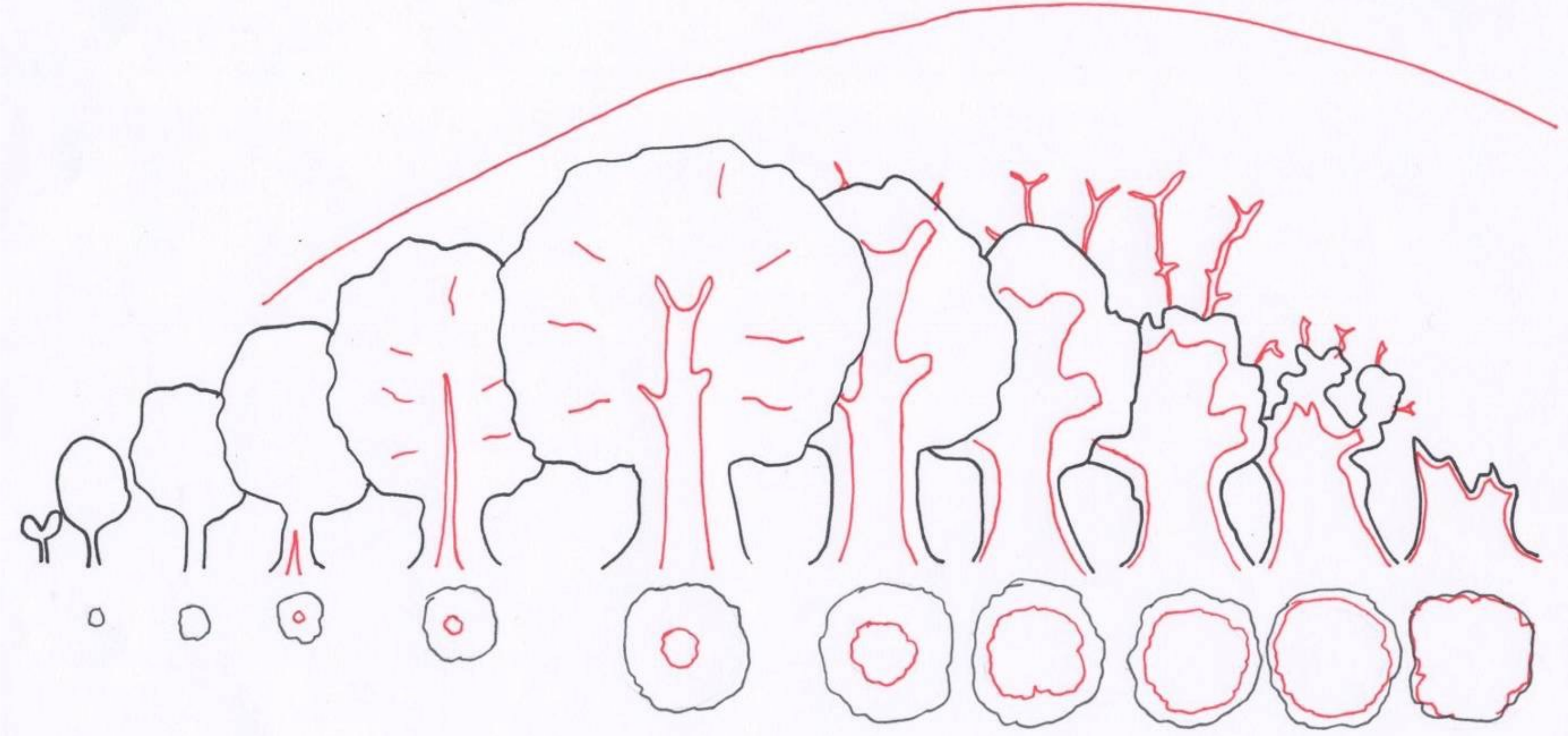
Interestingly there are direct and invariant scaling relationships for plant annualised biomass production and metabolism. Demonstrated by Niklas and Enquist in 2000, in their fascinating paper of the same name: “Invariant scaling relationships for interspecific plant biomass production rates and body size” from 1999.

Here they argue, convincingly, that annualised rates of growth G (Biomass production) scales as the 3/4-power of body mass M over 20 orders of magnitude of Mass (i.e., G ~ M3/4) in plant taxa;

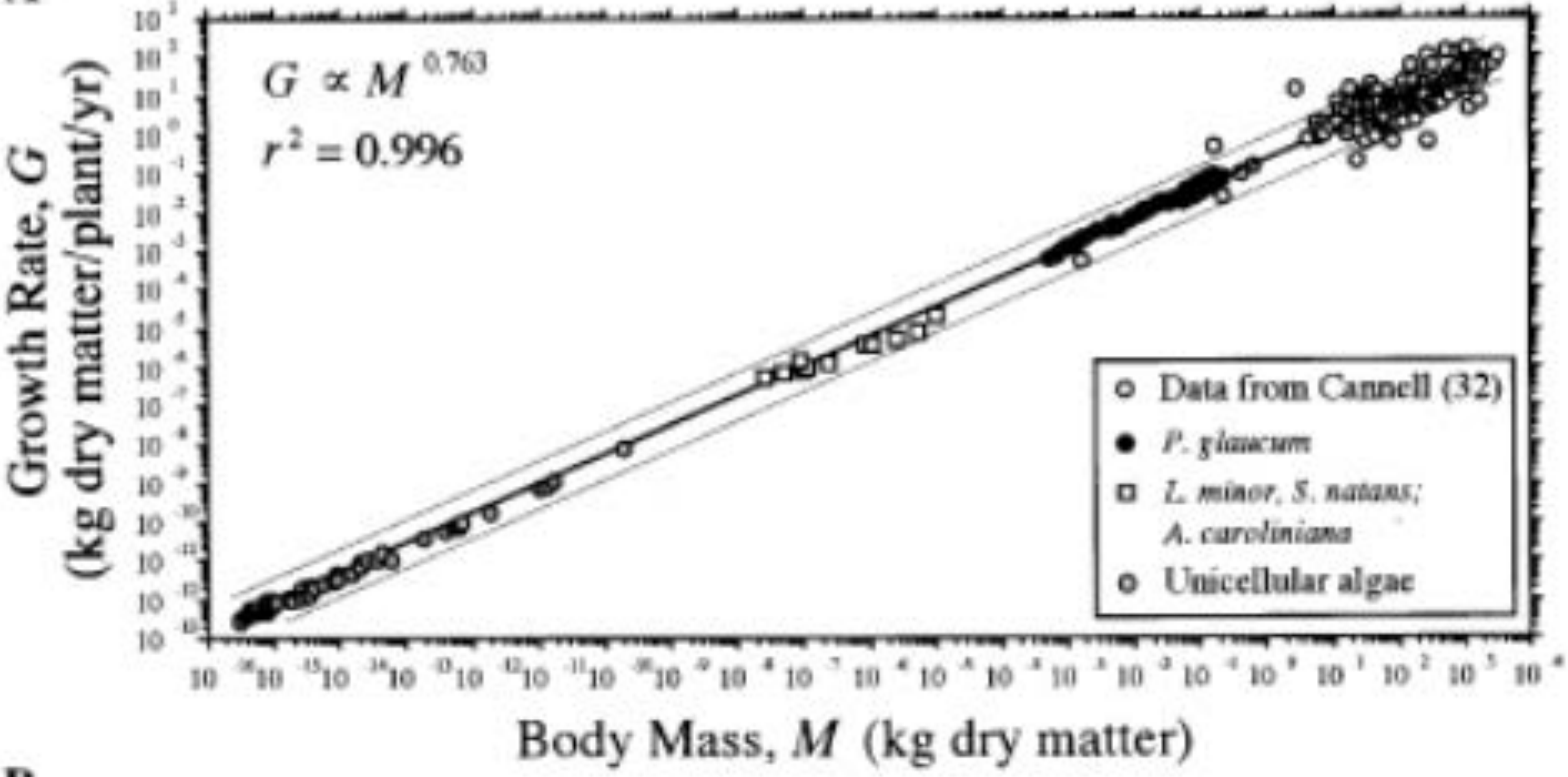
Plant body length L (i.e. cell length or plant height) scales, on average, as the 1/4-power of Total biomass (M) over 22 orders of magnitude of M:
L ~ M1/4;
and photosynthetic biomass (Mp) scales as the 3/4-power of non-photosynthetic biomass (Mn), that means Mp ~ Mn 3/4.

Because these scaling relationships are indifferent to phylogenetic affiliation and habitat, they have far-reaching ecological and evolutionary implications (e.g., net primary productivity is predicted to be largely insensitive to community species composition or geological age).

These allometric scaling relationships indicate that annualised plant growth and the bio-mechanical influences of wood density and biomass allocation have profound effects upon the mechanical stability of large trees, this is because:
Standing leaf mass will scale as the 3/4 power of stem mass and as the 3/4 power of root mass such that stem mass scales isometrically with respect to root mass across very large vascular plant species with self supporting stems.



A


$G \propto M^{0.763}$
$r^2 = 0.996$
Growth Rate, G (kg dry matter/plant/yr)
Body Mass, M (kg dry matter)
Data from Cannell (32)
P. glaucum
L. minor, S. natans; A. caroliniana
Unicellular algae

B

The arborist is drilling into the stem where the fungi is exiting, at or around the fruiting body and concluding the tree/or trees are too decayed.

The decay its' self is not so interesting.

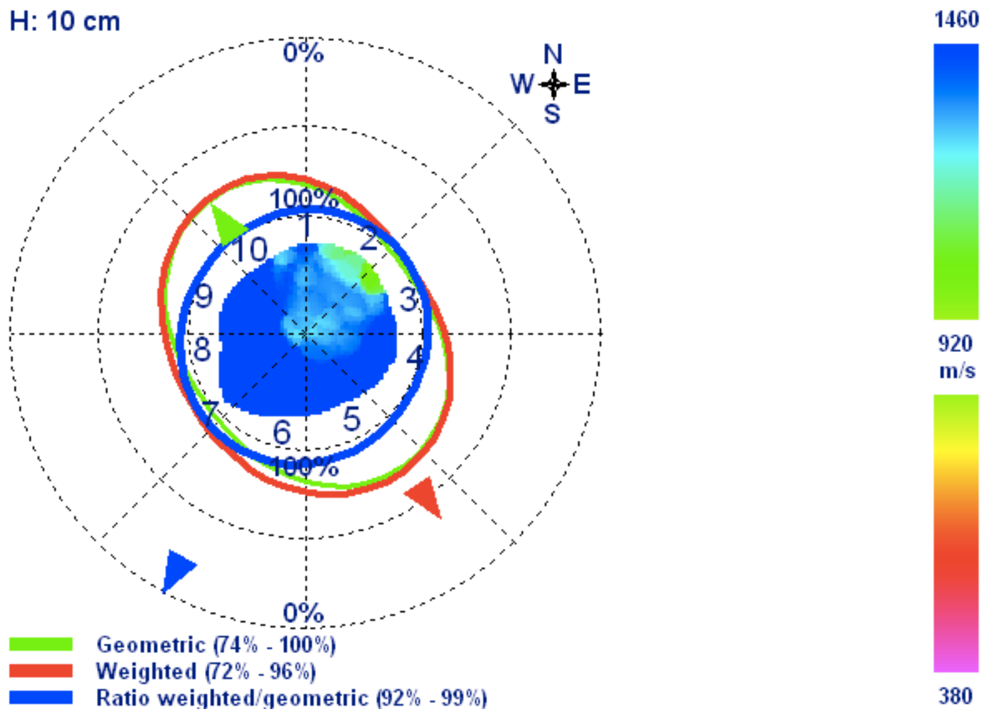
What is interesting, is how much sound sapwood remains. Because this is the load bearing material, that may be reliably measured.

In this case, the decayed area only represents a 7% relative strength loss.

Project:
Location:

Tree: 485
Tree species: Tilia

Date: 2014-03-20
North: 0°



🟩 Geometric (74% - 100%)
🟥 Weighted (72% - 96%)
🟦 Ratio weighted/geometric (92% - 99%)

Dynamics oscillation and oscillation bending

- An important aspect of the transfer of energy from wind, to the stem and roots, is the damping of oscillations.

- Damping causes a decrease in the amplitudes of free oscillations and these reduces the danger of resonance catastrophe in dynamic winds.

- There are two principle types of damping.
Fluid damping and viscous damping.

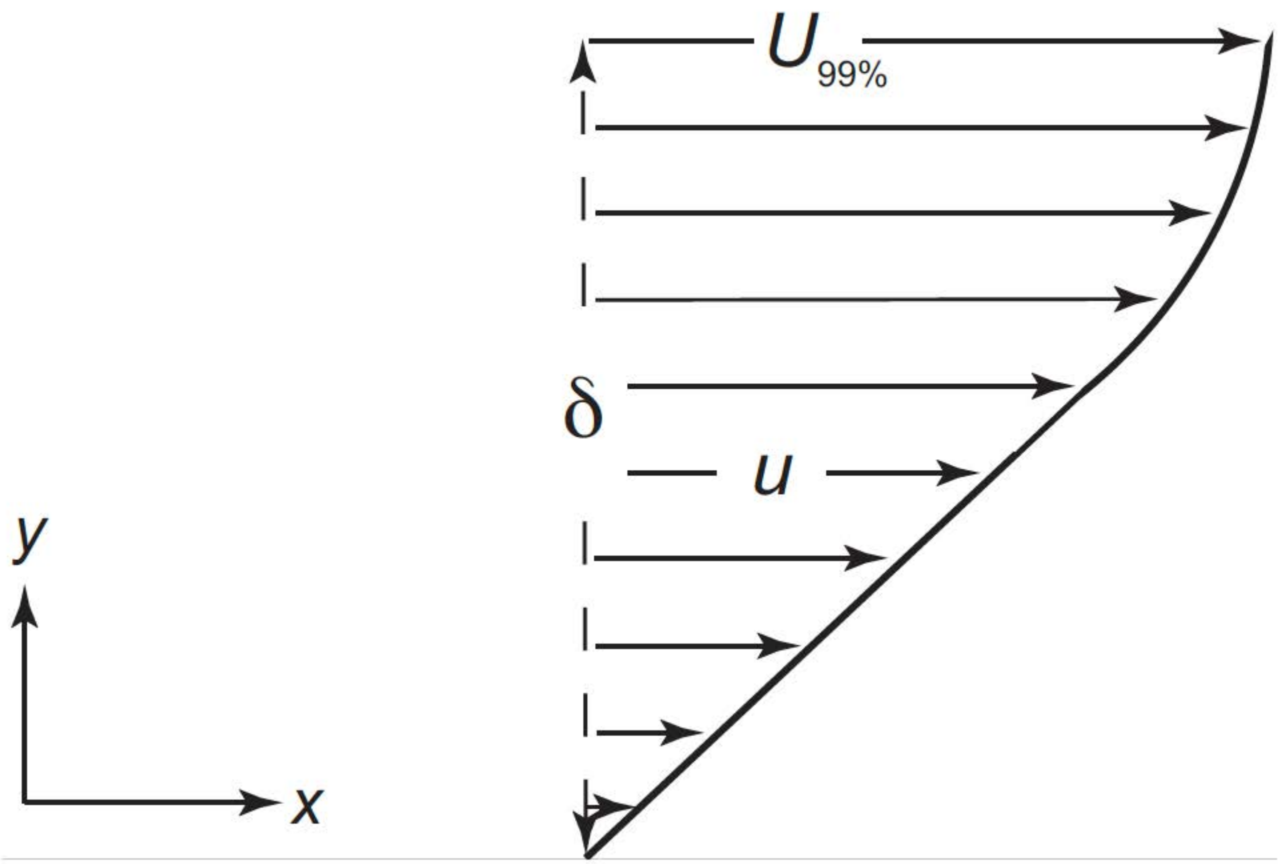
- Fluid damping is the distribution of energy into the surrounding medium, in this case wind, essential during fl

- Viscous damping is related to the relative movement of adjoining branches moving in consort with one another, usually this energy is dissipated as heat through the wood.

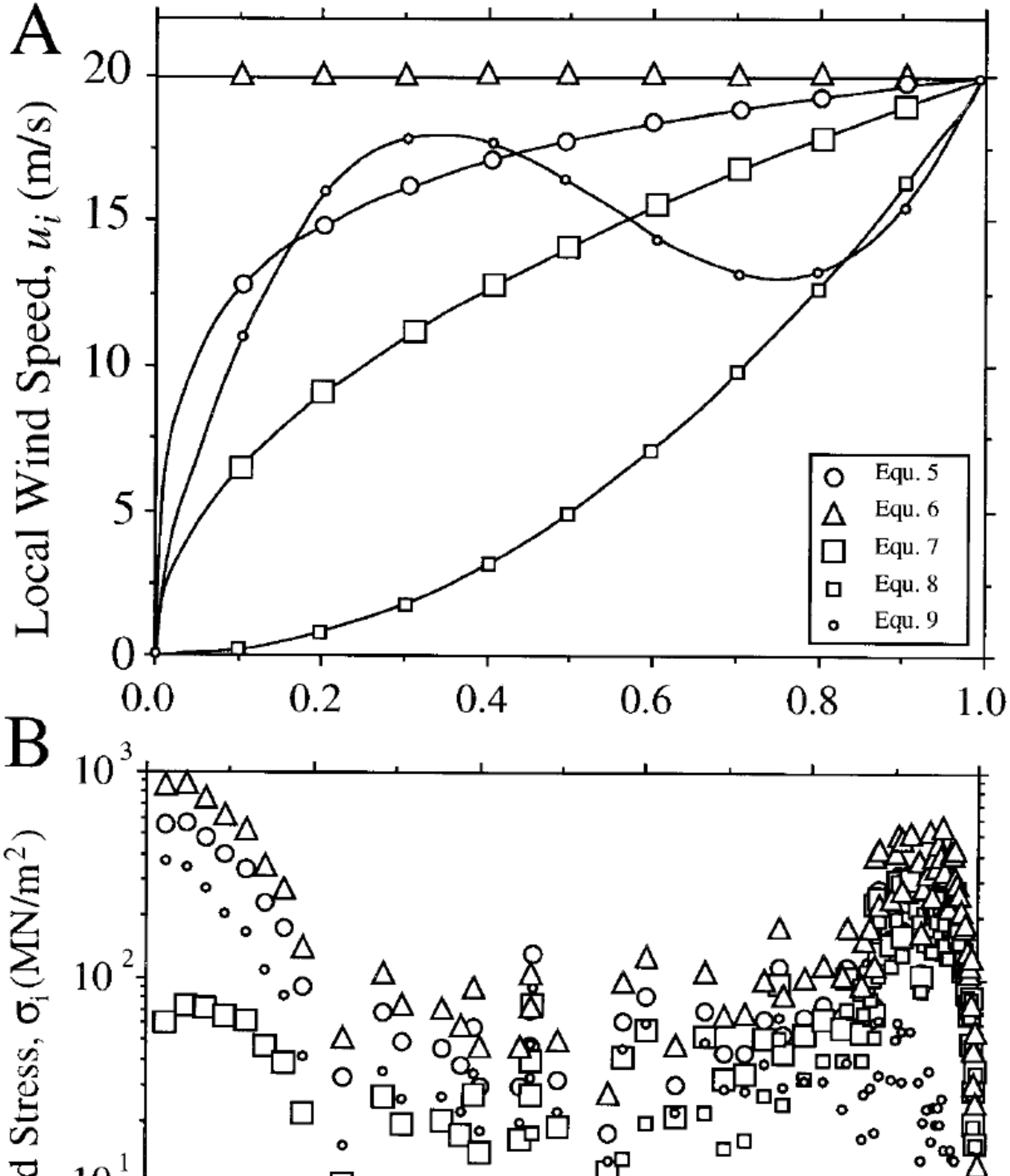
- What are the sequences of damping in canopies?
- Branches do not sway in line with one another, rather the move independently of the subtending limbs effectively counteracting the movement.
- Energy is dissipated between twigs and branches

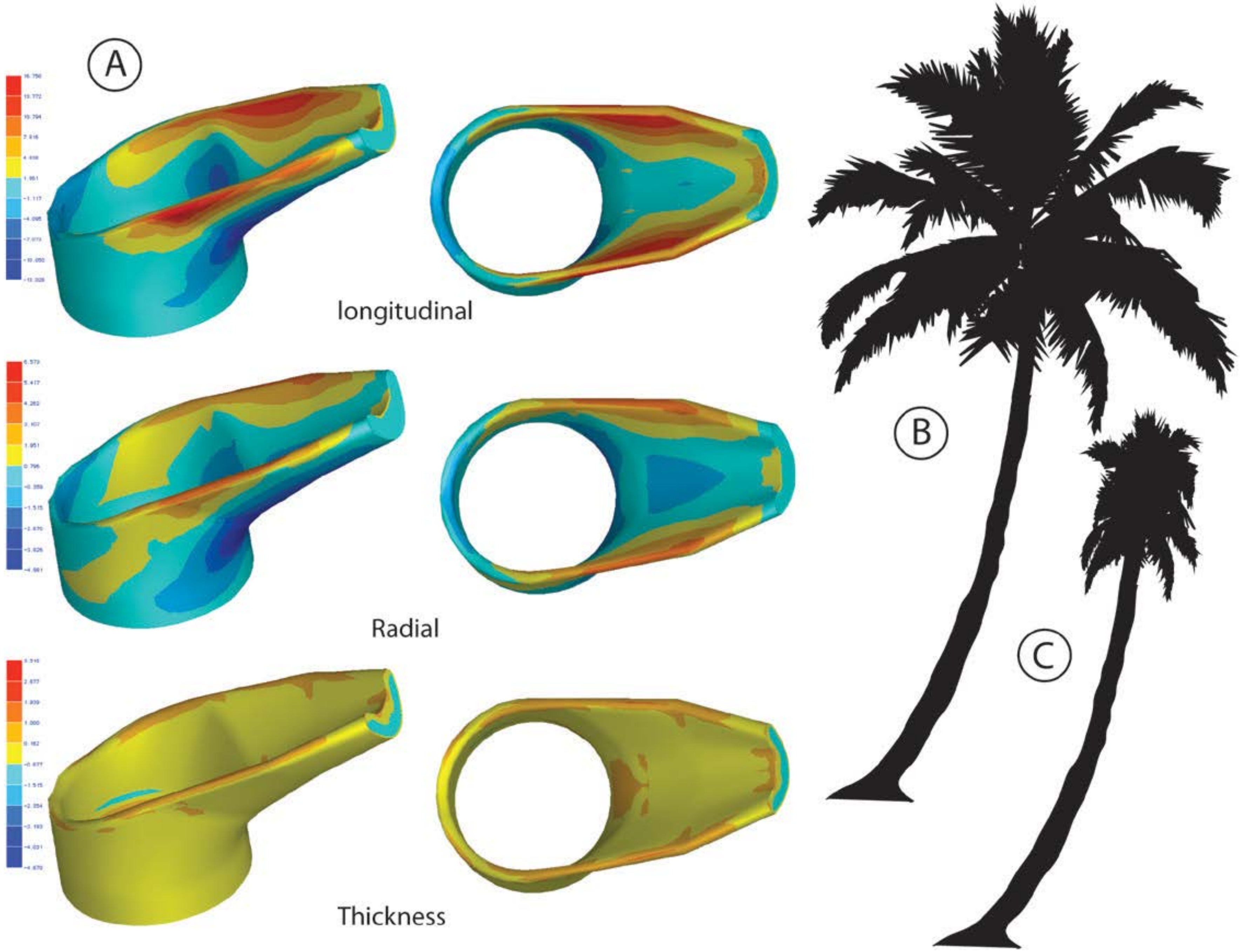
- Multiple resonance dampening is essential to reduce strain on the stem and major roots in windy environments.

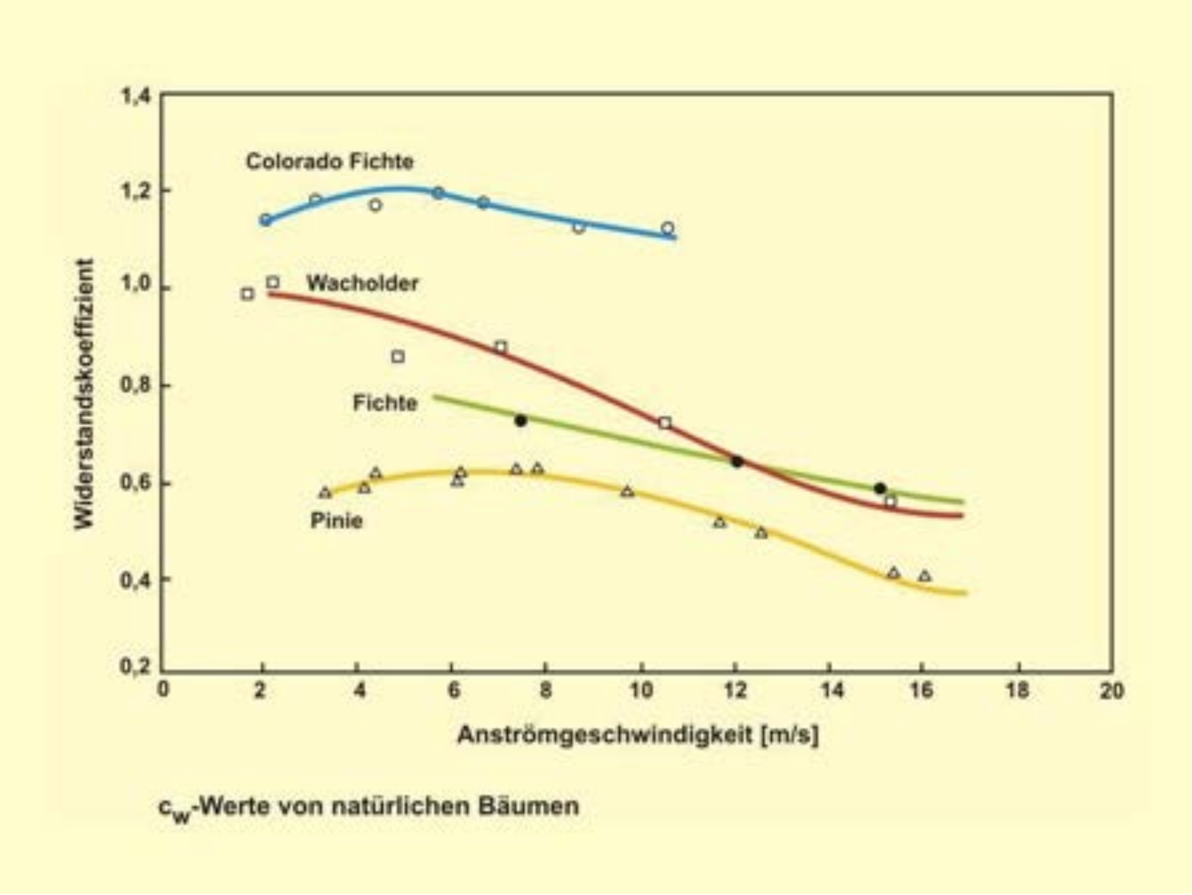
Light thinning of the tips of branches will destroy dampening and increase drag induced wind load.



$U_{99\%}$
δ
u
y
x


A
Local Wind Speed, u_i (m/s)
0
5
10
15
20
0.0
0.2
0.4
0.6
0.8
1.0
Equ. 5
Equ. 6
Equ. 7
Equ. 8
Equ. 9
B
d Stress, σ_i (MN/m^2)
10^3
10^2
10^1


A
16.750
13.772
10.794
7.816
4.838
1.861
-1.117
-4.095
-7.073
-10.050
-13.028
longitudinal
6.573
5.417
4.262
3.107
1.951
0.796
-0.359
-1.515
-2.670
-3.826
-4.981
Radial
3.516
2.677
1.839
1.000
0.162
-0.677
-1.515
-2.354
-3.193
-4.031
-4.870
Thickness
B
C



c_W-Werte von natürlichen Bäumen

- Drag and flexibility
- Tree scan and do change their shape
- Stems bend, leaves and shoots reshape.
- This reconfiguration dramatically reduces drag by reducing the projected surface areas and increasing fluid flow.
- Note, the arrangement of the central pith of shoots, their geometry and the microfibril angles of wood fibres in twigs are dimensioned for very high safety factors. Pruning, particularly reduction and subsequent regrowth, changes the material properties and flexural strength of these structures in wind.

How relevant is flexibility to stability?

Elastic modulus of Anisotropic material, living wood and Poisson ratios.

Some biological materials and many fabricated materials, such as metals, can be treated as isotropic elastic materials, or nearly so; therefore, ν and E alone can be used to predict their mechanical behavior. **For anisotropic materials, however, the relationship between stresses and strains and the material moduli must be empirically determined.** For these materials, the moduli must be reviewed in greater detail, starting with the elastic range at which stress and strain are proportionally related to one another (for linear elastic materials) and then progressing to a treatment of the range at which stresses and strains are not proportionally related (for nonlinear elastic materials).

Unfortunately, the literature rarely provides the elastic modulus for each of the various directions in which forces can act on an anisotropic plant material (or the Poisson's ratios from which some of the elastic moduli could be calculated). Nonetheless, these elastic moduli are essential. For instance, **the elastic modulus of wood submitted to uniaxial compression along the direction of the grain, symbolized by EL, can differ by one or two orders of magnitude from the elastic moduli measured in the tangential and radial directions to the grain** (denoted by ET and ER; see fig. 4.5).