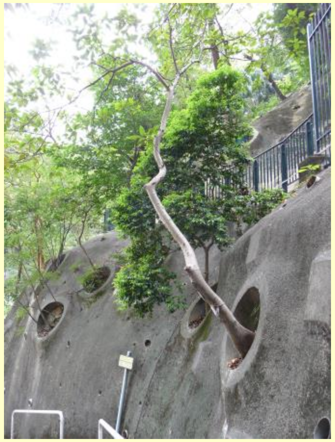
Urban trees are not stand alone structures

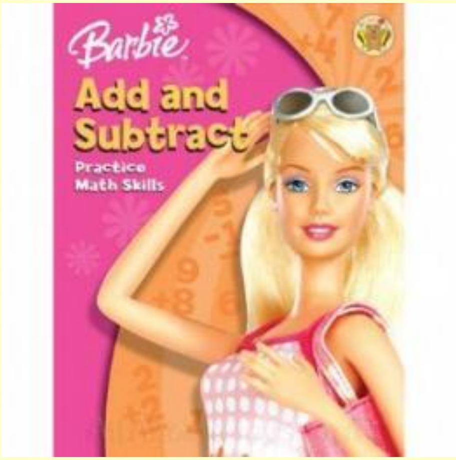
Improving knowledge of mechanical stability by considering local environmental conditions

Alexia Stokes

Botany & Plant Architectural Modelling Lab, INRA Montpellier, France


Disclaimer



I am not an engineer or a mathematician or a modeller…

Biomechanics helps me to:

- to understand why trees behave the way they do
- to describe in a quantitative way what I can see **intuitively**

The first major publication incorporating all the elements (stems, roots and soil) required to describe a tree's mechanical stability was published >50 years ago by A.I. Fraser.

The Soil and Roots as Factors in Tree Stability

A. I. FRASER 1962

Forestry Commission Research Station

Scientific research is like a detective story. There are clues and red herrings. Since the first paper in 1962, several hundred journal papers and book chapters have been published. Which have driven the field forward, and are there any red herrings?

Agatha Christie

*A **Red herring** distracts the reader from the original story. It is also a literary device that leads readers or characters towards a false conclusion, often used in mystery or detective fiction.*

Red Herring No 1 – Biomechanics is hard

Biomechanics is intuitive…..

….to a point

What is hard is putting numbers to it and providing an assessment…

Intuitively…..
Where will this tree break in the next big storm?

- *Fraxinus pennsylvanica*
- About 60 years old
-Growing at the Morton Arboretum, Illinois, USA,
-There is no dominant prevailing wind direction

Clue: in a dense stand next to a field.

To fully understand biomechanics ‘intuitively’ – we need to consider a tree’s ecological context

Tall pioneer species

Tall tree species which reach the canopy at the end of succession

Short understory tree species

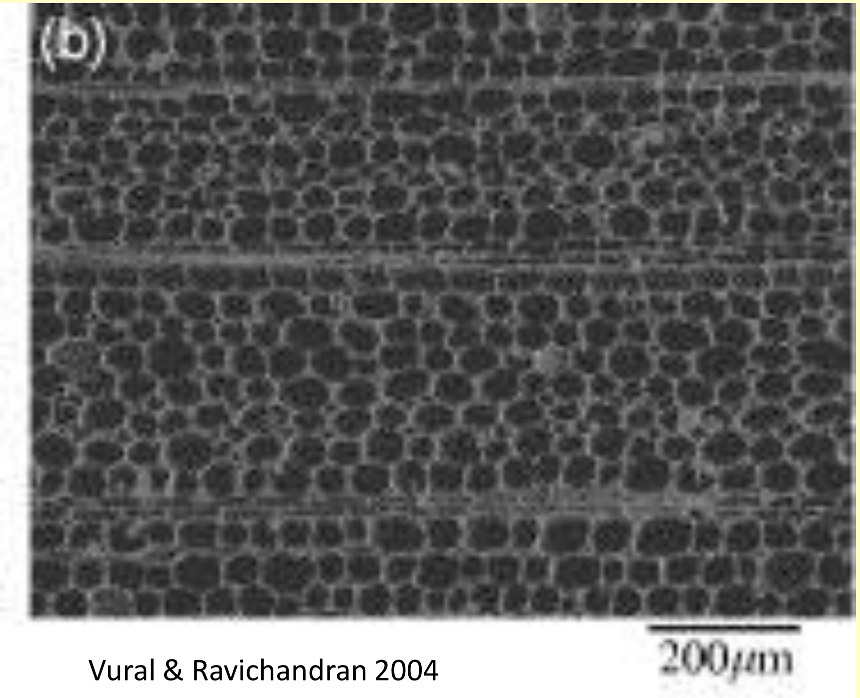
Or why do trees grow where and how they do?

Van Gelder et al 2006

$$\textit{Wood density} = \frac{\textit{Dry mass of a volume of wood}}{\textit{Equal mass of a volume of water}}$$

Depends on wood structure

Low density = Balsa wood
Weak wood



High density = Ebony
Strong wood

A study of 30 rainforest tree species in Bolivia

Tall, sun-loving & short-lived pioneer species want to grow quickly towards the canopy. Therefore the wood is less dense for faster growth.

Branches, fruits etc drop onto the short , shade tolerant, understory trees. Their wood is more dense so that they can resist failure from the debris falling on them.

Tall long-lived tree species which grow slowly and move in at the final succession phases have more dense wood so that they keep their place in the tall canopy. They are more resistant to wind loading.

Van Gelder et al (2006); Larjavaara and Muller-Landau (2010)

If we take a tree out of its ecological context – and put it into another environment – does it behave the same?

Red herring no 2:

50 years research into Sitka spruce (*Picea sitchensis*) stability in Great Britain

http://www.geolocation.ws/v/W/File:Knocklaird%20-%20geograph.org.uk%20-%20440408.jpg/-/en

'Not a real tree' A.R. Ennos

Sitka spruce is supposed to grow in N. America on deep soils….

http://www.forestryimages.org/browse/detail.cfm?imgnum=5369199

In UK, a very shallow root system

Picea sitchensis
Downward growing roots
asphyxiated by winter water table

BC Nicoll

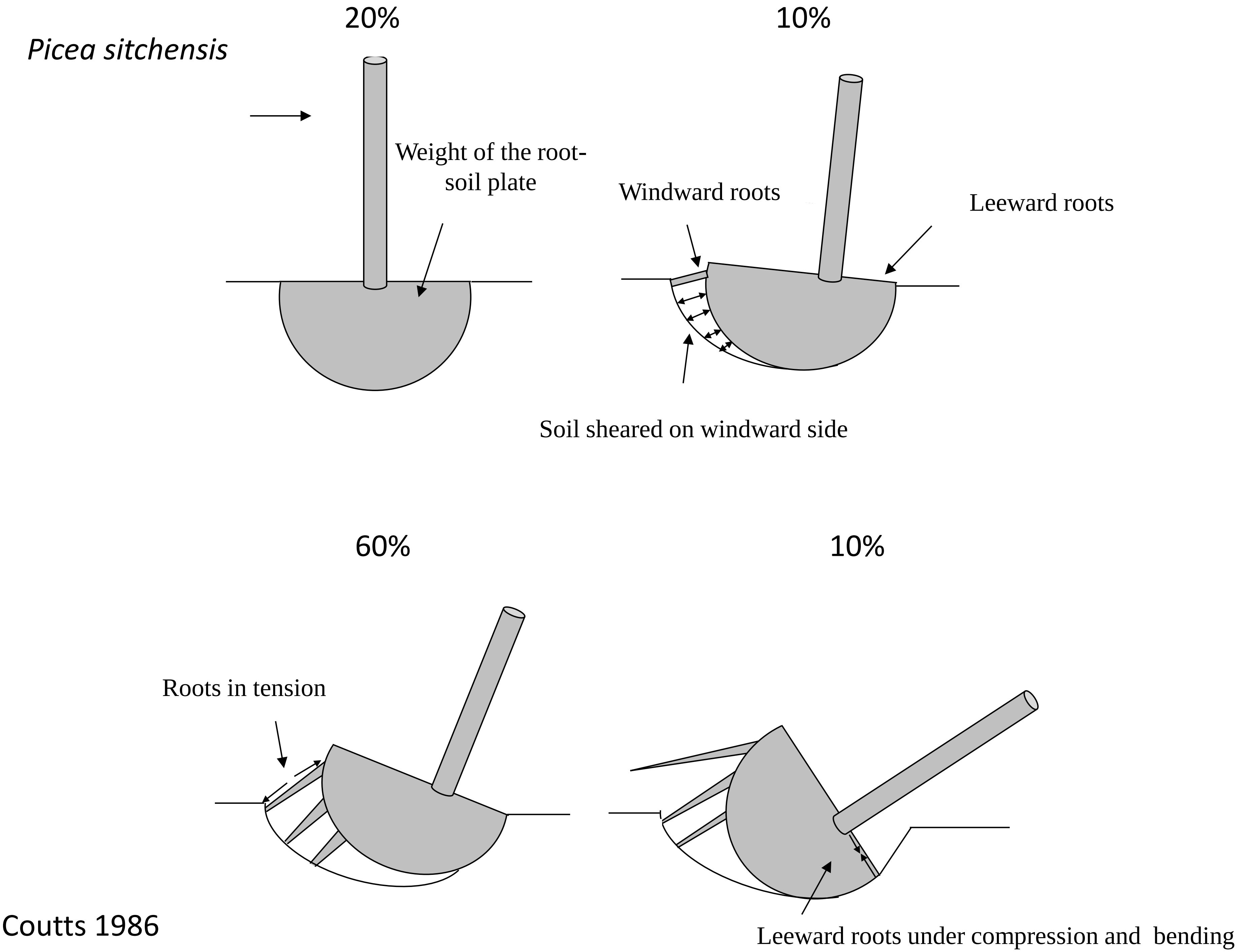
Forestry *(1986) 59 (2): 173-197*

Components of Tree Stability in Sitka Spruce on Peaty Gley Soil

M. P. COUTTS

Forestry Commission, Northern Research Station, Roslin, Midlothian, EH25 9SY, UK

Cited 181 times, which is huge for a paper on tree root biomechanics!



20%
10%
Picea sitchensis
Weight of the root-soil plate
Windward roots
Leeward roots
Soil sheared on windward side
60%
10%
Roots in tension
Leeward roots under compression and bending
Coutts 1986

The Soil and Roots as Factors in Tree Stability

A. I. FRASER

Forestry Commission Research Station

1962

(With 1 plate)

SUMMARY

The paper describes a method of studying the factors affecting tree stability by measuring the forces required to pull trees over. It indicates that *Fomes annosus* root rot may reduce a tree's resistance to overturning by about 30 per cent. and that drainage in shallow peat soils can increase resistance by some 25 per cent.

Concluding sentence:

'It is a fundamental prinicple of soil mechanics that increase in soil moisture decreases the soil strength and must therefore be expected to influence tree resistance to windthrow'

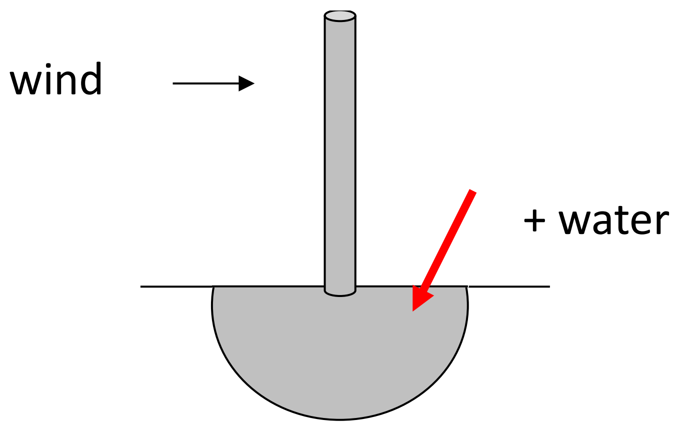
After 50 years…

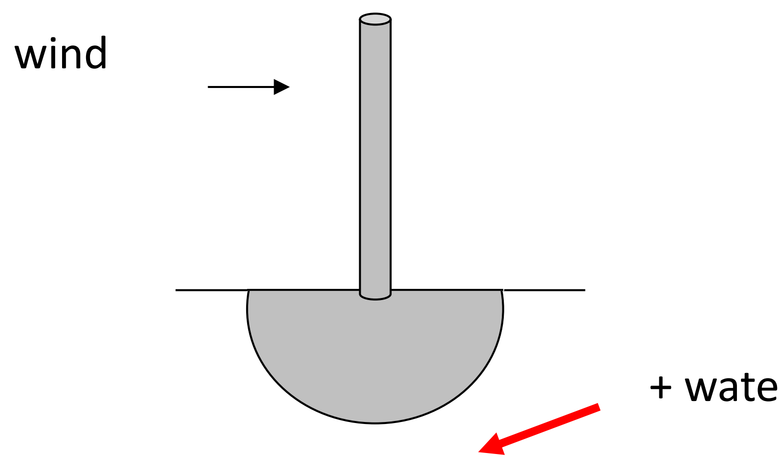
Eur J Forest Res (2012) 131:219–227
DOI 10.1007/s10342-011-0508-2

ORIGINAL PAPER

Root anchorage of hinoki (*Chamaecyparis obtuse* (Sieb. Et Zucc.) Endl.) under the combined loading of wind and rapidly supplied water on soil: analyses based on tree-pulling experiments

K. Kamimura · K. Kitagawa · S. Saito ·
H. Mizunaga

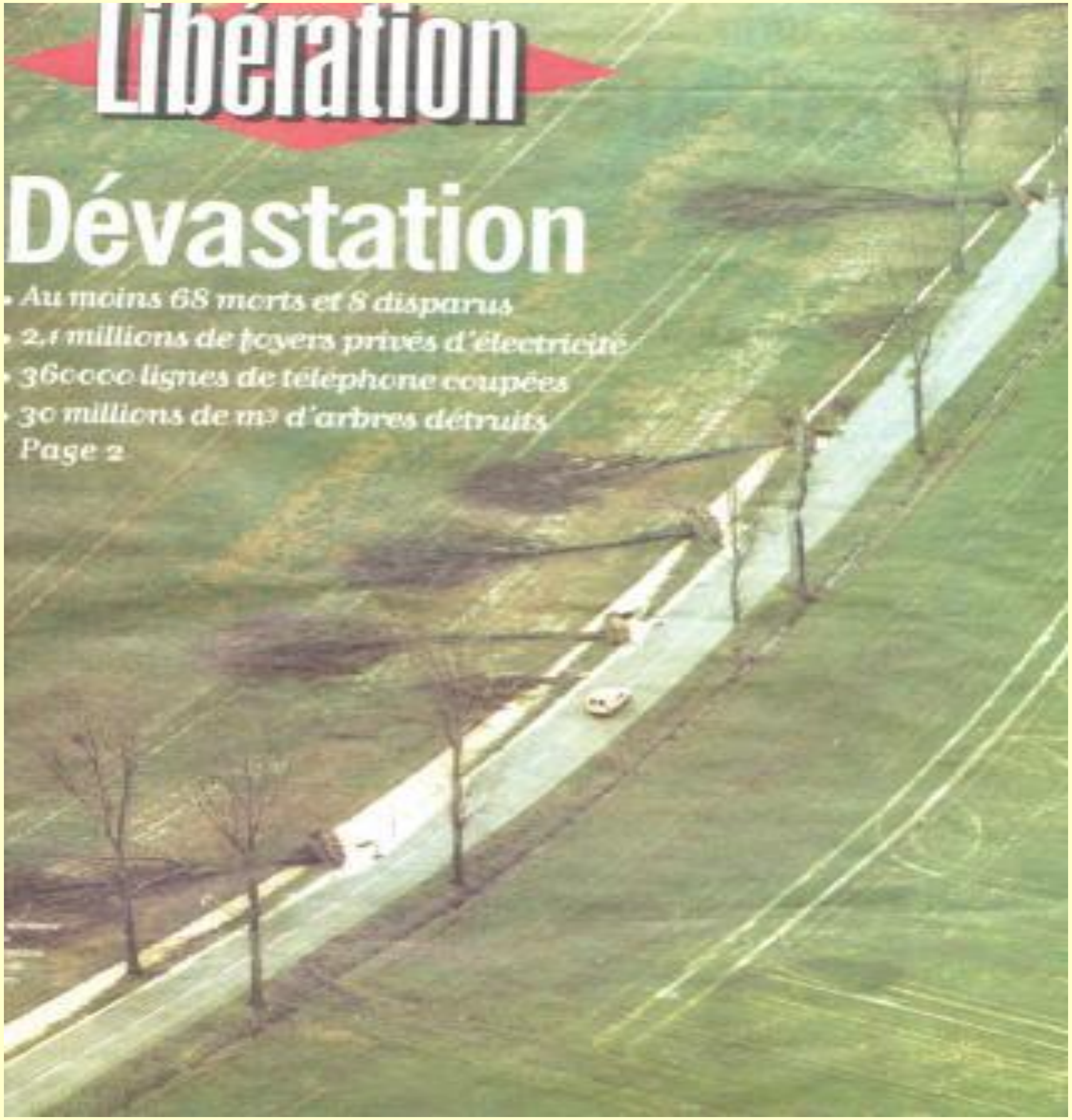




Add water to **INSIDE** the root-soil plate = increases anchorage because the weight of the plate increases

Add water to **BELOW** the root-soil plate = decreases anchorage because roots slip out of wet soil more easily and cohesion is decreased

Why did the trees on the left fall over?



Libération

Dévastation

- Au moins 68 morts et 8 disparus
- 2,1 millions de foyers privés d'électricité
- 360000 lignes de téléphone coupées
- 30 millions de m³ d'arbres détruits

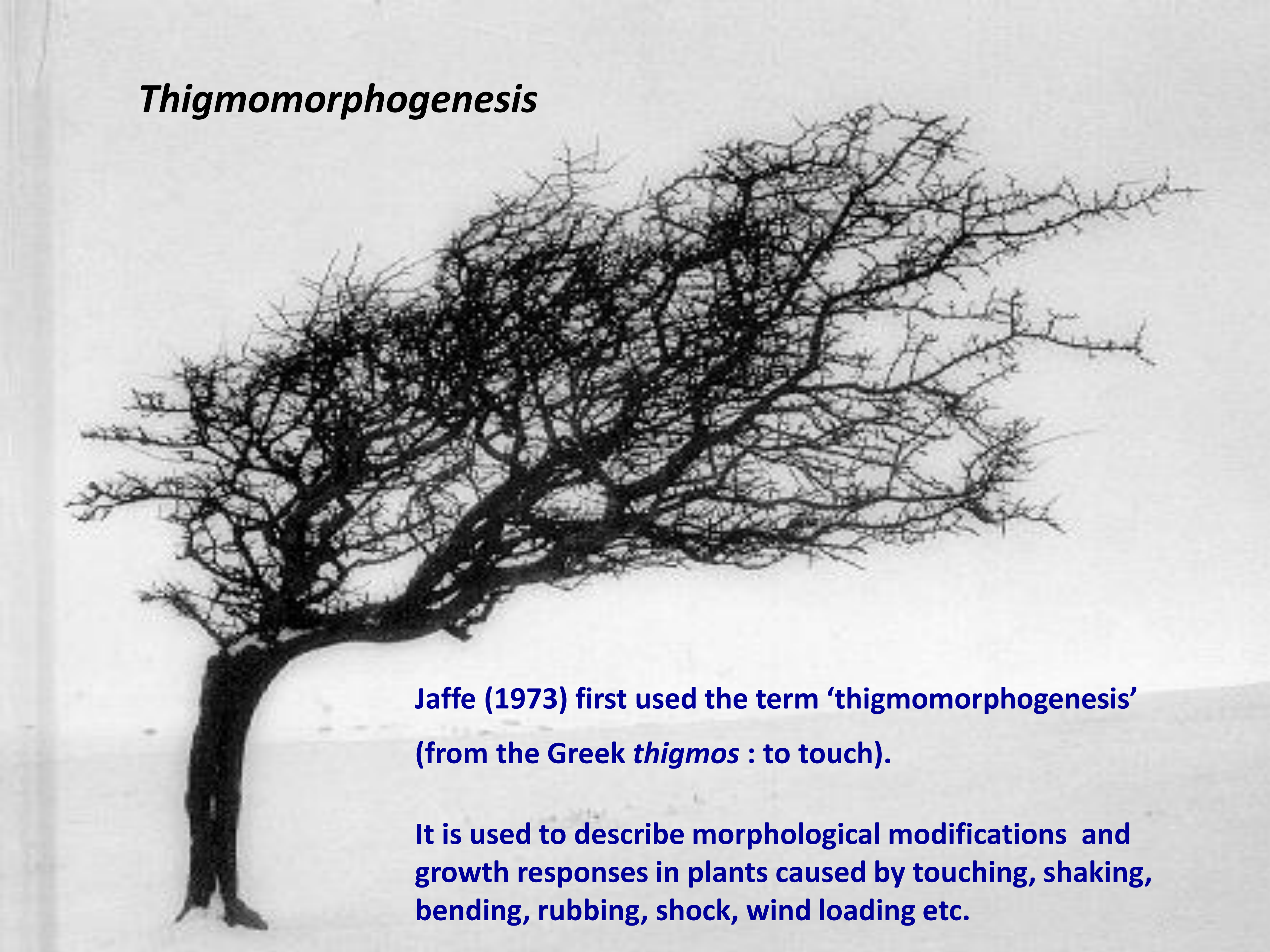
Page 2

Clue - Road

If growing in a windy environment, the tree will undergo certain growth processes to help resist mechanical failure

Pacific Rim National Park, Vancouver Island

Thigmomorphogenesis



Jaffe (1973) first used the term 'thigmomorphogenesis'

(from the Greek *thigmos* : to touch).

It is used to describe morphological modifications and growth responses in plants caused by touching, shaking, bending, rubbing, shock, wind loading etc.

Guying

After 2 years, the roots were thicker in the controls (no guying).
The guyed trees fell over after the first major wind storm.

Maxwell Jacobs 1954

Flexing machine

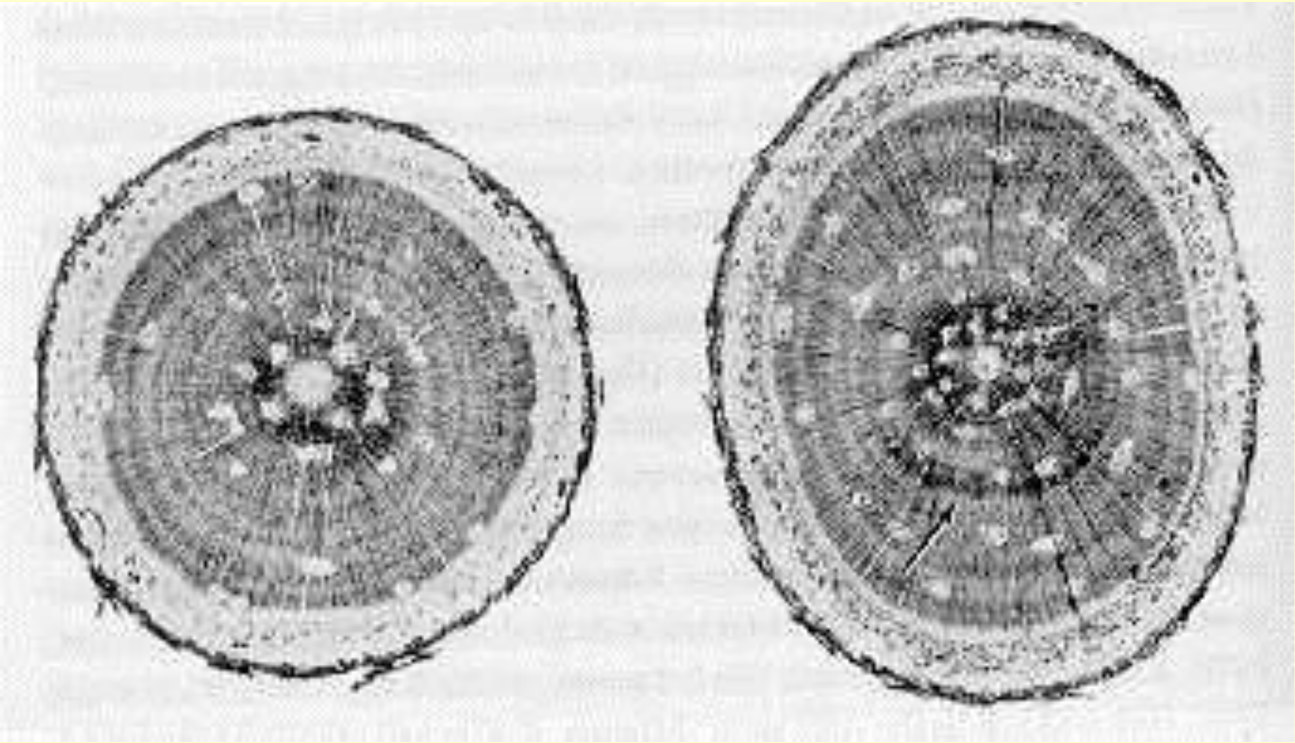

Wind tunnel

Pinus pinaster

WIND

30 km/h

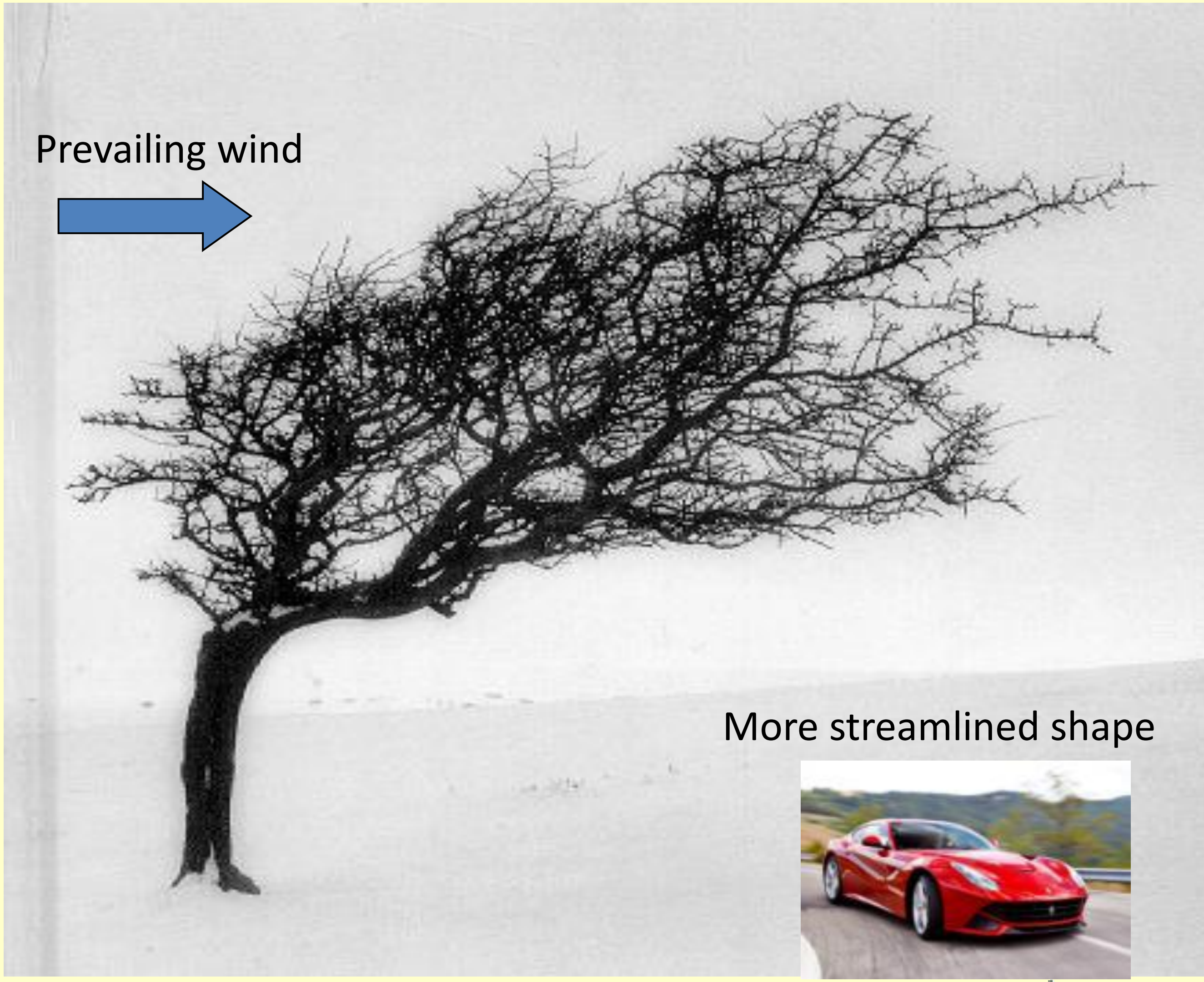
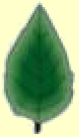
Cross-sections of young *Pinus taeda* stems

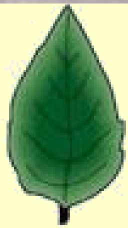


Control Plant **Flexed Plant**

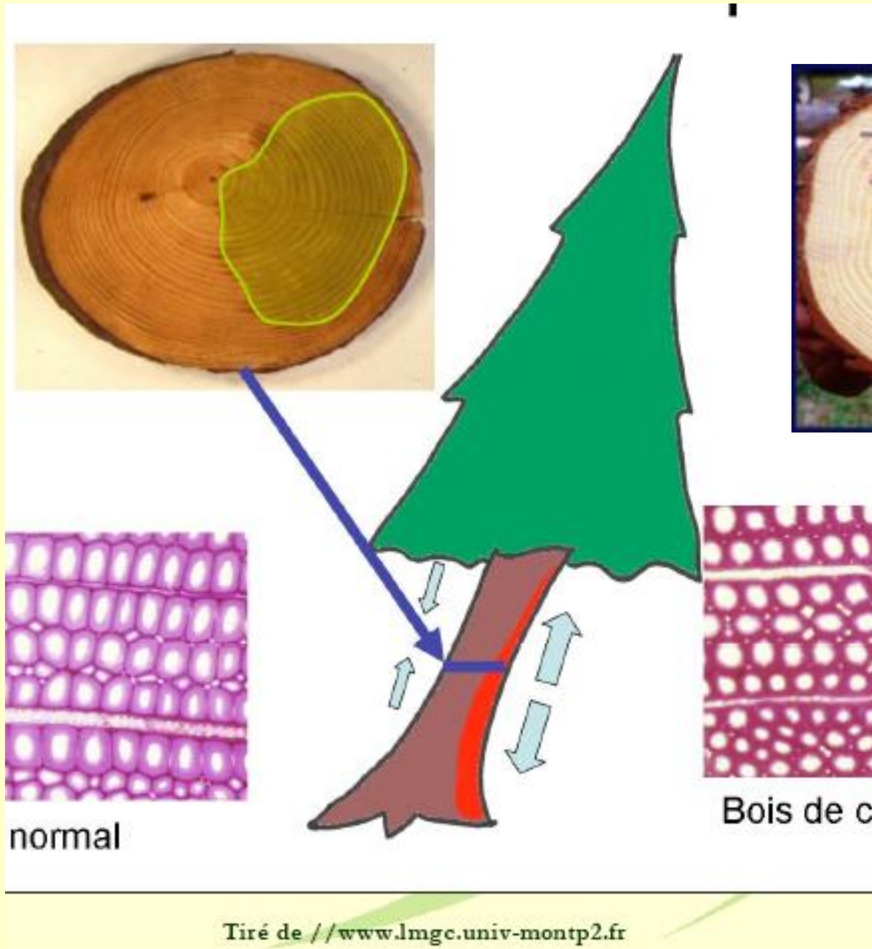
Direction of flexing (in two directions only)

(Telewski 1990)


Prevailing wind
More streamlined shape

Smaller
leaves


Bigger leaves

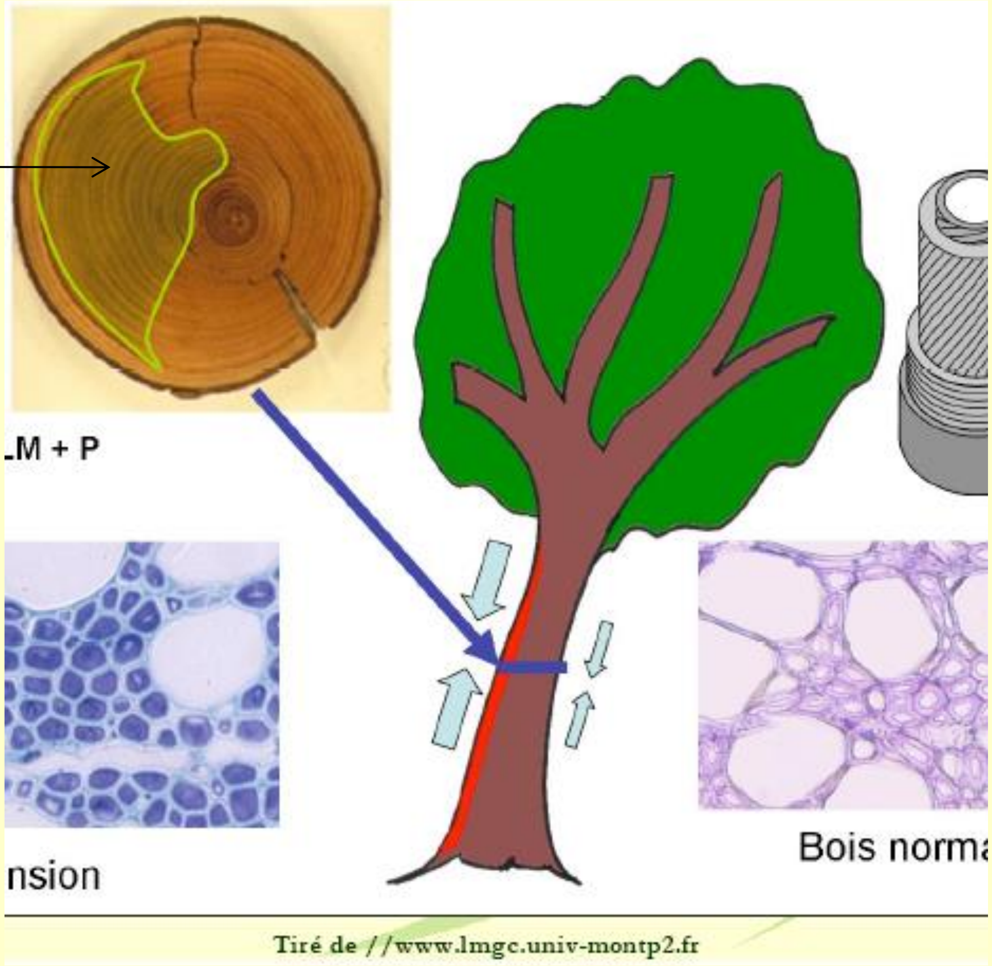
GYMNOSPERMS (CONIFERS)



If tree is displaced during wind loading – can produce reaction wood (or ‘compression’ wood) on one side of leaning tree

ANGIOSPERMS (BROADLEAVES)

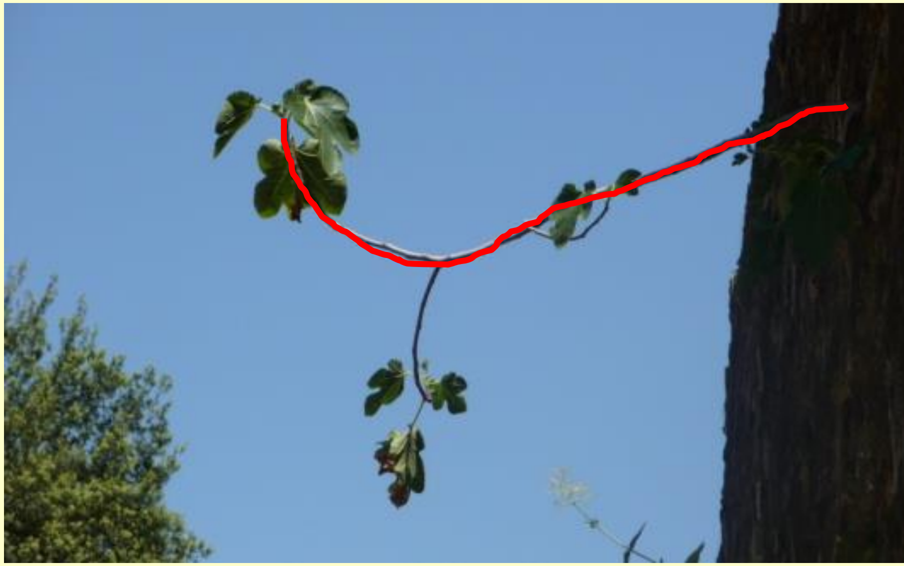
Tension wood



If tree is displaced during wind loading – can produce reaction wood (or 'tension' wood) on one side of leaning tree

Red herring No 3 – Trees want to grow straight

Fraxinus pennsylvanica



‘Wall’ tree (Fig) in Florence, Italy

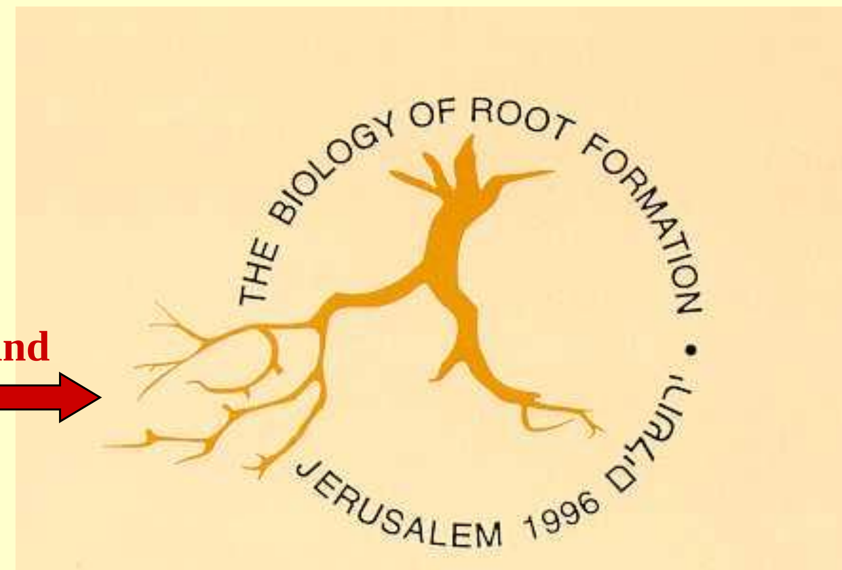
These trees are happy to lean to the sunlight.

Roots

Roots on the windward ‘tension’ side of tree were thinner and more branched in young *Picea* growing in a wind tunnel

Young *Picea* in a wind tunnel

wind



50 year old *Pinus pinaster*

Le Monde

Pinus pinaster
50 years

Comparison of root systems from trees uprooted or still standing after the 1999 storm

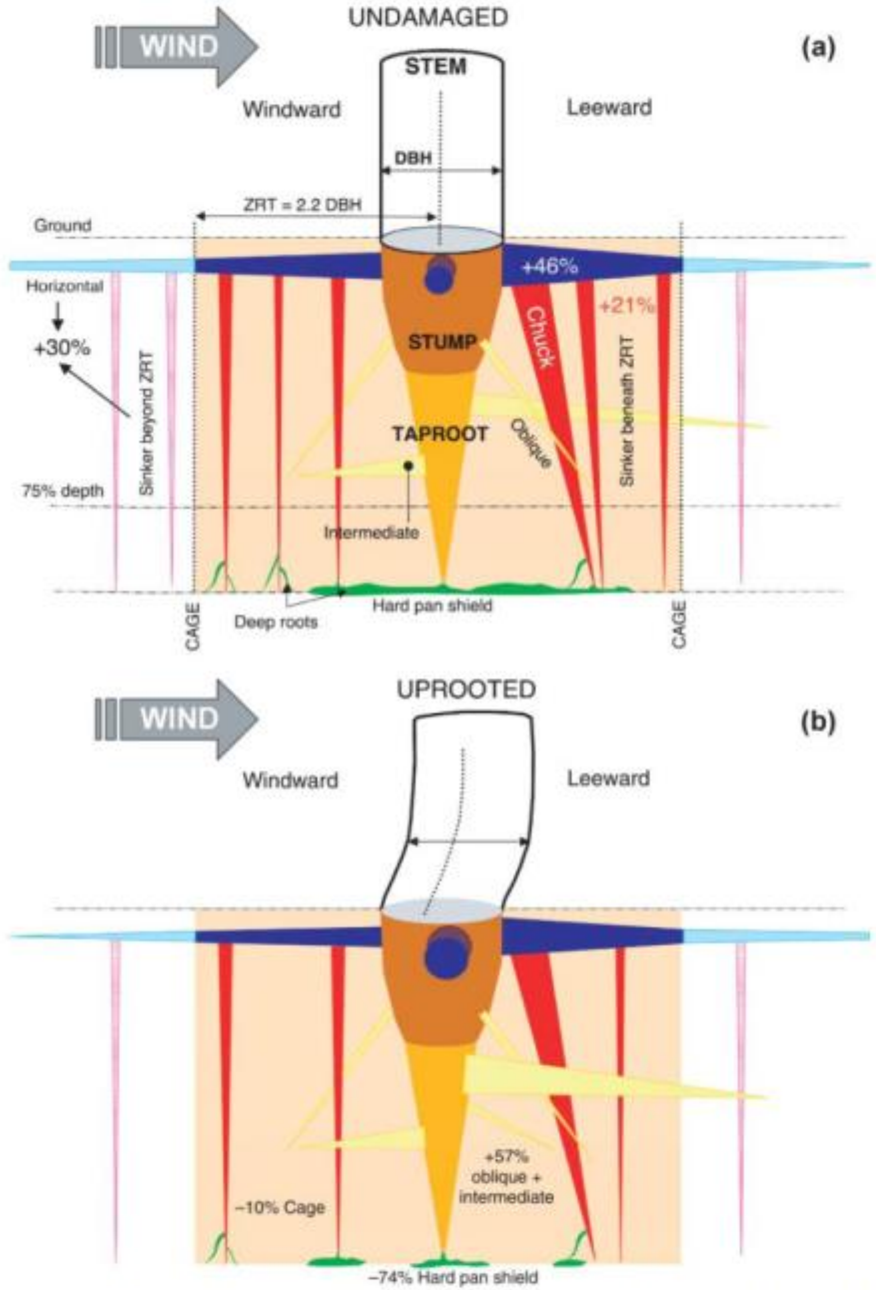
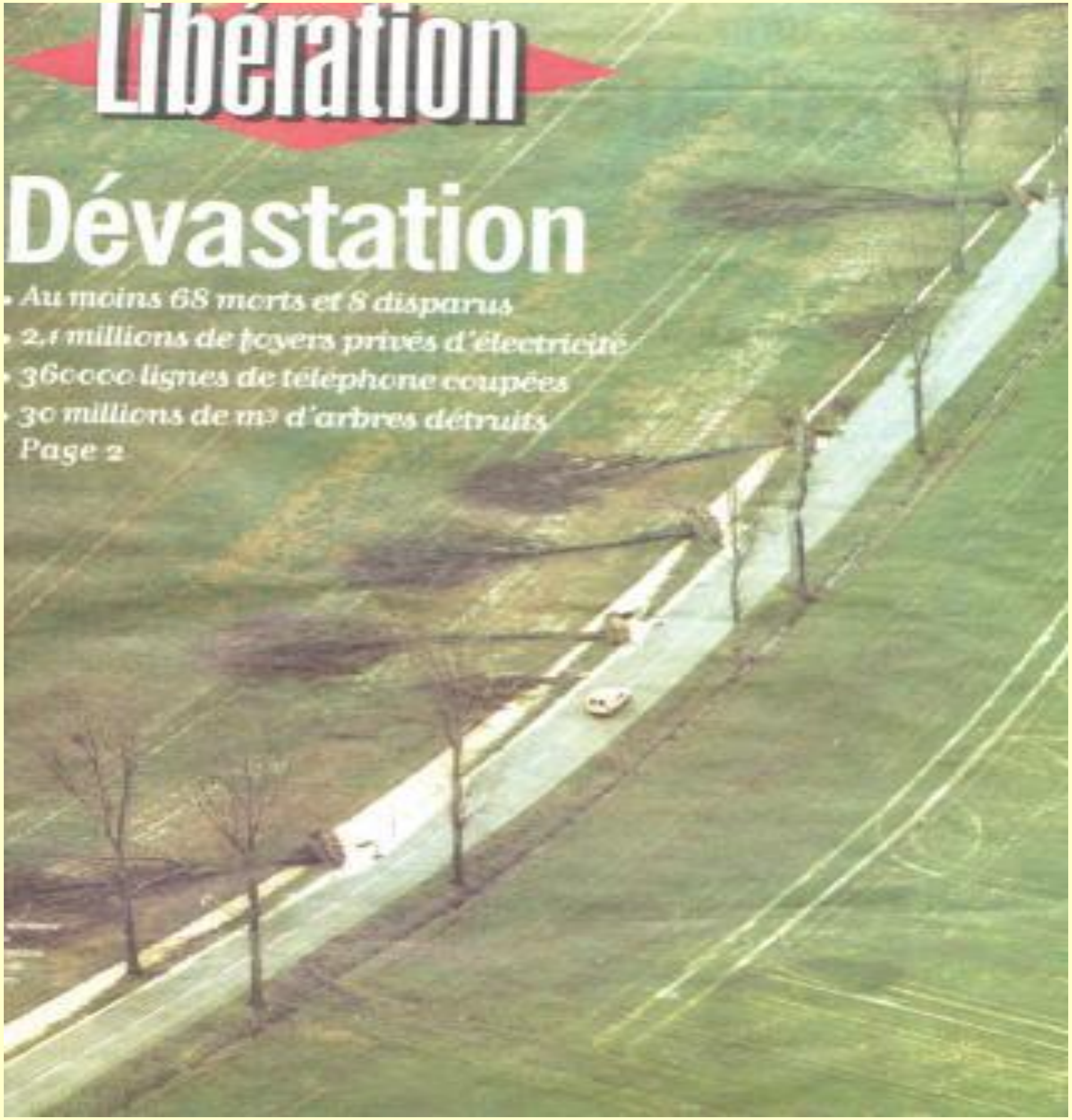


Fig. 4 Schematic representation of mature *Pinus pinaster* root systems grown on sandy spodosol. Root number and size is arbitrary. (a) Undamaged tree, the percentages refer to the prevailing wind oriented reinforcement in the corresponding compartments. (b) Uprooted tree, the percentages refer to the difference in root volume proportion compared with undamaged trees; uprooted trees exhibited wind-oriented reinforcement only in the intermediate and oblique roots compartment (+50% leeward).

Danjon, et al (2005)

Why did the trees on the left fall over?



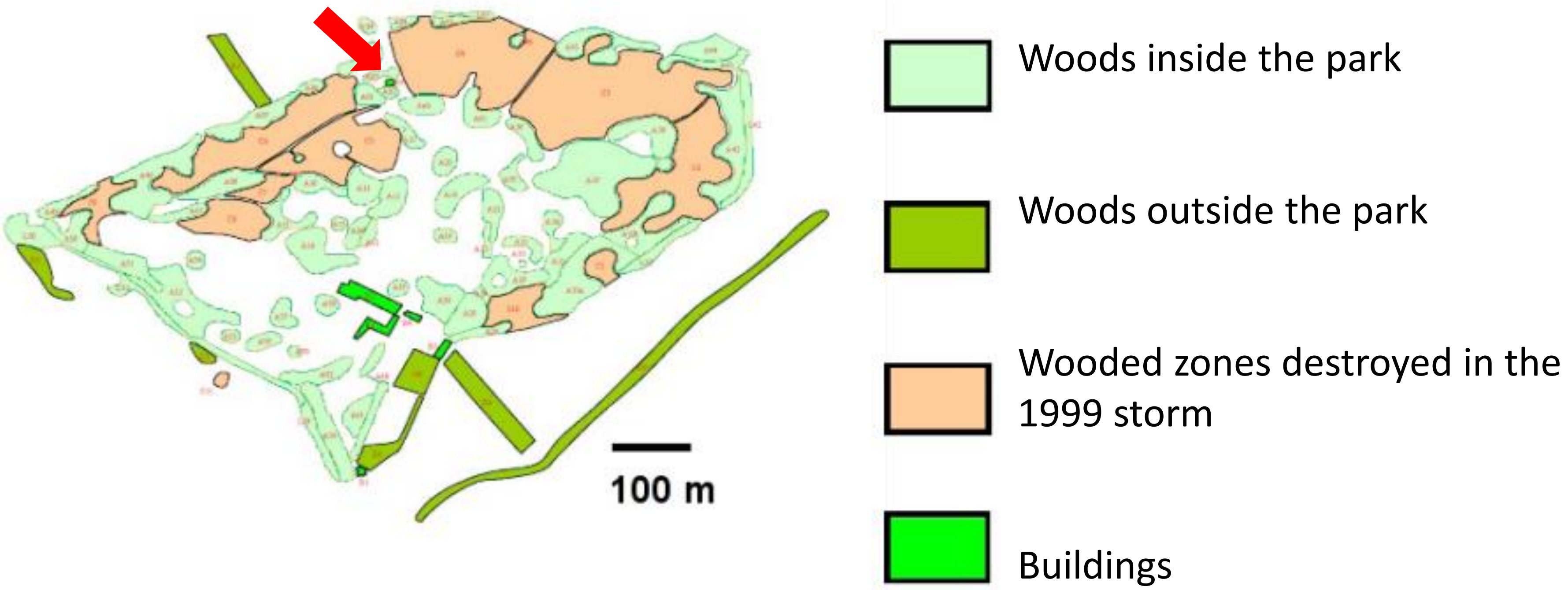
Sooooo……

A tree's life seems to be composed of a series of trade-offs and it will never be optimised for one single function

So a tree can be prepared for all sorts of eventualities

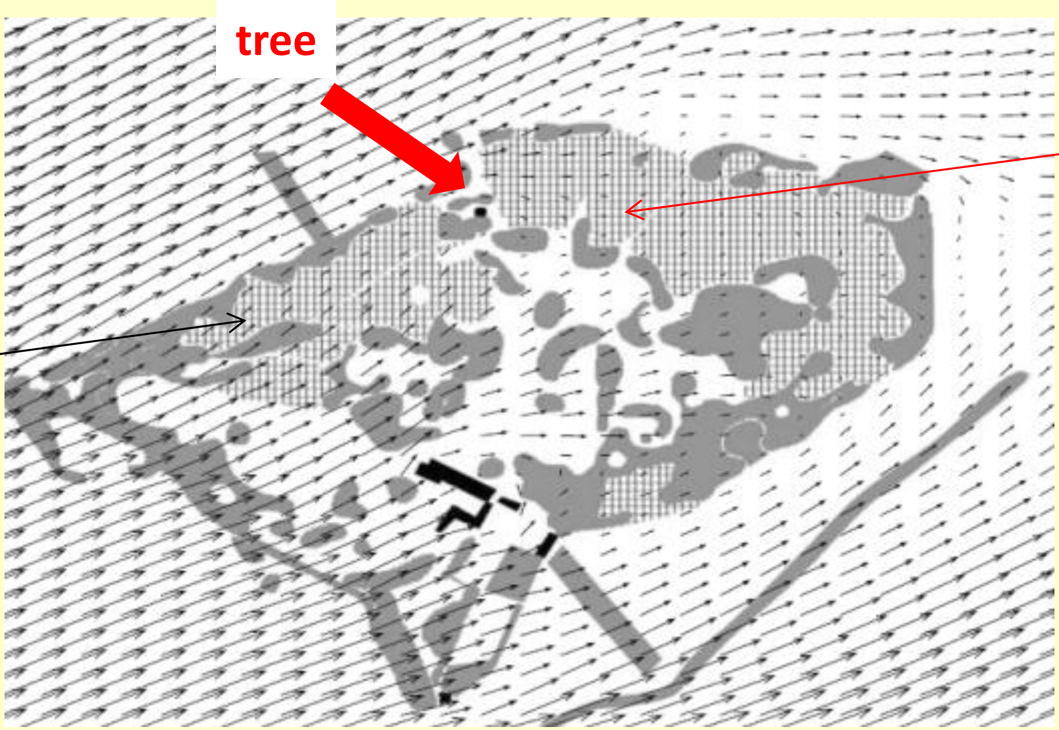
As long as its local environment does not change suddenly…

Parc de Pourtalès, Strasbourg, Northern France in 2003.
A London plane tree - 40 m tall & weighing 70 tonnes fell in a summer storm & killed 13 people, injuring over 100 people



(Dupont et Brunet, 2007)

Wind intensity and direction at 3 m above the ground



Zones without trees (after the 1999 storm)

High level of turbulence

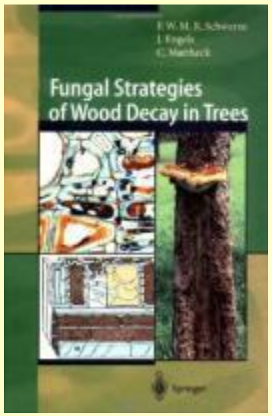
Long arrows = high windspeed

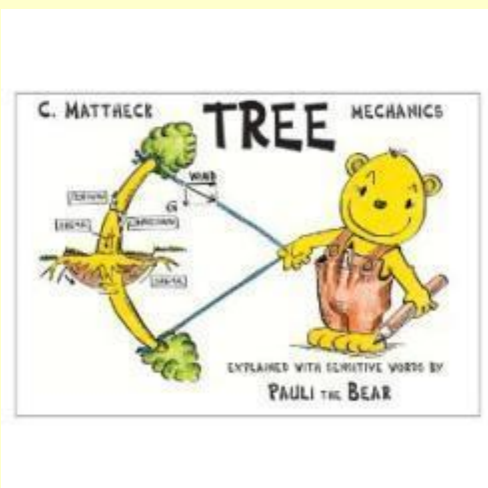
Because the neighbouring trees had fallen in the 1999 storm, turbulence around the plane tree occurred and it was not acclimated to the new windy environment.

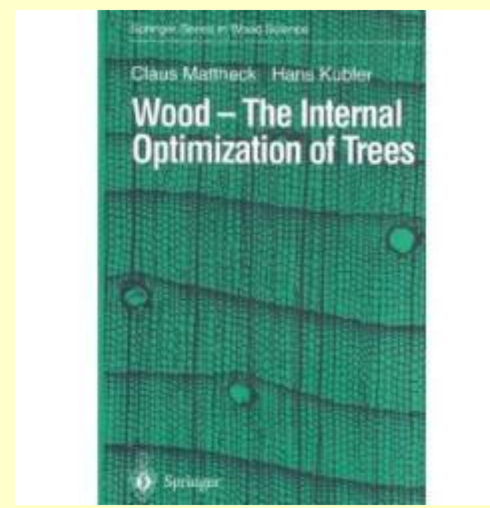
We live in a highly fragmented landscape = turbulence and wind corridors!

Wind maps for managers of parks and urban forests – the field is wide open…

Claus Mattheck has gone a long way to help us understand biomechanics ‘intuitively’







Red Herring No 4 - A tree is not a 'chain of equal links' nor is it fully optimised for mechanical stability

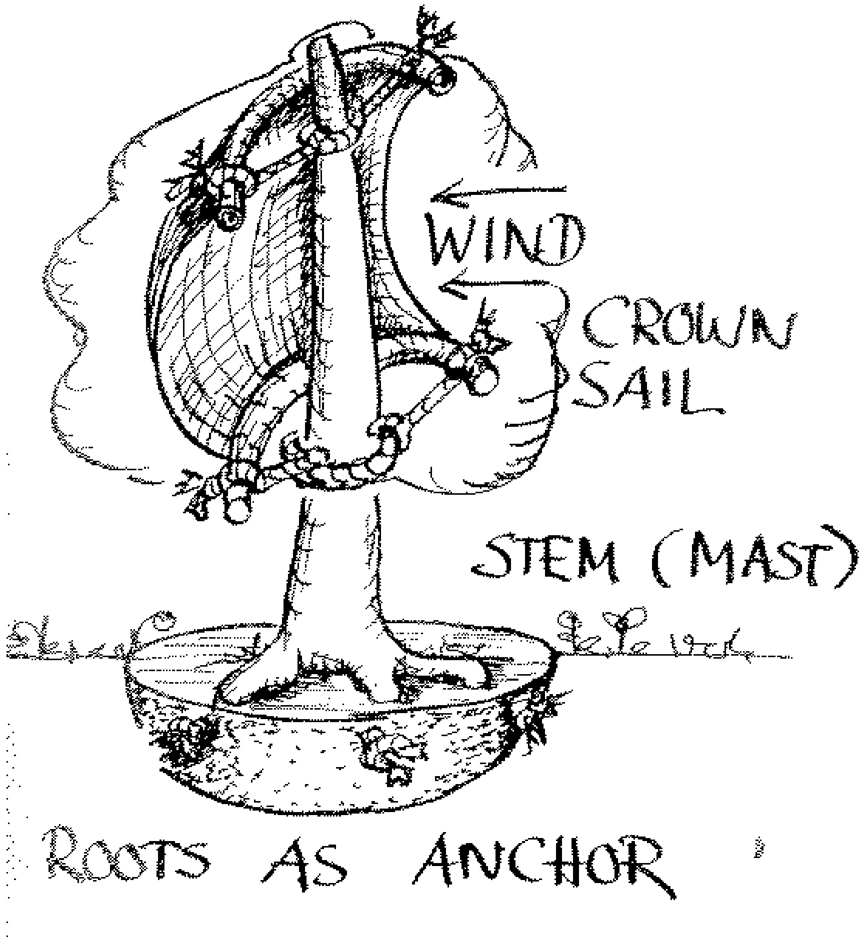


Fig 50. The tree as a chain of equal links. The incoming wind load is transferred via the stem into the root ball and from there into the ground.

Journal of Experimental Botany, Vol. 51, No. 344, pp. 617–633, March 2000

Journal of Experimental Botany

Brittleness of twig bases in the genus *Salix*: fracture mechanics and ecological relevance

Heike Beismann[1,6], Hiltrud Wilhelmi[2], Henri Baillères[3], Hanns-Christof Spatz[4], Arno Bogenrieder[1] and Thomas Speck[5]

Looked at branch mechanics of several *Salix* species

http://spiralis123.files.wordpress.com/2011/07/salix-fragilis1.jpg

Salix fragilis (riparian)

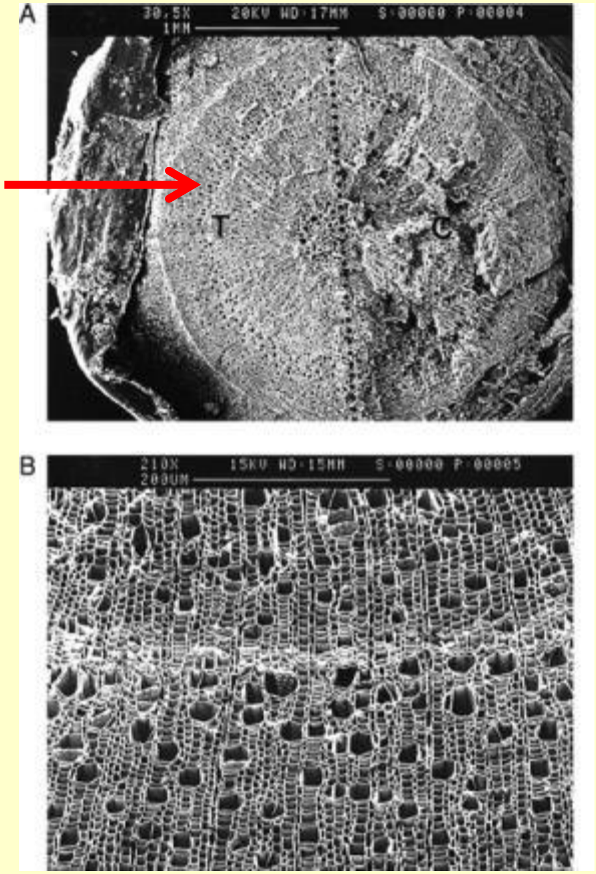
Salix appendiculata (subalpine)

River species (flooding)

Mountain species (snow loading)

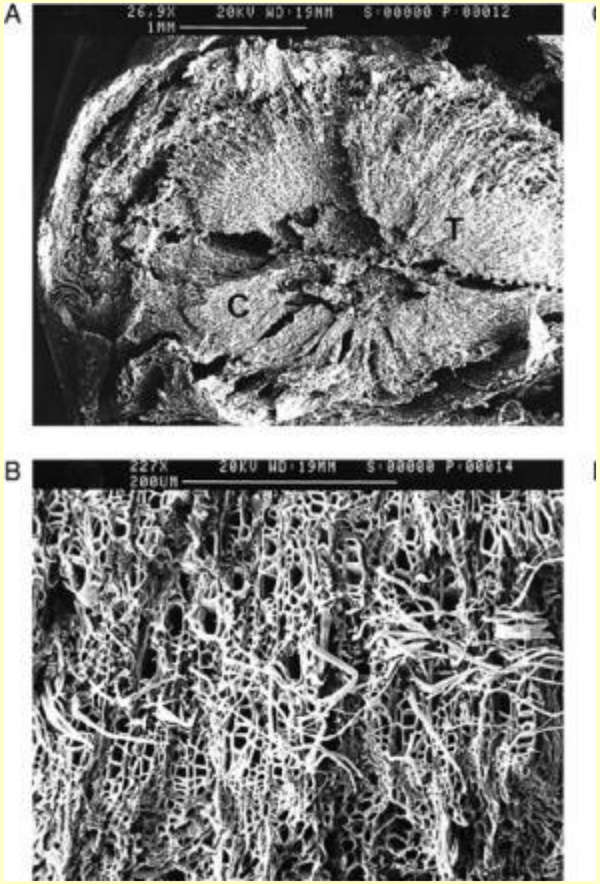
Salix fragilis.

Tension side of failed branch



Smooth failure surface. Easy to break. Very brittle.

Salix appendiculata.



Rough failure surface. Difficult to break. Very flexible. Not brittle.

River species (flooding)

Salix fragilis.

Mountain species (snow loading)

Salix appendiculata.

Brittleness of twig bases seems to be an adaptation to mechanical loads, where it can function as a safety mechanism - **mechanical fuse** - reducing the probability of stem breakage by allowing twigs to be lost. For some species (*S. fragilis*) it also seems to be an adaptation to provide an additional reproduction mechanism, due to the transportation and subsequent establishment of the broken off twigs in new habitats.

So trees can benefit from ‘weak links’ in the chain

Can we use this knowledge in tree risk assessment?

Red Herring No 5 – A pruned tree is a more mechanically sound tree

The wind-sailing pruning technique is supposed to make trees ‘safer’ in the wind by allowing wind to pass through the canopy of a tree, thus reducing movement and strain on a tree

Wind-sailed tree

http://lukenstree.com/trees/the-myth-of-wind-sail-reduction/

Branches provide ‘damping effect’

Auracaria

– with branches, STABLE,

No branches, so tree whips around in the wind

- without branches, UNSTABLE

Sellier and Fourcaud 2005

Photos - Ken James

Derecho in Cedar Rapids, IA

http://www.youtube.com/watch?v=SH2JAd7dlT4

The outside branches can divert some wind from the center of the tree and act as a buffering shield.

Aggressive thinning can also make the remaining branches more vulnerable to failure now that they are isolated.

And as we have seen, trees know how to acclimate to windy conditions. They know better than us!

http://lukenstree.com/trees/the-myth-of-wind-sail-reduction/

Where will that tree break?

- *Fraxinus pennsylvannica*
-About 50 years old
- Very inclined
- Growing at the Morton Arboretum in a dense stand

Where will that tree break?

The ash’s need for sunlight was more important than its need to grow vertically.
So it deliberately grew inclined and was happy doing so!
It probably had a different wood anatomy to a straight tree.
Where would the reaction wood be?

What is governing tree growth and changes?

Karl Philipp Sprengel (1787 –1859) Sprengel was the first to formulate the "theory of minimum", meaning that plant growth is limited by the essential nutrient at the lowest concentration.

So if you have a pool of nutrients, growth is limited by the nutrient in shortest supply (even if all the other nutrients are abundant)

wikipedia

…not necessarily nutrients

At a given point in time, a tree's growth will be regulated by its biggest need – be it nutritive, mechanical, or physical

For example, if there is little wind, but light is limiting, a shade-intolerant tree will grow towards light patches in the forest canopy (up or outwards):

Fraxinus pennsylvanica

Even if it is a mechanical risk for the tree:

Cecropia peltata

CIRAD

Environmental factors to think about when considering tree stability

- Species
- Soil
- Wind
- Light
- Ecological niche
- Ecotype (or where does the tree material come from)?

Can explain many behavioural aspects of trees

My take home message……

Observation is the Mother of Hypothesis

Tree Biomechanics Research Symposium

August 15 - 16
Davey Institute
Kent, Ohio

Tree

Earn 8.5 CEUs

Learn about:

- tree stability, risk
- tree strength
- tree structure

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