Urban forest resilience through species selection

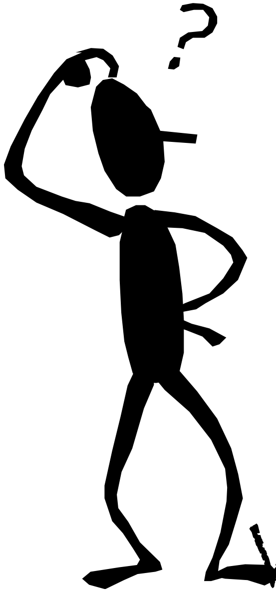
Andrew Hirons

Myerscough College

Arboricultural Association's 49th Annual Amenity Arboriculture Conference

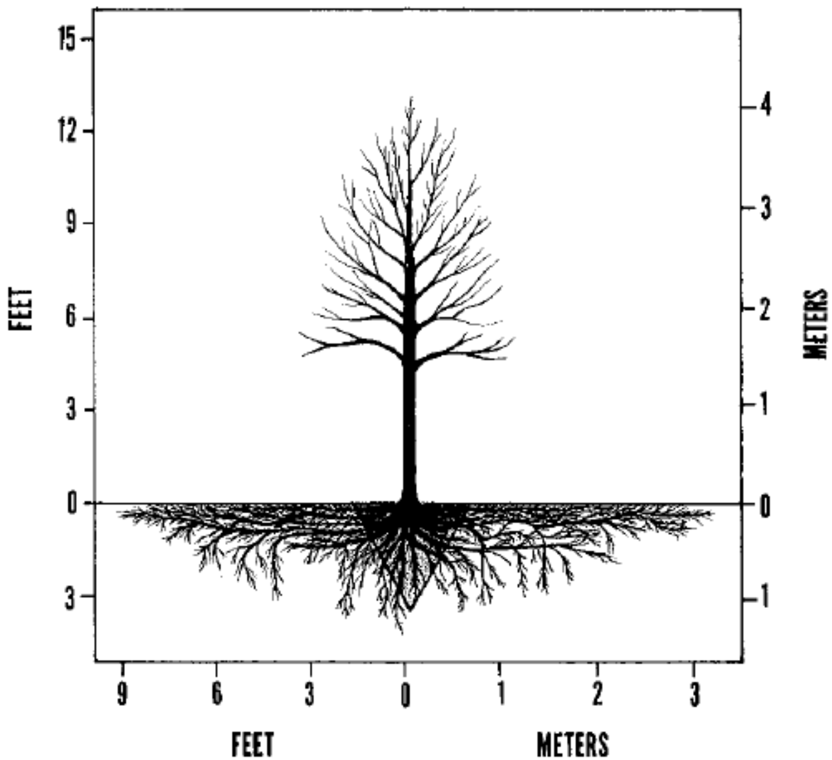
21st September 2015


Wide variation in growth environments
within urban areas.



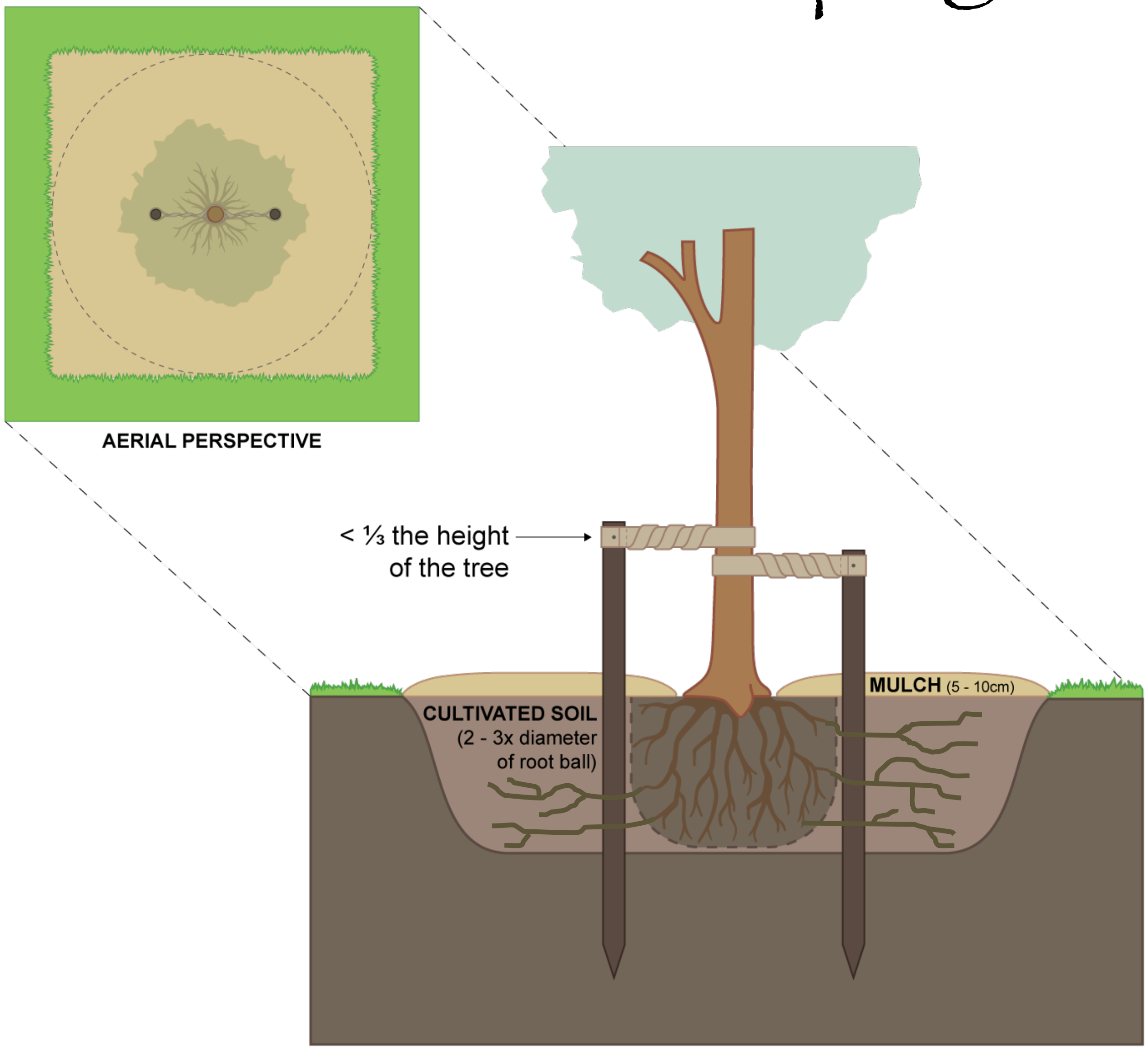
What are the major limitations to tree establishment in challenging urban environments?

Tree spades may remove 98% of the root system



Watson and Himelick (1982)

Root-Soil Coupling



Restricted soil volume

Impermeable surfaces

Few roots + small soil volumes + poor surface permeability = water deficits!

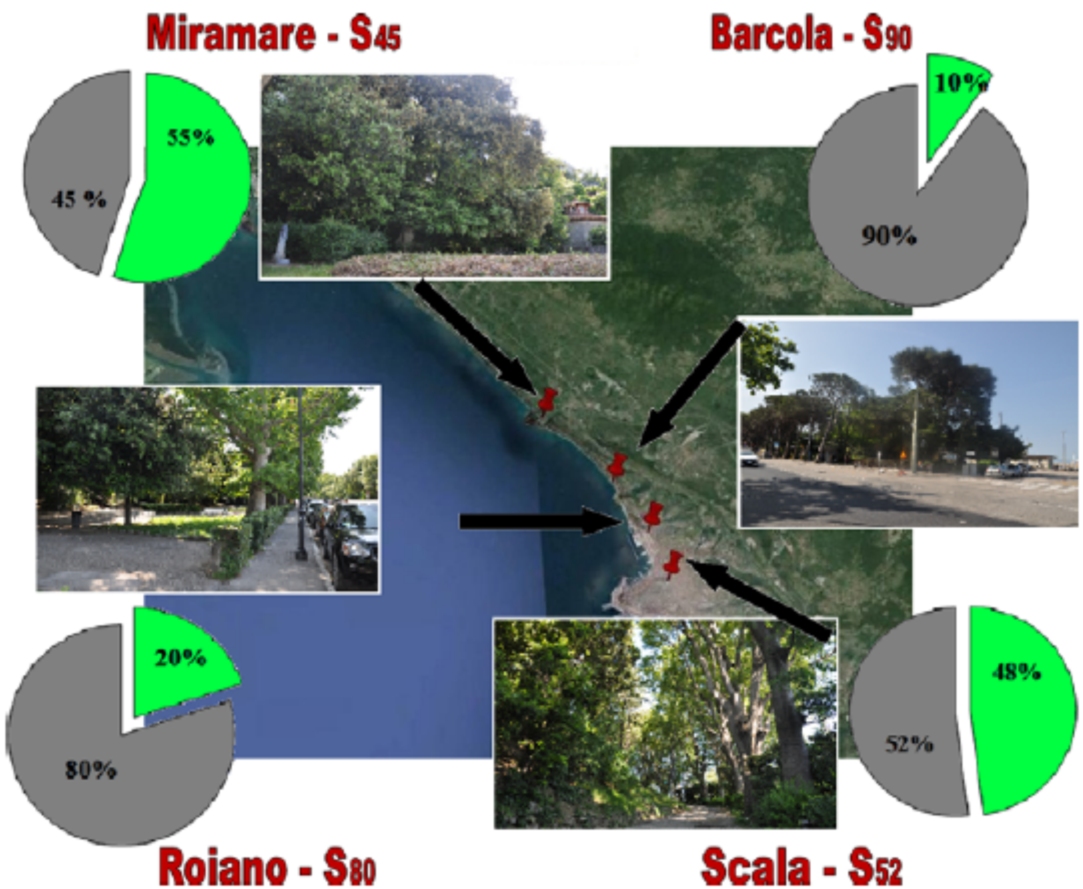
New Phytologist

Research

Drought-induced xylem cavitation and hydraulic deterioration: risk factors for urban trees under climate change?

Tadeja Savi, Stefano Bertuzzi, Salvatore Branca, Mauro Tretiach and Andrea Nardini

Dipartimento di Scienze della Vita, Università di Trieste, Via L. Giorgieri 10, Trieste 34127, Italy

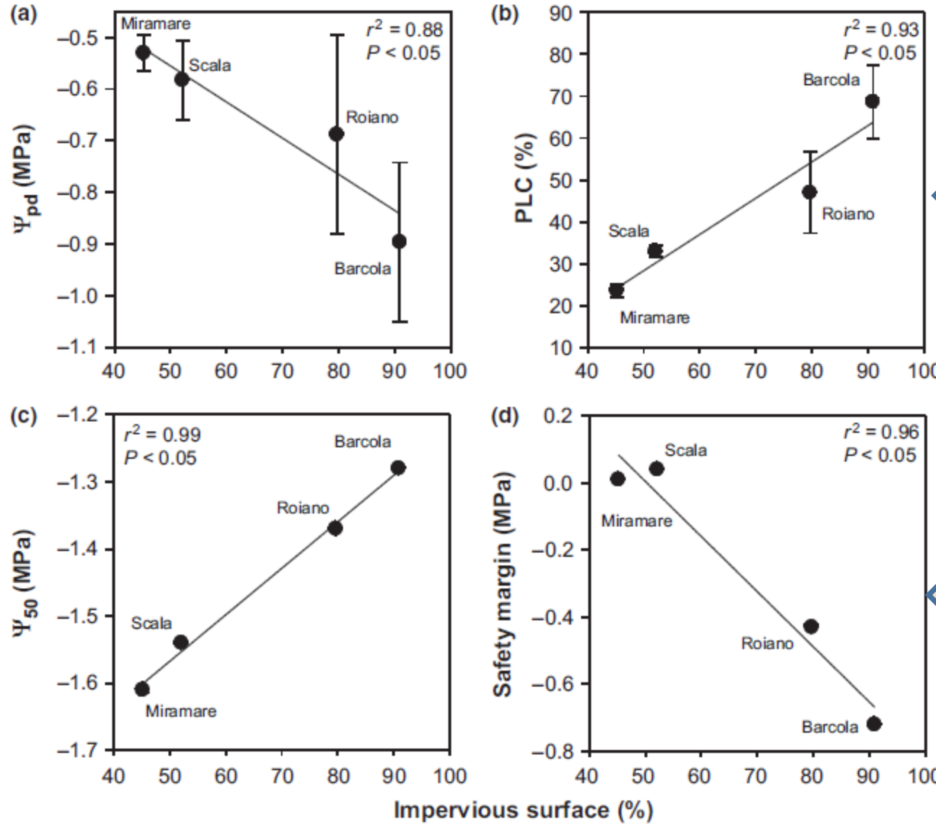


Savi *et al.,* (2014)

Impact of impervious surface

Water stress increases

Percentage loss of conductivity increases



Trees became more vulnerable to water stress

Safety margin is eroded to negative values

Correlations between percentages of soil surface covered by impervious pavement and (a) predawn leaf water potential (Ψ_{pd}), (b) percentage loss of hydraulic conductivity (PLC), (c) xylem water potential inducing 50% PLC (Ψ_{50}) and (d) safety margin calculated as the difference between Ψ_{50} and minimum seasonal xylem water potential (Ψ_{xyl}), as measured in Quercus ilex trees growing at four experimental sites. Mean values are reported (' SD). The regression lines together with r_2 and P values are also reported.

Savi *et al.*, (2014)

Why should we care?

Trees need hydraulic integrity if they are to provide ecosystem services.

- Transpiration → Evaporative cooling
- Growth → Carbon sequestration, Shading,

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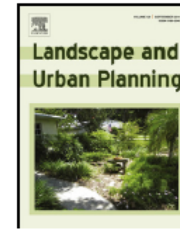


Research Paper

Determinants of establishment survival for residential trees in Sacramento County, CA

Lara A. Roman[a,b,*], John J. Battles[a], Joe R. McBride[a]

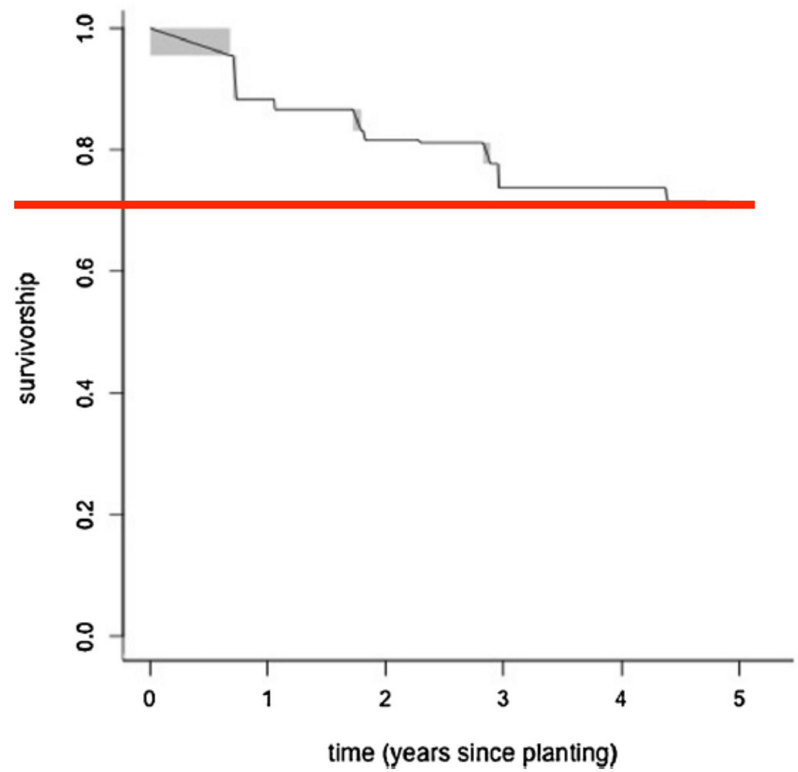
"Sacramento Tree Foundation may implement further changes including planting a higher proportion of drought tolerant trees."

"We observed higher survival for species with low water use demand…"

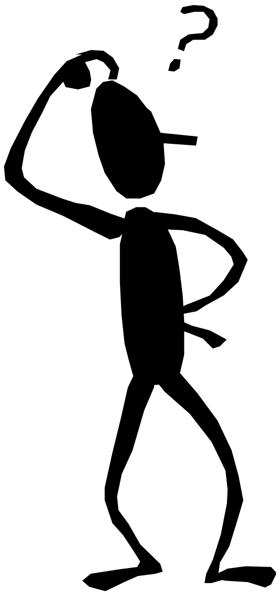
"… drought tolerant trees may be more able to withstand irrigation neglect."

"… it may be prudent for this program to plant more drought tolerant trees."

"… climate appropriate species selection influenced urban tree survival during the establishment phase."

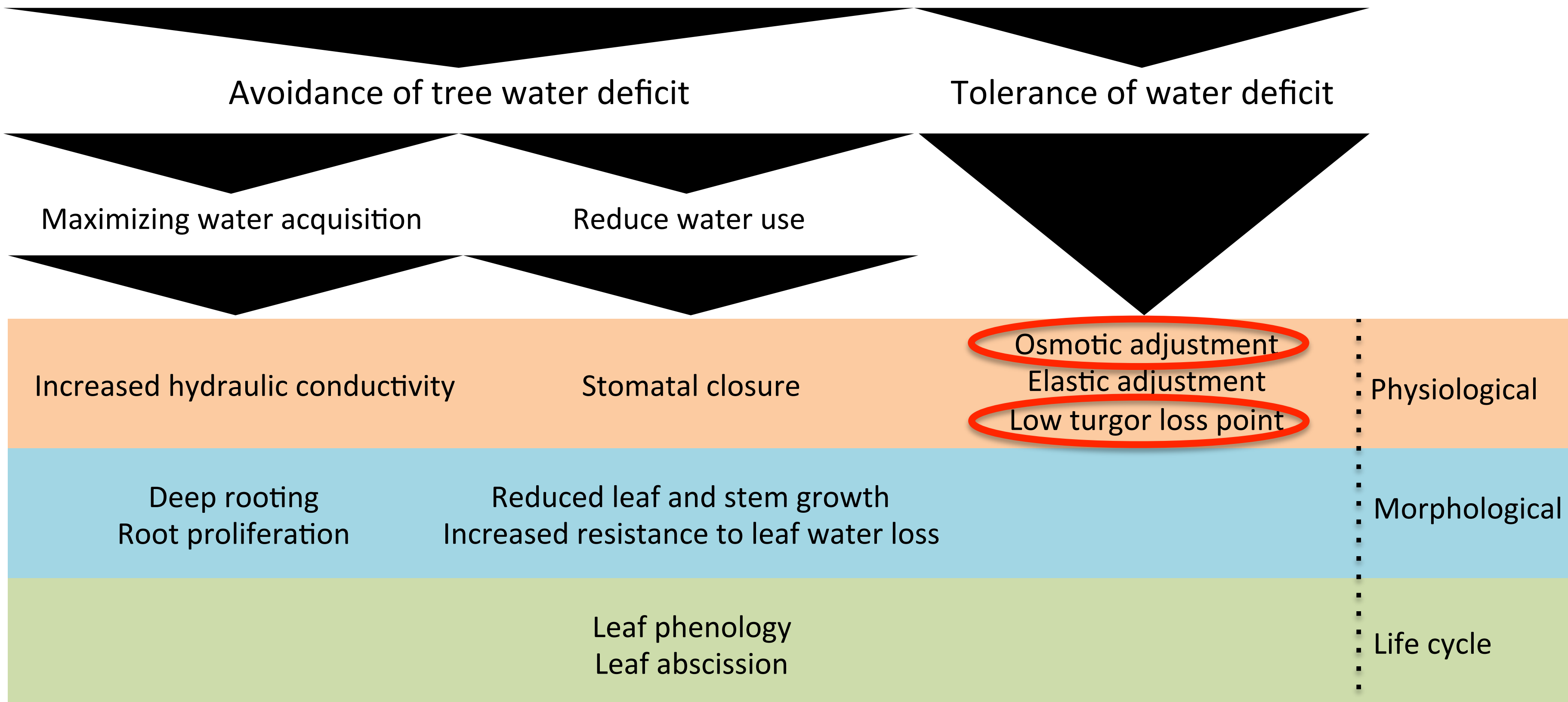


Overall survivorship for all planted shade trees (n = 370).



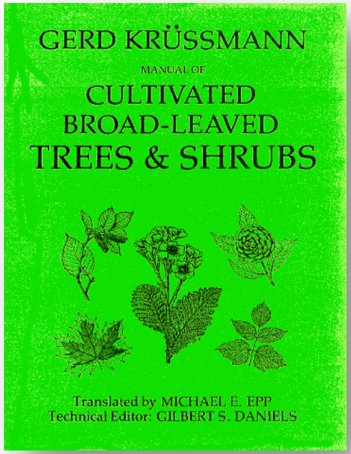
Can we select for drought tolerance?

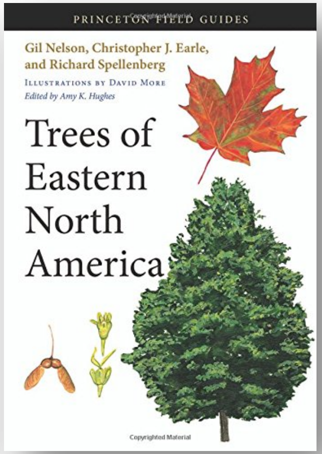
Adaptations to limited water availability

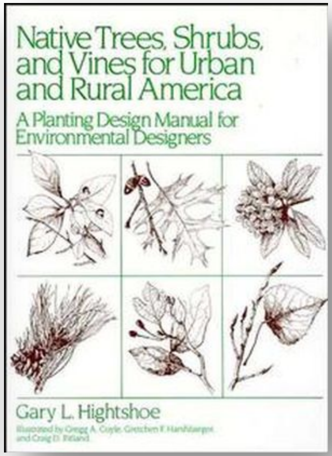


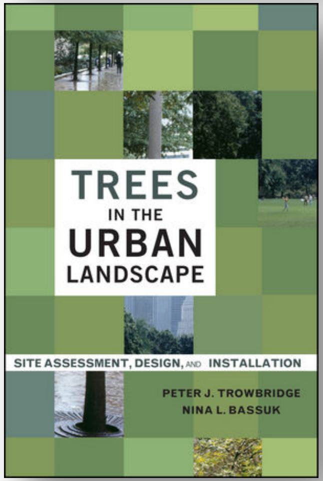
Hirons 2013

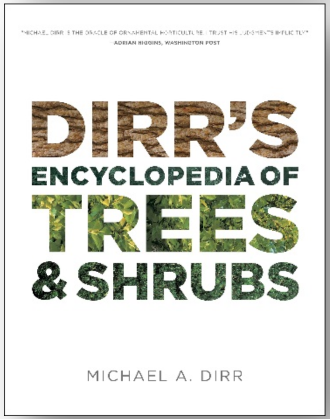
Advice from literature?











Acer nigrum

- Heat and drought tolerant (Dirr (2009)
- Sensitive for heat and drought (Hightshoe 1988)
- Prefers sites that are more humid (Beaulieu 2003)
- Has a higher drought tolerance than sugar maple (Bassuk et al. 2009)

Acer negundo

- Useful for sandy, dry to sterile soil (Krüssmann 1982)
- Drought tolerant (Stoecklein 2001)
- Its native habitat is along streams and ponds (Grimm 2002)
- Native in moist habitats but perform well also in poor, wet, or dry habitats (Dirr 2009)
- Very heat and drought tolerant (Hightshoe 1988)
- Grows along shores of permanent bodies of water (Krüssmann, 1986)
- Like humid areas (Beaulieu 2003)
- Grows along stream banks, flood plains, swamps (Spellenberg et al. 2014)

Drought Tolerance Index

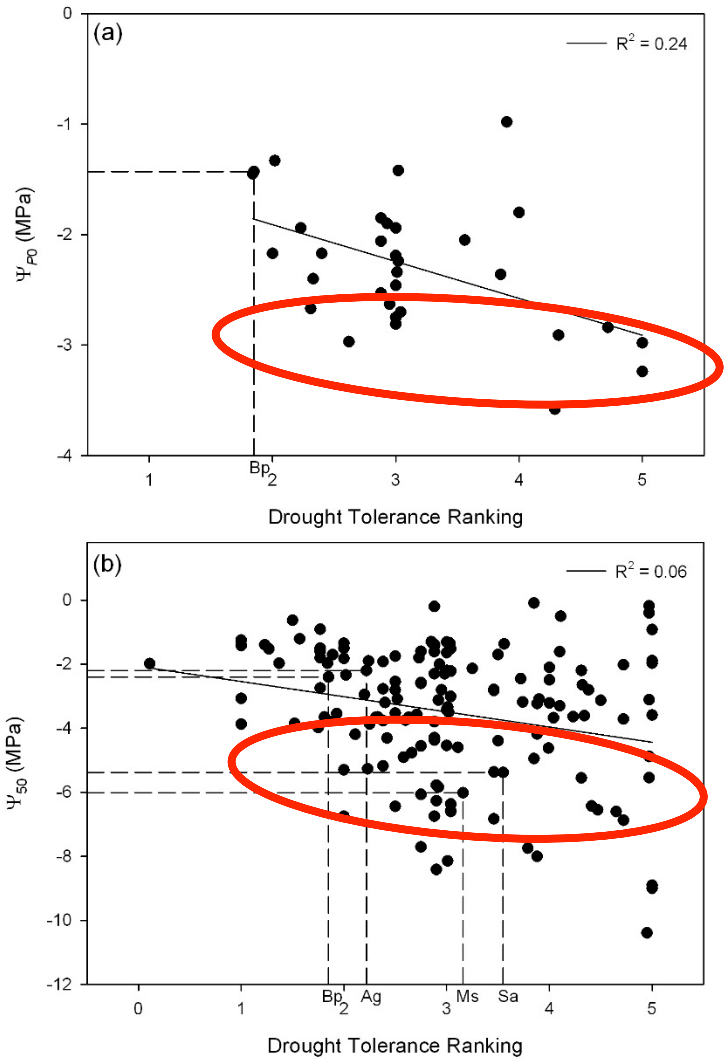
Scale ranking	Annual precipitation (mm)	Distribution of precipitation (coefficient of variation)	P:PET ratio	Soil water potential (MPa)	Duration of dry period
1	>600	Minimal	>3.0	> -0.3	A few days
2	500-600	<10%	1.5:3	-0.3 to -0.8	A few weeks
3	400-500	10-15%	0.8-1.5	-0.8 to -1.5	Up to a month
4	300-400	20-25%	0.5:0.8	-1.5 to -3	Two to three months
5	<300	>25%	<0.5	< -3	More than three months

Niinemets and Valladares 2006

Comparing different 'drought' traits with drought tolerance ranking

- Meta-analysis using data from:
  - Niinemets and Valladares, (2006);
  - Bartlett *et al.,* (2012)
  - Choat *et al.,* (2012)
- Key drought tolerance traits often become more variable rather than scale linearly with drought tolerance ranking.

Good candidates for urban trees?



Why turgor loss?

- Leaf turgor loss point can be used as a universal measure of physiological drought tolerance that is quantifiable and measurable

ECOLOGY LETTERS

Ecology Letters, (2012) 15: 393–405 doi: 10.1111/j.1461-0248.2012.01751.x

IDEA AND PERSPECTIVE

The determinants of leaf turgor loss point and prediction of drought tolerance of species and biomes: a global meta-analysis

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Abstract

Increasing drought is one of the most critical challenges facing species and ecosystems worldwide, and improved theory and practices are needed for quantification of species tolerances. Leaf water potential at turgor loss, or wilting (π_{tlp}), is classically recognised as a major physiological determinant of plant water stress response. However, the cellular basis of π_{tlp} and its importance for predicting ecological drought tolerance have been controversial. A meta-analysis of 317 species from 72 studies showed that π_{tlp} was strongly correlated with water availability within and across biomes, indicating power for anticipating drought responses. We derived new equations giving both π_{tlp} and relative water content at turgor loss point (RWC_{tlp}) as explicit functions of osmotic potential at full turgor (π_o) and bulk modulus of elasticity (ε). Sensitivity analyses and meta-analyses showed that π_o is the major driver of π_{tlp}. In contrast, ε plays no direct role in driving drought tolerance within or across species, but sclerophylly and elastic adjustments act to maintain RWC_{tlp}, preventing cell dehydration, and additionally protect against nutrient, mechanical and herbivory stresses independent of drought tolerance. These findings clarify biogeographic trends and the underlying basis of drought tolerance parameters with applications in comparative assessments of species and ecosystems worldwide.

Keywords

Biogeography, biomes, climate, plant hydraulics, plant traits.

Ecology Letters (2012) 15: 393–405

INTRODUCTION

Climate change is predicted to increase the incidence and severity of droughts in ecosystems worldwide (Sheffield & Wood 2008). Species differences in drought tolerance are integral determinants not only of present distributions but also of future scenarios, including the probability of extinctions (Engelbrecht *et al.* 2007; Bonan 2008; Feeley *et al.* 2011). Predicting the impact of climate change on plant performance and survival is a major challenge facing plant science and ecology (Grierson *et al.* 2011). However, there remain fundamental gaps in our knowledge of which traits can be used to assess ecological drought tolerance. Cell turgor loss is arguably the best recognised classical indicator of plant water stress, having impacts on cellular structural integrity, metabolism and whole-plant performance (Kramer & Boyer 1995; McDowell 2011). Consequently, the leaf water potential at turgor loss, or bulk turgor loss point (π_{tlp}, units MPa) has been used to assess physiological drought tolerance for decades. Despite its potential use for quantifying ecological drought tolerance (Niinemets 2001; Brodribb & Holbrook 2003; Lenz *et al.* 2006; Blackman *et al.* 2010), no study to our knowledge has tested the relationship between π_{tlp} and water supply within or across biomes, or its performance as an indicator of drought tolerance relative to other plant traits. In addition, significant ambiguities concerning the underlying physiological and anatomical determinants of π_{tlp} are featured prominently in textbooks of physiological and whole plant ecology (e.g. Jones 1992; Larcher 2003; Nobel 2009). We undertook new analyses to clarify this topic and its importance, given the critical need for physiological measures that can be used to assess species' drought tolerances and thus their likely sensitivity to ongoing climate change.

The π_{tlp} is classically measured in assessments of drought tolerance, as one of six key bulk leaf parameters relating to cellular composition and structural properties typically calculated from a plot of leaf water potential (Ψ_{leaf}) against water volume in drying leaves, known as the pressure-volume (p-v) curve (see primer in Fig. 1 and Table 1). The π_{tlp} is often recognised as the 'higher-level' trait that quantifies leaf and plant drought tolerance most directly, because a more negative π_{tlp} extends the range of Ψ_{leaf} at which the leaf remains turgid and maintains function (Sack *et al.* 2003; Lenz *et al.* 2006). Plants with low π_{tlp} tend to maintain stomatal conductance, hydraulic conductance, photosynthetic gas exchange and growth at lower soil water potential (Ψ_{soil}), which is especially important when droughts occur during the growing season (Abrams & Kubiske 1990; Sack *et al.* 2003; Baltzer *et al.* 2008; Mitchell *et al.* 2008; Blackman *et al.* 2010). The π_{tlp} is thus a trait quantifying the ability to 'tolerate' drought, rather than to 'avoid' drought by ceasing gas exchange and surviving on stored water, shedding leaves or dying back to below-ground parts or to seeds (e.g. as done by annuals, deep-rooted perennials, or phreatophytes, CAM succulents or drought-dormant species; Chaves *et al.* 2002; Brodribb & Holbrook 2005; Ogburn & Edwards 2010). The π_{tlp} also defines the Ψ_{soil} below which the plant cannot take up sufficient water to recover from wilting. Known as the 'permanent wilting point', this was previously thought to correspond to a Ψ_{soil} of − 1.5 MPa (Veihmeyer & Hendrickson 1928), but the π_{tlp} is now known to vary across species, and thus may influence ecological distributions with respect to water availability. Some have focused on a second p-v curve parameter as a possible determinant of drought tolerance, the relative water content at π_{tlp} (RWC_{tlp}). The other four parameters, i.e. the apoplastic water fraction (a_f), modulus of elasticity (ε), osmotic potential at full

Method

- Assess osmotic potential at full turgor in leaf discs based on Bartlett *et al.* (2012) and subsequent meta-analysis
- Apply regression equation to determine leaf water potential at turgor loss
- Rank species in terms of their physiological drought tolerance

Methods in Ecology and Evolution
Methods in Ecology and Evolution 2012, 3, 880–888 doi: 10.1111/j.2041-210X.2012.00230.x

Rapid determination of comparative drought tolerance traits: using an osmometer to predict turgor loss point

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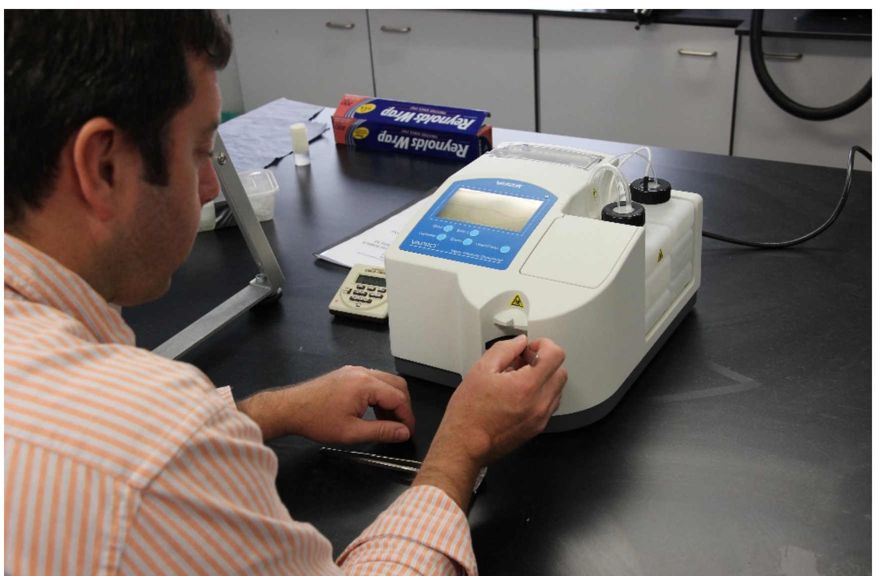
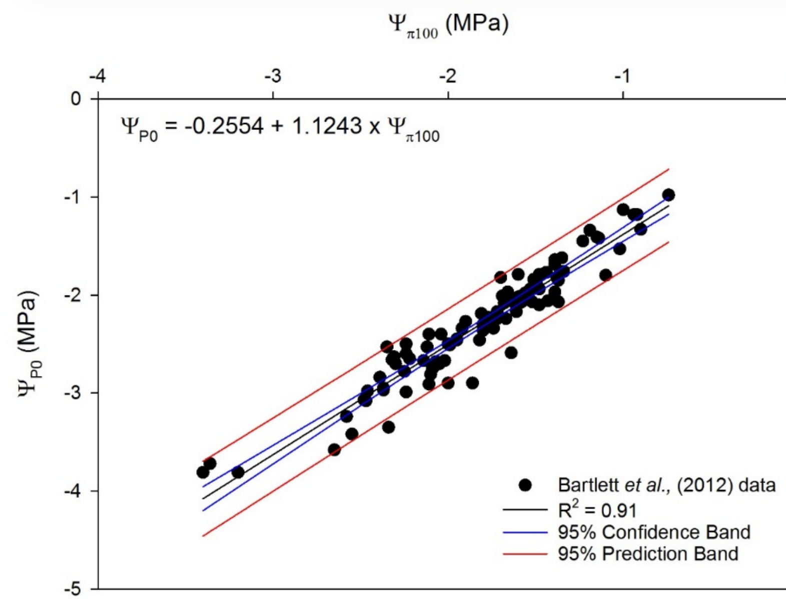
ECOLOGY LETTERS
Ecology Letters, (2012) 15: 393–405 doi: 10.1111/j.1461-0248.2012.01751.x

IDEA AND PERSPECTIVE

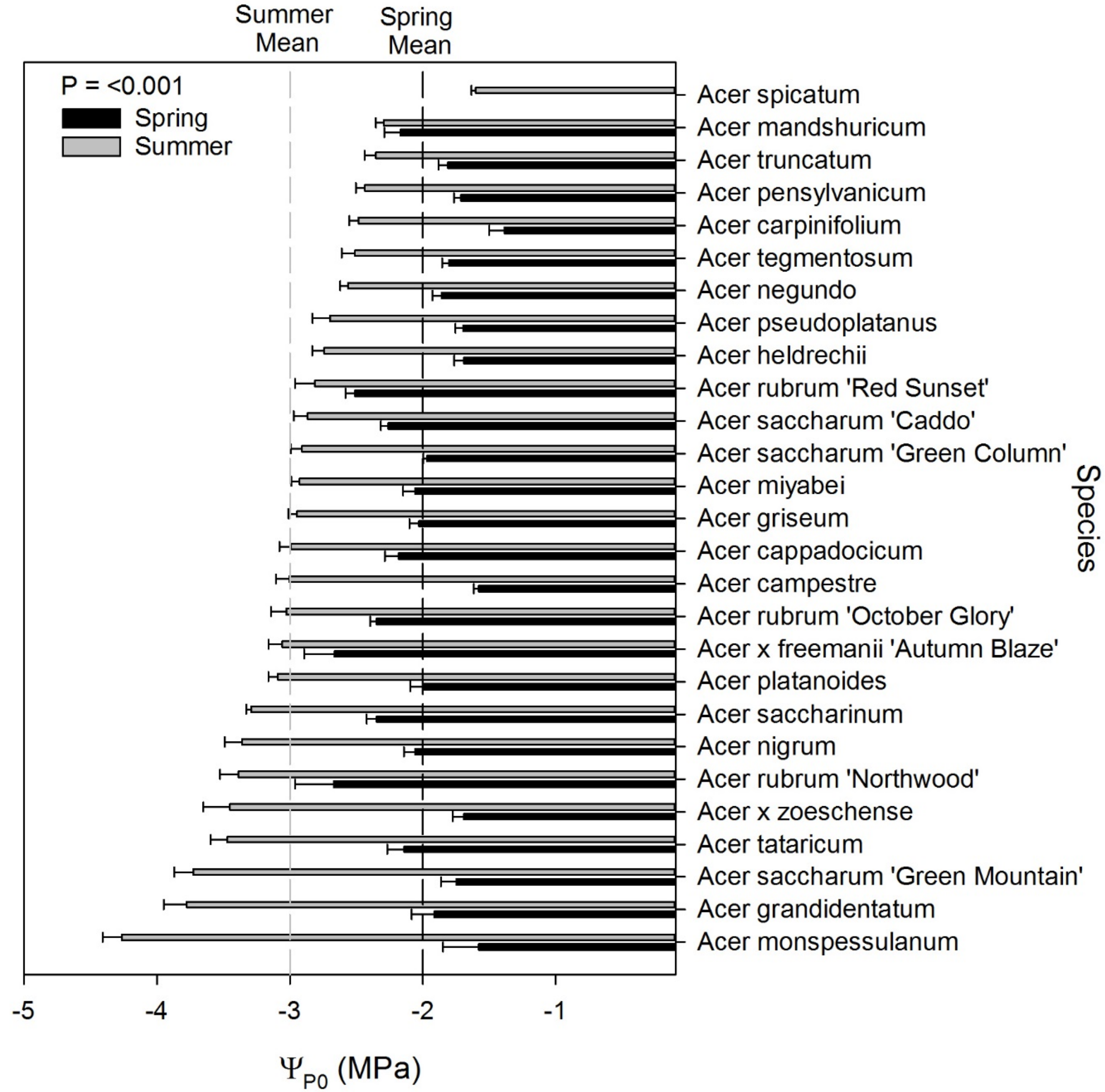
The determinants of leaf turgor loss point and prediction of drought tolerance of species and biomes: a global meta-analysis





Acer genotypes

Acer carpinifolium (H Sjöman)



Sjöman, H., Hirons, A.D. and Bassuk, N. – 2015

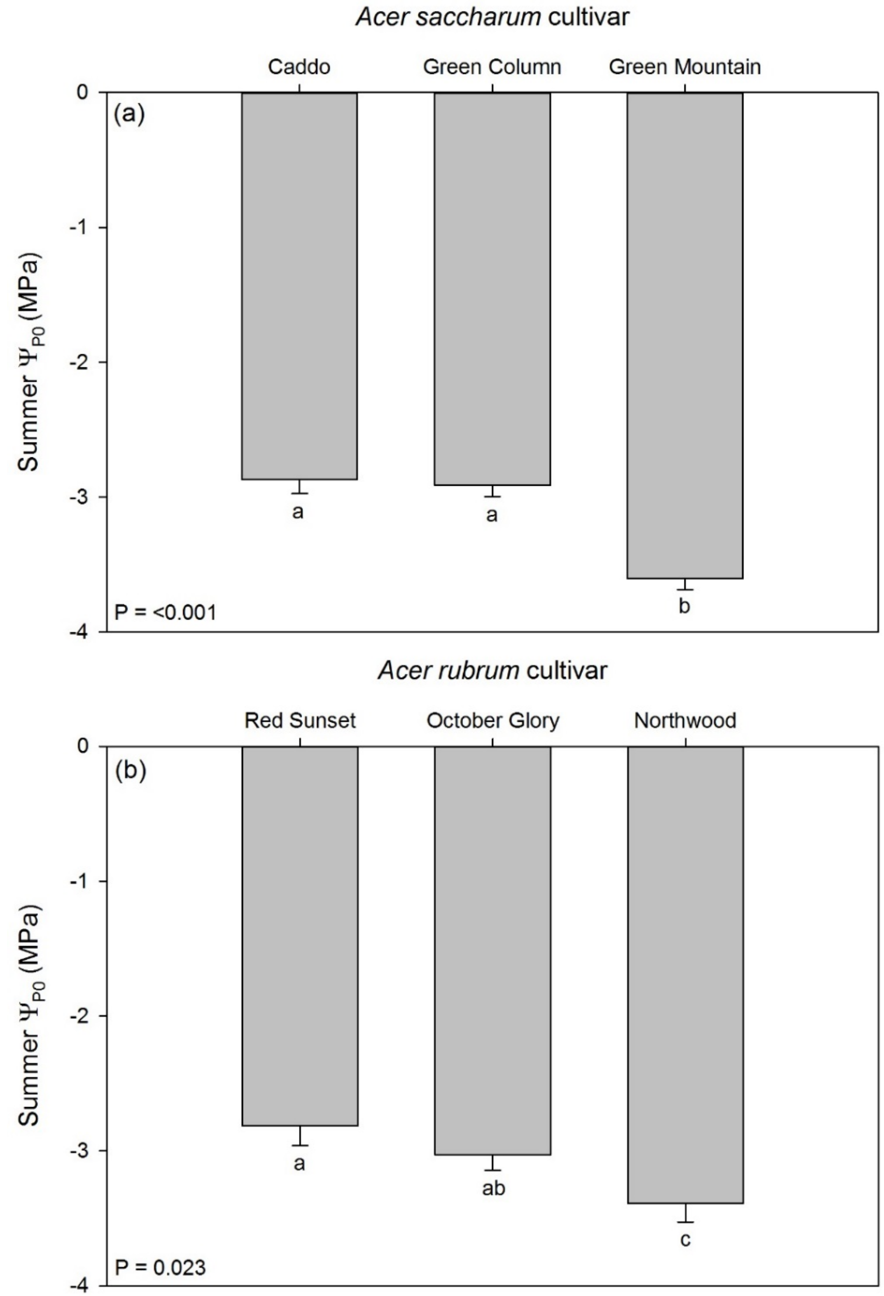

Ψ_{P0} -1.6 MPa
Acer spicatum, NY, USA

Acer truncatum, Qingling Mt., China (Photo: Henrik Sjöman)

Acer tataricum & Quercus pubescens, Steppe Forest in Eastern Romania. (Photo: Henrik Sjöman)

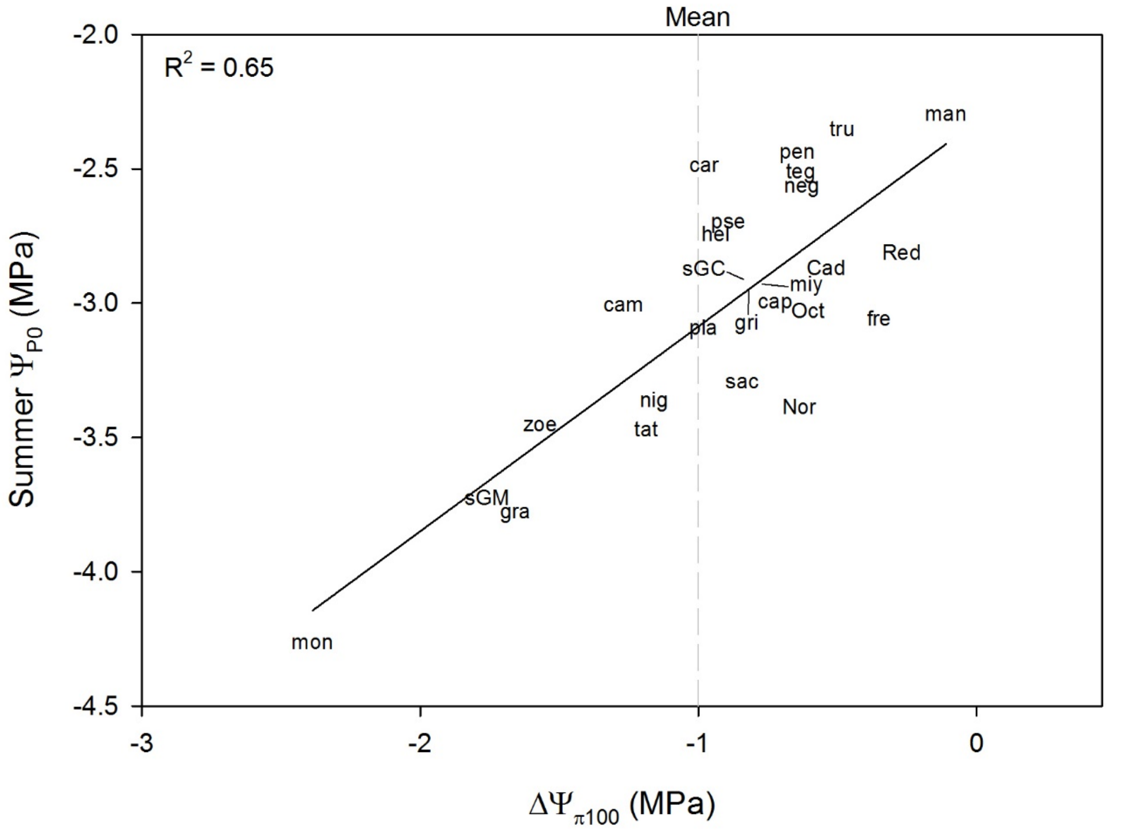
Acer grandidentatum, Utah, USA (Photo: Henrik Sjöman)

Acer cultivars



Sjöman, H., Hirons, A.D. and Bassuk, N. – 2015

Seasonal osmotic adjustment



Sjöman, H., Hirons, A.D. and Bassuk, N. – 2015

Urban planting beds in Ithaca, NY, USA

Conclusions of study

- Wide variation in physiological drought tolerance across closely related species and cultivars.
- May be a useful trait for the selection of urban trees.
- Should provide evidence for nurseries to reduce the risk of taking on new plant material.

Urban Forestry & Urban Greening 14 (2015) 858–865

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Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Urban forest resilience through tree selection—Variation in drought tolerance in *Acer*

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[b] Myerscough College, Bilsborrow, Preston, Lancashire PR3 0RY, UK
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ABSTRACT

It is widely recognized that trees contribute a range of ecosystem services in urban environments. However, the magnitude of their contribution is closely related to their physiological condition and capacity to persist within our towns and cities. Root loss during transplanting, limited soil volume, disruption to soil hydrological processes and impermeable surfaces result in water deficits being major physiological stress limiting the performance of urban trees. The leaf water potential at turgor loss (Ψ_{P0}) provides a robust measure of drought tolerance since a more negative Ψ_{P0} allows the leaf to maintain physiological function over a wider range of leaf water potentials and, by implication, soil matric potentials (Ψ_{soil}). In this study, Ψ_{P0} was calculated for 27 maple (*Acer*) genotypes based on a known linear relationship between the osmotic potential at full turgor ($\Psi_{\pi 100}$) and Ψ_{P0}. In spring, Ψ_{P0} varied between −1.4 MPa in *Acer carpinifolium* and −2.7 in both *Acer rubrum* 'Northwood' and *Acer ×freemanii* 'Autumn Blaze'. During summer, *Acer spicatum* had the highest Ψ_{P0} at −1.6 MPa and *Acer monspessulanum* had the lowest Ψ_{P0} at −4.3 MPa. Significant differences in Ψ_{P0} were found between cultivars of *A. rubrum* and *Acer saccharum*. A highly significant relationship was found between seasonal osmotic adjustment and summer Ψ_{P0} suggesting that osmotic adjustment is a driving force for summer Ψ_{P0} in *Acer* leaves. These data confirm the wide range of tolerance to water deficits in *Acer* and give important insight into the potential of species to tolerate periods of low water availability by providing quantitative data not previously available. The technique shows great promise as a screening tool for the drought tolerance of new and traditional plant material. This data will be highly relevant for those selecting trees for urban sites as well as for nurseries seeking to evaluate genotypes for production purposes.

1. Introduction

Trees are major components of the green infrastructure in urban environments and their contribution to a range of ecosystem services is widely recognized. These services include mitigation of flood risk, reduced energy use in buildings, increased thermal comfort, mitigation of the urban heat island effect, recreational values, and the enhancement of cultural and aesthetic qualities, etc. (in e.g. Akbari et al., 2001; Xiao and McPherson, 2002; Grahn and Stigsdotter, 2003; Gill et al., 2007; Tyrväinen et al., 2005; Tzoulas et al., 2007).

Since the provision of these services is reliant on healthy trees, assessments of projected ecosystem services frequently assume large, mature trees with good growth rates (Gómez-Muñoz et al., 2010). This assumption is misguided as many urban sites do not provide a high quality growth environment. Variation in the rooting environment of *Pyrus calleryana* Decne. trees lead to an approximately 80% reduction in evapotranspirational cooling as a result of suppressed stomatal conductance (Rahman et al., 2011). Tree height and girth (DBH at 1.3 m) of *Quercus robur* L. showed marked variation across urban sites with different levels of soil aeration (Weltecke and Gaertig, 2012) suggesting carbon sequestration is reduced where soil gas diffusivity is reduced. These data provide evidence that the magnitude of at least some ecosystem services provided by trees will be closely related to their physiological performance and condition.

Water deficits in trees develop when root uptake of water does not meet the evapotranspirational demand from the crown. In

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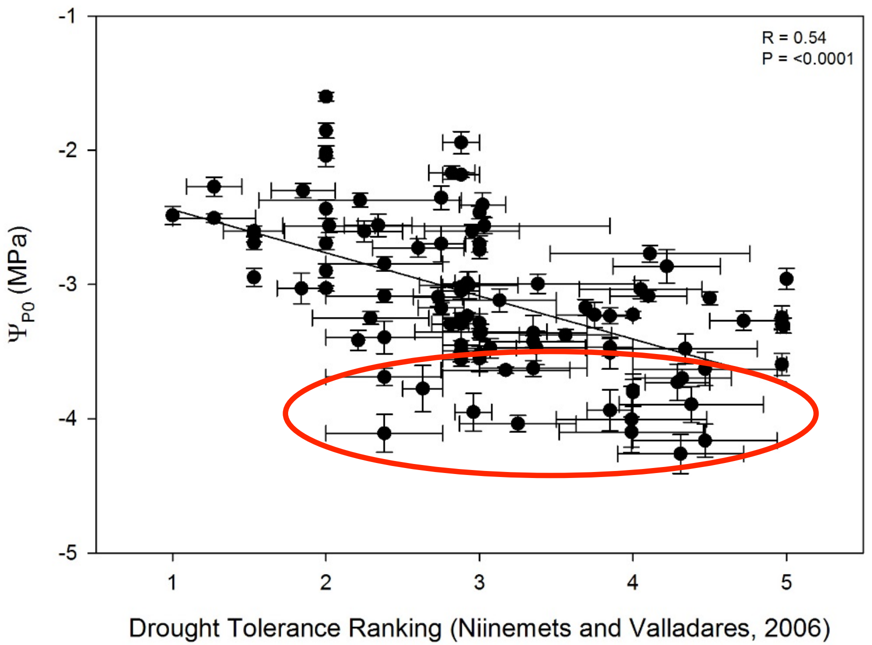
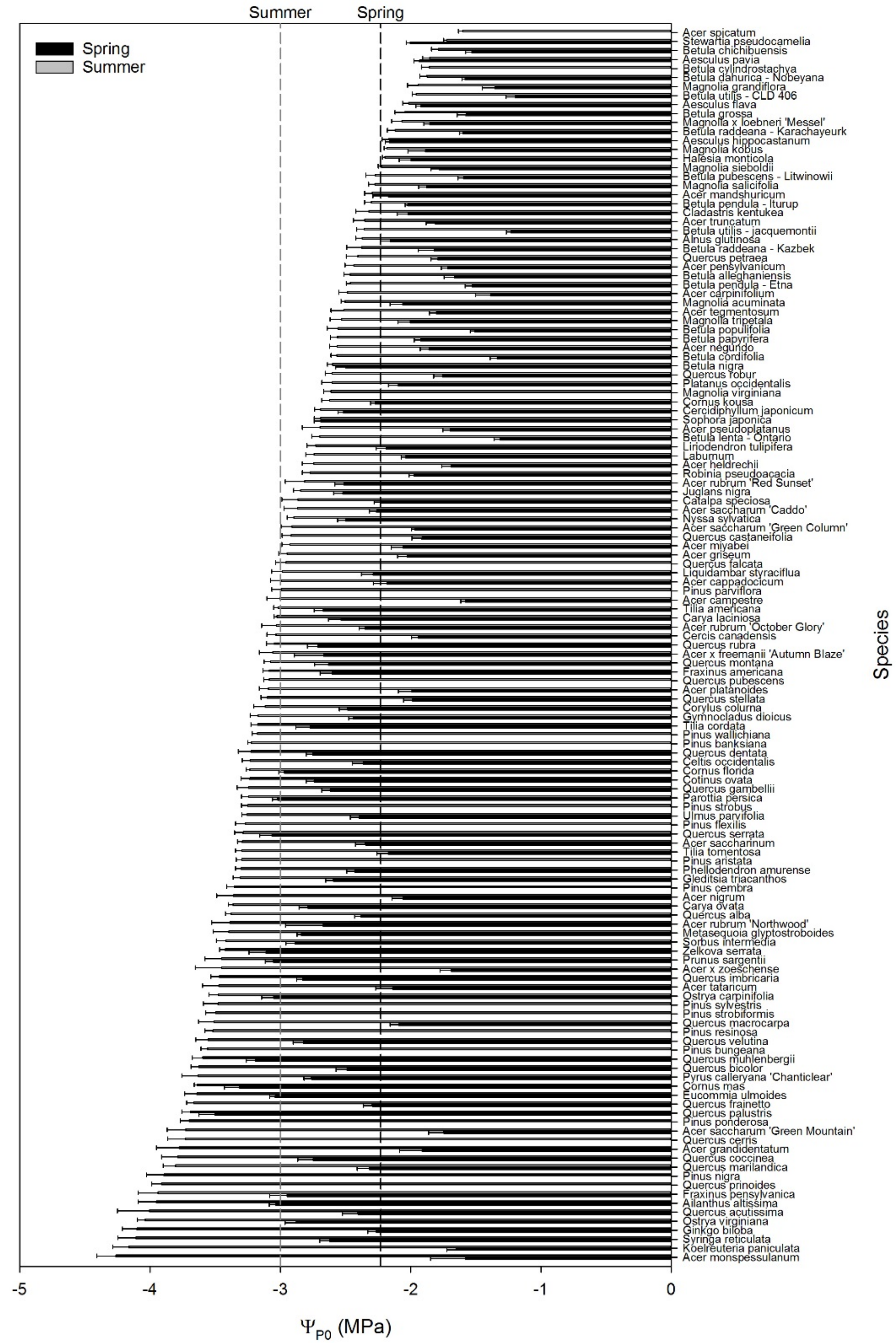
http://dx.doi.org/10.1016/j.ufug.2015.08.004

A combined picture… so far





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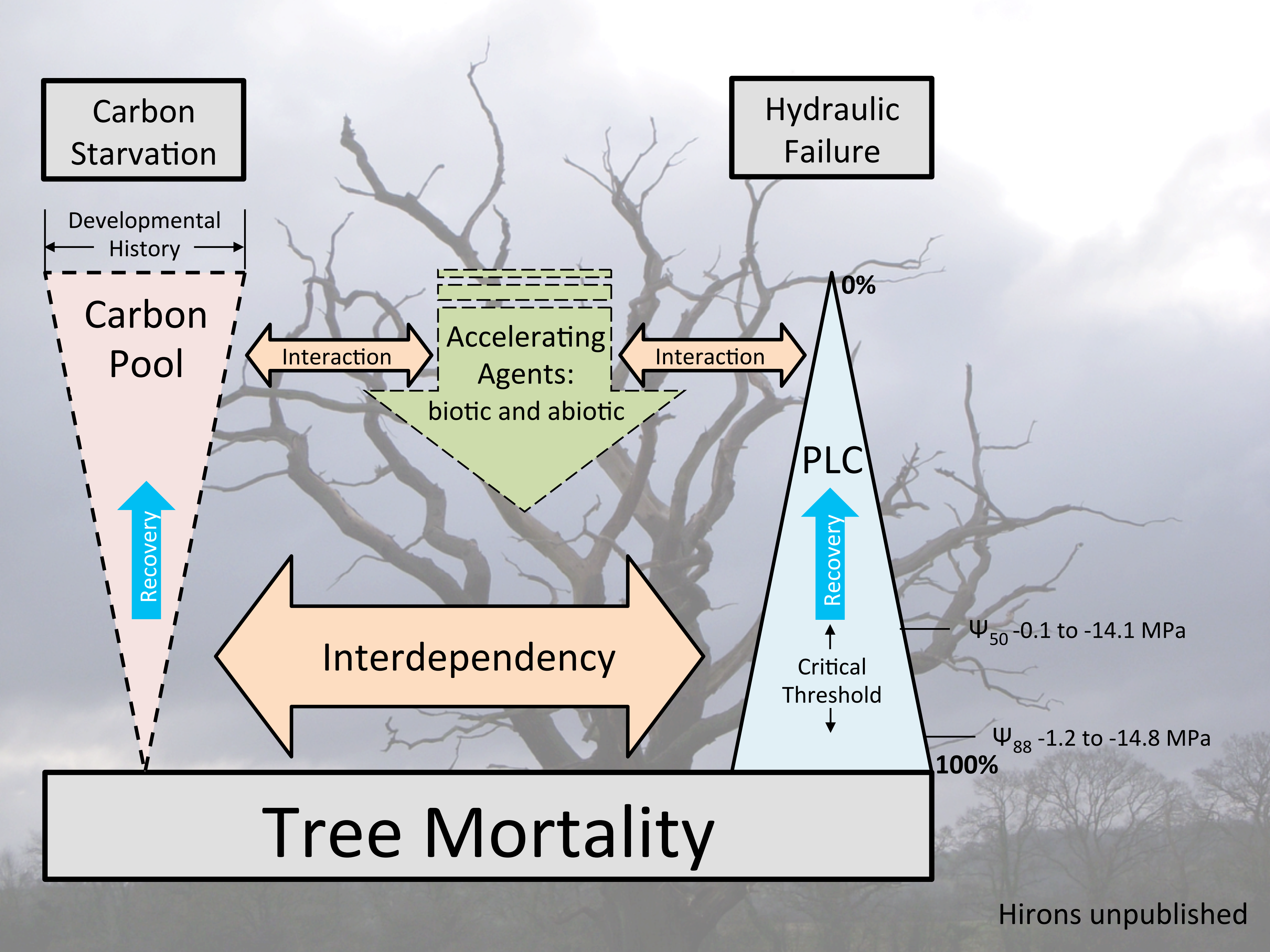
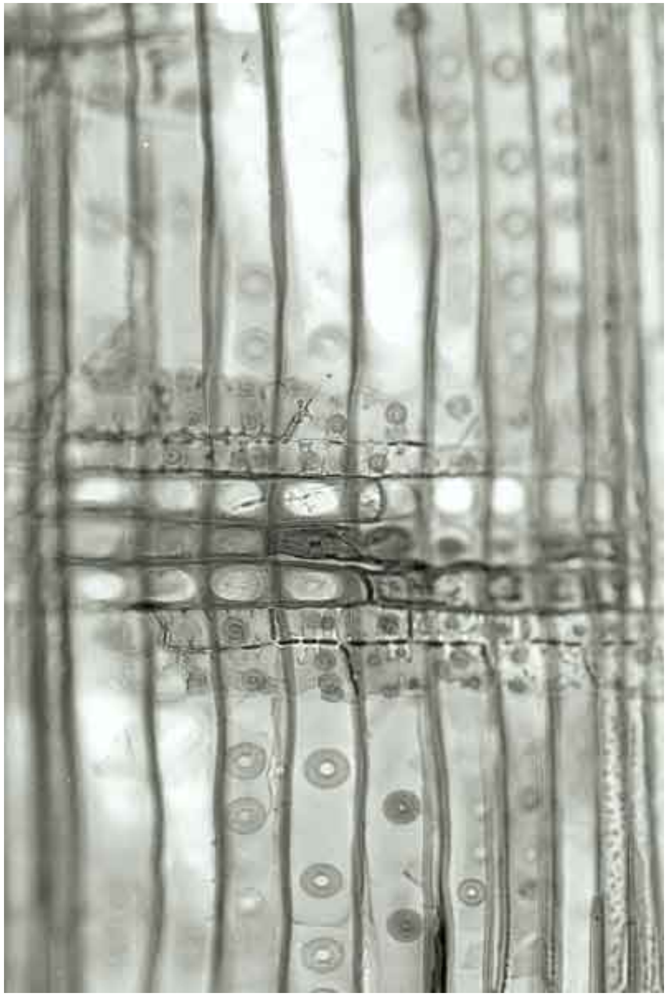
TREE FUND
Cultivating Innovation

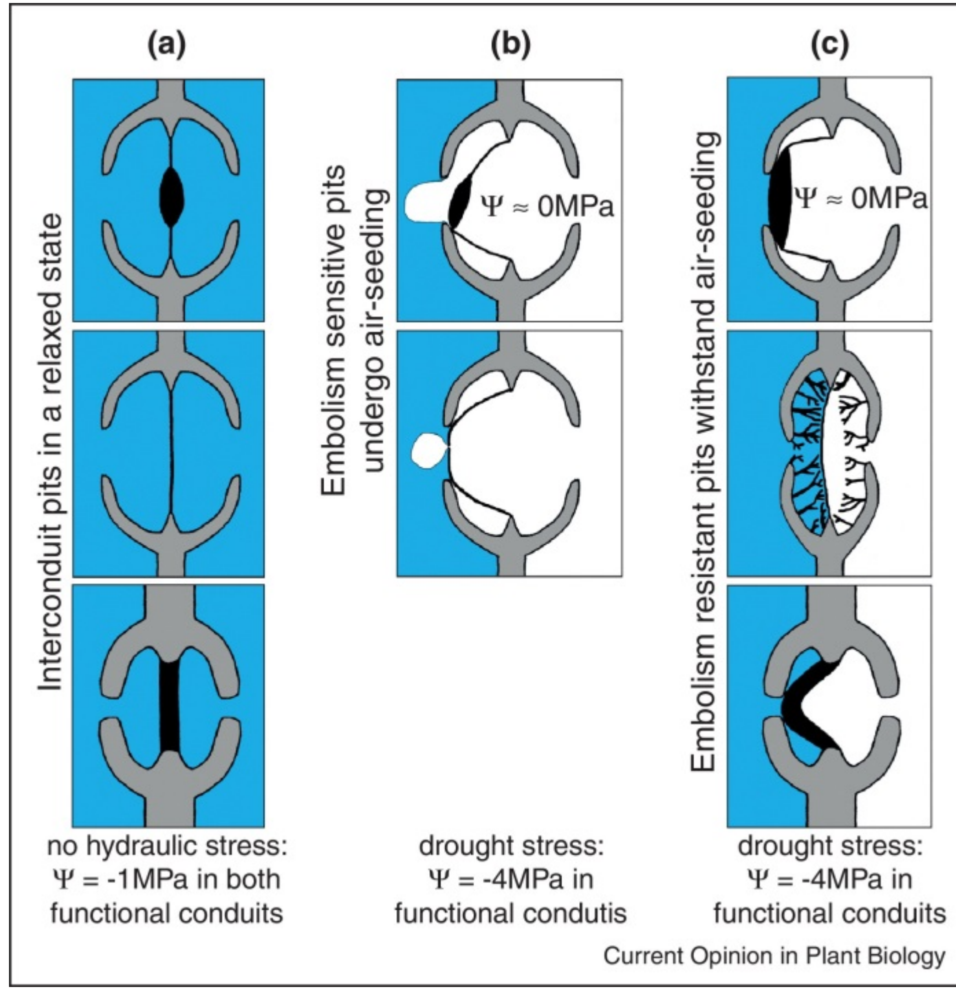

What's on the horizon?


Carbon Starvation
Developmental History
Carbon Pool
Recovery
Interaction
Accelerating Agents: biotic and abiotic
Interaction
Hydraulic Failure
0%
PLC
Recovery
Critical Threshold
Ψ_{50} -0.1 to -14.1 MPa
Ψ_{88} -1.2 to -14.8 MPa
100%
Interdependency
Tree Mortality
Hirons unpublished

Embolism in Trees



Pinus sylvestris (RLS)

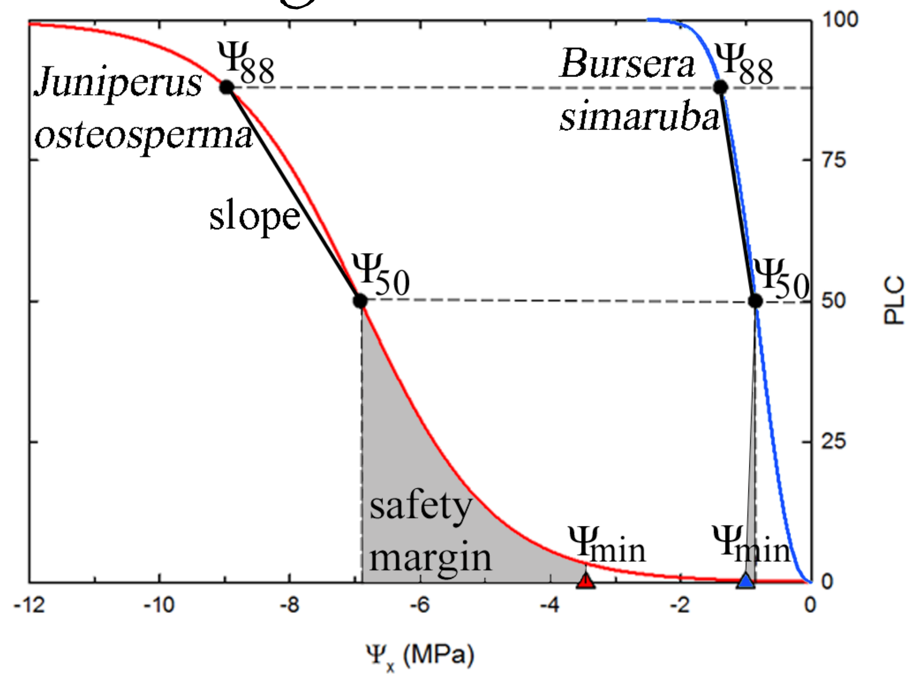


Lens *et al.*, 2013 Embolism resistance as a key mechanism to understanding adaptive plant strategies

Percentage Loss of Hydraulic Conductivity – Embolism Vulnerability Curve

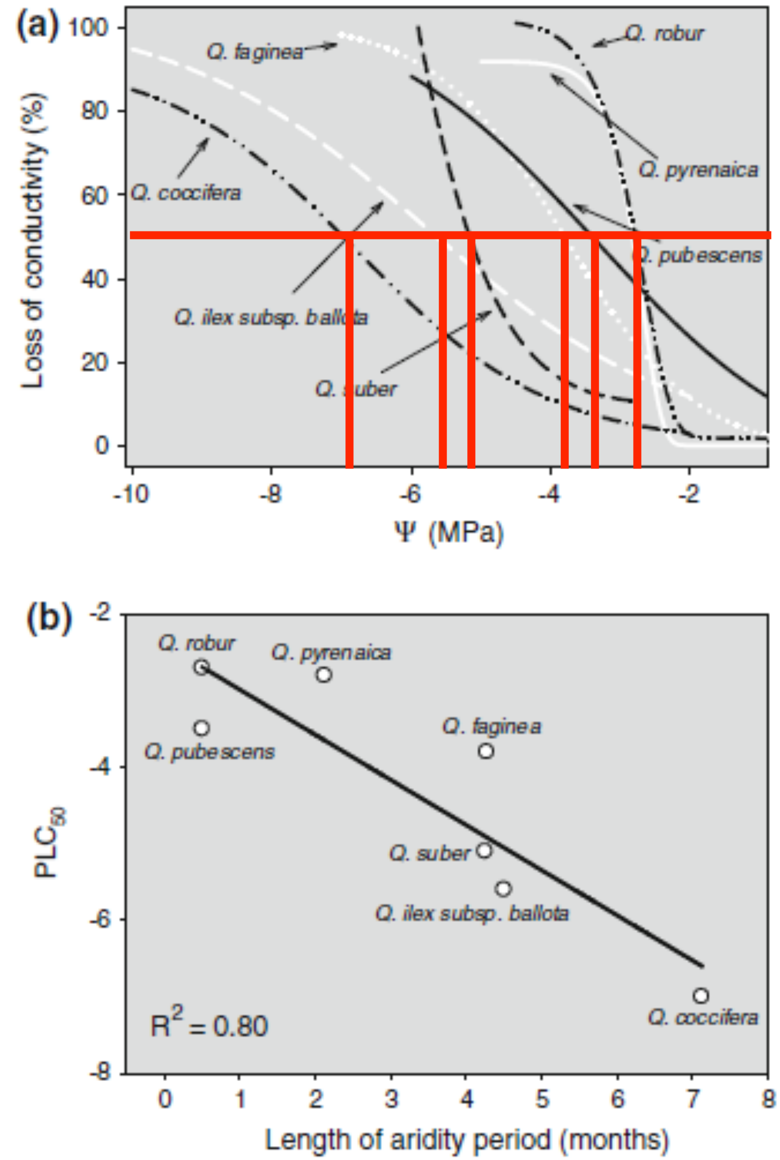
Choat *et al.*, 2012 Global convergence in the vulnerability of forests to drought – From supplementary information

Study evaluated 226 species from 81 sites around the world



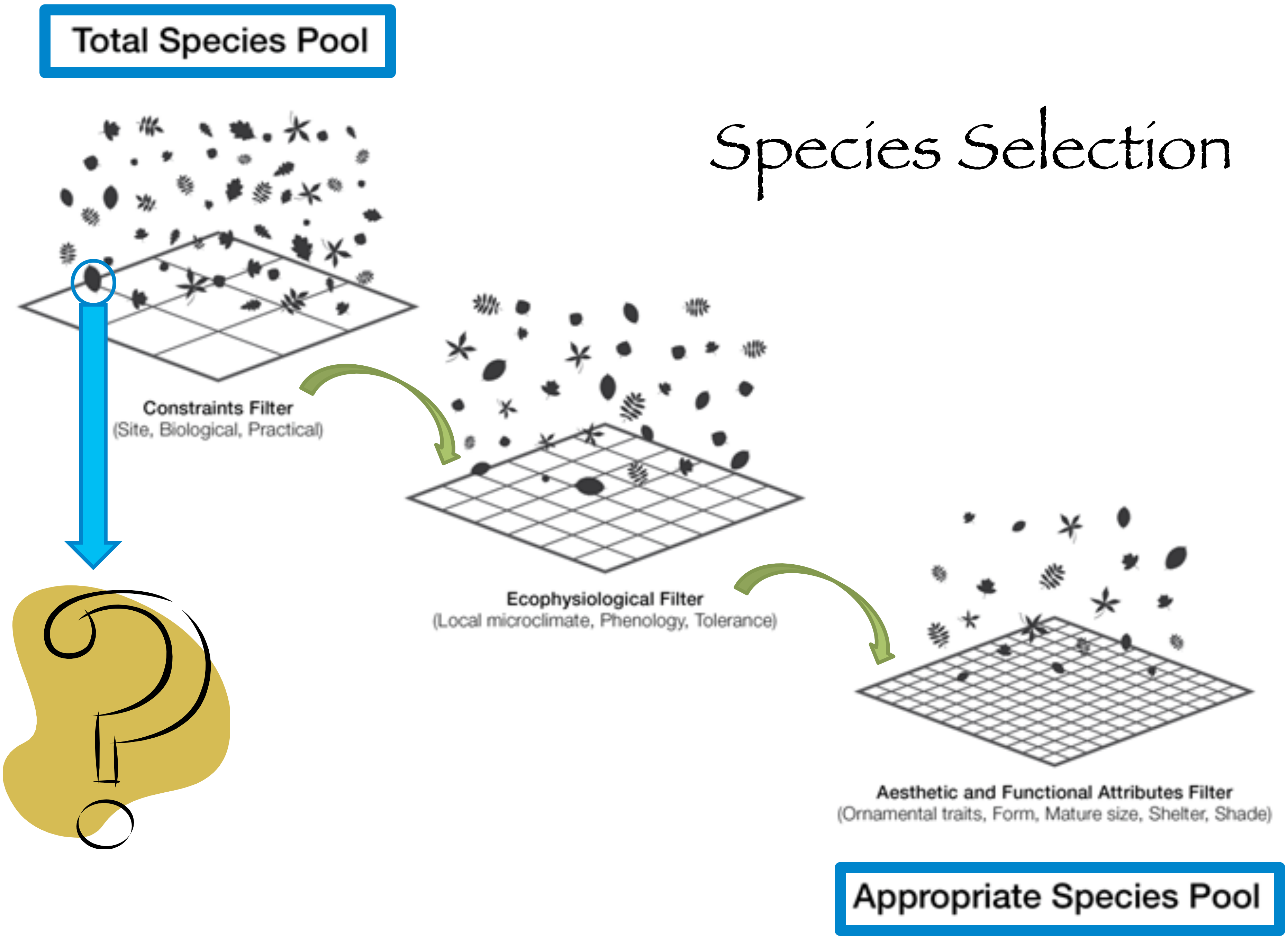
Embolism vulnerability curves showing percentage loss of hydraulic conductivity (PLC) as a function of xylem pressure (Ψ_x). Curves are shown for the angiosperm species *Bursera simaruba*, a tropical rainforest species (blue curve), and the gymnosperm *Juniperus osteosperma*, a dry forest species (red curve). Points show the xylem pressures at which PLC = 50% Ψ_{50}) and PLC = 88% Ψ_{88}) for each species (Ψ_{50} = -6.9 MPa and Ψ -1 MPa for *J. osteosperma* and *B. simaruba*, respectively). A smaller decrease in xylem pressure is required Ψ_{50} Ψ_{88} in *B. simaruba* because of the steeper slope of the curve between Ψ_{50} and Ψ_{88}. Ψ_{min} values are indicated by triangles and represent the minimum Ψ_x measured in the field. The difference between Ψ_{min} and Ψ_{50} (grey area) corresponds to a "safety margin", which is 3.4 MPa for *J. osteosperma*, while Ψ_{min} passes the Ψ_{50} point marginally for *B. simaruba*, resulting in a slightly negative safety margin and thus a more risky hydraulic strategy than *J. osteosperma*.

Quercus: Vulnerability to Cavitation



Vulnerability curves to drought-induced cavitation in several European Quercus species from different habitats. In this figure, Loss of conductivity or PLC is plotted as function of water potential.

Vilagrosa *et al.,* 2012


Total Species Pool
Species Selection
Constraints Filter
(Site, Biological, Practical)
Ecophysiological Filter
(Local microclimate, Phenology, Tolerance)
Aesthetic and Functional Attributes Filter
(Ornamental traits, Form, Mature size, Shelter, Shade)
Appropriate Species Pool

Fundamentals of Tree Establishment

Adapted from: Hirons and Percival 2012