# Study of the adaptability of trees to drought:phenological monitoring of assisted growth sensors, in the Botanical Garden of Villa Thuret.

Catherine Ducatillon, Richard Bellanger, Tristan Charron, Joelle Chevallier, Christine Heinz, Cecilia Marchal, Yannick Mellerin, Yves Caraglio, Thierry Ameglio

# STUDY OF THE ADAPTABILITY OF TREES TO DROUGHT: PHENOLOGICAL MONITORING OF ASSISTED GROWTH SENSORS, IN THE BOTANICAL GARDEN OF VILLA THURET

Photo credit : PepiPiaf sensor on Eucalyptus dorrigoensis tree, *Inra PACA Villa Thuret*

**Ducatillion Catherine[1], Bellanger Richard[1], Charron Tristan[1], Chevallier Joëlle[1], Heinz Christine[2], Marchal Cécilia[1], Mellerin Yannick[1], Caraglio Yves[2] & Ameglio Thierry[3]**

[1] Unité expérimentale Villa Thuret et jardin botanique - INRA centre Provence Alpes Côte d'Azur (PACA) 90, chemin Raymond – F 06160 Cap d'Antibes
catherine.ducatillion@paca.inra.fr

[2] Unité mixte de recherche AMAP - CIRAD - boulevard de la Lironde TA 40/PS26 - F 34398 Montpellier Cedex 5

[3] Unité mixte de recherche PIAF Site INRA de Crouël - F 63000 Clermont-Ferrand

> Keywords PHENOLOGY DIAMETER GROWTH DLVDT SENSOR MICRO-DENDROMETER ABIOTIC STRESS

# 05. Abstract

- *Ducatillion Catherine*
- *Bellanger Richard*
- *Charron Tristan*
- *Chevallier Joëlle*
- *Heinz Christine*
- *Marchal Cécilia*
- *Mellerin Yannick*
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**THE ADAPTING OF TREES TO CLIMATE CHANGE IS ONE OF THE BIGGEST CHALLENGES WE FACE PRESENTLY. THE GOAL OF THE PHENOTOOLS PROGRAMME IS TO MEASURE THE IMPACT OF CLIMATE ON THE PHENOLOGY OF GROWTH OF A SAMPLE OF EXOTIC TREES INTRODUCED AT THE VILLA THURET BOTANICAL GARDEN IN A MEDITERRANEAN CLIMATE.**

These trees are from very diverse taxonomic groups, biogeographic origins and have different growth patterns. They are deciduous or conifer species, with rhythmic or perennial growth. The method used lets us observe and compare their primary growth and their secondary growth simultaneously. The approach requires the use of autonomous micro-dendrometers to record and continuously monitor micro-variations in trunk or branch diameter. The initial results highlight contrasted growth and drought-adaptation strategies at the same site.

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# 05. Introduction

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Photo credit : PepiPiaf sensor on Eucalyptus dorrigoensis tree,
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**THE ADAPTING OF TREES TO CLIMATE CHANGE IS ONE OF THE BIGGEST CHALLENGES WE FACE PRESENTLY. IN ORDER TO SURVIVE, THESE LIVING ORGANISMS, THAT GENERALLY HAVE A LONG LIFESPAN, MUST BE ABLE TO WITHSTAND INCREASINGLY FREQUENT AND MORE INTENSE CLIMATIC EVENTS.**

Climate changes affect the phenology of species and have consequences on the growth and reproduction of trees. The question of which species to plant is one faced by forestry, orchard and urban landscape managers.

In the Mediterranean climate, water resources are highly fluctuating, with a variation coefficient of 30% (Rambal, 2002). Over the decades to come, we will see an increase in more intense droughts around the Mediterranean and a reduction in rainfall events, which will become more unpredictable and violent. Will the flora be able to withstand more and more pronounced drought conditions? Some species are able to limit water loss by reducing their leaf surfaces, the number of stomata or conditions for transpiration from stomata (leaf hairs, waxes, etc.). Others have greater capacity to access groundwater, i.e. deep root systems. On a physiological level, transpiration, which is a vital process for tree growth and its temperature regulation, is heavily affected by the water shortages linked to edaphic drought. The higher the deficit, the slower growth. In an extreme drought, even if the stomata are fully closed, dehydration continues and can cause xylem vessel embolism and eventually death of the tree (Cruiziat *et al.,* 2001, 2003).

One of the findings we made at the Villa Thuret, located in southeast France, is that many exotic trees can withstand the excesses of the Mediterranean climate (proven in the fact that they have continued to thrive in the garden for several decades, some for a century or more), apparently irrespective of their phylogenetic positioning or biogeographic origin. However, they demonstrate diverse –indeed contradictory – phenologies: some grow while others are “paused”, they flow once or several times depending on year, stop growing in some winters or some summers but not others, etc. Some retain their original phenology (e.g. southern hemisphere) while others adapt to the seasons in the host country, according to conditions that have yet to be explained.

Due to the influence of climate on phenology, the plants’ exposure to environmental fluctuations and the taking into account of global chang-

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05.

## Introduction

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es, studies on phenology have increased in number over the last ten years (Gordo & Sanz, 2010). In 2005, Rathgeber et al. put forward a hypothesis on the influence of global change (climate and $CO_2$ increases) on forest ecosystem production. Some studies have demonstrated a correlation between the earlier appearance of the first phenological stages in spring and rising temperatures over recent years (Cleland *et al.*, 2007), which is consistent with an increase in the length of the vegetation period. Current changes lead to modifications in plant phenology and, due to high temperatures and drought conditions in summer (Cleland *et al.*, 2007), this can lead to a reduction in radial growth and hence in forest productivity (Michelot *et al.*, 2012). Among the studies into the impact of climate on plant phenology, some focus on primary meristem events that lead to longer stems (Cleland *et al.* 2007; Gordo & Sanz, 2010), while others deal with the modulation of secondary meristem functioning and the consequences on thickness growth (Rathgeber *et al.*, 2000; Rossi *et al.*, 2011; Cuny *et al.*, 2012; Klein *et al.*, 2013; Michelot *et al.*, 2012). These results may appear contradictory and raise the question of the relationship between these types of growth. Furthermore, in the Mediterranean region, the climate creates growth conditions that alternate frequently between two winter dormancy phases and two vegetation phases: we refer to this as bimodal growth (Camarero *et al.*, 2010).

The methods currently applied in studies into the impact of climate change on phenology come up against some methodological limitations. For example, knowledge about the development and growth of some species, in particular Mediterranean and/or exotic species in a Mediterranean climate, which varies from one year to another, remains underdeveloped at this stage and lacks hindsight (some permanent sites exist in the natural environment: Puechabon, Fontblanche, St Michel de l'Observatoire). To benefit from historical data and diverse situations, it is therefore necessary to set up robust, automated methodological tools to supply the databases and phenological models, and also help us understand the development phases of these species and assess their capacity for adaptation in relation to this characteristic (phenology), which has not been the subject of extensive study so far.

Since 2013, in the framework of the "Perpheclim" (Perennial fruit crops and forest phenology evolution facing climatic change - Database, Modelling and Observatory network) project of the ACCAF metaprogramme (Adaptation of agriculture and forest to climate change) run by INRA (French national institute for agricultural research), we have set up a primary and secondary growth phenology monitoring system at Jardin Thuret, on a diversified sample of trees to highlight and characterise the underlying physiological and morphological processes. What is the impact of climate and its excesses on growth and what are the long-term effects. What morphological, phenological and physiological determiners can we observe and monitor? Can we pinpoint growth strategies when faced with the risk of edaphic drought for these species? These are some of the questions that our study will endeavour to answer.

## Materials & methods

The sample currently comprises 68 adult trees belonging to 17 taxa with forestry potential. The selection criteria are as follows: taxonomic and biogeographic diversity, primary growth mode diversity, growth phenology diversity, exoticism and acclimatisation (the trees are all adult and have well accommodated to the pedoclimatic conditions at Jardin Thuret), presence of control

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# 05. Materials & methods


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species (native taxa, some of which belong to the same genus as the exotic taxa), trees enabling testing of a new phenological criterion: sudden bark shedding. The exotic species belong to the *Arbutus*, *Corymbia*, *Eucalyptus* and *Quercus* genera and the native species to the *Arbutus*, *Ostrya* and *Quercus* genera. The trees form three groups: deciduous species with rhythmic growth and evergreen species with rhythmic or perennial growth.

## 1. PRIMARY GROWTH MONITORING

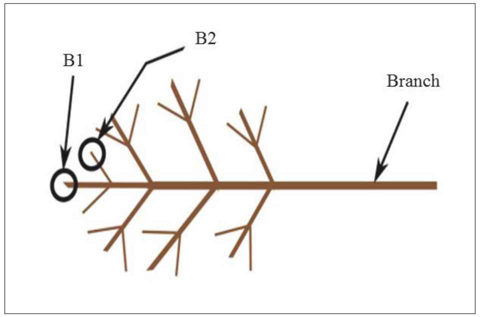
The weekly monitoring is inspired by the BBCH scale, with a universal decimal code for the phenological stages of the plants grown (**Table 1**) (Meier, 2001).

| Code | Stage | Stage description |
|---|---|---|
| 9 | Leaves | The end of the first leaves extends beyond the end of bud scales |
| 11 | Leaves | The first leaves are plated on about 10% of the crown |
| 15 | Leaves | The first leaves are plated on about 50% of the crown |
| 51 | Flowers | The majority of flower buds began to swell |
| 52 | Flowers | The majority of flower buds began to open |
| 61 | Flowers | 10% of the flowers or kittens are anthesis |
| 65 | Flowers | 50% of the flowers or kittens are anthesis |
| 69 | Flowers | 90% of the flowers or kittens are anthesis |
| 71 | Fruits | 10% of fruit have reached their maximum size |
| 85 | Fruits | 50% of fruit is ripe (changed color, or are dried and dehiscent, or fell) |
| 91 | Senescence | 10% of the leaves have turned color or fell |
| 95 | Senescence | 50% of the leaves have turned color or fell |

> TABLE 1.

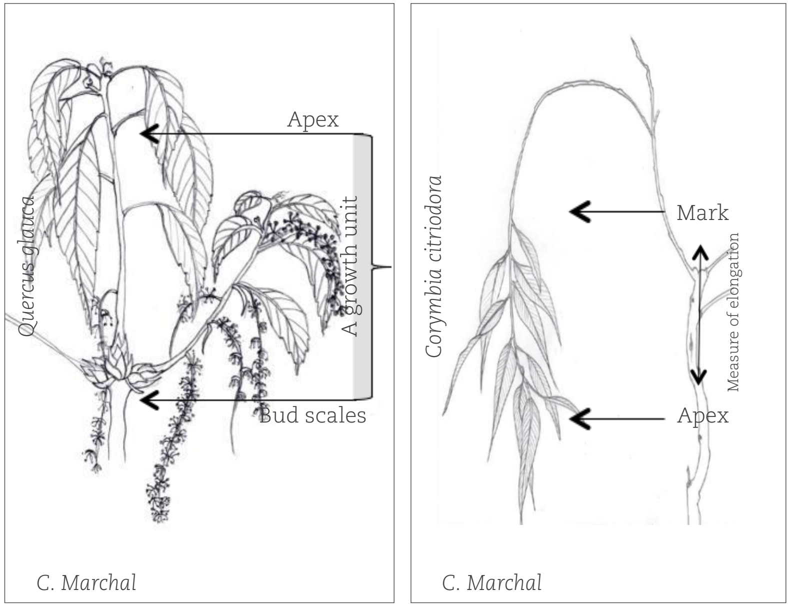
Phenological stages

The elongation of branches is also measured weekly along at least two axes per tree: a main B1 axis and a secondary B2 axis (**fig. 1** and **2**).




> FIGURE 1

Measured up branches




> FIGURE 2

Elongation measurement techniques for rhythmic or aperiodic growth

## 2. SECONDARY GROWTH MONITORING

Dendrochronology has been used for several decades to analyse year-on-year variations in tree diameter growth and the effects of age, cultural practices and climate variations. Variations in the diameter of a trunk, branch or fruit are continuously monitored with LVDT (Linear Variable Differential

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# 05. Materials & methods

> PHOTO 1 & 2

*Left:* PepiPIAF sensor
*Right:* Micro dendrometer

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Transformer) type sensors of sufficient resolution (1 µm), and reflect the action of four factors: 1) irreversible cell growth, reversible swelling or contracting of the organ in relation to 2) the moisture level and 3) thermal expansion of the organ (Kozlowski, 1971; Klepper *et al.*, 1971; McBurney & Costigan, 1984; Améglio & Cruiziat, 1992; Simonneau *et al.*, 1993; Zweifel *et al.*, 2000; Cochard *et al.*, 2001; Daudet *et al.*, 2005) and 4) the contraction or expansion of conductive elements under the impact of internal pressure related to water status of those conductive parts (Irvine & Grace, 1997; Offenthaler *et al.*, 2001; Sevanto *et al.*, 2002). We have used PépiPIAF sensors (Améglio *et al.*, 2010) which give very accurate (sensitivity to microns) continuous measurements of the diameter of an organ and memorise the data (diameter and temperature) without disrupting its functioning, using wireless technology (**Photo 1**).

Micro-dendrometers are used for twice-weekly trunk diameter measurements (**Photo 2**). We have taken weekly micro-core samples to track cambium/cork cambium activity. Finally, we monitored bark shedding in the species concerned, the objective being to explore a new simple phenological character for use in looking at cork cambium functioning (Ducatillion *et al.*, 2013). The entire device is on the **Table 2**.

| Latin name | Family | Native | Primary growth | Fall leaves | Fall bark | Flowers season | Place of flowering | Trees number | Sensors PépiPiaf number | Growth measure | BBCH stages | Micro-coring | Microwave dendrometers | Followed bark fall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Aesculus californica* | Hippocastanaceae | California | R | D | PG | P | T | 2 | 1 | 2 | 2 | 1 | 2 | 0 |
| *Arbutus andrachne* | Ericaceae | Eastern Mediterranean | R | E | S | H | T | 4 | 0 | 2 | 3 | 1 | 1 | 4 |
| *Arbutus canariensis* | Ericaceae | Canary Islands | R | E | S | W | T | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *Arbutus glandulosa* | Ericaceae | Central America | R | E | S | W | T | 1 | 0 | 0 | 0 | 0 | 0 | |
| *Arbutus menziesii* | Ericaceae | South of North America | R | E | S | W | T | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| *Arbutus unedo* | Ericaceae | Western Mediterranean | R | E | PG | W | T | 2 | 1 | 2 | 2 | 0 | 2 | 2 |
| *Arbutus x andrachnoides* | Ericaceae | Greece | R | E | PG | W | T | 3 | 0 | 2 | 3 | 1 | 2 | 3 |
| *Arbutus x thuretiana* | Ericaceae | Hybrid | R | E | S | W | T | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| *Corymbia citriodora* | Myrtaceae | North East Australia | A | E | S | S, E | T | 2 | 2 | | 2 | 2 | 2 | 2 |
| *Corymbia maculata* | Myrtaceae | Australia : Q, NSW, V | A | E | S | E | T | 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| *Eucalyptus dorrigoensis* | Myrtaceae | Eastern Australia | A | E | S | E | T | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| *Ostrya carpinifolia* | Betulaceae | Mediterranean | R | D | P | S | A | 3 | 0 | 1 | 3 | 1 | 1 | 0 |
| *Quercus glauca* | Fagaceae | East and South Asia | R | E | P | S | A | 4 | 0 | 2 | 4 | 0 | 2 | 0 |
| *Quercus ilex* | Fagaceae | Mediterranean | R | E | P | S | A | 10 | 2 | 2 | 10 | 2 | 6 | 0 |

> TABLE 2

Synthesis device.

Primary growth: rhythmic (R), aperiodic (A). Fall leaves: deciduous (D), evergreen (E). Fall bark: progressive (PG), sudden (S), persistent (P). Flower season: spring (S), summer (E), autumn (A), winter (W). Place of flowering: terminal (T), axillary (A)

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# 05. Results and discussion

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For each of these species, measurements in diameter variations have been set against climate data, elongation periods, different phenophases and bark shedding. We now have eight years' worth of phenophase observations for several species, but only two and a half years with the use of sensors and bark shed observation. The initial results nonetheless reveal some significant trends. The effect of climate on the growth of the three initial tree categories is compared in **Table 3**.

Group 1, illustrated by *Arbutus* x *thuretiana* (a hybrid between A. *canariensis* and A. *andrachne* naturalised at Jardin Thuret), reveal a number of axes in the growth or flowering phase, between autumn and early summer. Normal winter temperatures do not affect growth. However, environmental conditions affect the phenophase dates. Growth stops during the summer period. Trees in group 2, illustrated by *Eucalyptus dorrigoensis*, show pretty regular, opportunist growth throughout the year. In the *Aesculus californica* (group 3), budburst is very early (February) with brief primary growth. Leaves cease their activity earlier at the end of spring and fall in summer middle while it normally should shed in autumn for deciduous trees.

Under the same Mediterranean climate, the trees measured in the Botanical Garden in Villa Thuret demonstrate very contrasted primary and secondary growth depending on species, with variable sensitivity to climate factors (i.e. winter temperatures: e.g. *Eucalyptus dorrigoensis* vs. *Aesculus californica* or summer rainfall and drought; *Aesculus californica* vs. *Quercus ilex*) ). Some species as *Aesculus californica* seem to avoid potential summer drought, regardless of the year's rainfall, with early leaf fall with no apparent link to

**Climate action on 3 tree types. Some examples**

| Type of growth | Species example | Bud break and primary growth | Secondary growth | Climate action on growth |
|---|---|---|---|---|
| **1 -** Evergreen. Rhythmic growth | *Arbutus x thuretiana* | All the time except in summer. | Spring and beginning of summer | Impact on the phenophases and impact of extreme events |
| | *Quercus ilex* | Short and rapid growth in spring. Sometimes growth in autumn | Spring and summer | Impact of temperature on bud break |
| **2 -** Evergreen. Aperiodic growth | *Eucalyptus dorrigoensis* | Long growing with at least two short stops (winter and summer) | Only a stop in summer | Impact of extreme events |
| **3 -** Deciduous. Rhythmic growth | *Aesculus californica* | From late winter to late spring | Spring and summer | Slight impact on phenophases |

> **TABLE 3**

Climate action on three tree types. Some examples

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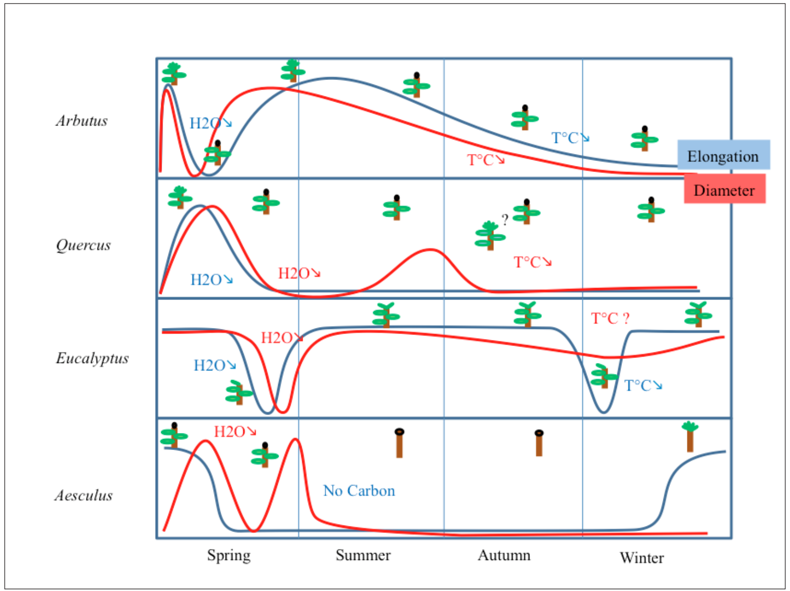
a climatic factor (no marked water stress). The physiology of these species in terms of phenophases, water flows and carbon management may thus be approached through the continual analysis of diameter variations and shows high diversity in functioning under the same climate. The annual phenological cycles of the four species groups are shown in **Fig. 3.**




> FIGURE 3

Diagram of the phenological cycles of 4 groups of species, according to the seasons. The curve in blue gives the average elongation for the 4 group of species independently of the climate. The red curve gives the same average for the diameter growth. For each season, we indicated the effect of the main climatic factor on elongation (in blue) or diameter growth (in red). For example, the diameter growth of the Eucalyptus is greatly attenuated by water stress (H2O) in late spring and early summer in comparison with the average diameter growth for this site at this period. For this species, diameter growth was also impacted in winter in response to the colder temperatures (T°C) of one year in comparison to the average temperature during winter for this site.

For example for *Eucalyptus*, when you measure diameter growth, you can observe an almost constant rate of growth decreased in late spring and early summer only by the soil water reserve (rainfall during this period) and during winter if the temperature decreased below +10°C. For *Aesculus californica*, the pattern of growth diameter appears the same as that measured in its original area in California (Mooney & Hays, 1973) but our continuous diameter measurements indicate that the fall of the leaves in this species is not related to water stress (no more shrinkage during the day indicated no strong mobilization of water reserves in the bark). Here we have a typical adaptation to the Mediterranean climate by an avoidance of drought stress by leaves fall with no stress and a drastic reduction of transpiration.

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# 05. Conclusion

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By monitoring both primary growth and secondary growth, we can obtain an overall view of the effect of climate on a plant's functioning. At the same site, the three groups of trees show contrasting growth modes, responding or not to climate conditions. The choice and positioning of the axes monitored, within the tree's architecture, provides more realistic information on the tree's behaviour in response to climate variations.

Thus, the study over a few years on the same site of primary or secondary growth dynamics can quickly permits to extract the phenophase of these growths for different species, but also to conclude on climatic factors (water or temperature) affecting them.

Thus observation of the bark phenology through the continuous acquisition of micrometric variations of branch or trunk diameter measurements using the PépiPIAF sensors therefore makes it possible to track not only secondary growth (resumption of cambial activity, growth rhythm) but also leaf phenology (budburst, leaf growth and senescence) by providing new information on the physiology of species which are little or so far unknown. This new tool therefore allows for the acquisition of phenology measurements in numerous situations (isolated tree, arboretum, acclimatisation gardens, orchards, forests, vines, trees in towns, etc.) while contextualising the different phenophases observed in the climatic environment (e.g. heat conditions), but also the physiological environment (e.g. water constraints), both of which can be addressed using the same measurement.

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