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Water in Trees
An essay on astonishing processes, structures and periodicities

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Abstract. This essay shows that the relations between water and trees have far-reaching, unexpected aspects and consequences. The local and the global terrestrial water cycles are directly or indirectly linked to the presence of trees and forests. A more precise consideration of photosynthesis reveals that this process is not only producing biomass and oxygen, but is also the place of water synthesis. This newly formed water probably shows properties according to the new water-paradigma proposed by G. Pollack (2013). This must also be the case for the water absorbed in the soil and flowing upwards through capillar wood structures, forming vortices at the microscopic cellular and at the macroscopic tree level. Another lesser-known phenomenon is linked to periodical changes in the wood-water relation, according not only to the solar influence (photoperiodism, seasonality), but also to more subtle lunar rythmicities having an effect on wood properties. This last aspect represents a kind of rehabilitation of traditional practices often considered as mere superstitions.

Keywords. Water cycle, photosynthesis, water synthesis, wood structure, vortices, lunar rythmicities.

WATER AT THE CENTER OF THE FUNDAMENTAL PROCESS OF LIFE

Photosynthesis is the common process to all plants, but trees, due to their outreaching dimensions and to the formation of forests in specific multispecies associations, perform 2/3 of the global photosynthesis on earth. A closer study of this process reveals that there is a hidden face of photosynthesis. In many textbooks or even dictionaries, an uncomplete equation of photosynthesis is still usual, which is misleading for a correct understanding of the most important physiological process making life possible on earth. Effectively, following equation is often figuring:

"6 molecules of carbon dioxide + 6 molecules of water + light →
1 molecule glucose + 6 molecules oxygen"

$$6CO_2 + 6H_2O \xrightarrow[\text{Sunlight energy}]{} C_6H_{12}O_6 + 6O_2$$

Where: CO_2 = carbon dioxide
H_2O = water
Light energy is required
$C_6H_{12}O_6$ = glucose
O_2 = oxygen

The researcher who finally refutes this incomplete and tenacious portrayal is the microbiologist Cornelis Van Niel (1897–1985) of Stanford University, following work as a young student on the photosynthetic activities of various types of bacteria. One particular group of these – the purple sulphurous bacteria (Thiorhodobacteria) – is capable of reducing the CO_2 into carbohydrates, in an atmosphere devoid of oxygen (anaerobic conditions) and without emission of oxygen. The substrate necessary here is not water H_2O, but hydrogen sulphide H_2S. What is released by the process, on the other hand, in addition to the carbohydrates, is water H_2O and elemental sulphur S_2 accumulated in the globules within the bacteria and identifiable under a microscope. Van Niel did not stop here and he extrapolated his discovery by proposing a generalised equation for photosynthesis. This came down to affirming that the source of the oxygen produced by chlorophyllian photosynthesis was in fact the water and not the carbon dioxide.

This brilliant speculation put forward in the 1930's received its proof in the following decade when researchers from Berkeley used a heavy isotope of oxygen ($_{18}O$) to mark the water molecule entering the reaction. Result: the oxygen released comes exclusively from the H_2O molecule. In terms of process, this comes down to understanding that the primary action of the sun's rays in photosynthesis consists of the splitting or photolysis of water. The newly produced water takes its oxygen from the carbon dioxide absorbed (Ray 1972; Lance 2013).

The complete and balanced equation for the production of glucose by photosynthesis, within a living system without which nothing can happen, thus includes an extra constituent. The destination of the atoms of the water molecules taking part in the reaction can be shown by using colours and bold type:

$$6\ CO_2 + 12\ \mathbf{H}_2\mathbf{O} + \text{light energy \& living system} \rightarrow$$
$$\underset{\text{Glucose}}{C_6\mathbf{H}_{12}O_6} + 6\ \mathbf{O}_2 + 6\ \mathbf{H}_2O$$

By converting into moles (molecule-grammes, according to chemists' terminology), it is possible to illustrate the flows of matter by weight (in grammes), with indication of the energy required (in kilo-Joules):

6 Mol CO_2 +	12 Mol H_2O +	light & life →
264 g	216 g	2897 kJ

1 Mol $C_6H_{12}O_6$ +	6 Mol O_2 +	6 Mol H_2O
180 g	192 g	108 g

Figure 1 also presents the values corresponding to the synthesis of wood, originally based on glucose, but characterised by a slightly different formula used by physiologists (Zimmer and Wegener, 1996). Some remarkable facts emerge from this new vision of the process:

- For each dry tonne of wood made by the tree, a mass of 1.851 tonnes of gaseous CO_2 is removed from the atmosphere, reducing by that amount the greenhouse effect and global warming which preoccupy humanity at present. We have here a 'carbon sink', persisting as long as the wood is not burned or decomposed releasing an analogous quantity of CO_2 into the atmosphere. It will therefore be important in the future to incorporate wood on a long-term basis either into buildings as a material or into soils in order to increase the content of stable organic matter.
- Each anhydrous tonne of wood made by the tree is accompanied by a mass of 1.392 tonnes of newly-formed oxygen, coming from the photolysis of water. This represents a considerable volume: 973 m^3 of pure oxygen, or 4,636 m^3 mixed at a proportion of 21% into the air we breathe to stay alive. A rather unorthodox question, coming from a quality point of view: Does newly-formed oxygen of this kind, entering the biosphere for the first time in this form, have different properties from "old" oxygen? Could this possibly be one of the reasons why forest air has always been felt to be particularly beneficial to health?
- Each anhydrous tonne of wood made by the tree is accompanied by a mass of 541 kilos of newly-formed water. As for the preceding component, we have here perfectly pure water, which has never before entered into the great cycle "evapotranspiration – cloud formation – condensation / precipitation – running-off / percolating – accumulation – resurgence". It is likely that this new water soaks the green parts of the plants and circulates with the elaborated (phloem) sap down to their lower organs, contributing to their growth. Here too arises the question of qualities, properties or specific virtues of such water, especially given the many forms of pollution to which the external water cycle is subjected. Such a question can be placed in a modern scientific debate, very con-

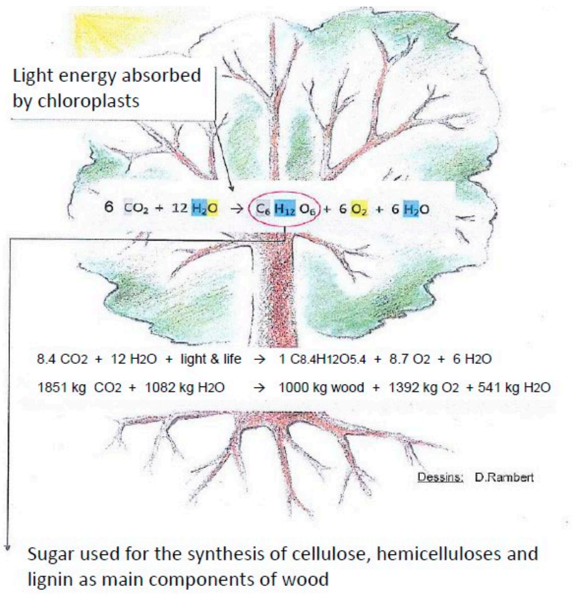

Figure 1. Complete general equation of photosynthesis, with an indication of the destination of components (above) and average proportions accepted for wood, with indication of weight ratios compared to the dry matter of wood, according to Zimmer and Wegener (1996) (below) [drawing D. Rambert].

troversial at the outset, but finding more and more renowned defenders: that of the 'memory of water', as developed by pioneers such as Jacques Benveniste, Xy Vinh Luu, Marc Henry, Luc Montagnier or Gerald Pollack. We should mention here, to underline the credibility of the protagonists and the importance of the subject, that Professor Luc Montagnier received the Nobel Prize for Medicine in 2008.

TREES AND THE LATEST FINDINGS ABOUT WATER

The emergence of a new understanding of water allows us to adjust our view of the structures and functioning of trees. A chance observation made in a Japanese laboratory followed by a series of experiments starting at the beginning of this century has led to a progressive confirmation of a hitherto-unknown property of water. In the presence of hydrophilic membranes (natural or synthetic) and over a distance reaching sometimes several tenths of a millimetre, water acquires a state which seems both liquid and solid at once, a fact which suggested to the discoverer, a researcher and professor of bioengineering already well-known for his book 'Cells, Gels and the Engines of Life (Pollack 2001), the expressions of 'exclusion zones, EZ' (EZ water / linked to its particularly pure state) and 'fourth phase of water'. in addition to the solid, liquid and vapour phases. The research on the subject which continues to this day has recently received a coherent overall structure in the form of a publication which did not go unnoticed by the scientific community: 'The Fourth Phase of Water – Beyond solid, liquid and vapor' (Pollack 2013).

The anatomical structures of plants and trees in particular, composed of a complex system of membranes and cells with hydrophilic walls showing dielectric properties (as postulated by Pollack) and the mechanisms of transport of water towards the crown and the metabolism linked to photosynthesis can, through this new concept, be interpreted more precisely. It should be mentioned that this water close to hydrophilic membranes can be distinguished from 'normal' water by many criteria such as level of purity, pH, viscosity, refraction index, the absorption of light energy, electrical charge, oxygen content or again the formation of a supramolecular network.

The formation of 'new' water resulting from photosynthesis, in addition to the carbohydrates and oxygen, thus gains additional significance, since it occurs within complex membrane systems, corresponding to the criteria of formation of water of the 'EZ' type. The fact that this new water takes 89% of its mass from part of the oxygen of the atmospheric CO_2 is already remarkable in itself, making the plant – and in a particular way the tree – both a consumer and a producer of water. It is recognised that carbohydrates and oxygen are necessary for life. We may now ask whether new water with its special properties (which still need analysing) might not also be of fundamental importance.

STRUCTURES

A functional approach / Xylem as water conducting system

The function of conducting water requires bringing water from the root system to the crown, where the assimilation takes place. This occurs through a conducting system made of cells called tracheids in conifers and connecting alignments of cells called vessels in broadleaved species. The first engineering problem is: How to bring cold water (heavy) up to the high parts exposed to heat, sometimes more than 100 metres for the largest trees? How can the physical law of gravity be overcome?

The solution is proposed by the physiologists with the 'theory of cohesion – tension': Water is sucked up, with its diluted mineral salts, along the cellular channels by the 'negative pressure' resulting from the foliar transpiration of the tree (Zimmermann 1989; Koch et al. 2004; Johnson 2013). To go beyond the critical height of 10 metres (linked to the atmospheric pressure), the water must contain absolutely no gas bubbles and thus have access to the totality of its internal cohesive forces (which allow, for example, two glass plates to stick together). This state of liquid purity is made possible in conifers by bordered pits. These are mobile contact structures between a tracheid and its neighbour with an effect simultaneously of valve and sieve in order to avoid any embolism due to air bubbles which could accumulate. This system of water transport with special specifications functions at the periphery of the bole's section, in the xylem, the living part of the wood characterised by bio-electric fields. Gerald Pollack's recent discovery (mentioned above) reveals that water running through tracheids or vessels the most directly in contact with the hydrophilic cell wall acquires a particular structure ('liquid crystals') and unexpected physical, chemical and electrical properties, probably essential to the physiological exploits of trees. Running through capillary systems allows the water to stay liquid down to low temperatures, around – 15°C for certain species, instead of damaging the structures by the formation of ice crystals in winter. As for the electrophysiologists, they observe that the differences in electrical potential generated by the living tissues stimulate the flow of raw sap. These observations follow on logically from old experiments testing the effect of glass capillaries on the fluidity and sensibility of water (Maag 1928).

This function of conducting water in an upward direction is fulfilled in conifers by tracheids of earlywood (formed in the spring and the beginning of summer) containing many bordered pits. The latter represent the points where water passes from one cell to its neighbour during its flow towards the crown, site of photosynthesis. Comparatively, the tracheids of late wood (formed towards the end of the vegetative period) possess a much thicker cell wall endowed with fewer pits; their function is no longer conducting raw sap, but primarily the support of the whole structure. The functioning of a bordered pit, a local cell wall modification essential to the security of the conduction system, is presented in Figure 2: we have here an efficient and 'ingenious' system, a characteristic component of the functional anatomy of conifers.

Compared to conifers, the anatomy of broad-leaved trees is much more complex, with its forms of functional specialisation. Depending on the tree species, we find generally two types of arrangement of vessels: in porous zones in the case of a marked contrast between early and late wood, or in diffuse pores, when the vessels are of practically constant diameter, spread regularly over the whole of the annual ring.

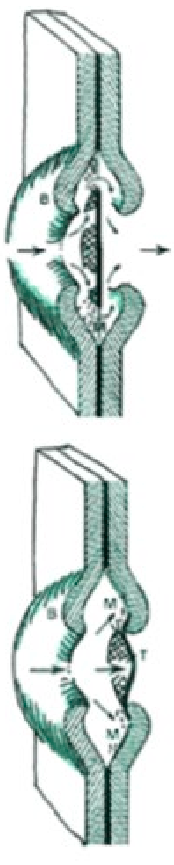

Figure 2. Diagramme of the workings of a bordered pit: when functioning normally (top), the water skirts the central impermeable zone of the shared membrane and enters the neighbouring tracheid; in the case of a wound with air bubbles (accidental entry of air), the relative increase in pressure causes the membrane to be flattened, by suction, against the inside of the opposite pit (bottom), blocking the flow of water in the damaged part [modifies after Zimmermann 1983]. The recent discoveries about water encourage the supposition that this forced passage through the fibrillar weave of the peripheral membrane confer on the water an additional proportion in the 'cristalline-liquid' phase with high viscosity and lowered freezing point, an essential characteristic for species growing in cold regions.

Spirality and the Golden Ratio

The helical arrangement observed in the needles of a young Scots Pine shoot follows a general principle of pronounced geometrical nature, which Goethe (1749–1832) considered as fundamental and called "spiral tendency, which reigns in Nature", and which is always found in combination with the "vertical tendency". It was shown by a philosopher and naturalist from Geneva, Charles Bonnet (1720–1793), that the position of leaves or needles along a stem (subject of phyllotaxy) or the

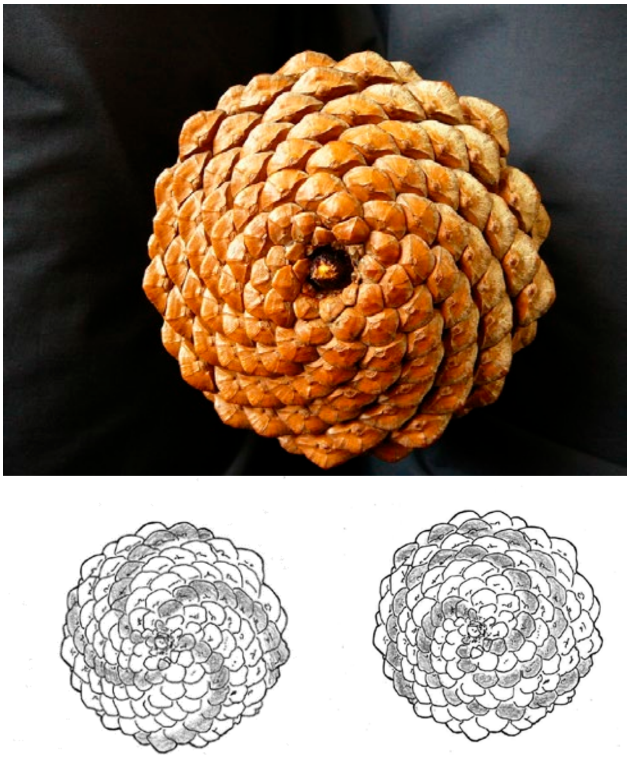

Figure 3. Cone of a Maritime pine (*Pinus pinaster*) growing in the western Mediterranean (above), showing an arrangement of the scales according to two series of spirals with a ratio 13 / 8 (below).

structure of a fir-cone or pine-cone, or indeed that of a thistle flower head, follow a series of crossed spirals. These are subject to a particular relationship: the Golden Ratio. This ratio, originally defined by Euclid (325–265 BC), is found among others in the famous number sequence developed by Leonardo of Pisa, also called Fibonacci (approx. 1170 – 1250) :
1 – 1 – 2 – 3 – 5 – 8 – 13 – 21 – 34 – 55 – 89 – 144 - … ,
where each element is the sum of the two preceding ones. This series allows the constitution of a set of rational ratios 2/1, 3/2, 5/3, 8/5, 13/8, … 144/89, … , which tend towards the number Phi (ф) = 1.61803 … . Similarly, the series 1/2, 2/3, 3/5, 5/8, … etc. converges towards the number phi (ф) = 0.61803 … (ф = ф - 1). A cone of the Scots Pine (*Pinus sylvestris*) observed from its base shows an arrangement of scales (also called bracts) according to two spiral systems: a group of 13 rightward (clockwise) spirals and a group of 8 leftward (anti-clockwise) spirals. An Eastern White (*Weymouth*) Pine (*Pinus strobus*) is also formed according to the Golden Ratio, but with a ratio of 8/5. These arrangements are illustrated by the example of a Maritime Pine in Fig. 3. Analysis of a specimen of Spear thistle (*Cirsium vulgare*), an annual plant, shows the seeds on a dried head to be arranged according to a double spiral system with a ratio of 26/16, which can also be written 13*2 / 8*2, thus is part of the Fibonacci series. Interestingly - and to make a link with the 2019 International Year of the Periodic Table of Chemical Elements – the elements of the Mendeleyev's table can be geometrically arranged according to a spiral following the Fibonacci pattern (Morton 1977).

Where Life surges up

Usually (as was the case in Figure 3), the right-handed and left-handed spiral patterns (also called parastiches) are counted from the base either clockwise or anti-clockwise, which corresponds to an upwards direction for the axis of the cone or for the stem carrying leaves or buds.

But we could also consider, like the famous Austrian forester-hydrologist Viktor Schauberger (1885-1958), that in the genesis of plant organs, series of upward spirals cross downward spirals. In his vision of the living world, he talks of female upward energies which are fertilised by male downward energies moving in the opposite direction. In practice, the axillary buds arranged along the shoot and the seeds developing at the receptacle or along the axis of the cone (at the base of the scales) could be understood as germs of life appearing within a "flow – counterflow" system according to the precise mathematical-geometrical ratios of the Golden Ratio. In a conception of the plant as interacting with the astronomical rhythms modulating among others gravitational forces, these germs of life would thus appear at the points where terrestrial and cosmic 'force lines' meet and cross-fertilise (Fig. 4).

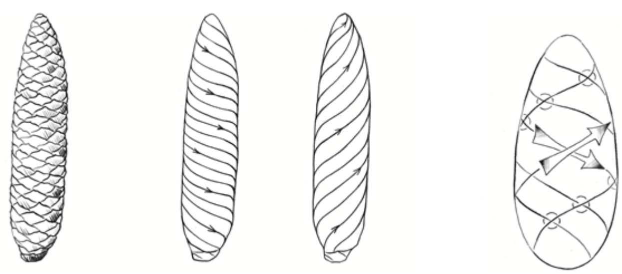

Figure 4. Left: diagrammatic representation of two "energy flows (male downwards / female upwards)" intersecting in a helical fashion (in Coats 1996). Right: Spatial arrangement of the seed location at the intersections of the spiral patterns characteristic of the species; the seed represent dormant meristematic points, destined to develop as new specimen. Drawing D. Rambert.

Viktor Schauberger (1885–1958)

Austrian forester remaining voluntarily outside university circles, Viktor Schauberger was a hydrologist and inventor who stupefied the technical and academic circles of his time. His first achievement was making channels for floating wood of a revolutionary type, seeming to defy the laws of physics of the time. A great observer of natural phenomena, he explored the diverse properties of water and drew from them technical applications including regeneration systems. He saw water as the basis not only of all life, but also of the whole of the 'terrestrial consciousness'. His thoughts and discoveries led him to direct applications in forestry, agriculture and hydrology (waterways, dams, vitalising water, organisation of forest areas). He designed an ecology in symbiosis with nature well before the contemporary approach (Alexandersson 2002; Bartholomew 2014).

This concept of special places for life to surge up where two flows meet can also be applied to the first cambial cells separating the conducting bundles of young stems, and to the widened 'secondary' cambium forming a closed cylindrical meristematic layer, in charge of the growth in thickness of the trunk: both are placed exactly between the upward xylem flow (in the wood) of raw sap and the downward phloem flow of phloem sap.

Vortex flows revealed

By means of injections of liquid colourings into the sapwood at the base of the trunk, some physiologists (see Bosshard 1974; Harris 1989 on this subject) found that the upward flow of raw sap does not occur in a straight line, but in a manner which is generally helical, in a progression around the axis of the tree. According to the species, but also according to their growth conditions, five ways of transporting water up to the branches were described, of which four were clearly not straight, in the form of upward spirals turning towards the right, or towards the left, or even swinging from one direction to the other (Fig. 5). These flows are linked to the anatomical structure of the wood, presenting a 'spiral grain', with conducting cells deviating from the axis to a greater or lesser extent, including radical changes in direction during the change from juvenile to adult status in many conifers. These phenomena serve to guarantee that each root can provide water to each branch or nearly, with priority given to the apex, the most essential part of the crown.

An analogous experiment remains to be carried out with the downward flow in the phloem: will we find downward spirals in the opposite direction?

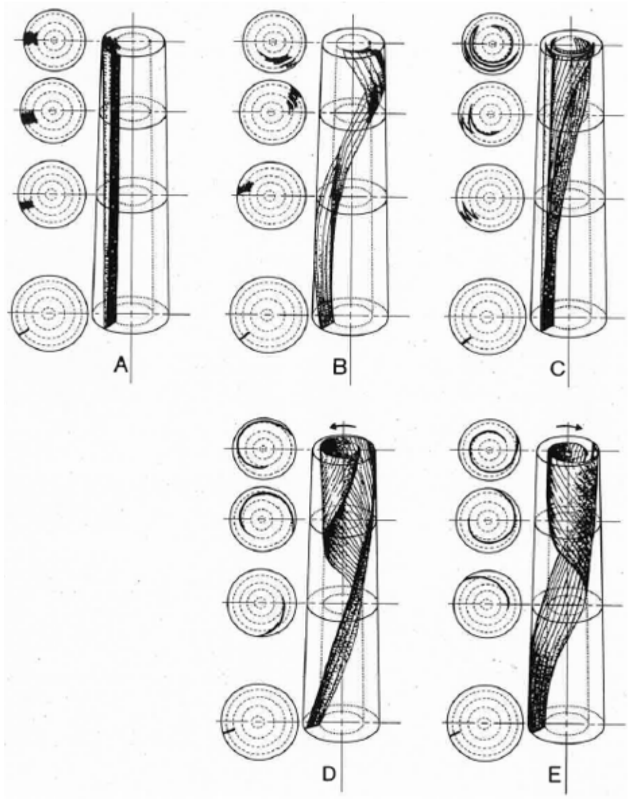

Figure 5. Ascent of dye solutions in stems of standing trees, after injections radially at the base of the stem. A: sectorial straight; B: sectorial winding; C: interlocked; D: spiral turning left; E: spiral turning right (In Harris 1989, after Vité 1967).

This elucidation of the upward flow of raw sap using dye solutions injected at the base of the stem showed the paths to the crown were not direct but helical (in a vortex) compared to the axis of the trunk. An interesting similarity underlining the coherence of biological systems: the flow of blood in the large vessels and in the human heart, studied using Doppler echocardiography and cardiac magnetic resonance, also form vortexes (Day 1998; Sengupta et al. 2012; Caro et al. 2013). In the more recent development of research on water, based on the discovery of a "fourth phase of water', particularly in contact with organic hydrophilic membranes, the part played by vortex flows appears in a new light. One of the particularities is that the vortexes increase the oxygenation of the water and its amount of energy-rich hydrogen bonds (Ignatov et al. 2015). Simultaneously, the emission of energy by radiation is reduced, while significantly decreasing the temperature when before and after vortexing is compared (Pollack 2013). This last feature had been discovered by Viktor Schauberger mentioned above, who considered it very important for the health

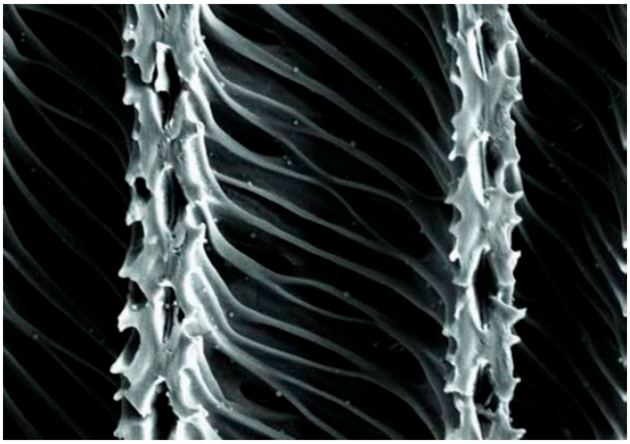

Figure 6. The clematis (*Clematis vitalba*) is a woody plant which is not self-supporting, belonging to the group of lianas, which have the highest-known speeds of transport of the raw sap. A maximum of 222 metres per hour was measured by Kucera and Bossard (1981). The strongly helical structure of the vessel walls probably plays here an essential role (Photo T. Volkmer).

of 'biological systems' such as trees or even waterways. Figure 6 may illustrate the phenomenon at the anatomical level.

PERIODICITIES

Chronobiological studies on felling dates of trees and properties of wood related to water

The exact moment when a tree is felled to harvest the wood, or simply the moment when samples are taken, has an importance which is generally ignored or underestimated. Indeed, we should think of this material as a dense tissue of organic matter saturated with water by forces and to an extent which fluctuate in a cyclic manner. The behaviour when drying (loss of water, shrinkage) and the resulting final density, as well as mechanical resistance (to compression for example) and even resistance to decomposing agents such as fungi or insects, will all be influenced one way or the other by the date of harvesting.

Traditional practices which are still very much alive

Still today, maxims about felling linked to the moon are applied by certain workers of wood. An interesting fact: these rules come from traditions which persist in many regions of the world where links remain with ancestral culture. Here we will not deal with the multiple "lunar calendars", very trendy nowadays, covering numerous areas fairly comprehensively, without any experimental basis. The examples which follow concern cases known directly to the author, or taken from scientifically documented sources; their aim is to illustrate the great variety of uses of wood for which the moon factor is considered important for obtaining certain exceptional properties. It should be pointed out that in most cases this factor comes only in second or third position, the most important being in general the time of year, with a high value placed on "winter wood", and the situation in terms of the growing conditions, mountain wood from slow-growing natural forest stands being particularly appreciated. Sometimes winds are mentioned, such as the Foehn in the Alps, which could negatively impact certain properties of the wood.

Large-scale research

In order to tackle the question more fundamentally and with a large data base, a new trial was carried out simultaneously on 4 sites in Switzerland, with 48 successive fellings (each Monday and each Thursday) – not linked to any experimental hypothesis – of 3 trees per site over 5 ½ months, representing a total of more than 600 trees felled over the winter of 2003-2004 (Zürcher et al. 2010). The species were Spruce (*Picea abies*) and Sweet Chestnut (*Castanea sativa*). Before the beginning of the experiment, a reference sample was taken the same day from each of the trees which were later felled (a prismatic sample at chest level). Each tree provided at different levels of the trunk a series of samples of sapwood and a series of samples of heartwood. The drying behaviour of this material was followed under standardised laboratory conditions.

Among the different rhythmicities first observed and then confirmed statistically for three principal criteria, let us mention here the water loss, which varied systematically in Spruce, particularly between the fellings immediately preceding the full Moon and those following it. The type of variation is probably due not to differences in initial water content, but to the fact that the forces binding the water to the cell wall of the ligneous tissues could be subject to fluctuations. The ratio between the water easily extractable from the wood, designated 'free', and the water extracted below the saturation point of the fibres, or 'bound' water, fluctuates according to lunar cycles, and probably also according to the seasons, the 'lunar' variations being more marked during the period from October to February (Zürcher et al. 2012). Moreover, the rhythmicities are manifested differently according to the species: the Chestnut also

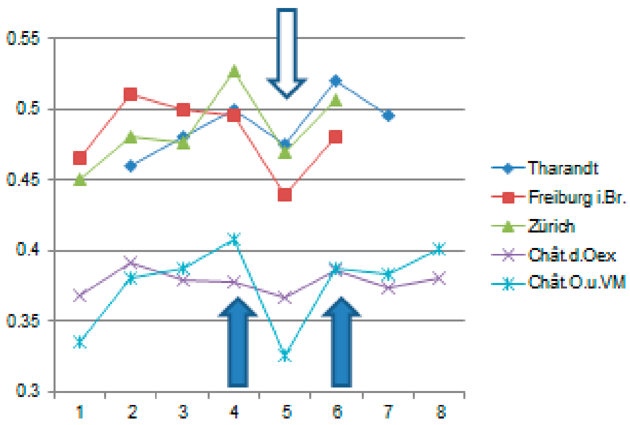

Figure 7. Variation of dry (andhydrous) densities of wood (sapwood) of Spruce (*Picea abies*) with felling period and moon phases, according to research done in different places and years. Upper: Tharandt 1996-97 (Triebel 1998); Freiburg i.Br., 1997-98 (Seeling and Herz 1998, 2000); Zürich, 1998-99 (Bariska and Rösch 2000) / lower: Château-d'Oex 2003-04 (Zürcher et al. 2012) Means waxing Moon – waning, resp. Château-d'Oex 2003-04 around the Full Moon – before / after). Waxing Moon dates 1, 3, 5, 7; waning Moon dates 2, 4, 6, 8. Similar variations can be observed especially in the second half of the trial period, from December onwards (4). Reminder: most of the technological properties of wood are closely linked to its density.

shows statistically significant lunar variations, but distinct from those of the Spruce.

These systematic variations in water loss cause a variation in the density of the wood after drying: - For the case of Spruce, it confirms what the previous studies mentioned had already observed (Fig. 7 – lower).

Drying wood felled around the Full Moon

In the Spruce samples (*Picea abies*; sapwood and heartwood together), a systematic and statistically significant variation of water loss is detectable. This fluctuation occurs according to the synodic lunar cycle on felling, subdivided into 8 periods of 3.7 days, beginning with the moment of the New Moon. The most marked variations occur during the passage from the period preceding the Full moon (high water loss) to the one beginning with the Full moon (minimal water loss) then the one preceding the Last quarter (high water loss). [Zürcher et al. 2010]

The statistical analysis indicates unexpectedly not only rhythms of a synodic type, but also a marked sidereal rhythmicity. Scientific research is thus able to affirm that behind the 'lunar' phytopractices of foresters resides a kernel of objective observations. This the case both for synodic lunar phases (the cycle New Moon – Full Moon linked to the position of our satellite relative to the Sun) and for the sidereal cycle (position of the Moon compared to fixed constellations), also mentioned in a roundabout and somewhat curious way in certain felling rules. Note that these results, while confirming the existence of the 'Moon' factor as mentioned in country lore, appear in a much more complex form than imagined at the start of this research, Theophrastus's rule seeming to be very close to the synodic phenomena observed in Spruce (see below).

Focus on a representative site

The systematic variations over the course of the synodic lunar month can be illustrated in another fashion with the graph of variation around the general mean of this same criterion 'water loss' for the 48 successive felling dates, using a representative series: the sapwood samples of the site of Château-d'Oex (Zürcher et al. 2012). This material is relatively homogeneous because all the trees are of the same age, belonging to an even-age-managed mountain forest deriving from a plantation. Figure 8 A shows the visible change which occurred around the Full Moons of November, December and January. Even if the February Full Moon is included, where there was almost no difference between the values before and after the Full Moon, the respective variations around the Full Moon for this winter period of four months are not insignificant, the general mean indicating a reduction in water loss of 4.5%.

Tests of water absorption (after drying)

One of wood's most important physical properties, decisive for its bad-weather behaviour and its resistance to rot, is its hygroscopic nature – a very hygroscopic wood is more prone to rot than one which is less hygroscopic. This property is generally expressed by the equilibrium state in a given atmosphere, with a given temperature and relative humidity. When they are completely waterlogged, the cell walls are in a state designated 'fibre saturation point', below which the loss of bound water following the drying process causes deformations (shrinkage). The test method chosen for estimating the hygroscopic variations due to felling date was to expose the samples to a direct contact with water (Zürcher et al. 2012). A series of measurements was made using small rods from felled trees, previously air-dried under controlled conditions. They were all fixed (12 x 48 = 576 samples per site) by one end to a slab, the other end being immerged over a length of 5mm for 9 minutes in

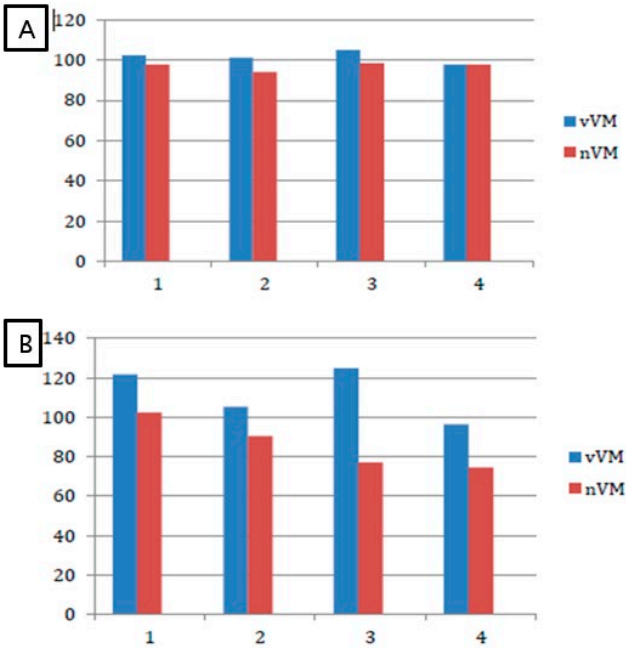

Figure 8A. Variation of water loss during drying of Spruce (*Picea abies*) samples, comparing the felling dates occurring in the 3.5 days running up to the Full Moon (vVM), with those of felling occurring during the 3.5 days after the Full Moon (nVM), for the months of November 2003 (1), December (2), January 2004 (3) and February (4). The samples from before the Full Moon of November, December and January lost slightly more water than those from fellings performed after the Full Moon. Values calculated from the general mean.

Figure 8B. Variation of capillary water absorption by the dried Spruce (*Picea abies*) samples, comparing the felling dates occurring in the 3.5 days running up to the Full Moon (vVM), with those of felling occurring during the 3.5 days after the Full Moon (nVM), for the months of November 2003 (1), December (2), January 2004 (3) and February (4). The samples from before the Full Moon of November, December, January and February absorbed considerably more water than those coming from fellings performed after the Full Moon. Values calculated from the general mean.

a bowl of water with ink as a dye. Figure 8B shows the variations in absorption of water by capillarity in the samples taken during this experimental period. Both the limitation of the lunar effect to the 4 winter months and the systematic and marked decrease in water absorption directly after the Full Moon are very similar to what was observed concerning initial water loss described above at Figure 8A. It is noteworthy that for the reabsorption of water by capillarity, the mean amplitude of the decrease (25.9%) for the samples taken just after the Full Moon is comparatively much more pronounced than for water loss and is evident even for February.

The second test method for quantifying the degree of hygroscopicity was applied by immersion of samples previously used for the determination of the density. In the same way, 576 cubic samples for each site (4 per tree, 12 for the felling date) were immersed in water at 20°C for 7 days. The absorption is expressed in this case as the percentage increase in mass. There too, systematic lunar variations in hygroscopicity occur, in obvious coherence with the loss of water. For the four months from November to February, the mean reduction between the days before the Full Moon and the days immediately after is 12.6%, half the value obtained for absorption of water by capillarity.

These results show us that the reversible variations linked to the Moon are not limited to the loss of water and the relative density (and shrinkage) in the course of drying: the phenomenon is even more marked for the absorption of water (by capillarity and by immersion) of previously dried wood samples. It should however be pointed out that these hygroscopic variations linked to the lunar cycles are much weaker than the differences due to the site and the type of forestry, since Spruce samples from a naturally-regenerating mountain forest show much lower water absorption than those from a plantation.

These encouraging results have to be confirmed by tests of durability before definitive conclusions can be made about Spruce wood for outdoor use. It could nevertheless be expected that differences in the resistance to decay of Spruce wood might follow the following rule: “low durability of wood cut not long before the full moon, because very hygroscopic; higher durability of less hygroscopic wood cut immediately after the full moon between November and February” – which would correspond to the oldest documented rule, written by the Greek naturalist Theophrastus (371–287 b.C), stipulating that the best construction timber is obtained when trees are felled in winter, in the first days after full moon. Indeed, it is well known that woods whose fibres can be highly saturated by water are more easily attacked by fungi and xylophagous insects than woods with a comparatively low saturation level of their cell walls.

Implications and perspectives concerning periodicities

This insight into lunar cycles detected in the plant world, and in particular in trees and their wood, shows a real phenomenon, which is additional to the exogenous rhythms of mostly solar origin whose action is well known, both on a daily and a seasonal level, and linked over the longer term to the cycle of sunspot activity, varying over an 11 year period. The Moon modulates this principal exogenous rhythm on an hourly basis, through the gravimetric tides occurring with two high and two low tides per day, as well as over the week and the lunar month, according to the synodic, tropical, sidereal or anomalistic (perigee and apogee) cycle. It seems that the lunar rhythms become apparent when the influence of the sun is reduced, either naturally or due to an experimental set-up.

What kind of forces are involved here? Where the synodic and anomalistic rhythms are concerned, the gravitational force causing tides is too weak to explain even a tiny part of the lunar phenomena observed in plants: it is not more than 0.08 millionths of the force exerted by gravity on a mass situated at the surface of the Earth.

For the largest tree measured in Europe, described by Klein in 1908, a Silver Fir Abies alba in the Black Forest (height 68m, diameter 380cm, bole volume 140 m3, weight estimated at 100 t), the tidal (gravitational) lunar force represents a light daily pull then relaxation of 8 grammes only – the weight of two sugar lumps!

The variations of the geomagnetic field, weak but distinct, with a period of half a lunar day (12 hours 25 minutes), due to the gravimetric tides, present a similar situation.

The French chronobiologist Lucien Baillaud (2004) points out quite rightly: "Where the moon is concerned, the supporter […] wants to be shown the basis of the link between the Moon and the living being, with a breakdown of how the phenomena fit together – or at least wishes us to suggest a hypothesis".

It seems to us more and more obvious, as has been mentioned several times, that this basis is none other than the essential element for every organic process: water. This was the direction of the conclusions of researchers working on the cyclic variations of certain chemical reactions in aqueous medium in controlled laboratory conditions, such as Giorgio Piccardi, Joseph Eichmeier or Soco Tromp. We should mention also the work of Vladimir Voeikov and Emilio Del Giudice (2009) on the fluctuations of water in its electronic charge and its capacity to react with oxygen, bringing them to the concept of " water respiration".

Already in the 1920s, experiments had been performed on the variations in surface tension of water using extremely fine glass capillary tubes, where the frequency of drop formation was observed (Maag 1928). They demonstrated lunar rhythmicities (monthly, but also daily) appearing as soon as the capillaries became fine enough, showing then the effect of certain planetary conjunctions. Meanwhile, it was observed that when it is in capillary systems, either of glass or organic like plant cells (with their vacuole and their partially porous membrane), water undergoes an important change in its properties, like for example the ability to remain liquid at temperatures as low as – 15°C. It would be interesting to analyse again the effect of the 'time' factor on these essential properties of water using modern technologies.

A relatively recent double publication in theoretical physics by Gerhard Dorda (2004), co-author with von Klitzing of the discovery of the "Quantum Hall Effect", winner of the Nobel Prize for Physics 1985, puts forward a new astro-geophysical model of the role of gravitation in living processes. This model integrates static and dynamic aspects of gravitation according to the orbital movement of celestial bodies, leads to a 'quantisation' of gravitation and of time, and demonstrates a reversible effect linked to the Sun on one hand and to the Moon on the other, on the supra-molecular structure of water. This model leads to the determination of reversible states of aggregation or coherence ('clusters') of water, in a quantitative ratio of a considerable size, from 1 to 2200, according to whether the interaction involved is Sun-Earth or Moon-Earth, the latter being modulated by the lunar day, but also according to the waxing/waning phase. Dorda considers that this rhythmic fluctuation of water in a system with 3 celestial bodies, constitutes the biological clock sought up to now in organic structures. This model was validated independently thanks to experimental measurements already published by Mario Cantiani et al. (1994) and interpreted in keeping with lunar chronobiology by E. Zürcher, M.-G. Cantiani, F. Sorbetti-Guerri and D. Michel in 1998.

Martial Rossignol and his colleagues, some years before (1990), highlighted the role of electromagnetic phenomena linked to lunar cycles (polarisation of light, modulation of wavelength, ionisation of the atmosphere, atmospheric pressure) and considered a possible link with the induction of bio-electric potentials at the cell level.

Not long after, in 2004, Philippe Vallée devised a new experimental method for proving in a reproducible manner that weak, low-frequency electromagnetic fields have a durable effect on water. This researcher stresses the importance of interfaces between water and its solid or gaseous inclusions: an essential aspect, since interfacial water plays a fundamental role in the organic world.

And now, a new scientific sensation has just come out, and brings an essential component to reinforce the hypotheses formulated here: 'The Fourth phase of Water' (Pollack 2013). The discovery and the demonstration of a "liquid crystal" phase of water in contact with hydrophilic membranes with dielectrical properties (wood corresponds to these criteria) allows Pollack to explain a whole series of 'anomalies' of water which were until now unexplained, and to open horizons beyond expectation.

All these discoveries and interpretations on a purely physical level do not however provide a reply to the question of why differences are observed between certain living plant species, both annual and woody, in their physiological reactions to lunar cycles and the behaviour of their wood. Indeed, trials on germination and initial growth have shown that simultaneously growing plants of different species are actually impacted by the factor "Moon", but in counterphase, some species being positively stimulated of days before the New Moon, while others start their growth better in days before Full Moon (Zürcher 1992).

ENDANGERED GLOBAL CONTEXT

The described processes, structures and periodicities probably play a major role in the water cycles activated by forests, especially in equatorial zones. The last ones are probably of much higher existential importance for the life on earth than commonly admitted.

Trees produce clouds, but forests make also their own rain. Be it above the Amazonian tropical forest or boreal coniferous forests, the formation of clouds and the rainfall that follows happen thanks to a form of 'seeding' by micro-particles of organic origin. The gaseous substances given off by the trees, volatile organic compounds, undergo a photochemical condensation caused by light and behave as 'cloud condensation nuclei'. Mushroom spores, pollen grains and microscopic vegetable debris which are also given off into the atmosphere have the same effect (Pöschl et al. 2010; Ehn et al. 2014). It is then easy to imagine that the rain regime could dramatically change if the forest cover should be reduced, not only because of then lacking "cloud producers", but also because of the absence of "rain provokers".

In his description of the geoclimatic role of the Amazonian forest, Peter Bunyard (editor of the British journal The Ecologist, 2015) draws attention to the new geoclimatic model developed by Victor Gorshkov and Anastassia Makarieva, of the Department of Theoretical Physics of the Institute of Nuclear Physics of Saint-Petersburg (2007, 2014). The analysis of the climatological and hydrological data leads them to the conclusion that it is not the movement of air masses which set off the hydrological cycle (the generally accepted model up to now), but on the contrary the changes in phase of the water in the atmosphere above forests which bring about the movement of air masses. Indeed, water needs considerable energy to evaporate from forests (around 600 calories per gramme, depending on temperature and atmospheric pressure), and it returns this energy as heat in the high atmosphere when it condenses to form rain. Thus, the extreme impact of solar radiation around the equator is absorbed, thanks to the ecosystems rich in water and biomass found in these zones of the globe. In parallel, the rapidity of the condensation process compared to the slowness of the evapo-transpiration creates a pressure difference with a suction effect. The Amazonian forest thus acts like a gigantic hydrological heart ('biotic pump'), attracting air masses from the Atlantic and enriching them in water, performing half a dozen cycles of evapo-transpiration – precipitation, moving from East to West, and finally rising in the Andes and moving north (Central and North America) and south (Argentina) giving rise to warm rains in latitudes far from the equator. The tropical forests can therefore be seen as components of the biosphere ensuring both the functioning and the stability of the great geoclimatic water cycle. In this context, the researchers bring to light another essential phenomenon: if a coastal zone is deforested over a width of 600 km or more, the masses of humid ocean air can no longer move inland, thus condemning their forests to perish.

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