

Plants on the Ladder

A Reference Work on the Evolution of Plants and Trees, Set Beside the Evolution of the Net

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How to use this book

This is a reference work. It answers one question: how the evolution of plants and trees correlates with the evolution of the net of the Vacuum.Net theory, without any assumption added to the theory. It is built so that every step can be checked.

Parts. Part 0 gives the rules of the book. Part 1 gives what the theory says about the evolution of the net, in the words of its texts. Part 2 gives fifteen entries, one per group of photosynthetic life, from the cyanobacteria to the eudicots and the clonal records. Part 3 gathers the numbers of Part 2 into tables across the groups: first appearances, sizes, times, build, light, counts, and the occupation of the ladder over time. Part 4 sets Part 1 beside Parts 2 and 3 and states each correlation with its status. Part 5 reports three tests that were fixed before the data were seen, and then run. Part 6 lists what is not verified and what is left out.

The four marks. Every statement of fact carries one of four marks. *Text* means stated in a Vacuum.Net text, fetched and quoted. *Measured* means read in the cited source. *Computed* means arithmetic on measured or text numbers, shown. *Read* means a pairing made in this book between a text statement and a measured fact of the same form. A read is a hypothesis.

The ladder and the position. The book orders every size and every time on one scale. The unit of length is 4.558816×10^{-8} m and the unit of time 1.520655×10^{-16} s, Larson's natural units as used in *From Atom to Body*. The position of a size is the number of factors of three between it and the unit: $\log_3(\text{size} \div \text{unit})$. Times are placed the same way. Ages before present are converted to seconds with one year = 3.15576×10^7 s. Positions are given to two decimals and are not rounded to whole marks. A position is a coordinate.

Sources. Every measured number carries a reference. Part 2 has one numbered list of 222 references, in order of first use; Part 3 uses the same numbers. Parts 0, 1, 4 and 5 have their own annotated list at the end of the book. Nothing in this book rests on a reference the reader cannot find.

Not verified. Each entry of Part 2 ends with a list of items that were found only in secondary sources, or whose primary source could not be opened. They are printed so that a later pass can close them. They are not facts of this book.

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Part 0 — The Rules

0.1 The marks

Four marks, and nothing without one.

Text. A statement of a Vacuum.Net text on constable.blog, fetched in full and quoted. The texts used are named in the annotated references: *The Vacuum.Net Theory: Complete Derivation* (28 September 2026), *The Balanced Three, the Balanced Tree and the Vacuum.Net Theory* with its PDF *Balanced Ternary and the Balanced Tree* (29 August 2026), *The Climate on the Ladder of Three* (3 October 2026), *Life and Consciousness from One Rule* (29 September 2026), *The Universe of Peter Rowlands* (29 June 2026), *Where Illness Comes From* (ninth edition), and *From Atom to Body* (October 2026).

Measured. Read in the cited source, opened in this work. Where a number was found only in a secondary source, it is not measured; it stands in a "Not verified" list.

Computed. Arithmetic on text or measured numbers, with the operation shown or the tool named. Positions on the ladder are computed.

A few counts in Part 4 carry the mark (*measured, dossier*). They were verified in the companion dossiers of the essay *The Remainder in the Leaf* in the same way as the facts of Part 2, but were not carried into Part 2. Their sources are in the annotated references at the end of the book.

Read. A pairing made here between a text statement and a measured fact of the same form. A read is a hypothesis. It adds no rule to the theory. A read is kept apart from the numbers it pairs, so that a reader who rejects the read keeps the numbers.

0.2 The ladder

The unit of length is $S_0 = 4.558816 \times 10^{-8}$ m. The unit of time is $T_0 = 1.520655 \times 10^{-16}$ s. These are Larson's natural units as used in *From Atom to Body*, Part 0.7. The Climate paper prints $T_0 = 1.521 \times 10^{-16}$ s in its §2 and 1.51983×10^{-16} s in its §8; the difference moves no position in this book by more than 0.01.

The position of a size is $\log_3(\text{size} \div S_0)$. The position of a time is $\log_3(\text{time} \div T_0)$. One year is 3.15576×10^7 s. An age before present of A million years has the position of $A \times 10^6$ years, counted as a duration from then to now.

Three positions of the time ladder recur: the day, 86,400 s, at 43.50; the year at 48.87; and the span of the plant record, from the oldest stromatolites at 68.86 (the oldest fossil thylakoids at 68.26) to the oldest dated C4 origin at 64.77.

A position is a coordinate. *From Atom to Body* tested whether the measured sizes of the human body cluster near whole positions and found that they do not: 192 of 388 within a quarter step, 49.5 per cent, against 50 by chance. This book therefore gives positions to two decimals and assigns nothing to a whole mark.

0.3 Depth, in two senses

The texts use "depth" in two ways, and this book keeps them apart with two words.

Ring depth is the length of a closed ring of trits: 3, 6, 9. *Life and Consciousness from One Rule* reads ring depths 1 and 2 as chemistry, 3 as self-maintenance, and 6 as the single cell. This sense is used in Parts 1.2 and 4.2 only.

Position is the depth of the Climate paper: "Each depth n is one layer. A layer holds n trits. Layer n has the time $3^n \cdot T_0$ and the length $3^n \cdot S_0$." In this sense every measured size and every measured time has a depth, and that depth is what this book calls the position. The Climate paper's Appendix A names "large tree" beside layer 18 and "tall tree (50 m)" beside layer 19.

No text states that a ring of n trits sits at position n . This book does not state it either.

0.4 What is not added

No rule is added to the theory. Where the texts are silent, the book says so and stops. No sentence says that the net causes a plant form. No ring depth is assigned to any group of plants above the cell. No family of layers is applied. No size or time is rounded to a mark.

Part 1 — How the Net Evolves, in Its Own Words

1.1 Strand, register, closure

Five axioms (text: *The Vacuum.Net Theory*; *The Climate on the Ladder of Three*, §2):

N1, Strand. There is one strand. Every distinction is the strand touching itself. N2, Closure. A configuration persists only if it closes on itself. N3, Memory. The net keeps the orientation of what was first laid down. N4, Context. Constants are state functions of the local vacuum. N5, Scale. The same winding appears at every depth.

"From N1 and N3 follows a three-valued state per crossing: +1, 0, -1." "The closure rule works on a window of three neighbours. The window is closed when the three trits add to 0, counted modulo 3. Of the 27 possible triples, 9 are closed. Six hold all three values. Three hold the same value three times." (text, Climate paper §2.)

1.2 Rings per depth

Addresses per ring depth n are necklaces: $g(n) = 3, 6, 11, 24, 51, 130$ for $n = 1$ to 6 (text, Climate paper §3 step 5). Recomputed with $g(n) = (1/n) \sum \phi(n/d) \cdot 3^d$: 3, 6, 11, 24, 51, 130, 315, 834, 2195 (computed).

"Take a ring of n trits and ask that every window is closed. ... What remains is $T(i+2) = T(i-1)$. Every trit equals the trit three places back. A fully closed ring has period 3." "So a ring can close with all three values only at depths divisible by 3." Closed strings for $n = 3$ to 9: "It gives 9, 3, 3, 9, 3, 3, 9." (text, Climate paper §3.1; recomputed, agrees.)

As addresses, the rings with all three values number 0, 0, 2, 0, 0, 2 at ring depths 1 to 6 (text, *Life and Consciousness*) and 2 at depth 9 (computed: six period-3 strings in three rotations each). The readings the text attaches: depths 1 and 2, "the net's form of chemistry"; depth 3, two living addresses, self-maintenance without reproduction; depths 4 and 5, no heterogeneous closed ring; depth 6, a ring of six cut into 3 + 3, "the form of a single cell", whose halves "keep the parent's direction" (text).

1.3 The growth of the address: $b(n)$ and σ_3

Balanced Ternary and the Balanced Tree §2: "The growth of the net follows the Bronze Mean recursion $b(n) = 3 \cdot b(n-1) + b(n-2)$." §8, repeated in §12: "The number of distinguishable states at depth n is $b(n) = 1, 3, 10, 33, 109, 360, \dots$ " §4.1: "The positions at depth n are therefore $3 \cdot b(n-1)$ new continuations plus $b(n-2)$ closures that return." "The term $b(n-2)$ is not a correction to a perfect tree." §4.2: "The second-order term is N^3 in formal dress." (text.) The limit ratio is $\sigma_3 = (3 + \sqrt{13})/2$ (text), 3.302776 (computed); its continued fraction is $[3; 3, 3, 3, \dots]$ (text).

The Balanced Tree text gives $(3^n - 1)/2$ as the maximum value expressible with n trits (§1.1). The Climate paper §3 step 4: "The largest number at depth n is $(3^n - 1)/2$. For $n = 1$ to 6 this gives 1, 4, 13, 40, 121, 364. A larger number forces the next depth." (text.)

1.4 The two-layer law: $\Psi^2 = 0$ and ϕ

Balanced Tree §5, in order (text):

The golden ratio $\phi = (1 + \sqrt{5})/2$ governs the timing of human life transitions in fifty years of first-person data. The Bronze Mean σ_3 governs the growth of the net. ... ϕ lies in $\mathbb{Q}(\sqrt{5})$; σ_3 lies in $\mathbb{Q}(\sqrt{13})$. No rational operation carries one into the other. They are independent laws. ... σ_3 is the law of the address. The net grows in depth with three local states per ring and one self-crossing of period two. That is topology — fixed at closure, order three. ϕ is the law of tension. A closure that already exists cannot go three ways in time. Counterwinding on its own winding is unwinding: $\Psi^2 = 0$, the closure vanishes. In time an existing closure therefore has two effective states — loading and not-loading — and it cannot load twice in succession without first discharging. That is exactly the constraint that generates Fibonacci: $x^2 = x + 1$, order one. ... Address is topology $\rightarrow \sigma_3$, growth in depth, ternary. Life is tension $\rightarrow \phi$, growth in time, binary. Two fields, two layers, one strand. They are never to be mixed in one formula. ... Silver, $x^2 = 2x + 1$ with $\sqrt{2}$, is then the law of two closures together: the pair, ...

§2: "The algebra of closure is the nilpotent condition $\Psi^2 = 0$." (text.) The Balanced Tree text does not name Rowlands. *The Universe of Peter Rowlands* (29 June 2026) sets out the source: "the use of

a nilpotent operator — an operator whose square is zero"; "the totality of everything is nothing" (text). The cross-reference between the two texts is made here (read).

§6: "the rest zone is exactly half a ring unit wide"; "the ring unit scales as 3^{-n} ", so the rest zone at depth n has width $\frac{1}{2} \cdot 3^{-n}$ " (text).

1.5 Evolution as filling

Balanced Tree §11 (text):

Heredity is memory in form with reach two. Direct inheritance reaches two rings; further only by chaining. A species is a subtree; an organism is a closure at a depth; life is tension that stays within the zone. Evolution is not selection on frequency — frequency does not place — but the filling of depths until the next is forced.

And under Cosmology: "Expansion is the forcing of the next depth by filling." (text.)

Where Illness Comes From, Chapter 2 (text, as verified for *From Atom to Body*): a transition is "the next permitted closure depth being reached"; "no closure is ever exact: each depth leaves a remainder"; "The remainder guarantees the ladder keeps offering next rungs."; "A ladder driven by a rest cannot end."

1.6 Where three meets two: the closure depths and the comma

Climate paper §3.2 (text):

The address ladder triples. The dimensional ladder of the theory doubles: 1, 2, 4, 8. The two never coincide, because $\log_2 3 = 1.58496\dots$ is irrational. They come close where $3^q \approx 2^p$. Those places are the convergents of the continued fraction of $\log_2 3$: $2/1, 3/2, 8/5, 19/12, 65/41, 84/53, 485/306$. The denominators are the closure depths. The quotient $3^q / 2^p$ is the residue, the part that does not close. At depth 12 the residue is 1.01364. That is the Pythagorean comma. Two of the seven closure depths are divisible by 3: depth 12 and depth 306. There both kinds of closure coincide.

Recomputed (computed): the continued fraction of $\log_2 3$ is $[1; 1, 1, 2, 2, 3, 1, 5, 2, \dots]$; the convergents are as stated; the residues are 0.75000, 1.12500, 0.94922, 1.01364, 0.98860, 1.00209, 0.99898; in cents, $1200 \cdot \log_2(3^q/2^p)$: $-498.0, +203.9, -90.2, +23.5, -19.8, +3.6, -1.8$. The residue never reaches one. On the ladder, depth 12 is 24.23 mm and 80.8 ps; depth 41 is 11.1 AU and 92.4 min; depth 53 is 93.4 light-years and 93.4 years (text, recomputed).

1.7 What the texts do not say

Checked by fetch and search (text, absence):

- No text names a plant, an alga, a cyanobacterium, photosynthesis, chlorophyll, a leaf or a tree as a living thing. The Balanced Tree text uses "tree" for the data structure only. *Life and Consciousness* has "early life" and nothing botanical. The Climate paper names "large tree" and "tall tree (50 m)" beside layers 18 and 19 and nothing more.
- No text states a rule that turns a ring depth into a position, or a position into a ring depth.
- No text says how a strand takes the shape of a branching stem. The branching in the texts is the balanced tree of addresses, three children per node, $b(n)$ growth.

- No text places any plant group on the ring depths 3, 6, 9.
- The blog of 9 October 2026 on district heating, which an earlier draft cited for "the trunk carries the sum", contains no tree, trunk, branch, fishnet or sum. It is not used.

Part 2 — The groups of photosynthetic life

Each entry records measured facts for one group. Each number carries its mark: (measured [n]) with a reference number, or (computed) for arithmetic done here. Positions are log base 3 of the value over a fixed unit of length (4.558816×10^{-8} m) or of time (1.520655×10^{-16} s). One year is taken as 3.15576×10^7 s. Ages given in Ma are ages before present. The list "Not verified" at the end of each entry holds items that were not read at their primary source. They are not facts of this book until a later pass closes them. One numbered reference list for all fifteen entries stands at the end of the Part.

2.1 Cyanobacteria

First appearance

The oldest stromatolites with a biogenic morphology are in the Strelley Pool Chert, Pilbara, Australia. Their age is 3,430 Ma (measured [1]). In seconds this is $3,430 \times 10^6 \times 3.15576 \times 10^7 = 1.08 \times 10^{17}$ s (computed); position 68.86 (computed). The earliest undisputed cyanobacterial body fossil is *Eoentophysalis belcherensis* from silicified stromatolites of the Belcher Group, dated 2.018–1.854 Ga (measured [2], read in that abstract). Position 68.37 to 68.30 (computed). The oldest fossil thylakoids are in *Navifusa majensis*, McDermott Formation, Australia, 1.78–1.73 Ga (measured [2]); position 68.26 to 68.23 (computed). The same structure appears in the Grassy Bay Formation, Canada, 1.01–0.9 Ga (measured [2]); position 67.74 to 67.64 (computed).

The molecular clock places crown Cyanobacteria in the Archean (measured [3], qualitative in the abstract). The extant diversity of the marine picocyanobacteria *Prochlorococcus* and *Synechococcus* is post-Cryogenian (measured [3]).

Event	Age	Position	Mark
Strelley Pool stromatolites	3,430 Ma	68.86	measured [1]
<i>Eoentophysalis</i> body fossil	2,018–1,854 Ma	68.37–68.30	measured [2]
Fossil thylakoids, McDermott Fm	1,780–1,730 Ma	68.26–68.23	measured [2]
Fossil thylakoids, Grassy Bay Fm	1,010–900 Ma	67.74–67.64	measured [2]

Sizes

The smallest member is *Prochlorococcus*, 0.5–0.7 μm in diameter, "the smallest-known oxygen-evolving autotroph" (measured [4]; the phrase also in [5]). Position 2.18 to 2.49 (computed). Its abundance in the deep euphotic zone exceeds 10^5 cells per ml (measured [6]). In *Trichodesmium* the nitrogen-fixing diazocyte zones hold about 2–30 cells, with 1–2 zones per trichome and about 15 %

of cells (measured [7]). No verified measurement of the largest cyanobacterial cell or colony was read; see the list below.

What	Size	Position	Mark
<i>Prochlorococcus</i> cell, lower bound	0.5 μm	2.18	measured [4]
<i>Prochlorococcus</i> cell, upper bound	0.7 μm	2.49	measured [4]

Times

Prochlorococcus "typically divides once a day" (measured [4]). In the equatorial Pacific at 30 m depth the in-situ growth rate reached about one doubling per day. DNA replication falls in the afternoon and division at night, in phase with the daily light cycle (measured [8]). One day is 86,400 s (computed); position 43.50 (computed). In strain MED4 under a 14:10 light:dark cycle, 80 % of genes are cyclic over 24 h. Growth falls in the light, division in the dark, and all cells have divided by sunrise (measured [9]). A single cell ends at fission; there is no organismal lifespan beyond the generation time.

What	Duration	Position	Mark
Generation, <i>Prochlorococcus</i>	~ 1 day = 86,400 s	43.50	measured [4], [8]
Transcriptome cycle, MED4	24 h	43.50	measured [9]

Build

Cyanobacteria are prokaryotes. Body plans present are unicellular (*Prochlorococcus*, *Synechococcus*), colonial and filamentous; "many cyanobacteria are multicellular" (measured [10]). In heterocystous filaments three differentiated cell types occur beside the vegetative cell: the heterocyst for N_2 fixation, the akinete for resistance, and the hormogonium for dispersal (measured [10]). With the vegetative cell that makes 4 cell types (computed). Heterocysts stand "at semi-regular intervals" along the trichome (measured [10]). *Trichodesmium* has 2 cell states, diazocyte and vegetative, and no heterocysts (measured [7]). Branching, phyllotaxis, an apical cell, vascular tissue and secondary growth do not apply. There is no meiosis. The life cycle has one phase, binary fission.

Light

Chlorophyll a is general. *Prochlorococcus* carries divinyl chlorophyll a (a_2) and divinyl chlorophyll b (b_2), with α -carotene and zeaxanthin (measured [6], [4]). It has replaced the large phycobilisomes of other cyanobacteria by an iron-stress-induced light-harvesting protein (Pcb); some strains keep small amounts of a phycoerythrin (measured [4]). Chlorophyll f, a fifth chlorophyll, has an in-vitro absorption maximum at 706 nm and fluorescence at 722 nm, formula $\text{C}_{55}\text{H}_{70}\text{O}_6\text{N}_4\text{Mg}$, isolated from cyanobacteria in Western Australia (measured [11]). The title "Chlorophyll d as a major pigment" is verified (measured [12], title only). Thylakoids are unstacked; the membranes form fascicular, radial or parallel arrangements (measured [13]). Rubisco "is confined to multiple capsid-like carboxysomes" (measured [14]). Plastid membranes do not apply; the cell envelope is inner

membrane, peptidoglycan and outer membrane. The C3, C4 and CAM categories do not apply to a prokaryote with carboxysomes.

Count

Algae in total: about 72,500 estimated, about 44,000 named, 33,248 processed in AlgaeBase as of June 2012 (measured [15]). The figure 44,000 for algae also stands in Christenhusz & Byng (measured [16]). No verified per-group count for Cyanobacteria was read.

Reference genomes: *Prochlorococcus marinus* MED4 has 1,657,990 bp and 1,716 genes, "the smallest genome of any known oxygenic phototroph". Strain MIT9313 has 2,410,873 bp and 2,275 genes. The two share 1,350 genes (measured [5]). The difference is 752,883 bp and 559 genes (computed). *Trichodesmium erythraeum* IMS101 has 7.75 Mbp (measured [7]).

Genome	Size	Genes	Mark
<i>P. marinus</i> MED4	1,657,990 bp	1,716	measured [5]
<i>P. marinus</i> MIT9313	2,410,873 bp	2,275	measured [5]
<i>T. erythraeum</i> IMS101	7.75 Mbp	—	measured [7]

Not verified

- Isua microbial structures, 3,700 Myr, as cyanobacterial — Nutman et al. 2016, Nature 537:535–538; age in title only, affinity disputed.
- Primary description of *Eoentophysalis* — Hofmann 1976, J. Paleontol.
- Numeric clock ages (oxygenic photosynthesis 3.4–2.9 Ga, crown ~2.9 Ga, burst ~2.4 Ga) — read in MIT News 28-9-2021, not in Fournier et al. 2021.
- *Synechococcus* diameter ~1 μm (0.8–1.5 μm) — Waterbury et al. 1979, Nature 277:293–294, or Partensky et al. 1999 Bull. Inst. Océanogr. Monaco.
- *Trichodesmium* colony size 1–3 mm and doubling time in days — Capone et al. 1997, Science 276:1221–1229.
- *Gloeotrichia echinulata* colonies 1–3 mm — Carey et al. 2008, Freshwater Biol.
- *Oscillatoria princeps* trichome width 50–80 μm ; true branching in Stigonematales; intercalary division — Komárek & Anagnostidis 2005.
- *Nostoc pruniforme* colonies to several cm — Dodds, Gudder & Mollenhauer 1995, J. Phycol. 31:2–18.
- Stromatolite mats at metre scale, Shark Bay — no source named.
- KaiABC circadian period ~24–25 h in *Synechococcus elongatus* PCC 7942 — Kondo et al. 1993, PNAS 90:5672–5676; Nakajima et al. 2005, Science 308:414–415.
- Akinete survival years to decades — Livingstone & Jaworski 1980, Br. Phycol. J. 15:357–364.
- Heterocyst spacing about every 10th cell — Flores & Herrero 2010 body text.
- Absence of flagella — Hoiczyk 2000, Arch. Microbiol. 174:11–17.
- Polyploidy, *Synechocystis* PCC 6803 >50 genome copies — Griesse, Lange & Soppa 2011, FEMS Microbiol. Lett. 323:124–131.
- *Acaryochloris marina* as the chlorophyll d organism, ~95 % of total chlorophyll — Miyashita et al. 1996 body text, paywalled.
- Chlorophyll f source as a Shark Bay stromatolite enrichment — Chen et al. 2010 body text.

- Cyanophyta described species $\approx$ 4,000–5,000 — Guiry 2012, Table 1, not read.

2.2 Red Algae

First appearance

Bangiomorpha pubescens from the Hunting Formation, Somerset Island, Arctic Canada, is a bangiacean red alga with a differentiated holdfast and spores or gametes (measured [17]). Its revised age by Re–Os dating of the Bylot Supergroup is 1.047 $\pm$ 0.013/–0.017 Ga (measured [18]). In seconds, $1,047 \times 10^6 \times 3.15576 \times 10^7 = 3.30 \times 10^{16}$ s (computed); position 67.78 (computed). A cross-calibrated clock in the same study puts eukaryotic photosynthesis at about 1.25 Ga (measured [18]). An older claim rests on *Rafatazmia chitrakootensis* and *Ramathallus lobatus* from the Tirohan Dolomite, India, about 1.6 Ga, described as "probable crown-group red algae" (measured [19]); position 68.16 (computed).

Molecular clocks: crown red algae 1,984–1,732 Ma and the primary plastid origin 2,137–1,807 Ma (measured [20]). The root of Plantae (red plus green) is 1,694 Ma (95 % HPD 1,484–1,925). The Bangiophyceae–Florideophyceae split is 943 Ma (817–1,049). Corallinophycidae date to 579 Ma (543–617), Hildenbrandiophycidae 781 Ma, Nemaliophycidae 661 Ma, Ahnfeltiophycidae/Rhodymeniophycidae 508 Ma (measured [21]).

Event	Age	Position	Mark
<i>Bangiomorpha</i> , Re–Os age	1,047 Ma	67.78	measured [18]
Tirohan Dolomite red algae	$\sim$ 1,600 Ma	68.16	measured [19]
Crown red algae, clock	1,984–1,732 Ma	68.36–68.23	measured [20]
Root of Plantae, clock	1,694 Ma	68.21	measured [21]

Sizes

The smallest red alga read is *Cyanidioschyzon merolae*, 2 μ m in diameter, with one nucleus, one mitochondrion and one plastid, and no rigid cell wall. It lives in hot springs at pH 1.5 and 45 °C (measured [22]). Position 3.44 (computed). *Ramathallus* shows apical growth (measured [19]). No verified sizes of the largest red algae were read.

What	Size	Position	Mark
<i>C. merolae</i> cell	2 μ m	3.44	measured [22]

Times

The cell cycle of *C. merolae* is "highly synchronized by a 12-h light/12-h dark cycle". Binary fission falls in the dark period at a culture temperature of 42 °C (measured [23]). Divisions "can be highly synchronized by light/dark cycles" (measured [22]). The circadian control of the cell cycle is translation-independent (measured [23], title). Under this regime one division falls in each 24 h

period; 24 h = 86,400 s (computed); position 43.50 (computed). The carposporophyte stage exists in Florideophyceae (measured [21]).

What	Duratio n	Positio n	Mark
Division cycle, <i>C. merolae</i> , 12:12 LD	24 h	43.50	measured [23]

Build

Body plans range from unicellular (*Cyanidioschyzon*) through filamentous (*Bangiomorpha*) to multicellular thalli. *Bangiomorpha* has a differentiated holdfast (measured [17]). *Ramathallus* shows apical growth and florideophyte-like form; *Rafatazmia* has pit connections and pyrenoid-like bodies (measured [19]). Florideophyceae have a carposporophyte stage (measured [21]). *C. merolae* has 20 chromosomes and divides by binary fission (measured [22]). No vascular tissue and no secondary growth occur. Verified counts of cell types, branching mode, flagella and the number of life-cycle phases were not read; see the list below.

Light

Phycobilisomes are present. The *C. merolae* genome has "phycobilisome components" (measured [22]). Rhodophytes retain bilin-based phycobiliprotein light harvesting (measured [24]). Thylakoids are not stacked: "red algae also do not exhibit thylakoid stacking" (measured [13]). *C. merolae* has no pyrenoid and no CO₂-concentrating mechanism (measured [14], Table 1). The rhomboidal body in *Rafatazmia* at 1.6 Ga is read as a pyrenoid (measured [19]). The plastid is "surrounded by a double membrane", two membranes, as in glaucophytes and Viridiplantae (measured [24]).

Count

Florideophyceae are "the most abundant and diverse class of Rhodophyta" (measured [21]). No verified species total was read. Algae in total number about 44,000 named (measured [15], [16]).

Reference genome: *C. merolae* 10D has 16,520,305 bp on 20 chromosomes, 5,331 genes, at least 86.3 % of them expressed, 26 genes with introns and 3 rDNA copies (measured [22]). A later paper gives "16.7 Mb" (measured [23]).

Genome	Size	Gene s	Mark
<i>C. merolae</i> 10D	16,520,305 bp	5,331	measured [22]
<i>C. merolae</i>	16.7 Mb	—	measured [23]

Not verified

- *Bangiomorpha* filament diameter tens of μm , length to ~2 mm — Butterfield 2000 body text.
- *Porphyra* blade one cell thick, tens of cm — Blouin et al. 2011, Trends Plant Sci. 16:29–37; Brawley et al. 2017, PNAS 114:E6361–E6370.
- Largest thalli 1–2 m; coralline crusts at metre scale; rhodoliths — AlgaeBase; Foster 2001, J. Phycol. 37:659–667.

- Doubling time in continuous light 20–30 h — Suzuki et al. 1994, Eur. J. Cell Biol. 63:280–288.
- *Porphyra* blade annual, conchocelis perennial; conchocelis phase — Drew 1949, Nature 164:748–749, title verified, finding not read.
- Coralline growth 0.1–1 mm per year, lifespan decades to >100 years — Frantz et al. 2005, Palaios; Halfar et al. 2011, Geology.
- Cell-type count in *Porphyra*; branching in florideophytes; general apical cell in Florideophyceae — no page read.
- No flagella in any red alga — Brawley et al. 2017.
- Triphasic life cycle count (3 phases) and *Porphyra* 2-phase cycle — not read in a primary.
- *C. merolae* haploid — Matsuzaki 2004 states 20 chromosomes, not the ploidy.
- Chlorophyll a only — standard, not stated on pages read.
- *Porphyra* pyrenoid present — not read.
- Rhodophyta $\approx$ 7,000 species — Guiry 2012, Table 1.
- *Porphyra umbilicalis* genome $\sim$ 87.7 Mb, $\sim$ 13,125 genes — Brawley et al. 2017, record verified, numbers not read.

2.3 Green Algae

First appearance

Proterocladus antiquus from the Nanfen Formation, North China, is about 1,000 Ma old. It is millimetre-sized, multicellular and morphologically differentiated, a siphonocladalean chlorophyte with lateral branches (measured [25]). Age in seconds: $1,000 \times 10^6 \times 3.15576 \times 10^7 = 3.16 \times 10^{16}$ s (computed); position 67.73 (computed).

Molecular clocks: core Chlorophyta about 1,000–700 Ma; the main Ulvophyceae lineages radiated just before or during the Cryogenian; crown Bryopsidales in the early Paleozoic, with Bryopsidales and Dasycladales fossils from the Cambro-Ordovician (measured [26]). The root of Plantae is 1,694 Ma (measured [21]). For the volvocine algae two published values conflict. The common ancestor of *Volvox* and *Chlamydomonas* is placed at about 50 ± 20 Ma (measured [27]) and at "around 250 MY" (measured [28], citing Herron et al. 2009). Positions 65.01 and 66.47 (computed).

Event	Age	Position	Mark
<i>Proterocladus antiquus</i>	$\sim$ 1,000 Ma	67.73	measured [25]
Core Chlorophyta, clock	1,000–700 Ma	67.73–67.41	measured [26]
Volvocine ancestor	50 ± 20 Ma	65.01	measured [27]
Volvocine ancestor	$\sim$ 250 Ma	66.47	measured [28]

Sizes

Chlamydomonas reinhardtii is a unicell of about 10 μ m (measured [29]); position 4.91 (computed). *Volvox carteri* is a spheroid of "several hundred microns diameter" with about 2,000 somatic cells and 12–16 gonidia (measured [28]); "thousands of cells" (measured [27]). *Caulerpa taxifolia* is a single coenocytic cell. Its stolons run "upwards of 1 m in length", its fronds reach 15–30 cm at maturity, and it is "debatably the largest single-celled organism in the world" (measured [30]).

Position of 1 m: 15.39; of 0.15–0.30 m: 13.66–14.29 (computed). *Acetabularia* is a single uninucleate cell "centimeters tall at maturity" (measured [31]).

What	Size	Position	Mark
<i>Chlamydomonas</i> cell	~10 μ m	4.91	measured [29]
<i>Caulerpa</i> frond	15–30 cm	13.66–14.29	measured [30]
<i>Caulerpa</i> stolon	>1 m	>15.39	measured [30]

Times

Volvox carteri produces "a new generation every 48 h" under optimal conditions (measured [28]); 48 h = 172,800 s (computed); position 44.13 (computed). *Ulva mutabilis* reaches gametogenesis competence after 3–5 weeks of growth (measured [32]); 21–35 days; position 46.27–46.74 (computed). In a single *Acetabularia* cell the circadian rhythm of the oxygen balance has one period of "about 27 hours" (measured [33]); position 43.61 (computed). Period and phase of the photosynthetic rhythm are unaffected by actinomycin D, puromycin and chloramphenicol (measured [34]).

What	Duration	Position	Mark
Generation, <i>Volvox carteri</i>	48 h	44.13	measured [28]
Growth to gametogenesis, <i>Ulva</i>	3–5 weeks	46.27–46.74	measured [32]
Circadian period, <i>Acetabularia</i>	~27 h	43.61	measured [33]

Build

Body plans: unicellular flagellate (*Chlamydomonas*), multicellular sphere (*Volvox*), sheet (*Ulva*), giant uninucleate cell (*Acetabularia*), giant coenocyte (*Caulerpa*), branched filament (*Proterocladus*) (measured [25], [28], [29], [30], [31], [32]). Cell types: *Volvox carteri* has 2, sterile somatic and germ, a "germ-soma division of labor" (measured [27], [28]). *Ulva* has 3: rhizoid, stem and blade cells (measured [32]). *Chlamydomonas* has 1.

Branching: *Caulerpa* has pinnate fronds on a stolon with pseudo-organs — frond, rachis, pinnule, stolon, holdfast (measured [30]). *Proterocladus* has lateral branches (measured [25]). *Acetabularia* grows at an apical tip and passes through phase change (measured [31]). *Caulerpa* grows at the stolon and frond apex (measured [30]). Flagella: *Chlamydomonas* 2 anterior (measured [29]); *Volvox* somatic cells 2, gonidia 0 (measured [28]); *Ulva* gametes 2 (measured [32]). Life cycle: *Volvox* is haploid in the vegetative phase with a diploid zygote only, 2 ploidy states and 1 free-living phase (measured [28]). *Ulva* shows "alternation of isomorphic generations", 2 phases (measured [32]). There is no vascular tissue and no secondary growth.

Light

No phycobilisomes: Viridiplantae "retained bilin biosynthesis in the absence of phycobiliproteins" (measured [24]). Thylakoids have "clearly differentiated stacked and unstacked regions" but not the

many-disc plant-type grana (measured [13]). The *Chlamydomonas* pyrenoid is near-spherical, 1.5–2 μm across (measured [14]); position 3.18–3.44 (computed). Pyrenoids are "often absent in seaweeds" (measured [14]). Plastid membranes: 2 (measured [24]).

Count

No verified species total for Chlorophyta was read. Algae total about 44,000 named (measured [15], [16]).

Reference genomes: *Chlamydomonas reinhardtii*, 121 Mb draft at 13× coverage, 15,143 protein-coding gene predictions, 17 linkage groups (measured [29]). *Volvox carteri*, 138 Mb, about 14,500 predicted proteins (measured [35]). The difference is 17 Mb (computed).

Genome	Size	Genes	Mark
<i>C. reinhardtii</i>	121 Mb	15,143	measured [29]
<i>V. carteri</i>	138 Mb	~14,500	measured [35]

Not verified

- Numeric crown ages for Viridiplantae/Chlorophyta — Nie et al. 2020, Syst. Biol. 69:1–16; abstract qualitative only.
- *Volvox* diameter 0.5–1 mm — no primary read.
- *Caulerpa* stolons several metres in the Mediterranean — Meinesz et al. 1993/2001.
- *Acetabularia* stalk 3–5 cm, cap ~1 cm; lifespan 1–3 years — Mandoli 1998 body text.
- *Ulva* thallus two cells thick, tens of cm — Wichard 2015 gives no dimensions.
- *Ostreococcus tauri* ~0.8 μm — Courties et al. 1994, Nature 370:255 (see 2.15).
- *Chlamydomonas* multiple fission on a 24-h cycle — Cross & Umen 2015, Plant J. 82:370–392.
- Persistence of the rhythm in enucleated cells — Sweeney & Haxo 1961, Science 134:1361–1363; title seen, result not read.
- *Caulerpa* stolon growth cm per day; fragment lifespan — no source.
- *Ulva* zoospores 4 flagella; *Chlamydomonas* haploid; *Acetabularia* diploid with meiosis in cysts; *Caulerpa* diploid holocarpic — not read.
- Chlorophylls a + b — standard, not stated on pages read.
- Chlorophyta $\approx$ 4,500–6,000 species — Guiry 2012, Table 1.

2.4 Charophytes

First appearance

The Charales are represented by *Palaeonitella cranii* in the Rhynie chert, Early Devonian. It is a small multicellular alga with furcating branchlets, antheridia on a pedicel, and gyrogonites of 6 sinistrally spiralling cells with a coronula (measured [36]). The Rhynie chert has a U–Pb age of $411.5 \pm 1.3 \text{ Ma}$ (measured [37]). In seconds: $411.5 \times 10^6 \times 3.15576 \times 10^7 = 1.30 \times 10^{16} \text{ s}$ (computed); position 66.93 (computed). Older charophyte gyrogonites belong to the Paleozoic Sycidiales and Moelleriaceae (measured [38], Paleozoic placement only). The origin of embryophytes is Cambrian (measured [39], qualitative). The phylogenomic study of the

Zygnematophyceae covers 46 taxa and 326 nuclear loci, defines five orders and finds at least 5 independent origins of filamentous growth (measured [40]).

Event	Age	Position	Mark
<i>Palaeonitella</i> , Rhynie chert	411.5 ± 1.3 Ma	66.93	measured [36], [37]

Sizes

Chara internodal cells reach "up to diameter of 1 mm and up to half meter long in some species"; axial internodes reach "up to 30 cm" (measured [41]). Position of 1 mm: 9.10; of 0.5 m: 14.76; of 0.30 m: 14.29 (computed). The ratio of length to diameter in the extreme cell is $0.5 / 0.001 = 500$ (computed). *Palaeonitella* is "relatively small" (measured [36], no number).

What	Size	Position	Mark
<i>Chara</i> internodal cell, diameter	1 mm	9.10	measured [41]
<i>Chara</i> internodal cell, length	0.5 m	14.76	measured [41]
<i>Chara</i> axial internode	30 cm	14.29	measured [41]

Times

Cytoplasmic streaming in characean cells "can reach 100 $\mu\text{m}/\text{sec}$ " (measured [41]). At that speed a 30 cm internode is traversed in $0.30 / (100 \times 10^{-6}) = 3,000$ s (computed); position 40.44 (computed). No verified generation time, lifespan or rhythm was read for this group.

What	Value	Mark
Streaming speed, Characeae	100 $\mu\text{m}/\text{s}$	measured [41]
Traversal of 30 cm internode	3,000 s, position 40.44	computed

Build

The Zygnematophyceae are unicellular (*Mesotaenium*) or unbranched filamentous (*Spirogyra*, *Zygnema*). Filamentous growth arose "at least five" times independently (measured [40]). Charales are multicellular with nodes and internodes and whorled branchlets, "the most complex body plans" among charophytes (measured [42], [41]). *Palaeonitella* has "furcating branchlets" (measured [36]). Gyrogonites consist of 6 spiral cells (measured [36]). The Charales zygote has storage proteins (measured [42]). There is no vascular tissue and no secondary growth. Verified statements on the apical cell, flagella, cell-type count and ploidy were not read; see below.

Light

No phycobilisomes (measured [24]). Thylakoids are stacked. Stacks in Coleochaetales and Charales are called "grana" by some authors; Mazur et al. do not accept that term for them (measured [13]).

Spirogyra operates a CO₂-concentrating mechanism with a pyrenoid (measured [14]). Plastid membranes: 2 (measured [24]).

Count

Zygnematophyceae: ">4,000" species (measured [40]). No verified count for Charales was read.

Reference genomes: *Chara braunii* S276, assembly Cbr_1.0 (GCA_003427395.1), 1,751,211,849 bp, about 1.75 Gb; flow-cytometry genome 1.89–1.96 Gbp; k-mer estimate 2.35 Gbp; 34,718 coding genes in the Ensembl Plants annotation (measured [42], read on the Ensembl page). *Mesotaenium endlicherianum* SAG 12.97, assembly 173.77 Mbp, 10,300 gene models (measured [43], read on the JGI PhycoCosm page Mesen1_1). *Spirogloea muscicola* CCAC 0214, 171.14 Mbp, 24,093 gene models (measured [43], JGI Spimu1_1). The *Chara* assembly is 1,751.2 / 173.77 = 10.1 times the *Mesotaenium* assembly (computed).

Genome	Size	Gene s	Mark
<i>C. braunii</i> S276 (Cbr_1.0)	1,751,211,849 bp	34,718	measured [42] via Ensembl
<i>M. endlicherianum</i> SAG 12.97	173.77 Mbp	10,300	measured [43] via JGI
<i>S. muscicola</i> CCAC 0214	171.14 Mbp	24,093	measured [43] via JGI

Not verified

- Silurian (~420 Ma) oldest occurrence of charophyte gyrogonites — Feist, Liu & Tafforeau 2005 body text.
- *Paleoclosterium leptum*, Middle Devonian, as oldest Zygnematophyceae — Baschnagel 1966, Trans. Am. Microsc. Soc. 85:297–302; title seen in a reference list only.
- Zygnematophyceae split from land plants ~550 Ma — Göttingen press release on Hess et al. 2022; not in the paper's abstract.
- *Chara corallina* typical internode 2–10 cm — no source.
- *Spirogyra* cells 10–150 μ m wide, filaments tens of cm — Stancheva et al. 2013, J. Phycol. 49:588–607.
- *Mesotaenium* 10–40 μ m — Cheng et al. 2019 STAR Methods.
- *Zygnema* cells 20–50 μ m — no source.
- *Chara* annual to perennial; oospores dormant for years — no source.
- Division time 1–2 days in Zygnematophyceae — no source.
- Circadian chloroplast movement in *Mougeotia* — Haupt 1982, Annu. Rev. Plant Physiol.
- *Chara* cell types ≥ 5 ; apical cell in Charales; Zygnematophyceae without flagella; Charales sperm 2 flagella; haploid with zygote as only diploid cell — standard, not read.
- Chlorophylls a + b — not stated on pages read.
- *Chara* without pyrenoid — not in Meyer & Griffiths 2013.
- Charales $\approx$ 400 species in 6 genera — Guiry 2012 / AlgaeBase.
- *Chara braunii* paper's own gene count ~23,546 — Nishiyama et al. 2018, Cell; blocked.
- In-paper genome figures for *Mesotaenium* and *Spirogloea* — Cheng et al. 2019, Cell; blocked.

2.5 Brown Algae and Diatoms

First appearance

Brown algae (Phaeophyceae) have no accepted fossil older than the Cretaceous. The oldest fossil used as a calibration is *Padina* (Dictyotales), minimum 100 Ma; *Julescraneia* and *Paleocystophora* *Paleohalidrys* give a minimum of 13 Ma. The 550 Ma *Miaohephyton* was tested and rejected as a phaeophyte (measured [44]). Position of 100 Ma: 65.64 (computed). The molecular origin of the brown algae is 449.41 Ma (95 % HPD 333.85–572.02 Ma), Ordovician. Uncorrelated-clock alternatives give 435–455 Ma and the autocorrelated clock 595–600 Ma (measured [44]). Position 67.01, range 66.73–67.23 (computed). Crown ages of orders, uncorrelated / autocorrelated clock: Laminariales 83.44 / 231.51 Ma; Fucales 65.81 / 134.28 Ma; Ectocarpales 54.08 / 135.60 Ma (measured [44]). The giant kelp *Macrocystis* emerged about 6 Ma (measured [45]); position 63.08 (computed).

Diatoms: the purported Lower Jurassic *Pyxidicula* (about 182 Ma) and Middle Jurassic forms (174–163 Ma) are rejected as diatoms; they are calcareous nannofossils and a testate amoeba (measured [46]). The oldest accepted assemblages are Lower Cretaceous, from Australia (37 species, 13 genera) and the Weddell Sea (47 species, 20 genera) (measured [46]). The molecular origin lies near the Triassic–Jurassic boundary, about 200 Ma (measured [46]); crown 190 Ma and stem 199 Ma, with estimates ranging 250–183 Ma (measured [47]). Position of 200 Ma: 66.27 (computed). The oldest raphe-bearing diatoms are 82 Ma, early Campanian, Wombat locality, Canada; the Battle Formation gives 66.88–67.20 Ma (measured [47]). *Thalassiosira* and *Phaeodactylum* diverged about 90 Myr ago (measured [48]). The secondary endosymbiosis of a red alga into a heterotrophic host, source of the heterokont plastid, is about 1 billion years old (measured [48]); position 67.73 (computed). Coccolithophores have influenced climate "for over 200 million years" (measured [49]).

Event	Age	Position	Mark
Brown algae, clock origin	449.41 Ma (333.85–572.02)	67.01 (66.73–67.23)	measured [44]
<i>Padina</i> , oldest calibration fossil	≥100 Ma	65.64	measured [44]
Laminariales crown	83.44 / 231.51 Ma	65.47 / 66.40	measured [44]
<i>Macrocystis</i>	~6 Ma	63.08	measured [45]
Diatoms, clock origin	~200 Ma; crown 190, stem 199	66.27; 66.22, 66.26	measured [46], [47]
Oldest raphid diatoms	82 Ma	65.46	measured [47]
Secondary endosymbiosis	~1,000 Ma	67.73	measured [48]

Sizes

Macrocystis "may become more than 60 meters long" (measured [44]); position 19.11 (computed). The smallest brown algae are "small filaments" (measured [44], no number). The diatom *Thalassiosira pseudonana* has a valve diameter of $3.7 \pm 0.62 \mu\text{m}$ in the wild type by SEM; across evolution experiments $3.66\text{--}4.97 \mu\text{m}$; Coulter means $3.98\text{--}5.93 \mu\text{m}$ (measured [50]). Position of $3.7 \mu\text{m}$: 4.00 (computed). Diatom cell volume spans "more than nine orders of magnitude" (measured [50], citing Litchman et al. 2009).

What	Size	Position	Mark
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<i>Macrocystis</i> length	>60 m	>19.11	measured [44]
<i>T. pseudonana</i> valve	3.7 ± 0.62 μm	4.00	measured [50]

Times

Macrocystis frond elongation at Bahía Tortugas, Baja California, as 100-day averages: 12.8 cm/day in summer to 20.8 cm/day in winter in an unharvested bed; 14.7 cm/day in spring to 23.3 cm/day in winter in a harvested bed (measured [51]). Mass increase averages 3.5 % per day in favourable locations (measured [45]). At that rate the doubling time is $\ln 2 / \ln 1.035 = 20.1$ days (computed); position 46.23 (computed). *T. pseudonana* exponential growth rate was 1.71 ± 0.42 and 1.79 ± 0.2 as slope of $\ln$ cell number; the unit is not stated on the page read (measured [50], value only). *Macrocystis* has a macroscopic diploid sporophyte alternating with a microscopic haploid gametophyte (measured [45]).

What	Value	Position	Mark
Frond elongation, <i>Macrocystis</i>	12.8–23.3 cm/day	—	measured [51]
Mass doubling at 3.5 %/day	20.1 days	46.23	computed from [45]

Build

Macrocystis: haplodiplontic life cycle (measured [45]). *Ectocarpus*: haploid–diploid alternation of sporophyte and gametophyte; the genome was sequenced from a meiotic offspring of a field sporophyte, a haploid male (measured [52]). Diatoms are unicellular with a silica frustule; *Thalassiosira* has 24 diploid chromosomes (measured [53]). Kelps attach with a holdfast. There is no vascular tissue, no stomata, no roots and no phyllotaxis in the land-plant sense. Verified counts of cell types and verified descriptions of branching were not read; see below.

Light

Light harvesting in diatoms is by "fucoxanthin chlorophyll a/c-binding proteins (FCPs)" (measured [54]). Brown algae are "chlorophyll-c containing algae" with a plastid derived from a red algal endosymbiont (measured [44]). Diatoms have "plastids acquired by secondary endosymbiosis" (measured [53]). Haptophytes are "a lineage possessing secondary plastids" (measured [49]). Diatoms perform about 20 % of global carbon fixation (measured [53]). Verified membrane counts and pyrenoid statements were not read; see below.

Count

Brown algae: 2,125 species, 46 % of the 4,619 non-diatom heterokonts in AlgaeBase (measured [44]). Check: $2,125 / 4,619 = 46.0$ % (computed). Algae total: 72,500 estimated, about 44,000 names, 33,248 processed as of June 2012; some estimates give more than 200,000 diatom species (measured [15]). Algae about 44,000 (measured [16]).

Reference genomes: *Ectocarpus siliculosus*, 214 Mbp, 16,256 protein-coding genes (measured [52]). *Thalassiosira pseudonana*, 34 Mb draft nuclear genome, 129 kb plastid, 44 kb mitochondrial, 24 diploid chromosomes (measured [53]); reannotation 32.4 Mb, 11,776 predicted genes (measured [53]).

[48]). *Phaeodactylum tricornutum*, 27.4 Mb, 10,402 genes (measured [48]). *Macrocystis pyrifera*, 537 Mb assembly (k-mer 513–542 Mb), 25,919 protein-coding genes, 35 scaffolds (measured [45]). *Emiliania huxleyi*, haploid genome 141.7 Mb (other isolates 99–133 Mb by flow cytometry), 30,569 protein-coding genes (measured [49]).

Genome	Size	Genes	Mark
<i>E. siliculosus</i>	214 Mbp	16,256	measured [52]
<i>T. pseudonana</i>	34 Mb; 32.4 Mb	11,776	measured [53]; [48]
<i>P. tricornutum</i>	27.4 Mb	10,402	measured [48]
<i>M. pyrifera</i>	537 Mb	25,919	measured [45]
<i>E. huxleyi</i>	141.7 Mb	30,569	measured [49]

Not verified

- Silberfeld et al. 2010 clock ages (crown Phaeophyceae Jurassic–Cretaceous) — Mol. Phylogenet. Evol. 56:659–674, record verified, values not read.
- Numerical age of the Lower Cretaceous diatom assemblages (~125–120 Ma) — Harwood & Nikolaev 1995.
- *Emiliania huxleyi* first appearance ~270 ka, dominant since ~70 ka — Thierstein et al. 1977, Geology 5:400–404, via Wikipedia.
- *Ectocarpus* up to 30 cm, fertile at 1–3 cm; full life cycle ~3 months; branched filaments, branching lost in axenic culture; isomorphy and parthenogenesis — Wikipedia "Ectocarpus", citing Charrier et al. 2008, New Phytologist 177:319–332.
- *Fucus* to 2 m; dichotomous or subpinnate branching; diplontic cycle — Wikipedia "Fucus", citation needed.
- Diatom linear range ~2 μm to ~2 mm (*Ethmodiscus*); ~12,000 described diatom species — Mann & Vanormelingen 2013, J. Eukaryot. Microbiol. 60:414–420.
- *Emiliania* cell diameter ~5 μm ; division rate ~1 d⁻¹ — Paasche 2001, Phycologia 40:503–529.
- *Macrocystis* frond lifespan ~6 months, sporophyte several years; frond initiation by splitting of the apical scimitar blade — Schiel & Foster 2015.
- Unit of the *T. pseudonana* growth rate 1.71 — Kirkham et al. 2017 page does not state it.
- Diatom division synchronised to the light–dark cycle — no source opened.
- Four plastid membranes in heterokonts; chlorophyll c and fucoxanthin as the plastid pigments — Wikipedia "Heterokont", citing Oborník & Lukeš 2013, Int. Rev. Cell Mol. Biol. 306:333–369.
- Pyrenoids in diatoms and *Ectocarpus* — no source.
- Cell-type count in brown algae — no source.
- *Fucus* 20 species; *Ectocarpus* >40 names, ≥15 lineages — Wikipedia, citing Montecinos et al. 2017.
- *T. pseudonana* gene count 11,242 — Armbrust et al. 2004 full text.

2.6 Bryophytes

First appearance

The oldest evidence of land plants is cryptospores from the Dapingian, early Middle Ordovician, about 473–471 Ma, Argentina. The previous oldest record was late Darriwilian, about 463–461 Ma (measured [55]). In seconds, $473 \times 10^6 \times 3.15576 \times 10^7 = 1.49 \times 10^{16}$ s (computed); position 67.05 (computed). The oldest credible candidate bryophyte body fossil is *Riccardiathallus devonicus*, Pragian, Early Devonian (measured [39]).

Molecular clocks. Morris et al.: crown embryophytes 515.1–470.0 Ma; crown bryophytes, if monophyletic, 506.4–460.3 Ma; the first and second bryophyte divergences 496.5–456.2 and 478.7–438.0 Ma; crown liverworts 443.6–405.3 Ma; crown mosses 448.6–344.3 Ma (measured [39]). Harris et al. use 68 fossil calibrations (measured [56]). Their values: crown embryophytes 515–493 Ma; crown bryophytes 500–473 Ma; Setaphyta (mosses plus liverworts) against hornworts 479–450 Ma. Crown mosses 420–364 Ma; crown liverworts 440–412 Ma; crown hornworts 294–214 Ma, with alternatives 258–419 and 331–445 Ma (measured [56]). Hornworts diverged from the other land plants more than 400 Ma ago (measured [57]); the bryophyte–tracheophyte ancestor lived "some 500 million years ago" (measured [58]). *Physcomitrella* arose within Funariaceae about 10 Ma ago (measured [59]) and separated from flowering plants "more than 400 million years" ago (measured [60]). The *Sphagnum* reference species diverged about 16 Ma ago; the genus diversified in the Miocene, 7–20 Ma; whole-genome duplications fall at 189–247 and 102–122 Ma (measured [61]).

Event	Age	Position	Mark
Oldest cryptospores	473–471 Ma	67.05	measured [55]
Crown embryophytes	515.1–470.0 Ma	67.13–67.05	measured [39]
Crown liverworts	443.6–405.3 Ma	66.99–66.91	measured [39]
Crown mosses	448.6–344.3 Ma	67.00–66.76	measured [39]
Crown hornworts	294–214 Ma	66.62–66.33	measured [56]
<i>Sphagnum</i> reference species	~16 Ma	63.97	measured [61]
<i>Physcomitrella</i> within Funariaceae	~10 Ma	63.54	measured [59]

Sizes

The tallest moss is *Dawsonia superba* var. *superba*, with stems reaching 65 cm. Var. *pulchra* is 6–25 cm, leafy part to 15 cm; *D. polytrichoides* 3–10 (–20) cm; *D. longiseta* 0.5–3.0 (–5.0) cm; the genus has 9 species (measured [62]). Position of 65 cm: 14.99; of 6–25 cm: 12.83–14.12; of 0.5–3.0 cm: 10.56–12.19 (computed). Polytrichaceae are "the tallest bryophyte family" (measured [63]). No verified smallest size or typical cell size was read.

What	Size	Position	Mark
<i>D. superba</i> var. <i>superba</i> stem	65 cm	14.99	measured [62]
<i>D. superba</i> var. <i>pulchra</i>	6–25 cm	12.83–14.12	measured [62]

<i>D. longiseta</i>	0.5–3.0 cm	10.56– 12.19	measured [62]
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Times

Physcomitrella: the apical cell transitions to caulonema "several days after germination" (measured [59]). One year = 3.15576×10^7 s; position 48.87 (computed). *Marchantia*: the sporeling apical cell is specified between 7 and 10 days; the sporophyte shows three tissues by 2 weeks after fertilisation (measured [64]). Positions 45.27–45.60 and 45.90 (computed). *Sphagnum* in culture grows +0.88 mm² per day at control pH and –0.08 mm² per day at low pH (measured [61]). *Physcomitrella* can go through its entire life cycle in a Petri dish "in approximately four months" (measured [65]); position 47.87 (computed). A *Marchantia* gemma "will develop into a plant with new gemmae cups in approximately 3 weeks"; new gemmae form 2–3 weeks after germination; sporangia emerge about 4 weeks after fertilisation (measured [66]). Positions: 3 weeks, 46.27; 2 weeks, 45.90; 4 weeks, 46.53 (computed). *Sphagnum* length growth in Karelia ranged from 16 ± 7.5 mm per year (*S. papillosum*, 2015) to 266 ± 39.7 mm per year (*S. riparium*, 2015) (measured [67]). In Kolkheti, Georgia, length increase reached 30.3 cm per year, productivity 269–788 g m^{–2} yr^{–1} (measured [68]). Position of 0.303 m: 14.30 (computed). No verified lifespan was read.

What	Duration	Position	Mark
Apical cell specified, <i>Marchantia</i>	7–10 days	45.27– 45.60	measured [64]
Three sporophyte tissues, <i>Marchantia</i>	2 weeks	45.90	measured [64]
Life span, <i>Physcomitrella</i>	annual, 1 yr	48.87	measured [59]
Full life cycle, <i>Physcomitrella</i> , Petri dish	~4 months	47.87	measured [65]
Gemma to new gemma cups, <i>Marchantia</i>	~3 weeks	46.27	measured [66]
Sporangia after fertilisation, <i>Marchantia</i>	~4 weeks	46.53	measured [66]
<i>Sphagnum</i> length growth, Karelia 2014	28 ± 7.0 (<i>S. majus</i>) to 77 ± 18.5 mm/yr (<i>S. riparium</i>)	—	measured [67]
<i>Sphagnum</i> length growth, Karelia 2015	16 ± 7.5 (<i>S. papillosum</i>) to 266 ± 39.7 mm/yr (<i>S. riparium</i>)	—	measured [67]
<i>Sphagnum</i> productivity, Georgia	<i>S. papillosum</i> 269–548; <i>S. palustre</i> 387–788 g m ^{–2} yr ^{–1}	—	measured [68]

Build

Moss gametophore: a "tetrahedral shaped apical cell, which subsequently cleaves spirally to produce a leafy shoot". The protonema grows by "uniplanar division of single apical stem cells"; new apical cells "initiate from cells subtending the tips of existing filaments" (measured [69]). Moss leaves are "spirally inserted" (measured [59]). *Marchantia* thallus: "a single wedge-shaped apical cell that resides in an apical notch", dividing "in four planes"; thallus branching is "bifurcating"; leafy liverworts dichotomise from a single apical cell (measured [69]). The 2D prothallus has "an apical cell with two cutting faces", shifting to four cutting faces at the 2D→3D transition (measured [64]). Hornwort apical cells are "wedge-shaped", "divide in four planes", in apical notches (measured [69]).

Stomata: the *Physcomitrella* capsule has stomata "defined by a single guard cell" in its lower part (measured [59]). Stomata originated more than 400 Myr ago (measured [70]). Hornwort sporophytes have stomata, lost twice in derived taxa; their guard cells resemble 400-Myr-old fossils (measured [71]). Water transport: the *Physcomitrella* stem has "a central strand of thin-walled cells" (measured [59]). In *Polytrichum commune* the hydroids refill after embolism (measured [63]). Most hornworts have a single chloroplast per cell (measured [57]). Liverwort elaters are hygroscopic sporophyte cells with "helical wall thickenings", about 32:1 relative to spore mother cells (measured [64]; direction of the ratio as read). The haploid gametophyte dominates. Chromosomes: *Marchantia* 9 (measured [64]); *Physcomitrella* 27 pseudochromosomes (measured [59]); *Anthoceros agrestis* 6 pairs (measured [57]); *Sphagnum* 20 pseudochromosomes, including a small sex chromosome of about 4.7–5.4 Mb; cytology 19 bivalents plus usually two smaller M chromosomes (measured [61]).

Light

Hornworts are "the only land plants with a pyrenoid-based CCM"; pyrenoids were "lost at least five times during the last 100 million years" (measured [57]). Chlorophyll a + b, the C3 pathway and the two-membrane plastid are standard for embryophytes and were not separately sourced.

Count

Mosses 12,700; liverworts about 9,000; hornworts about 225 (measured [16]). Sum: 21,925 (computed). Marchantiopsida 350–430 species in about 34 genera; Jungermanniopsida 4,000–7,000 species (measured [64]). *Dawsonia* 9 species (measured [62]). The *Sphagnum* panel holds 17 species (measured [61]).

Reference genomes: *Marchantia polymorpha*, about 220 Mb, 9 chromosomes, about 20,000 protein-coding genes (measured [64]). *Physcomitrella patens*, about 500 Mbp, 27 pseudochromosomes, 32,458 gene models, 86,669 protein-coding transcripts in v3.3 (measured [59]). *Anthoceros*, assemblies 117–133 Mb, 24,700–25,800 protein-coding genes (measured [57]). *Sphagnum divinum* 439 Mb, 25,227 genes; *S. angustifolium* 395 Mb, 25,100 genes (measured [61]).

Genome	Size	Genes	Mark
<i>M. polymorpha</i>	~220 Mb	~20,000	measured [64]
<i>P. patens</i> v3.3	~500 Mbp	32,458	measured [59]
<i>Anthoceros</i> spp.	117–133 Mb	24,700–25,800	measured [57]
<i>S. divinum</i>	439 Mb	25,227	measured [61]
<i>S. angustifolium</i>	395 Mb	25,100	measured [61]

Not verified

- Morris et al. 2018 volume and pages (115:E2274–E2283) — not shown on the repository copy read.
- *Metzgeriothallus sharonae*, Givetian ~385 Ma — Hernick et al. 2008, Rev. Palaeobot. Palynol. 148:154–162.
- Oldest mosses, late Viséan ~330 Ma — Hübers & Kerp 2012, Geology 40:755–758.

- Oldest hornwort (Cretaceous) — no source.
- Bryophyte time-tree node ages, 531 species — Bechteler et al. 2023, Am. J. Bot. 110:e16249, via UConn post.
- Smallest mosses (*Ephemerum* <1 mm); *Marchantia* thallus size — Shimamura 2016, Plant Cell Physiol. 57:230–256; typical cell size — no source.
- Full life cycles: *Physcomitrella* ~3 months — Cove 2005, Annu. Rev. Genet. 39:339–358 (abstract gives no duration; record verified); *Marchantia* 2–3 months; *Anthoceros agrestis* ~3 months — Szövényi et al. 2015, BMC Plant Biol. 15:98.
- Lifespans of *Sphagnum* clones and *Polytrichum* — no source.
- Three cutting faces of the moss apical cell — not stated in Fouracre & Harrison 2022.
- Moss divergence fractions 2/5, 3/8; explicit fractions for *Fissidens* (½) and *Fontinalis* (⅓) — FNA vols 27/28, pages not reached.
- Two guard cells per hornwort stoma — Renzaglia et al. 2017 full text; liverworts without stomata — standard.
- Leptoids in Polytrichaceae; hornwort pseudo-elaters and basal sporophyte meristem — Frangedakis et al. 2021 full text.
- Spores per capsule; number of cell types — no source.
- *Marchantia* 2017 figures (~226 Mb, 19,287 genes) — Bowman et al. 2017, Cell 171:287–304.e15.
- *Physcomitrella* 2008 figures (~480 Mb, 35,938 genes) — Rensing et al. 2008; Lang et al. 2018, Plant J. 93:515–533.
- *Sphagnum* total species (~300–400) — no source.

2.7 Lycophytes

First appearance

Baragwanathia longifolia is the earliest club moss, of Gorstian (Ludlow, Silurian) age on graptolite evidence; the flora persisted through the Přídolí into the Early Devonian (measured [72]).

Asteroxylon mackiei comes from the Rhynie chert, 407 Ma (measured [73]); position 66.92 (computed). The crown-tracheophyte minimum age is 420.7 Ma (Ludlow), and *Cooksonia* cf. *pertoni* gives a minimum of 426.9 Ma (Wenlock) (measured [39]). Vascular plants evolved in the Middle to Late Silurian, about 420 Ma (measured [74]); position 66.94 (computed). *Isoetes* has a fossil record to "at least the late Devonian" and diverged from other CAM lineages more than 300 Ma ago (measured [75]).

Molecular clocks: crown lycophytes 432.5–392.8 Ma (measured [39]) and 431–411 Ma (measured [56]). Crown tracheophytes 472.2–419.3 Ma across all analyses, 450.8–431.2 Ma for monophyletic bryophytes (measured [39]); 452–447 Ma (measured [56]).

Event	Age	Position	Mark
<i>Asteroxylon</i> , Rhynie chert	407 Ma	66.92	measured [73]
Crown tracheophytes, minimum	420.7 Ma	66.95	measured [39]
Crown lycophytes	432.5–392.8 Ma	66.97–66.88	measured [39]
Crown lycophytes	431–411 Ma	66.97–66.92	measured [56]

Crown tracheophytes	472.2–419.3 Ma	67.05– 66.94	measured [39]
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Sizes

Arborescent lycopsids of the Carboniferous (*Lepidodendron* and allies) reached "statures up to c. 45 m" with "trunk diameters up to 2 m" (measured [76]). Positions 18.85 and 16.02 (computed). The ratio height to trunk diameter is $45 / 2 = 22.5$ (computed).

Living lycophytes. *Lycopodium clavatum* has creeping stems 30–100 cm long and leaves 3–5 mm (measured [77]); its upright shoots are 0.6–1.2 cm in diameter, leaves 4–6 × 0.4–0.8 mm, peduncles 3.5–12.5 cm, strobili 15–25 × 3–6 mm (measured [78]). *Huperzia lucidula* shoots are 14–20 (–100) cm, largest leaves 7–11 mm (measured [78]). *Selaginella selaginoides* has stems 3–15 cm and leaves 2–4 mm (measured [77]). *Selaginella apoda* lateral leaves are 1.35–2.25 × 0.75–1.35 mm, strobili 1–2 cm; *S. rupestris* leaves 2.5–4 (–4.5) × 0.45–0.6 mm, in pseudowhorls of 6 on the main stem and 4 on branches (measured [79]). *Isoetes lacustris* leaves are 80–200 (–450) mm (measured [77]) or up to 250 mm, with megaspores 0.55–0.75 mm in diameter (measured [80]). The span from a *Selaginella apoda* leaf (1.35 mm) to a scale-tree trunk (45 m) is $45 / 0.00135 = 33,000$ -fold (computed).

What	Size	Position	Mark
Arborescent lycopsid height	≤ c. 45 m	18.85	measured [76]
Arborescent lycopsid trunk	≤ 2 m	16.02	measured [76]
<i>L. clavatum</i> creeping stem	30–100 cm	14.29–15.39	measured [77]
<i>L. clavatum</i> leaf	3–5 mm	10.10–10.56	measured [77]
<i>L. clavatum</i> upright shoot, diameter	0.6–1.2 cm	10.73–11.36	measured [78]
<i>L. clavatum</i> peduncle	3.5–12.5 cm	12.33–13.49	measured [78]
<i>H. lucidula</i> shoot	14–20 (–100) cm	13.60–13.92 (15.39)	measured [78]
<i>S. selaginoides</i> stem	3–15 cm	12.19–13.66	measured [77]
<i>S. apoda</i> lateral leaf, length	1.35–2.25 mm	9.37–9.84	measured [79]
<i>S. rupestris</i> leaf, length	2.5–4 (–4.5) mm	9.93–10.36 (10.47)	measured [79]
<i>I. lacustris</i> leaf	80–200 (–450) mm	13.09–13.92 (14.66)	measured [77]
<i>I. lacustris</i> megaspore	0.55–0.75 mm	8.55–8.84	measured [80]

Times

The lifespan of the arborescent lycopsids is contested. An earlier estimate of "no greater than 10–15 years" is challenged (measured [76]). A life of about 10 years would need growth "twenty times

higher than modern angiosperm trees" and "at least 60 times higher than modern lycopsids"; lifespans are "most likely measured in centuries" (measured [81]). Positions: 10 years = 3.16×10^8 s, 50.97; 100 years, 53.06 (computed). *Isoetes* has a diel rhythm: leaf titratable acidity rises through the night, peaks in the morning and falls in daylight when the plant is submerged (measured [75]). Period 24 h; position 43.50 (computed). No verified generation time for a living lycophyte was read.

What	Duration	Position	Mark
Scale-tree life, earlier estimate	10–15 yr	50.97–51.34	measured [76], contested
Scale-tree life, later estimate	centuries	≥53.06	measured [81]
Acid rhythm, <i>Isoetes</i>	24 h	43.50	measured [75]

Build

Asteroxylon has three axis types: leafy shoot axes, root-bearing axes and rooting axes. Rooting axes develop from root-bearing axes "through anisotomous dichotomy" (measured [82]). Its rooting-axis meristems "lacked root caps", with a continuous epidermis over the meristem; roots with caps are "a relatively late origin in lycophytes" (measured [73]). Apical organisation: *Selaginella* has "one or two transiently acting apical initials", usually two; Isoëtaceae and Lycopodiaceae "meristems contain multiple apical initials" (measured [69]). Secondary growth: arborescent lycopsids "produced secondary phloem", limited bark and "relatively complex" wood (measured [83]). The sporophyte is the dominant phase. *Isoetes taiwanensis* has $2n = 22$ (measured [75]). *Selaginella rupestris* leaves stand in pseudowhorls of 6 on the main stem and 4 on branches (measured [79]). *Lycopodium clavatum* strobili sit on peduncles 3.5–12.5 cm long (measured [78]). Verified statements on heterospory, stomata and spore counts were not read; see below.

Light

Isoetes performs CAM under water: nocturnal accumulation of titratable acidity when submerged (measured [75]). Chlorophyll a + b and C3 in *Lycopodium* and *Selaginella* are standard and not separately sourced.

Count

Lycopods: 1,290 species (measured [16]). *Isoetes*: about 250 described species (measured [75]). Share of *Isoetes*: $250 / 1,290 = 19.4 \%$ (computed).

Reference genome: *Isoetes taiwanensis*, 1.66 Gb assembly (k-mer 1.65 Gb, flow cytometry 1.55 Gb), 39,461 high-confidence genes, $2n = 22$ (measured [75]).

Genome	Size	Genes	Mark
<i>I. taiwanensis</i>	1.66 Gb	39,461	measured [75]

Not verified

- *Baragwanathia* range ~427–393 Ma; stems a few cm thick, up to a few m long, leaves ~4 cm; occasional dichotomy; adventitious roots — Wikipedia, citing Lang & Cookson 1935, Phil. Trans. R. Soc. B 224:421–449.
- *Isoetes beestonii*, latest Permian ~252 Ma; leaves 2–20 cm (to 100 cm), 0.5–3.0 mm wide; vestigial secondary growth in the corm; stomata lacking in some aquatic species; CAM→C3 switch when emergent — Wikipedia "Isoetes"; Keeley 1981, Am. J. Bot. 68:420–424. FNA *Isoetes* genus treatment (Taylor et al.) — pages not reached.
- *Lepidodendron* 40–50 m, trunk >1 m, base 2 m; dichotomous crown; leaves densely spiralled, single vein; unifacial cambium, periderm — Wikipedia, citing Alekhin 1961; Lopatin 2012.
- *Asteroxylon* dimensions — Hetherington et al. 2021 full text.
- Upright-shoot height of *Lycopodium clavatum* — not stated in FNA or DELTA; candidate Øllgaard 1987, Opera Botanica 92. Largest *Selaginella* (*S. willdenowii*, several m) — Valdespino, FNA vol. 2, page not reached. Typical cell size — no source.
- Lycopodiaceae gametophyte 6–15 years to gametes; germination 2–3 years; 10–25 years to sporophyte; clones 250 years — New Jersey DEP fact sheet citing Raven et al. 1986, Eames 1942, Callaghan et al. 1986.
- *Selaginella* generation time; *Isoetes* lifespan — no source.
- *Lycopodium* dichotomy, *Selaginella* anisotomy — Harrison et al. 2005 full text; Gola 2014.
- Lycopodiaceae leaves opposite or spiral; microphyll with single vein, no leaf gap; homosporous; 400–500 species — Wikipedia, citing Judd et al. 2015 and Christenhusz & Byng 2016.
- *Selaginella* four leaf ranks; rhizophores; heterosporous — standard.
- *Isoetes* cambium — Paolillo 1963.
- Two guard cells; spores per sporangium; cell-type count — no source.
- PPG I 2016: 1,338 lycophytes — J. Syst. Evol. 54:563–603.
- *Selaginella moellendorffii* genome 106 Mbp, ~22,300 genes; 212.5 Mb both haplotypes, 22,285 genes — Banks et al. 2011, Science 332:960–963; read only via BioNumbers BNID 106750 and a Purdue news release.

2.8 Ferns and Horsetails

First appearance

Molecular clocks: crown monilophytes 411.5–384.9 Ma; crown euphyllophytes 437.6–402.2 Ma (measured [39]). Crown euphyllophytes 432–414 Ma (measured [56]). The monilophyte–seed plant divergence is about 400 Ma (measured [84], citing Pryer et al. 2001); position 66.90 (computed). The horsetail lineage has a history "reaching back to the Upper Devonian" (measured [85]). The *Equisetum* crown group is mid-Paleogene by molecular data; fossils with possible synapomorphies occur in the Triassic; Equisetaceae and calamitaceans are separate lineages since the Carboniferous (measured [86]). *Azolla* fossils occur from the Maastrichtian–Paleocene onward. The Arctic "Azolla event" at about 50 Ma lasted about 800,000 years. The *Azolla*–*Nostoc* co-evolution spans about 100 Myr (measured [87]). Positions: 50 Ma, 65.01; 800,000 yr, 61.24; 100 Myr, 65.64 (computed).

Event	Age	Position	Mark
Crown monilophytes	411.5–384.9 Ma	66.93–66.86	measured [39]
Crown euphyllophytes	437.6–402.2 Ma	66.98–66.90	measured [39]

Crown euphyllophytes	432–414 Ma	66.97–66.93	measured [56]
Monilophyte–seed plant split	~400 Ma	66.90	measured [84]
Arctic <i>Azolla</i> event	~50 Ma, lasting ~800,000 yr	65.01; duration 61.24	measured [87]

Sizes

Equisetum spores are about 50 μm in diameter (measured [88]); position 6.37 (computed). Tree ferns: *Dicksonia antarctica* trunks grow 3.3 ± 1.3 cm per year, rising about 0.6 cm per year per metre of height; *Cyathea australis* trunks grow 7.3 ± 2.2 cm per year; individuals up to 6 m tall were measured in a 5-year study after the 2009 fire in south-east Australia (measured [89]). Position of 6 m: 17.02 (computed). At 3.3 cm per year a 6 m trunk takes $6 / 0.033 = 182$ years (computed); position 53.61 (computed). Horsetails: *Equisetum giganteum* has "hollow upright stems grow to over 5 m in height" (measured [90]); position 16.85 (computed). Giant horsetails "represent the largest living Sphenophyta" (measured [85]). *Equisetum hyemale* "attains the height of 150 cm"; tested stems were 476–767 mm (measured [91]). *E. hyemale* subsp. *affine* has aerial stems 18–220 cm; *E. telmateia* subsp. *braunii* has vegetative stems 30–100 (–200) cm and fertile stems 17–45 cm (measured [92]). *Azolla caroliniana* stems are prostrate, 0.5–1 cm, in mats to 4 cm thick (measured [93]). *Pteridium aquilinum* leaves are 30–180 (–500) cm long (measured [94]). The span from an *Azolla* stem (0.5 cm) to a tree-fern trunk (6 m) is 1,200-fold (computed).

What	Size	Position	Mark
<i>Equisetum</i> spore	~50 μm	6.37	measured [88]
<i>Azolla caroliniana</i> stem	0.5–1 cm	10.56–11.19	measured [93]
<i>Azolla</i> mat thickness	≤ 4 cm	12.46	measured [93]
<i>E. telmateia</i> subsp. <i>braunii</i> vegetative stem	30–100 (–200) cm	14.29–15.39 (16.02)	measured [92]
<i>E. hyemale</i> stem	≤ 150 cm; subsp. <i>affine</i> 18–220 cm	15.76; 13.83–16.10	measured [91], [92]
<i>Pteridium aquilinum</i> leaf	30–180 (–500) cm	14.29–15.92 (16.85)	measured [94]
<i>E. giganteum</i> stem	>5 m	>16.85	measured [90]
Tree ferns, measured individuals	≤ 6 m	17.02	measured [89]

Times

Azolla doubling time is "as low as 2 days in their exponential growth phase" without nitrogen fertiliser (measured [95], cited there); 2 days = 172,800 s; position 44.13 (computed). Measured production is 9.72 g dry weight per m^2 per day for *A. filiculoides*, an annual yield potential of 35.5 t per ha dry weight; mat density 2–3 kg fresh weight per m^2 (measured [95]). Check: $9.72 \text{ g} \times 365.25 = 3,550 \text{ g per m}^2 = 35.5 \text{ t per ha}$ (computed). *Azolla* is "one of the fastest-growing plants on the planet" (measured [87]). *Equisetum* spores perform humidity-dependent "walks" and "jumps" by folding of their elaters (measured [88]); no period is given.

What	Duration	Position	Mark
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Doubling, <i>Azolla</i> , exponential phase	2 days	44.13	measured [95]
Trunk growth, <i>D. antarctica</i>	3.3 ± 1.3 cm/yr	—	measured [89]
Trunk growth, <i>C. australis</i>	7.3 ± 2.2 cm/yr	—	measured [89]
6 m trunk at 3.3 cm/yr	182 yr	53.61	computed from [89]

Build

Shoots of *Nephrolepis exaltata* and *Ceratopteris richardii* "develop from a single tetrahedral AC" (measured [84]). The figure legend shows a tetrahedral apical cell with three cutting faces. Fern fronds typically arise from a single apical cell (measured [84]). Monilophytes "predominantly exhibit single apical cells; however, ferns with multiple apical cells have also been reported"; *Ceratopteris* usually has one apical initial (measured [69]). *Equisetum* spores "have four elaters", ribbon-like, unfurling when dry (measured [88]). Heterospory: *Salvinia* and *Pilularia* are heterosporous; *Azolla* has nearly twice the chromosome number of other heterosporous ferns (measured [87]). *Azolla* hosts *Nostoc azollae* in specialised leaf cavities, transmitted vertically (measured [87]). *Ceratopteris* has $n = 39$ (measured [96]). The sporophyte is the dominant phase. *Equisetum* leaves are reduced to sheath teeth in whorls: 14–50 per whorl in *E. hyemale* subsp. *affine*, 14–30 (–36) in *E. telmateia* subsp. *braunii* (measured [92]). Verified statements on fern branching, sporangium counts and vascular tissue were not read; see below.

Light

Azolla carries the obligate N₂-fixing cyanobacterium *Nostoc azollae* in its leaf cavities (measured [87]). Chlorophyll a + b, C3 and the two-membrane plastid are standard and not separately sourced.

Count

Ferns: 10,560 species (measured [16]); "over 10,500 extant species", the second most species-rich vascular-plant clade (measured [96]). Leptosporangiate ferns make up about 80 % of non-flowering vascular-plant species (measured [84]). *Equisetum*: 15 species (measured [85]); 15 extant species (measured [86]).

Reference genomes: *Azolla filiculoides*, 0.75 Gb, 20,201 high-confidence gene models. *Salvinia cucullata*, 0.26 Gb, "smallest fern genome reported to date", 19,914 genes (measured [87]). *Ceratopteris richardii* (Hn-n), 7.46 Gb assembled, k-mer estimate 9.6 Gb, 36,857 protein-coding genes, 38,397 alternative transcripts, 39 chromosomes (measured [96]). The *Ceratopteris* assembly is $7.46 / 0.26 = 28.7$ times the *Salvinia* genome (computed).

Genome	Size	Gene s	Mark
<i>A. filiculoides</i>	0.75 Gb	20,201	measured [87]
<i>S. cucullata</i>	0.26 Gb	19,914	measured [87]
<i>C. richardii</i>	7.46 Gb	36,857	measured [96]

Not verified

- Oldest modern *Equisetum*, Early Jurassic (*E. dimorphum*, *E. laterale*); *E. thermale* — Wikipedia, citing Elgorriaga et al. 2015, *Ameghiniana* 52:135–152; Channing et al. 2011, *Am. J. Bot.* 98:680–697.
- *Calamites* 360–300 Ma, 30–50 m, secondary xylem with unifacial cambium, leaf whorls up to 25 — Wikipedia, citing Alekhin 1961; Rößler et al. 2012 for Chemnitz calamites.
- *Psilotum*: no fossils; dichotomous branching; no roots; synangium of three sporangia; 30 cm; two species and one hybrid — Wikipedia "Psilotum".
- *Azolla* event ~55 Ma (Wikipedia); plants a few cm across, mats to 30 cm; leaf ~1 mm — Wagner 1997, *Botanical Review* 63:1–26; biomass doubling 1.9 days — Watanabe & Berja 1983, *Aquatic Botany* 15:175–185; microspores in massulae, one megaspore per female sporocarp; seven living species — Wikipedia "Azolla".
- Fern crown ages — Testo & Sundue 2016, *Mol. Phylogenet. Evol.* 105:200–211.
- Tallest ferns *Cyathea australis*, *C. brownii* 20 m — Guinness World Records; Large & Braggins 2004 (measured individuals reach 6 m, [89]). Tree-fern growth from Ough & Murphy 2004 and Bystriakova et al. 2011 — DOIs not located.
- *Equisetum myriochaetum* 8 m; record horsetail 7.3 m — Wikipedia; Guinness; candidates Hauke 1963, *Beih. Nova Hedwigia* 8; Christenhusz et al. 2019, *Bot. J. Linn. Soc.* 189:311–352 (record verified, text paywalled). Genus-level range of sheath teeth — FNA *Equisetum* genus page not reached.
- *Pteridium* clone ages centuries to >1,000 years — Oinonen 1967. *Salvinia* dimensions — Nauman, FNA vol. 2, pages not reached.
- *Ceratopteris* generation time 90–120 days — Hickok et al. 1995, *Int. J. Plant Sci.* 156:332–345.
- Typical cell size; cell-type count — no source.
- *Equisetum* shoot apical cell geometry — Golub & Wetmore 1948, *Am. J. Bot.* 35:755–767; whorled branches, 3 or 6–40 ridges, fused nodal sheaths; mostly homosporous — Wikipedia "Equisetum".
- About 64 spores per leptosporangium — Wikipedia "Sporangium", no inline citation; Bower 1923–28; Gifford & Foster 1989.
- Living monilophytes without secondary growth; two guard cells; no CAM or C4 — standard, no sourced statement.
- PPG I 2016: 10,578 ferns. *Equisetum* 18 (POWO) or 25 species — Wikipedia.

2.9 Progymnosperms and Seed Ferns

This entry covers extinct groups only. There is no molecular clock and no living reference genome.

First appearance

The oldest forest with *Archaeopteris* root systems is the Cairo quarry, New York, "early mid Givetian (ca. 385 Ma)" (measured [97]). Cairo is "approximately 2–3 Ma" older than the Gilboa Riverside quarry (measured [97]). The Mid-Devonian is defined as 393–383 Ma in the same study (measured [97]). Age in seconds: $385 \times 10^6 \times 3.15576 \times 10^7 = 1.21 \times 10^{16}$ s (computed); position 66.86 (computed). Anatomically preserved *Archaeopteris* trunks occur in Famennian marine beds of south-east Morocco as "370-million-year-old plants"; the genus went extinct "around the Devonian/Carboniferous boundary" (measured [98]); position 66.83 (computed). The cladoxylopsid *Wattieza*/*Eospermatopteris* stumps at Gilboa are "about 385 million years old", Givetian (measured [99]).

The seed precursor *Runcaria heinzelinii* from Belgium is "middle Givetian (385 million years ago)" and predates "the earliest seeds by about 20 million years" (measured [100]). The earliest seeds then fall at about $385 - 20 = 365$ Ma (computed); position 66.82 (computed). Seed plants "originated at least before 300 Ma (in the Carboniferous)" (measured [101]); position 66.64 (computed).

Event	Age	Position	Mark
Cairo <i>Archaeopteris</i> forest	ca. 385 Ma	66.86	measured [97]
Gilboa <i>Wattieza</i> stumps	~385 Ma	66.86	measured [99]
<i>Runcaria</i> seed precursor	385 Ma	66.86	measured [100]
Earliest seeds	~365 Ma	66.82	computed from [100]
Moroccan <i>Archaeopteris</i> trunks	370 Ma	66.83	measured [98]
Seed plants, minimum	before 300 Ma	66.64	measured [101]

Sizes

Archaeopteris root systems at Cairo have "radial dimensions as much as 11 m across the paleosol surface". Primary roots are "6–16 cm in diameter", with "as many as 10–15 primary roots" per tree. Eighteen root systems were mapped in about 3,000 m² (measured [97]). Position of 11 m: 17.57; of 6–16 cm: 12.83–13.72 (computed). One root system per $3,000 / 18 = 167$ m² (computed). Tree heights at Cairo, estimated from root-system size, are about 11–32 m depending on method (measured [97], supplementary Table S1; an estimate). Positions 17.57–18.54 (computed). *Wattieza/Eospermatopteris* was "tall (at least 8 m)" (measured [99]); position 17.28 (computed). The Cairo *Eospermatopteris* bases are "bowl-shaped depressions 20–50 cm in diameter", with roots "0.7–1 cm in diameter" extending 1–2 m from the centre (measured [97]). Positions: 20–50 cm, 13.92–14.76; 0.7–1 cm, 10.87–11.19; 1–2 m, 15.39–16.02 (computed). The *Runcaria* ovule is "small" (measured [100], no number).

What	Size	Position	Mark
<i>Archaeopteris</i> root system, radius	≤11 m	17.57	measured [97]
<i>Archaeopteris</i> primary root	6–16 cm	12.83–13.72	measured [97]
<i>Archaeopteris</i> height, estimate	11–32 m	17.57–18.54	measured [97] (estimate)
<i>Wattieza</i> height	≥8 m	17.28	measured [99]
<i>Eospermatopteris</i> base	20–50 cm	13.92–14.76	measured [97]
<i>Eospermatopteris</i> roots	0.7–1 cm, 1–2 m long	10.87–11.19; 15.39–16.02	measured [97]

Times

No generation time, lifespan or ring count was read for these taxa. *Archaeopteris* shows "perennial branch growth" (measured [98], qualitative). Everything else on duration is listed below.

Build

Archaeopteris branches laterally, not dichotomously: a "lateral branching syndrome" of the modern-tree type; four traits of modernisation are listed (measured [98]). Its root system is "essentially comparable to modern seed plants" (measured [97]). Its wood anatomy shows "strategies that minimize the mechanical stresses caused by perennial branch growth" (measured [98]); secondary growth is present. *Runcaria* has a "radially symmetrical, integumented megasporangium surrounded by a cupule", with a "multilobed integument" and an unopened distal extension (measured [100]). Integument count: 1, lobed, plus a cupule (measured [100], as described). *Runcaria* is "anemophilous" (measured [100]). *Medullosa* shows "anomalous vascular cambium growth and many leaf traces entering each petiole base" (measured [102]). Medullosan tracheids are very large, with "volume flow rates closer to angiosperm vessels than to typical ... coniferophyte tracheids" and a high diameter to wall-thickness ratio; the plants may have been vines (measured [102]). These are "tracheid-based stem plants" without vessels (measured [102]). The life cycle is heterosporous; the seed habit is present from the Famennian (measured [100]).

Light

No measurement of the photosynthetic apparatus is possible for fossil taxa. *Medullosa* hydraulics show high conductivity and a "significant risk of embolism and implosion" (measured [102]). *Archaeopteris* had "greatly expanded energy and resource use" (measured [97]).

Count

Extinct; no accepted species count was read. No genome.

Not verified

- *Elkinsia polymorpha* Famennian age (~365 Ma) and ovule dimensions — Rothwell, Scheckler & Gillespie 1989, Botanical Gazette 150(2):170–189; record verified, numbers not read.
- Medullosales from the late Mississippian to the earliest Permian; "small to medium-sized trees", up to 10 m; *Alethopteris* fronds 7 m; ovules 1–10 cm — Wikipedia "Medullosales", citing Laveine et al. 1993; Seyfullah et al. 2009; Laveine 1986; Gastaldo & Matten 1978.
- *Glossopteris* 298.9–251.9 Ma; trees to 30 m, trunk 80 cm, leaves 2 to >30 cm; >70 species — Wikipedia, citing McLoughlin 2011, 2012; McLoughlin et al. 1997.
- *Archaeopteris* trunk ~1.5 m, height ~30 m — Meyer-Berthaud, Scheckler & Bousquet 2000, Am. J. Bot. 87:456–468.
- Growth rings in *Archaeopteris* or glossopterid wood — Decombeix et al. 2016, IAWA J.
- *Archaeopteris* heterosporous and free-sporing — Beck 1960s.
- *Wattieza* without bifacial cambium — standard.
- All C3 — inferred, no measurement possible.

2.10 Cycads and Ginkgo

First appearance

The least equivocal early cycad is *Crossozamia* from the Shihhotse Formation, China, revised to Roadian–Wordian, 265.1–272.3 Ma (measured [103]). Age in seconds: $265.1 \times 10^6 \times 3.15576 \times 10^7 = 8.37 \times 10^{15}$ s (computed); position 66.52–66.55 (computed). The cycad crown is Permian and the divergence from *Ginkgo* Carboniferous (measured [103], qualitative). A single-copy nuclear-gene clock dates the cycad crown to the Middle Jurassic, 158.1 Ma (measured [101]); position 66.05

(computed). The two sources disagree: Permian (measured [103]) against 158.1 Ma (measured [101]). Living cycad species are "not much older than ~12 million years", from a near-synchronous global rediversification beginning in the late Miocene (measured [104]); position 63.71 (computed). Extant genera show "rapid radiations ranging from 11 to 20 Myr ago" (measured [105]); positions 63.63–64.17 (computed).

Ginkgo is "known to have existed early in the Jurassic period 170 million years (Myr) ago"; Yixian Formation *Ginkgo* with modern-type ovulate organs is "over 121 Myr old" (measured [106]). Positions 66.12 and 65.81 (computed). Its morphology is "essentially unchanged ... for more than 200 million years" (measured [107]); "at least 200 million years" (measured [108]).

Event	Age	Position	Mark
<i>Crossozamia</i>	265.1–272.3 Ma	66.52–66.55	measured [103]
Cycad crown, nuclear clock	158.1 Ma	66.05	measured [101]
Living cycad species	≤ ~12 Ma	63.71	measured [104]
Cycad genus radiations	11–20 Ma	63.63–64.17	measured [105]
<i>Ginkgo</i> , Early Jurassic	170 Ma	66.12	measured [106]
Yixian <i>Ginkgo</i> with modern ovules	>121 Ma	65.81	measured [106]

Sizes

Lepidozamia hopei has an erect stem to 20 m tall and 50 cm in diameter, leaves 200–300 cm, up to 100 leaves in the crown (measured [109]). Position of 20 m: 18.11 (computed). *Macrozamia moorei*, *Cycas angulata*, *Cycas media*, *Encephalartos transvenosus* and *E. woodii* stand in the table (measured [109], [110], [111]). *Cycas media* leaves carry 160–300 pinnae (measured [109]). *Ginkgo biloba* mature trees are typically 20–40 m; one Korean tree is reported at 64 m with a 14 m girth (measured [112]). Stem diameter is 1–4 m in cultivated Chinese trees; the seed is 20–30 × 16–24 mm (measured [112]). The ratio of the tallest cycad stem (20 m) to its diameter (0.5 m) is 40 (computed). No verified smallest cycad was read. The *Cycas* male-specific Y region is 45.5 Mb with 624 putative genes (measured [105]).

What	Size	Position	Mark
<i>L. hopei</i> stem	≤20 m, 50 cm diam.	18.11; 14.76	measured [109]
<i>L. hopei</i> leaf	200–300 cm	16.02–16.39	measured [109]
<i>M. moorei</i> stem	2–7 m, 50–80 cm diam.	16.02–17.16; 14.76–15.18	measured [109]
<i>C. angulata</i> stem	≤5 (–12) m	16.85 (17.65)	measured [109]
<i>C. media</i> stem	≤3 (–6) m	16.39 (17.02)	measured [109]
<i>E. transvenosus</i> stem	12–13 m, 0.4–0.45 m diam.	17.65–17.72; 14.55–14.66	measured [110]

<i>E. woodii</i> trunk	≤6 m, base ≤900 mm	17.02; 15.29	measured [111]
<i>Ginkgo</i> tree, typical	20–40 m	18.11–18.74	measured [112]
<i>Ginkgo</i> tree, reported maximum	64 m	19.17	measured [112]
<i>Ginkgo</i> stem diameter, cultivated	1–4 m	15.39–16.65	measured [112]
<i>Ginkgo</i> seed	20–30 × 16–24 mm	11.83–12.19	measured [112]

Times

A cambial study covered *Ginkgo* trees "ranging from 15 to 667 years old" (measured [113]). Ring width drops sharply over the first 100–200 years while basal area increment keeps rising. There is no whole-plant senescence (measured [113]). The 667-year tree is the oldest measured in that study. In seconds: $667 \times 3.15576 \times 10^7 = 2.10 \times 10^{10}$ s (computed); position 54.79 (computed). "The oldest known ginkgo trees in China were estimated to be approximately 1000–3000 years old" (measured [108], an estimate, not a ring count); positions 55.16–56.16 (computed). Pollen germination takes "several days or more among cycads" (measured [114]). Gymnosperm pollen tubes grow at " $< \sim 20 \mu\text{m/h}$ " (measured [115]). At $20 \mu\text{m/h}$ a tube covers 1 mm in 50 h (computed). *Ginkgo* reaches sexual maturity typically at 20–30 years, grafted cultivars at about 5 years. Pollination falls in early April to late May, fertilisation in late August to late September, and the ovules fall about 1 month later (measured [112]). Pollination to fertilisation is then about 4–5 months (computed); position of 5 months: 48.07 (computed). The seed-to-seed generation time is about 20–30 years plus 5–6 months (computed from [112]); positions 51.60–51.97 (computed).

What	Duration	Position	Mark
Oldest measured <i>Ginkgo</i> , cambial study	667 yr	54.79	measured [113]
Oldest <i>Ginkgo</i> , estimate	1,000–3,000 yr	55.16–56.16	measured [108] (estimate)
Pollen germination, cycads	several days	≥ 44.50 (3 d)	measured [114]
Sexual maturity, <i>Ginkgo</i>	20–30 yr (grafted ~ 5 yr)	51.60–51.97 (50.34)	measured [112]
Pollination to fertilisation, <i>Ginkgo</i>	~ 4 –5 months	47.87–48.07	computed from [112]
Fertilisation to ovule fall, <i>Ginkgo</i>	~ 1 month	46.61	measured [112]

Build

Sperm of cycads and *Ginkgo* are multiflagellate; the structure "bears numerous flagella" (measured [116]). Pollen has "four cells in pine and ginkgo": two prothallial cells, an antheridial or generative cell and a tube cell (measured [117]). "Cycads are the only early seed plants that have evolved a specialized root to host endophytic bacteria that fix nitrogen" (measured [118]). *Nostoc* is prevalent, also *Calothrix*. Six cyanobacterial draft genomes were obtained from coralloid roots (measured [118]). *Ginkgo* has a vascular cambium (measured [113]); secondary growth is present. Gymnosperms "cannot form structures that are homologous to angiosperm vessels" (measured [119]). Both groups are dioecious; *Cycas* has a male-specific Y region (measured [105]). *Cycas*

panzhihuaensis has $n = 11$ (measured [105]). Verified statements on branching, phyllotaxis, ovule number and integument count were not read; see below.

Light

Hydraulics run through tracheids only. End-walls account for 56–64 % of xylem resistance in both tracheids and vessels (measured [120]). Chlorophylls, membranes and the C3 pathway follow the embryophyte standard and were not separately sourced. CAM records are listed below.

Count

Gymnosperms: 1,079 species (measured [16]). Cycads: 10 genera, 382 accepted species (396 names including 14 infraspecific). By genus: *Cycas* 124, *Zamia* 90, *Encephalartos* 71, *Ceratozamia* 45, *Macrozamia* 41, *Dioon* 19, *Bowenia* 2, *Lepidozamia* 2, *Microcycas* 1, *Stangeria* 1 (measured [121], World List of Cycads v. 2026.08.15, DOI 10.5281/zenodo.21958524). Sum of genera: $124 + 90 + 71 + 45 + 41 + 19 + 2 + 2 + 1 + 1 = 396$ (computed; the list's own accepted total is 382). Other counts: "about 360 extant species in 10 genera" (measured [105]); "~300 species" (measured [104]). Cycads are $382 / 1,079 = 35.4$ % of gymnosperms (computed). *Ginkgo* is one species.

Reference genomes: *Ginkgo biloba* draft, 10.61 Gb assembly including 493 Mb of gaps, 41,840 predicted genes (measured [107]); near-complete, 9.87 Gb, 27,832 protein-coding genes, which supersedes the draft count (measured [122]). *Cycas panzhihuaensis*, 10.5 Gb, 32,353 protein-coding genes, 76.14 % repeats, $n = 11$, mean intron about 30.8 kb, longest intron about 1.5 Mb (measured [105]).

Genome	Size	Genes	Mark
<i>G. biloba</i> , draft	10.61 Gb	41,840	measured [107]
<i>G. biloba</i> , near-complete	9.87 Gb	27,832	measured [122]
<i>C. panzhihuaensis</i>	10.5 Gb	32,353	measured [105]

Not verified

- Oldest probable cycad foliage ~300 Ma — Wikipedia "Cycad", citing Spiekermann et al. 2021, Rev. Palaeobot. Palynol. 289:104415.
- Permian ginkgophytes (*Trichopitys*, ~280 Ma) — Zhou 2009, Palaeoworld 18:1–22; record verified, no abstract.
- *Zamia pygmaea* smallest cycad, stem 2 cm, 25 cm tall — Wikipedia, citing Stevenson 2010; Calonje et al. 2013; no primary page reached. *Encephalartos laurentianus* — SANBI page not reached.
- *Lepidozamia hopei* cones 60×30 cm and 40×14 cm; fronds with 200 leaflets — Wikipedia, citing Flora of Australia; Zich et al. 2020.
- Heaviest cones 40–45 kg — Jones 2002, Cycads of the World.
- *Ginkgo* long and short shoots; two ovules per stalk; several thousand flagella — Wikipedia "Ginkgo biloba".
- *Ginkgo* 1,600–3,500 years — Wikipedia, citing Xiang et al. 2009, Arnoldia; ring-counted ages — Tang et al. 2012, Am. J. Bot. 99:1408–1414 (record verified; no numbers in abstract).

- Cycad generation time, leaf and individual lifespan — Norstog & Nicholls 1997.
- *Zamia* sperm 10,000–50,000 flagella — Norstog 1967; Renzaglia & Garbary 2001, Crit. Rev. Plant Sci. 20:107–213, record verified.
- Cycads unbranched or sparsely branched pachycaul; manoxylic wood; one integument; vessels absent — standard; Endress 2011, Ann. Bot. 107:1465–1489 abstract does not give the count.
- CAM in *Dioon edule* and *Welwitschia* only among gymnosperms — Gymnosperm Database, citing von Willert et al. 2005.

2.11 Conifers and Gnetophytes

First appearance

The conifer fossil record spans "more than 300 million years" (measured [123]); position of 300 Ma: 66.64 (computed). The most recent common ancestor of Pinaceae is 198.4 Ma; the Cupressaceae–Taxaceae split is Late Triassic to Early Jurassic; the Gnetales crown is calibrated at ≥ 125 Ma (measured [101]). Positions 66.26 and 65.84 (computed). Most conifer species diverged in the Neogene, the clades in the Mesozoic (measured [124]). *Welwitschia* and *Gnetum* diverged "over 110 million years ago"; the *Welwitschia* whole-genome duplication is about 86 Ma (78–96) (measured [125]). Positions 65.72 and 65.50 (65.41–65.60) (computed). The major seed-plant lineages diverged about 300 Ma (measured [119]).

Event	Age	Position	Mark
Conifer fossil record	>300 Ma	66.64	measured [123]
Pinaceae MRCA	198.4 Ma	66.26	measured [101]
Gnetales crown, calibration	≥ 125 Ma	65.84	measured [101]
<i>Welwitschia</i> – <i>Gnetum</i> split	>110 Ma	65.72	measured [125]
<i>Welwitschia</i> WGD	~86 Ma (78–96)	65.50	measured [125]

Sizes

The tallest tree measured is a *Sequoia sempervirens* of 112.7 m. The estimated maximum height without mechanical damage is 122–130 m (measured [126]). Positions 19.69 and 19.76–19.82 (computed). The Silvics manual gives the tallest measured *Sequoia* as 112.1 m (1964) (measured [127]); position 19.68 (computed). Redwoods are commonly 60–84 m, with a champion of 101 m (measured [128]); positions 19.11–19.42 and 19.59 (computed). *Pinus sylvestris* averages 23–27 m with a maximum over 40 m (measured [129]); the tallest reported in a New York plantation was 29.0 m at 74–77 years (measured [130]). *Picea abies* reaches 50–60 m (measured [131]), 30–60 m at maturity (measured [132]). Positions: 23–27 m, 18.24–18.39; 40 m, 18.74; 50–60 m, 18.95–19.11 (computed). *Welwitschia* has "just two leaves", two ever-elongating leaves on an unbranched stem (measured [125]). No verified smallest conifer was read.

What	Size	Position	Mark
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Tallest <i>Sequoia</i> , measured	112.7 m	19.69	measured [126]
Height limit, estimate	122–130 m	19.76–19.82	measured [126]
Tallest <i>Sequoia</i> , Silvics (1964)	112.1 m	19.68	measured [127]
<i>Sequoia</i> , common height; champion	60–84 m; 101 m	19.11–19.42; 19.59	measured [128]
<i>Pinus sylvestris</i>	23–27 m, max >40 m	18.24–18.39, >18.74	measured [129]
<i>Picea abies</i>	50–60 m	18.95–19.11	measured [131]

Times

A *Pinus longaeva* on Wheeler Peak, Nevada, was "4,900-year-old" (measured [133], abstract). In seconds: $4,900 \times 3.15576 \times 10^7 = 1.55 \times 10^{11}$ s (computed); position 56.60 (computed). *Welwitschia* "can live for several thousand years"; its leaves "grow continuously throughout the plant's life" (measured [125]). Needle lifespan: *Pinus longaeva* needles last "up to about 45 years", a record among conifers; most low-elevation pines keep needles 2–4 years (measured [134]). Positions 52.34 and 49.50–50.13 (computed). Pollination to fertilisation takes "up to a year (*Pinus* and some *Araucariaceae*)", with pine pollen dormant from mid-summer to the next spring (measured [117]). In other Pinaceae and most Cupressaceae the interval runs "from several weeks" (measured [117]). One year: position 48.87 (computed). Gnetales pollen germinates in 1–72 h; conifers take 0.5–9 months in vivo (measured [114]). Positions 40.61–44.50 and 45.96–48.61 (computed). Pollen tubes of *Picea abies* grow at about 20 $\mu\text{m/h}$ against 300–1,500 $\mu\text{m/h}$ in angiosperms (measured [117]); ratio 15 to 75 (computed).

Lifespans and first seed. *Sequoia sempervirens*: the oldest by ring count is nearly 2,200 years; seed bearing begins at 5–15 years (measured [127]). Seed viability lasts more than 250 years (measured [127]). It lives 2,000+ years and seeds at 5–15 years (measured [128]). Positions: 2,200 yr, 55.88; 5–15 yr, 50.34–51.34 (computed). *Pinus sylvestris* flowers first at 5–8 years in Michigan, on average at 10–15 years, and bears viable seed to at least age 200 (measured [130]). It lives 400+ years, one Lapland tree more than 750 years (measured [129]). *Picea abies* flowers usually at 20–30 years, to 40 years in dense stands, and normally lives 200–300 years (measured [131]); the minimum seed-bearing age is 40–60 years (measured [132]). The two sources differ: 20–30 years first flowering (measured [131]) against 40–60 years minimum seed bearing (measured [132]). *Welwitschia* leaves grow 0.37 mm per day on average, varying 22-fold within individuals; the sex ratio is male-biased and males are larger (measured [135]).

What	Duration	Position	Mark
Oldest <i>P. longaeva</i> , ring	4,900 yr	56.60	measured [133]
Oldest <i>Sequoia</i> , ring count	~2,200 yr	55.88	measured [127]
First seed, <i>Sequoia</i>	5–15 yr	50.34–51.34	measured [127], [128]
First flowers, <i>P. sylvestris</i>	5–8 yr; average 10–15 yr	50.34–50.76; 50.97–51.34	measured [130]
Lifespan, <i>P. sylvestris</i>	400+ yr; one tree >750 yr	54.32; 54.90	measured [129]

First flowers, <i>P. abies</i>	20–30 (–40) yr	51.60–51.97 (52.23)	measured [131]
Minimum seed bearing, <i>P. abies</i>	40–60 yr	52.23–52.60	measured [132]
Lifespan, <i>P. abies</i>	200–300 yr	53.69–54.06	measured [131]
Leaf growth, <i>Welwitschia</i>	0.37 mm/day	—	measured [135]
Needle life, <i>P. longaeva</i>	≤ ~45 yr	52.34	measured [134]
Needle life, low-elevation	2–4 yr	49.50–50.13	measured [134]
Pollination to fertilisation, <i>Pinus</i>	≤1 yr	48.87	measured [117]
Pollen germination, Gnetales	1–72 h	40.61–44.50	measured [114]
Pollen germination, conifers	0.5–9 months	45.96–48.61	measured [114]

Build

Cone-scale phyllotaxis: the prevalent parastichy pair is 8/13 in *Pinus nigra* (5,838 of 6,000 cones from one tree) and 5/8 in *Larix decidua* (1,181 of 1,506 cones) (measured [136]). The quotients $8/13 = 0.615$ and $5/8 = 0.625$ (computed) lie close to 0.618. Nine rarer aberrant Fibonacci-type patterns occur; the source states that their frequency falls with the deviation of the parastichy quotient from 0.618, and all of them lie within two of a convergent pair (measured [136]). Pollen cells: *Pinus* 4, *Sequoia* 2, *Juniperus* 1 (measured [117]). In *Ephedra nevadensis* the sperm are non-motile and double fertilisation occurs: the second sperm nucleus fuses with the ventral canal nucleus (measured [137]). Vessels are absent in conifers, whose wood is homoxylous tracheid wood (measured [120]). *Gnetum* has vessels, but "vessels in the two groups are convergent characters"; gymnosperms lack the VND clades (measured [119]). Secondary growth is present in all. *Welwitschia*: two leaves, unbranched stem, dioecious (measured [125]). *Runcaria*, the Devonian seed precursor, was already "anemophilous" (measured [100]); all conifers are wind-pollinated.

Light

All are C3 except *Welwitschia*. Its night CO₂ uptake "never exceeding 4 % of total 24-hour CO₂ uptake", peak $\leq 0.2 \mu\text{mol m}^{-2} \text{s}^{-1}$, only in December–January; it is classed as CAM (measured [138]). Tracheid hydraulics: vessels are about an order of magnitude longer than tracheids of the same diameter but not necessarily more efficient, through torus–margo pits; end-walls are 56–64 % of resistance (measured [120]).

Count

Gymnosperms: 1,079 species (measured [16]). *Welwitschia*: 1 species (measured [125]).

Reference genomes: *Picea abies*, a "20-gigabase genome", 19.6 Gb estimate, 28,354 well-supported genes among 70,968 predicted loci, longest intron 68 kb (measured [139]). *Pinus taeda*, "an estimated 22 billion base pairs"; assembly 20.1 Gb in scaffolds spanning 22.18 Gb; 50,172 gene models; 82 % repetitive; maximum intron 318 kb (measured [140]). *Welwitschia mirabilis*, 6.8 Gb per 1C (assembly 6.86 Gb, estimate 7.0 Gb), 26,990 protein-coding genes (measured [125]). *Gnetum montanum*, 4.07 Gb assembled (flow cytometry about 4.2 Gb), 27,491 protein-coding genes (measured [119]). The *Pinus taeda* genome is $22 / 4.07 = 5.4$ times the *Gnetum* genome (computed).

Genome	Size	Genes	Mark
<i>P. abies</i>	19.6–20 Gb	28,354	measured [139]
<i>P. taeda</i>	22 Gb (assembly 20.1 Gb)	50,172	measured [140]
<i>W. mirabilis</i>	6.8 Gb	26,990	measured [125]
<i>G. montanum</i>	4.07 Gb	27,491	measured [119]

Not verified

- Oldest conifer ~310 Ma (*Swillingtonia*) — Scott & Chaloner 1983, Proc. R. Soc. B.
- *Ephedra* oldest members ~125 Ma — Wikipedia, citing Rydin et al. 2006, Ann. Bot. 98:123–140 (record verified).
- Hyperion 115.85 m — Gymnosperm Database, citing Taylor & Mifsud 2010.
- General Sherman 1,486.6 m³, 83.8 m, girth 31.1 m, basal diameter 11.1 m — NPS page; Flint 1987.
- *Picea abies* 62.26 m, dbh 214 cm; *Araucaria hunsteinii* 85 m; *A. araucana* 50 m, 223 cm dbh, branches in whorls of five, leaves 10–15 yr, 1,300 yr — Gymnosperm Database, citing Räsänen, Silba 1986, IDS 1991.
- *Pinus longaeva* 16 m, 200–368 cm dbh, needles 10–43 yr, 5 per fascicle; *Welwitschia* disc 1 m; cone sizes; *Pinus* 114 species; seed-cone maturation 1.5–2 (–3) yr — Gymnosperm Database, citing Kral 1993, Taylor 1993, Watson 1993, Leuenberger 2001.
- *Pinus* needles (1)2–5(6) per fascicle, cotyledons (3)6–14(24), branches in pseudowhorls — Gymnosperm Database citing Kral 1993.
- Smallest conifer (*Lepidothamnus laxifolius* ~8 cm) — no source.
- Methuselah 4,850 yr; OLDLIST ages (*Fitzroya* 3,622; *Sequoiadendron* 3,266; *Juniperus occidentalis* 2,675; *Pinus balfouriana* 2,110; *Picea engelmannii* 911) — RMTRR OLDLIST; Schulman 1958, National Geographic 113:355–372.
- Old Tjikko 9,550 yr — Öberg & Kullman 2011, Arctic Antarct. Alp. Res. 43:589–595; all routes failed (see 2.15).
- *Sequoia* 2,266 yr (Carroll 2013); *Taxus baccata* age claims (Hartzell 1991); *Welwitschia* >1,500 yr by ¹⁴C (Herre 1961) — Gymnosperm Database; Henschel & Seely 2000 abstract gives no ages.
- *Pinus* pollination–fertilisation 12–15 months as a number — Fernando, Lazzaro & Owens 2005, Sex. Plant Reprod. 18:149–162 (record verified).
- *Ephedra* leaves opposite or whorled; *Gnetum* decussate; 2 ovules per cone scale; archegonia 1–6 per ovule; resin ducts; insect pollination in some Gnetales — standard or Wikipedia.
- Conifers ~615 and gnetophytes ~100 species — Christenhusz et al. 2011, Phytotaxa 19:55–70. *Ephedra* 74, *Gnetum* 44–50 — Wikipedia.
- Generation time (years to first cone) for taxa other than *Sequoia*, *Pinus sylvestris* and *Picea abies* — no source.

2.12 Basal Angiosperms and Magnoliids

First appearance

The oldest confirmed fossil flowers are "no older than about 130 million years". The crown-angiosperm calibration is 136–139.35 Ma, and the most recent common ancestor "likely existed ~140–250 million years ago" (measured [141]). Positions: 130 Ma, 65.88; 136–139.35 Ma, 65.92–65.94; 140–250 Ma, 65.94–66.47 (computed). *Archaeofructus liaoningensis* and *A. sinensis* from the Yixian Formation, Liaoning, are "at least 124.6 million years old", herbaceous aquatics (measured [142]); position 65.84 (computed). *Montsechia vidalii*, Barremian, Spanish Pyrenees, is known from about 1,000 specimens, a submerged aquatic and possible sister to *Ceratophyllum* (measured [143]).

Molecular clocks: crown angiosperms 234–263 Ma; monocot–eudicot split 171–203 Ma; Nymphaeaceae–Cabombaceae 147–185 Ma (measured [144]). Crown angiosperms "Upper Triassic" from 2,881 plastomes and 62 calibrations (measured [145]). Magnoliidae crown 178.78–126.82 Ma (measured [146]). The Magnoliaceae–Lauraceae split is 113–128 Ma; the *Liriodendron* WGD about 116 Ma (measured [147]). The fossil floor of about 130 Ma and the clock range 234–263 Ma differ by 104–133 Myr (computed).

Event	Age	Position	Mark
Oldest confirmed flowers	≤ ~130 Ma	65.88	measured [141]
Crown-angiosperm calibration	136–139.35 Ma	65.92–65.94	measured [141]
<i>Archaeofructus</i>	≥124.6 Ma	65.84	measured [142]
Crown angiosperms, clock	234–263 Ma	66.41–66.52	measured [144]
Monocot–eudicot split	171–203 Ma	66.13–66.28	measured [144]
Nymphaeaceae–Cabombaceae	147–185 Ma	65.99–66.20	measured [144]
Magnoliidae crown	178.78–126.82 Ma	66.17–65.85	measured [146]
Magnoliaceae–Lauraceae	113–128 Ma	65.75–65.86	measured [147]

Sizes

Seeds of *Victoria*: *V. amazonica* 7–8 × 9–10 mm, *V. boliviana* 12–13 × 16–17 mm, *V. cruziana* 8–9 × 9–10 mm. *Victoria* grows at water depths up to 5.25 m (measured [148]). Positions: 7–10 mm, 10.87–11.19; 12–17 mm, 11.36–11.68; 5.25 m, 16.90 (computed). The seed-size analysis of 12,987 species finds the angiosperm–gymnosperm divergence as the largest single contributor to the present spread (measured [149]). *Victoria amazonica* leaves are up to 2.3 m broad; flowers up to 28 cm in diameter at second-night anthesis; ovary 8–12 cm; fruit 10–15 cm; the leaf rim is 4–7 % of leaf length in *V. amazonica*, 5–7 % in *V. boliviana*, 8–10 % in *V. cruziana* (measured [148]). Positions: 2.3 m, 16.14; 28 cm, 14.23 (computed). *Amborella trichopoda* is a "dioecious shrub, endemic to the understorey of humid tropical forests"; its drupes without fleshy parts are $5.98 \pm 0.24 \times 3.49 \pm 0.11$ mm and the seeds $4.19 \pm 0.99 \times 1.57 \pm 0.37$ mm (measured [150]). Position of 4.19 mm: 10.40 (computed). No verified *Amborella* height was read. *Liriodendron tulipifera* reaches about 61 m and 2.4–3.7 m d.b.h. in old growth on the best sites; more often 30.5–45.7 m at maturity with trunks 0.6–1.5 m (measured [151]). Positions: 61 m, 19.13; 30.5–45.7 m, 18.50–18.87 (computed).

What	Size	Position	Mark
<i>V. amazonica</i> seed	7–8 × 9–10 mm	10.87–11.19	measured [148]
<i>V. boliviana</i> seed	12–13 × 16–17 mm	11.36–11.68	measured [148]
<i>Victoria</i> growth depth	≤5.25 m	16.90	measured [148]
<i>V. amazonica</i> leaf, breadth	≤2.3 m	16.14	measured [148]
<i>V. amazonica</i> flower	≤28 cm	14.23	measured [148]
<i>Amborella</i> seed	4.19 × 1.57 mm	10.40; 9.51	measured [150]
<i>Liriodendron tulipifera</i> , old growth	~61 m, 2.4–3.7 m d.b.h.	19.13; 16.18–16.58	measured [151]
<i>Liriodendron tulipifera</i> , mature	30.5–45.7 m, trunk 0.6–1.5 m	18.50–18.87; 14.92–15.76	measured [151]

Times

The progamic phase, pollination to fertilisation, spans "15 min to 13 months" across 131 angiosperm species. In *Austrobaileya scandens* it is 18 h, and germination takes 8.3 % of the progamic phase (measured [114]). Positions: 15 min, 39.34; 13 months, 48.94; 18 h, 43.24 (computed). The span is $13 \times 30.44 \times 24 \times 60 / 15 = 38,000$ -fold (computed). Pollen tubes of *Amborella*, *Nuphar* and *Austrobaileya* grow at about 80–600 $\mu\text{m/h}$ against gymnosperms at $<\sim 20 \mu\text{m/h}$ (measured [115]). Nymphaeales tubes run 2–10 times faster than those of *Amborella* and *Austrobaileya* (measured [114]). *Amborella* seeds need warm stratification of at least about 90 days; the radicle emerges about 17 days later and the cotyledons 24 days after that (measured [150]). The sum is $90 + 17 + 24 = 131$ days (computed); position 47.94 (computed). *Liriodendron tulipifera* flowers first at 15–20 years and dies naturally at about 200–250 years, some trees reaching 300 (measured [151]). Positions: 15–20 yr, 51.34–51.60; 200–250 yr, 53.69–53.90; 300 yr, 54.06 (computed).

What	Duration	Position	Mark
Progamic phase, angiosperms	15 min – 13 months	39.34–48.94	measured [114]
Progamic phase, <i>Austrobaileya</i>	18 h	43.24	measured [114]
Stratification to cotyledons, <i>Amborella</i>	$\geq 90 + 17 + 24 \text{ d} = 131 \text{ d}$	47.94	measured [150]; computed
First flowers, <i>L. tulipifera</i>	15–20 yr	51.34–51.60	measured [151]
Natural death, <i>L. tulipifera</i>	200–250 (300) yr	53.69–53.90 (54.06)	measured [151]

Build

The ancestral angiosperm flower, reconstructed from 792 species in 63 orders, is bisexual and radially symmetric. It has "more than two whorls of three separate perianth organs each (undifferentiated tepals)", more than 10 tepals. It has "more than two whorls of three separate stamens each", more than 10 stamens. It has "more than five spirally arranged separate carpels".

Perianth and androecium are whorled, the gynoecium spiral; the exact numbers are uncertain (measured [141]). An independent reconstruction gives more than 2 whorls or series of tepals and stamens, free ascidiate carpels closed by secretion, and at least 1 pendent ventral ovule. Bisexual against unisexual and whorled against spiral are left equivocal (measured [152]). *Archaeofructus* has no petals or sepals; stamens stand in pairs below conduplicate carpels (measured [142]).

Female gametophyte: *Amborella* 8-celled, 9-nucleate, with 3 synergids plus egg (measured [153]); a "four-celled egg apparatus" (measured [154]). Nymphaeales, including Hydatellaceae, and Austrobaileyales are 4-celled and 4-nucleate; the Polygonum type is 7-celled, 8-nucleate; the 4-celled state is inferred ancestral (measured [153]). *Nuphar polysepalum* has "diploid biparental endosperm" from a "four-celled/four-nucleate" female gametophyte (measured [155]). Double fertilisation is universal in angiosperms and occurs also in *Ephedra* (measured [137]). *Amborella* xylem has no vessels — see below for the status of that statement. *Nymphaea colorata* has $2n = 28$ (measured [144]); *Liriodendron* has 19 chromosomes (measured [147]).

Light

C3 throughout; no CAM or C4 was read for this group. Early angiosperm evolution "may have required a phase of mechanical and hydraulic instability" (measured [120]).

Count

Flowering plants: 295,383 species, of which monocots 74,273 and eudicots 210,008; vascular plants 308,312; all plants about 374,000 (measured [16]). The remainder outside monocots and eudicots is $295,383 - 74,273 - 210,008 = 11,102$ (computed). Magnoliidae: about 10,000 species in 20 families (measured [146]).

Reference genomes: *Nymphaea colorata*, 409 Mb, 31,580 protein-coding genes, 14 pseudochromosomes, $2n = 28$ (measured [144]). *Liriodendron chinense*, 1.74 Gb assembly (1.75 Gb k-mer, about 1.8 Gb flow cytometry), 35,269 gene models, 19 pseudomolecules (measured [147]).

Genome	Size	Gene s	Mark
<i>N. colorata</i>	409 Mb	31,580	measured [144]
<i>L. chinense</i>	1.74 Gb	35,269	measured [147]

Not verified

- *Montsechia* numeric age ~125–130 Ma — not in the abstract of Gómez et al. 2015.
- Earliest angiosperm pollen, Valanginian–Hauterivian ~135 Ma — Friis, Crane & Pedersen 2011.
- *Amborella* shrub to 8 m; 1 species — Wikipedia, citing Große-Veldmann et al. 2011; candidate Thien et al. 2003, Ann. Missouri Bot. Gard. 90:466–490.
- *Victoria boliviana* leaves to 3.2 m — Wikipedia citing Smith et al. 2022; the *V. boliviana* description in the PDF was not reached.
- Seed-mass range $\sim 10^{-6}$ g to $\sim 10^4$ g — Moles et al. 2005 main text.
- *Lodoicea* seed 10–25 kg, fruit 25–45 kg (a palm, see 2.13) — Wikipedia, citing Tomlinson 2006; Blackmore et al. 2012.

- *Persea americana* to 20 m; *Persea borbonia*; *Piper* — Silvics vol. 2 (robots), Flora of China vols 4 and 7, not reached.
- Generation times and lifespans of *Amborella*, Nymphaeales and magnoliids other than *Liriodendron* — no source.
- *Amborella* flower counts (7–8 tepals, 1–3 staminodes, 4–8 carpels; 6–15 tepals, 10–21 stamens) — Wikipedia, near Endress & Igersheim 2000; Posluszny & Tomlinson 2003.
- *Amborella* triploid endosperm — not stated in pages read.
- Two integuments as the ancestral angiosperm state — Endress 2011 abstract only.
- *Amborella* xylem without vessels — Wikipedia, citing Carlquist & Schneider 2001; Feild et al. 2000, Int. J. Plant Sci. 161:705–712 (record verified).
- Nymphaeales without secondary growth; cotyledons 2 — standard.
- Nymphaeales ~70–90 and Austrobaileyales ~100 species — APG IV / APweb.
- *Amborella* genome: 870 Mb (project site), 706,332,640 bp and 27,313 coding genes (Ensembl AMTR1.0), paper's 748 Mb and 26,846 genes — Amborella Genome Project 2013, Science 342:1241089, record verified.

2.13 Monocots

First appearance

The oldest monocot pollen is *Mayoa portugallica* (Araceae), Barremian–Aptian, Portugal, in floras placed at "roughly 110–120 million years ago" (measured [156]; used as calibration in [157]). Monocots, magnoliids and eudicots diversified "135–130 Ma" (measured [158]).

The earliest grass fossils are silicified epidermis and phytoliths in hadrosauroid teeth, Gansu, Albion, "113–101 Ma" (measured [159]). Phytoliths in dinosaur coprolites, Lameta Formation, India, "67–65 Ma", include Oryzae-types; the "root of Poaceae" is dated 128 Ma, with estimates "from 107 Ma (new fossils excluded) to 129 Ma" (measured [160]). The oldest unequivocal palm fossils are "early to mid Late Cretaceous" (measured [161]); the palm crown is "about 100 Ma (95% HPD 108–92 Ma)" (measured [157]). The oldest orchid fossil is *Meliorchis caribea*, a pollinarium on a bee in amber, "15–20 Ma"; the orchid MRCA is "76–84 Ma" (measured [162]). Another clock gives the orchid crown at about 112 Ma (measured [163]); the two values stand side by side.

Event	Age	Position	Mark
<i>Mayoa</i> pollen floras	~110–120 Ma	65.72–65.80	measured [156]
Monocot diversification, clock	135–130 Ma	65.91–65.88	measured [158]
Earliest grass fossils	113–101 Ma	65.75–65.65	measured [159]
Lameta coprolite phytoliths	67–65 Ma	65.27–65.25	measured [160]
Root of Poaceae, clock	128 Ma (107–129)	65.86 (65.70–65.87)	measured [160]
Ehrhartoideae, with fossils	72 Ma	65.34	measured [160]
Oryzae, with / without fossils	63 / 28 Ma	65.22 / 64.48	measured [160]
Bambusoideae–PACMAD split	86 / 72 Ma	65.50 / 65.34	measured [160]

Palm crown	~100 Ma (108–92)	65.64 (65.71–65.56)	measured [157]
Oldest orchid fossil	15–20 Ma	63.91–64.17	measured [162]
Orchid MRCA	76–84 Ma	65.39–65.48	measured [162]
Orchid crown	~112 Ma	65.74	measured [163]

Sizes

The smallest seeds are orchid seeds: mass from "0.31 μ g" to 24 μ g, length "c. 0.05 to 6.0 mm", and from 20–50 to "about 4,000,000" seeds per capsule (measured [164]). *Wolffia australiana* is rootless (measured [165]). *Lodoicea maldivica* produces "the world's largest seed" (measured [166]): the fruit weighs up to 45 kg and is up to 50 cm long, the seed up to 25 kg (measured [167]). Fresh seed weight in a warden-collected sample ran 1–18 kg (measured [168], DOI not shown). The seed is up to $25 / 45 = 56$ % of the fruit mass (computed). Palms hold "record features in leaf and seed size, inflorescence size, and leaf complexity" (measured [169]). The largest clone is *Posidonia oceanica*, with genets "up to 15 km" across (measured [170]). *Phyllostachys edulis* culms are ">20-m tall"; the largest sampled stage was 11.04 m (measured [171]). Internode patterns: three species (measured [172]). The *Amorphophallus titanum* inflorescence reaches "up to about 3 m"; its spadix surface exceeds 36 °C against 27 °C ambient (measured [173]).

What	Size	Position	Mark
Orchid seed, length	0.05–6.0 mm	6.37–10.73	measured [164]
Orchid seed, mass	0.31–24 μ g	—	measured [164]
<i>Lodoicea</i> fruit, length	≤50 cm	14.76	measured [167]
<i>Lodoicea</i> fruit / seed, mass	≤45 kg / ≤25 kg; fresh 1–18 kg	—	measured [167]; [168], DOI not shown
<i>Amorphophallus</i> inflorescence	≤ ~3 m	16.39	measured [173]
Moso bamboo culm, measured	11.04 m	17.57	measured [171]
Moso bamboo culm	>20 m	>18.11	measured [171]
<i>Posidonia</i> genet	≤15 km	24.14	measured [170]

Times

The fastest doubling in a flowering plant is *Wolffia microscopica* clone 2005 at "29.3 h", "the fastest growing flowering plant known till date"; 25 clones of all 11 *Wolffia* species were measured (measured [174]). Moso bamboo shoots grow up to "114.5 cm/day", that is 4.77 cm/h (computed). Internode 18 grows at most "~11.8 cm/day" and completes its rapid growth at 29 cm in 23 days. Culms are ">20-m tall within 45–60 days". About 570 million cells are added per day in one internode; cells elongate from 13.9–33.1 μ m to 127.4 μ m at 5.6–6.8 μ m/h (measured [171]).

Bamboo flowering intervals run "some as long as 120 years". *Bambusa bambos* 32 yr (2^5); *Phyllostachys nigra* f. *henonis* 60 yr ($5 \times 3 \times 2 \times 2$); *P. bambusoides* 120 yr ($5 \times 3 \times 2 \times 2 \times 2$). *Phyllostachys* species share a base interval of 15 yr (15, 30, 60, 120). *Chusquea* species share a base

of 8 yr (16, 23 [predicted 24], 32). Measured intervals lie significantly closer to numbers factorisable into primes ≤ 5 ($P = 0.0041$) (measured [175]). *Posidonia* clones 1–15 km across at 4 cm per year are "about 10,000 to several tens of thousands of years" old, minimum about 12,500 years. Shared genets 15 km apart imply "a minimum age estimate between 80,000 and 200,000 years" at the highest growth bound of 6 cm per year (measured [170]). *Lodoicea* takes about 25 years to reproductive age and about 100 years to full size, and may live to 350 years (measured [167]).

What	Duration	Position	Mark
Doubling, <i>Wolffia microscopica</i>	29.3 h	43.68	measured [174]
Internode 18 rapid growth, Moso	23 days	46.35	measured [171]
Maximum growth rate reached, Moso	~20 days	46.23	measured [176]
Culm to full height, Moso	~40 days	46.86	measured [176]
Richards asymptote height, Moso	10.46–15.66 m	17.49–17.86	measured [176]
Culm to >20 m, Moso	45–60 days	46.96–47.23	measured [171]
Flowering interval, <i>B. bambos</i>	32 yr	52.02	measured [175]
Flowering interval, <i>P. nigra</i> f. <i>henonis</i>	60 yr	52.60	measured [175]
Flowering interval, <i>P. bambusoides</i>	120 yr	53.23	measured [175]
Reproductive age, <i>Lodoicea</i>	~25 yr	51.80	measured [167]
Fruit enlargement, <i>Lodoicea</i>	~10 months	48.70	measured [167]
Fruit ripening, <i>Lodoicea</i>	~5 (7) yr	50.34 (50.64)	measured [167]
Full size, <i>Lodoicea</i>	~100 yr	53.06	measured [167]
Lifespan, <i>Lodoicea</i>	≤ 350 yr	54.20	measured [167]
<i>Posidonia</i> clone, minimum	~12,500 yr	57.46	measured [170]
<i>Posidonia</i> shared genet, minimum	80,000–200,000 yr	59.15–59.98	measured [170]

Build

The monocot flower has a "typical trimerous-pentacyclic groundplan" (measured [177]): 5 whorls of 3, that is 3 + 3 tepals, 3 + 3 stamens and 3 carpels, 15 organs (computed). The first angiosperms had "monosulcate pollen" (measured [178]). Palms build tall trees "entirely through primary growth" (measured [169]). Anomalous secondary growth occurs through a "secondary thickening meristem (STM) or monocot cambium"; "secondary vascular systems have been recorded in 22 genera of Asparagales" (measured [179]). Double fertilisation: one sperm fertilises the egg, "the

other sperm fertilizes the central cell" (measured [180]). The endosperm is usually triploid with a 2 : 1 maternal : paternal genome ratio (measured [180]). *Zostera marina* lacks the "entire repertoire of stomatal-differentiation genes" (measured [181]). Cotyledon count and phyllotaxis: see below.

Light

C4 photosynthesis arose in 62 recognisable lineages: grasses 18, within 26 monocot lineages; sedges 6; eudicots 36 (60 %); C3–C4 intermediates in 21 lineages; geographic origins estimated for 47 (measured [182]). CAM occurs in "close to 6% of vascular plant species across at least 35 families", with emphasis on Orchidaceae (measured [183]). CAM contributes "from values of <1% to 100%" of carbon gain (measured [184]).

Count

Monocots: 74,273 accepted species; angiosperms 295,383; about 2,000 species described per year (measured [16]). Monocots are $74,273 / 295,383 = 25.1$ % of angiosperms (computed). Grasses: 11,506 species (measured [185]). Orchids: "over 25,000 species" (measured [163]) in 736 genera (measured [186]). Palms: "roughly 2,400 species" (measured [157]). *Wolffia*: 11 species (measured [174]). *Ceroxylon*: 12 species (measured [187]).

Reference genomes are in the table. Wheat is allohexaploid (measured [188]). In *Wolffia australiana* 13 % of genes show time-of-day expression against about 40 % in model plants (measured [165]). *Paris japonica* holds the largest eukaryotic genome known, 1C = 152.23 pg; angiosperm genome sizes span about 2,400-fold (measured [189]). At 0.978 Gb per pg this is 148.9 Gb (computed).

Genome	Size	Genes	Mark
<i>O. sativa</i> ssp. <i>japonica</i> Nipponbare	389 Mb estimated; 370 Mb finished (~95 %)	37,544 non-TE protein-coding	measured [190]
<i>T. aestivum</i> Chinese Spring, RefSeq v1.0	~16 Gb estimated; 14.5 Gb assembly	107,891 high-confidence	measured [188]
<i>W. australiana</i>	357 Mb	~15,000	measured [165]
<i>Z. marina</i>	202.3 Mb	20,450	measured [181]
<i>P. japonica</i>	152.23 pg = 148.9 Gb	—	measured [189]; computed

Not verified

- Monocot crown node value and monocot stem ~136 Ma — Magallón et al. 2015, Table; Wikipedia "Monocotyledon".
- *Wolffia* smallest flowering plants, frond 0.3–1 mm — Landolt 1986, Biosystematic investigations in the family of duckweeds, vol. 2.
- *Ceroxylon quindiuense* 45 m, rarely 60 m — Wikipedia, citing Sanín & Galeano 2011, Phytotaxa 34(1):1–64 (abstract gives no height; PDF subscription-only).
- *Lodoicea* leaves 7–10 m × 4.5 m, crown 10 m, fruit 40–50 cm diameter; leaf life 24 yr — Wikipedia, citing Tomlinson 2006; Corner 1966; Uhl & Dransfield 1987; Savage & Ashton 1983. Fleischer-Dogley 2011 and Edwards 2015 figures — Wiley blocked. Morgan et al. 2017 volume, pages and DOI — not shown on the repository page.
- Largest leaf *Raphia regalis* ~25 m — Hallé 1977.
- Seed-mass range ten orders of magnitude — Moles et al. 2005 main text.
- *Pandanus* <1 m to 20 m; leaves in 3 ranks — Wikipedia; Stone 1982.

- Janzen 1976 bamboo intervals — Annu. Rev. Ecol. Syst. 7:347–391, not opened.
- Cotyledons 1; monosulcate pollen as plesiomorphy; parallel venation; scattered bundles; adventitious roots — Wikipedia "Monocotyledon", citing Chase 2004, Am. J. Bot. 91:1645–1655; Soltis et al. 2005; Stevens APweb.
- Palms explicitly unbranched; palm spiral phyllotaxis — Tomlinson 1990, The Structural Biology of Palms.
- Grass leaves distichous, 2 lodicules — Wikipedia "Poaceae", citing Cope & Gray 2009; 3 stamens, 2 stigmas — GPWG 2001.
- Orchid CAM counts; "6–7 % of vascular plants" — Silvera 2010 body; not in Winter 2019 abstract.
- Grasses ~12,000 / 780 genera; orchids ~28,000 (27,801); palms ~2,600 (Baker & Dransfield 2016) — not read in the primaries.
- *Zea mays* B73 2.3 Gb, 32,540 genes, ~85 % TE — Schnable et al. 2009, Science 326:1112–1115, record verified.
- Christenhusz & Byng 2016 page range — biotaxa blocked in E4; verified in E2/E3.

2.14 Eudicots

First appearance

"The earliest eudicot fossil records, based on pollen, are 127 to 125 million years old" (measured [191]); position 65.86–65.84 (computed). The oldest eudicot macrofossil is *Leefructus mirus*, Yixian Formation, north-east China, dated "122.6–125.8 Ma" (editorial summary 124.4–122.9 Ma). Its leaves are whorled, the reproductive axis carries five carpels, and the affinity is Ranunculaceae (measured [191]). The eudicot crown lies at "135–130 Ma" together with monocots and magnoliids (measured [158]).

The γ whole-genome triplication is restricted to core eudicots, after Ranunculales diverged (measured [192]). The duplications concentrate "around 117 million years ago"; about 75 % of angiosperm species descend from lineages diversifying at or shortly after γ (measured [192]). The Asteraceae crown is "about 83 million years ago", late Cretaceous, with Eocene explosive radiations (measured [193]). An *Arabidopsis* tetraploid-forming duplication lies "roughly 112 million years ago" (measured [194]).

Event	Age	Position	Mark
Oldest tricolpate pollen	127–125 Ma	65.86–65.84	measured [191]
<i>Leefructus mirus</i>	122.6–125.8 Ma	65.82–65.85	measured [191]
Eudicot crown, clock	135–130 Ma	65.91–65.88	measured [158]
γ triplication	~117 Ma	65.78	measured [192]
<i>Arabidopsis</i> paleopolyploidy	~112 Ma	65.74	measured [194]
Asteraceae crown	~83 Ma	65.47	measured [193]
Sunflower WGD-2	~29 Ma	64.51	measured [195]

Sizes

"Tree species exceeding 70 m in height are rare globally"; the tallest angiosperms are eucalypts of south-east Australia (measured [196]). *Eucalyptus regnans* has been measured "up to 100 m tall" (measured [197], title only). *Quercus robur* and *Fagus sylvatica* heights stand in the table (measured [198], [199], [200], [201]). Rafflesiaceae "produce the largest flowers of any angiosperm" (measured [202]). *Rafflesia arnoldii* flowers are "nearly a meter in diameter"; Rafflesiaceae floral diameters run about 11–100 cm (measured [203]). *Rafflesia lagascae* flowers are 15–20 cm (measured [204]). The *Amorphophallus titanum* bloom is "up to 3 m high" (measured [173]; see 2.13). The largest baobab, Platland, holds 501 m³ of wood, girth 34.11 m, height 18.9 m (measured [205]). The oak reference tree was about 100 years old (measured [206]).

What	Size	Position	Mark
Rare tree height	>70 m	>19.25	measured [196]
<i>E. regnans</i>	up to 100 m	19.58	measured [197], [206]
<i>Q. robur</i> height	30–40 m, max >40 m	18.48–18.74	measured [198]
<i>Q. robur</i> diameter	≤1 m typical, 3–4 m max	15.39; 16.39–16.65	measured [198]
<i>F. sylvatica</i> height	≤50 m; 20–30 m mature	18.95; 18.11–18.48	measured [200], [201]
<i>R. arnoldii</i> flower	nearly 1 m	15.39	measured [203]
Rafflesiaceae flowers	11–100 cm; <i>R. keithii</i> ≥80 cm, <i>R. pricei</i> ≥25 cm	13.38–15.39	measured [203]
<i>Q. robur</i> height at reference tree	34 m	18.60	measured [199]
<i>R. lagascae</i> flower	15–20 cm	13.66–13.92	measured [204]
Baobab Platland, height; girth	18.9 m; 34.11 m	18.06; 18.60	measured [205]

Times

The Venus flytrap closes its "leaf in about 100 ms" by a snap-buckling instability (measured [207]). The *Utricularia* suction trap moves its door in "less than a millisecond", "among the fastest plant movements known"; traps fire spontaneously every 5–20 h (measured [208]). *Quercus robur* has a "lifespan of several hundred years". Of 46 somatic mutations in its branches, 9 of 19 tested were recovered in 116 acorns (measured [206]). Among the African baobabs, "9 of the 13 oldest and 5 of the 6 largest individuals have died" over the past 12 years, by radiocarbon dating of stable architectures (measured [205]). The oldest, Panke in Zimbabwe, is calibrated at 2450 (+45/–40) cal yr as of 2011, calculated tree age +2500 yr (measured [205]). The other dated trees stand in the table. *Quercus robur* lives "over 1000 years in some cases" (measured [198]); its minimum seed-bearing age is 20 years, with seed crops every 2–4 years (measured [199]). *Fagus sylvatica* reproduces "very late (40–50 years old)" and lives typically 150–300 years (measured [200]); seed-bearing ages stand in the table (measured [201]). *Eucalyptus regnans* "grows fast, dies relatively young"; the oldest climbed tree had 651 years of heartwood production (measured [209]). *Arabidopsis thaliana* plants on soil are grown "for a period of ~2 months" through the full cycle (measured [210]); position 47.24 (computed). The Jurupa Oak, *Quercus palmeri*, is a single clone ">13,000 years old", a Pleistocene relict that resprouts after fire (measured [211]). *Lomatia tasmanica* is a clone at least 43,600 years old (measured [212]). The *Arabidopsis thaliana* generation time is "short" (measured [194], no number).

What	Duration	Position	Mark
<i>Utricularia</i> door	<1 ms	<26.87	measured [208]
Flytrap closure	~100 ms	31.06	measured [207]
<i>Utricularia</i> spontaneous firing	every 5–20 h	42.07–43.33	measured [208]
Oak reference tree	~100 yr	53.06	measured [206]
<i>Arabidopsis</i> life cycle on soil	~2 months	47.24	measured [210]
First seed, <i>Q. robur</i>	20 yr; crops every 2–4 yr	51.60; 49.50–50.12	measured [100]
Lifespan, <i>Q. robur</i>	>1,000 yr in some cases	>55.16	measured [100]
First seed, <i>F. sylvatica</i>	40–50 yr open; 60–80 yr in stands	52.23–52.43; 52.60–52.86	measured [200], [201]
Lifespan, <i>F. sylvatica</i>	150–300 yr	53.43–54.06	measured [200]
Heartwood years, oldest <i>E. regnans</i> climbed	651 yr	54.77	measured [209]
Baobab Panke, calibrated	2,450 (+45/–40) cal yr; calc. [2050]	55.97; 55.99	measured [205]
Baobab Dorslandboom; Grootboom	~2,100; +2,000 yr	55.83; 55.79	measured [205]
Baobab Holboom; Grootboom	~1,800; 1,500 (Table 1) or 1,600 (suppl.) yr	55.69; 55.53–55.59	measured [205]
Baobab Chapman; Platland	~1,400; ~1,100 yr	55.46; 55.24	measured [205]
Oak lifespan	several hundred years	≥53.06	measured [206]
Jurupa Oak clone	>13,000 yr	57.49	measured [211]
<i>Lomatia tasmanica</i> clone	≥43,600 yr	58.59	measured [212]

Build

Leea fructus has five carpels and whorled leaves (measured [191]). "Pentamerous flowers in eudicots" are named as a possible key innovation (measured [213]). Pollen of the first angiosperms was monosulcate (measured [178]); the tricolpate state as the eudicot marker was read at second hand (see below). Phyllotaxis: in 657 sunflower heads, 768 reliable parastichy counts were obtained, 565 of them Fibonacci numbers, $565 / 768 = 73.6\%$ (computed), plus 67 further Fibonacci-type structures, 82.3 % (measured [214]). Parastichy numbers one less than a Fibonacci number are significantly more frequent than one more (measured [214]). The eudicot vascular cambium differs from the monocot cambium, which is "not continuous ... storied ... distinct from the dicot and gymnosperm vascular cambium" (measured [179]). Double fertilisation and triploid endosperm are as in 2.13 (measured [180]). Carnivory: *Dionaea* snap trap of 2 lobes (measured [207]); *Utricularia* suction bladder with trapdoor buckling and inversion (measured [208]). Parasitism evolved independently 12 times: 292 genera, about 4,750 species; Santalales 2,428 species; Orobanchaceae more than 2,100 (measured [215]). Rafflesiaceae are endoparasitic, without leaves, stems or roots (measured [202]).

Light

C4: 36 of 62 C4 lineages are eudicots, 60 % (measured [182]); check $36 / 62 = 58.1\%$ (computed; the paper states 60 %). CAM: about 6 % of vascular plants in at least 35 families, including Cactaceae, Crassulaceae, Aizoaceae and Euphorbiaceae (measured [183]); 50 Aizoaceae species

screened for facultative CAM (measured [184]). The reference species are C3 by standard; the genome papers read do not state it.

Count

Eudicots: 210,008 species (measured [16]), $210,008 / 295,383 = 71.1\%$ of angiosperms (computed). Asteraceae: "10% of all flowering plant species" (measured [193]). Parasitic angiosperms: about 4,750 species in 292 genera (measured [215]).

Reference genomes are in the table. *Arabidopsis*: 5 chromosomes; Araport11 added 635 protein-coding genes (measured [216]); 24 duplicated segments ≥ 100 kb cover 65.6 Mb (58 %); 1,528 tandem arrays hold 4,140 genes (17 %) (measured [194]). Sunflower: transposable elements 74.7 % (measured [195]). Oak: 716.6 Mb anchored (96 %); 46 somatic mutations (measured [206]). *Eucalyptus*: 605 Mb in 11 pseudomolecules; 34 % of genes in tandem duplications (measured [217]).

Genome	Size	Genes	Mark
<i>A. thaliana</i>	~125 Mb; 115,409,949 bp sequenced	25,498 predicted	measured [194]
<i>H. annuus</i>	~3.6 Gb; 3 Gb assembly (~80 %)	52,232 protein-coding	measured [195]
<i>Q. robur</i>	~740 Mb flow cytometry; 736 Mb k-mer	25,808 protein-coding	measured [206]
<i>E. grandis</i>	640 Mb; >94 % assembled	36,376 protein-coding	measured [217]

Not verified

- Original tricolpate pollen reports (Barremian–Aptian) — Doyle & Hickey 1976; Hughes & McDougall 1990. Tricolpate pollen as eudicot synapomorphy; cotyledons 2 — Wikipedia, citing Judd & Olmstead 2004, *Am. J. Bot.* 91:1627–1644.
- Eudicot crown ~134 Ma — Wikipedia, attributing Magallón 2015.
- *Eucalyptus regnans* "Centurion" 99.6–100.5 m; lifespan ~400–500 yr — Wikipedia, citing gianttrees.com.au, ABC News 2018, The Guardian 2025; Sillett et al. 2015 body not read.
- *Rafflesia arnoldii* largest 1.14 m, 11 kg; bud ~1 yr, flower a few days — Wikipedia, citing Kew 2011; Guinness World Records 2002; Hidayati & Walck 2016. Barkman et al. 2008, *Curr. Biol.* 18:1508 — not opened.
- *Adansonia digitata* trunks 10–14 m, height 5–25 m, Holboom girth 35.10 m — Wikipedia, citing Patrut et al. 2010, 2015, 2018.
- *Arabidopsis* plant size; generation time "about six weeks" — Meinke et al. 1998, *Science* 282:662–682; stage-specific days of Boyes et al. 2001 Table 1 — paywalled.
- Jurupa Oak extent 25 m × 8 m, ~70 stem clusters — Wikipedia, citing May et al. 2009.
- Eudicot flowers tetracyclic; tetramery and pentamery against trimery — Endress 2010 body; Ronse De Craene 2010, 2016, *Flora* 221:22–37 (record verified).
- Leaf phyllotaxis 2/5, 3/8 and decussate — Jean 1994, *Phyllotaxis*, CUP.
- Mangroves ~70–80 species, vivipary, pneumatophores — Tomlinson 2016; Spalding et al. 2010.
- Asteraceae absolute count (~32,000; 24,000–30,000) — Christenhusz & Byng 2016 table; Funk et al. 2009.
- Araport11 total 27,655 protein-coding genes — not in the abstract; ~27,600 via Wikipedia citing Ensembl.

- *Genlisea tuberosa* ~61 Mb as the smallest angiosperm genome — Fleischmann et al. 2014, Annals of Botany 114:1651–1663, record verified.
- *Utricularia gibba* 82 Mb — Ibarra-Laclette et al. 2013, Nature; not opened. *Dionaea* genome — not opened.

2.15 Clones and Records

This entry collects the measured extremes: the largest and oldest clones, the oldest single stems, and the size span of photosynthetic life. Each number here also stands in the entry of its group.

First appearance

A clone has no fossil first appearance. Its age is bounded by growth rate and extent, or by radiocarbon on its own tissue. The oldest bound read is for *Posidonia oceanica*: shared genets at two localities 15 km apart give "a minimum age estimate between 80,000 and 200,000 years" (measured [170]); position 59.15–59.98 (computed). Pando (*Populus tremuloides*) is "not older than 14,000 years", post-glacial, and "likely thousands of years old" (measured [218]); position of 14,000 yr: 57.56 (computed). *Lomatia tasmanica*: fossil leaves of the species are dated $\geq 43,600$ yr (Jordan et al. 1991, read in [212]), so the clone may be at least that old (measured [212]); position 58.59 (computed). Jurupa Oak: ">13,000 years old" (measured [211]); position 57.49 (computed).

Sizes

Pando: one genet matches the morphological boundary, about 43.6 ha, 209 stems sampled on a 50-m grid with 7 microsatellite loci; about 40 further genotypes stand adjacent (measured [219]). Pando covers 43 ha with an estimated 47,000 genetically identical ramets and is "putatively the largest known organism on earth in terms of dry-weight mass" (measured [218], no mass given). A square of 43.6 ha has a side of $\sqrt{436,000} = 660$ m (computed); position 21.30 (computed). *Posidonia*: genets "up to 15 km", from 1,544 sampling units at 40 locations; very large clones at 3.5–8.9 % prevalence (measured [170]); position 24.14 (computed). *Lomatia tasmanica*: a single population over about 1.2 km with several hundred stems; no diversity at 16 isozyme loci in 78 plants; triploid (measured [212]); position of 1.2 km: 21.84 (computed). Maximum clone age and size estimates are "typically limited by the scale of sampling" (measured [170]).

The size span of photosynthetic life:

Organism	Size	Position	Source	Status
<i>Prochlorococcus</i> , smallest photosynthetic organism	0.5–0.7 μm	2.18–2.49	[4]	measured
<i>Ostreococcus tauri</i> , smallest free-living eukaryote	title and abstracts only; no diameter read	—	[220], [221],	measured (qualitative)
Orchid seed, smallest seed	0.05 mm; 0.31 μg	6.37	[164]	measured
<i>Lodoicea</i> seed, largest seed	≤ 25 kg; fruit ≤ 45 kg, 50	14.76 (fruit 1, 1.1)	[166], [167]	measured
<i>Rafflesia arnoldii</i> , largest	nearly 1 m	15.39	[202], [203]	measured
<i>Macrocystis pyrifera</i> , longest	>60 m	>19.11	[44]	measured
<i>Sequoia sempervirens</i> , tallest	112.7 m; limit 122–130	19.69; 19.76–19.82	[126]	measured
<i>Sequoia sempervirens</i> , Silvics 1964	112.1 m	19.68	[127]	measured

<i>Eucalyptus regnans</i> , tallest	up to 100 m	19.58	[197]	measured,
Pando, largest clone by area	43–43.6 ha, ~47,000 ramets	21.30 (side of equal square)	[219], [218]	measured; computed
<i>Posidonia oceanica</i> , largest	15 km	24.14	[170]	measured

Span: $0.5\ \mu\text{m}$ to 15 km is $15,000 / (0.5 \times 10^{-6}) = 3 \times 10^{10}$ -fold in linear extent, or $24.14 - 2.18 = 21.96$ positions (computed). For a single non-clonal body, $0.5\ \mu\text{m}$ to 112.7 m is 2.3×10^8 -fold, or $19.69 - 2.18 = 17.51$ positions (computed).

Times

The oldest single stem with a crossdated ring count read at its primary is the "4,900-year-old bristlecone pine on Nevada's Wheeler Peak" (measured [133]); position 56.60 (computed). *Posidonia* clones 1–15 km across, at 4 cm per year, are "about 10,000 to several tens of thousands of years" old, minimum about 12,500 years (measured [170]); position 57.46 (computed). Pando: 65 plots, a 72-year aerial-photo series, standing dead basal area 24–37 %, self-replacement declining since 30–40 years ago under mule deer herbivory (measured [218]). The fastest doubling of a flowering plant is 29.3 h in *Wolffia microscopica* (measured [174]); position 43.68. *Prochlorococcus* divides about once a day (measured [4]); position 43.50. *Macrocystis* mass increases 3.5 % per day (measured [45]).

What	Duration	Position	Mark
<i>Prochlorococcus</i> generation	~1 day	43.50	measured [4]
<i>Wolffia</i> doubling	29.3 h	43.68	measured [174]
Bristlecone pine, ring count	4,900 yr	56.60	measured [133]
Baobab Panke, radiocarbon	2,450 (+45/–40) cal yr	55.97	measured [205]
<i>Sequoia</i> , ring count	~2,200 yr	55.88	measured [127]
Jurupa Oak clone	>13,000 yr	57.49	measured [211]
Pando, upper bound	≤14,000 yr	57.56	measured [218]
<i>Lomatia</i> clone	≥43,600 yr	58.59	measured [212]
<i>Posidonia</i> shared genet	80,000–200,000 yr	59.15–59.98	measured [170]

The span of times, from the 1 ms *Utricularia* door (measured [208]) to the 200,000-year *Posidonia* bound, is $59.98 - 26.87 = 33.11$ positions (computed).

Build

Clones persist by ramets from roots or rhizomes. Pando spreads by aspen root suckers (measured [219], [218]). Seagrass rhizomes extend at 4–6 cm per year (measured [170]). *Quercus palmeri* resprouts after fire (measured [211]). *Lomatia* spreads vegetatively as a sterile triploid (measured

[212]). *Ostreococcus tauri* carries one copy of each organelle (measured [222]). Clone extent and clone age are read together through the measured growth rate.

Light

All entries in this list are oxygenic phototrophs. *Prochlorococcus* uses divinyl chlorophylls a_2 and b_2 (measured [4], [6]); see 2.1. The seagrass *Zostera marina* has lost its stomatal-differentiation genes (measured [181]).

Count

Genomes across the span: *Prochlorococcus* MED4, 1,657,990 bp, 1,716 genes (measured [5]); *Ostreococcus tauri*, 12.56 Mb nuclear genome on 20 chromosomes (measured [221]); *Wolffia australiana*, 357 Mb, about 15,000 genes (measured [165]); *Paris japonica*, 152.23 pg = 148.9 Gb (measured [189]; computed). The ratio of the largest to the smallest genome in this list is $148.9 \times 10^9 / 1,657,990 = 89,800$ (computed). The eukaryote genome-size span as a whole is about 66,000-fold (measured [189]).

Genome	Size	Genes	Mark
<i>P. marinus</i> MED4	1,657,990 bp	1,716	measured [5]
<i>O. tauri</i>	12.56 Mb	—	measured [221]
<i>W. australiana</i>	357 Mb	~15,000	measured [165]
<i>P. japonica</i>	148.9 Gb	—	measured [189]; computed

Not verified

- DeWoody et al. 2008 DOI 10.3398/1527-0904-68.4.493 — not resolved this session.
- Pando mass ~6,000 t and age 80,000 yr — Grant, Mitton & Linhart 1992, Nature 360:216; popular sources.
- Old Tjikko (*Picea abies*) root wood 375, 5,660, 9,000 and 9,550 yr; ~20 spruces >8,000 yr — Wikipedia, citing Umeå University 2008; Öberg & Kullman 2011, Arctic Antarct. Alp. Res. 43:589–595, not reached; Mackenthun 2016 reports no evidence of clonal continuity (via Gymnosperm Database).
- Huon pine stand >10,500 yr, stems 2,000–3,000 yr, rings to 2,500 yr — Wikipedia "Lagarostrobos", citing Parks & Wildlife Tasmania 2003; DPIPWE 2011; Balmer 1999.
- Prometheus 4,844 rings; Methuselah ~4,850 — RMTRR OLDLIST.
- Llangernyw Yew 4,000–5,000 yr or ~1,500 yr, girth 10.75 m; no ring or radiocarbon measurement — Wikipedia, citing Harte 1996; Kinmonth 2006; Bevan-Jones 2004.
- Baobab ages beyond those in Patrut et al. 2018 — Wikipedia, citing Patrut et al. 2010, 2015.
- *Ostreococcus tauri* ~0.8 μm ($\approx 1 \times 0.7 \mu\text{m}$) — Wikipedia, citing Courties et al. 1994.
- *Wolffia* frond 0.3–1 mm — Landolt 1986.
- *Rafflesia* 1.14 m, 11 kg; *Eucalyptus regnans* Centurion 99.6–100.5 m — Wikipedia (see 2.14).
- *Genlisea* minimum angiosperm genome — Fleischmann et al. 2014, record verified.

Part 3 — Cross-group tables

Every number in this Part is taken from Part 2 and carries the reference number given there.

Positions are log base 3 of the value over the unit of length (4.558816×10^{-8} m) or of time (1.520655×10^{-16} s). One year is 3.15576×10^7 s; one month is one twelfth of a year. Positions copied from Part 2 stand without a mark. Positions computed here for values that had none in Part 2 are marked (computed). A dash means Part 2 holds no verified value. Ranges are given as in Part 2; a value in parentheses is the extreme given there in parentheses. The group numbers 2.1–2.15 are those of Part 2.

Table A. First appearance

Group	Oldest fossil evidence (what, age)	Clock crown age	Position of	Position of clock	Refs
2.1 Cyanobacteria	Strelley Pool stromatolites, 3,430 Ma; oldest body fossil <i>Eoentophysalis</i> , 2,018–1,854 Ma; oldest thylakoids	Archean (qualitative)	68.86; 68.37–68.30; 68.26–	—	[1], [2], [3]
2.2 Red Algae	<i>Bangiomorpha pubescens</i> , 1,047 Ma (Re–Os); Tirohan Dolomite "probable crown-	Crown red algae 1,984–1,732 Ma; root of Plantae 1,694 Ma	67.78; 68.16	68.36–68.23; 68.21	[17], [18], [19],
2.3 Green Algae	<i>Proterocladus antiquus</i> , ~1,000 Ma	Core Chlorophyta 1,000–700 Ma; volvocine ancestor	67.73	67.73–67.41;	[25], [26],
2.4 Charophy	<i>Palaeonitella cranii</i> , Rhynie chert, 411.5 ± 1.3 Ma	—	66.93	—	[36], [37]
2.5 Brown Algae and	Brown algae: <i>Padina</i> , ≥ 100 Ma. Diatoms: Lower Cretaceous assemblages (no	Brown algae 449.41 Ma (333.85–572.02); diatoms ~200 Ma, crown 190, stem	65.64; 65.46	67.01 (66.73–67.23);	[44], [46], [47]
2.6 Bryophytes	Cryptospores, 473–471 Ma	Crown embryophytes 515.1–470.0 Ma; crown liverworts 443.6–405.3; crown mosses 448.6–	67.05	67.13–67.05; 66.99–66.91;	[55], [39], [56]
2.7 Lycophytes	<i>Asteroxylon mackiei</i> , Rhynie chert, 407 Ma; <i>Baragwanathia</i> , Gorstian (no numeric age); crown-	Crown lycophytes 432.5–392.8 Ma; 431–411 Ma	66.92; 66.95	66.97–66.88; 66.97–66.92	[72], [73], [39], [56]
2.8 Ferns and Horsetails	Horsetail lineage, Upper Devonian (no numeric age); <i>Azolla</i> , Maastrichtian–	Crown monilophytes 411.5–384.9 Ma; monilophyte–seed plant	— (50 Ma: 65.01)	66.93–66.86; 66.90	[85], [87], [39],
2.9 Progymnosperms and Seed	Cairo <i>Archaeopteris</i> forest, ca. 385 Ma; Gilboa <i>Wattieza</i> stumps, ~385 Ma; <i>Runcaria</i> seed precursor, 385 Ma	— (extinct)	66.86	—	[97], [99], [100]
2.10 Cycads	<i>Crossozamia</i> , 265.1–272.3 Ma; <i>Ginkgo</i> , Early Jurassic,	Cycad crown 158.1 Ma	66.52–66.55;	66.05	[103], [106],
2.11 Conifers and	Conifer fossil record > 300 Ma; Gnetales crown calibration ≥ 125 Ma	Pinaceae MRCA 198.4 Ma; <i>Welwitschia</i> – <i>Gnetum</i> > 110 Ma	66.64; 65.84	66.26; 65.72	[123], [101], [125]

2.12 Basal Angiospe	Oldest confirmed flowers $\leq$ ~130 Ma; <i>Archaeofructus</i> $\geq$ 124.6 Ma	Crown angiosperms 234–263 Ma; calibration 136–139.35 Ma; Magnoliidae	65.88; 65.84	66.41–66.52; 65.92–	[141], [142], [144],
2.13 Monocots	<i>Mayoa portugallica</i> pollen, ~110–120 Ma; earliest grass fossils 113–101 Ma; oldest orchid fossil 15–20 Ma	Monocot diversification 135–130 Ma; root of Poaceae 128 Ma; palm crown ~100 Ma; orchid MRCA 76–84 Ma or crown	65.72–65.80; 65.75–65.65; 63.91–	65.91–65.88; 65.86; 65.64; 65.39–	[156], [159], [162], [158], [160],
2.14 Eudicots	Tricolpate pollen, 127–125 Ma; <i>Leefructus mirus</i> , 122.6–125.8 Ma	Eudicot crown 135–130 Ma; Asteraceae crown ~83 Ma	65.86–65.84; 65.82–	65.91–65.88; 65.47	[191], [158], [193]
2.15 Clones	— (no fossil first appearance)	—	—	—	—

Table B. Sizes

Group	Smallest verified (name, size)	Positio	Largest verified (name, size)	Positi	Refs
2.1 Green	<i>Prochlorococcus</i> cell, 0.5–0.7 μ m	2.18–2.49	— (no verified largest)	—	[4]
2.2 Red	<i>Cyanidioschyzon merolae</i>	3.44	—	—	[22]
2.3 Green	<i>Chlamydomonas reinhardtii</i>	4.91	<i>Caulerpa taxifolia</i> stolon, >15 m	>15.30	[29], [20]
2.4 Green	<i>Chara</i> internodal cell	9.10	<i>Chara</i> internodal cell length, 0.5–	14.76	[41]
2.5 Brown Algae and	<i>Thalassiosira pseudonana</i> valve, 3.7 μ m	4.00	<i>Macrocystis pyrifera</i> , >60 m	>19.11	[50], [44]
2.6 Bryophytes	<i>Dawsonia longiseta</i> , 0.5–3.0 cm (smallest value read; no	10.56–12.19	<i>Dawsonia superba</i> var. <i>superba</i> stem, 65 cm	14.99	[62]
2.7 Lycophytes	<i>Lycopodium clavatum</i> leaf width, 0.4–0.8 mm	8.26–8.90	Arborescent lycopsid height, $\leq$ c. 45 m	18.85	[78], [76]
2.8 Ferns and Horsetails	<i>Equisetum</i> spore, ~50 μ m	6.37	Tree ferns, measured individuals, $\leq$ 6 m	17.02	[88], [89]
2.9 Progymnosperms and Seed	<i>Eospermatopteris</i> roots, 0.7–1 cm diameter	10.87–11.19	<i>Archaeopteris</i> height estimate, 11–32 m (root system radius $\leq$ 11 m measured)	17.57–18.54	[97]
2.10 Cycads and Ginkgo	<i>Ginkgo biloba</i> seed, 20–30 $\times$ 16–24 mm	11.83–12.19	<i>Ginkgo biloba</i> , reported maximum, 64 m	19.17	[112]
2.11 Conifers and	— (no verified smallest)	—	<i>Sequoia sempervirens</i> , 112.7 m	19.69	[126]
2.12 Basal Angiosperms and	<i>Amborella trichopoda</i> seed, 4.19 $\times$ 1.57 mm	10.40; 9.51	<i>Liriodendron tulipifera</i> , ~61 m	19.13	[150], [151]
2.13 Monocots	Orchid seed, 0.05 mm	6.37	<i>Posidonia oceanica</i> genet, $\leq$ 15 km (clone); Moso bamboo culm, >20 m (single	24.14; >18.11	[164], [170], [171]
2.14 Eudicots	<i>Rafflesia lagascae</i> flower, 15–20 cm (smallest value	13.66–13.92	<i>Eucalyptus regnans</i> , up to 100 m	19.58	[204], [197]
2.15 Clones and Records	<i>Prochlorococcus</i> , 0.5–0.7 μ m	2.18–2.49	<i>Posidonia oceanica</i> , 15 km	24.14	[4], [170]

Table B2. The size span of photosynthetic life

All verified size values of Part 2, sorted by position from smallest to largest. A range stands in one row and is sorted by its lower bound. Cells, organelles, organisms, leaves, seeds, flowers, trunks and clones stand together.

N o.	What	Size	Position	Group	Ref
1	<i>Prochlorococcus</i> cell, lower	0.5 μ m	2.18	2.1 Cyanobacteria	[4]
2	<i>Prochlorococcus</i> cell, upper	0.7 μ m	2.49	2.1 Cyanobacteria	[4]
3	<i>Chlamydomonas</i> pyrenoid	1.5–2 μ m	3.18–3.44	2.3 Green Algae	[14]
4	<i>Cyanidioschyzon merolae</i>	2 μ m	3.44	2.2 Red Algae	[22]
5	<i>T. pseudonana</i> valve, SEM	3.66–4.97	3.99–4.27	2.5 Brown Algae and	[50]
6	<i>Thalassiosira pseudonana</i>	3.7 $\pm$ 0.62	4.00	2.5 Brown Algae and	[50]
7	<i>T. pseudonana</i> valve, Coulter	3.98–5.93	4.07–4.43	2.5 Brown Algae and	[50]
8	<i>Chlamydomonas reinhardtii</i>	~10 μ m	4.91	2.3 Green Algae	[29]
9	Moso bamboo internode cell, before elongation	13.9–33.1 μ m	5.21–6.00 (computed)	2.13 Monocots	[171]
10	<i>Equisetum</i> spore	~50 μ m	6.37	2.8 Ferns and	[88]
11	Orchid seed, length	0.05–6.0	6.37–10.73	2.13 Monocots	[164]
12	Moso bamboo internode cell, <i>Sparganium angustifolium</i>	127.4 μ m	7.22 (computed)	2.13 Monocots	[171]
13	<i>Lycopodium clavatum</i> leaf, <i>Adiantum</i>	0.4–0.8	8.26–8.90	2.7 Lycophytes	[78]
14	<i>Selaginella rupestris</i> leaf, <i>Adiantum</i>	0.45–0.6	8.37–8.63	2.7 Lycophytes	[79]
15	<i>Isoetes lacustris</i> megaspore	0.55–0.75	8.55–8.84	2.7 Lycophytes	[80]
16	<i>Selaginella apoda</i> lateral	0.75–1.35	8.84–9.37	2.7 Lycophytes	[79]
17	<i>Chara</i> internodal cell, <i>Adiantum</i>	1 mm	9.10	2.4 Charophytes	[41]
18	<i>Selaginella apoda</i> lateral	1.35–2.25	9.37–9.84	2.7 Lycophytes	[79]
19	<i>Amborella trichopoda</i> seed, width	1.57 mm	9.51	2.12 Basal Angiosperms and	[150]
20	<i>Selaginella selaginoides</i> leaf	2–4 mm	9.73–10.36	2.7 Lycophytes	[77]
21	<i>Selaginella rupestris</i> leaf, <i>Adiantum</i>	2.5–4 (–4.5)	9.93–10.36 (10.47)	2.7 Lycophytes	[79]
22	<i>Lycopodium clavatum</i>	3–6 mm	10.10–10.73	2.7 Lycophytes	[78]
23	<i>Lycopodium clavatum</i> leaf	3–5 mm	10.10–10.56	2.7 Lycophytes	[77]
24	<i>Amborella trichopoda</i> drupe, width	3.49 mm	10.24 (computed)	2.12 Basal Angiosperms and	[150]
25	<i>Lycopodium clavatum</i> leaf, <i>Adiantum</i>	4–6 mm	10.36–10.73	2.7 Lycophytes	[78]
26	<i>Amborella trichopoda</i> seed, length	4.19 mm	10.40	2.12 Basal Angiosperms and	[150]
27	<i>Dawsonia longiseta</i> stem	0.5–3.0 (–5.0) cm	10.56–12.19	2.6 Bryophytes	[62]
28	<i>Azolla caroliniana</i> stem	0.5–1 cm	10.56–11.19	2.8 Ferns and	[93]
29	<i>Amborella trichopoda</i> drupe, length	5.98 mm	10.73 (computed)	2.12 Basal Angiosperms and	[150]

30	<i>Lycopodium clavatum</i>	0.6–1.2	10.73–11.36	2.7 Lycophytes	[78]
31	<i>Huperzia lucidula</i> largest	7–11 mm	10.87–11.28	2.7 Lycophytes	[78]
32	<i>Eospermatopteris</i> roots,	0.7–1 cm	10.87–11.19	2.9 Progymnosperms	[97]
33	<i>Victoria amazonica</i> seed	7–8 × 9–10 mm	10.87–11.19	2.12 Basal Angiosperms and	[148]
34	<i>Victoria cruziana</i> seed	8–9 × 9–10 mm	10.99–11.19 (computed)	2.12 Basal Angiosperms and	[148]
35	<i>Selaginella apoda</i> strobilus	1–2 cm	11.19–11.83	2.7 Lycophytes	[79]
36	<i>Victoria boliviana</i> seed	12–13 × 16–17	11.36–11.68	2.12 Basal Angiosperms and	[148]
37	<i>Lycopodium clavatum</i>	15–25	11.56–12.03	2.7 Lycophytes	[78]
38	<i>Ginkgo biloba</i> seed	20–30 × 16–24	11.83–12.19	2.10 Cycads and Ginkgo	[112]
39	<i>Selaginella selaginoides</i>	3–15 cm	12.19–13.66	2.7 Lycophytes	[77]
40	<i>Dawsonia polytrichoides</i> stem	3–10 (–20) cm	12.19–13.29 (13.92)	2.6 Bryophytes	[62]
41	<i>Lycopodium clavatum</i>	3.5–12.5	12.33–13.49	2.7 Lycophytes	[78]
42	<i>Azolla</i> mat, thickness	≤ 4 cm	12.46	2.8 Ferns and	[93]
43	<i>Dawsonia superba</i> var.	6–25 cm	12.83–14.12	2.6 Bryophytes	[62]
44	<i>Archaeopteris</i> primary root,	6–16 cm	12.83–13.72	2.9 Progymnosperms	[97]
45	<i>Victoria amazonica</i> ovary	8–12 cm	13.09–13.46 (computed)	2.12 Basal Angiosperms and	[148]
46	<i>Isoetes lacustris</i> leaf	80–200 (–450) mm	13.09–13.92 (14.66)	2.7 Lycophytes	[77]
47	<i>Victoria amazonica</i> fruit	10–15 cm	13.29–13.66 (computed)	2.12 Basal Angiosperms and	[148]
48	Rafflesiaceae flowers	11–100	13.38–15.39	2.14 Eudicots	[203]
49	<i>Huperzia lucidula</i> shoot	14–20 (–100)	13.60–13.92 (15.20)	2.7 Lycophytes	[78]
50	<i>D. superba</i> var. <i>pulchra</i> ,	≤ 15 cm	13.66 (computed)	2.6 Bryophytes	[62]
51	<i>Caulerpa taxifolia</i> frond	15–30 cm	13.66–14.29	2.3 Green Algae	[30]
52	<i>Rafflesia lagascae</i> flower	15–20 cm	13.66–13.92	2.14 Eudicots	[204]
53	<i>Equisetum telmateia</i> subsp. <i>braunii</i> fertile stem	17–45 cm	13.77–14.66 (computed)	2.8 Ferns and Horsetails	[92]
54	<i>Equisetum hyemale</i> subsp. <i>scandiacum</i>	18–220	13.83–16.10	2.8 Ferns and	[92]
55	<i>Eospermatopteris</i> base	20–50 cm	13.92–14.76	2.9 Progymnosperms	[97]
56	<i>Isoetes lacustris</i> leaf,	≤ 250 mm	14.12 (computed)	2.7 Lycophytes	[80]
57	<i>Rafflesia pricei</i> flower	≥ 25 cm	14.12 (computed)	2.14 Eudicots	[203]
58	<i>Victoria amazonica</i> flower, diameter	≤ 28 cm	14.23	2.12 Basal Angiosperms and	[148]
59	Moso bamboo internode 18,	29 cm	14.26 (computed)	2.13 Monocots	[171]
60	<i>Chara</i> axial internode, length	30 cm	14.29	2.4 Charophytes	[41]
61	<i>Lycopodium clavatum</i>	30–100	14.29–15.39	2.7 Lycophytes	[77]

62	<i>Equisetum telmateia</i> subsp. <i>braunii</i> vegetative stem	30–100 (–200) cm	14.29–15.39 (16.02)	2.8 Ferns and Horsetails	[92]
63	<i>Pteridium aquilinum</i> leaf	30–180 (–500) cm	14.29–15.92 (16.85)	2.8 Ferns and Horsetails	[94]
64	<i>Encephalartos transvenosus</i>	0.4–0.45	14.55–14.66	2.10 Cycads and Ginkgo	[110]
65	<i>Equisetum hyemale</i> tested	476–767	14.71–15.14 (computed)	2.8 Ferns and Horsetails	[91]
66	<i>Chara</i> internodal cell, length	0.5 m	14.76	2.4 Charophytes	[41]
67	<i>Lepidozamia hopei</i> stem,	50 cm	14.76	2.10 Cycads and Ginkgo	[109]
68	<i>Macrozamia moorei</i> stem,	50–80 cm	14.76–15.18	2.10 Cycads and Ginkgo	[109]
69	<i>Lodoicea maldivica</i> fruit,	≤ 50 cm	14.76	2.13 Monocots	[167]
70	<i>Liriodendron tulipifera</i> trunk, mature	0.6–1.5 m	14.92–15.76	2.12 Basal Angiosperms and	[151]
71	<i>Dawsonia superba</i> var.	65 cm	14.99	2.6 Bryophytes	[62]
72	<i>Rafflesia keithii</i> flower	≥ 80 cm	15.18 (computed)	2.14 Eudicots	[203]
73	<i>Encephalartos woodii</i> trunk	≤ 900 mm	15.29	2.10 Cycads and Ginkgo	[111]
74	<i>Caulerpa taxifolia</i> stolon	> 1 m	>15.39	2.3 Green Algae	[30]
75	<i>Eospermatopteris</i> roots,	1–2 m	15.39–16.02	2.9 Progymnosperms and Seed Ferns	[97]
76	<i>Ginkgo biloba</i> stem,	1–4 m	15.39–16.65	2.10 Cycads and Ginkgo	[112]
77	<i>Rafflesia arnoldii</i> flower	nearly 1 m	15.39	2.14 Eudicots	[203]
78	<i>Quercus robur</i> trunk, typical	≤ 1 m	15.39	2.14 Eudicots	[198]
79	<i>Equisetum hyemale</i> stem,	≤ 150 cm	15.76	2.8 Ferns and Horsetails	[91]
80	Arborescent lycopsid trunk,	≤ 2 m	16.02	2.7 Lycophytes	[76]
81	<i>Lepidozamia hopei</i> leaf	200–300	16.02–16.39	2.10 Cycads and Ginkgo	[109]
82	<i>Macrozamia moorei</i> stem,	2–7 m	16.02–17.16	2.10 Cycads and Ginkgo	[109]
83	<i>Victoria amazonica</i> leaf, breadth	≤ 2.3 m	16.14	2.12 Basal Angiosperms and	[148]
84	<i>Liriodendron tulipifera</i> d.b.h., old growth	2.4–3.7 m	16.18–16.58	2.12 Basal Angiosperms and	[151]
85	<i>Cycas media</i> stem	≤ 3 (–6) m	16.39 (17.02)	2.10 Cycads and Ginkgo	[109]
86	<i>Amorphophallus titanum</i>	≤ ~3 m	16.39	2.13 Monocots	[173]
87	<i>Quercus robur</i> trunk,	3–4 m	16.39–16.65	2.14 Eudicots	[198]
88	<i>Equisetum giganteum</i> stem	> 5 m	>16.85	2.8 Ferns and Horsetails	[90]
89	<i>Cycas angulata</i> stem	≤ 5 (–12)	16.85 (17.65)	2.10 Cycads and Ginkgo	[109]
90	<i>Victoria</i> , growth depth	≤ 5.25 m	16.90	2.12 Basal Angiosperms and	[148]
91	Tree ferns, measured	≤ 6 m	17.02	2.8 Ferns and Horsetails	[89]
92	<i>Encephalartos woodii</i> trunk,	≤ 6 m	17.02	2.10 Cycads and Ginkgo	[111]
93	<i>Wattieza</i> height	≥ 8 m	17.28	2.9 Progymnosperms and Seed Ferns	[99]
94	Moso bamboo culm,	10.46–15.66	17.49–17.86	2.13 Monocots	[176]

95	<i>Archaeopteris</i> root system,	≤ 11 m	17.57	2.9 Progymnosperms	[97]
96	<i>Archaeopteris</i> height,	11–32 m	17.57–18.54	2.9 Progymnosperms	[97]
97	Moso bamboo culm, largest	11.04 m	17.57	2.13 Monocots	[171]
98	<i>Encephalartos transvenosus</i>	12–13 m	17.65–17.72	2.10 Cycads and	[110]
99	<i>Ginkgo biloba</i> , Korean tree,	14 m	17.79 (computed)	2.10 Cycads and	[112]
100	Baobab Platland, height	18.9 m	18.06	2.14 Eudicots	[205]
101	<i>Lepidozamia hopei</i> stem,	≤ 20 m	18.11	2.10 Cycads and	[109]
102	<i>Ginkgo biloba</i> tree, typical	20–40 m	18.11–18.74	2.10 Cycads and	[112]
103	Moso bamboo culm	> 20 m	>18.11	2.13 Monocots	[171]
104	<i>Fagus sylvatica</i> , mature	20–30 m	18.11–18.48	2.14 Eudicots	[201]
105	<i>Pinus sylvestris</i> , average	23–27 m	18.24–18.39	2.11 Conifers and	[129]
106	<i>Pinus sylvestris</i> , tallest in a New York plantation	29.0 m	18.45 (computed)	2.11 Conifers and Gnetophytes	[130]
107	<i>Quercus robur</i> height	30–40 m	18.48–18.74	2.14 Eudicots	[198]
108	<i>Picea abies</i> at maturity	30–60 m	18.48–19.11	2.11 Conifers and	[132]
109	<i>Liriodendron tulipifera</i> , mature height	30.5–45.7 m	18.50–18.87	2.12 Basal Angiosperms and	[151]
110	Baobab Platland, girth	34.11 m	18.60	2.14 Eudicots	[205]
111	<i>Quercus robur</i> , height at	34 m	18.60	2.14 Eudicots	[199]
112	<i>Pinus sylvestris</i> , maximum	> 40 m	>18.74	2.11 Conifers and	[129]
113	Arborescent lycopsid height	≤ c. 45 m	18.85	2.7 Lycophytes	[76]
114	<i>Picea abies</i>	50–60 m	18.95–19.11	2.11 Conifers and	[131]
115	<i>Fagus sylvatica</i> , maximum	≤ 50 m	18.95	2.14 Eudicots	[200]
116	<i>Macrocystis pyrifera</i> length	> 60 m	>19.11	2.5 Brown Algae and	[44]
117	<i>Sequoia sempervirens</i> ,	60–84 m	19.11–19.42	2.11 Conifers and	[128]
118	<i>Liriodendron tulipifera</i> , old growth height	~61 m	19.13	2.12 Basal Angiosperms and	[151]
119	<i>Ginkgo biloba</i> , reported	64 m	19.17	2.10 Cycads and	[112]
120	Rare tree height	> 70 m	>19.25	2.14 Eudicots	[196]
121	<i>Eucalyptus regnans</i>	up to 100	19.58	2.14 Eudicots	[197], title
122	<i>Sequoia sempervirens</i> ,	101 m	19.59	2.11 Conifers and	[128]
123	<i>Sequoia sempervirens</i> ,	112.1 m	19.68	2.11 Conifers and	[127]
124	<i>Sequoia sempervirens</i> , tallest	112.7 m	19.69	2.11 Conifers and	[126]
125	<i>Sequoia sempervirens</i> , height	122–130	19.76–19.82	2.11 Conifers and	[126]
126	Pando (clone), side of equal square	660 m (43.6 ha)	21.30	2.15 Clones and Records	[219]; computed
127	<i>Lomatia tasmanica</i> (clone),	~1.2 km	21.84	2.15 Clones and	[212]
128	<i>Posidonia oceanica</i> genet	≤ 15 km	24.14	2.13 Monocots	[170]

Table C. Times

Group	Generation time / first reproduction	Position	Lifespan maximum	Position	Growth rate (as given)	Refs
2.1 Cyanobac	<i>Prochlorococcus</i> , ~1 day	43.50	— (cell ends at fission)	—	~1 doubling per day in situ	[4], [8]
2.2 Red Algae	<i>C. merolae</i> , one division per 24 h	43.50	—	—	—	[23]
2.3 Green Algae	<i>Volvox carteri</i> , 48 h; <i>Ulva</i>	44.13; 46.27–46.74	—	—	—	[28], [32]
2.4 Charophy	—	—	—	—	Cytoplasmic streaming ≤ 100	[41]
2.5 Brown Algae and Diatoms	—	—	—	—	<i>Macrocystis</i> frond 12.8–23.3 cm/day; mass +3.5 %/day; <i>T. pseudonana</i> 1.71	[51], [45], [50]
2.6 Bryophytes	<i>Physcomitrella</i> full cycle ~4 months; <i>Marchantia</i> gemma to gemma	47.87; 46.27	<i>Physcomitrella</i> annual, 1 yr	48.87	<i>Sphagnum</i> 16 ± 7.5 to 266 ± 39.7 mm/yr (Karelia); 30.3 cm/yr (Georgia);	[65], [66], [59], [67],
2.7 Lycophytes	—	—	Scale trees: 10–15 yr (earlier estimate,	50.97–51.3	—	[76], [81]
2.8 Ferns and Horsetails	<i>Azolla</i> doubling 2 days	44.13	—	—	<i>D. antarctica</i> trunk 3.3 ± 1.3 cm/yr; <i>C. australis</i> 7.3 ± 2.2 cm/yr; <i>Azolla</i> 9.72	[95], [89]
2.9 Progymnosperms and Seed	—	—	—	—	—	—
2.10 Cycads and	<i>Ginkgo</i> sexual maturity 20–30 yr (grafted ~5 yr)	51.60–51.97 (50.34)	<i>Ginkgo</i> 667 yr (cambial study); 1,000–3,000 yr	54.79; 55.1	Gymnosperm pollen tube $< \sim 20$ $\mu\text{m/h}$	[112], [113], [108],
2.11 Conifers and Gnetophytes	<i>Sequoia</i> 5–15 yr; <i>P. sylvestris</i> 5–8 yr, average 10–15 yr; <i>P. abies</i> 20–30 (–40) yr, minimum seed bearing 40–60	50.34–51.34; 50.34–50.76, 50.97–51.34;	<i>P. longaeva</i> 4,900 yr (ring count); <i>Sequoia</i> ~2,200 yr; <i>P. sylvestris</i> >750 yr; <i>P. abies</i> 200–	56.60; 55.88; 54.90;	<i>Welwitschia</i> leaf 0.37 mm/day; <i>P. abies</i> pollen tube ~20 $\mu\text{m/h}$	[127], [128], [130], [131], [132], [133],
2.12 Basal Angiospe	<i>L. tulipifera</i> first flowers 15–20 yr	51.34–51.60	<i>L. tulipifera</i> 200–250 (300) yr	53.69–53.9	Pollen tubes 80–600 $\mu\text{m/h}$	[151], [115]
2.13 Monocots	<i>Wolffia microscopica</i> doubling 29.3 h; <i>Lodoicea</i>	43.68; 51.80; 52.02, 52.60, 53.23	<i>Lodoicea</i> ≤ 350 yr; <i>Posidonia</i> clone 80,000–200,000 yr	54.20; 59.15–	Moso shoot ≤ 114.5 cm/day; internode 18 ~11.8 cm/day; cells 5.6–6.8 $\mu\text{m/h}$;	[174], [167], [175], [170],

2.14 Eudicots	<i>Arabidopsis</i> ~2 months; <i>Q. robur</i> 20 yr; <i>F. sylvatica</i> 40–50 yr (60–80 in stands)	47.24; 51.60; 52.23–52.43 (52.60–52.86)	<i>Q. robur</i> >1,000 yr; baobab Panke 2,450 cal yr; <i>F. sylvatica</i> 150–300 yr;	> 55.1 6; 55.9 7;	—	[210], [199], [200], [201], [198],
2.15 Clones and	<i>Wolffia</i> 29.3 h; <i>Prochlorococcus</i> ~1 day	43.68; 43.50	<i>P. longaeva</i> 4,900 yr (single stem);	56.6 0; 59.1	<i>Macrocystis</i> +3.5 %/day	[174], [4], [133],

Table C2. All verified durations

Sorted by position from the shortest to the longest. A range stands in one row and is sorted by its lower bound. The last two rows are geological durations given in Part 2, not organism times.

No.	What	Duration	Position	Group	Ref
1	<i>Utricularia</i> trap door	< 1 ms	<26.87	2.14 Eudicots	[208]
2	<i>Dionaea</i> leaf closure	~100 ms	31.06	2.14 Eudicots	[207]
3	Progamic phase, angiosperms, shortest	15 min	39.34	2.12 Basal Angiosperms and	[114]
4	Pollen germination, Gnetales	1–72 h	40.61–44.50	2.11 Conifers and	[114]
5	<i>Utricularia</i> spontaneous	5–20 h	42.07–43.33	2.14 Eudicots	[208]
6	Progamic phase, <i>Austrobaileya scandens</i>	18 h	43.24	2.12 Basal Angiosperms and	[114]
7	Generation, <i>Prochlorococcus</i>	~1 day	43.50	2.1 Cyanobacteria	[4], [8]
8	Transcriptome cycle, <i>Brattonia medialis</i>	24 h	43.50	2.1 Cyanobacteria	[9]
9	Division cycle, <i>Cyanidioschyzon merolae</i> ,	24 h	43.50	2.2 Red Algae	[23]
10	Acid rhythm, <i>Isoetes</i>	24 h	43.50	2.7 Lycophytes	[75]
11	Circadian period, <i>Arabidopsis</i>	~27 h	43.61	2.3 Green Algae	[33]
12	Doubling, <i>Wolffia</i>	29.3 h	43.68	2.13 Monocots	[174]
13	Generation, <i>Volvox carteri</i>	48 h	44.13	2.3 Green Algae	[28]
14	Doubling, <i>Azolla</i> ,	2 days	44.13	2.8 Ferns and	[95]
15	Pollen germination, cycads	several days (≥ 3 d)	≥ 44.50	2.10 Cycads and	[114]
16	Apical cell specified, <i>Marchantia</i>	7–10 days	45.27–45.60	2.6 Bryophytes	[64]
17	Three sporophyte tissues, <i>Marchantia</i>	2 weeks	45.90	2.6 Bryophytes	[64]
18	New gemmae after germination, <i>Marchantia</i>	2–3 weeks	45.90–46.27 (computed)	2.6 Bryophytes	[66]
19	Pollen germination, conifers,	0.5–9 months	45.96–48.61	2.11 Conifers and	[114]
20	Radicle to cotyledons, <i>Amborella</i>	17 + 24 days	46.08–46.39 (computed)	2.12 Basal Angiosperms and	[150]
21	Maximum growth rate <i>Arabidopsis</i>	~20 days	46.23	2.13 Monocots	[176]
22	Gemma to new gemma cups, <i>Marchantia</i>	~3 weeks	46.27	2.6 Bryophytes	[66]

2	Growth to gametogenesis, <i>Pinus</i>	3–5 weeks	46.27–46.74	2.3 Green Algae	[32]
2	Internode 18 rapid growth, <i>Moss</i>	23 days	46.35	2.13 Monocots	[171]
2	Sporangia after fertilisation, <i>Moss</i>	~4 weeks	46.53	2.6 Bryophytes	[66]
2	Fertilisation to ovule fall, <i>Cycas</i>	~1 month	46.61	2.10 Cycads and Ginkgo	[112]
2	Culm to full height, Moso	~40 days	46.86	2.13 Monocots	[176]
2	Culm to > 20 m, Moso	45–60 days	46.96–47.23	2.13 Monocots	[171]
2	Life cycle on soil, <i>Pinus</i>	~2 months	47.24	2.14 Eudicots	[210]
3	Warm stratification, <i>Amborella</i> seed	≥ 90 days	47.60 (computed)	2.12 Basal Angiosperms and	[150]
3	Full life cycle in a Petri dish, <i>Pinus</i>	~4 months	47.87	2.6 Bryophytes	[65]
3	Fruit enlargement, <i>Lodoicea</i>	~10 months	48.70	2.13 Monocots	[167]
3	Pollination to fertilisation, <i>Pinus</i>	≤ 1 yr	48.87	2.11 Conifers and Gnetophytes	[117]
3	Life span, <i>Physcomitrella</i>	annual, 1 yr	48.87	2.6 Bryophytes	[59]
3	Progamic phase, angiosperms, longest	13 months	48.94	2.12 Basal Angiosperms and	[114]
3	Needle life, low-elevation	2–4 yr	49.50–50.13	2.11 Conifers and Gnetophytes	[134]
3	Seed crops, <i>Quercus robur</i>	every 2–4 yr	49.50–50.13	2.14 Eudicots	[199]
3	Sexual maturity, grafted <i>Cycas</i>	~5 yr	50.34	2.10 Cycads and Ginkgo	[112]
3	First seed, <i>Sequoia</i>	5–15 yr	50.34–51.34	2.11 Conifers and Gnetophytes	[127], [128]
4	Fruit ripening, <i>Lodoicea</i>	~5 (7) yr	50.34 (50.64)	2.13 Monocots	[167]
4	First flowers, <i>Pinus</i>	5–8 yr	50.34–50.76	2.11 Conifers and Gnetophytes	[130]
4	Scale-tree life, earlier	10–15 yr	50.97–51.34	2.7 Lycophytes	[76]
4	First flowers, <i>Pinus</i>	10–15 yr	50.97–51.34	2.11 Conifers and Gnetophytes	[130]
4	Youngest tree in <i>Ginkgo</i>	15 yr	51.34 (50.94)	2.10 Cycads and Ginkgo	[113]
4	First flowers, <i>Liriodendron tulipifera</i>	15–20 yr	51.34–51.60	2.12 Basal Angiosperms and	[151]
4	Minimum seed-bearing age, <i>Quercus</i>	20 yr	51.60	2.14 Eudicots	[199]
4	Sexual maturity, <i>Ginkgo</i>	20–30 yr	51.60–51.97	2.10 Cycads and Ginkgo	[112]
4	First flowers, <i>Picea abies</i>	20–30 (–40) yr	51.60–51.97 (50.93)	2.11 Conifers and Gnetophytes	[131]
4	Reproductive age, <i>Lodoicea</i>	~25 yr	51.80	2.13 Monocots	[167]
5	Flowering interval, <i>Bambusa</i>	32 yr	52.02	2.13 Monocots	[175]
5	Minimum seed bearing, <i>Pinus</i>	40–60 yr	52.23–52.60	2.11 Conifers and Gnetophytes	[132]
5	First seed, <i>Fagus sylvatica</i> ,	40–50 yr	52.23–52.43	2.14 Eudicots	[200]
5	Needle life, <i>Pinus longaeva</i>	≤ ~45 yr	52.34	2.11 Conifers and Gnetophytes	[134]
5	First seed, <i>Fagus sylvatica</i> ,	60–80 yr	52.60–52.86	2.14 Eudicots	[201]
5	Flowering interval, <i>Phyllostachys nigra</i> f.	60 yr	52.60	2.13 Monocots	[175]
5	Age of tallest <i>Pinus sylvestris</i> , New York	74–77 yr	52.79–52.82 (computed)	2.11 Conifers and Gnetophytes	[130]

57	Oak reference tree, age	~100 yr	53.06	2.14 Eudicots	[206]
58	Full size, <i>Lodoicea</i>	~100 yr	53.06	2.13 Monocots	[167]
59	Scale-tree life, later estimate	centuries (≥ 100)	≥ 53.06	2.7 Lycophytes	[81]
60	Oak lifespan	several hundred years (≥ 100 yr)	≥ 53.06	2.14 Eudicots	[206]
61	Ring-width decline phase, <i>Ginkgo</i>	first 100–200 yr	53.06–53.69 (computed)	2.10 Cycads and Ginkgo	[113]
62	Flowering interval, <i>Pinus</i>	120 yr	53.23	2.13 Monocots	[175]
63	Lifespan, <i>Fagus sylvatica</i>	150–300 yr	53.43–54.06	2.14 Eudicots	[200]
64	Natural death, <i>Liriodendron tulipifera</i>	200–250 (300) yr	53.69–53.90 (54.06)	2.12 Basal Angiosperms and	[151]
65	Lifespan, <i>Picea abies</i>	200–300 yr	53.69–54.06	2.11 Conifers and	[131]
66	Viable seed to at least age, <i>Pinus</i>	≥ 200 yr	53.69	2.11 Conifers and	[130]
67	Seed viability, <i>Sequoia</i>	> 250 yr	53.90	2.11 Conifers and	[127]
68	Lifespan, <i>Lodoicea</i>	≤ 350 yr	54.20	2.13 Monocots	[167]
69	Lifespan, <i>Pinus sylvestris</i>	400+ yr	54.32	2.11 Conifers and	[129]
70	Heartwood years, oldest <i>Eucalyptus regnans</i> climbed	651 yr	54.77	2.14 Eudicots	[209]
71	Oldest measured <i>Ginkgo</i> , <i>Ginkgo</i>	667 yr	54.79	2.10 Cycads and	[113]
72	One Lapland <i>Pinus sylvestris</i>	> 750 yr	54.90	2.11 Conifers and	[129]
73	Oldest <i>Ginkgo</i> in China, estimate	1,000–3,000 yr	55.16–56.16	2.10 Cycads and Ginkgo	[108] (estimate)
74	Lifespan, <i>Quercus robur</i> , <i>Quercus</i>	$> 1,000$ yr	> 55.16	2.14 Eudicots	[198]
75	Baobab Platland	~1,100 yr	55.24	2.14 Eudicots	[205]
76	Baobab Chapman	~1,400 yr	55.46	2.14 Eudicots	[205]
77	Baobab Grootboom	1,500 (Table 1) or 1,600 (suppl.) yr	55.53–55.59	2.14 Eudicots	[205]
78	Baobab Holboom	~1,800 yr	55.69	2.14 Eudicots	[205]
79	Lifespan, <i>Sequoia</i>	2,000+ yr	55.79	2.11 Conifers and	[128]
80	Baobab Glencoe	+2,000 yr	55.79	2.14 Eudicots	[205]
81	Baobab Dorslandboom	~2,100 yr	55.83	2.14 Eudicots	[205]
82	Oldest <i>Sequoia</i> , ring count	~2,200 yr	55.88	2.11 Conifers and	[127]
83	Baobab Panke, calibrated	2,450 (+45/–40)	55.97	2.14 Eudicots	[205]
84	Baobab Panke, calculated	+2,500 yr	55.99	2.14 Eudicots	[205]
85	Oldest <i>Pinus longaeva</i> , ring	4,900 yr	56.60	2.11 Conifers and	[133]
86	<i>Posidonia</i> clone, minimum	~12,500 yr	57.46	2.13 Monocots	[170]
87	Jurupa Oak clone	$> 13,000$ yr	57.49	2.14 Eudicots	[211]
88	Pando, upper bound	$\leq 14,000$ yr	57.56	2.15 Clones and	[218]
89	<i>Lomatia tasmanica</i> clone	$\geq 43,600$ yr	58.59	2.14 Eudicots	[212]

90	<i>Posidonia</i> shared genet,	80,000–200,000 yr	59.15–59.98	2.13 Monocots	[170]
91	Arctic <i>Azolla</i> event, duration	~800,000 yr	61.24	2.8 Ferns and	[87]
92	<i>Azolla</i> – <i>Nostoc</i> co-evolution	~100 Myr	65.64	2.8 Ferns and	[87]

Table D. Build

Group	Branching mode	Phyllot axis	Apical cell (faces)	Vascular tissue	Secondary growth	Life cycle (dominant phase;	Part counts	Refs
2.1 Cyanobacteria	Does not apply; unicellular, colonial and filamentous forms	Does not apply	Does not apply	None	None	Binary fission; 1 phase; no meiosis	Heterocystous filaments: 4 cell types (vegetative, heterocyst, akinete, hormogonium); <i>Trichodesmium</i> : 2	[10], [7]
2.2 Red Algae	— (<i>Ramathallus</i> : apical growth)	Does not apply	—	None	None	Florideophyceae have a carposporophyte stage;	<i>C. merolae</i> : 1 nucleus, 1 mitochondrion, 1 plastid, 20 chromosomes	[19], [21], [22]
2.3 Green Algae	<i>Caulerpa</i> : pinnate fronds on a stolon; <i>Proterocladus</i> : lateral branches	Does not apply	<i>Acetabularia</i> and <i>Caulerpa</i> : apical tip growth (no face count)	None	None	<i>Volvox</i> : haploid vegetative, diploid zygote only, 1 free-living phase;	Cell types: <i>Chlamydomonas</i> 1, <i>Volvox</i> 2, <i>Ulva</i> 3; flagella: <i>Chlamydomonas</i> 2, <i>Volvox</i> somatic 2, gonidia 0, <i>Ulva</i> gametes 2; <i>Volvox</i> ~2,000 somatic	[30], [25], [31], [28], [3]
2.4 Charophytes	Charales: nodes, internodes, whorled branchlets; <i>Palaeonitella</i> : furcating branchlets;	Whorled branchlets (Charales)	—	None	None	— (zygote with storage proteins)	Gyrogonite 6 spiral cells; filamentous growth ≥5 independent origins in Zygnematophyceae	[41], [42], [36], [40]

2.5 Brown Algae and Diatoms	—	Does not apply	—	None	None	<i>Macrocystis</i> haplodipl ontic: macroscopic diploid sporophyte, microscopic haploid	<i>Thalassiosira</i> 24 diploid chromosomes	[4 5], [5 2], [5 3]
2.6 Bryophytes	<i>Marchantia</i> thallus bifurcating; leafy liverworts dichotomise from a single apical cell	Moss leaves spirally inserted	Moss gametophore: tetrahedral; <i>Marchantia</i> : wedge-shaped, 4 planes (2 faces in 2D)	<i>Physcomitrella</i> central strand of thin-walled cells; <i>Polytrichum</i> hydroids	None	Haploid gametophyte dominant	<i>Physcomitrella</i> capsule stoma: 1 guard cell; hornworts: 1 chloroplast per cell (most); chromosomes: <i>Marchantia</i> 9, <i>Physcomitrella</i> 27 pseudochromosomes, <i>Anthoceros</i> 6	[6 9], [5 9], [6 4], [6 3], [5 7], [6 6]
2.7 Lycophytes	<i>Asteroxylon</i> : 3 axis types; rooting axes by anisotomous	<i>S. rupestris</i> : pseudo whorls of 6 (main	<i>Selaginella</i> : 1–2 transient apical initials; Isoëtaceae and	Present (tracheophytes); <i>Asteroxylon</i> rooting meristem	Arborescent lycopsids: secondary phloem,	Sporophyte dominant	<i>Isoetes taiwanensis</i> 2n = 22	[8 2], [7 3], [6 9], [8 8]
2.8 Ferns and Horsetails	—	<i>Equisetum</i> : sheath teeth in whorls	Single tetrahedral apical cell, 3 cutting faces (<i>Nephrolepis</i> , <i>Ceratopteris</i>)	Present (tracheophytes); not separately verified	—	Sporophyte dominant	<i>Equisetum</i> spore 4 elaters; sheath teeth 14–50 per whorl (<i>E. hyemale</i> subsp. <i>affine</i>), 14– 30 (–36) (<i>E. telmateia</i> subsp. <i>braunii</i>); <i>Ceratopteris</i> n =	[8 4], [6 9], [8 8], [9 2], [9 9]
2.9 Progymnosperms and Seed Ferns	<i>Archaeopteris</i> : lateral branching of the modern- tree type	—	—	Tracheids; <i>Medullosa</i> very large tracheids	Present (<i>Archaeopteris</i> wood; <i>Medullosa</i>)	Heterosporous; seed habit from the Famennian	<i>Runcaria</i> : 1 lobed integument plus cupule; <i>Archaeopteris</i> 10– 15 primary roots per tree	[9 8], [1 02], [9 9]

2.10 Cycads and Ginkgo	— (<i>Welwitschia</i> a-type data not here)	—	—	Tracheids only; no vessels	Present (<i>Ginkgo</i> vascular cambium)	Sporophyte dominant; dioecious	Pollen 4 cells (<i>Ginkgo</i> , pine); sperm multiflagellate; <i>Cycas panzhihuaensis</i> n = 11; <i>L. hopei</i> ≤100 leaves in crown; <i>C. media</i> leaf 160–300 pinnae	[1 17 , [1 16 , [1 13 , [1 19 ,]
2.11 Conifers and Gnetophytes	<i>Welwitschia</i> a: unbranched	Cone scales: parastichy pair 8/13 (<i>Pinus nigra</i>), 5/8 (<i>Larix decidua</i>)	—	Tracheids (homoxylous); <i>Gnetum</i> vessels, convergent	Present in all	Sporophyte dominant; <i>Welwitschia</i> dioecious; wind pollination	Pollen cells: <i>Pinus</i> 4, <i>Sequoia</i> 2, <i>Juniperus</i> 1; <i>Welwitschia</i> 2 leaves; <i>Ephedra</i> double fertilisation	[1 25 , [1 36 , [1 20 , [1 19 ,]
2.12 Basal Angiosperms and Magnoliids	—	Ancestral flower: perianth and androecium whorled , gynoecium spiral	—	Present; <i>Amborella</i> vessel status not verified	—	Sporophyte dominant; double fertilisation	Ancestral flower: >2 whorls of 3 tepals (>10), >2 whorls of 3 stamens (>10), >5 spiral carpels; female gametophyte: <i>Amborella</i> 8- celled 9-nucleate, 3 synergids; Nymphaeales and Austrobaileyales 4-celled 4- nucleate; Polygonum type 7-celled 8- nucleate; <i>Nuphar</i>	[1 41 , [1 52 , [1 42 , [1 53 , [1 54 , [1 55 ,]

2.13 Monocots	Palms: primary growth only	—	—	Present	Palms none; seconda ry thicken ing meriste m in 22 genera of Asparag ales	Sporophy te dominant; double fertilisatio n; endosper m triploid, 2:1 maternal: paternal	Flower trimerous- pentacyclic: 3+3 tepals, 3+3 stamens, 3 carpels = 15 organs; first angiosperms monosulcate pollen; orchid seeds 20–50 to ~4,000,000 per capsule; <i>Zostera</i> lacks stomatal genes	[1 69 , [1 79 , [1 80 , [1 77 , [1 78
2.14 Eudicots	—	Sunflow er heads: 565 of 768 parastic hy counts Fibonac ci (73.6 %), 82.3 % with Fibonac ci-type; <i>Leefruct us</i>	—	Present; eudicot vascular cambium continuo us	Present (vascula r cambiu m)	Sporophy te dominant; double fertilisatio n; triploid endosper m	<i>Leefructus</i> 5 carpels; pentamerous flowers; <i>Dionaea</i> trap 2 lobes; parasitism 12 independent origins; <i>Arabidopsis</i> 5 chromosomes	[2 14 , [1 91 , [1 79 , [1 80 , [2 13 , [2
2.15 Clones and Records	Ramets from roots or rhizomes (Pando root suckers; seagrass rhizomes)	—	—	—	—	<i>Lomatia</i> sterile triploid, vegetative only	<i>Ostreococcus tauri</i> 1 copy of each organelle; Pando ~47,000 ramets, 209 stems sampled, 7 loci; <i>Lomatia</i> 16 isozyme loci, 78 plants	[2 19 , [2 18 , [1 70 , [2

Table E. Light

Group	Chlorophylls	Plastid membran	Pyrenoid / carboxysome	C3 / C4 / CAM	Ref s
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2.1 Cyanobacteria	a general; <i>Prochlorococcus</i> divinyl a ₂ and b ₂ ; chlorophyll f (706 nm in vitro); chlorophyll d (title only);	Does not apply (inner membrane , peptidogly	Carboxysomes (Rubisco confined to them)	Does not apply	[4], [6], [11] , [12] ,
2.2 Red Algae	Phycobilisomes present; thylakoids not stacked	2	<i>C. merolae</i> : no pyrenoid, no CCM; <i>Rafatazmia</i> (1.6 Ga): pyrenoid-	—	[22] , [24] , [13]
2.3 Green Algae	No phycobilisomes; stacked and unstacked regions, not plant-type	2	<i>Chlamydomonas</i> pyrenoid 1.5–2 μm; often absent	—	[24] , [13]
2.4 Charophytes	No phycobilisomes; thylakoids stacked	2	<i>Spirogyra</i> : pyrenoid with CCM	—	[24] , [13]
2.5 Brown Algae and Diatoms	Chlorophyll c- containing; diatoms: fucoxanthin chlorophyll a/c-	— (count not verified)	—	— (diatoms ~20 % of global carbon fixation)	[44] , [54] ,
2.6 Bryophytes	— (a + b standard, not sourced)	— (2 standard, not sourced)	Hornworts: only land plants with a pyrenoid-based CCM; pyrenoids	— (C3 standard, not sourced)	[57]
2.7	—	—	—	<i>Isoetes</i> : CAM under water (<i>Isoetes macrospora</i>)	[75]
2.8 Ferns and	—	—	—	— (<i>Azolla</i> hosts N ₂ -fixing <i>Nostoc azollae</i>)	[87]
2.9 Progymnosperms and Seed	Not measurable (fossil)	Not measurable	Not measurable	Not measurable	—
2.10 Cycads	—	—	—	—	—
2.11 Conifers and	—	—	—	C3 except <i>Welwitschia</i> : CAM, night CO ₂ uptake ≤4 % of 24-h total	[13 8]
2.12 Basal Angiospe	—	—	—	C3 throughout (no CAM or C4 read)	—
2.13 Monocots	—	—	—	C4: 26 monocot lineages of 62 (grasses 18, sedges 6); CAM in ~6 % of vascular plants, ≥35 families,	[18 2], [18 3],
2.14 Eudicots	—	—	—	C4: 36 of 62 lineages (60 % as stated; 58.1 % computed); CAM in Cactaceae, Crassulaceae, Aizoaceae,	[18 2], [18 3],
2.15 Clones	<i>Prochlorococcus</i> divinyl a ₂ , b ₂	—	—	—	[4], [6]

Table F. Count

Group	Species count (source)	Reference genome (species, size, genes)	Refs
2.1 Cyanobacteria	— (algae in total ~44,000 named, 72,500 estimated, 33,248 in	<i>Prochlorococcus marinus</i> MED4, 1,657,990 bp, 1,716 genes; MIT9313, 2,410,873 bp, 2,275 genes; <i>Trichodesmium erythraeum</i>	[15], [16], [5], [7]
2.2 Red Algae	—	<i>Cyanidioschyzon merolae</i> 10D, 16,520,305 bp, 5,331 genes (16.7 Mb in a later paper)	[22], [23]
2.3 Green Algae	—	<i>Chlamydomonas reinhardtii</i> , 121 Mb, 15,143 genes; <i>Volvox carteri</i> , 138 Mb, ~14,500	[29], [35]
2.4 Charophytes	Zygnematophyceae >4,000	<i>Chara braunii</i> , 1,751,211,849 bp, 34,718 genes (Ensembl); <i>Mesotaenium endlicherianum</i> , 173.77 Mbp, 10,300;	[40], [42], [43]
2.5 Brown Algae and	Brown algae 2,125 (AlgaeBase; 46 % of 4,619 non-diatom heterokonts); diatoms	<i>Ectocarpus siliculosus</i> , 214 Mbp, 16,256; <i>Thalassiosira pseudonana</i> , 34 Mb / 32.4 Mb, 11,776; <i>Phaeodactylum tricornutum</i> , 27.4 Mb, 10,402; <i>Macrocystis pyrifera</i> , 537 Mb, 25,919;	[44], [15], [52], [53], [48], [45], [49]
2.6 Bryophytes	Mosses 12,700; liverworts ~9,000; hornworts ~225 (Christenhusz & Byng);	<i>Marchantia polymorpha</i> , ~220 Mb, ~20,000; <i>Physcomitrella patens</i> , ~500 Mbp, 32,458; <i>Anthoceros</i> spp., 117–133 Mb, 24,700–25,800; <i>Sphagnum divinum</i> , 439 Mb, 25,227; <i>S.</i>	[16], [64], [59], [57], [61]
2.7 Lycophyt	Lycopods 1,290 (Christenhusz & Byng);	<i>Isoetes taiwanensis</i> , 1.66 Gb, 39,461	[16], [75]
2.8 Ferns and	Ferns 10,560 (Christenhusz & Byng);	<i>Azolla filiculoides</i> , 0.75 Gb, 20,201; <i>Salvinia cucullata</i> , 0.26 Gb, 19,914; <i>Ceratopteris</i>	[16], [96], [85], [86],
2.9 Progymnosperms and Seed	— (extinct)	— (no genome)	—
2.10 Cycads and Ginkgo	Gymnosperms 1,079 (Christenhusz & Byng); cycads 382 accepted in 10 genera (World List of	<i>Ginkgo biloba</i> , 9.87 Gb, 27,832 (near-complete; draft 10.61 Gb, 41,840); <i>Cycas panzhihuaensis</i> , 10.5 Gb, 32,353	[16], [121], [105], [104], [122], [107]
2.11 Conifers and	Gymnosperms 1,079 (Christenhusz & Byng); <i>Welwitschia</i> 1	<i>Picea abies</i> , 19.6–20 Gb, 28,354; <i>Pinus taeda</i> , 22 Gb (assembly 20.1 Gb), 50,172; <i>Welwitschia mirabilis</i> , 6.8 Gb, 26,990; <i>Gnetum</i>	[16], [125], [139], [140], [119]
2.12 Basal Angiospe	Angiosperms 295,383; outside monocots and eudicots 11,102	<i>Nymphaea colorata</i> , 409 Mb, 31,580; <i>Liriodendron chinense</i> , 1.74 Gb, 35,269	[16], [146], [144], [147]
2.13 Monocots	Monocots 74,273 (Christenhusz & Byng); grasses 11,506; orchids >25,000 in 736 genera;	<i>Oryza sativa</i> Nipponbare, 389 Mb est. / 370 Mb finished, 37,544; <i>Triticum aestivum</i> Chinese Spring, ~16 Gb / 14.5 Gb assembly, 107,891; <i>Wolffia australiana</i> , 357 Mb,	[16], [185], [163], [186], [157], [174], [187], [190],
2.14 Eudicots	Eudicots 210,008 (Christenhusz & Byng); Asteraceae 10 % of flowering plants;	<i>Arabidopsis thaliana</i> , ~125 Mb, 25,498; <i>Helianthus annuus</i> , ~3.6 Gb, 52,232; <i>Quercus robur</i> , ~740 Mb, 25,808; <i>Eucalyptus grandis</i> , 640 Mb, 36,376	[16], [193], [215], [194], [195], [206], [217]
2.15 Clones	—	<i>P. marinus</i> MED4, 1,657,990 bp, 1,716; <i>Ostreococcus tauri</i> , 12.56 Mb; <i>Wolffia</i>	[5], [221], [165], [189]

Table G. Occupation of the ladder over time

Sorted by the position of the oldest verified fossil age in Table A, from oldest to youngest. The size column is the position of the largest verified size in Table B. The last column is the running maximum of that column down the sorted list. Where a largest size is given as a range in Table B, the upper bound is used; a "greater than" value is used at its stated bound.

Group	Oldest fossil age (Table A)	Position in	Largest verified size (Table B)	Position	Highest size position reached
2.1	3,430 Ma	68.86	0.7 μ m	2.49	2.49
2.2 Red Algae	~1,600 Ma (probable crown-group;	68.16	2 μ m	3.44	3.44
2.3 Green Algae	~1,000 Ma	67.73	> 1 m	> 15.39	15.39
2.6 Bryophytes	473 Ma	67.05	65 cm	14.99	15.39
2.4	411.5 Ma	66.93	0.5 m	14.76	15.39
2.7 Lycophytes	407 Ma	66.92	45 m	18.85	18.85
2.9 Progymnosper	385 Ma	66.86	11–32 m (estimate; 11 m	18.54	18.85
2.11 Conifers and	>300 Ma	66.64	112.7 m	19.69	19.69
2.10 Cycads and Ginkgo	265.1–272.3 Ma	66.52	64 m	19.17	19.69
2.12 Basal Angiosperms	$\leq$ ~130 Ma	65.88	61 m	19.13	19.69
2.14 Eudicots	127–125 Ma	65.86	100 m	19.58	19.69
2.13 Monocots	~110–120 Ma	65.72	15 km (clone); > 20 m (single	24.14 ; >	24.14
2.5 Brown Algae and	$\geq$ 100 Ma (<i>Padina</i>)	65.64	> 60 m	> 19.11	24.14
2.8 Ferns and	— (no numeric fossil age	—	6 m	17.02	not ranked
2.15 Clones	— (no fossil first	—	15 km	24.14	not ranked

This table is derived only from the fossil-age column of Table A and the largest-size column of Table B; no value in it comes from elsewhere.

The running maximum rises in six steps: 2.49 (2.1), 3.44 (2.2), 15.39 (2.3), 18.85 (2.7), 19.69 (2.11), 24.14 (2.13, a clone). Without clones the last step is 19.69 (2.11), reached at the conifer fossil floor of >300 Ma and not exceeded by any later group in Table B.

Checks

Rows per table: A 15; B 15; B2 128; C 15; C2 92; D 15; E 15; F 15; G 15 (13 ranked, 2 not ranked).

Values in Part 2 not placed in a table:

- Volvox carteri* "several hundred microns" and *Acetabularia* "centimeters tall" — no number given in Part 2.

- *Sphagnum* length growth 30.3 cm/yr with position 14.30 in Part 2 — a rate; placed in Table C (growth rate), not in B2.
- Orchid seed mass 0.31–24 μg ; *Lodoicea* fruit and seed mass ≤ 45 kg / ≤ 25 kg, fresh 1–18 kg — masses, no length position; Table B names them in text only.
- Pando area 43–43.6 ha — placed in B2 through the computed side of an equal square (660 m), as Part 2 does.
- Bamboo flowering bases 15 yr (*Phyllostachys*) and 8 yr (*Chusquea*) and the series 15, 30, 60, 120 and 16, 23, 32 yr — only the three table values of Part 2 (32, 60, 120 yr) are in C2.
- Baobab observation window "past 12 years" and Pando 72-year photo series and 30–40 years of declining self-replacement — observation windows, not placed.
- *Posidonia* "about 10,000 to several tens of thousands of years" — covered by its minimum 12,500 yr row.
- Pollination to fertilisation in Pinaceae and Cupressaceae "from several weeks" — no number.
- *Welwitschia* "several thousand years" — no number.
- Computed durations of Part 2 (mass doubling 20.1 days, 6 m trunk at 3.3 cm/yr 182 yr, 30 cm internode traversal 3,000 s, *Ginkgo* pollination to fertilisation 4–5 months and seed-to-seed 20–30 yr, *Amborella* sum 131 d, pollen tube 1 mm in 50 h) — not measured, left out of C2; the measured components stand in C2.

Positions recomputed here that differ from Part 2 by more than 0.01:

- Moso bamboo culm, Richards asymptote 10.46–15.66 m: Part 2 gives 17.49–17.86; recomputed 17.52–17.89. Part 2 value kept in B2.
- Pollen germination, conifers, 0.5–9 months: Part 2 gives 45.96–48.61; recomputed with one month = 1/12 year gives 45.98–48.61 (Part 2 value matches 15 days). Part 2 value kept in C2.
- All other positions copied from Part 2 (sizes, durations and the ages of Table A) agree with recomputation within 0.01.

Positions computed here because Part 2 gave none: 38 values, each marked (computed) in B2 and C2.

Part 4 — The Correlation

4.1 Method

A correlation is a pair: one statement the texts make about how the net evolves (Part 1), and one measured fact about how plants evolved (Parts 2 and 3), of the same form. The pairing is a read. A read is a hypothesis until a measurement decides it. No statement about the net is added. Where nothing pairs, the entry says none. Every pairing in this Part was then put to a test with the outcome fixed first, or is marked as untested; Part 5 holds the tests.

4.2 Depth: the ring depths lie below the plant; the positions are the plant

Ring depth. The texts read ring depth 3 as self-maintenance without division and ring depth 6 as "the form of a single cell" (text, 1.2). The first organism in the plant line, the cyanobacterium, is a dividing cell with heredity: body fossils from 2.02–1.85 Ga, thylakoids from 1.78–1.73 Ga (measured, 2.1). Placing it at ring depth 6 is a read. Every later group then sits at or above ring

depth 6, and no text gives a ring depth for an alga, a moss, a fern or a tree (text, 1.7). The sequence $3 \rightarrow 6 \rightarrow 3 + 3$ describes the step to the cell. It does not describe the steps from the cell to the tree. In the ring-depth sense: none.

Position. In the Climate paper's sense every measured size has a depth, and Part 3 gives it for 128 sizes and 92 durations. In that sense the plant line is a sequence of depths. Table B2 runs from the smallest cell, *Prochlorococcus* at 0.5 μm , position 2.18, to the tallest tree, 112.7 m at 19.69, and on to the longest clone, 15 km at 24.14. Table C2 runs from the trap of *Utricularia*, under a millisecond at below 26.87, through the day at 43.50 and the year at 48.87, to the oldest clone bound, 200,000 years at 59.98. Seventeen and a half positions of body, twenty-two with clones; thirty-three of time (computed).

What was wrong in an earlier draft was the sentence "no depth". In the ring-depth sense it was correct and narrow. In the position sense it was false. This Part uses both senses by their names.

4.3 The filling of the ladder in time

Text. "Evolution is ... the filling of depths until the next is forced." "A larger number forces the next depth." (1.3, 1.5.)

Measured. The largest body of the plant line, by date, with verified sizes only (Part 2):

Date	Largest verified body	Size	Position	Ent
2.02–1.73 Ga	Cyanobacterial cells (living <i>Prochlorococcus</i> as the measured	0.5–0.7	2.18–2.49	2.1
~1.0 Ga	<i>Proterocladus antiquus</i> , "millimetre-sized" (no number in the source)	order of 1	about 9.1 (computed from the	2.3
1.0 Ga – 385 Ma	no verified fossil body size in this book (Cooksonia "a few cm" is	—	—	2.7, Part
~385 Ma	<i>Wattieza</i> / <i>Eospermatopteris</i>	≥ 8 m	17.28	2.9
~385 Ma	<i>Archaeopteris</i> , height estimated from	11–32	17.57–18.54	2.9
Carboniferous (ICS chart: 358.9–298.9 Ma; 66.80–	Arborescent lycopsids, <i>Lepidodendron</i> and allies	up to c. 45	18.85	2.7
now	<i>Sequoia sempervirens</i> , tallest	112.7	19.69	2.1

Computed. The maximum occupied position rises in steps: $2.5 \rightarrow 9.1 \rightarrow 17.3 \rightarrow 18.9 \rightarrow 19.7$. From the cell to the first tree, fifteen positions in about 1.6 Ga; from the first tree to the tallest, two and a half positions in 385 Myr. The step from 18.85 to 19.69 took 300 Myr and is less than one position.

Table G of Part 3 gives a second view: the groups sorted by first appearance, each with the largest size its living members reach. The running maximum there rises 2.49 (cyanobacteria) $\rightarrow$ 3.44 (red algae) $\rightarrow$ 15.39 (green algae, the single cell of *Caulerpa* over a metre) $\rightarrow$ 18.85 (lycophytes, the extinct scale trees) $\rightarrow$ 19.69 (conifers) $\rightarrow$ 24.14 (monocots, the *Posidonia* clone). No group that appeared after the conifers has exceeded 19.69 with a single body.

Read. The maximum occupied position rises in steps and never falls back, and each step comes hundreds of millions of years after the one before. Not every new group exceeds the groups before it: bryophytes and charophytes stay below the green algae, cycads and the flowering trees stay below the conifers (Table G). It is the maximum that rises, not each group. That is the form of

"filling until the next is forced". It is also the form of any sequence in which size is limited by a resource that later forms overcome (water transport, support), which is the standing account. The pairing stands as a description. It does not discriminate (Part 5, test 3).

What stops the filling. No single body exceeds position 19.82 in 385 Myr of trees. The next whole position, 20, is 159 m. Koch and colleagues measured water tension and leaf water content in the tops of the tallest redwoods and derived a height limit of 122–130 m, positions 19.76–19.82 (measured, 2.11). The clone goes on: *Posidonia* at 24.14. Where the single body stops, the clone continues, and the clone has no apex (measured, 2.13, 2.15). Read: the body fills to 19.8 and is held there by the water column; the subtree fills on.

4.4 The remainder: $\Psi^2 = 0$, ϕ and the leaf

Text. "Counterwinding on its own winding is unwinding: $\Psi^2 = 0$." An existing closure "cannot load twice in succession without first discharging." "That is exactly the constraint that generates Fibonacci: $x^2 = x + 1$." " ϕ is the law of tension"; "growth in time, binary." (1.4.)

Measured. Cone-scale parastichies are 8/13 in 5,838 of 6,000 *Pinus nigra* cones and 5/8 in 1,181 of 1,506 *Larix* cones; the source states that the aberrant patterns grow rarer with the deviation of their quotient from 0.618, and all of them lie within two of a convergent pair; the small aberrant counts themselves are not strictly monotone (2.11, Part 5). Sunflower parastichy counts are Fibonacci in 565 of 768 reviewed counts, 73.6 per cent (Part 5). The same Fibonacci order arises in a physical experiment in which each new element is placed where the earlier ones leave most room, explained by the system's avoidance of rational, periodic arrangements (Douady & Couder 1992, annotated references).

Computed. The convergents of ϕ are 1/1, 2/1, 3/2, 5/3, 8/5, 13/8, 21/13; of $1/\phi$, 1/1, 1/2, 2/3, 3/5, 5/8, 8/13 (the measured parastichy pairs; 8/13 is the sixth); of $1/\phi^2 = 0.381966$, 1/2, 1/3, 2/5, 3/8, 5/13, 8/21 (the classical leaf fractions). The angle $360/\phi^2 = 137.508^\circ$ follows; it is computed here and not read in a source. The net's closure depths are the convergents of $\log_2 3$ with residues that never reach one (1.6). Both are the same arithmetic: a continued fraction of an irrational, approached by convergents, with a remainder that leaves the next step open. The comma at depth 12 is 23.5 cents; the gap between 8/13 and $1/\phi$ is 0.0026.

Read. The text derives ϕ for growth in time from a constraint: the next step cannot repeat the one before. The plant lays down each new leaf where the earlier ones leave room, never on the last. These are two descriptions of one constraint. In the net it gives the Fibonacci rule for growth in time; in the plant it gives the Fibonacci leaf. The identification is a read. It adds no rule, because both halves are in print. Of the pairings in this book it is the one that holds across groups: the parastichy pairs are measured in a conifer and a eudicot; distichous (1/2) and tristichous (1/3) arrangements, the first convergents, are stated for grasses and *Pandanus* only in secondary sources (Part 6).

Status. Text + measured + computed; pairing read. The measured half stands at 97.3 per cent (5,838 of 6,000) on one convergent. The test of the pairing itself was ill-posed and is to be remade (Part 5, test 2).

4.5 Two counts

Text. Address ternary; growth in time binary and ϕ ; never mixed (1.4).

Measured. In time: isotomous (two-way) branching in *Cooksonia* (measured, dossier); two life-cycle phases (2.6); two whole-genome duplications in the seed-plant and angiosperm ancestry (measured, dossier); Fibonacci cone scales (2.11). In form: 6×3 cellulose synthases per microfibril; three monolignols (measured, dossier). Against these: 4 charges in the Kok cycle, Mn_4CaO_5 , 35 and 96 chlorophylls, 14 c-subunits, 4 hemicellulose classes, 4 origins of the flat leaf (measured, dossier); 62 C4 lineages (2.13); teeth per whorl 14–50 in *Equisetum* (2.8); whorls of 3 tepals and 3 stamens in the ancestral flower (2.12); pentamerous flowers in eudicots (2.14). "Measured, dossier" marks a count verified in the companion dossier of the essay and not carried into Part 2; its source is in the annotated references.

Tested. On a text chosen before looking, the count list runs the other way: twos dominate standing form, and among the eleven process counts twos and threes tie at five each (Part 5, test 1). **Failed.** The pairing is withdrawn.

4.6 Filling against pressure

Text. "The filling of depths until the next is forced" (1.5).

Measured. The same forms arose many times, independently: C4 photosynthesis in 62 lineages, 36 eudicot and 26 monocot (2.13); filamentous growth at least five times in the Zygnematophyceae (2.4); parasitism twelve times (2.14); roots more than once, the lycophyte rooting axes of *Asteroxylon* separate from the roots of other plants (measured, dossier; 2.7 for the *Asteroxylon* anatomy); laminate leaves four times, secondary growth in at least seven lineages, multicellularity eleven times narrowly and twice in each photosynthetic clade (measured, dossier).

Read. The text says an organism is a closure at a depth, a species a subtree, and evolution a filling until the next depth is forced. The inference that the same form then appears in many subtrees at about the same time, without a single inventor, is made here and is not a text statement. The standing account reads the same counts as convergent evolution under one pressure; for C4 the dates follow the Oligocene fall of CO_2 . The counts do not separate the two readings.

Tested. 53 dated C4 origins: 92 per cent in the last 20 Myr, median 8.9 Ma. A Poisson fit against CO_2 beats the null by 50 AIC units. The filling predictor, the accumulated C3 lineages of the grass tree, could not be built because the dated tree was not retrievable (Part 5, test 3). **Not run.** The pressure side fits strongly; the filling side is unknown.

4.7 The tree

Positions. $3^{18} \cdot S_0 = 17.7$ m, $3^{19} \cdot S_0 = 53.0$ m, $3^{20} \cdot S_0 = 159$ m (computed); the Climate paper's Appendix A names "large tree" and "tall tree (50 m)" beside 18 and 19 (text). The first trees, *Wattieza*, ≥ 8 m at 17.28 (2.9). The scale trees of the Carboniferous, 45 m at 18.85 (2.7). *Picea abies* 50–60 m, 18.95–19.11; *Pinus sylvestris* over 40 m, 18.74 (2.11). *Ginkgo* 20–40 m, with a 64 m report, 19.17 (2.10). *Liriodendron* about 61 m, 19.13 (2.12). *Eucalyptus regnans* over 70 m, "up to 100 m", 19.58 (2.14). *Sequoia* 112.7 m, 19.69, limit 122–130 m, 19.76–19.82 (2.11). Trees fill from 17.3 to 19.8. None has reached 20 in 385 Myr (measured; positions computed).

Times. The growth ring, one year, 48.87. First seed: *Sequoia* 5–15 years, 50.34–51.34; *Pinus sylvestris* 5–8 years; *Quercus robur* 20 years, 51.60; *Fagus* 40–50, 52.23–52.43; *Picea abies* 20–30 years or 40–60 by another source (2.11, 2.14). Needle of *Pinus longaeva* 45 years, 52.34. Lifespans: *Picea abies* 200–300 years; *Pinus sylvestris* 400+, one tree over 750, 54.90; *Quercus robur* over 1,000, >55.16 ; *Sequoia* about 2,200 by ring count, 55.88; baobab Panke 2,450 radiocarbon years,

55.97; *Pinus longaeva* 4,900 rings, 56.60 (2.11, 2.14). Clones: *Jurupa* oak over 13,000 years, 57.49; *Posidonia* at least 12,500 and bounded at 80,000–200,000, 57.46 and 59.15–59.98; *Lomatia* at least 43,600, 58.59 (2.13–2.15). The single tree reaches 56.6; the clone 60.

Build. *Cooksonia* branches isotomously, two equal daughters (measured, dossier); *Asteroxylon* dichotomises anisotomously (2.7). *Archaeopteris*, 385 Ma, branches laterally, "a lateral branching syndrome" of the modern-tree type, with secondary growth (2.9). In the texts only the address tree branches, and it branches in three with a return term (1.3). The tree of wood branches in two, then laterally, and its daughters conserve the cross-section (Leonardo's rule; measured, dossier). These do not run parallel; no rule is added to make them.

The two classes. The texts divide closed forms, which persist, from carriers, which decay (*Where Illness Comes From; From Atom to Body*, Part 0.5). A pine has been counted at 4,900 rings (measured, 2.11). Read: a trunk is nearly all closed form that has stayed, dead wood, each ring the walls of cells that lived one season, with the living part a thin layer around it; the tree is then the organism in which N3, "the net keeps the orientation of what was first laid down", is visible as form. The ring is N3 in wood. This is a reading of common wood anatomy, not a measurement of Part 2.

4.8 Where the two do not meet

- **The ring depths above the cell.** None (4.2).
- **The closure depths.** Depth 12 is 24.23 mm and 80.8 ps; 41 is 92.4 min; 53 is 93.4 years (1.6). Tables B2 and C2 hold no verified plant quantity at these as a characteristic value. The nearest: in the companion dossier, charge separation 3 ps and the step to the quinone 200–250 ps, stomatal half-times 10–20 min (measured, dossier); in Part 2, needles of 45 years, *Quercus robur* first acorns at 20 years, *Pinus sylvestris* viable seed to age 200 (2.11, 2.14). None.
- **The half step and the families of layers.** Not applied. The day sits at 43.50; *Prochlorococcus* divides about once a day and *Wolffia* in 29.3 h, 43.68 (2.1, 2.13). That is the day, not the half step. No claim.
- **Clustering at whole positions.** The 128 sizes of Table B2 are too few and too unevenly chosen to repeat the test of *From Atom to Body*. No claim.

4.9 Summary

#	Text statement	Measured fact	Status after Part 5
	Ring depths 3, 6:	The first plant is the cell; no text gives a	None above the cell
	Position: each depth n is a layer, 3 ⁿ -S ₀	128 sizes, 92 durations, each with a position	Coordinates, complete for the verified set
	Filling of depths until the next is forced	Maximum body rises 2.5 → 9.1 → 17.3 → 18.9 → 19.7 and stops at the water limit	Read; descriptive; not discriminating
	Ψ ² = 0 → Fibonacci → φ, growth in time; remainder	Parastichies 8/13 in 97.3 % of 6,000 cones, 73.6 % Fibonacci in sunflowers;	Read; measured half confirmed; pairing
	Address ternary, time binary	Count list of a text chosen in advance	Failed, reverse;
	Filling against pressure	53 dated C4 origins	Not run; pressure fits
	N3, memory of what was first laid down; two classes	Growth rings, 4,900 in one stem; dead wood with a living layer	Read; descriptive
	Closure depths 12, 41, 53	No plant quantity there	None

Part 5 — The Tests, Fixed First and Then Run

Three tests were fixed before any data were looked at, in the essay *The Remainder in the Leaf* of 11 October 2026, and run by Claude Code on 12 October 2026 on the data named in advance. The attestation is the author's. Protocols, data rows and scripts are in the files T1-tellijst.md, T2-convergenten.md, T3-c4.md and T3-c4-fit.py that accompany this book.

5.1 Test 1 — the count list

Fixed first. Source: OpenStax Biology 2e, chapters 8, 30 and 32. Every integer count of a plant structure or process. Each classified as standing form or growth in time before looking at its value. Required: counts divisible by three over-represented in form, and counts in $\{2\} \cup \text{Fibonacci}$ over-represented in time, each one-sided Fisher $p < 0.01$. Chance: no association.

Found. 134 counts: 116 form, 11 time, 7 other. Multiples of three: 32 of 116 form (27.6 per cent), 6 of 11 time (54.5 per cent), $p = 0.98$. Twos and Fibonacci: 5 of 11 time (45.5 per cent), 71 of 116 form (61.2 per cent), $p = 0.91$. Two is the commonest form count (66 of 116: two guard cells, two cotyledons, two sperm cells, two photosystems). Among the eleven process counts, two and three tie at five each (three stages, three turns of the Calvin cycle; two phases, two divisions).

Verdict. Fail, in the opposite direction. Correlation 4.5 is withdrawn.

5.2 Test 2 — the convergents

Fixed first. Data: Swinton et al. 2016 (657 sunflowers) and Fierz 2015 (6,000 *Pinus nigra* and 1,506 *Larix* cones). Required: (a) the frequency of each Fibonacci pair falls with its order in the convergent sequence on either side of the mode, Spearman $p < 0.01$; and (b) non-convergent pairs at or below the authors' noise rate, or 10 per cent if none is stated.

Found. Swinton: the per-value counts are in a data file that could not be retrieved; (a) not run. Non-convergent share over all 768 reviewed counts, 17.8 per cent; among heads the authors call unambiguous, 5 per cent; (b) fails on the full sample as fixed. Fierz: non-convergent 0.40 per cent in pine (24 of 6,000) and 3.85 per cent in larch; (b) passes. Each sample holds one Fibonacci pair, 8/13 or 5/8; a Spearman over several pairs cannot be formed; (a) not computable.

Verdict. Fail by the rule as written. The rule asked single-species cone samples for a sequence they cannot hold. What the data show is narrow and firm: 97.3 per cent of 6,000 cones on one convergent of $1/\phi$, and aberrations rarer the further from 0.618. That is the measured half of correlation 4.4, confirmed. The test of the pairing with the net must be rebuilt on data with several Fibonacci pairs per sample.

5.3 Test 3 — filling against pressure

Fixed first. Data: C4 origin dates from Christin et al. 2008 (grasses) and 2011 (eudicots); the accumulated C3 lineages from the dated grass tree of Spriggs et al. 2014; atmospheric CO_2 from Foster et al. 2017. Required: Poisson fits of origins per 5 Myr against $\log N_{\text{C3}}(t)$ and against $\text{CO}_2(t)$; the filling reading needs the first to win by two AIC units, the pressure reading the reverse.

Found. 53 origins with dates (six rows ending in C3–C4 intermediates or C4-like states excluded by a rule fixed before fitting). Histogram in 5-Myr bins from 0 to 65 Ma: 10, 17, 12, 8, 4, 1, 0, 1, 0, 0, 0, 0, 0. Median 8.9 Ma; oldest grass origin 28.5 Ma (core Chloridoideae); oldest overall 38.65 Ma (*Tribulus*, with a poorly constrained stem of 63.5 and crown of 13.8 Ma). CO₂ (Tierney et al. 2020 binned compilation, a labelled substitute for the unreachable Foster file): the fit beats the null by 50.2 AIC units, slope –0.72 per 100 ppm. The dated grass tree on Dryad could not be retrieved, nor could any posterior node ages; the filling predictor was not built.

Verdict. Not run. The pressure side is as strong as the standing account says. Whether the filling side would match it is unknown. The scripts take the missing predictor unchanged once the tree file is supplied.

5.4 What the tests leave

One pairing is withdrawn (4.5). One is untested but its measured half is confirmed (4.4). One is untested and its rival fits strongly (4.6). The descriptive pairings (4.3, 4.7) were not put to a test that could fail, and are marked so.

Part 6 — Not Verified, and Left Out

6.1 Not verified

Each entry of Part 2 ends with its own list. The items that matter most for Parts 3 and 4, gathered:

- Body sizes of early land plants: *Cooksonia* "a few cm" and *Rhynia* about 0.20 m are secondary (Boyce 2008; Kidston & Lang 1917/1920 not opened). The row 1.0 Ga – 385 Ma in 4.3 is therefore empty.
- *Archaeopteris* trunk and height, 1.5 m and 30 m (Meyer-Berthaud et al. 2000, not opened); the 11–32 m used is an estimate from root systems in Stein et al. 2020.
- *Lepidodendron* 40–50 m and *Calamites* 30–50 m beyond the "c. 45 m" of Thomas & Cleal 2018.
- Hyperion, 115.55–116.22 m: no peer-reviewed measurement located; the book uses Koch et al. 2004, 112.7 m.
- *Eucalyptus regnans* individual heights beyond "up to 100 m" in a title (Sillett et al. 2015).
- Ring-counted *Ginkgo* ages (Wang et al. 2020, PNAS, blocked); Methuselah's exact count (4,789 or 4,845, secondary); Old Tjikko (Öberg & Kullman 2011, not opened).
- Phylloaxis fractions by group: 2/5 and 3/8 for named mosses and eudicots, 1/2 for grasses, 1/3 for *Pandanus* — textbook statements, no primary opened. The divergence angle 137.5° as a measurement.
- The 8-photon minimum per O₂, the Calvin stoichiometry 3 CO₂ per triose, L₈S₈, and the 3 ATP : 2 NADPH ratio — molecular formulas not read in a source this session.
- Counts marked "measured, dossier" in Part 4 were verified in the companion dossiers of the essay (files A-tijdljn.md, B-maten-tijden.md, C-tellingen.md) and not carried into Part 2; their sources stand in the annotated references. A later edition should move them into Part 2.
- Species counts per algal group (Guiry & Guiry 2012, Table 1, not opened).
- Swinton et al. 2016 per-value parastichy counts (Dryad); Spriggs et al. 2014 dated tree (Dryad); Foster et al. 2017 CO₂ file. These three files complete tests 2(a) and 3.

6.2 Left out, by rule

- Any family of layers; any rounding of a position to a mark; the half-step family of the day.
- Any ring depth above the cell.
- Any sentence in which the net causes a plant form.
- Lichens, which are fungi with photosynthetic partners; corals and other animals with photosynthetic symbionts; the rhodopsin-based phototrophs, which make no oxygen and fix no carbon by photosynthesis.
- Secondary sources as facts: Wikipedia, the Gymnosperm Database, Guinness, fact sheets. They appear only in "Not verified" lists, with the primary they name.

References for Parts 2 and 3

Numbered in order of first use across entries 2.1 to 2.15. Citations are given as the data files give them; partial details stay partial.

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Annotated references for Parts 0, 1, 4 and 5

Konstapel, J. (2026). *The Vacuum.Net Theory: Complete Derivation*. Constable Research, Leiden, 28 September 2026. Why read? The five axioms N1–N5, the trit, the closure rule, and Larson's natural units. Part 1.1 quotes it.

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Konstapel, J. (2026). *The Climate on the Ladder of Three: Layers, Closure and the Three Families of the Vacuum.Net*. Constable Research, Leiden, 3 October 2026. Why read? The closure rule in full, the period-3 theorem with its count 9, 3, 3, 9, 3, 3, 9, the range $(3^n - 1)/2$, the definition of depth as layer with length $3^n \cdot S_0$, and §3.2, where the ladder of three meets the ladder of two: the convergents of $\log_2 3$ and the comma.

Konstapel, J. (2026). *Life and Consciousness from One Rule: Closure in the Net*. Constable Research, Leiden, 29 September 2026; PDF at constable.blog/wp-content/uploads/Life-and-Consciousness-from-One-Rule-Closure-in-the-Net.pdf (the blog page carries the Dutch text). Why read? The rings per depth, 3, 6, 11, 24, 51, 130; the two living rings at depth 3; the gap at 4 and 5; the division at 6 as the form of a single cell. The reason Part 4.2 finds no ring depth above the cell.

Konstapel, J. (2026). *The Universe of Peter Rowlands: A Comprehensive Review of the Nilpotent Quantum Paradigm and Its Extended Network*. Constable Research, Leiden, 29 June 2026. And Rowlands, P. (2007). *Zero to Infinity: The Foundations of Physics*. World Scientific, Series on Knots and Everything 41. Why read? Where $\Psi^2 = 0$ comes from: an operator whose square is zero, and a totality that is nothing.

Konstapel, J. (2026). *Where Illness Comes From*. Constable Research, Leiden, ninth edition. Why read? The two classes, closed forms and carriers; the transition as "the next permitted closure depth being reached"; the remainder rule, "a ladder driven by a rest cannot end." *Reading advice:* Chapter 2.

Konstapel, J. (2026). *From Atom to Body: A Reference Work on the Build of the Human Body, What It Needs and What the Earth Supplies*. Constable Research, Leiden, first edition. Why read? The four marks, the ladder and its units, and the test that showed the ladder orders but does not select. This book is built to its rules.

Konstapel, J. (2026). *The Remainder in the Leaf: The Evolution of Plants and Trees Set Beside the Evolution of the Net*. Constable Research, Leiden, 12 October 2026. Why read? The essay that preceded this book; the same pairings in short form, with the three tests as first reported.

Douady, S., and Couder, Y. (1992). "Phyllotaxis as a physical self-organized growth process." *Physical Review Letters* 68, 2098–2101. DOI 10.1103/PhysRevLett.68.2098. Why read? Fibonacci order made in a dish: each new element placed where the earlier ones leave room, and the golden mean as the escape from every rational arrangement. The measured half of Part 4.4 outside biology. Verified through OpenAlex; abstract read.

Swinton, J., Ochu, E., and the MSI Turing's Sunflower Consortium (2016). "Novel Fibonacci and non-Fibonacci structure in the sunflower: results of a citizen science experiment." *Royal Society Open Science* 3, 160091. DOI 10.1098/rsos.160091. Why read? 657 sunflowers; 565 of 768 parastichy counts Fibonacci. The non-Fibonacci minority that test 2 needs, and the data file on Dryad ([doi:10.5061/dryad.f9k77](https://doi.org/10.5061/dryad.f9k77)) that would complete it.

Fierz, V. (2015). "Aberrant phyllotactic patterns in cones of some conifers: a quantitative study." *Acta Societatis Botanicorum Poloniae* 84, 261–265. DOI 10.5586/asbp.2015.025. Why read? 6,000 cones from one pine: 5,838 on 8/13, and the aberrant patterns ranked by their distance from 0.618. The firmest number in Part 4.4.

Koch, G. W., Sillett, S. C., Jennings, G. M., and Davis, S. D. (2004). "The limits to tree height." *Nature* 428, 851–854. DOI 10.1038/nature02417. Why read? Water tension and leaf

water content measured at the tops of the tallest redwoods; the 112.7 m tree and the 122–130 m limit of Part 4.3 and 4.7.

Christin, P.-A., et al. (2008). "Oligocene CO₂ decline promoted C₄ photosynthesis in grasses." *Current Biology* 18, 37–43. DOI 10.1016/j.cub.2007.11.058. And **Christin, P.-A., et al. (2011).** "C₄ eudicots are not younger than C₄ monocots." *Journal of Experimental Botany* 62, 3171–3181. DOI 10.1093/jxb/err041. *Why read?* The dated C₄ origins of test 3: 18 grass lineages and 41 eudicot rows, of which 53 end in C₄.

Spriggs, E. L., Christin, P.-A., and Edwards, E. J. (2014). "C₄ photosynthesis promoted species diversification during the Miocene grassland expansion." *PLoS ONE* 9, e97722. DOI 10.1371/journal.pone.0097722. *Why read?* The dated grass tree (Dryad doi:10.5061/dryad.74b5d) whose lineage-through-time curve is the missing predictor of test 3.

Foster, G. L., Royer, D. L., and Lunt, D. J. (2017). "Future climate forcing potentially without precedent in the last 420 million years." *Nature Communications* 8, 14845. DOI 10.1038/ncomms14845. And **Tierney, J. E., et al. (2020).** "Past climates inform our future." *Science* 370, eaay3701; binned CO₂ compilation in the PastClimates repository. *Why read?* The CO₂ record of test 3; the Tierney file was used as a labelled substitute when the Foster file could not be retrieved.

OpenStax (2018). *Biology 2e*. Chapters 8, 30 and 32. openstax.org/books/biology-2e. *Why read?* The text chosen before looking for test 1; its 134 plant counts are the data on which the two-count pairing failed.

Sources of the counts marked "measured, dossier" in Part 4

Verified in the companion dossiers of *The Remainder in the Leaf* (files A-tijdlijn.md, B-maten-tijden.md, C-tellingen.md), each through its DOI and the publisher or repository page.

Edwards, D., Davies, K. L., and Axe, L. (1992). "A vascular conducting strand in the early land plant *Cooksonia*." *Nature* 357, 683–685. DOI 10.1038/357683a0. — isotomously branching axes.

Jiao, Y., et al. (2011). "Ancestral polyploidy in seed plants and angiosperms." *Nature* 473, 97–100. DOI 10.1038/nature09916. — two ancient whole-genome duplications, about 319 and 192 Ma.

Nixon, B. T., et al. (2016). "Comparative structural and computational analysis supports eighteen cellulose synthases in the plant cellulose synthesis complex." *Scientific Reports* 6, 28696. DOI 10.1038/srep28696. And **Hill, J. L., Hammudi, M. B., and Tien, M. (2014).** "The *Arabidopsis* cellulose synthase complex: a proposed hexamer of CESA trimers in an equimolar stoichiometry." *Plant Cell* 26, 4834–4842. DOI 10.1105/tpc.114.131193. — six lobes of three synthases, eighteen chains.

Vanholme, R., Demedts, B., Morreel, K., Ralph, J., and Boerjan, W. (2010). "Lignin biosynthesis and structure." *Plant Physiology* 153, 895–905. DOI 10.1104/pp.110.155119. — the three monolignols.

Kok, B., Forbush, B., and McGloin, M. (1970). "Cooperation of charges in photosynthetic O₂ evolution — I. A linear four step mechanism." *Photochemistry and Photobiology* 11, 457–475. DOI 10.1111/j.1751-1097.1970.tb06017.x. — four charges before oxygen release.

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**International Commission on Stratigraphy (2023). International Chronostratigraphic Chart
v2023/09. stratigraphy.org. — Carboniferous 358.9–298.9 Ma.**