

# Supplementary files

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## APPENDIX S1 – Supplementary texts

### LIST OF MORPHOLOGICAL CHARACTERS

Discrete and continuous morphological characters

#### Habit and vegetative morphology

- **1. Habit:** Based on character 7 of Rothwell (1999).
  - 0 Herbaceous
  - 1 Arborescent
- **2. Ribbed stem**
  - 0 Absent
  - 1 Present

- **3. Axes bearing spines (or trichomes):** Spiniform structures or trichomes borne on vegetative axes of certain stem monilophytes (e.g. *Anapaulia moodyi* (Berry and Edwards, 1996)), and early sphenophytes (e.g. *Hamatophyton verticillatum* (Wang and Guo, 2009)).
  - 0 Absent
  - 1 Present
- **4. Planation of vegetative appendages**
  - 0 Absent
  - 1 Present
- **5. Leaf (Planate and webbed sterile ultimate appendages)**
  - 0 Absent
  - 1 Linear and undivided
  - 2 Wedge-shaped
  - 3 Linear and divided
  - 4 Fimbriate
- **6. Successive dichotomous division of leaves**
  - 0 Absent
  - 1 Present but irregular
  - 2 Present and regular
- **7. Prominent heterophylly:** Corresponds to the presence of different leaf morphologies that are borne on the same organism. This character is particularly well observed in Sphenophyllales like *Hamatophyton*, *Sphenophyllum* species and to a smaller extent, in *Xihuphyllum megalofolium* (Huang *et al.*, 2017).
  - 0 Absent
  - 1 Present
- **8. Leaf sheaths:** Referring to the establishment of a foliar disc made of fused or partly fused vegetative leaves. Modified from the character 26 of Elgorriaga *et al.* (2018).
  - 0 Absent
  - 1 Partly present - leaves basally fused into a sheath.
  - 2 Entire leaf sheaths
- **9. Unfused part of leaves longer than sheath:** Same as the character 27 of Elgorriaga *et al.* (2018).
  - 0 Absent
  - 1 Present
- **10. Leaves per nodes**
  - 0 Whorls of four
  - 1 Whorls of six
  - 2 Whorls of >6
- **11. Branch taxis:** Same as the character 25 of Durieux *et al.* (2021)
  - 0 Irregular
  - 1 Helical

- 2 Whorled
- **12. Phyllotaxis or Taxis of homologous ultimate appendages:** Modified from the character 2 of Durieux et al. (2021). Vegetative ultimate appendages diverged from higher order branches; they have an overall simpler anatomy with a determinate growth and repeated morphology. Leaves are considered as highly derived, planate and webbed ultimate appendages.
  - 0 Irregular
  - 1 Helical
  - 2 Whorled
  - 3 Alternate-opposite
- **13. Branching of vegetative ultimate appendages (prior to the leaves):** Derived from the character 3 of Durieux et al. (2021).
  - 0 Iso-dichotomous
  - 1 Aniso-dichotomous
  - 2 Quadriseriate
- **14. Digitate branching (Low-angle branching producing sub-parallel distal branches):** Same as the character 26 of Durieux et al. (2021).
  - 0 Absent
  - 1 Present
- **15. Branching consistently associated with nodes**
  - 0 Absent
  - 1 Present
- **16. Ultimate appendages attached at same node as branches:** Same as the character 27 of Durieux et al. (2021).
  - 0 Absent
  - 1 Present
- **17. Branching of aerial shoot:** Same as the character 23 of Elgorriaga et al. (2018).
  - 0 Absent/irregular
  - 1 Present/regular
- **18. Num. of branching order**
  - 0 One
  - 1 Two
  - 2 >Two

### Anatomical features

- **19. Type of stele of aerial vegetative stems:** Based on character 29 of Rothwell (1999) for the use of the Equisetostele, modified from the character 13 of Elgorriaga et al. (2018) and the character 11 of Durieux et al. (2021) for the third state: Primary xylem dissected into multiple rib-like vascular segments, which is applied to the cladoxylopsids.
  - 0 Protostele (haplostele)
  - 1 Protostele (actinostele)
  - 2 Primary xylem dissected into multiple rib-like vascular segments
  - 3 Equisetostele

- **20. Triangular protosteles:**
  - 0 Absent
  - 1 Present
  
- **21. Medullary canal in aerial stems:** The character corresponds to the medullary central area, usually hollow in the equisetalean stems. Comparable to character 7 of Elgorriaga et al. (2018).
  - 0 Absent
  - 1 Present
  
- **22. Primary xylem maturation:** Comparable to characters 35 of Rothwell (1999), 12 of Elgorriaga et al. (2018) and 21 of Durieux et al. (2021).
  - 0 Endarch
  - 1 Mesarch
  - 2 Exarch
  
- **23. Metaxylem tracheid pitting:** Modified from the characters 18 of Rothwell and Serbet (1994), 37 of Rothwell (1999) and comparable to the character 18 of Durieux et al. (2021).
  - 0 *Psilophyton*-type (P-type)
  - 1 Scalariform
  - 2 Oval to circular pits
  - 3 Circular pits
  
- **24. Xylem rays:** Also called wood rays, they are sheets of parenchyma that radiates outward from the cambium, in the secondary xylem. Same as character 25 of Elgorriaga et al. (2018).
  - 0 Absent
  - 1 Present
  
- **25. Secondary xylem:** This character refers to radially aligned tracheids that are organised in files around protostelic or siphonostelic vascular tissues. Similar to the character 24 of Durieux et al. (2021).
  - 0 Absent
  - 1 Present
  
- **26. Bifacial cambium:** It refers to the presence of a bidirectional vascular cambium producing both secondary xylem and secondary phloem.
  - 0 Absent
  - 1 Present

### **Reproductive structures (fertile ultimate appendages)**

- **27. Homospory vs heterospory:** comparable to character 59 of Pryer *et al.* (1995), 80 of Rothwell (1999) and 59 of Elgorriaga *et al.* (2018).
  - 0 Homospory
  - 1 Heterospory
  
- **28. Strobili:** Implies a determinate growth of the fertile axis leading to the formation of a strobilus. It is based on the regulatory module RM2 defined by Tomescu *et al.* (2017). Comparable to character 43 of Elgorriaga *et al.* (2018).
  - 0 Absent
  - 1 Loosely constructed strobilus with long internodes

- 2 loosely constructed strobilus
  - 3 Compact strobilus
- **29. Division pattern of the fertile appendage:** Fertile ultimate appendages are often divided several times into stalks and sub-stalks bearing sporangia. This character emphasizes the complexity of the fertile ultimate appendages among sphenophytes and stem-group monilophytes.
  - 0 Absent (undivided)
  - 1 Dichotomous
  - 2 Trichotomous
  - 3 Polytomous
- **30. Number of divisions in the fertile appendage:** Modified from the character 4 of Durieux et al. (2021), which was applied to vegetative ultimate appendages. It refers to the number of successive divisions composing fertile appendages. These divisions can be dichotomous (conspicuous in the cladoxylopsids), trichotomous (e.g. *Rinistachya hilleri* and *Eviostachya hoegii*).
  - 0 One
  - 1 Two
  - 2  $\geq$  Three
- **31. Fertile appendage insertion:** This character refers to the overall diversity of fertile appendage insertions. An axillary insertion is more often encountered among the Late Devonian sphenophytes with almost two free components (a bract and the sporangium bearing unit). The coalescence between bracts and the fertile appendages occurs in derived Sphenophyllales (e.g. *Bowmanites*) and the internodal insertion is exclusively known in the Equisetales.
  - 0 Inserted in the bract axil
  - 1 (Partially) fused with the bract
  - 2 On the fertile axis (nodal insertion)
  - 3 On the fertile axis (internodal insertion)
- **32. Insertion angle of the fertile appendage:** Modified from character 52 of Elgorriaga et al. (2018). Acroscopic and basiscopic oblique angles were not differentiated as the basiscopic oblique angle is observed in one genus only: *Peltastrobus*, which have both acroscopic and basiscopic oblique angles. Moreover, this character is also applied to the Sphenophyllales, *Psilophyton* and Cladoxylopsids.
  - 0 Oblique angle
  - 1 Perpendicular (to the main axis)
- **33. Development of a shield or peltate tip on the fertile appendage:** Modified from character 49 of Elgorriaga et al. (2018). The shield corresponds to a layer of thick-walled cells that covers and protects the sporangia (Bateman, 1991). This structure is conspicuous among the equisetalean fertile ultimate appendages. A comparable shield is also observed in some Sphenophyllales like *Peltastrobus*, *Lilpopia* and in a lower extent to the genus *Bowmanites*. However, regarding the latter group, the shield is constrained to individual stalks, not the entire fertile appendage.
  - 0 Absent
  - 1 Shield development for individual stalks
  - 2 Shield development for the entire fertile appendage
- **34. Shield extension:** Same as the character 50 of Elgorriaga et al. (2018).
  - 0 Partly covering the sporangia

- 1 Covering entirely the sporangia but still distinct
  - 2 Sporangia and inter sporangium spaces are all covered
- **35. Bracts (laminar organs):** Comparable to the character 60 of Elgorriaga *et al.* (2018) and based on the fourth character of Bonacorsi and Leslie (2019). The laminar organ refers to a vegetative unit sometime called bract, which is associated to fertile appendages. The latter are also traditionally called “sporangiohores” in the Equisetales and some derived Sphenophyllales.
    - 0 Absent
    - 1 Present
  - **36. Sporangia per fertile appendage:** Comparable to the character 57 of Elgorriaga *et al.* (2018). Fertile appendages can be divided into multiple stalks, each bearing several sporangia. This character refers to the total amount of sporangia borne per fertile ultimate appendages (including all the subdivisions). Comparable to the character 57 of Elgorriaga *et al.* (2018).
    - 0 One
    - 1 Two
    - 2 Four
    - 3 Six or more
  - **37. Paired sporangia:** Same as the character 34 of Durieux *et al.* (2021). Refers to the presence of two sporangia per stalk in a fertile ultimate appendage. Widely observed among the cladoxylopsids *sensu lato* and Trimerophytes like *Psilophyton sp.* (Stein *et al.*, 1984).
    - 0 Absent
    - 1 Present
  - **38. Sporangium orientation:** Modified from the character 35 of Durieux *et al.* (2021). Pendulous sporangia are considered as long-stalked sporangium projections (e.g. in *Rotafolia songziensis*).
    - 0 Erect
    - 1 Recurved
    - 2 Pendulous
  - **39. Sporangium shape:** Modified from the character 36 of Durieux *et al.* (2021)
    - 0 Fusiform
    - 1 Elliptical
    - 2 Elongated
    - 3 Obovate
    - 4 Discoid
  - **40. Insertion mode of the sporangium:** The formation of a shield, occurring both in the Equisetales and derived Sphenophyllales, implies a sessile attachment of the sporangium. *Pseudobornia ursina* is also characterized by sessile and radially arranged sporangia on a cup- shaped and long stalked receptacle. *Peltastrobis reedae* shows another conformation of its sporangia. They are organized in two rows; the inner one is sessile, and the exterior one is stalked. Comparable to the characters 71 and 72 of Rothwell (1999).
    - 0 Stalked
    - 1 Sessile
    - 2 Sessile and stalked

- **41. Node internode differentiation within fertile phytomers** referring to the regulatory module RM3 of Tomescu *et al.* (2017). Same as the character 44 of Elgorriaga *et al.* (2018).
  - 0 Absent
  - 1 Present
- **42. Fertile appendage morphology:** Same as the character 33 of Durieux *et al.* (2021)
  - 0 Same as vegetative morphology
  - 1 Different from vegetative appendages
  - 2 Some include both fertile and vegetative parts
- **43. Position of fertile zones:** Same as the character 46 of Elgorriaga *et al.* (2018)
  - 0 On main stem
  - 1 On lateral branches
- **44. Whorled fertile appendages:** Feature commonly used to unite Sphenophyllales, Equisetales and some Iridopteridales (Berry and Edwards, 1996; Berry *et al.*, 2022; Fu *et al.*, 2011) as they all have whorled fertile ultimate appendages (Stein *et al.*, 1984).
  - 0 Absent
  - 1 Present
- **45. Fertile and foliar appendages diverging on alternate radii of the same node:** Character that is only observed in *Lilpopia raciborskii* (Kerp, 1984) and *Peltastrobus reedae* (Leisman and Graves, 1964).
  - 0 Absent
  - 1 Present
- **46. Whorls of vegetative units regularly alternating with whorls of fertile appendages at successive nodes:** Comparable to the character 45 of Elgorriaga *et al.* (2018). Whorls of fertile ultimate appendages are inserted on the internodes and are found in alternation with nodal inserted whorls of bracts. This morphological character is found among the Calamitaceae.
  - 0 Absent
  - 1 Present
- **47. Morphological differentiation of vegetative leaves and bracts:** This character points out an heterophylly between leaves borne on aerial stems and bracts, in the sphenophytes. It is comparable to the character 61 of Elgorriaga *et al.* (2018).
  - 0 Homogeneous morphology between leaves and bracts
  - 1 Differentiation of the bract morphology
- **48. Position of fertile appendage whorl(s) in relation to a sterile bract whorl within a single phytomer**
  - 0 Immediately above the bract (bract axil)
  - 1 Lower region of the internode
  - 2 Middle to upper region of the internode
- **49. Bract division**
  - 0 Absent
  - 1 One time divided (dichotomous)
  - 2 Polytomous division (trichotomous or more)
  - 3 Successive divisions
- **50. Bract margins**

- 0 Dissected
- 1 Toothed/serrate
- 2 Entire
- **51. Bract morphology (if different of the vegetative leaves)**
  - 0 Linear
  - 1 Falciforme-cuneate
  - 2 Cuneate/wedge-shaped
  - 3 Lanceolate
- **52. Laterally fused bracts:** It refers to the lateral basal fusion of the fertile leaves, forming a disk in some species of *Bowmanites* (e.g. *B. dawsoni* and *B. moorei* in (Good, 1978; Mamay, 1959)).
  - 0 Absent
  - 1 Present
- **53. Whorls of fertile appendages covering the internode:** Comparable to the character 51 of Elgorriaga *et al.* (2018). It refers to the coverage extent of the fertile ultimate appendage whorls per fertile internodes.
  - 0 Only one whorl per internode
  - 1 Partially (more than one whorl)
  - 2 Entirely (more than one whorl)

### Spores

- **54. Elaters:** Similar to characters 90 of Rothwell (1999) and 70 of Elgorriaga *et al.* (2018).
  - 0 Absent
  - 1 Present
- **55. Perispore:** Modified from characters 13 of Rothwell and Stockey (1994), 89 of Rothwell (1999) and comparable to the character 69 of Elgorriaga *et al.* (2018).
  - 0 Absent
  - 1 Present
- **56. Type of aperture:** Same as the character 75 of Elgorriaga *et al.* (2018), comparable to the character 86 of Rothwell (1999).
  - 0 Trilete
  - 1 Oval to sub-circular
  - 2 Monolete

### References

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## SCRIPTS FOR PHYLOGENIES

### Maximum parsimony analysis using extended implied weighting

```

macro= ;
mxram 512 ;
piwe=6;
collapse rule 1;
proc \Users\arast\OneDrive\Bureau\NewPhylo;
log \Users\arast\OneDrive\Bureau\NewPhylo_IWk6.out;
xpiwe=;
xmult: xss ratchet 200 drift 10 hits 5 replications 10 verbose;
bbreak: xbit safe tbr;
hold 1000000 ;
rseed 1234 ;
ttags= ;

xmult ;
bbreak ;

tsave D:\NewPhylo_IWk6.ctf;
save ;
tsave/ ;

export * + \Users\arast\OneDrive\Bureau\NewPhylo_IWk6.nex;

resample [mu1=ho1;] sym rep 10000 prob 33 freq from 0;
ttags ;

nelsen* ;
tchoose {strict};

```

```

len;

report- ;
var: themin themax CI RI TL;

set themin minsteps;
set themax maxsteps;
set TL length[0];

set CI 'themin'/'TL';
if ( 'themax' != 'themin' )
  set RI ( 'themax' - 'TL' ) / ( 'themax' - 'themin' );
else
  set RI 999 ; /* cas pathologique : RI non défini */
end

log + \Users\arast\OneDrive\Bureau\NewPhylo_IWk6.out;
macfloat 3 ;
quote \n--- Indices (consensus strict) ---\n ;
quote CI = 'CI' ;
if ( 'RI' == 999 ) quote RI = NA ; else quote RI = 'RI' ; end
quote TL = 'TL' ;
log/ ;

log / ;
quit ;

```

## Bayesian inference of phylogeny (Nexus file for MrBayes)

#NEXUS

BEGIN DATA;

DIMENSIONS NTAX=28 NCHAR=56;

format datatype=standard missing=? interleave=no gap=-;

MATRIX

```
Psilophyton_dawsonii      00000----00000-020-00000-00122-0-031100-110-----0?0
Panxia_gabata             ?0010----03(0 1)000012-012000001?2-0-0?0040-110-----???
Denglongia_hubeiensis    00010----23(0 1)010012-01100000122-0-030000-110-----010
Calamophyton_primaevum    10000----1(0 1)(0 1)100022-012?0-00122-0-031110-110-----0?0
Pseudosporochnus_nodosus 10000----10(0 1)100022-01200-00112-0-031010-210-----???
Ibyka_Anapaulia ?0100----2(1 2)0011021001300-00122-0-031(1 2)10-011-----???
Compsocradus_laevigatus  ?0000----2(1 2)001102(1 2)001200-00122-0-031(1 2)30-011-----???
Hamatophyton_verticillatum 0?103100-122-01-011102100-010-210-00011011(0 1)100-----0?0
Rinistachya_hillieri     00013200-(1 2)22-01-?????????0121000-1311101111000-(1 3)200-???
Eviostachya_hoegii      ?1?????0-122-01-??1102100-0221210-0311(1 2)011?100-----0?0
Bowmanites_dawsonii      01012(1 2)?0-(1 2)22-01-021102(1 2)111020-1-101101101111001-1221-01(0 2)
Bowmanites_moorei        01012(1 2)?0-(0 1)22-01-021102(1 2)111020-1-101101101111001-2221-0?(0 2)
Bowmanites_myriophyllus  0101(2 3)(1 2)10-122-01-02?????????020-1-101201101111001-11(2 3)0-002
Bowmanites_priveticensis 0101(2 3)(1 2)10-122-01-02?????????020-1-101201101111001-11(2 3)0-002
Leeites_oblongifolis     01012210-122-01-02?????????020-1-101101101111001-22(2 3)0-0?2
Cheirostrobos_pettycurensis ????-??-22-01-??1002(1 3)??020-00101201211??100?02220-000
Peltastrobos_reedae      ?????-??-22-01-??1102(1 2)??013?(0 2)(0 1)111301121??110?-1220-012
Lilpopia_raciborskii    ?0012010-122-01-?????????003?2112130?1?1111101-0220-???
Pseudobornia_ursina      1101(3 4)200-022-01-023-1????020-000-1300(2 3)11111001-1220-010
Protocalamostachys_arranensis ?1013200-(1 2)22-01-013-1(1 2)(1 3)110020-31220201(1 2)11111-1?-----2010
Cruciaetheca_patagonica  010110011222-01-11?????????00-31210201??1111-10202011??
Paracalamitina_striata   01011001?222-01-11?????????00-31210201??1111-10202012??
Palaeostachya_guanglongii 110110011222-01-113-101110120-3021120111111011002200110
Calamostachys_americana  110110011222-01-013-10(1 2 3)110120-3121120111111011102210110
Calamostachys_binneyana  110110011222-01-113-10(1 2 3)110020-3121120111111011102210110
Neocalamites_sp          (0 1)1011000-222-01-1(0 1)3-11?00-130-31220301?101(0 1)1-0-----??0
Equisetites_arenaceus    010110020222-01-1(0 1)3-11300-030-31220301(1 2)10111-0-----??(0 1)
Equisetum_spp            010110020222-01-(0 1)(0 1)3-11300-030-31220301210101-0-----1?1
```

;

END;

BEGIN mrbayes;

SET autoclose=no nowarn=yes;

LOG START filename=PHYLOSP.screenlog;

OUTGROUP Psilophyton\_dawsonii;

[LSET: set likelihood parameters]

LSET nst=1 rates=gamma coding=informative; [nst is number of substitution types, 1 forces all rates to be the same, this is what needs to be used in morpho datasets]

CALIBRATE Psilophyton\_dawsonii = uniform(393,407);

CALIBRATE Panxia\_gabata = uniform(382.7,387.7);

CALIBRATE Denglongia\_hubeiensis = uniform(372.2,382.7);

CALIBRATE Calamophyton\_primaevum = uniform(387.7,393.3);

CALIBRATE Pseudosporochnus\_nodosus = uniform(387.7,393.3);

CALIBRATE *Ibyka\_Anapaulia* = uniform(372.2,387.7);  
 CALIBRATE *Compsocradus\_laevigatus* = uniform(382.7,385);  
 CALIBRATE *Hamatophyton\_verticillatum* = uniform(358.9,372.2);  
 CALIBRATE *Rinistachya\_hilleri* = uniform(358.9,372.2);  
 CALIBRATE *Eviostachya\_hoegii* = uniform(358.9,372.2);  
 CALIBRATE *Peltastrobilus\_reedae* = uniform(315.2,323.2);  
 CALIBRATE *Bowmanites\_dawsoni* = uniform(315.2,323.2);  
 CALIBRATE *Bowmanites\_moorei* = uniform(307,315.2);  
 CALIBRATE *Bowmanites\_myriophyllus* = uniform(307,315.2);  
 CALIBRATE *Bowmanites\_priveticensis* = uniform(307,315.2);  
 CALIBRATE *Leeites\_oblongifolis* = uniform(293.5,298.9);  
 CALIBRATE *Cheirostrobilus\_pettycurensis* = uniform(330.9,346.7);  
 CALIBRATE *Lilpopia\_raciborskii* = uniform(293.5,303.7);  
 CALIBRATE *Pseudobornia\_ursina* = uniform(358.9,372.2);  
 CALIBRATE *Protocalamostachys\_arranensis* = uniform(346.7,358.9);  
 CALIBRATE *Cruciaetheca\_patagonica* = uniform(290.1,293.5);  
 CALIBRATE *Paracalamitina\_striata* = uniform(273,283.5);  
 CALIBRATE *Palaeostachya\_guanglongii* = uniform(307,315.2);  
 CALIBRATE *Calamostachys\_americana* = uniform(303.7,307);  
 CALIBRATE *Calamostachys\_binneyana* = uniform(315.2,323.2);  
 CALIBRATE *Neocalamites\_sp.* = uniform(266.9,273);  
 CALIBRATE *Equisetites\_arenaceus* = uniform(237,242);  
 CALIBRATE *Equisetum\_spp.* = uniform(192.9,199.5);

[Priors of the phylogeny]

PRSET applyto=(all) symdirihyperpr=fixed(infinity) Brlenspr=clock:fossilization Sampleprob=0.1  
 Fossilizationpr=beta(1,150) Speciationpr=exponential(1) Extinctionpr=beta(1,1) Samplestrat=fossiltip  
 Nodeagepr=calibrated clockratepr=lognorm(0.00627,0.5) Clockvarpr=igr [to allow relaxed clock rate using a  
 gamma distrib] Igrvarpr=exponential(1) [to set priors for the relaxed clock, values of exp1, exp3 and exp10  
 (default) have been published for fossils];

[Parameters of Markov Chain]

MCMC temp=0.1 ngen= 10000000 mcmcdiagn=yes stoprule=yes stopval=0.01 relburnin=yes burnfrac=0.25  
 printfreq=5000 samplefreq=1000 nchains=4 nruns=4 savebrlens=yes;

MCMC filename=PHYLOSPproc;

SUMP;

SUMT contype=allcompat;

LOG STOP;

END;

## R-script – Time scaled phylogenetic tree

```
data=read.tree(file.choose())
data = read.nexus(file.choose())
AGE = read.csv(file.choose(), sep = ";", dec = ",", header = TRUE)
AGEO = as.data.frame(AGE)
row.names(AGEO) <- AGEO[,1]
AGEX = AGEO[,-1]

Data2 = ladderize(data, right = TRUE)
plot(Data2)

tree_a <- DatePhylo(Data2, ages = AGEX, method = "equal", rlen = 2)
geoscalePhylo( tree_a, AGEX, boxes = "Age", x.lim = c(398, 150), cex.tip = 5.5, width = 8, cex.age = 3,
cex.ts = 3.5, ts.col=TRUE, erotate=0, arotate=90, urotate = 90, tick.scale = 50, vers = "ICS2015")
StratPhyloCongruence(tree_a, AGEX, rlen = 0, method = "basic", samp.perm = 100, rand.perm = 100,
hard = TRUE, randomly.sample.ages = FALSE, fix.topology = FALSE, fix.outgroup = FALSE,
outgroup.taxon = NULL, calculate.SCI = TRUE)
```

## Supplementary tables

Table S1: Matrix of morphoanatomical characters (character 1 to 18)

Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
<i>Psilophyton dawsonii</i>	0	0	0	0	0	-	-	-	-	-	0	0	0	0	0	-	0	2
<i>Panxia gabata</i>	?	0	0	1	0	-	-	-	-	-	0	3	0&1	0	0	0	0	1
<i>Denglongia hubeiensis</i>	0	0	0	1	0	-	-	-	-	-	2	3	0&1	0	1	0	0	1
<i>Calamophyton primaevum</i>	1	0	0	0	0	-	-	-	-	-	1	0&1	0&1	1	0	0	0	2
<i>Pseudosporochnus nodosus</i>	1	0	0	0	0	-	-	-	-	-	1	0	0&1	1	0	0	0	2
<i>Ibyka and Anapaulia</i>	?	0	1	0	0	-	-	-	-	-	2	1&2	0	0	1	1	0	2
<i>Compsocradus laevigatus</i>	?	0	0	0	0	-	-	-	-	-	2	1&2	0	0	1	1	0	2
<i>Hamatophyton verticillatum</i>	0	?	1	0	3	1	0	0	-	1	2	2	-	0	1	-	0	1
<i>Rinistachya hilleri</i>	0	0	0	1	3	2	0	0	-	1&2	2	2	-	0	1	-	?	?
<i>Eviostachya hoegii</i>	?	1	?	?	?	?	?	0	-	1	2	2	-	0	1	-	?	?
<i>Pelastrobos reedae</i>	?	?	?	?	?	?	?	?	?	?	2	2	-	0	1	-	?	?
<i>Bowmanites dawsoni</i>	0	1	0	1	2	1&2	?	0	-	1&2	2	2	-	0	1	-	0	2
<i>Bowmanites moorei</i>	0	1	0	1	2	1&2	?	0	-	0&1	2	2	-	0	1	-	0	2
<i>Bowmanite myriophyllus</i>	0	1	0	1	2&3	1&2	1	0	-	1	2	2	-	0	1	-	0	2
<i>Bowmanites priveticensis</i>	0	1	0	1	2&3	1&2	1	0	-	1	2	2	-	0	1	-	0	2
<i>Leeites oblongifolis</i>	0	1	0	1	2	2	1	0	-	1	2	2	-	0	1	-	0	2
<i>Cheirostrobos pettycurensis</i>	?	?	?	?	?	?	?	?	?	?	2	2	-	0	1	-	?	?
<i>Lilpopia raciborskii</i>	?	0	0	1	2	0	1	0	-	1	2	2	-	0	1	-	?	?
<b><i>Pseudobornia ursina</i></b>	1	1	0	1	3&4	2	0	0	-	0	2	2	-	0	1	-	0	2
<i>Protocalamostachys arranensis</i>	?	1	0	1	3	2	0	0	-	1&2	2	2	-	0	1	-	0	1
<i>Cruciaetheca patagonica</i>	0	1	0	1	1	0	0	1	1	2	2	2	-	0	1	-	1	1
<i>Paracalamitina striata</i>	0	1	0	1	1	0	0	1	?	2	2	2	-	0	1	-	1	1
<i>Palaeostachya guanglongii</i>	1	1	0	1	1	0	0	1	1	2	2	2	-	0	1	-	1	1
<i>Calamostachys americana</i>	2	1	0	1	1	0	0	1	1	2	2	2	-	0	1	-	0	1
<i>Calamostachys binneyana</i>	2	1	0	1	1	0	0	1	1	2	2	2	-	0	1	-	1	1
<i>Neocalamites</i> sp.	0&1	1	0	1	1	0	0	0	-	2	2	2	-	0	1	-	1	0&1
<i>Equisetites arenaceus</i>	0	1	0	1	1	0	0	2	0	2	2	2	-	0	1	-	1	0&1
<i>Equisetum</i> spp.	0	1	0	1	1	0	0	2	0	2	2	2	-	0	1	-	0&1	0&1

Table S1: (Continued) Matrix of morphoanatomical characters (character 19 to 37)

Taxa	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
<i>Psilophyton dawsonii</i>	0	-	0	0	0	0	0	-	0	0	1	2	2	-	0	-	0	3	1
<i>Panxia gabata</i>	2	-	0	1	2	0	0	-	0	0	1	?	2	-	0	-	0	?	0
<i>Denglongia hubeiensis</i>	2	-	0	1	1	0	0	-	0	0	1	2	2	-	0	-	0	3	0
<i>Calamophyton primaevum</i>	2	-	0	1	2	?	0	-	0	0	1	2	2	-	0	-	0	3	1
<i>Pseudosporochnus nodosus</i>	2	-	0	1	2	0	0	-	0	0	1	1	2	-	0	-	0	3	1
<i>Ibyka and Anapaulia</i>	1	0	0	1	3	0	0	-	0	0	1	2	2	-	0	-	0	3	1
<i>Compsocradus laevigatus</i>	1&2	0	0	1	2	0	0	-	0	0	1	2	2	-	0	-	0	3	1
<i>Hamatophyton verticillatum</i>	1	1	0	2	1	0	0	-	0	1	0	-	2	1	0	-	0	0	0
<i>Rinistachya hilleri</i>	?	?	?	?	?	?	?	?	0	1	2	1	0	0	0	-	1	3	1
<i>Eviostachya hoegii</i>	1	1	0	2	1	0	0	-	0	2	2	1	2	1	0	-	0	3	1
<i>Peltastrobis reedae</i>	1	1	0	2	1&2	?	?	?	0	1	3	?	0&2	0&1	1	1	1	3	0
<i>Bowmanites dawsoni</i>	1	1	0	2	1&2	1	1	1	0	2	0	-	1	-	1	0	1	1	0
<i>Bowmanites moorei</i>	1	1	0	2	1&2	1	1	1	0	2	0	-	1	-	1	0	1	1	0
<i>Bowmanite myriophyllus</i>	?	?	?	?	?	?	?	?	0	2	0	-	1	-	1	0	1	2	0
<i>Bowmanites priveticensis</i>	?	?	?	?	?	?	?	?	0	2	0	-	1	-	1	0	1	2	0
<i>Leeites oblongifolis</i>	?	?	?	?	?	?	?	?	0	2	0	-	1	-	1	0	1	1	0
<i>Cheirostrobis pettycurensis</i>	1	0	0	2	1&3	?	?	?	0	2	0	-	0	0	1	0	1	2	0
<i>Lilpopia raciborskii</i>	?	?	?	?	?	?	?	?	0	0	3	?	2	1	1	2	1	3	0
<b><i>Pseudobornia ursina</i></b>	3	-	1	?	?	?	?	?	0	2	0	-	0	0	0	-	1	3	0
<i>Protocalamostachys arranensis</i>	3	-	1	1&2	1&3	1	1	0	0	2	0	-	3	1	2	2	0	2	0
<i>Cruciaetheca patagonica</i>	?	-	?	?	?	?	?	?	?	0	0	-	3	1	2	1	0	2	0
<i>Paracalamitina striata</i>	?	-	?	?	?	?	?	?	?	0	0	-	3	1	2	1	0	2	0
<i>Palaeostachya guanglongii</i>	3	-	1	0	1	1	1	0	1	2	0	-	3	0	2	1	1	2	0
<i>Calamostachys americana</i>	3	-	1	0	1&2&3	1	1	0	1	2	0	-	3	1	2	1	1	2	0
<i>Calamostachys binneyana</i>	3	-	1	0	1&2&3	1	1	0	0	2	0	-	3	1	2	1	1	2	0
<i>Neocalamites</i> sp.	3	-	1	1	?	0	0	-	1	3	0	-	3	1	2	2	0	3	0
<i>Equisetites arenaceus</i>	3	-	1	1	3	0	0	-	0	3	0	-	3	1	2	2	0	3	0
<i>Equisetum</i> spp.	3	-	1	1	3	0	0	-	0	3	0	-	3	1	2	2	0	3	0

Table S1: (Continued) Matrix of morphoanatomical characters (character 38 to 56)

Taxa	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
<i>Psilophyton dawsonii</i>	1	0	0	-	1	1	0	-	-	-	-	-	-	-	-	-	0	?	
<i>Panxia gabata</i>	0	4	0	-	1	1	0	-	-	-	-	-	-	-	-	-	?	?	?
<i>Denglongia hubeiensis</i>	0	0	0	-	1	1	0	-	-	-	-	-	-	-	-	-	0	1	0
<i>Calamophyton primaevum</i>	1	1	0	-	1	1	0	-	-	-	-	-	-	-	-	-	0	?	0
<i>Pseudosporochnus nodosus</i>	0	1	0	-	2	1	0	-	-	-	-	-	-	-	-	-	?	?	?
<i>Ibyka and Anapaulia</i>	1&2	1	0	-	0	1	1	-	-	-	-	-	-	-	-	-	?	?	?
<i>Compsocradus laevigatus</i>	1&2	3	0	-	0	1	1	-	-	-	-	-	-	-	-	-	?	?	?
<i>Hamatophyton verticillatum</i>	1	1	0	1	1	0&1	1	0	0	-	-	-	-	-	-	-	0	?	0
<i>Rinistachya hilleri</i>	1	1	0	1	1	1	1	0	0	0	-	1&3	2	0	0	-	?	?	?
<i>Eviostachya hoegii</i>	1	1&2	0	1	1	?	1	0	0	-	-	-	-	-	-	-	0	?	0
<i>Peltastrobus reedae</i>	1	1	2	1	?	?	1	1	0	?	-	1	2	2	1	-	0	1	2
<i>Bowmanites dawsoni</i>	1	1	0	1	1	1	1	0	0	1	-	1	2	2	1	-	0	1	0&2
<i>Bowmanites moorei</i>	1	1	0	1	1	1	1	0	0	1	-	2	2	2	0	-	0	?	0&2
<i>Bowmanites myriophyllus</i>	1	1	0	1	1	1	1	0	0	1	-	1	1	2&3	0	-	0	0	2
<i>Bowmanites priveticensis</i>	1	1	0	1	1	1	1	0	0	1	-	1	1	2&3	0	-	0	0	2
<i>Leeites oblongifolis</i>	1	1	0	1	1	1	1	0	0	1	-	2	2	2&3	0	-	0	?	2
<i>Cheirostrobos pettycurensis</i>	1	2	1	1	?	?	1	0	0	?	0	2	2	2	0	-	0	0	0
<i>Lilpopia raciborskii</i>	?	1	?	1	1	1	1	1	0	1	-	0	2	2	0	-	?	?	?
<b><i>Pseudobornia ursina</i></b>	0	2&3	1	1	1	1	1	0	0	1	-	1	2	2	0	-	0	1	0
<i>Protocalamostachys arranensis</i>	1	1&2	1	1	1	1	1	-	1	?	-	-	-	-	-	2	0	1	0
<i>Cruciaetheca patagonica</i>	1	?	?	1	1	1	1	-	1	0	2	0	2	0	1	1	?	?	?
<i>Paracalamitina striata</i>	1	?	?	1	1	1	1	-	1	0	2	0	2	0	1	2	?	?	?
<i>Palaeostachya guanglongii</i>	1	1	1	1	1	1	1	0	1	1	0	0	2	2	0	0	1	1	0
<i>Calamostachys americana</i>	1	1	1	1	1	1	1	0	1	1	1	0	2	2	1	0	1	1	0
<i>Calamostachys binneyana</i>	1	1	1	1	1	1	1	0	1	1	1	0	2	2	1	0	1	1	0
<i>Neocalamites</i> sp.	1	?	1	0	1	0&1	1	-	0	-	-	-	-	-	-	-	?	?	0
<i>Equisetites arenaceus</i>	1	1&2	1	0	1	1	1	-	0	-	-	-	-	-	-	-	?	?	0&1
<i>Equisetum</i> spp.	1	2	1	0	1	0	1	-	0	-	-	-	-	-	-	-	1	?	1

Taxa	Original description	FAD (Ma)	LAD (Ma)	References for stratigraphy
<i>Psilophyton dawsonii</i>	Banks, Leclercq and Hueber, 1975	402	392	Banks et al., 1975; Hartman and Banks, 1980; Noetinger et al., 2018
<i>Panxia gabata</i>	Wang and Berry, 2006	388	383	Wang and Berry, 2006
<i>Denglongia hubeiensis</i>	Xue and Hao, 2008	383	372	Xue and Hao, 2008
<i>Calamophyton primaevum</i>	Weyland, 1925	391	379	Leclercq, 1969; Fairon-Demaret and Berry, 2000
<i>Pseudosporochnus nodosus</i>	Leclercq and Banks, 1962	390	386	Fairon-Demaret and Berry, 2000
<i>Anapaulia moodyi</i>	Berry and Edwards, 1996	383	379	Hammond and Berry, 2005
<i>Compsocradus laevigatus</i>	Berry and Stein, 2000	385	382	Berry & Gensel, 2019; Fu et al., 2011; Durieux et al., 2021
<i>Ibyka amphikoma</i>	Skog and Banks, 1973	388	383	Skog and Banks, 1973; Berry et al., 1997; Berry, 2005; Wang, 2008; Berry et al., 2022
<i>Hamatophyton verticillatum</i>	Li et al., 1995	372	359	Li et al., 1995; Wang et al., 2006a; Wang and Guo, 2009
<i>Rinistachya hilleri</i>	Prestianni and Gess, 2018	365	360	Prestianni and Gess, 2018
<i>Eviostachya hoegii</i>	Stockmans, 1948	366	336	Leclercq, 1957
<i>Peltastrobus reedae</i>	Baxter, 1950	323	310	Baxter, 1950
<i>Bowmanites dawsoni</i>	Taylor, 1969	323	315	Taylor, 1969, 1970
<i>Bowmanites moorei</i>	Mamay, 1959	315	307	Mamay, 1959
<i>Bowmanites myriophyllus</i>	Libertín et al., 2014	315	310	Libertín et al., 2014
<i>Bowmanites priveticensis</i>	Libertín et al., 2014	315	310	Libertín et al., 2014
<i>Leeites oblongifolis</i>	Zodrow et Gao, 1991	296	290	Zodrow et Gao, 1991; Libertín et al., 2021
<i>Cheirostrobus pettycurensis</i>	Neregato and Hilton, 2019	342	336	Neregato and Hilton, 2019
<i>Lilpopia raciborskii</i>	Lilpop, 1937	304	294	Lipiarski, 1972a; Kerp, 1984
<b><i>Pseudobornia ursina</i></b>	Nathorst, 1894	361	355	Schweitzer, 1967, 2006
<i>Protocalamostachys arranensis</i>	Bateman, 1991	350	335	Bateman, 1991; Bateman et al., 2016
<i>Cruciaetheca patagonica</i>	Cúneo and Escapa, 2006	295	284	Cúneo and Escapa, 2006
<i>Paracalamitina striata</i>	Naugolnykh, 2002	283	268	Naugolnykh, 2002
<i>Palaeostachya guanglongii</i>	Liu et al., 2017	315	299	Good, 1975; Liu et al., 2017
<i>Calamostachys americana</i>	Good, 1975	307	299	Good, 1975
<i>Calamostachys binneyana</i>	Good, 1975	323	307	Good, 1975
<i>Neocalamites</i> spp.	Escapa and Cúneo, 2006	273	259	Escapa and Cúneo, 2006
<i>Equisetites arenaceus</i>	Schenk, 1864	242	227	Kelber and van Konijnenburg-van Cittert, 1998
<i>Equisetum</i> spp.	Linnaeus, 1753	190	0	Elgorriaga et al., 2015 (Based on the FAD of <i>E. dimorphum</i> )

Table B: First and last appearance datum (FAD-LAD) of each taxon used in the time-scaled phylogenies associated with references of original descriptions.

<b>Taxa</b>	<b>Taxonomic groups (Orders)</b>	<b>References for taxonomy</b>
<i>Psilophyton dawsonii</i>	Trimerophytales	Banks, 1975
<i>Panxia gabata</i>	Cladoxylales	Durieux <i>et al.</i> , 2021
<i>Denglongia hubeiensis</i>	“Transitional cladoxylopsids”	Durieux <i>et al.</i> , 2021
<i>Calamophyton primaevum</i>	Pseudosporochnales	Fairon-Demaret and Berry, 2000
<i>Pseudosporochnus nodosus</i>	Pseudosporochnales	Fairon-Demaret and Berry, 2000
<i>Anapaulia moodyi</i>	Iridopteridales	Berry and Edwards, 1996; Durieux <i>et al.</i> , 2021
<i>Compsocradus laevigatus</i>	Iridopteridales	Berry and Stein, 2000; Durieux <i>et al.</i> , 2021
<i>Ibyka amphikoma</i>	Iridopteridales	Berry <i>et al.</i> , 2022; Durieux <i>et al.</i> , 2021
<i>Hamatophyton verticillatum</i>	Sphenophyllales	Wang <i>et al.</i> , 2006a; Wang and Guo, 2009
<i>Rinistachya hilleri</i>	Sphenophyllales	Prestianni and Gess, 2018
<i>Eviostachya hoegii</i>	Sphenophyllales	Leclercq, 1957
<i>Peltastrobis reedae</i>	Sphenophyllales	Baxter, 1950
<i>Bowmanites dawsoni</i>	Sphenophyllales	Taylor, 1969, 1970
<i>Bowmanites moorei</i>	Sphenophyllales	Mamay, 1959
<i>Bowmanites myriophyllus</i>	Sphenophyllales	Libertín <i>et al.</i> , 2014
<i>Bowmanites priveticensis</i>	Sphenophyllales	Libertín <i>et al.</i> , 2014
<i>Leeites oblongifolis</i>	Sphenophyllales	Libertín <i>et al.</i> , 2021
<i>Cheirostrobis pettycurensis</i>	Sphenophyllales	Neregato and Hilton, 2019
<i>Lilpopia raciborskii</i>	Sphenophyllales	Lipiarski, 1972a; Kerp, 1984
<b><i>Pseudobornia ursina</i></b>	Pseudoborniales	Nathorst, 1894; Schweitzer, 1967, 2006
<i>Protocalamostachys arranensis</i>	Equisetales	Bateman, 1991; Bateman <i>et al.</i> , 2016; Elgorriaga <i>et al.</i> , 2018
<i>Cruciaetheca patagonica</i>	Equisetales	Cúneo and Escapa, 2006; Elgorriaga <i>et al.</i> , 2018
<i>Paracalamitina striata</i>	Equisetales	Naugolnykh, 2002; Elgorriaga <i>et al.</i> , 2018
<i>Palaeostachya guanglongii</i>	Equisetales	Good, 1975; Liu <i>et al.</i> , 2017
<i>Calamostachys americana</i>	Equisetales	Good, 1975; Elgorriaga <i>et al.</i> , 2018
<i>Calamostachys binneyana</i>	Equisetales	Good, 1975; Elgorriaga <i>et al.</i> , 2018
<i>Neocalamites</i> spp.	Equisetales	Escapa and Cúneo, 2006; Elgorriaga <i>et al.</i> , 2018
<i>Equisetites arenaceus</i>	Equisetales	Elgorriaga <i>et al.</i> , 2018
<i>Equisetum</i> spp.	Equisetales	Dumortier, 1829

Table S3: Historical taxonomy at the order level of each discussed species involved in our phylogenetic analyses

## References

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# Supplementary figures

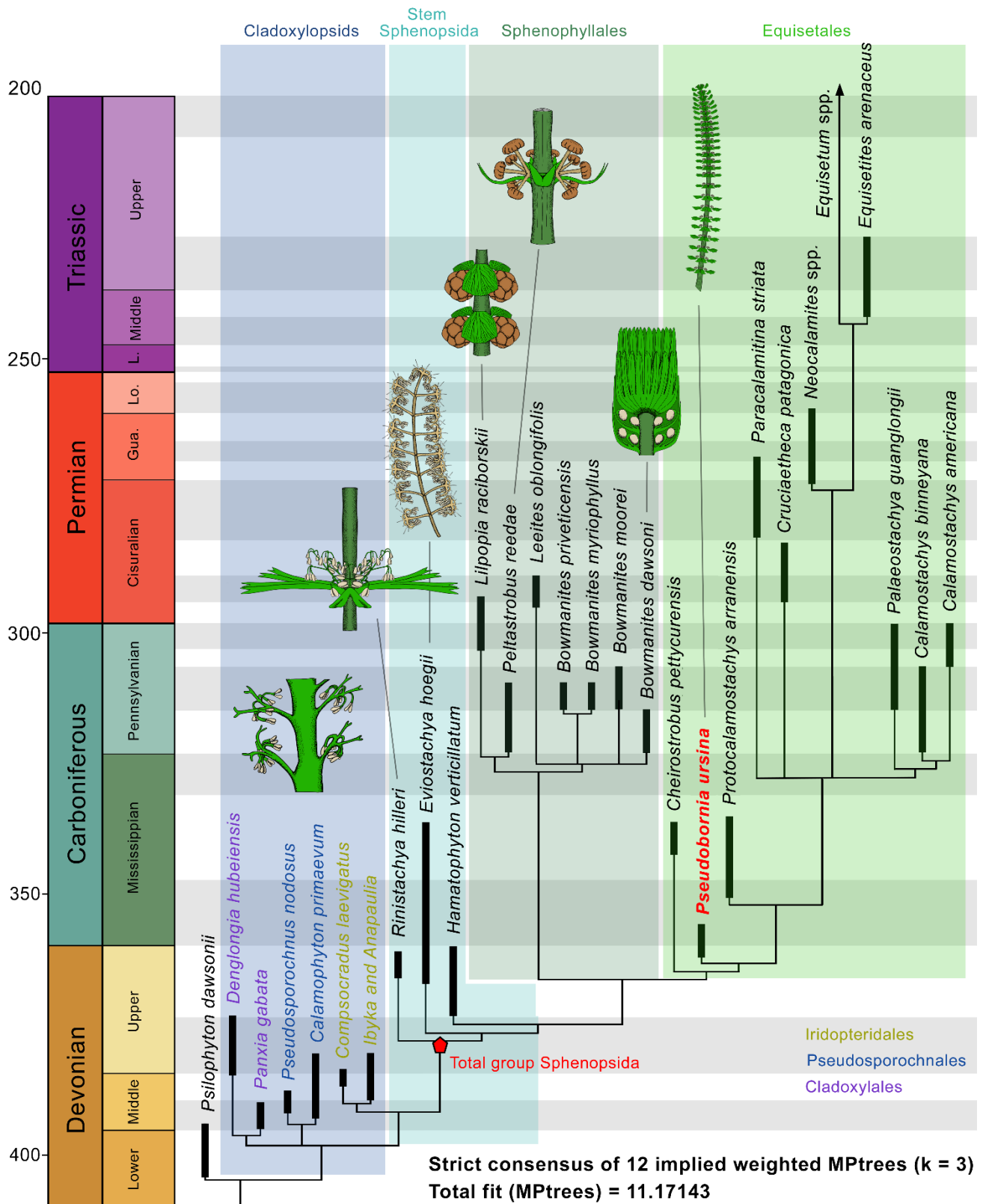


Figure S1: Relationships among sphenophytes and cladoxylopsids based on morphological evidence. The topology shown corresponds to the strict consensus tree based on 12 most parsimonious trees obtained from an implied weighted maximum parsimony analysis (k = 3). Total fit of MPtrees = 11.17143.

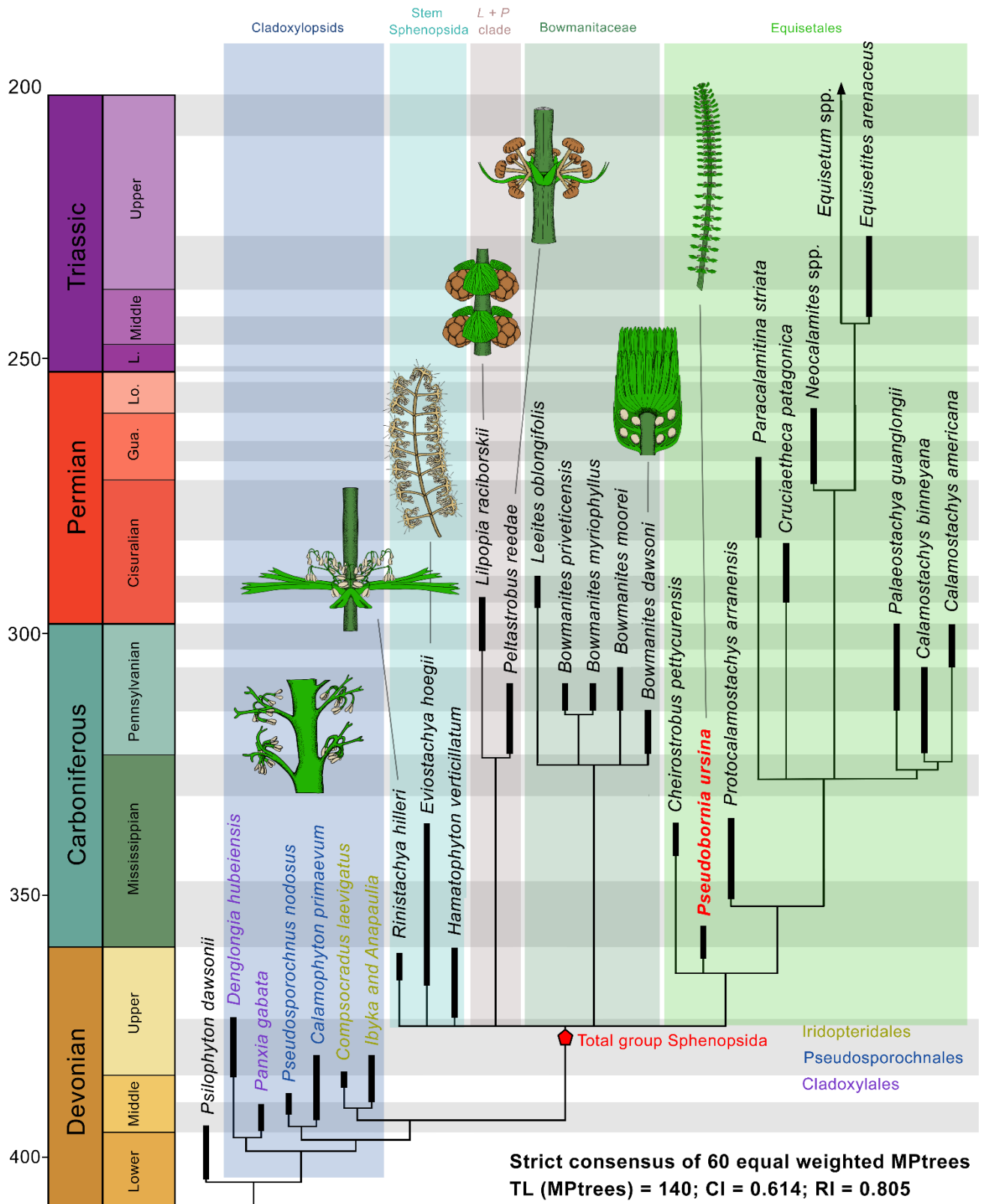


Figure S2: Relationships among sphenophytes and cladoxylopsids based on morphological evidence. The topology shown corresponds to the strict consensus tree based on 60 most parsimonious trees obtained from an equal weighted maximum parsimony analysis. Tree length (MPtrees) = 140; Consistency Index (MPtrees) = 0.614; Retention Index (MPtrees) = 0.805.