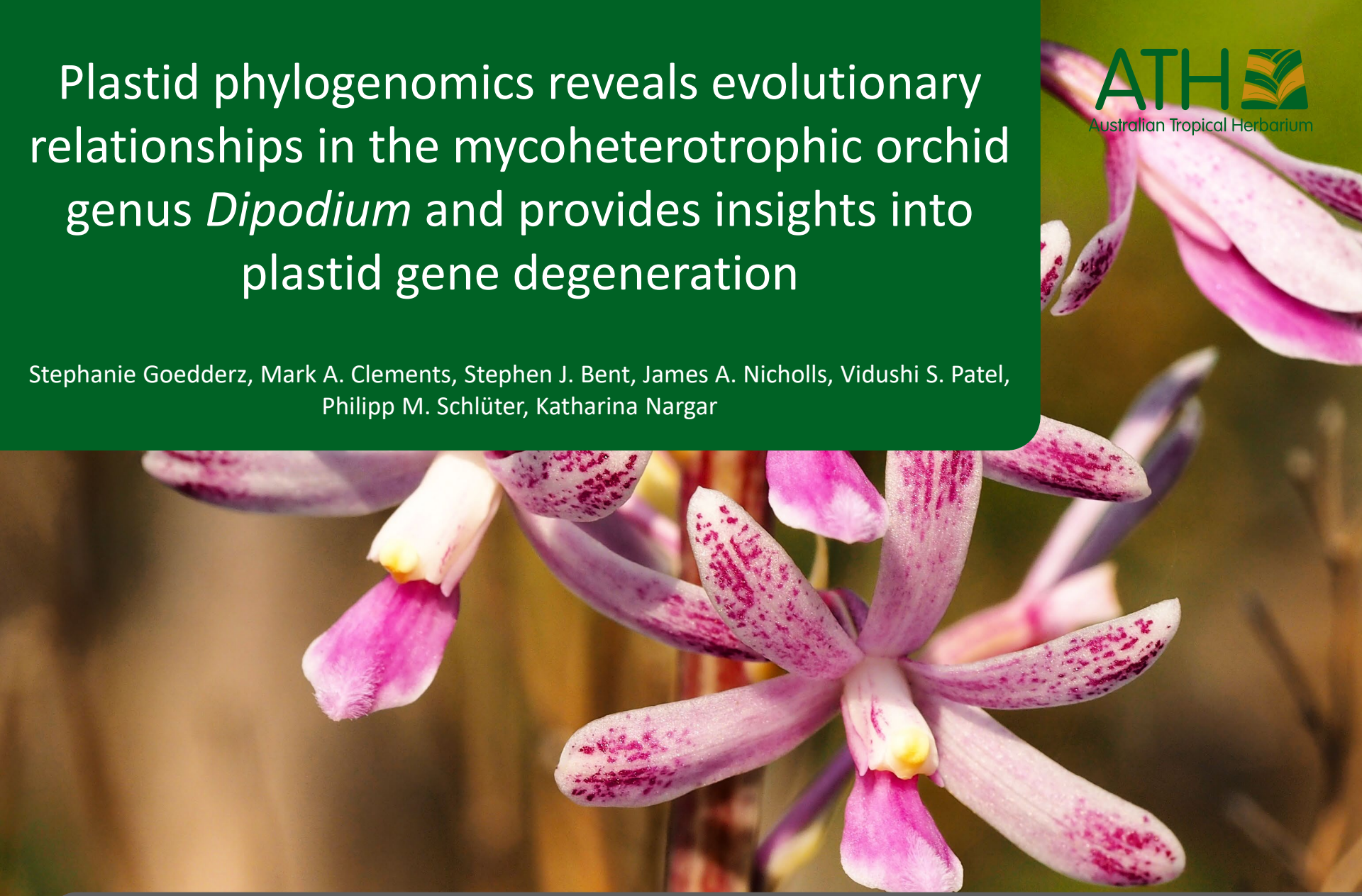
Plastid phylogenomics reveals evolutionary relationships in the mycoheterotrophic orchid genus *Dipodium* and provides insights into plastid gene degeneration

Stephanie Goedderz, Mark A. Clements, Stephen J. Bent, James A. Nicholls, Vidushi S. Patel, Philipp M. Schlüter, Katharina Nargar



ATH Australian Tropical Herbarium

Queensland Government

CSIRO

JAMES COOK UNIVERSITY AUSTRALIA

Australian Government Director of National Parks

UNIVERSITY OF HOHENHEIM

Heterotrophic plants

Australian Tropical Herbarium

Photo: D.L. Jones

-Epipogium roseum-

Photo: B. Gray; Gray & Low 2017

-Gastrodia umbrosa-

Photo: Susumu Yamaguchi; Delannoy et al. 2011

-Rhizanthella gadneri-

(Myco)-heterotrophy

Australian Tropical Herbarium

Photo: D.L. Jones

-Epipogium roseum-

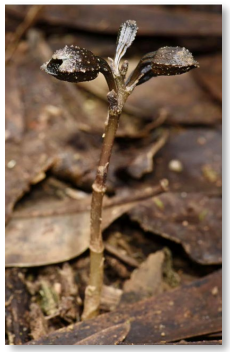


Photo: B. Gray; Gray & Low 2017

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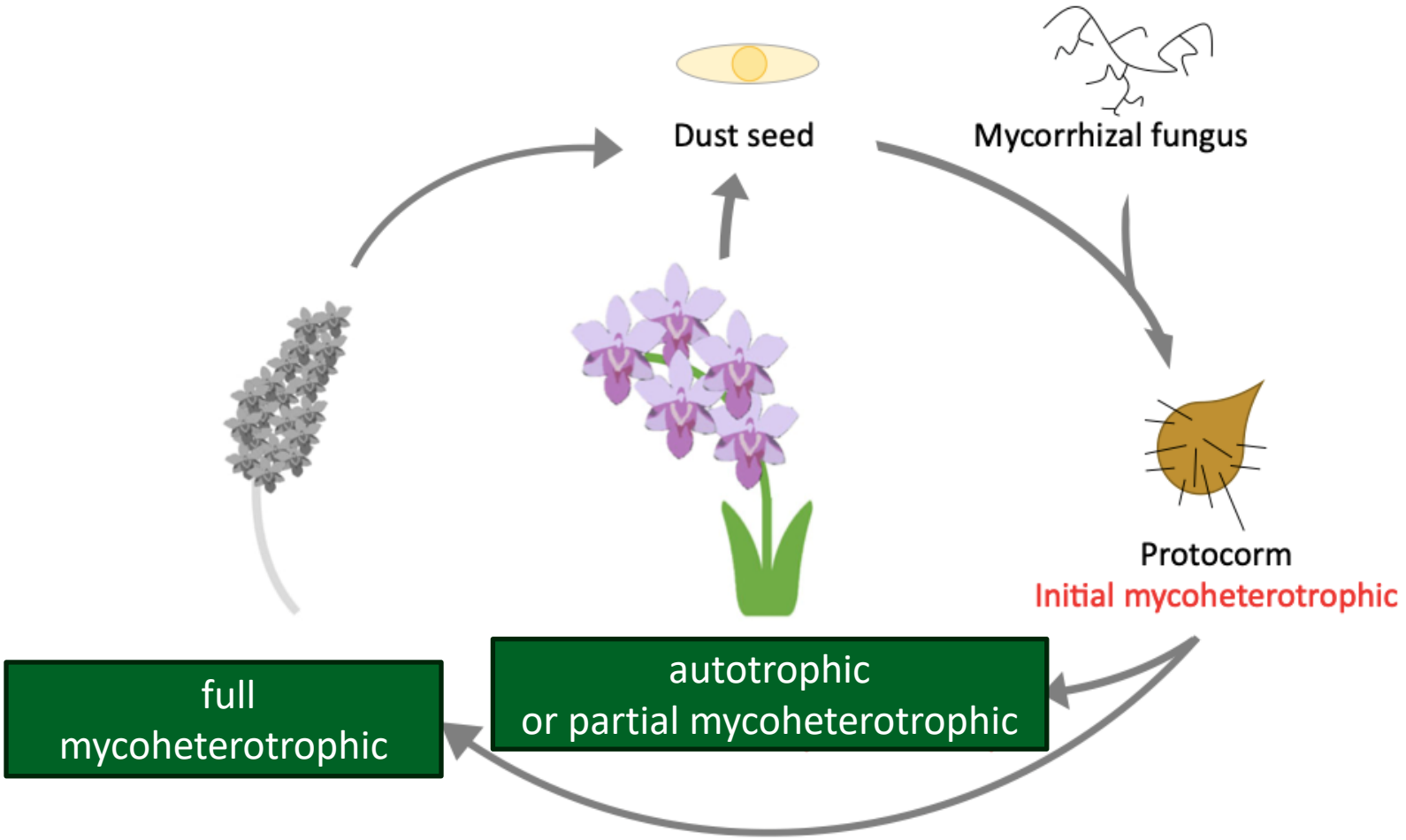
Photo: Susumu Yamaguchi; Delannoy et al. 2011

-Rhizanthella gadneri-

Orchidaceae – Life cycle – nutrition strategies

Australian Tropical Herbarium



Modified after Favre-Godal et al. 2020

Evolution of mycoheterotrophy

Australian Tropical Herbarium

Reduction in leaf size

Loss of photosynthetic activity

Loss of chlorophyll

Degradation of the plastid genome

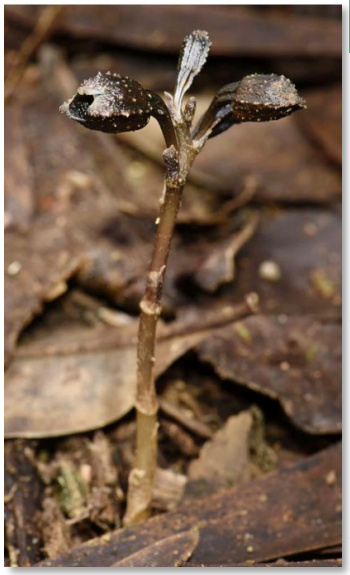


Photo: B. Gray; Gray & Low 2017

-Gastrodia umbrosa-

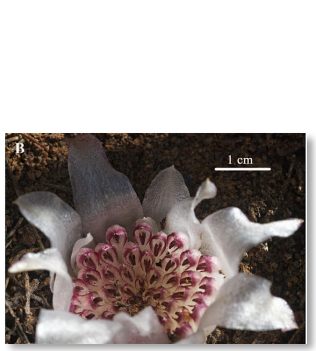


Photo: Susumu Yamaguchi; Delannoy et al. 2011

-Rhizanthella gadneri-

Photo: D.L. Jones

-Epipogium roseum-

Plastid genome (plastome) of mycoheterotrophs

ATH
Australian Tropical Herbarium

Rampant Gene Loss in the Underground Orchid *Rhizanthella gardneri* Highlights Evolutionary Constraints on Plastid Genomes

Etienne Delannoy,*[,1,2] Sota Fujii,[1] Catherine Colas des Francs-Small,[1] Mark Brundrett,[3] and Ian Small[1]

[1]Australian Research Council Centre of Excellence in Plant Energy Biology, University of Western Australia, Perth, Australia

[2]Laboratoire de Biologie du Développement des Plantes, Commissariat à l'Energie Atomique, Cadarache, St. Paul Les Durances, France

[3]School of Plant Biology, University of Western Australia, Perth, Australia

***Corresponding author:** E-mail: delannoy@evry.inra.fr.

Associate editor: Charles Delwiche

Average size of land plant plastomes: 152,858 kb

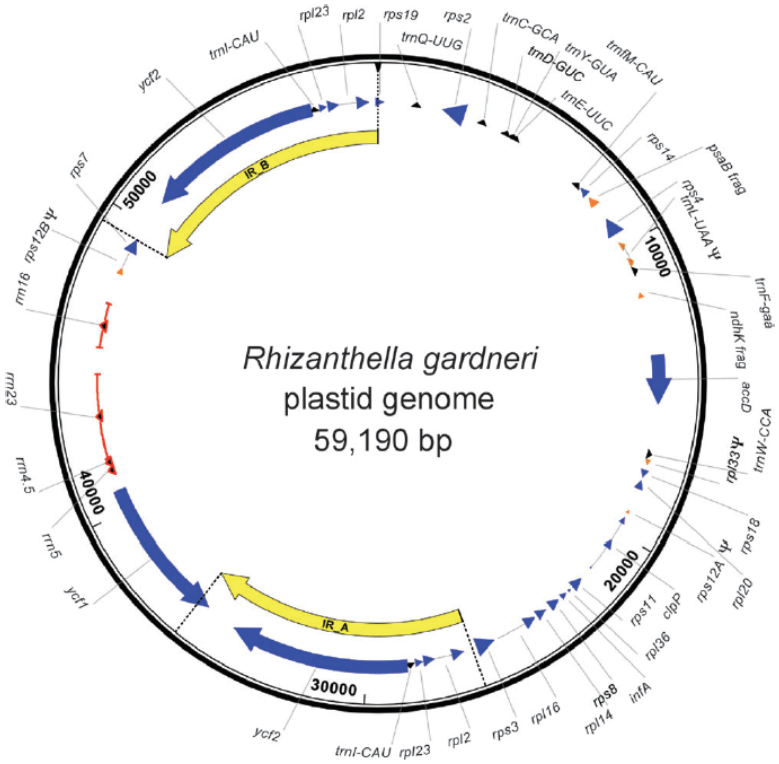


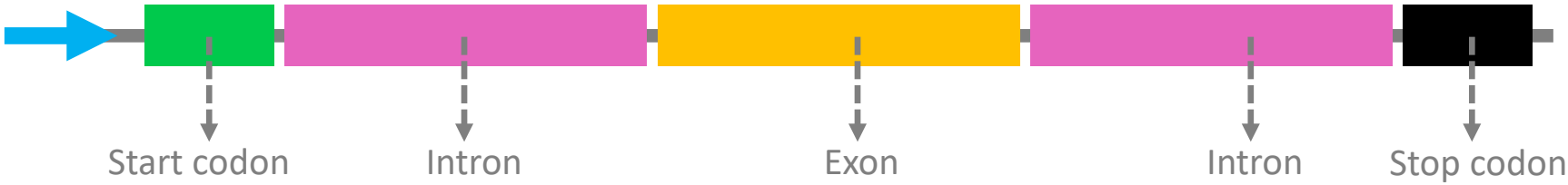
Photo: Susumu Yamaguchi; Delannoy et al. 2011

-Rhizanthella gadneri-

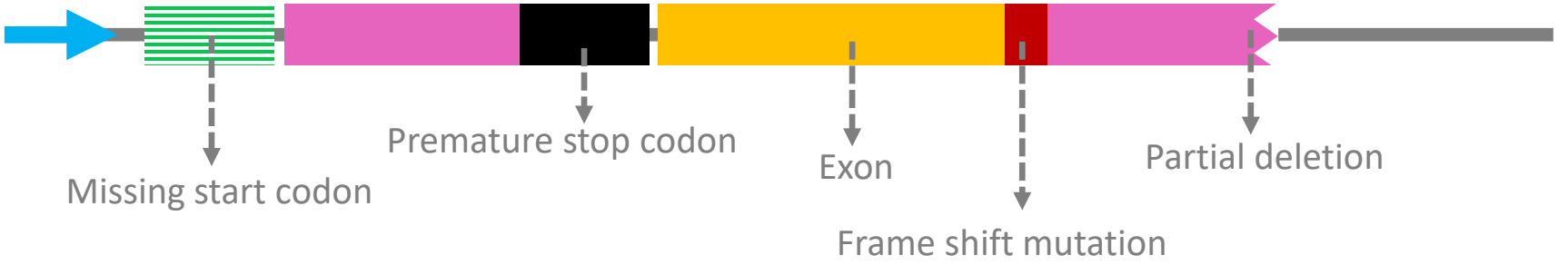
Plastid genes - degradation and loss

Australian Tropical Herbarium

Functional gene

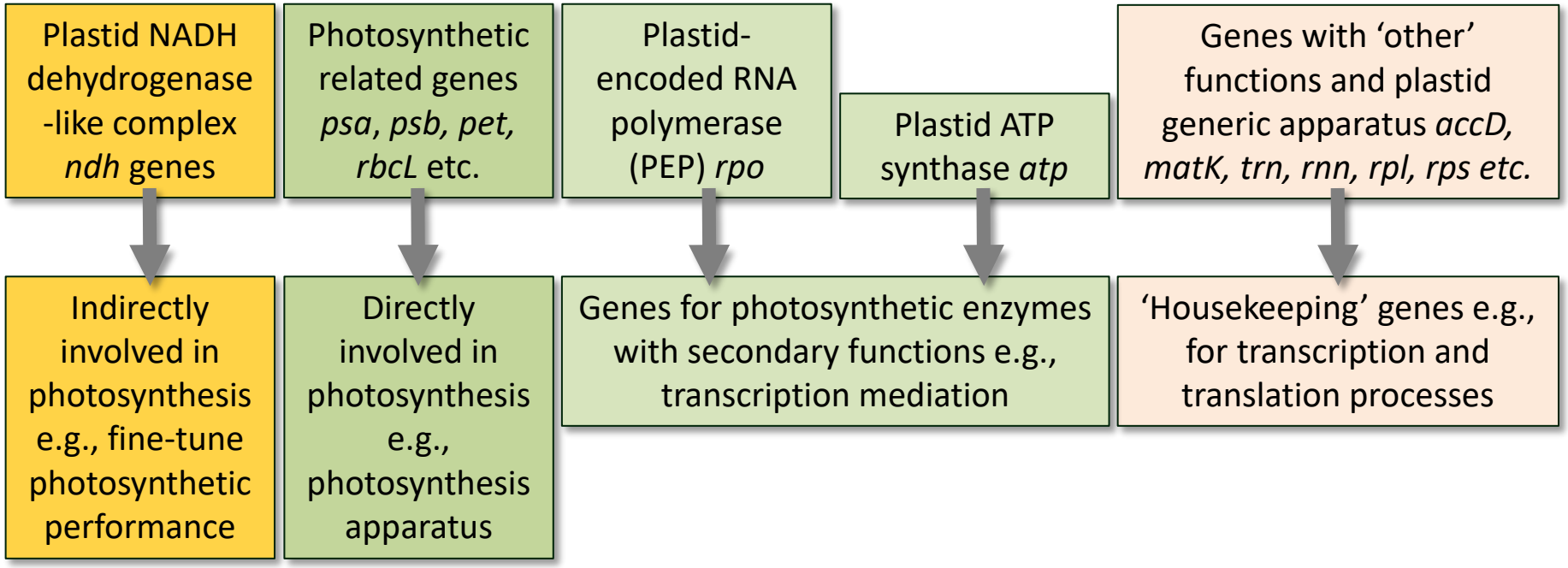


Functional loss: pseudogenised gene



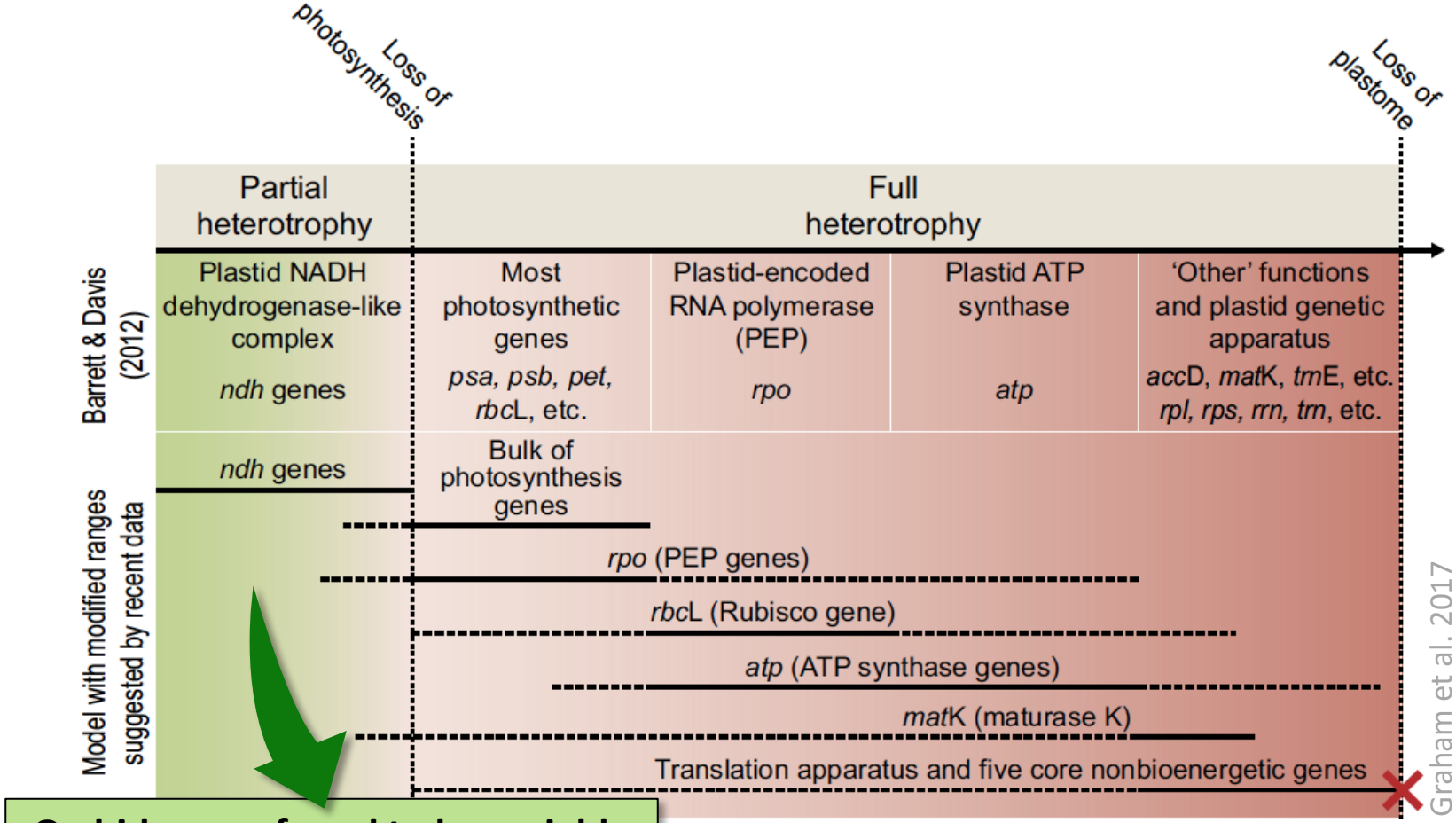
Physical loss: non-detectable gene

Plastid genes – gene groups



Plastid genes - degradation and loss

Australian Tropical Herbarium



Orchids were found to be variable in the conservation of *ndh* genes regardless of the nutrition status.

Dipodium R.Br.

Australian Tropical Herbarium

Photo: D.L. Jones

-Dipodium pandanum-

-Dipodium ensifolium-

-Dipodium elegantulum-

Dipodium R.Br.

Common name: Hyacinth orchids

Subfamily: Epidendroideae

Tribe: Cymbidieae

- 39 species

Divided in two section:

- Section *Dipodium*
- Section *Leopardanthus* (Blume) O. Kuntze

https://commons.wikimedia.org/wiki/File:BlankMap-World.svg

Section *Leopardanthus* in Australia

- ‘Leafy’, autotrophic species
- Adventitious roots, epiphytes and terrestrials

-Dipodium pandanum-

Photo: D.L. Jones

Section *Dipodium* in Australia

- ‘Leafy’, autotrophic species
- Non-adventitious roots, terrestrials

-Dipodium ensifolium-

Section *Dipodium* in Australia

- ‘Leafless’, mycoheterotrophic species
- Non-adventitious roots, terrestrials

Photo: M.A. Clements

-D. interaneum-

-D. elegantulum-

Photo: M.A. Clements

-D. punctatum-

Photo: M.A. Clements

-D. roseum-

Previous studies

ATH
Australian Tropical Herbarium

CSIRO PUBLISHING

CORRIGENDUM
https://doi.org/10.1071/BT22075_CO

Australian Journal of Botany

Corrigendum to: Retention of an apparently functional plastome in an apparently mycoheterotrophic orchid, *Dipodium roseum* D.L.Jones & M.A.Clem. (Orchidaceae)

Todd G. B. McLay, Michael J. Bayly, Michael R. Whitehead and Rachael M. Fowler

frontiers in Plant Science

ORIGINAL RESEARCH
published: 21 February 2020
doi: 10.3389/fpls.2020.00022

Check for updates

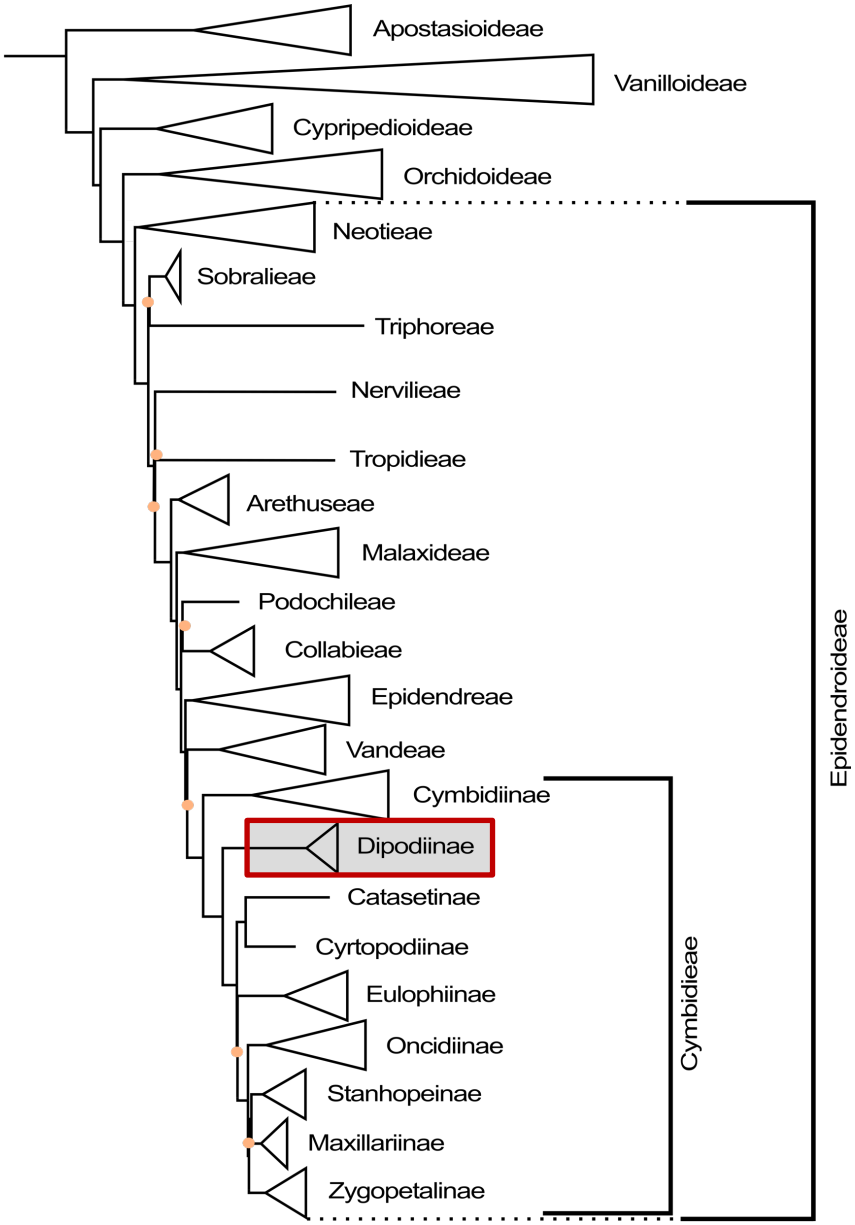
Plastome Evolution and Phylogeny of Orchidaceae, With 24 New Sequences

*Young-Kee Kim[1], Sangjin Jo[1], Se-Hwan Cheon[1], Min-Jung Joo[1], Ja-Ram Hong[1], Myounghai Kwak[2] and Ki-Joong Kim[1]**

[1] Division of Life Sciences, Korea University, Seoul, South Korea, [2] Department of Plant Resources, National Institute of Biological Resources, Incheon, South Korea

Phylogenomic resolution: Orchidaceae

Maximum likelihood phylogenetic tree: Based on 68 plastid loci and 148 taxa



• SH-aLRT/ufboot < 80/95

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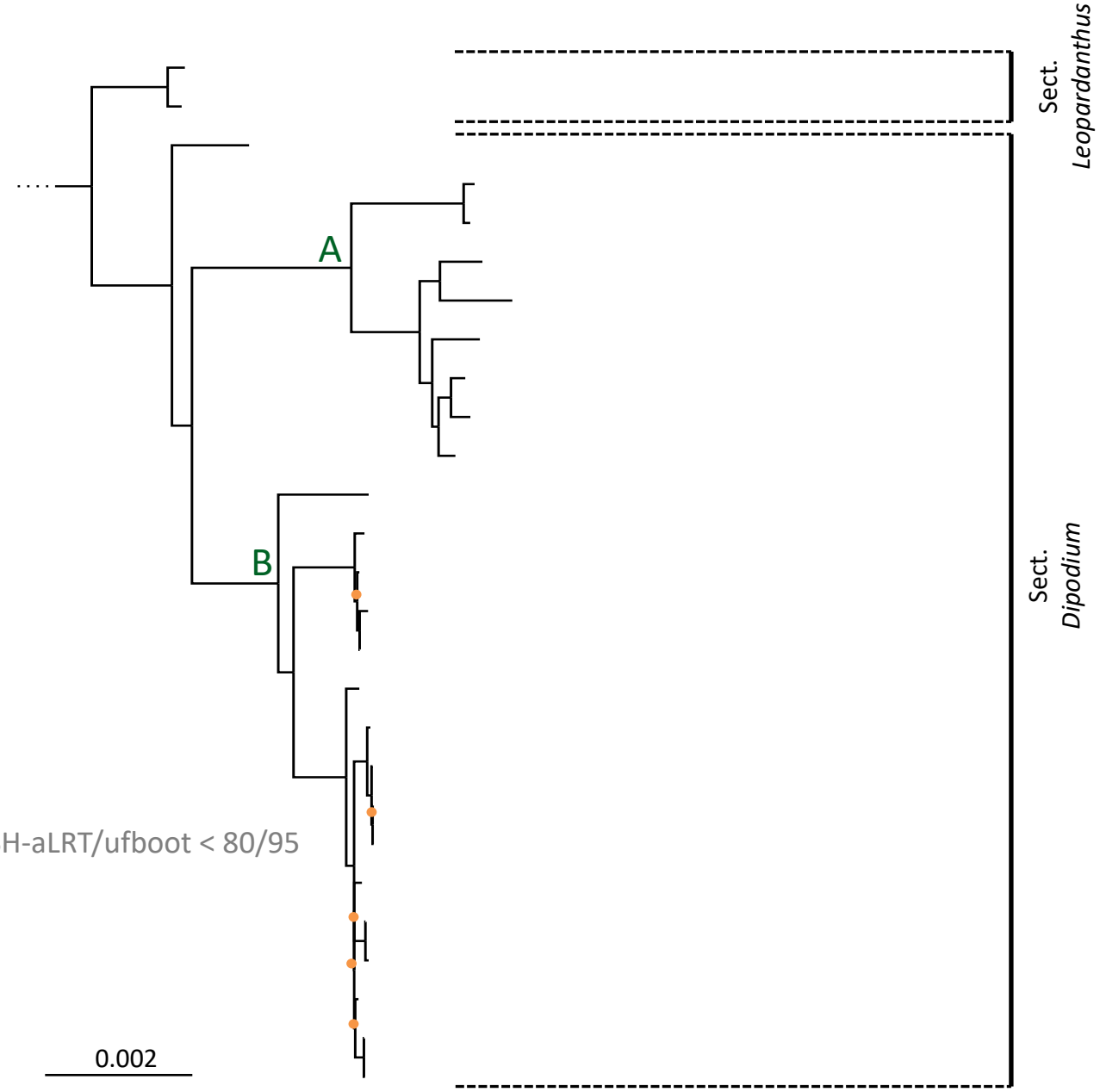
Phylogenomic resolution: Orchidaceae I Epidendroideae I Cymbidieae I Dipodiinea I *Dipodium*

Maximum likelihood phylogenetic tree: Based on 68 plastid loci and 148 taxa



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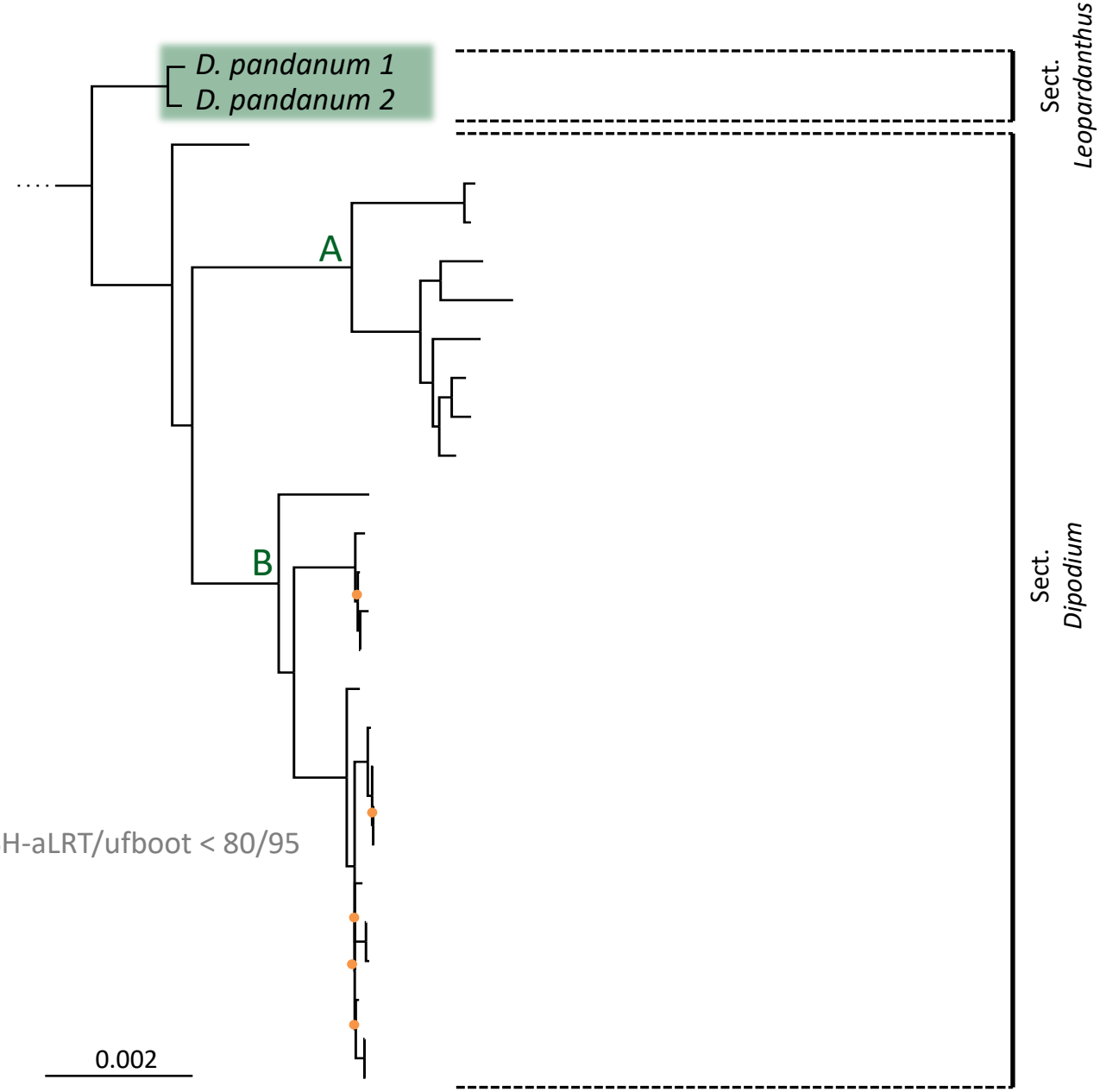

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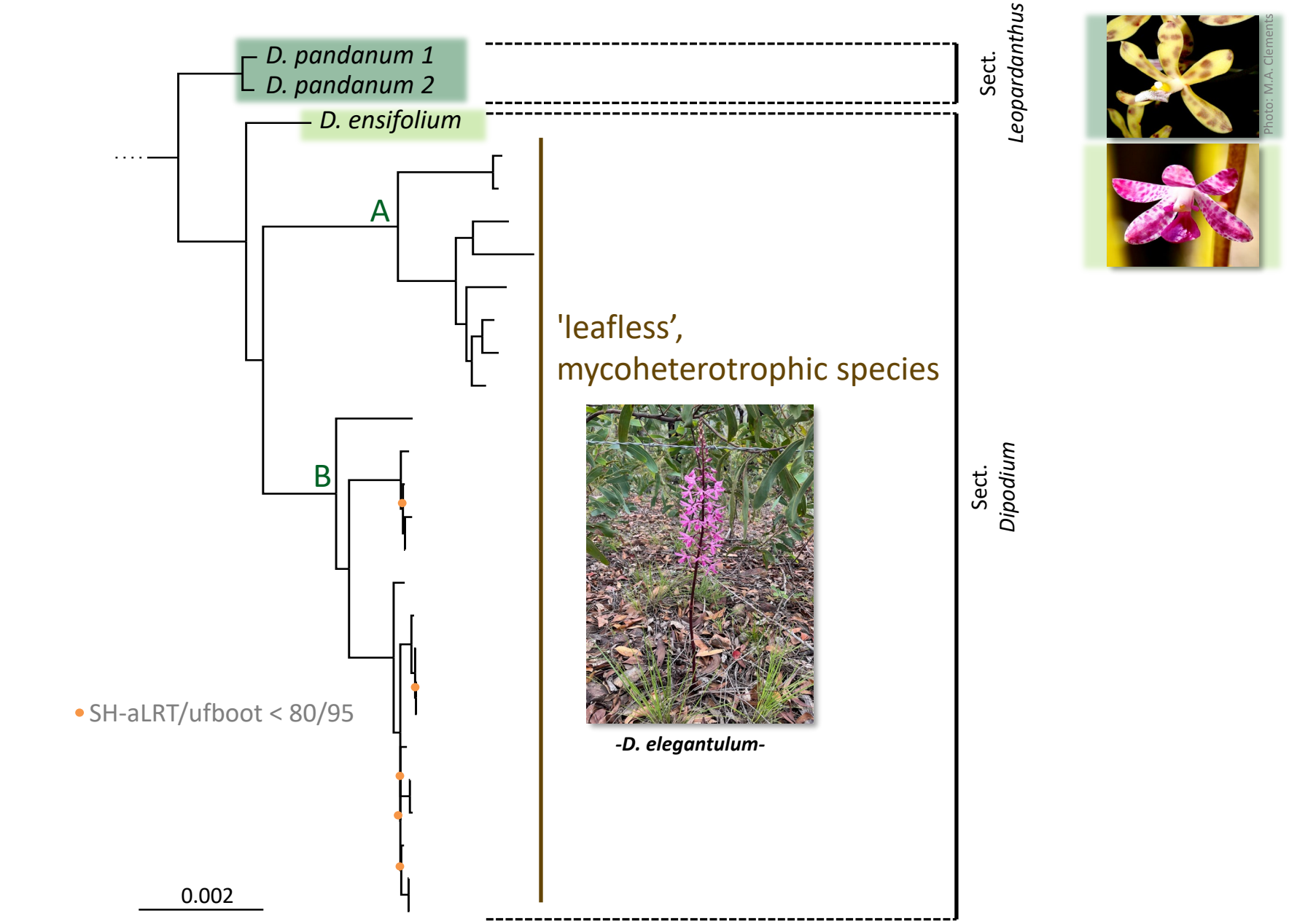

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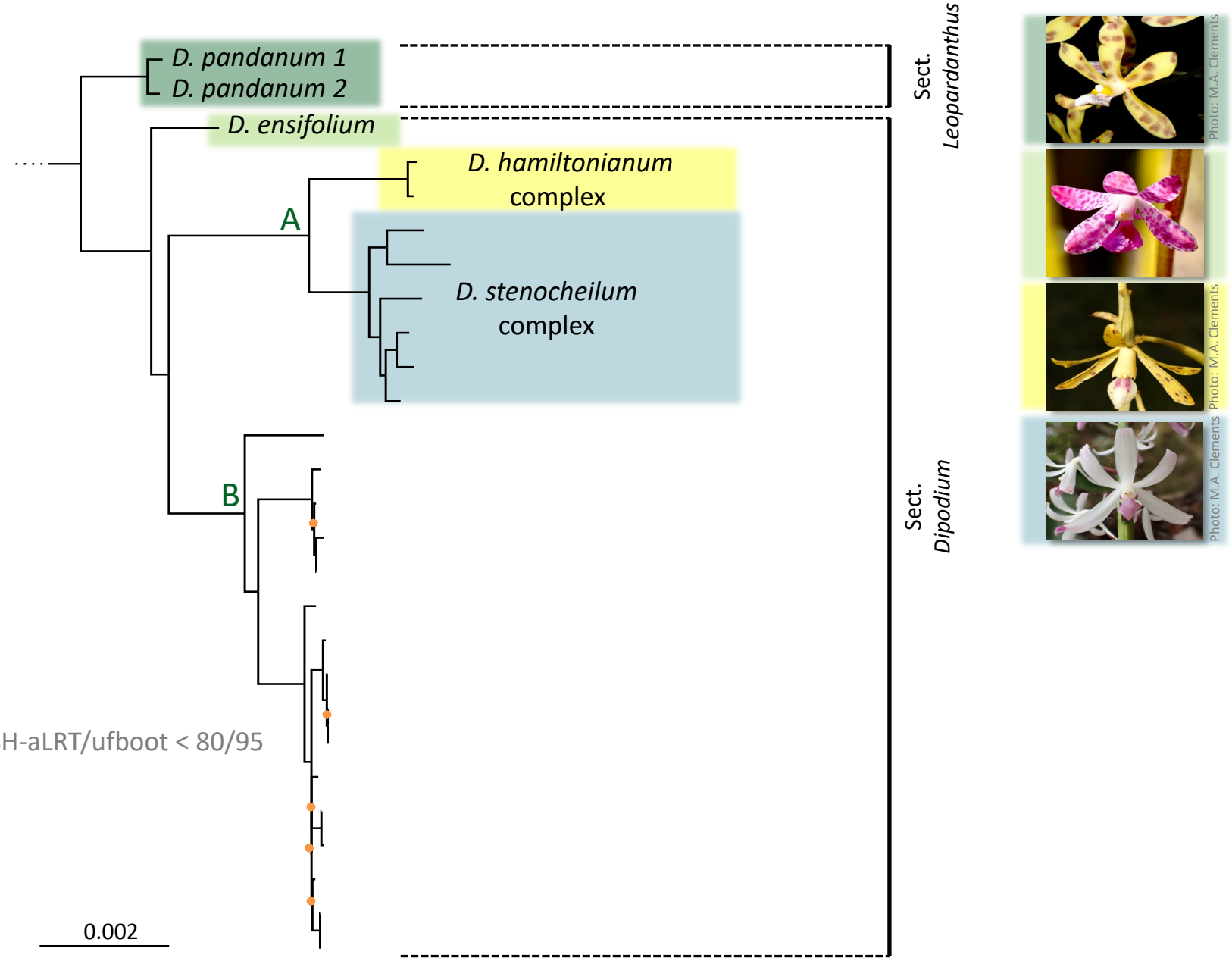

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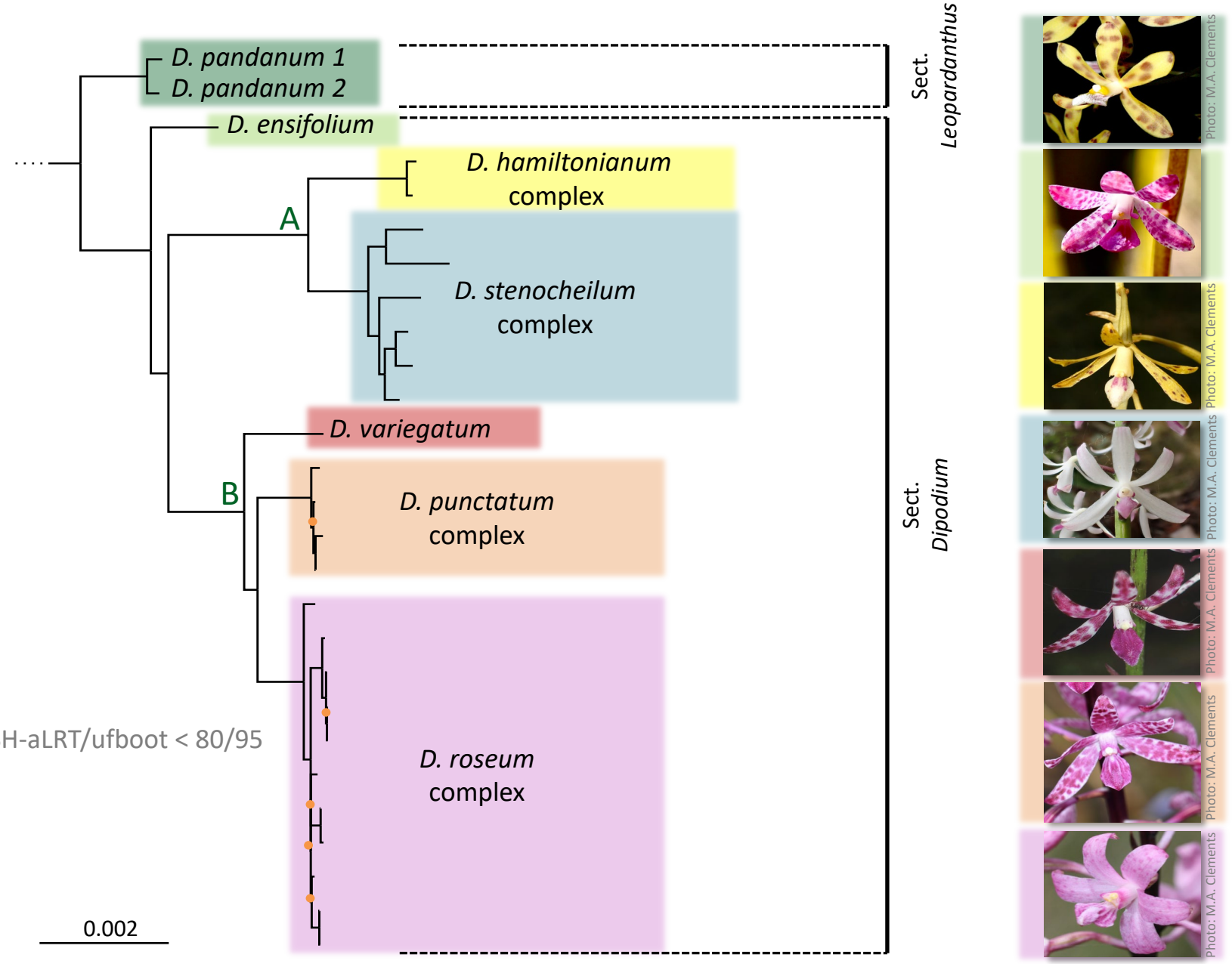
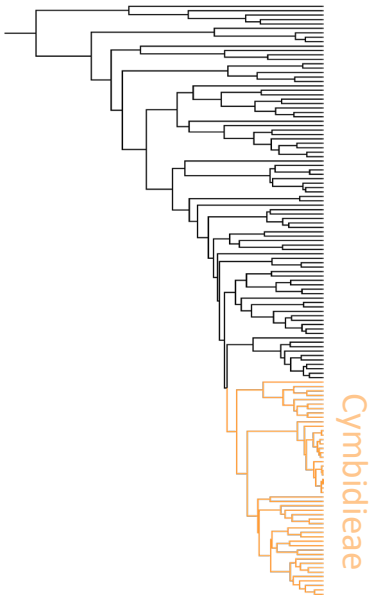


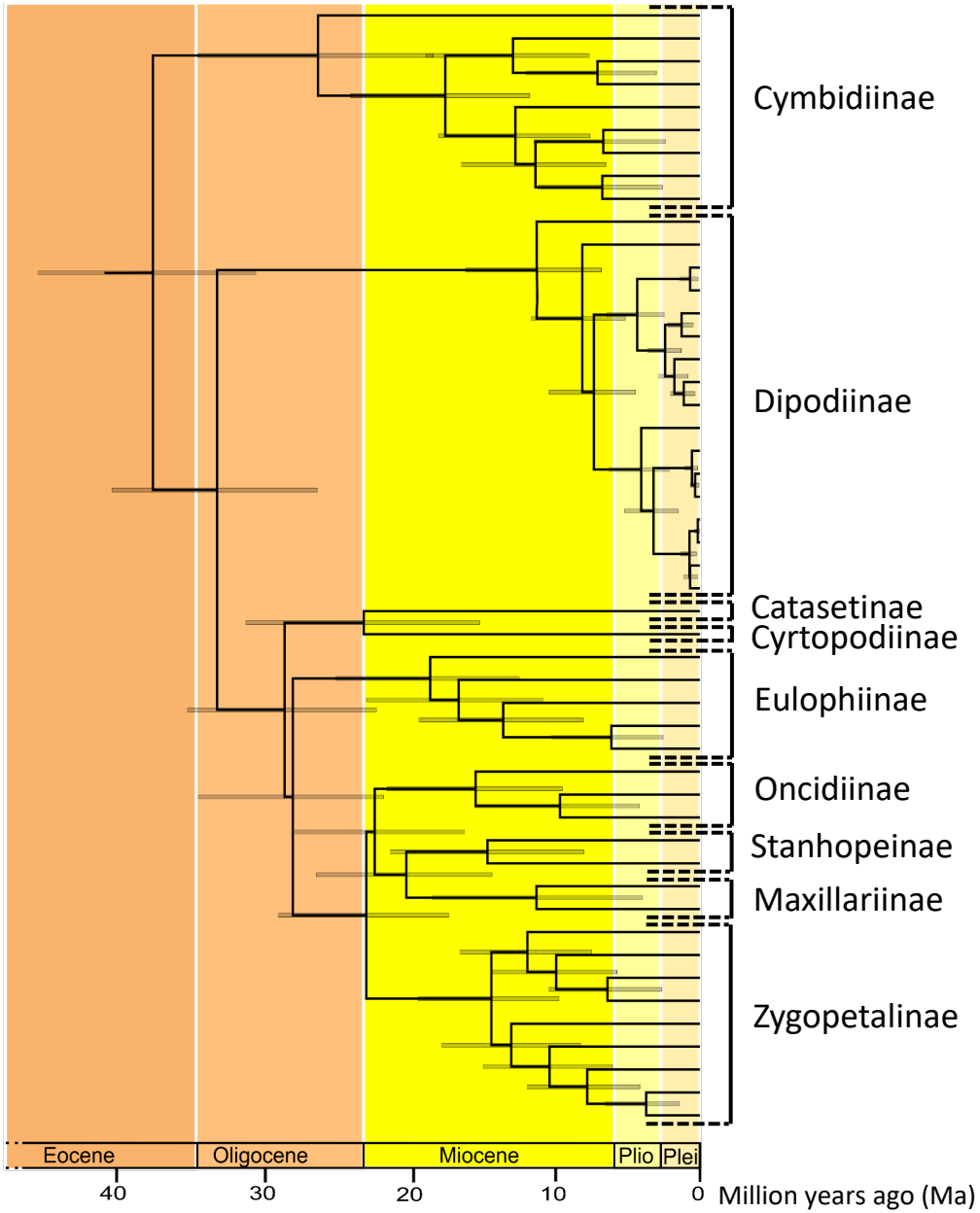
Divergence-time estimations: Orchidaceae I Epidendroideae I Cymbidieae

Bayesian analyses performed with BEAST 2: based on 30 plastid loci and 134 taxa; Best-fit model for the data set: Optimised relaxed clock/ birth-death (Model comparison by AICM; Fabozzi *et al*. 2014)

Orchid chronogram



95% highest posterior density (HDP) values



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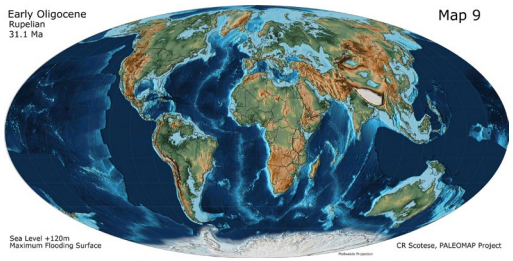
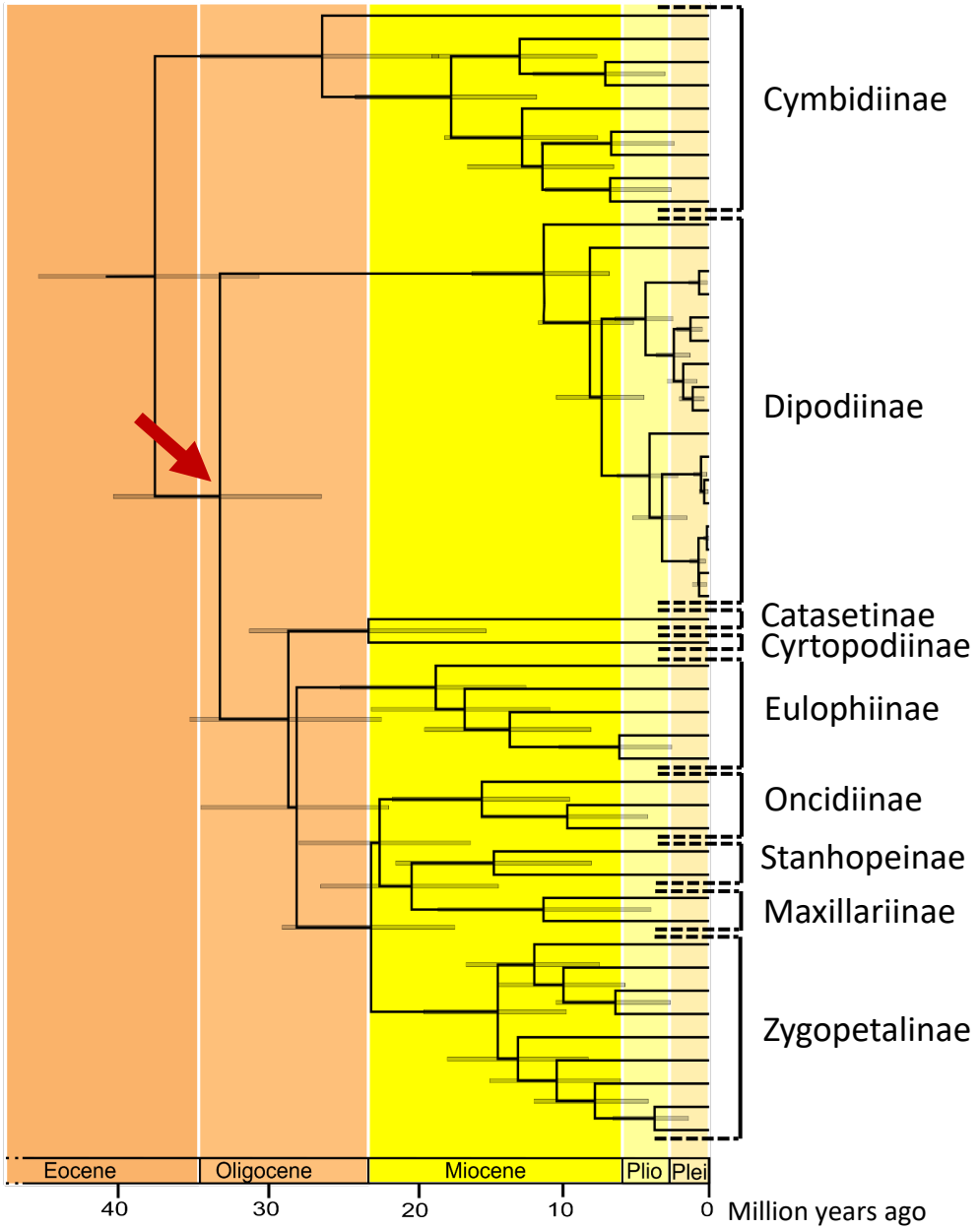


Scotese, C.R., 2014

Early Oligocene



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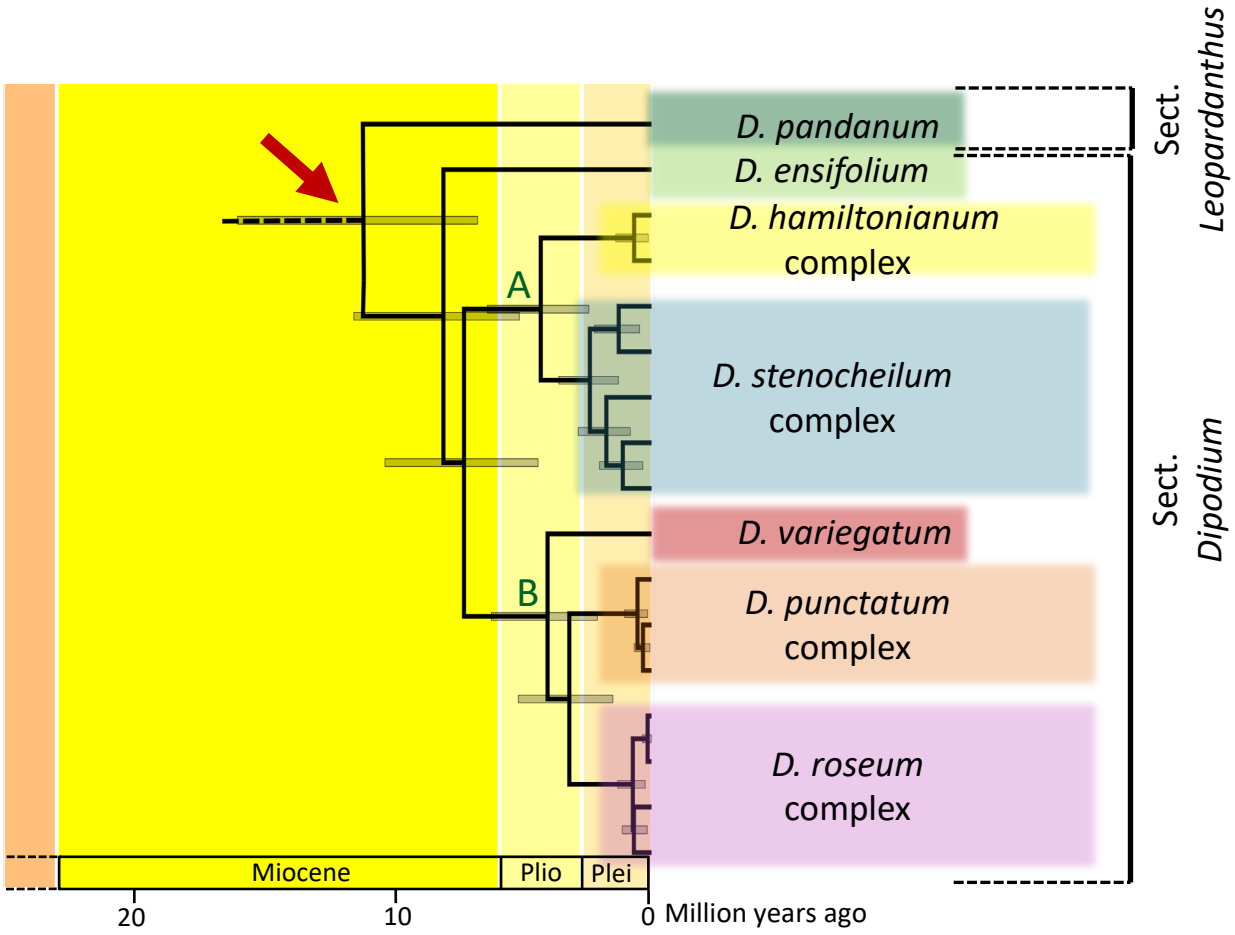
Scotese, C.R., 2014

Middle to late Miocene

Australia has arrived at today's geographical position



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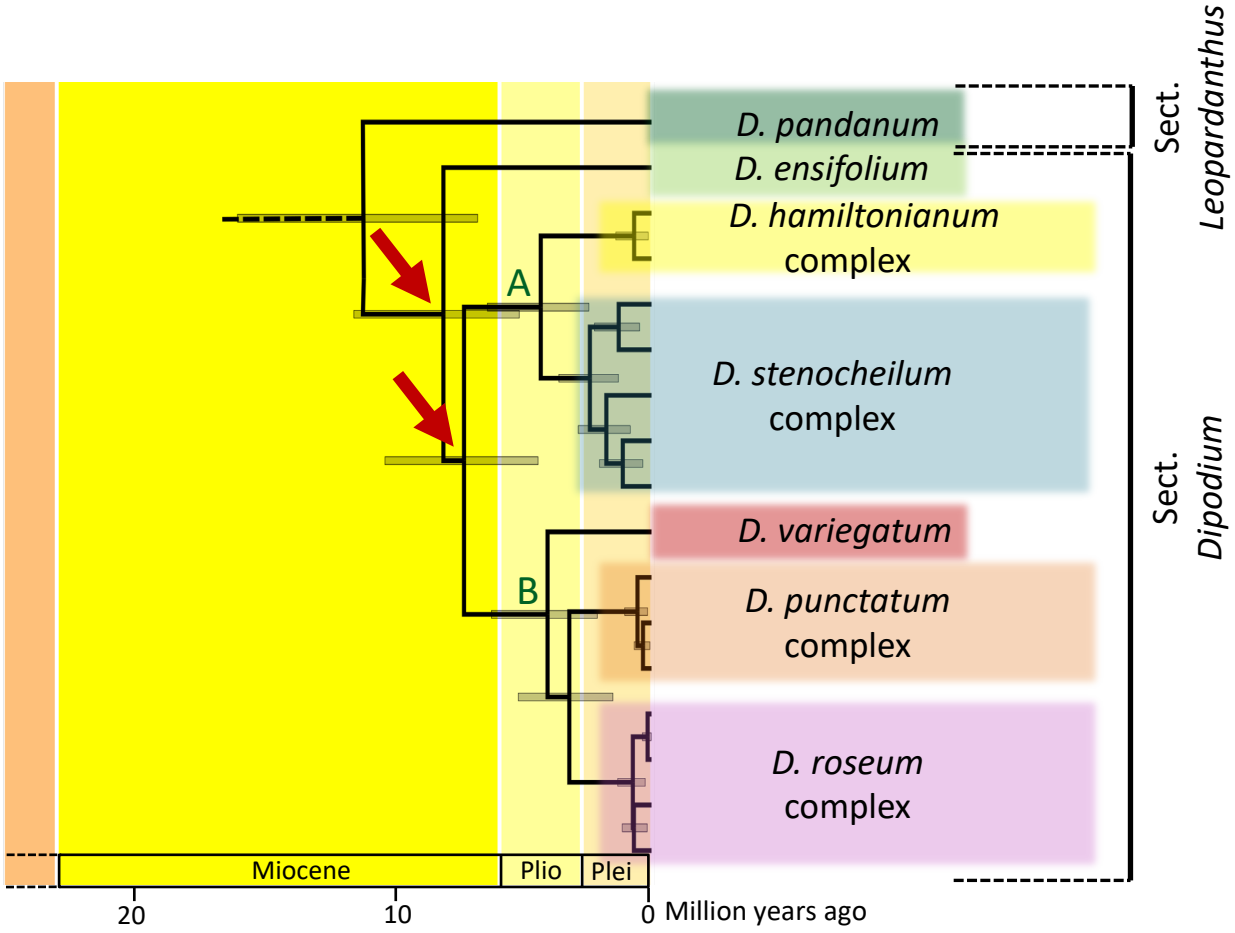
Scotese, C.R., 2014

Late Miocene

Australia's climatic conditions became increasingly arid



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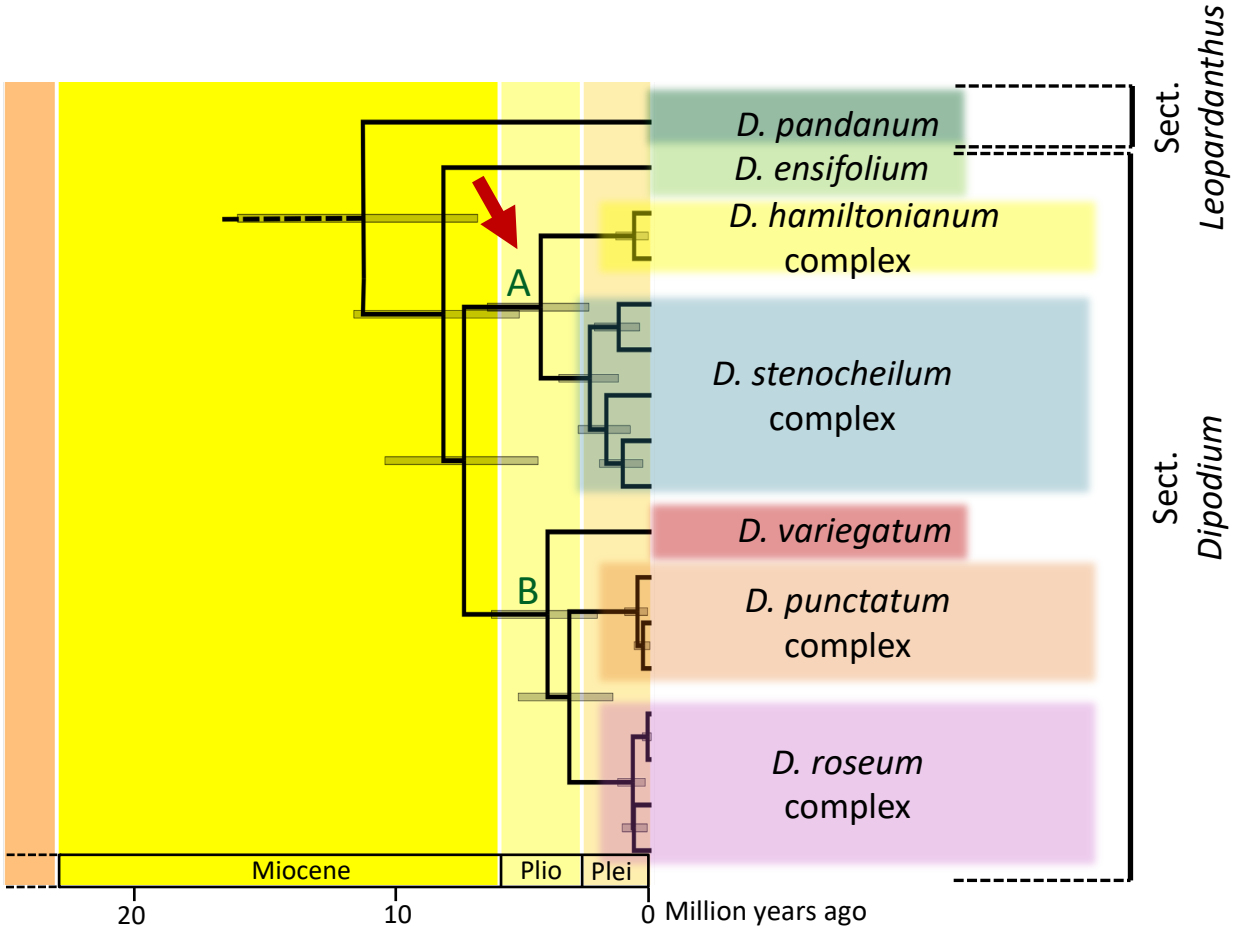
Scotese, C.R., 2013

Pliocene

Aridification of Australia continued



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Scotese, C.R., 2013

Pleistocene

Photo: M.A. Clements

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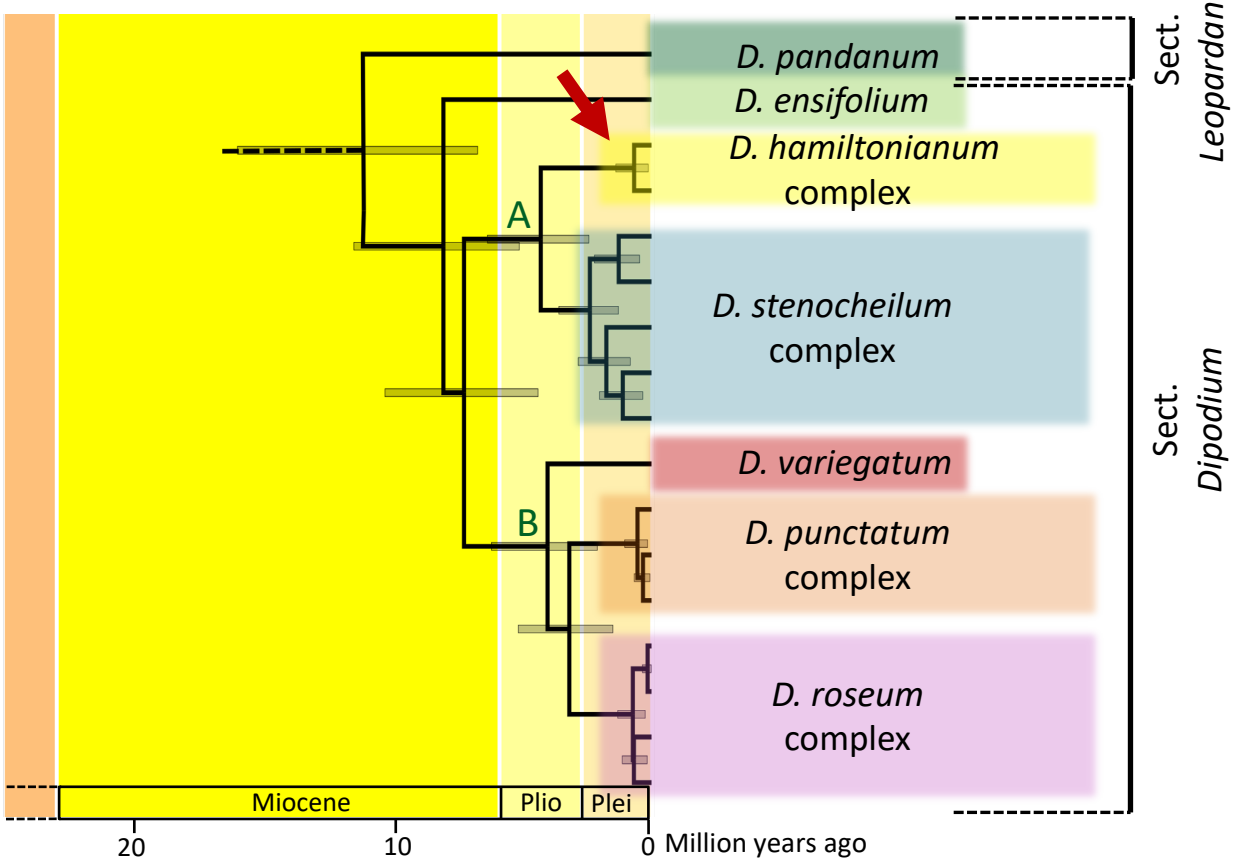
Photo: M.A. Clements

- **climatic oscillations**
- **Australia's landscape was similar to present day**



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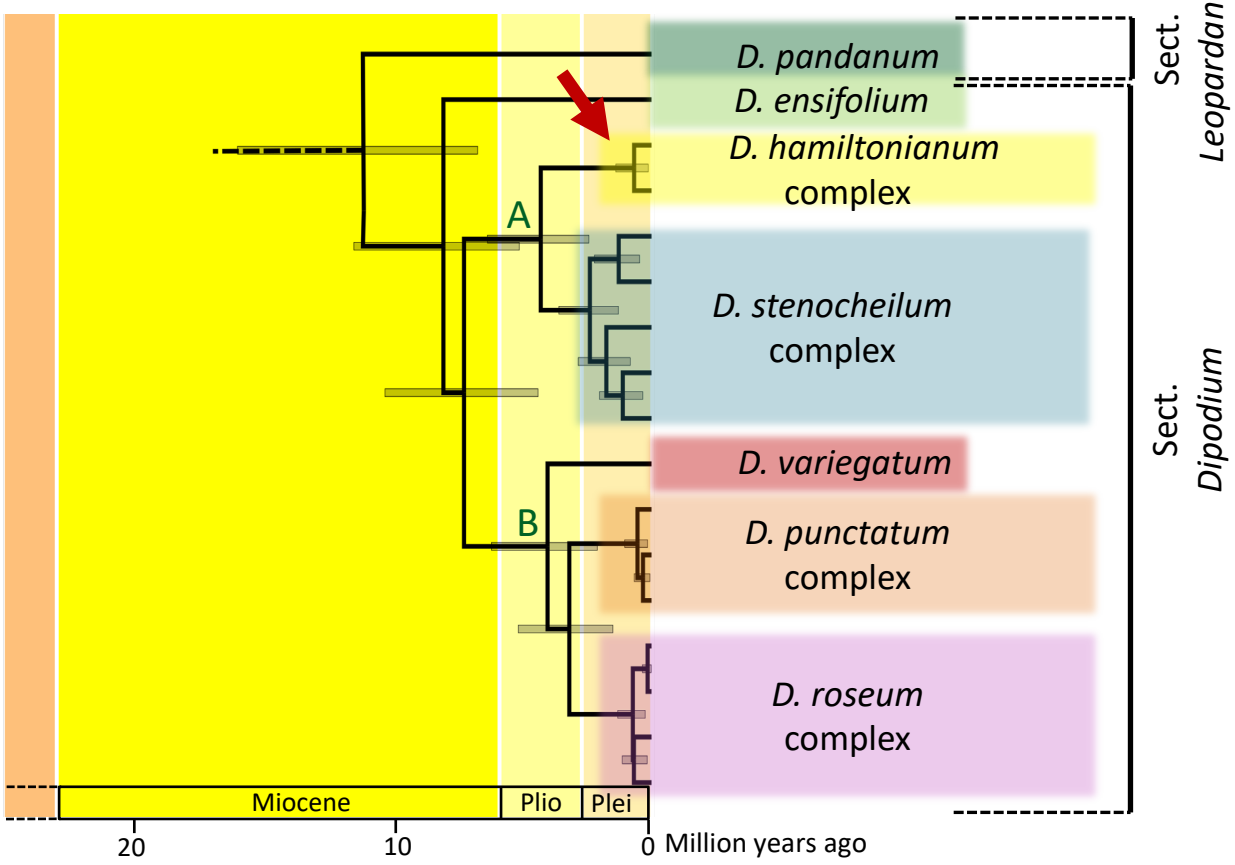

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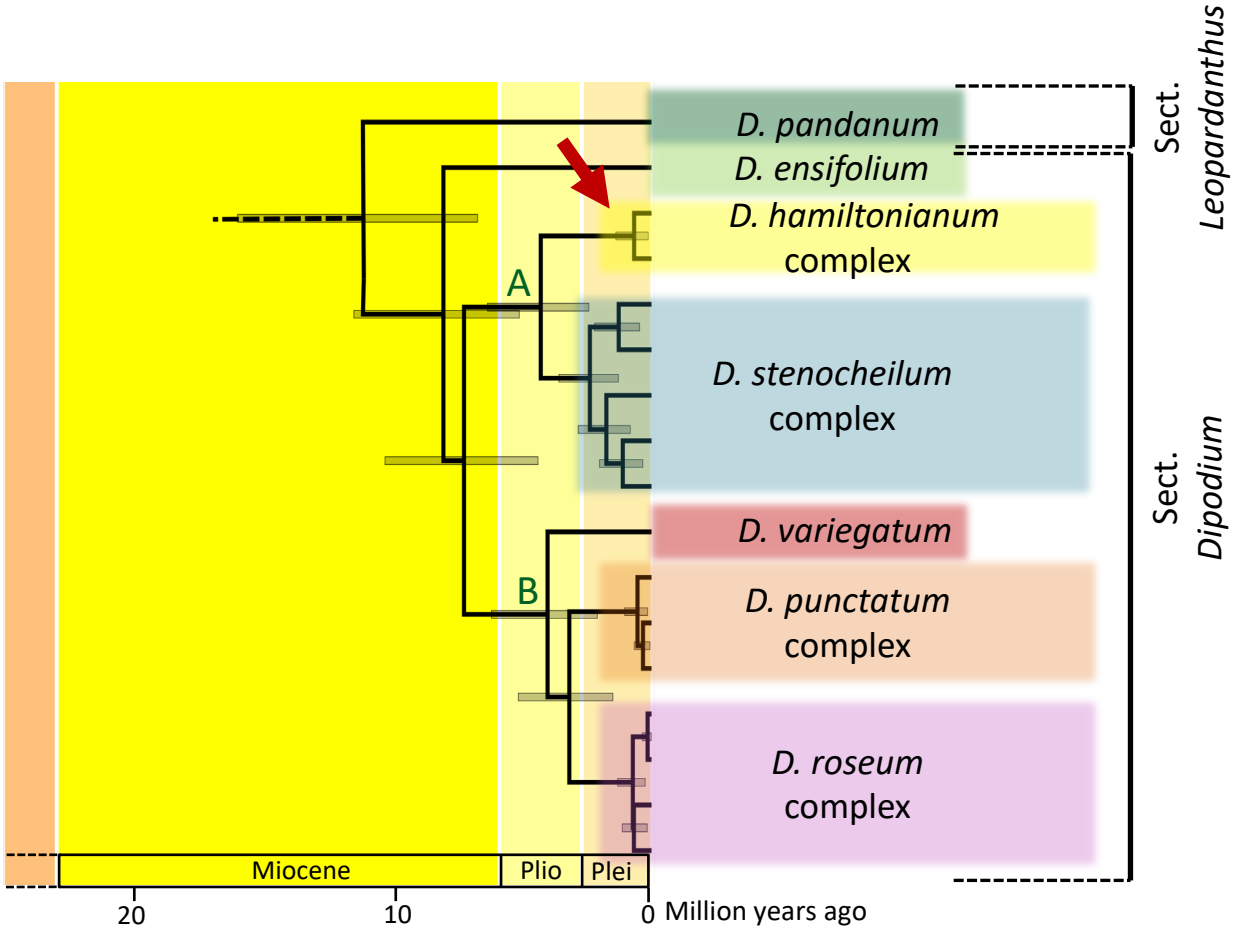
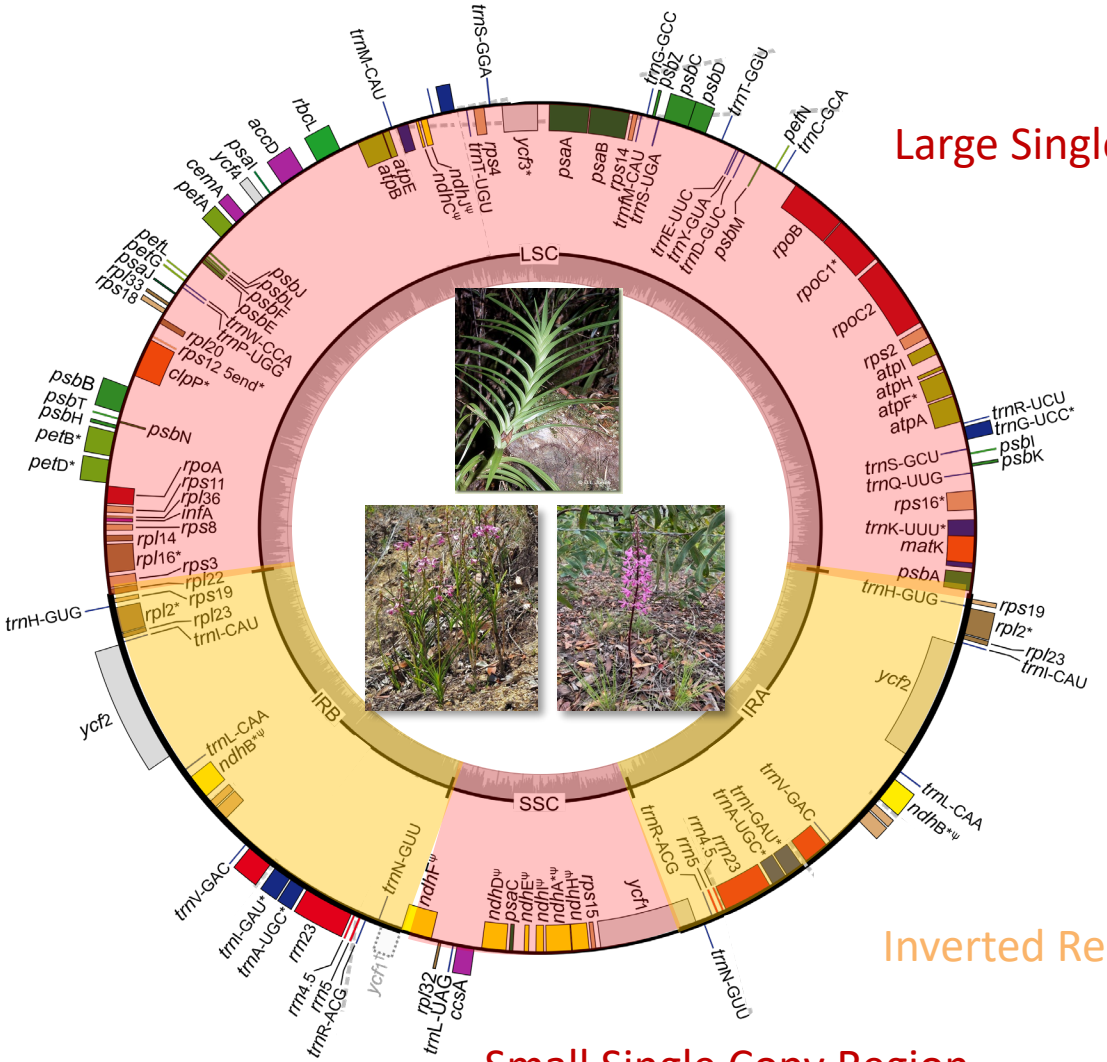


95% highest posterior density (HDP) values

Dipodium plastome: general features

Plastome assembly

- 24 *Dipodium* plastomes were assembled using Geneious Prime and a de novo & reference-guided assembly approach (reference plastomes *D. roseum* (MN200386) & *M. coccinea* (KP205432)).



Large Single Copy Region

Inverted Repeat Region A/B

Small Single Copy Region

- photosystem I
- photosystem II
- cytochrome b/f complex
- ATP synthese
- NADH dehydrogenase
- ribosomal RNAs
- clpP, matK
- other genes
- transfer RNAs
- RNA polymerase
- RubisCO large subunit
- ribosomal proteins (SSU)
- ribosomal proteins (LSU)
- hypothetical chloroplast reading frames (ycf)
- (*) Intron containing genes
- ψ moderate to severe pseudogenized genes

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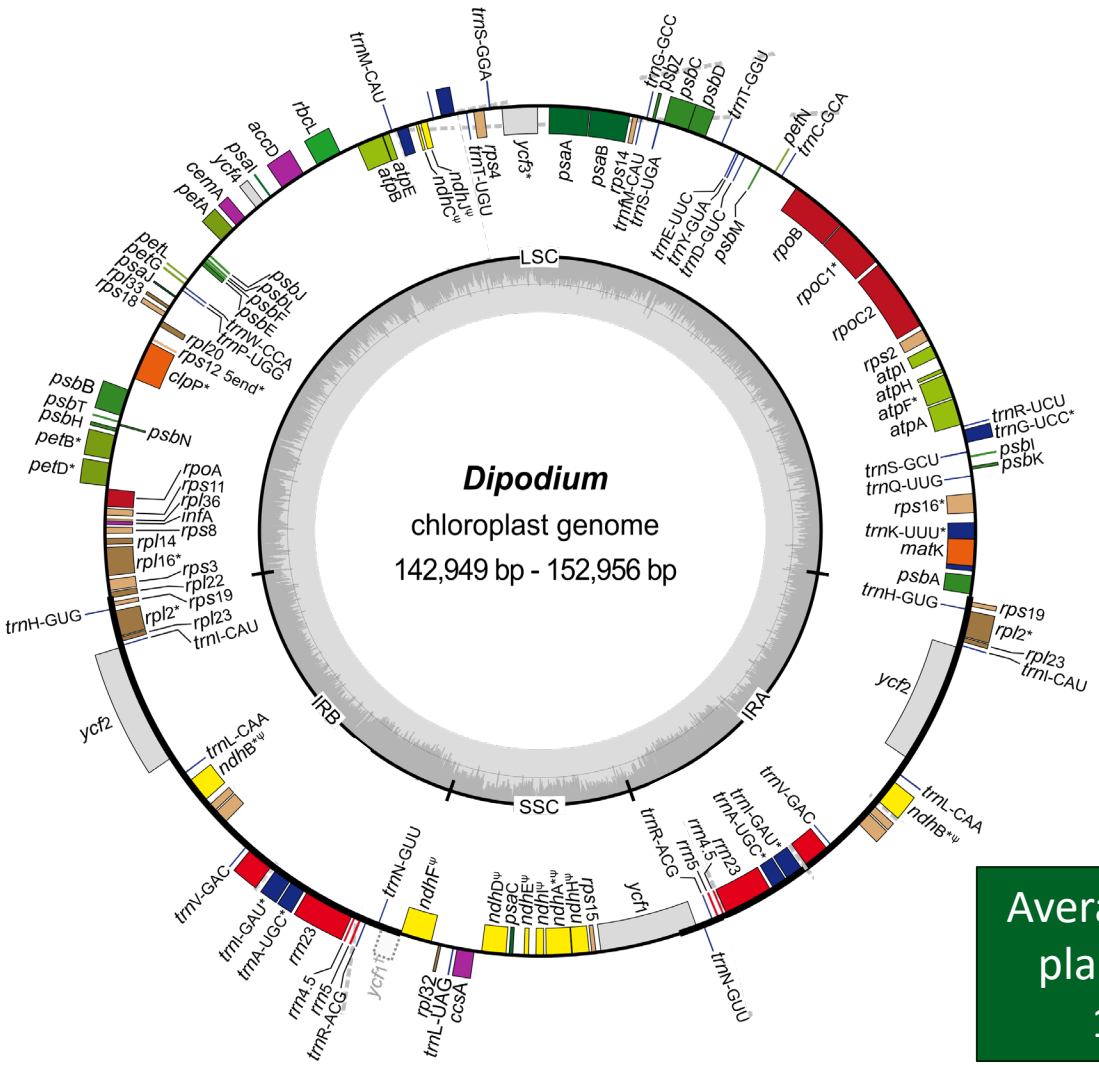

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Average size of land plant plastomes: 152,858 kb

***Dipodium* plastome:** structural hotspots – *ndh* genes pseudogenisation and loss

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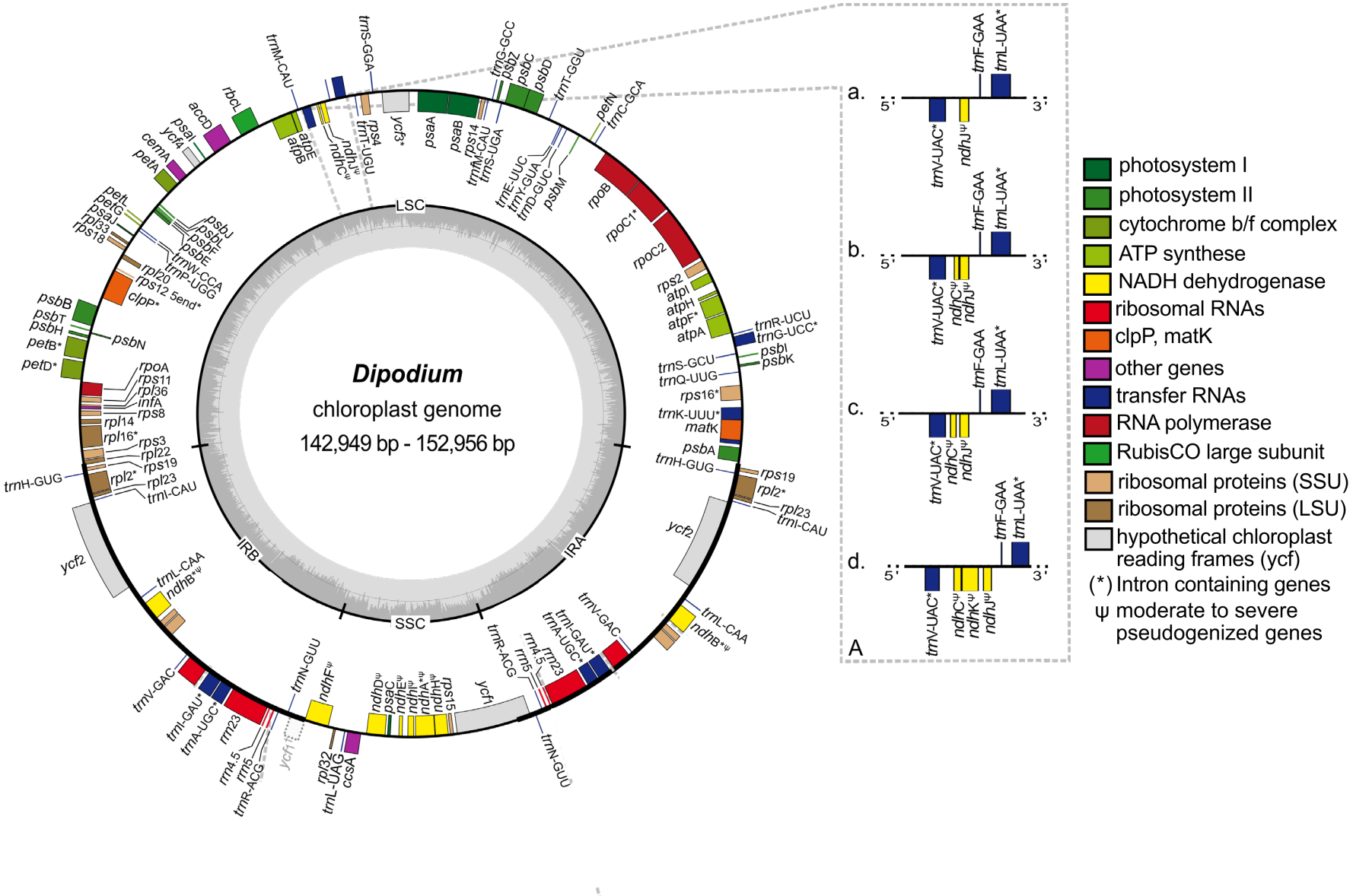

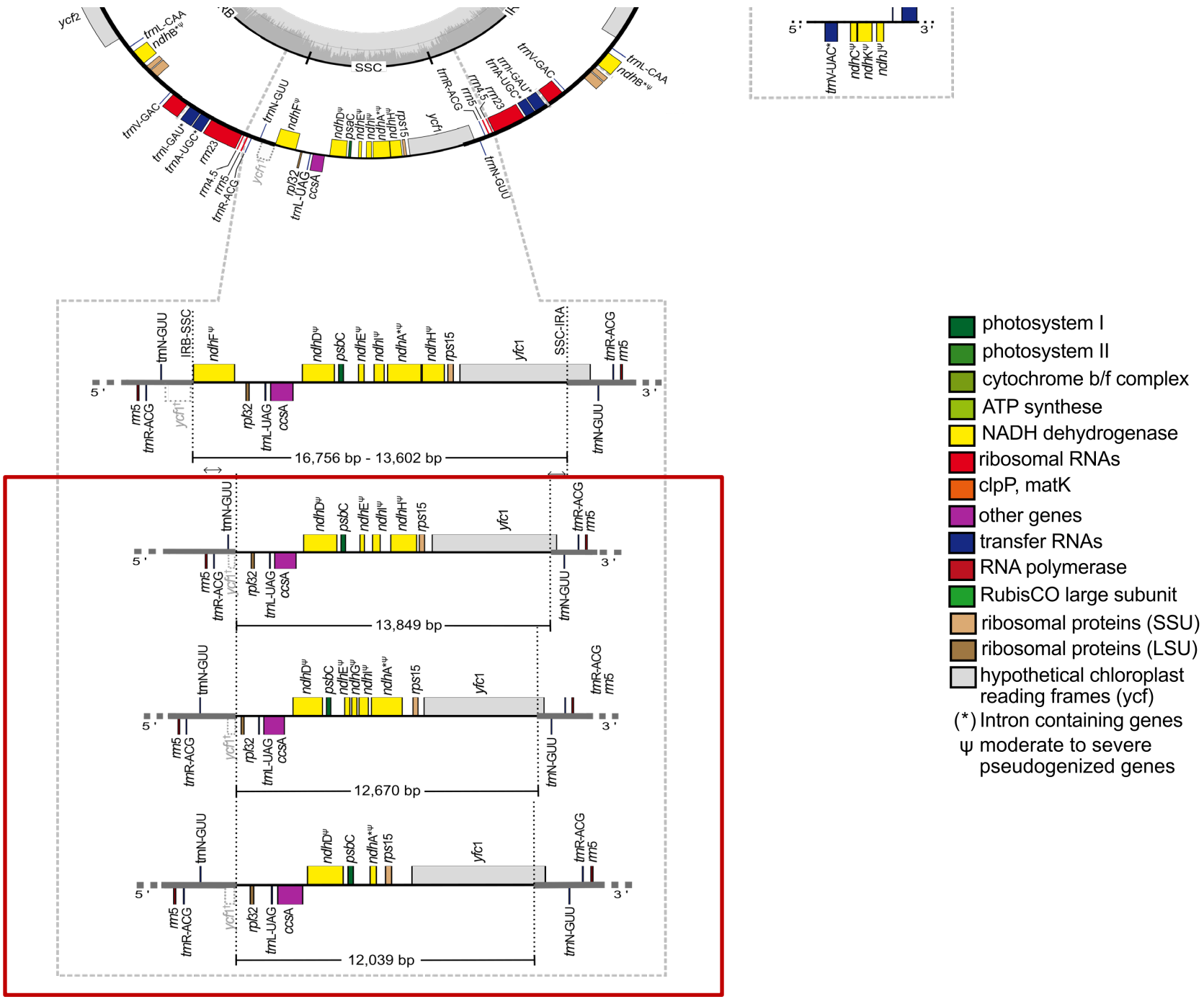
ycf2
trnL-CAA
ndhB*ψ
IRB
SSC
trnV-GAC
trnI-GAU*
trnA-UGC*
rrn23
rrn4.5
rrn5
trnR-ACG
trnN-GUU
ndhF*ψ
ycf1
rpl32
trnL-UAG
ccsA
ndhD*ψ
psaC
ndhE*ψ
ndhG*ψ
ndhI*ψ
ndhA*ψ
ndhH*ψ
rps15
ycf1
trnN-GUU
trnR-ACG
rrn5
rrn23
trnA-UGC*
trnI-GAU*
trnV-GAC
trnL-CAA
ndhB*ψ
5'
3'
trnV-UAC*
ndhC*ψ
ndhK*ψ
ndhJ*ψ
IRB-SSC
SSC-IRA
16,756 bp - 13,602 bp
13,849 bp
12,670 bp
12,039 bp
photosystem I
photosystem II
cytochrome b/f complex
ATP synthese
NADH dehydrogenase
ribosomal RNAs
clpP, matK
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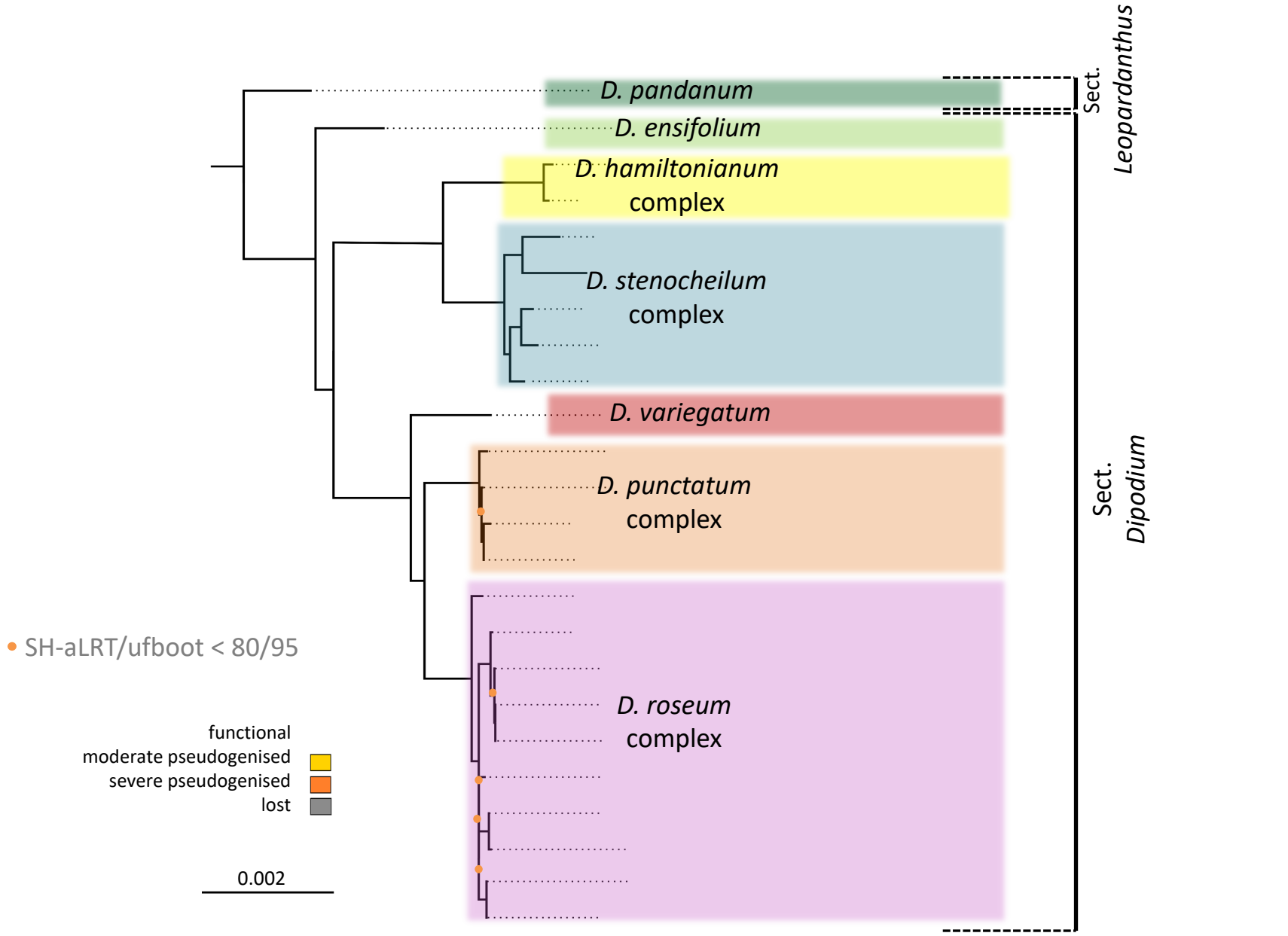
***ndh* gene degradation**: *Dipodium* plastomes

Maximum likelihood phylogenetic tree: Based on 68 concatenated plastid loci (69,335 bp) and 145 taxa; Best-fit model: GTR+I+I+F+R4 (IQ-TREE)



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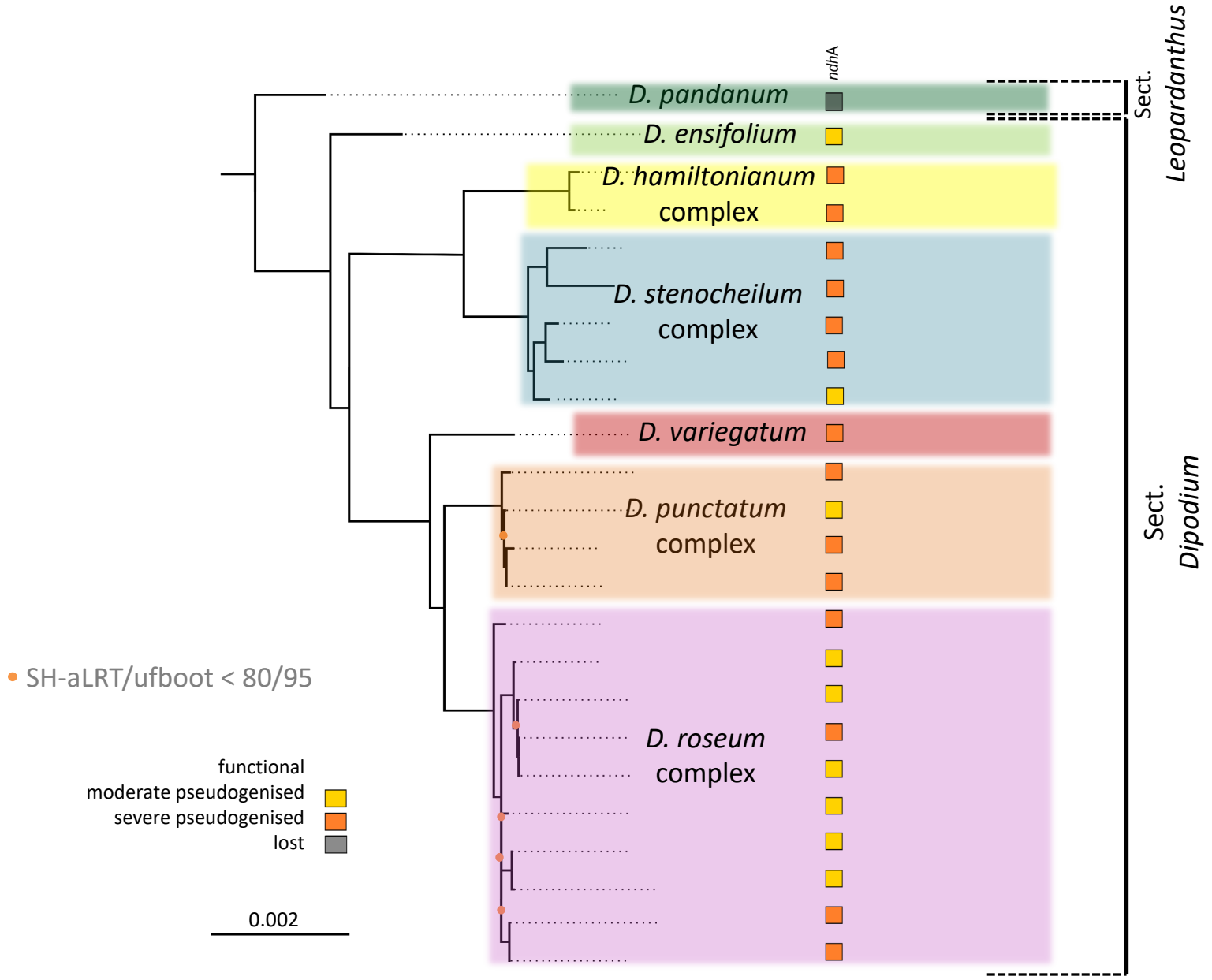
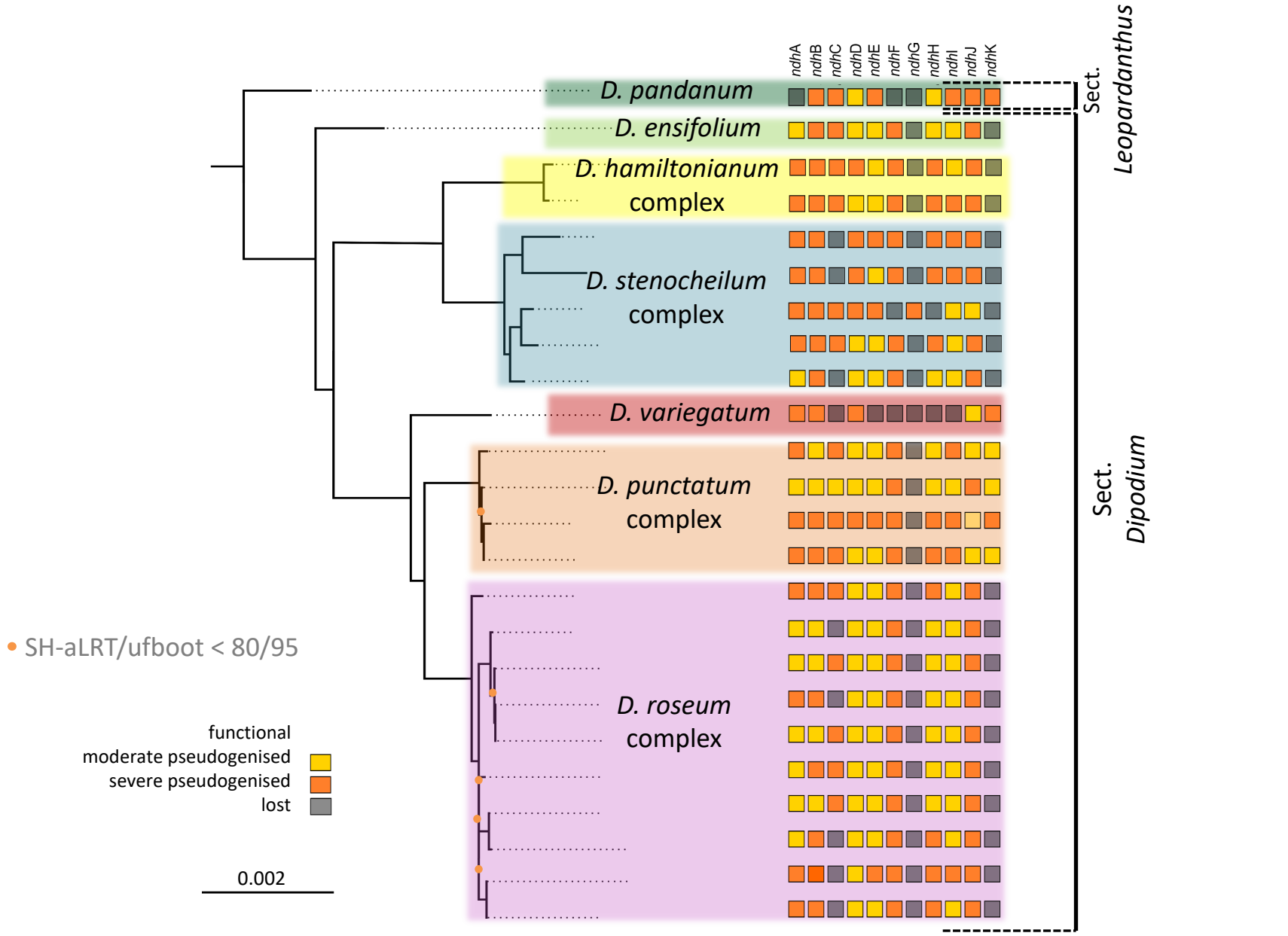


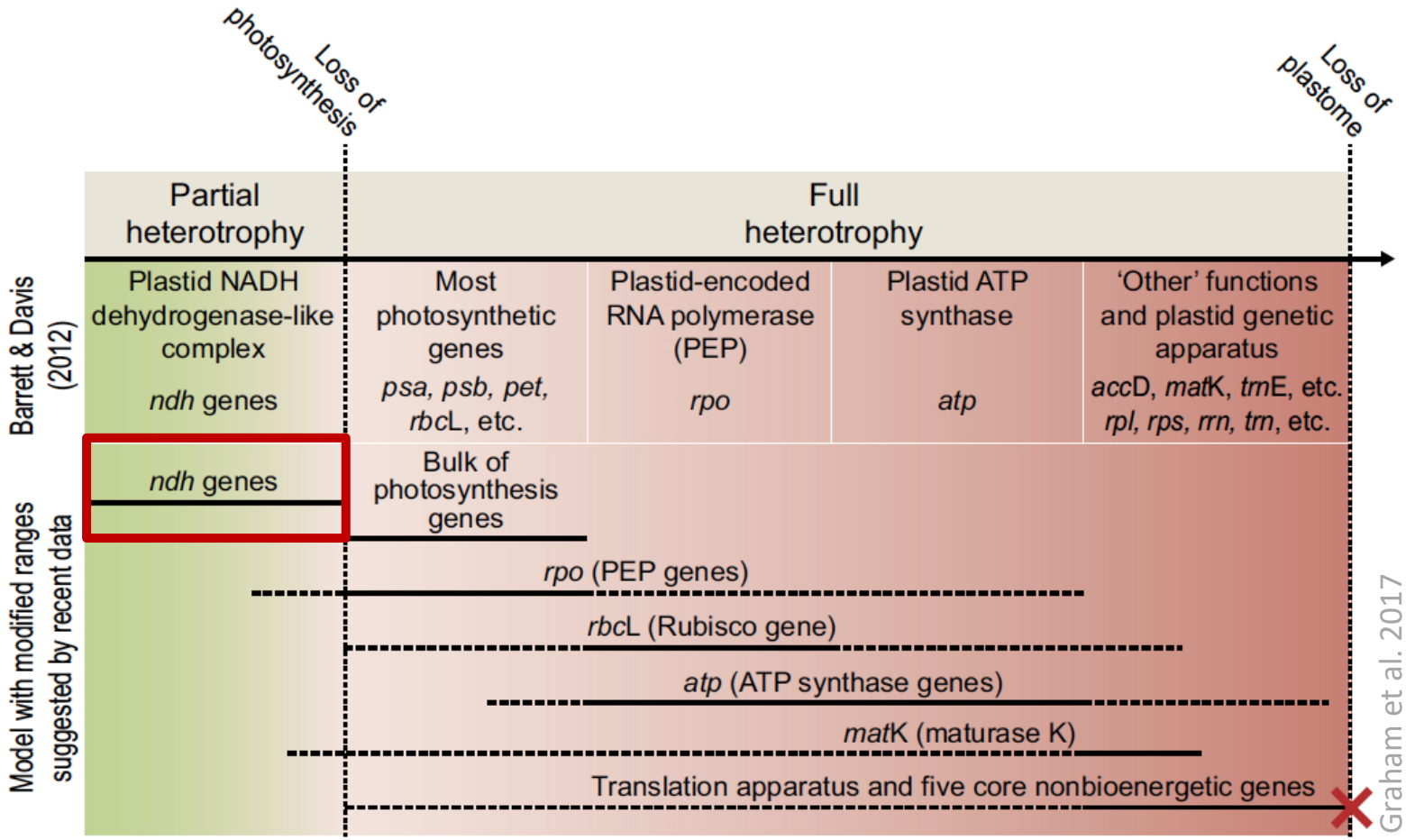
***ndh* gene degradation**: *Dipodium* plastomes

Maximum likelihood phylogenetic tree: Based on 68 concatenated plastid loci (69,335 bp) and 145 taxa; Best-fit model: GTR+I+I+F+R4 (IQ-TREE)



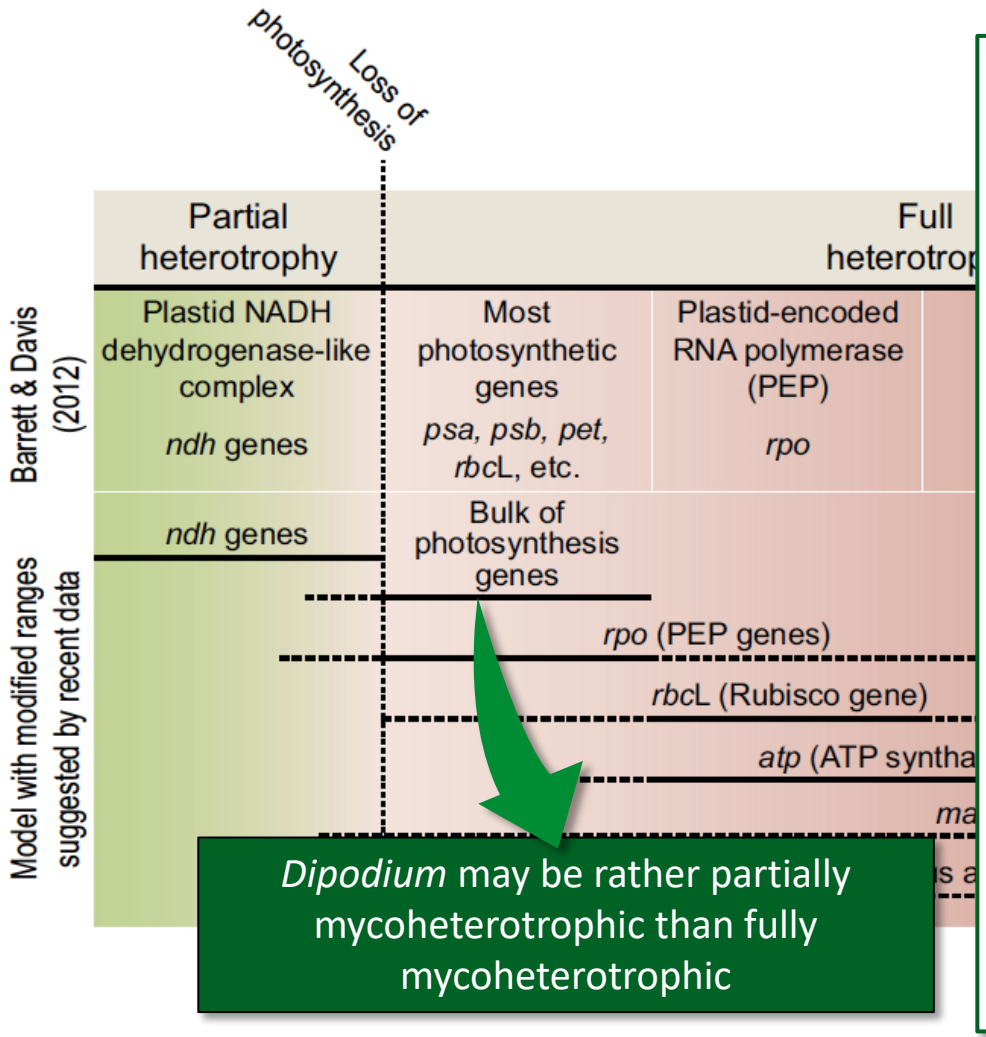
Plastid genes - degradation and loss

Australian Tropical Herbarium



Plastid genes - degradation and loss

Australian Tropical Herbarium



-D. elegantulum-

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Master's project supervisors:
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Phillip M. Schlueter (University of Hohenheim, Germany)