Les orchidées et leurs mycorhizes

M.-A. SELOSSE

Muséum nat. d'Histoire naturelle, Paris

Universités de Gdansk (Pologne) & Viçosa (Brésil)

Les réseaux mycorhiziens

Mycohétérotrophie et réseaux

Mixotrophie et réseaux mycorhiziens

La difficile transition vers l'hétérotrophie

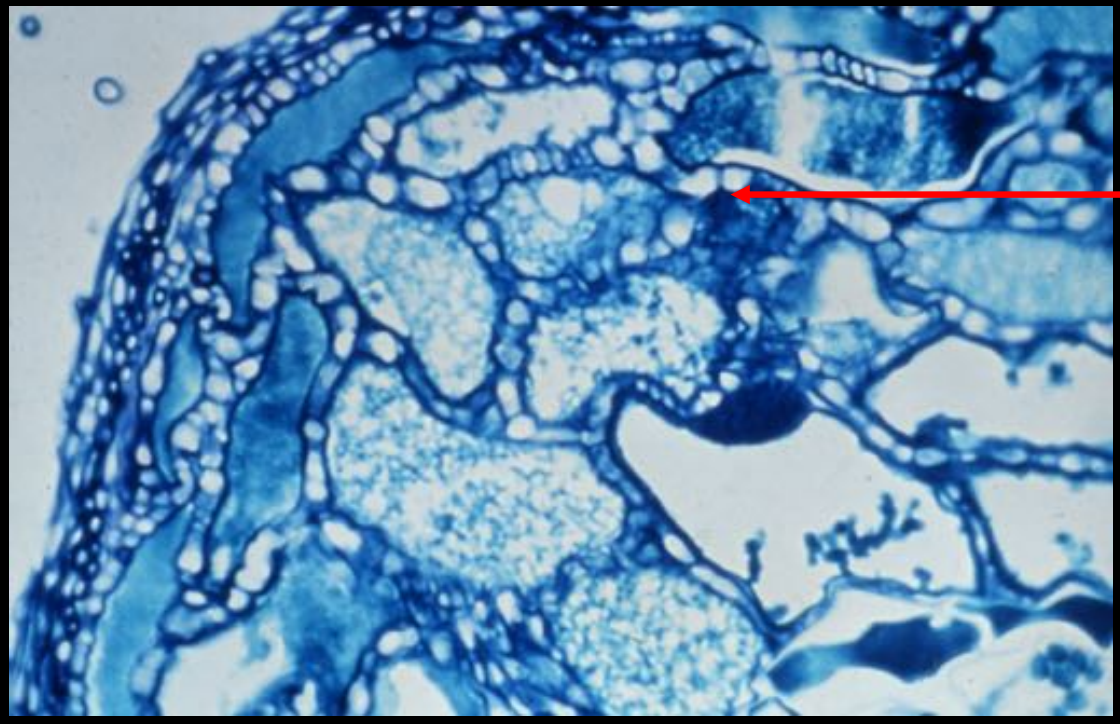
… due à un attachement fatal à la lumière ?

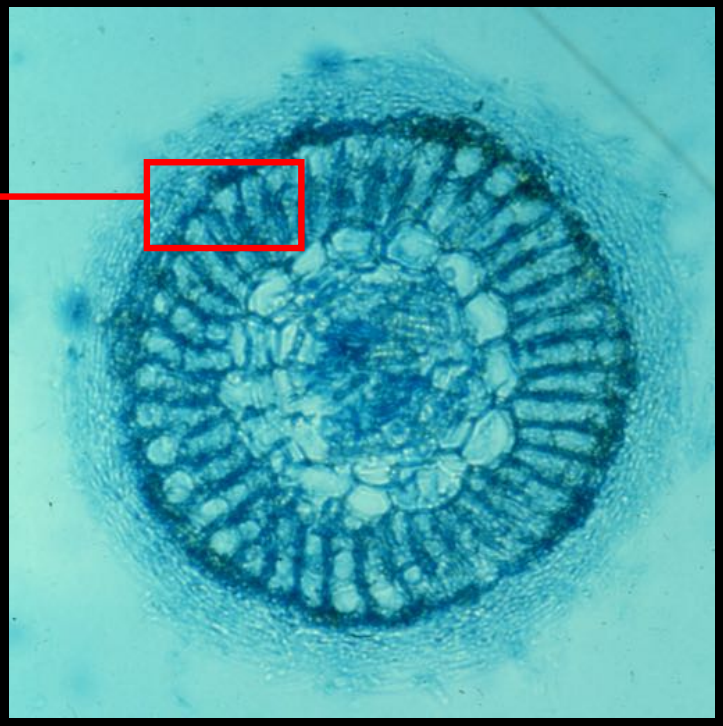
MYCORRHIZAL SYMBIOSIS

… a symbiosis between two partners

ECTO-MYCORRHIZAE

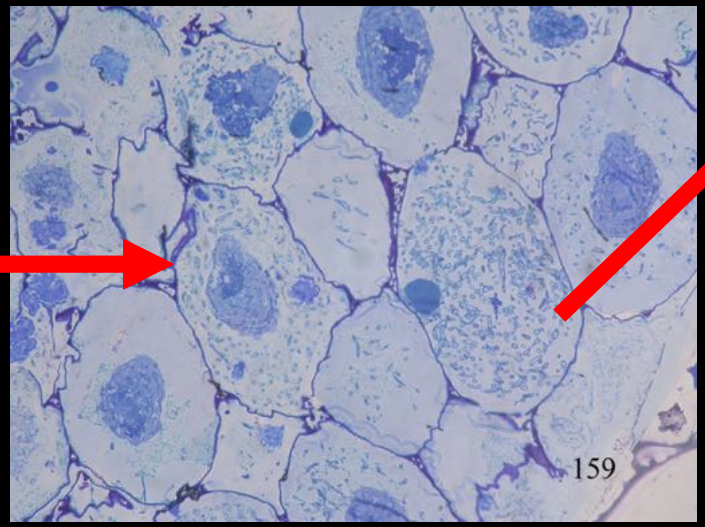
Asco- and Basidiomycetes on most trees in temperate regions

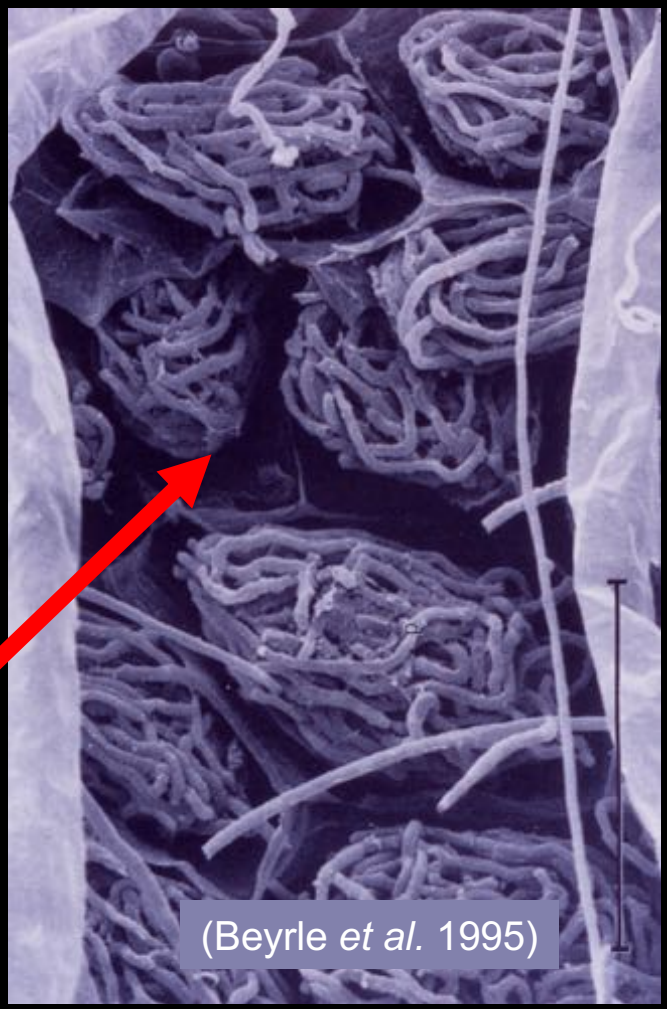




ORCHID MYCORHIZAE

Intracellular pelotons formed within root cells, usually with « rhizoctonias"



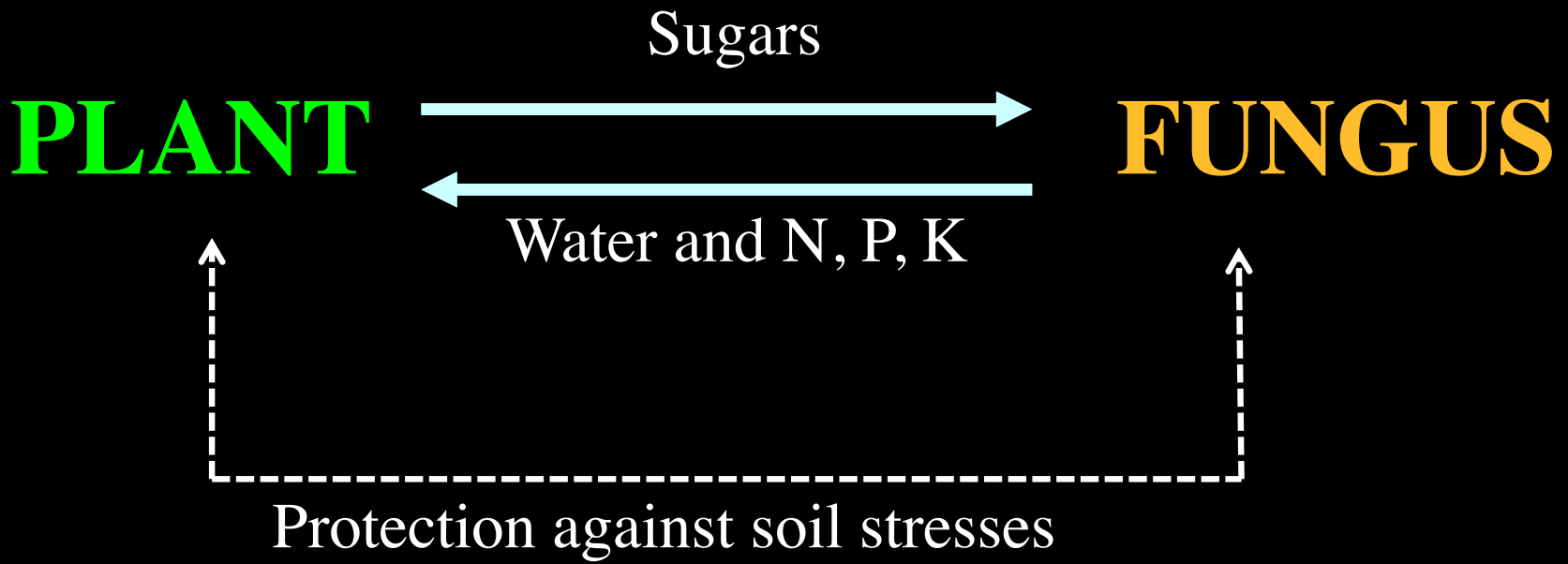


Orchid germination, usually involving rhizoctonias

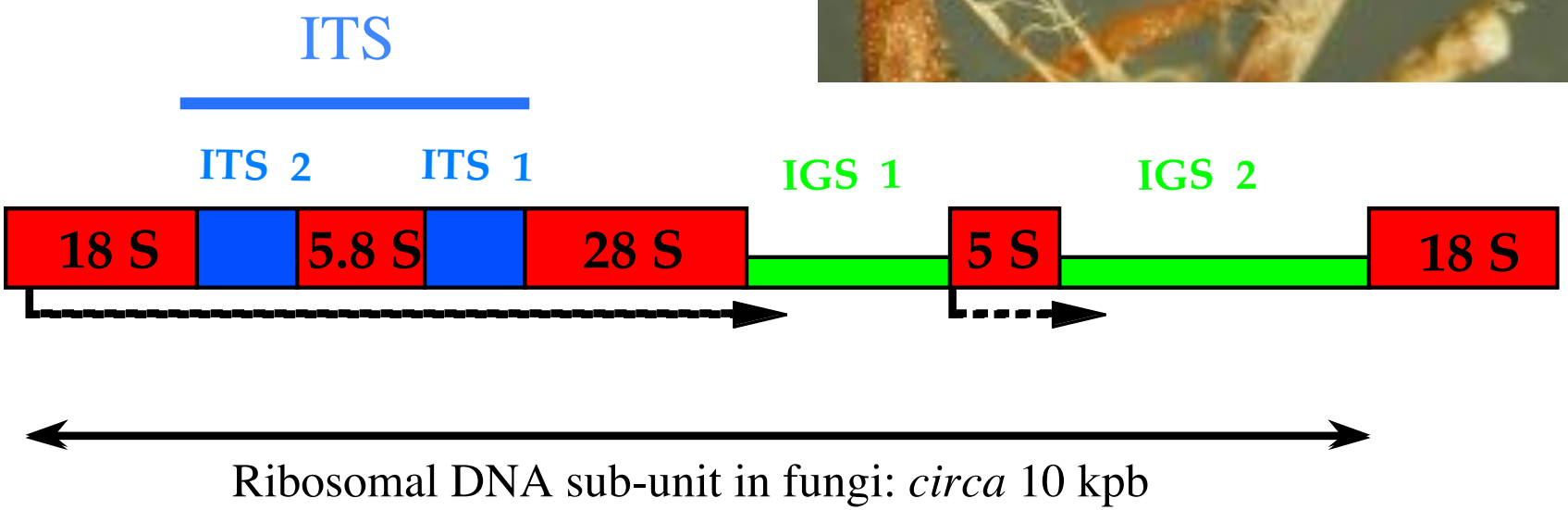
MYCORRHIZAL SYMBIOSIS

>85% of plants associate with soil fungi

Reciprocal nutrient exchanges + protection:



ITS BARCODING



Ribosomal DNA sub-unit in fungi: *circa* 10 kpb

Les réseaux mycorhiziens

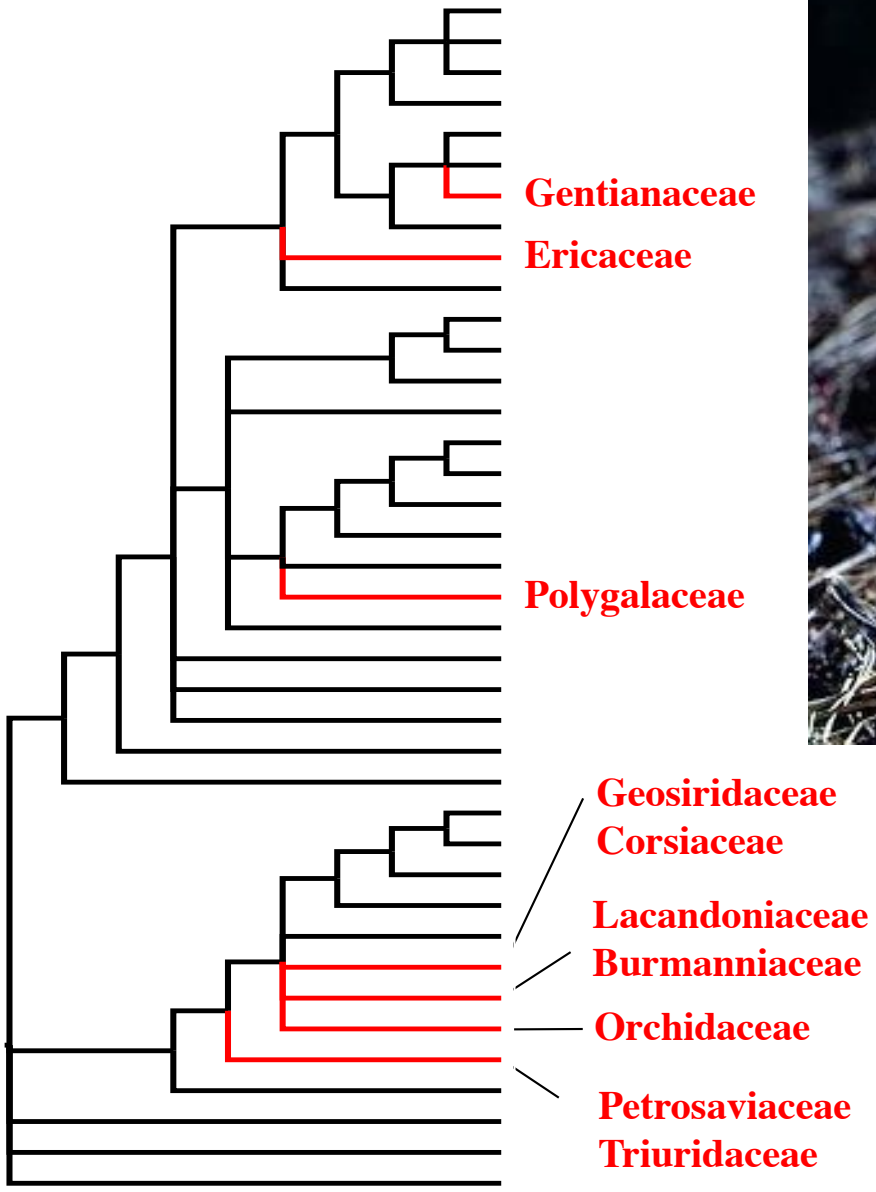
Mycohétérotrophie et réseaux

Mixotrophie et réseaux mycorhiziens

La difficile transition vers l'hétérotrophie

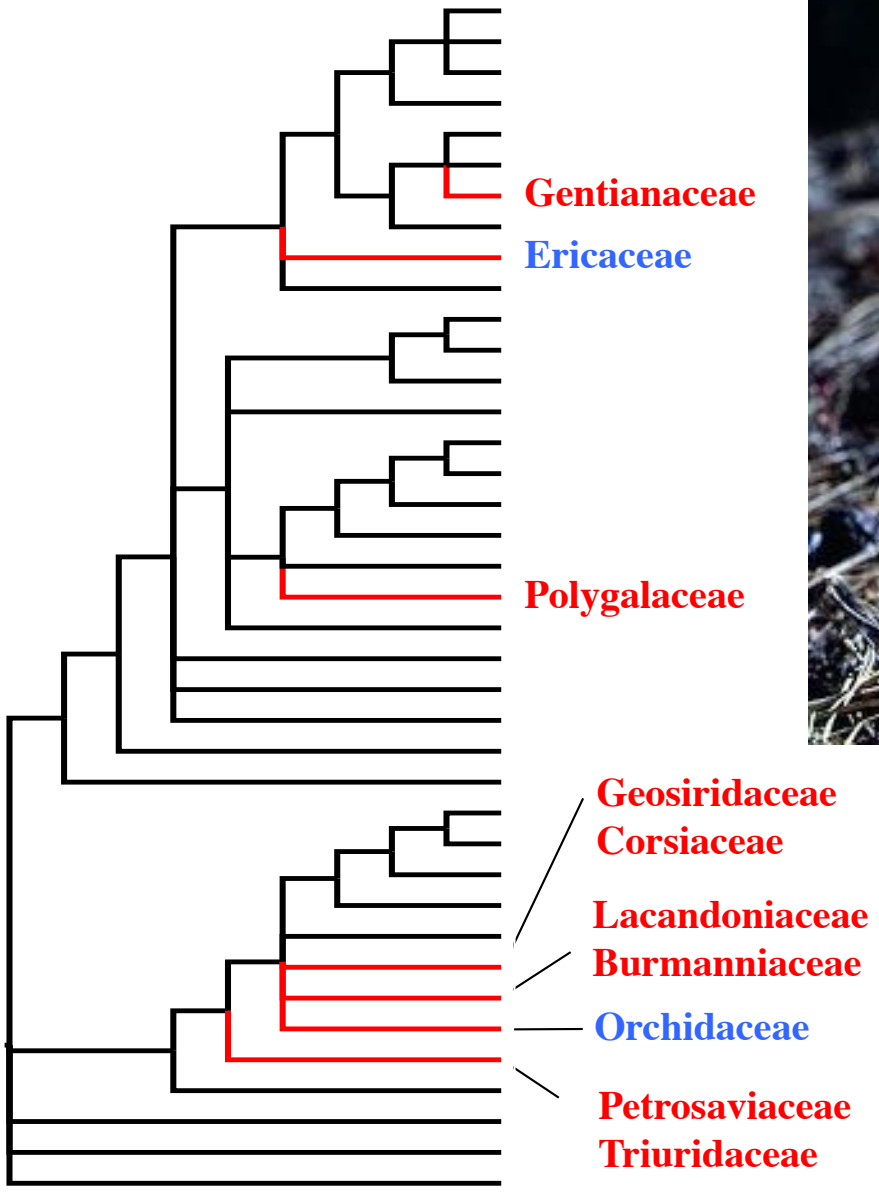
… due à un attachement fatal à la lumière ?

Mycoheterotrophs



(from Brundett, 2004)

Mycoheterotrophs



(from Brundett, 2004)

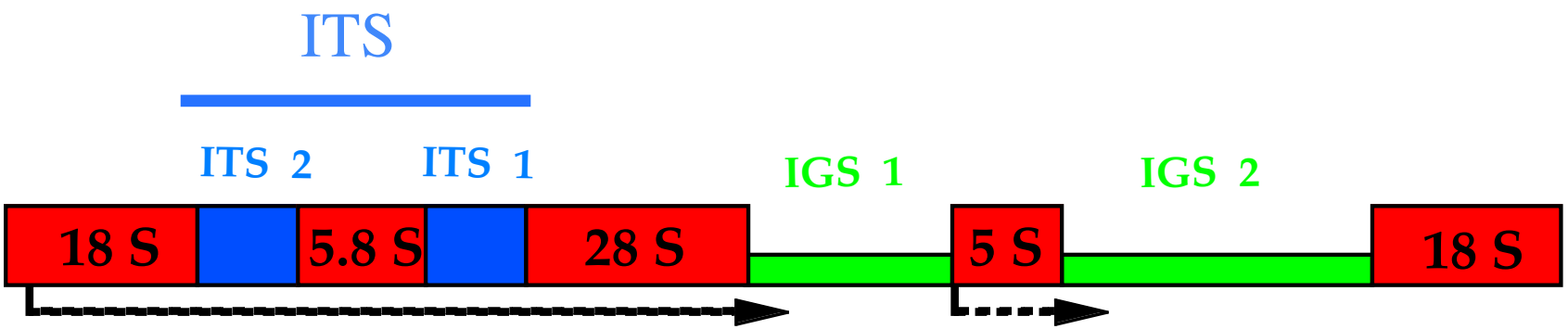
Neottia nidus-avis

Selosse *et al*., 2002, *Mol*. *Ecol*. 11, 1831
McKendrick *et al*., 2002, *New Phytol*. 145, 523
Selosse *et al*., 2002, *New Phytol*. 155, 183

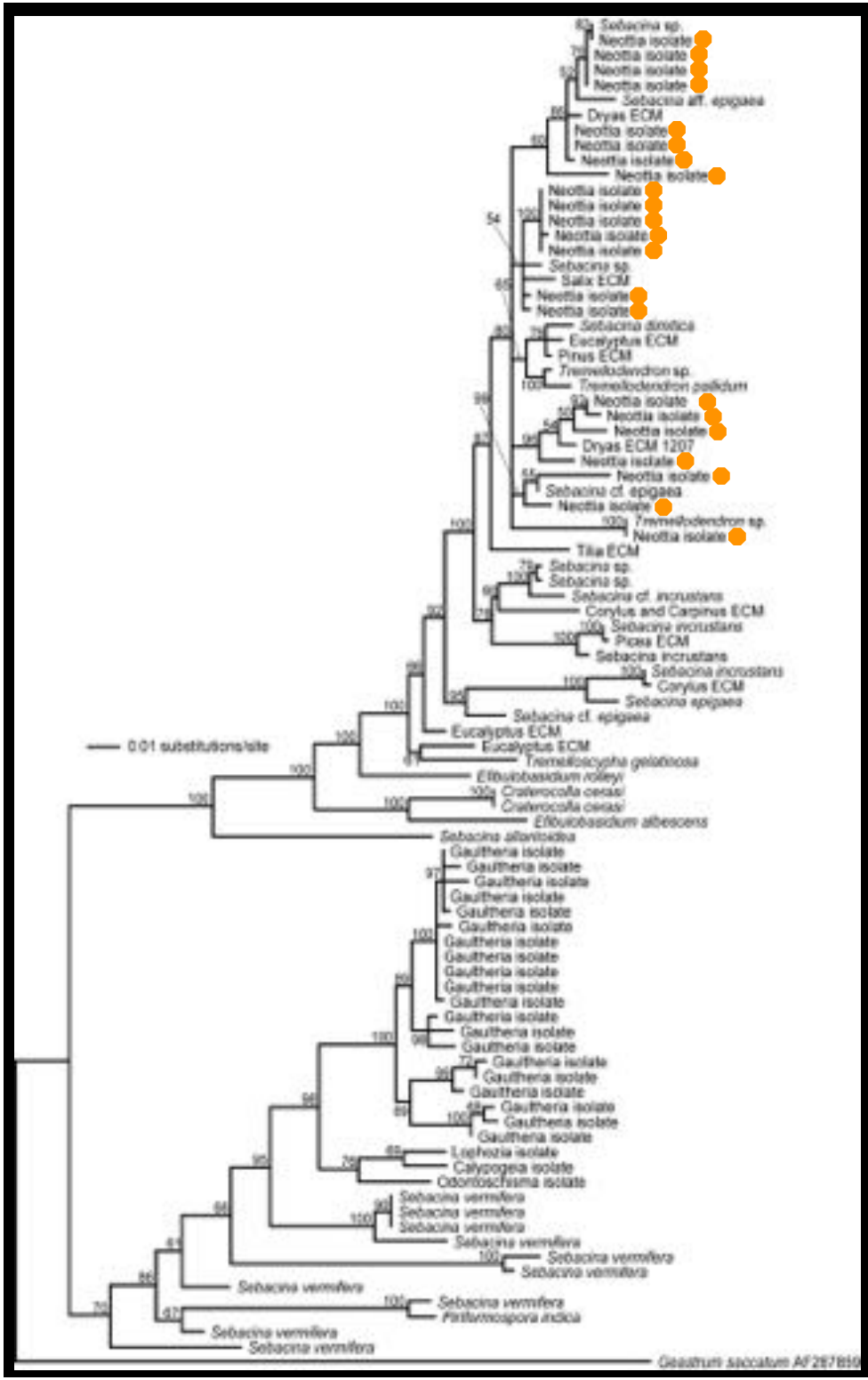
ITS BARCODING

Taxonomic resolution :

- Genus / order
- Species / sub-species
- Sub-species / genet

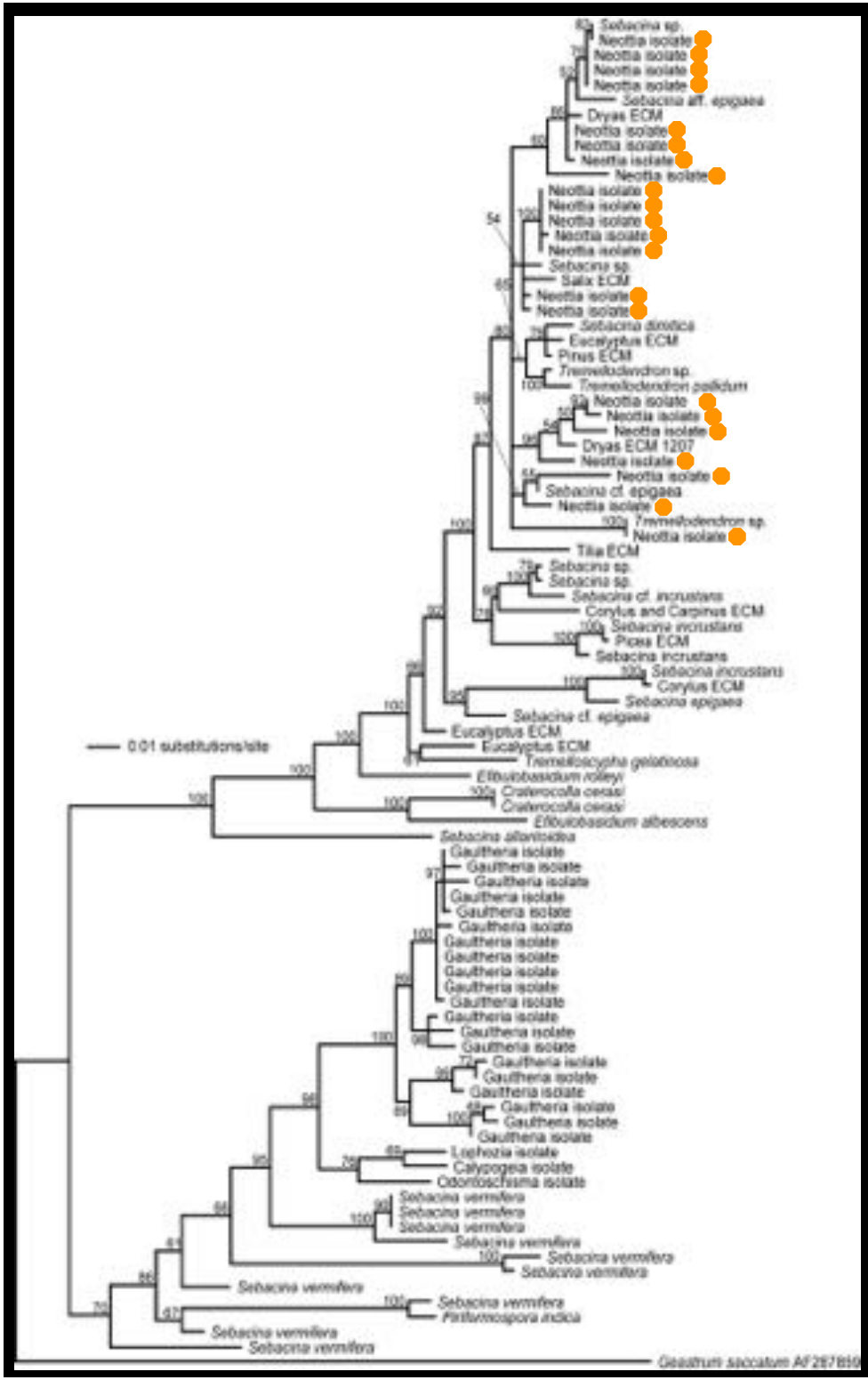


Ribosomal DNA sub-unit in fungi: *circa* 10 kpb



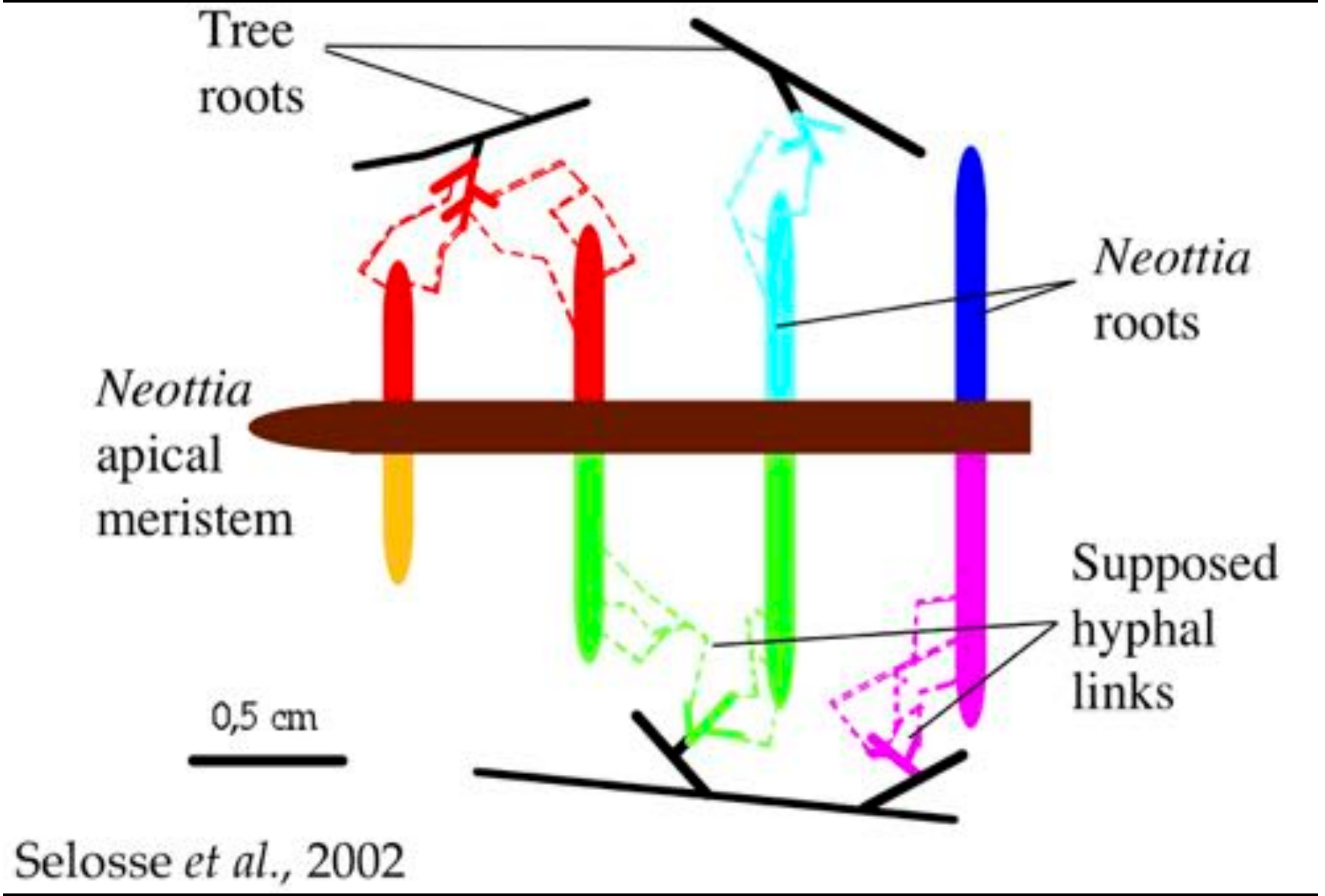
Neottia nidus-avis

associated with Sebacinales…



Neottia nidus-avis

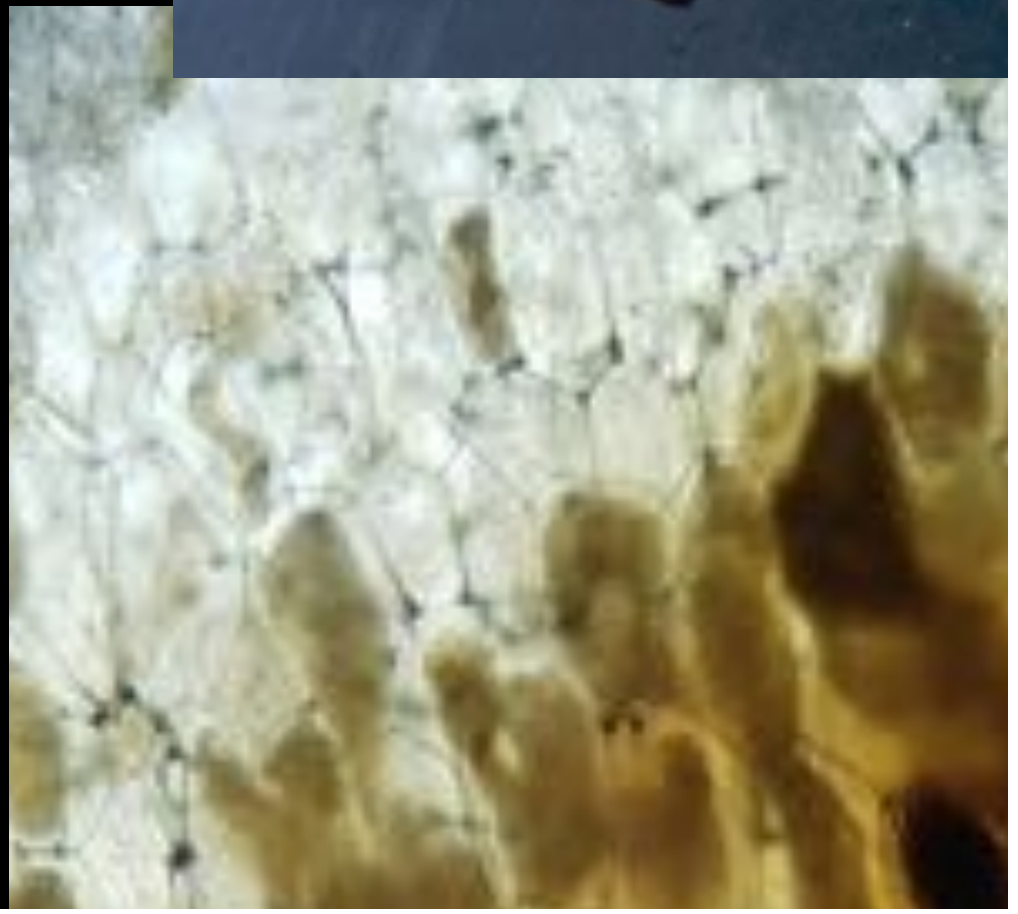
associated with Sebacinales…
themselves ectomycorrhizal
on nearby tree roots



Selosse *et al.*, 2002

Epipogium aphyllum

Epipogium aphyllum



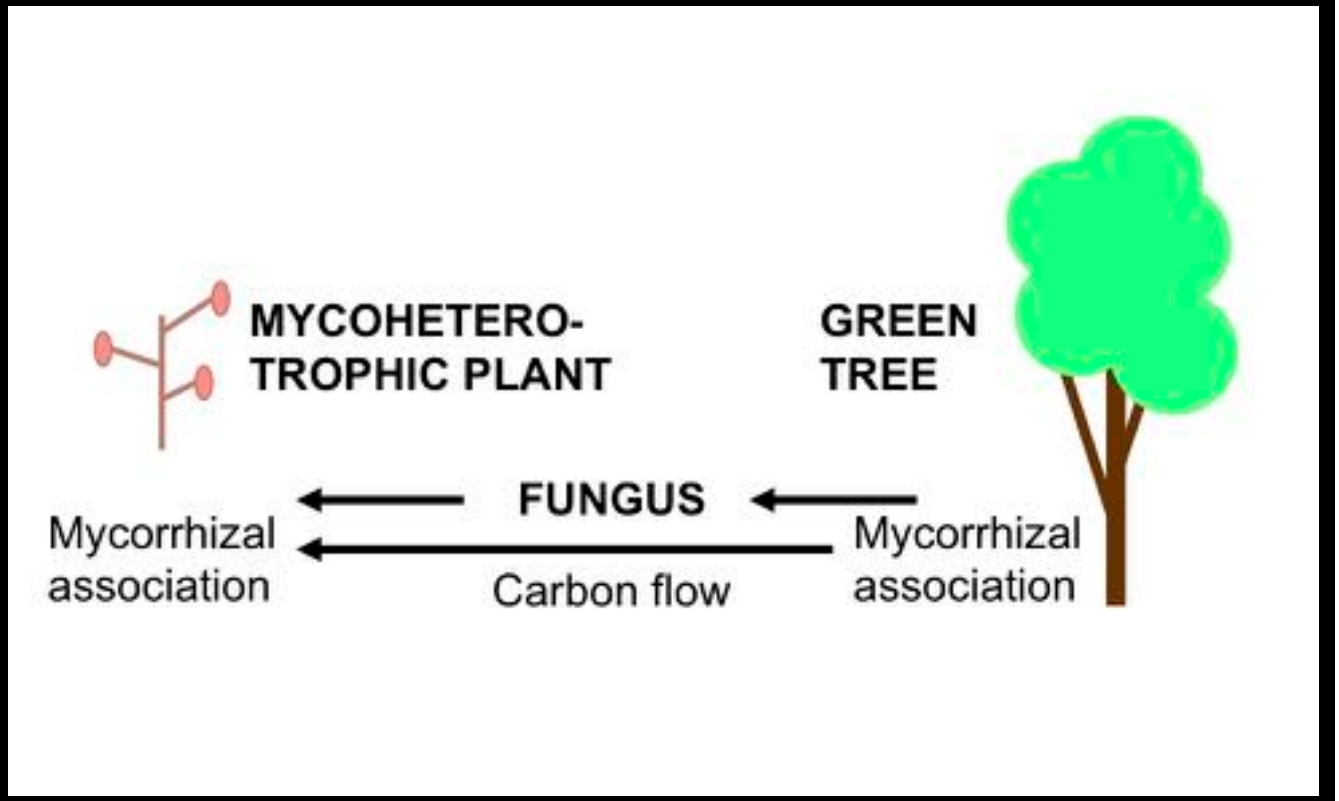
Epipogium aphyllum

… with *Inocybe* species

Roy *et al*., *Annals Bot*., 2009.

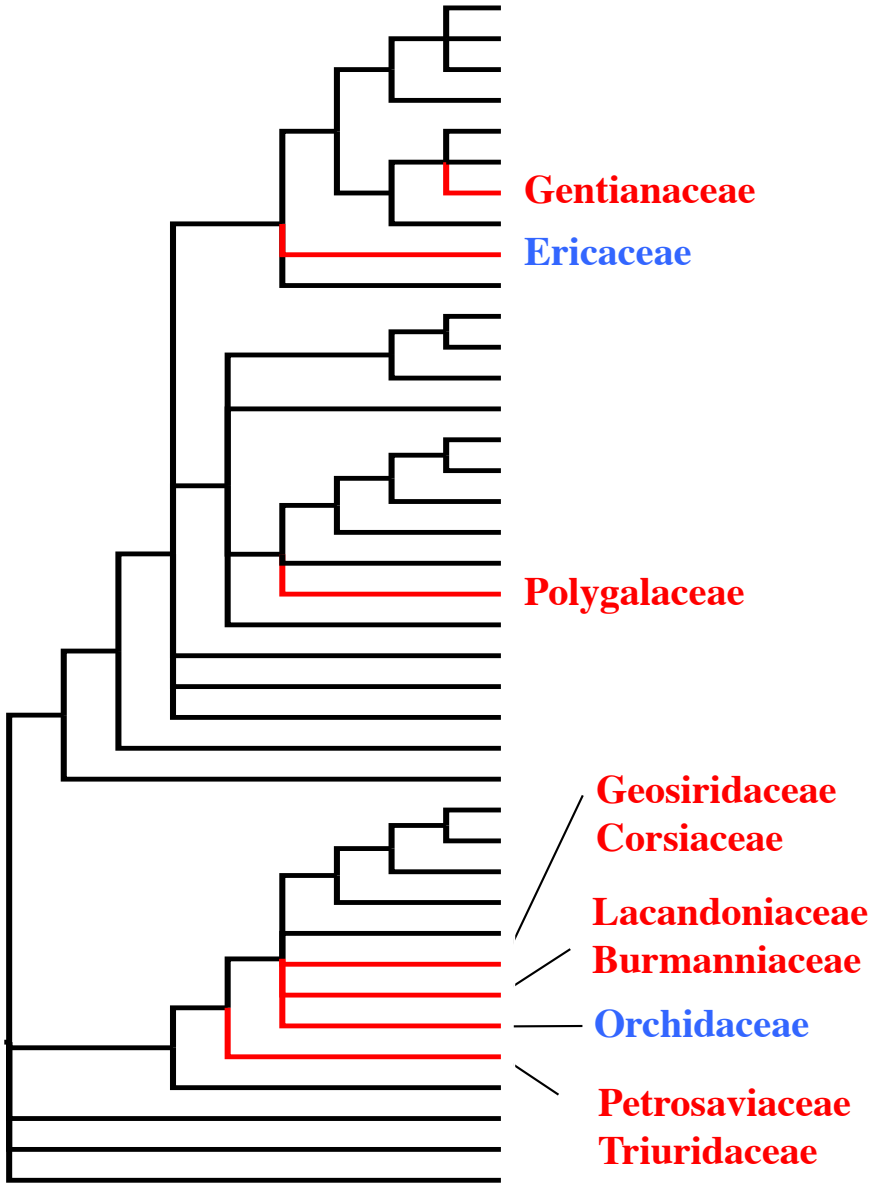
MYCOHETEROTROPHY

Exploiting the mycorrhizal network...

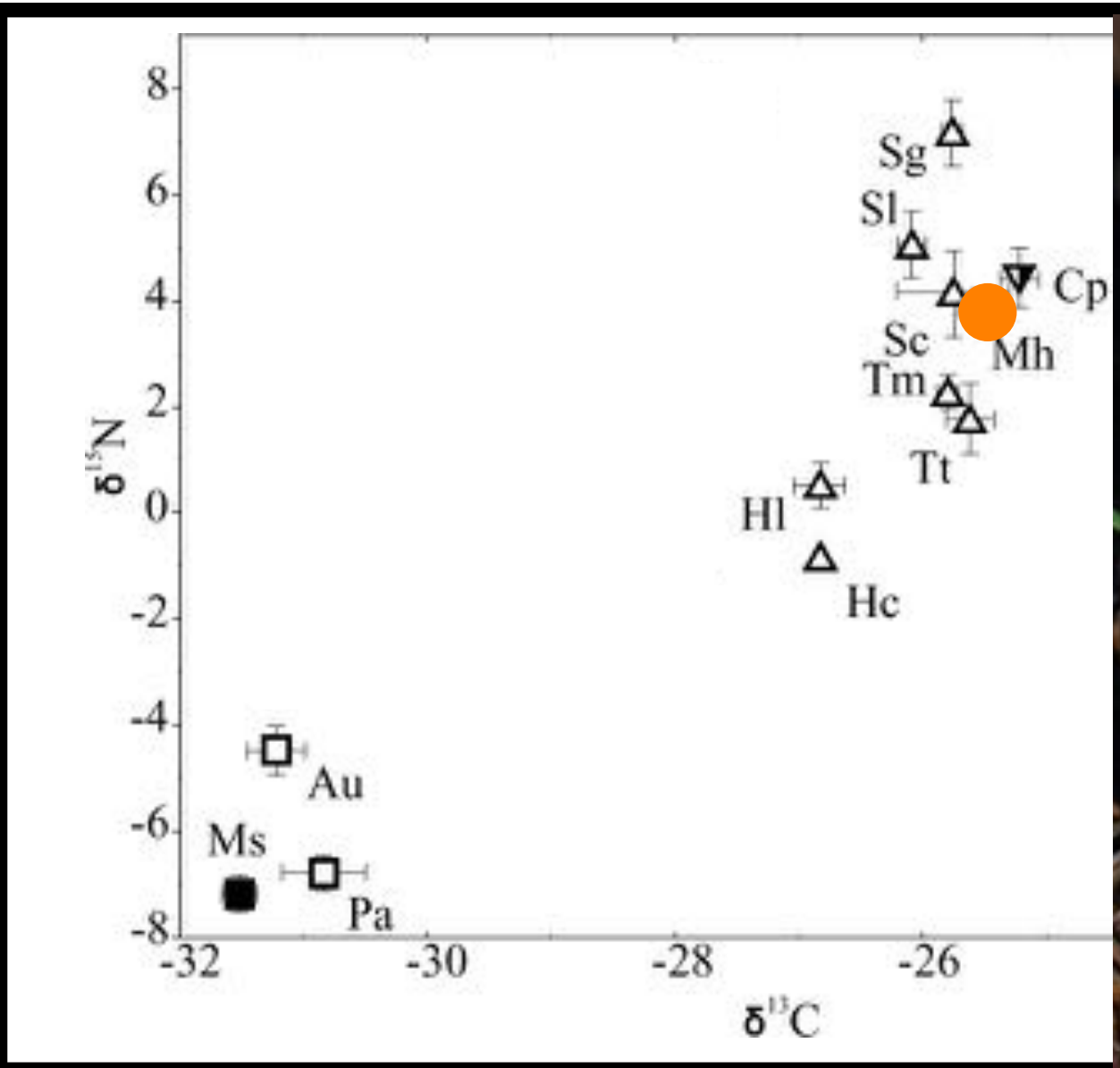


… as reflected in their spontaneous stable isotopes (^{13}C and ^{15}N) abundances

Mycoheterotrophs

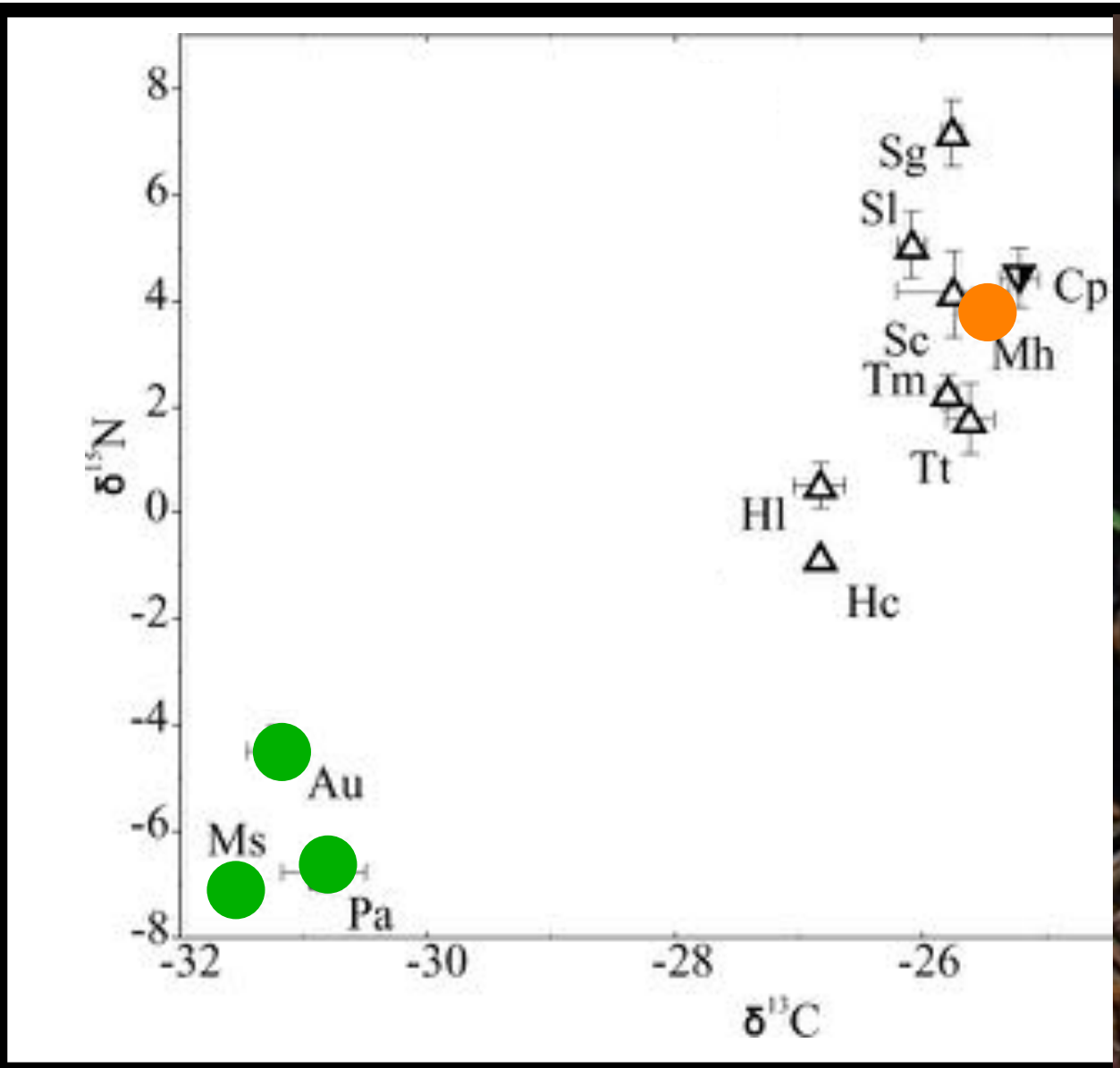


(from Brundett, 2004)

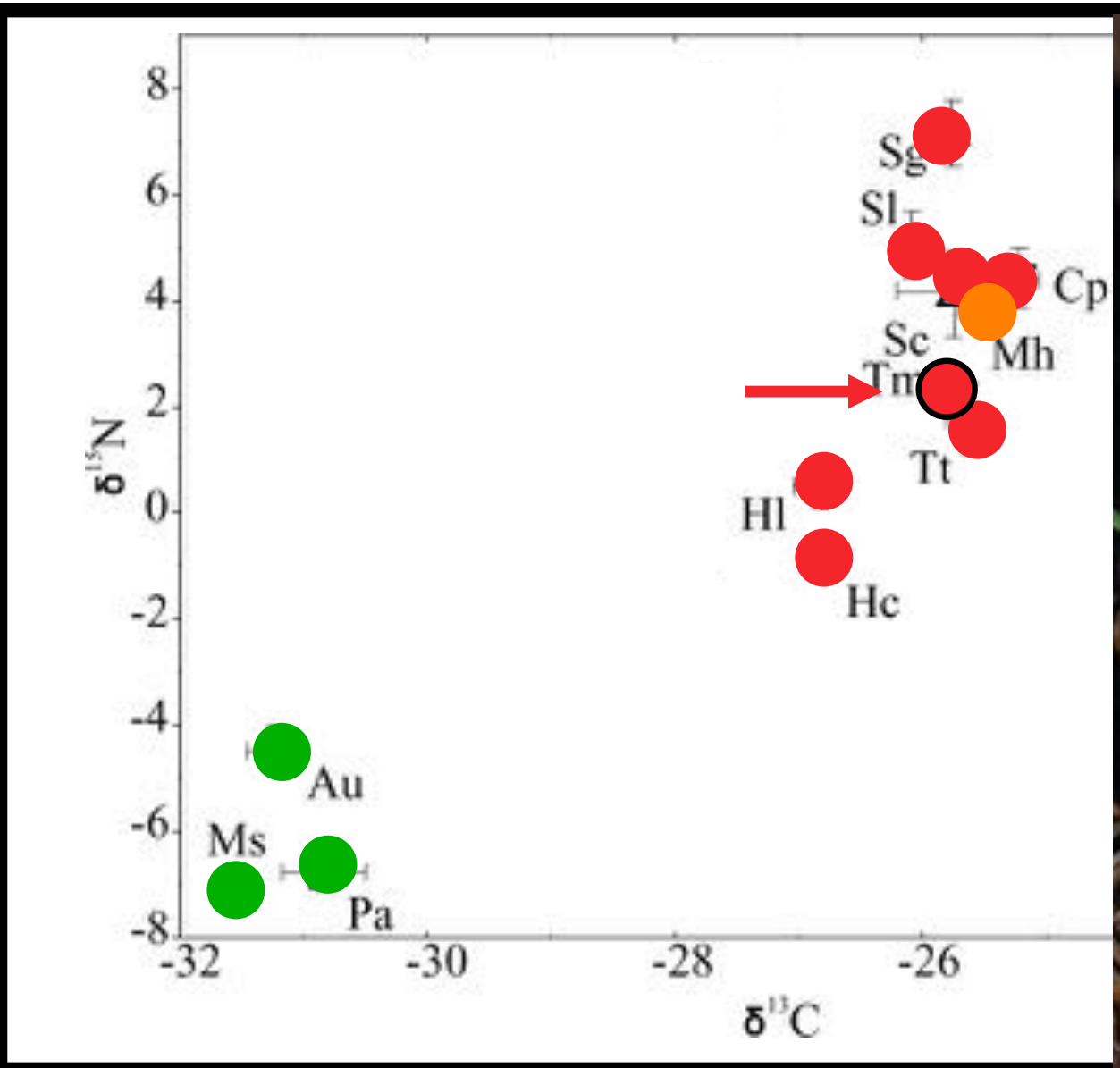


Tedersoo *et al.*, 2007, *Oecologia*

Mycoheterotrophic Ericaceae: *Hypopitys monotropa*

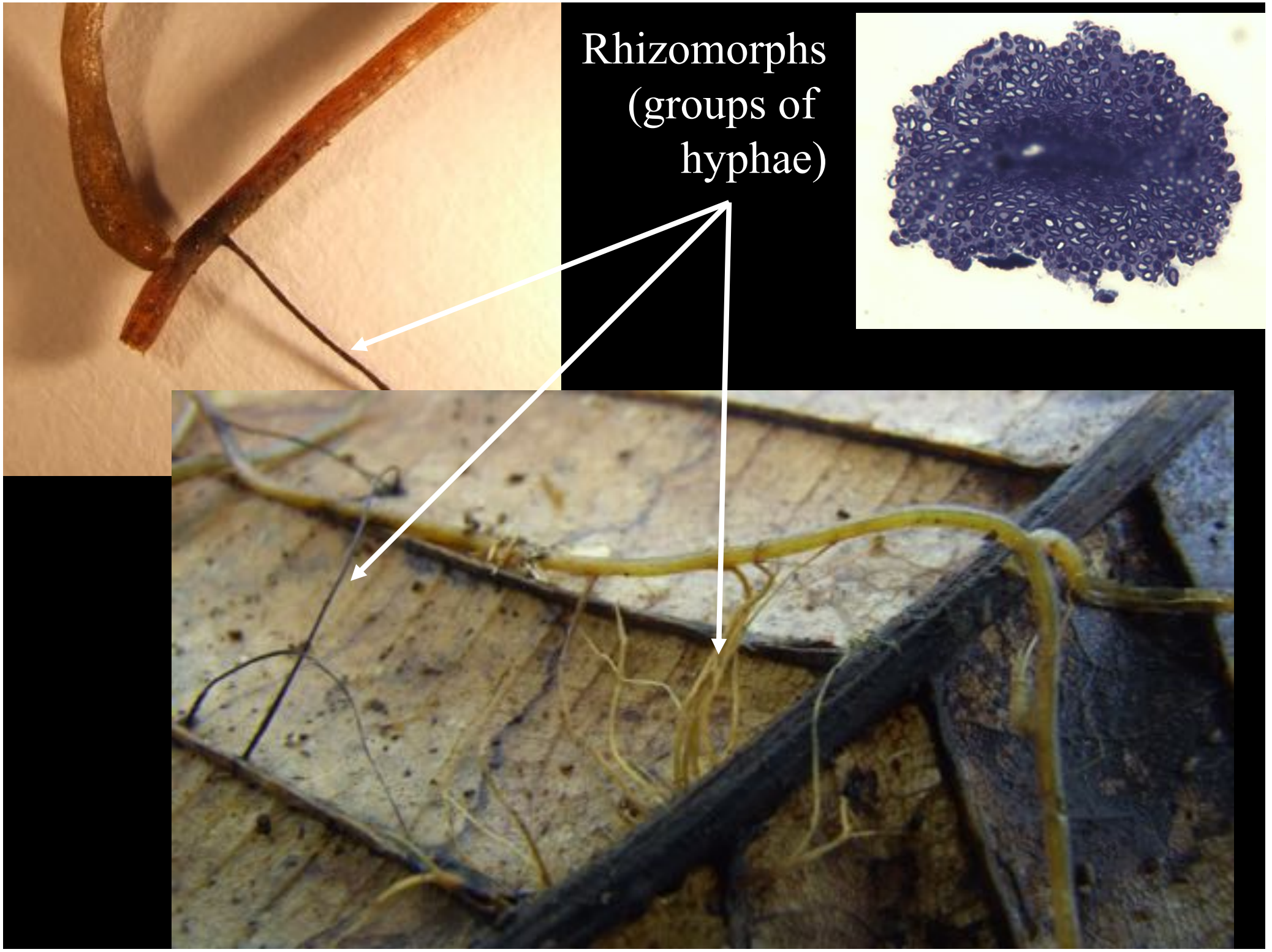


Autotrophs: *Arctostaphylos uva-ursi, Picea abies, Melampyrum sylvaticum*

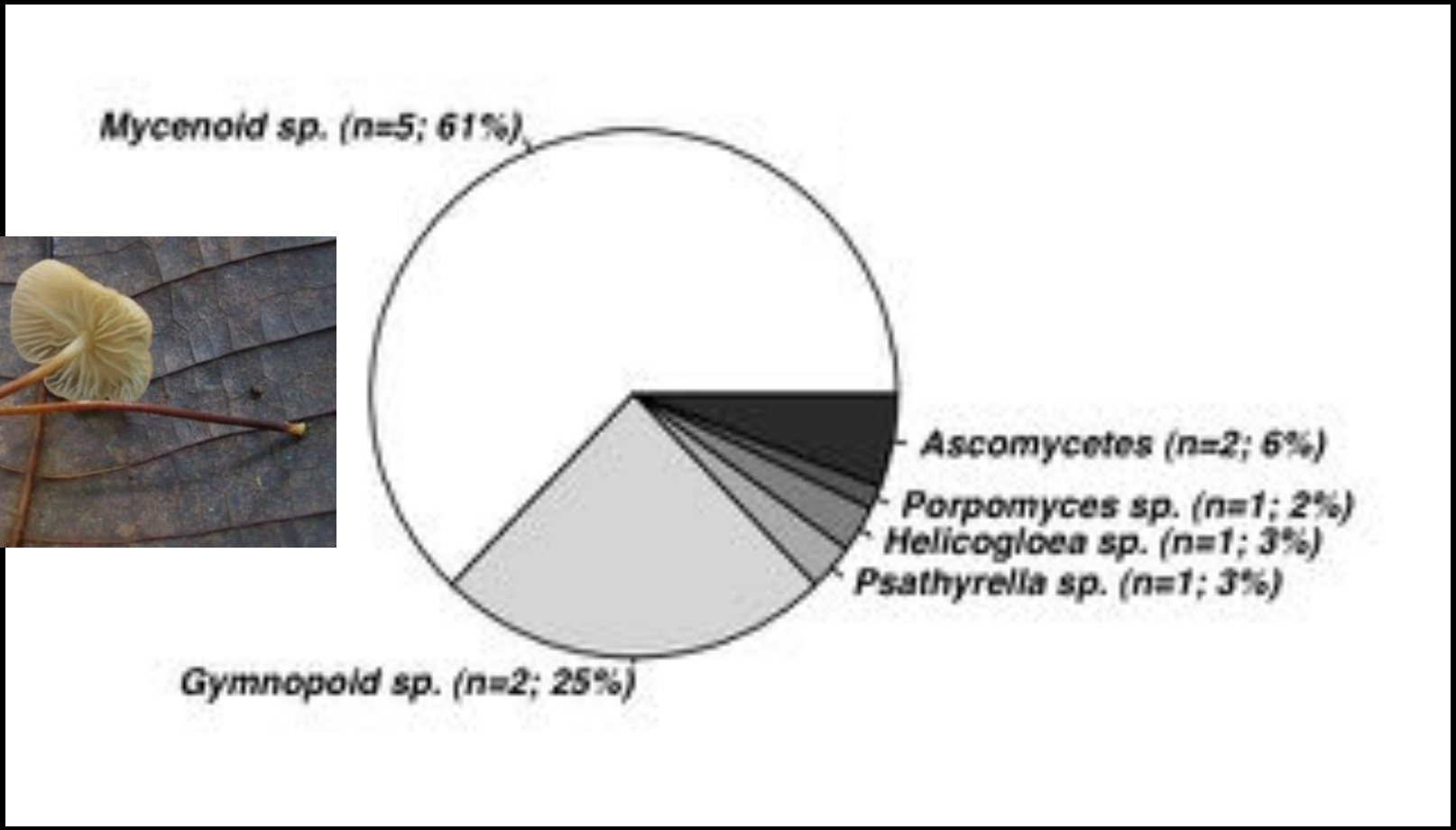


Ectomycorrhizal fungi, including *Tricholoma myomyces*, mycorrhizal on *H. monotropa*


Wullschlaegelia calcrata

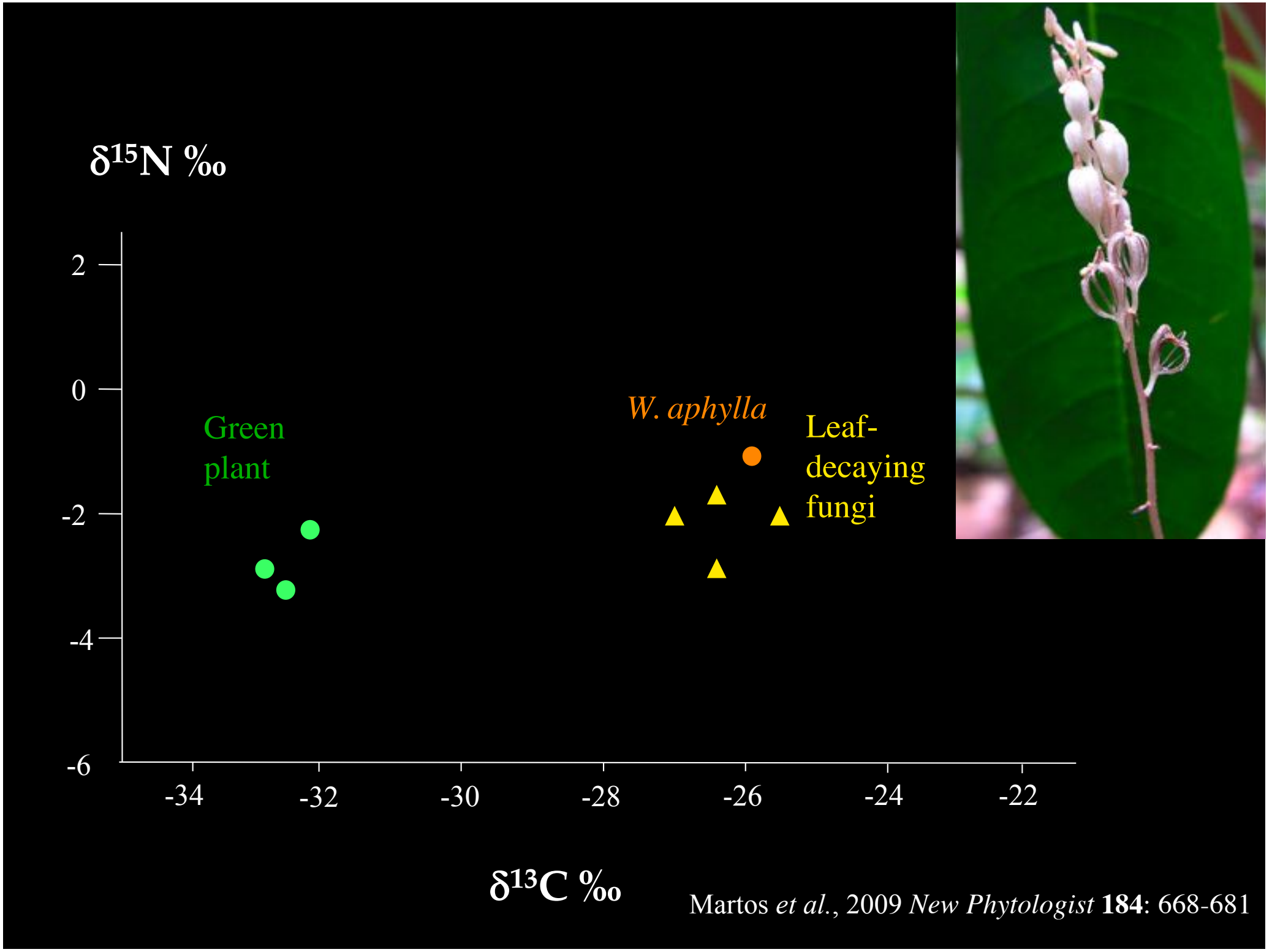

Rhizomorphs
(groups of
hyphae)

In 14 individuals from 4 sites: only saprotrophic fungi !



All are white rot and litter decaying fungi

No strict specificity at individual level


δ15N ‰
2
0
-2
-4
-6
-34
-32
-30
-28
-26
-24
-22
δ13C ‰
Green plant
W. aphylla
Leaf-decaying fungi
Martos et al., 2009 New Phytologist 184: 668-681

Les réseaux mycorhiziens

Mycohétérotrophie et réseaux

Mixotrophie et réseaux mycorhiziens

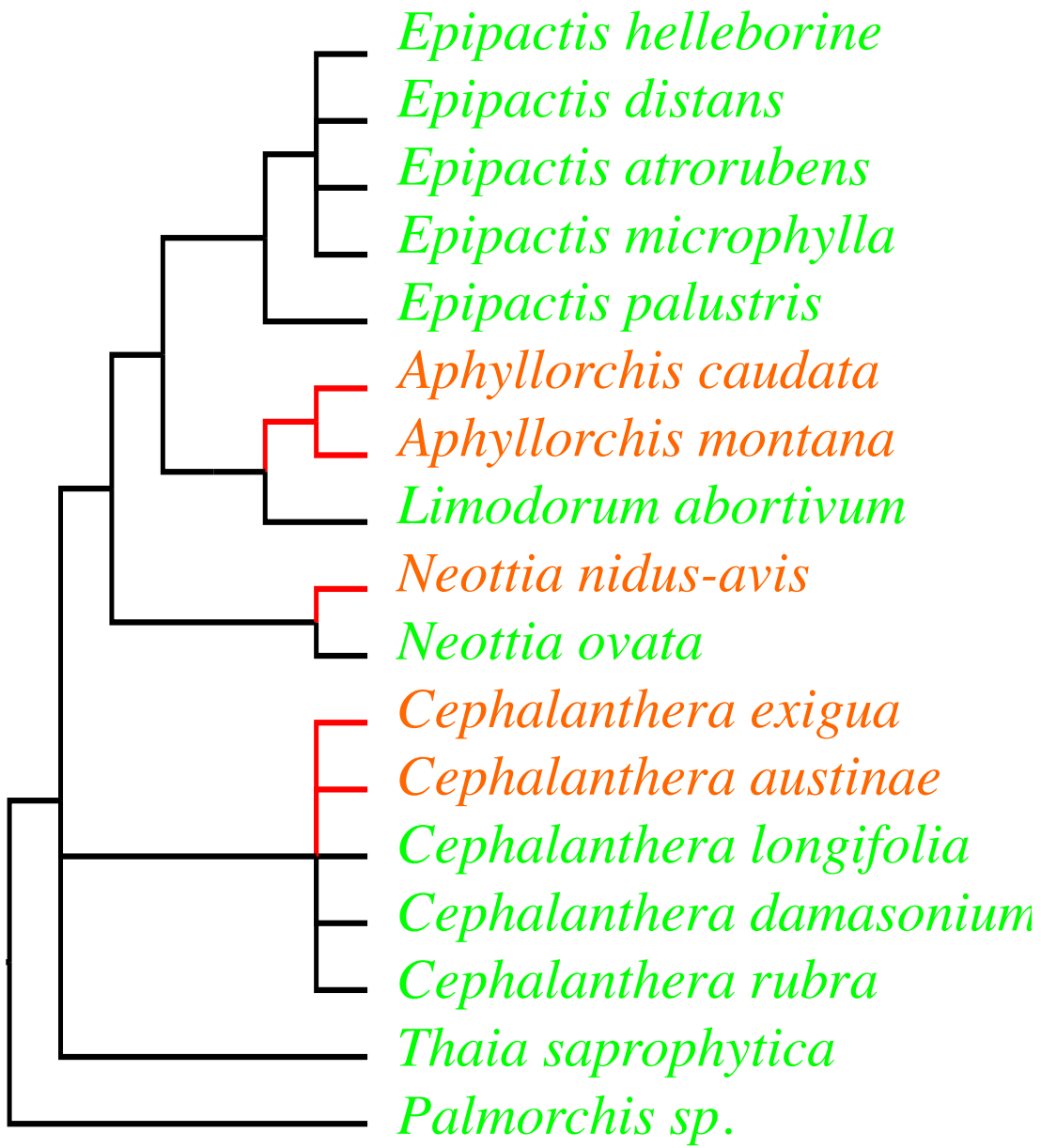
La difficile transition vers l'hétérotrophie

… due à un attachement fatal à la lumière ?

Green orchids related to mycoheterotrophs

E.g. the Neottieae tribe, mycoheterotrophy arose repeatedly, by convergent evolution among green species

… that associate with ectomycorrhizal fungi



Limodorum abortivum

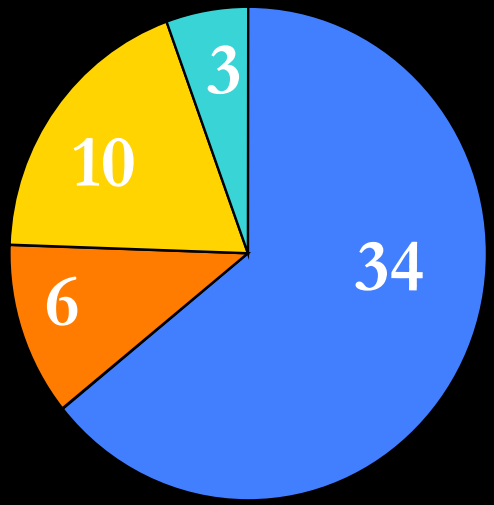
Russula delica group

Girlanda *et al.*, *Mol. Ecol.*, 2006

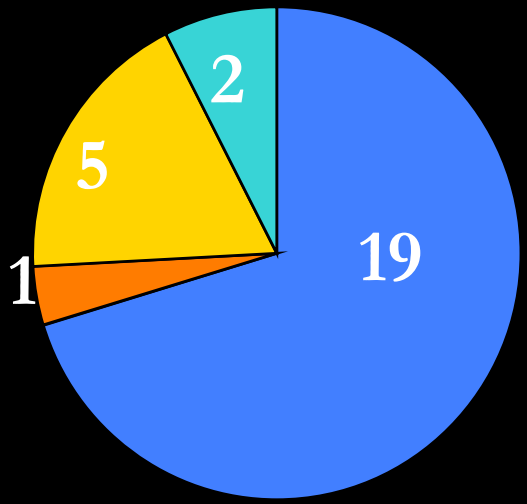
Cephalanthera damasonium & Cephalanthera longifolia

Cephalanthera damasonium & *Cephalanthera longifolia*

C. longifolia
Julou *et al.*, 2005



C. damasonium
Abadie *et al.*, 2006



« Rhizoctonias »
Saprophytes
Ectomycorhizal fungi
Plant endophytes or parasites

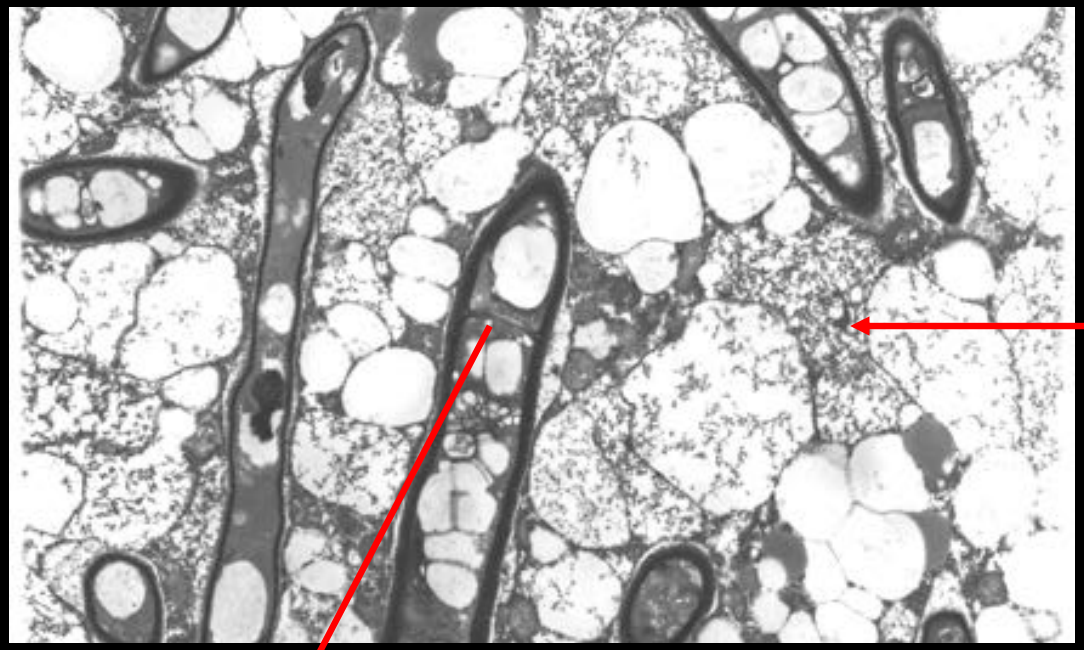
Ph. P. Pernot

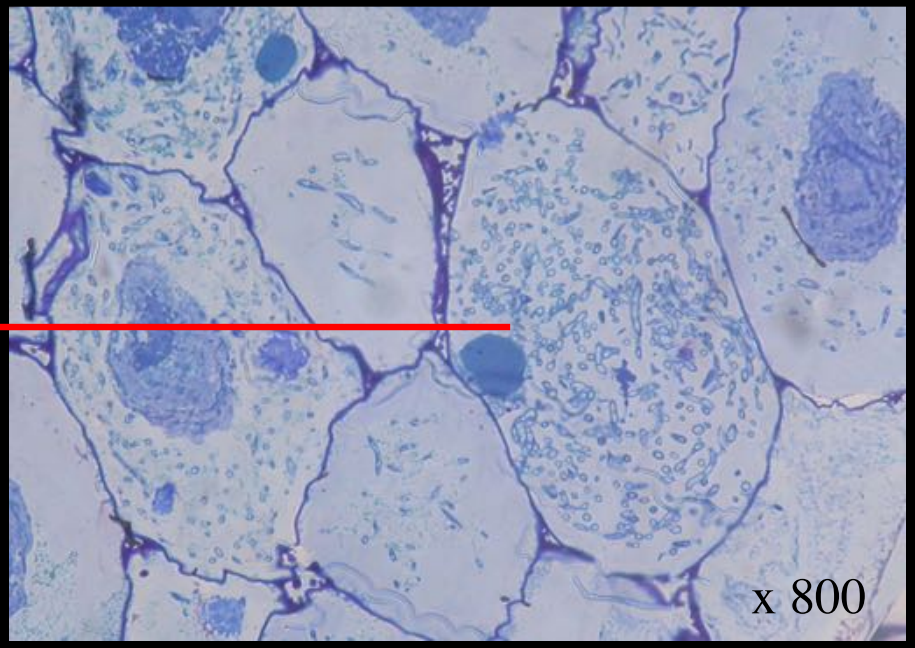
Epipactis microphylla

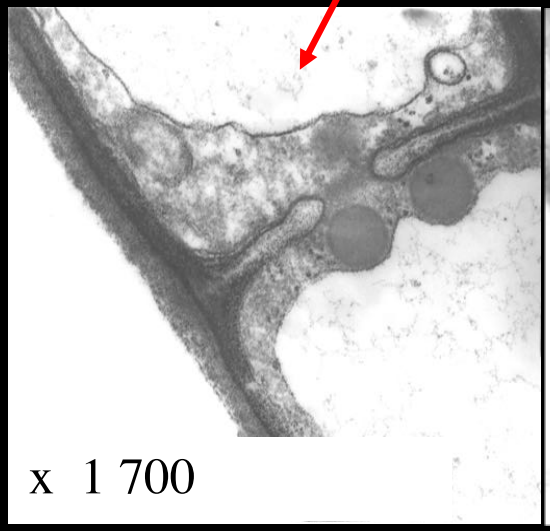
Diverse ectomycorrhizal fungi, mainly truffles spp.

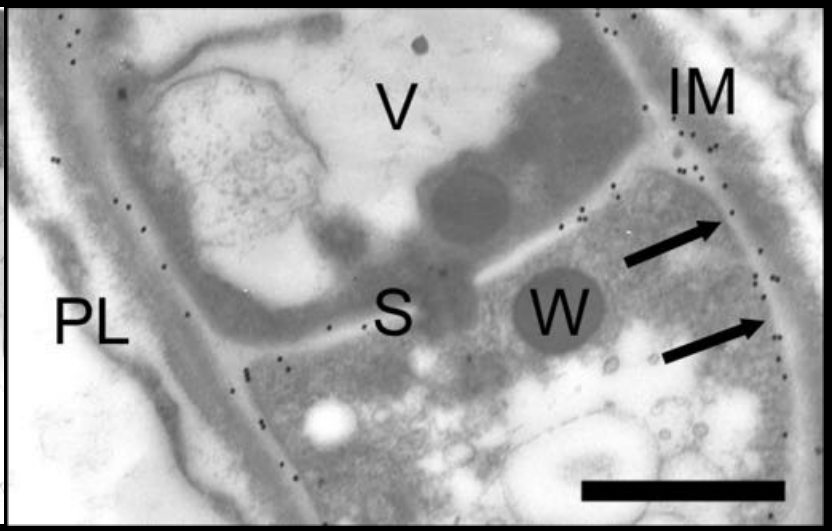
Selosse *et al.*, *Microb. Ecol.*, 2006

Epipactis microphylla associates with truffles

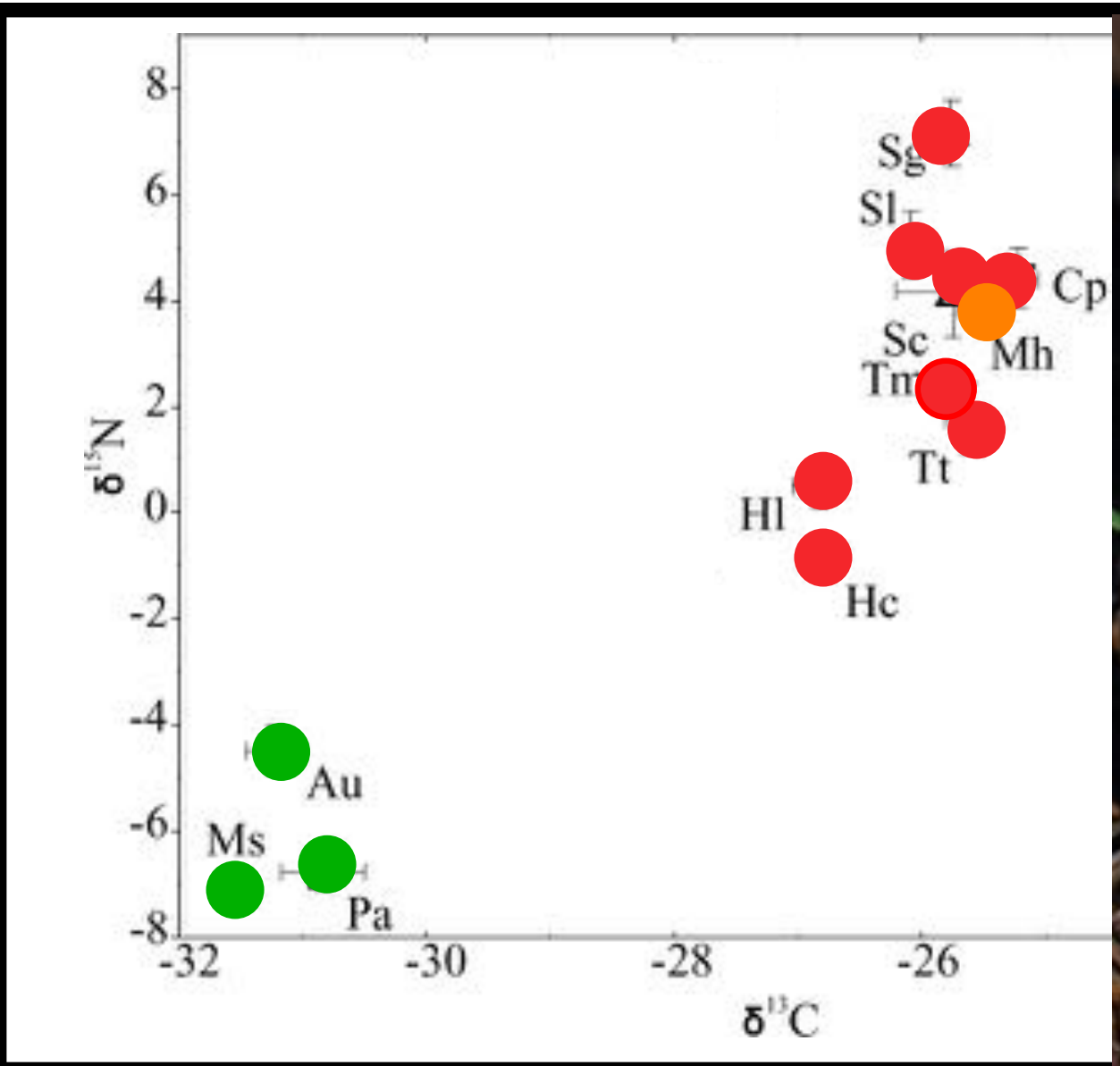




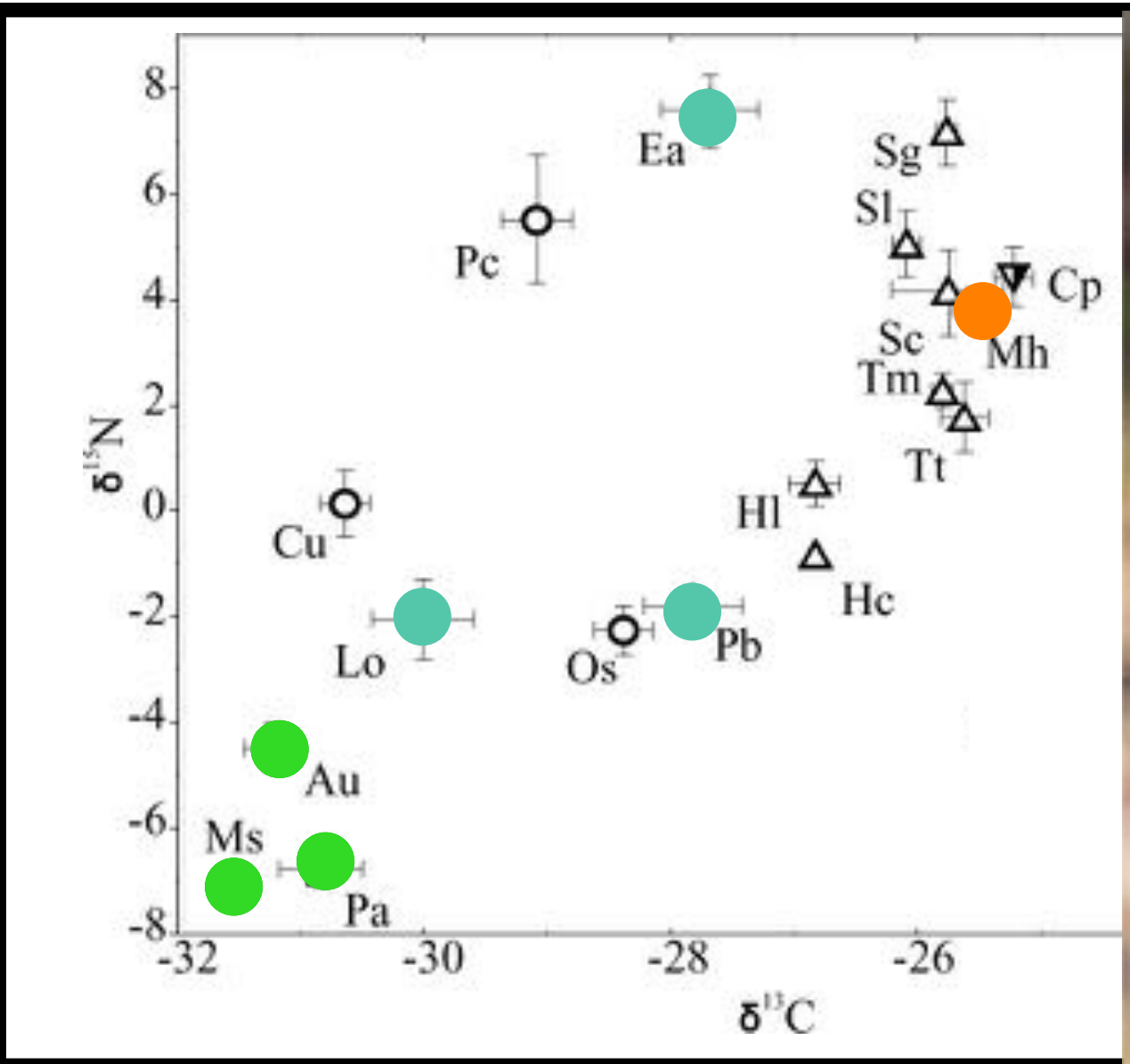




Microscopy and antibodies demonstrate that truffles are mycorrhizal (Selosse *et al.*, 2006 *Microbial. Ecol.*)



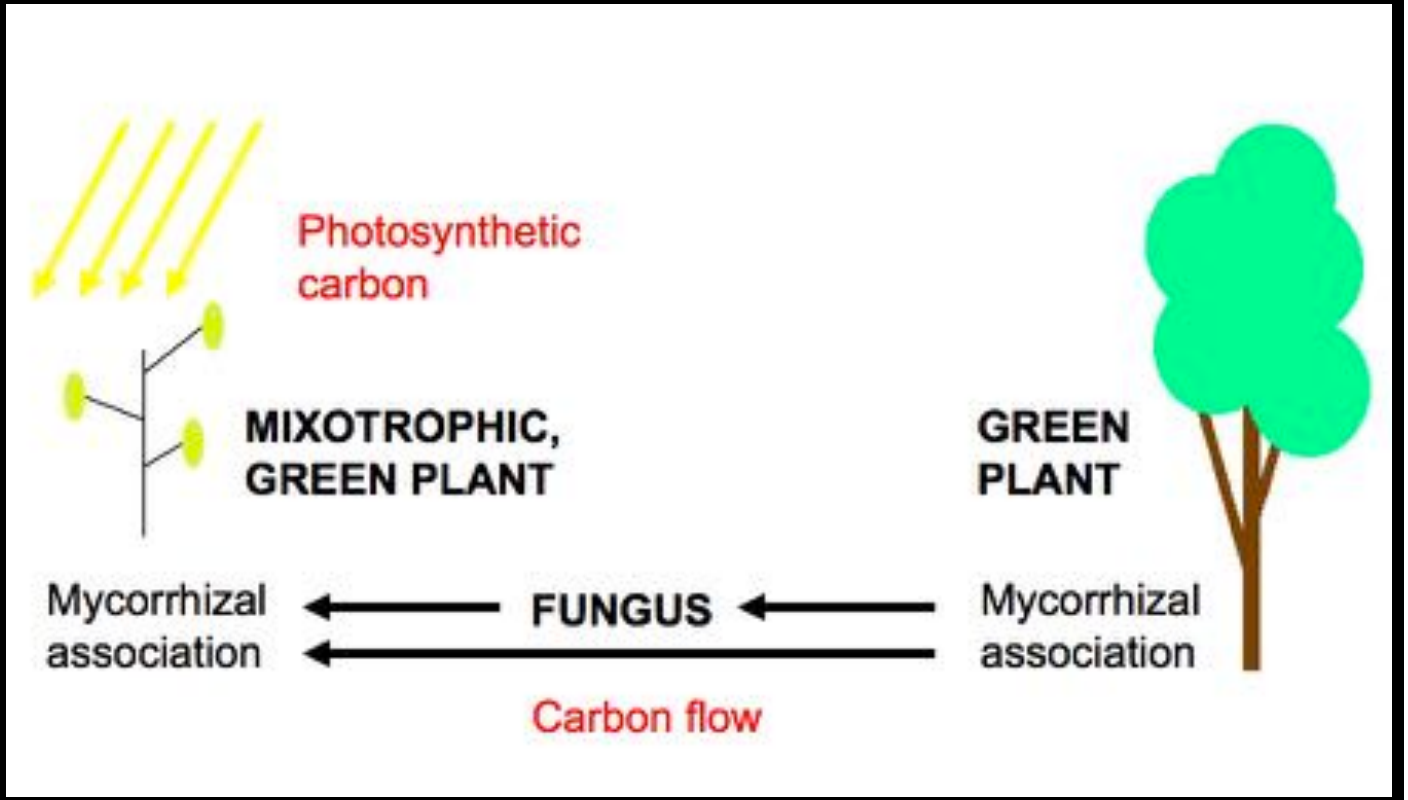
Tedersoo *et al*., 2007, *Oecologia*



« Green » orchids: *Listera ovata*, *Platanthera bifolia*, *Epipactis atrorubens*

MIXOTROPHY

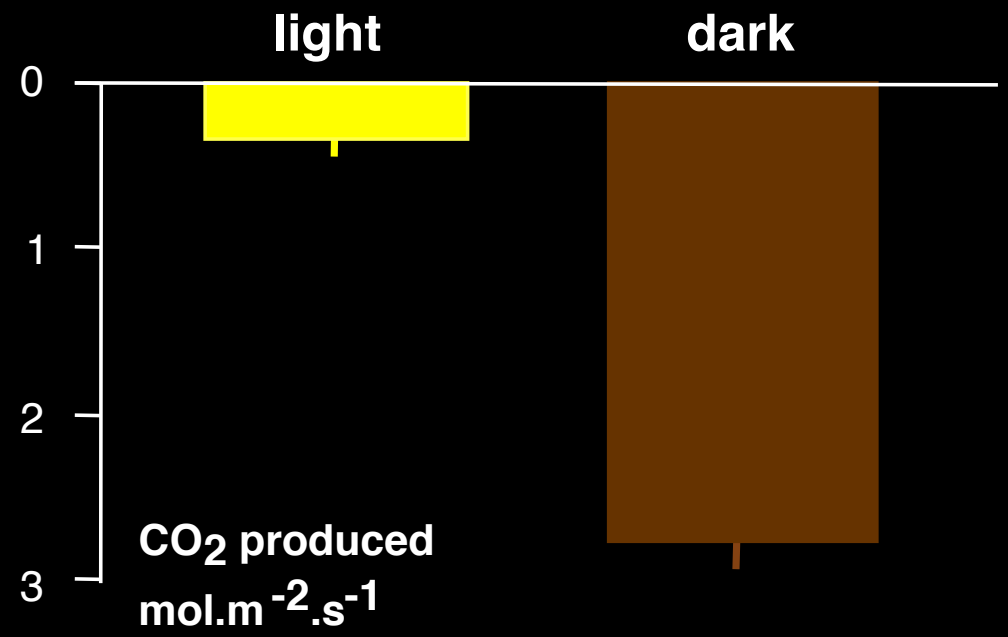
Exploiting both the mycorrhizal network & photosynthesis...



… as reflected in their ^{13}C &^{15}N abundances

Limodorum abortivum

A green orchid photosynthesizing
below the compensation point



Girlanda *et al.*, *Mol. Ecol.*, 2006

In mixotrophic orchid species, achlophyllous variants, the albinos,

… survive as mycoheterotrophs!

Cephalanthera damasonium

(P. Pernot & F. Dusak)

Epipactis purpurata

(A. Hasenfratz)

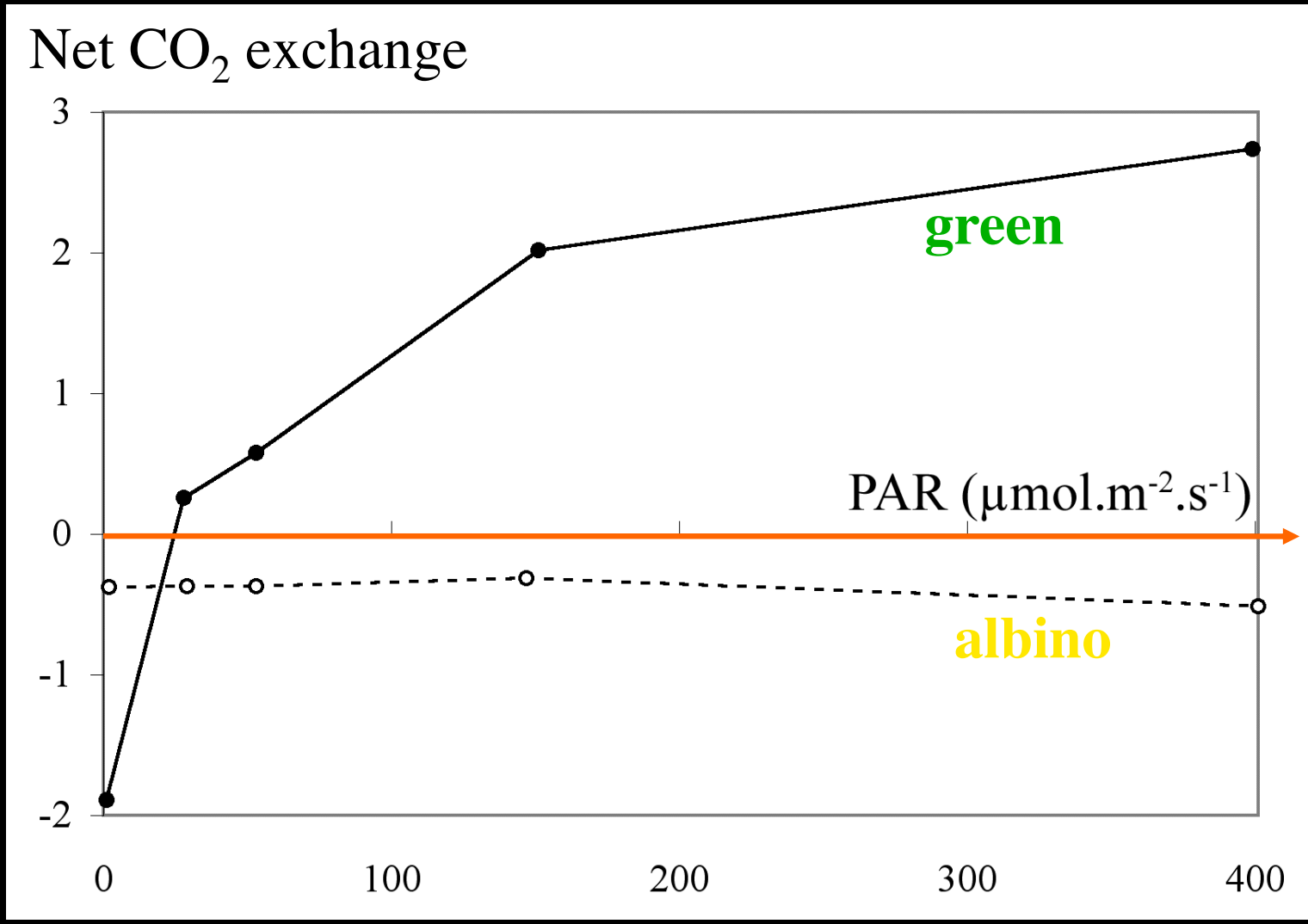

M. Roy


A. Soulié


J.C. Claessens


S. Acker

Gas exchange in *C. damasonium*



PAR = photosynthetic active radiations

Julou *et al*. 2005, *New Phytol*.

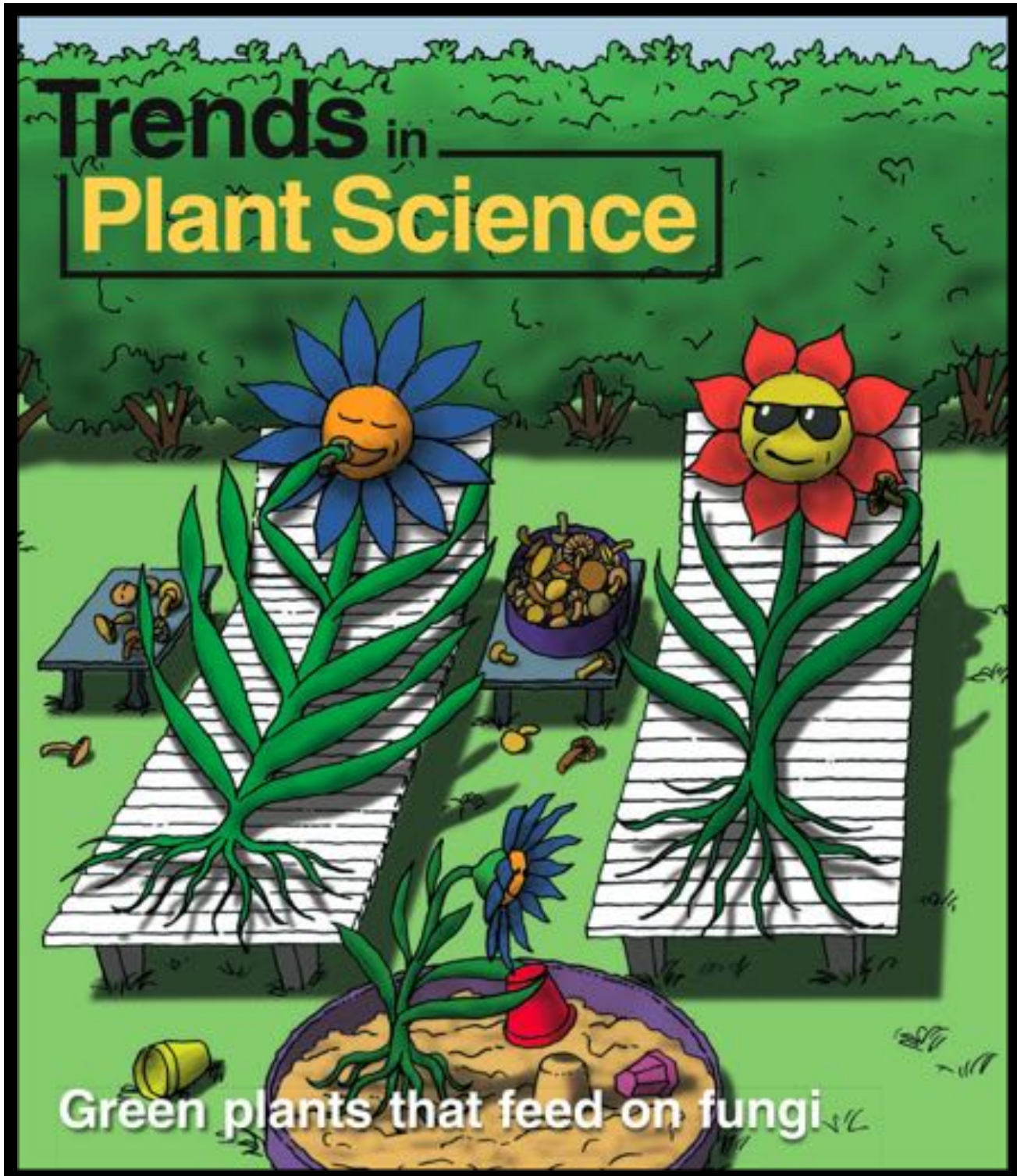
Isotopes in *C. longifolia*

albino

green

Green autotrophic plants

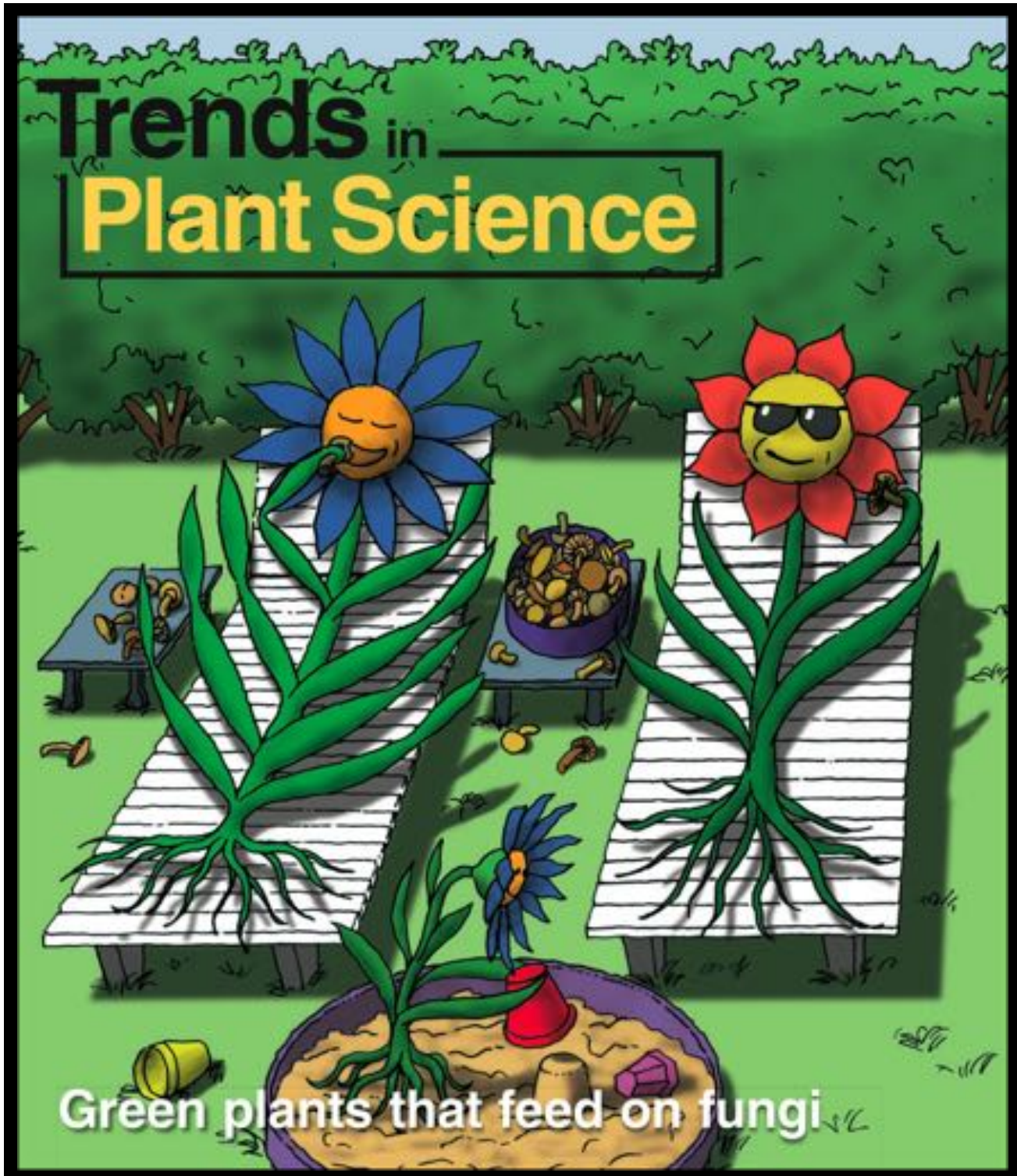
Abadie *et al*. 2006, *Botany*



Some green plants

- are mixotrophic and use mycorrhizal networks

Selosse & Roy, 2009

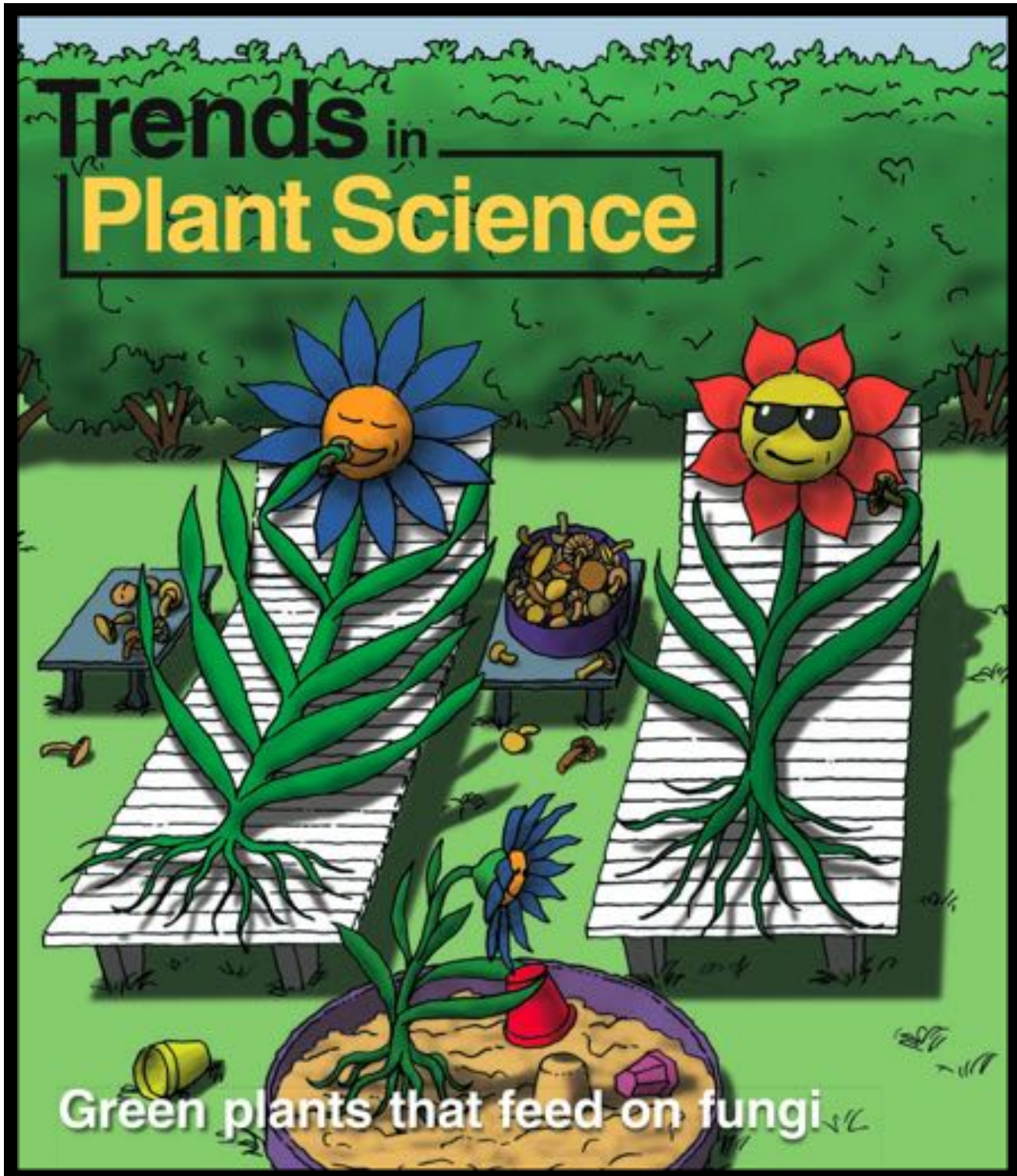


Some green plants

- are mixotrophic and use mycorrhizal networks

- are predisposed to evolve mycohetero-trophy

Selosse & Roy, 2009



Some green plants

- are mixotrophic and use mycorrhizal networks

- are predisposed to evolve mycohetero-trophy

- … with albinos as transitions?

Selosse & Roy, 2009

Les réseaux mycorhiziens

Mycohétérotrophie et réseaux

Mixotrophie et réseaux mycorhiziens

La difficile transition vers l'hétérotrophie

… due à un attachement fatal à la lumière ?

Many mutation could abolish greenness, yet albinos remain very rare in mixotrophic orchid populations…

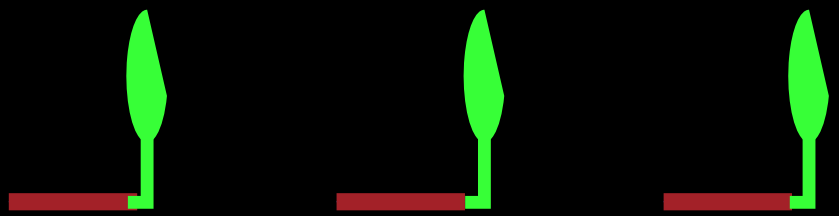
Why then?

Roy *et al*. 2013, *Ecol. Monographs* **83**: 95–117

A 4–year monitoring of two *Cephalanthera damasonium* populations, with 20-70 albinos

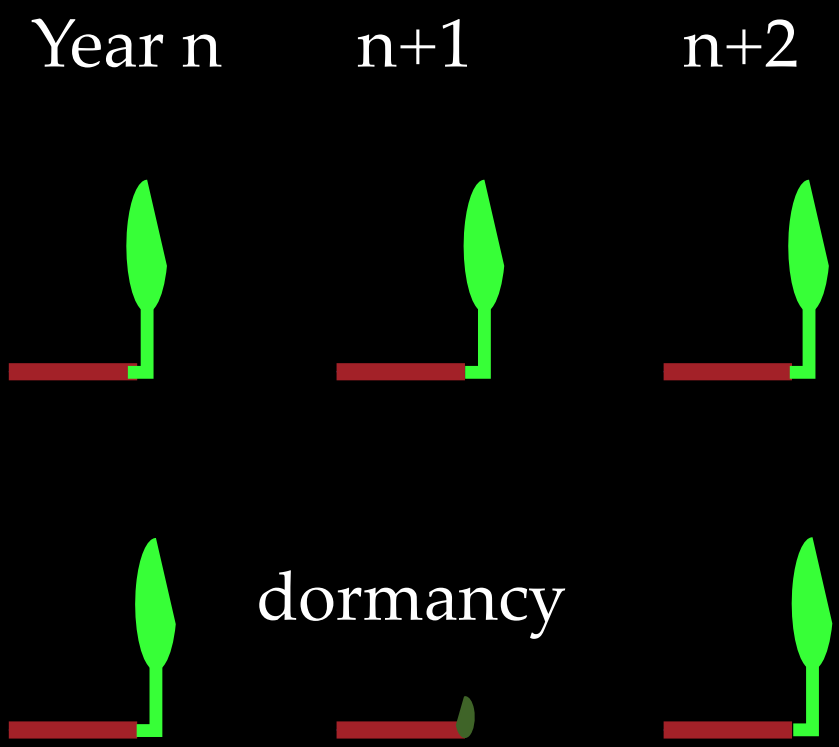
Dormancy…

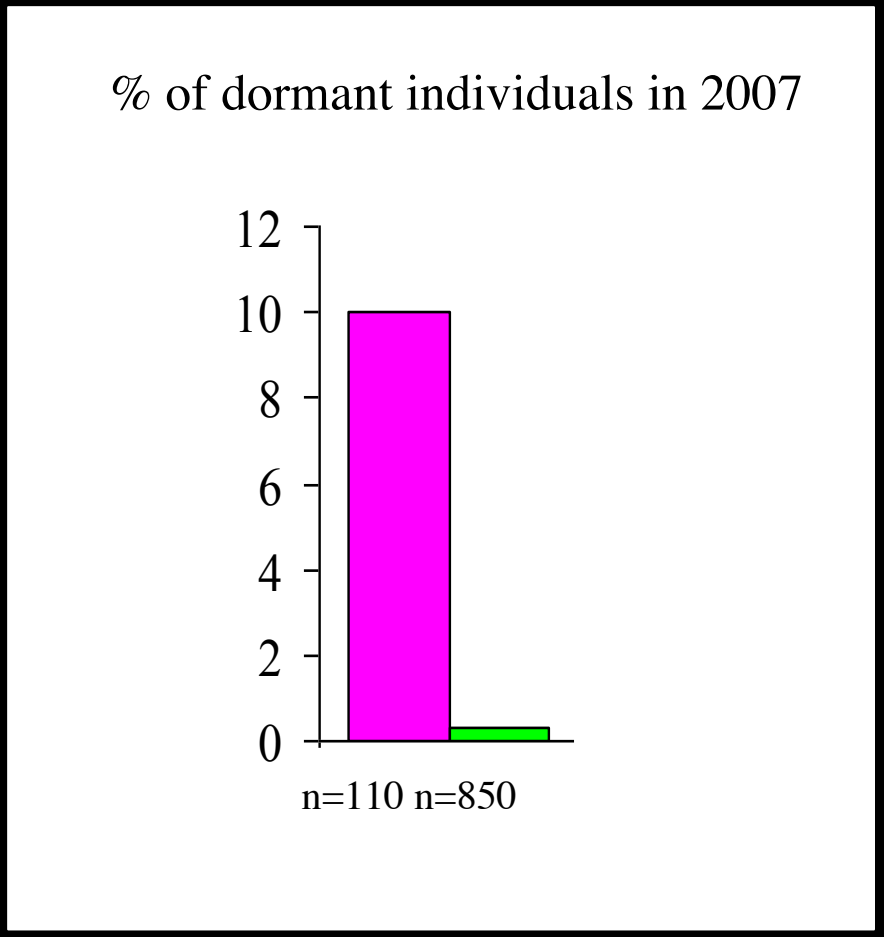
Year n n+1 n+2



dormancy

Dormancy: more frequent!

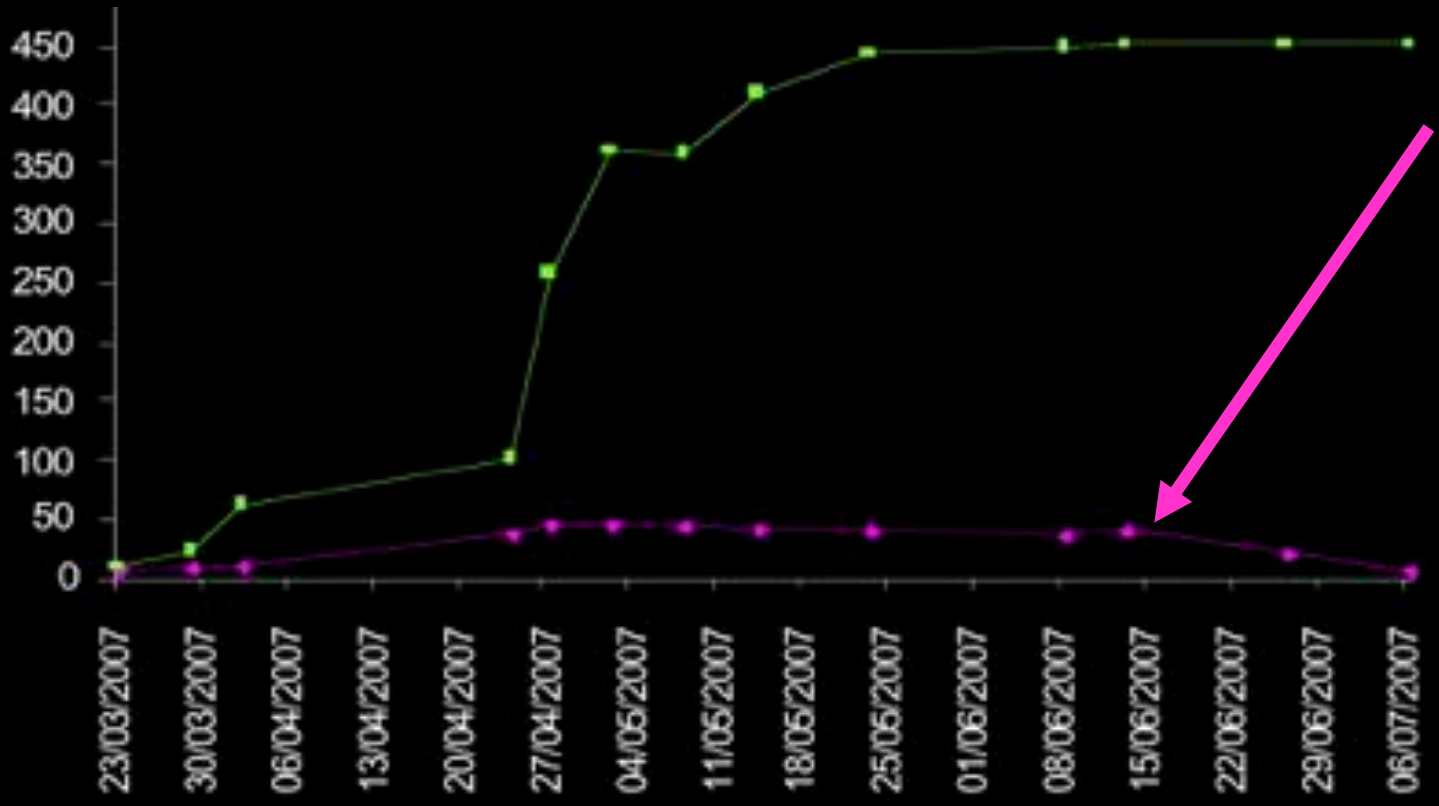




Albinos were 16.5x more often dormant than green individuals

Shoot survival…

Number of shoots

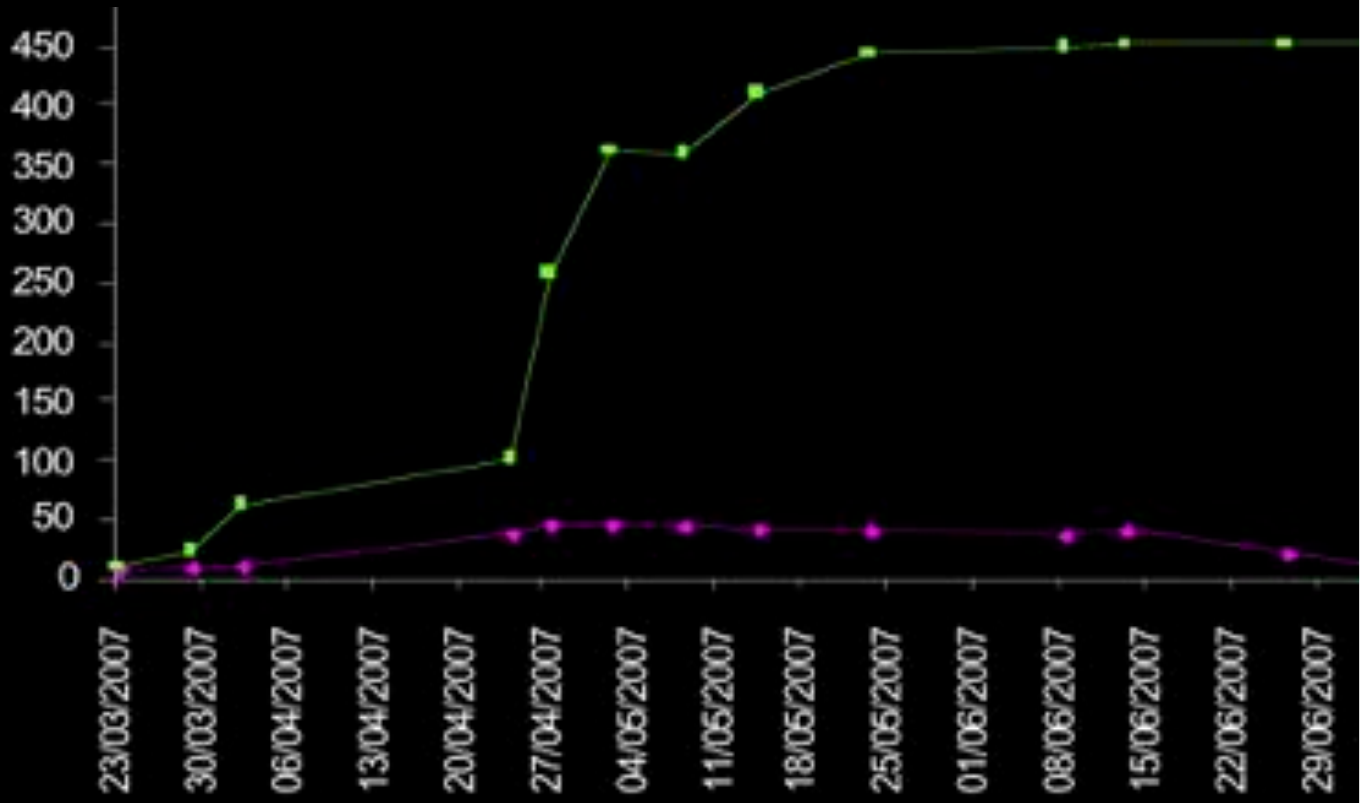


Apparition of shoots

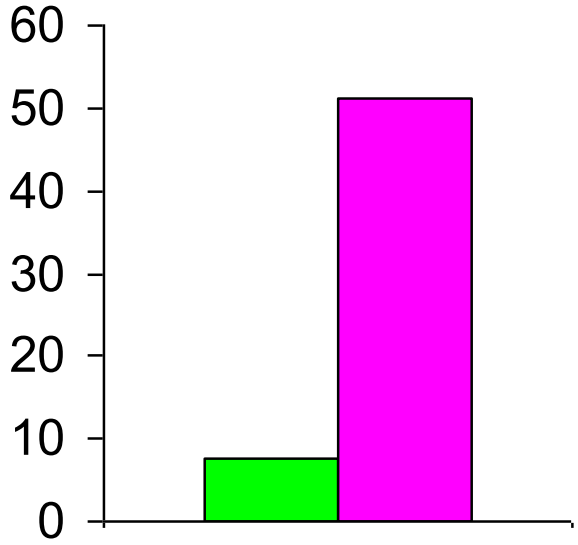
Flowering time

Shoot survival: lower!

Number of shoots



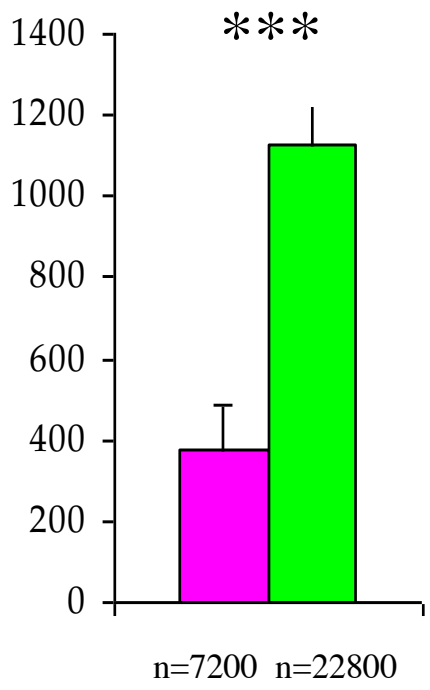
% shoots dried in late June 2007



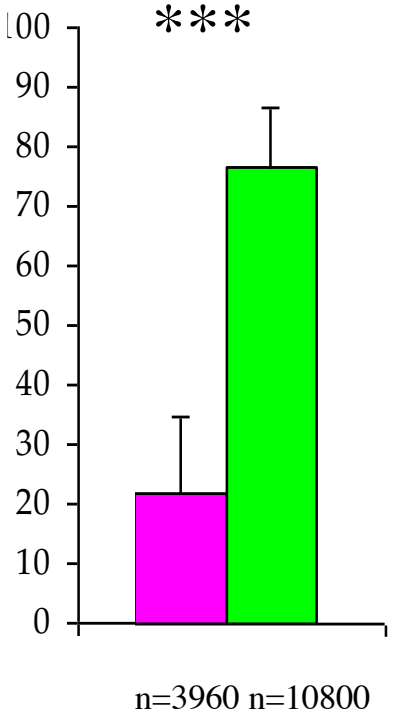
51% albino shoots dry in June (*vs* 7% for green ones) > no seeds!

Seed production and quality: lower…

Number of seeds
per fruits (x10)



% of seeds germinating *in situ*
in seeds pockets (3 months)



3 x 3 less viable seeds in albinos!

Comparison green ind. / albinos

Patterns of dormancy	**6.8x more**
Patterns of shoot survival	**16.5x less**
Seed production	**9x less**

= 10^3 x lower fitness

Roy *et al*. 2013, *Ecol*. *Monographs* **83**: 95–117

Comparison green ind. / albinos

Patterns of dormancy	**6.8x more**
Patterns of shoot survival	**16.5x less**
Seed production	**9x less**

= 10^3 x lower fitness

WHY DID ALBINOS FAIL THE TRANSITION ?

Les réseaux mycorhiziens

Mycohétérotrophie et réseaux

Mixotrophie et réseaux mycorhiziens

La difficile transition vers l'hétérotrophie

… due à un attachement fatal à la lumière ?

Allocation of mycoheterotrophic C *versus* photosynthetic C in mixotrophic orchids

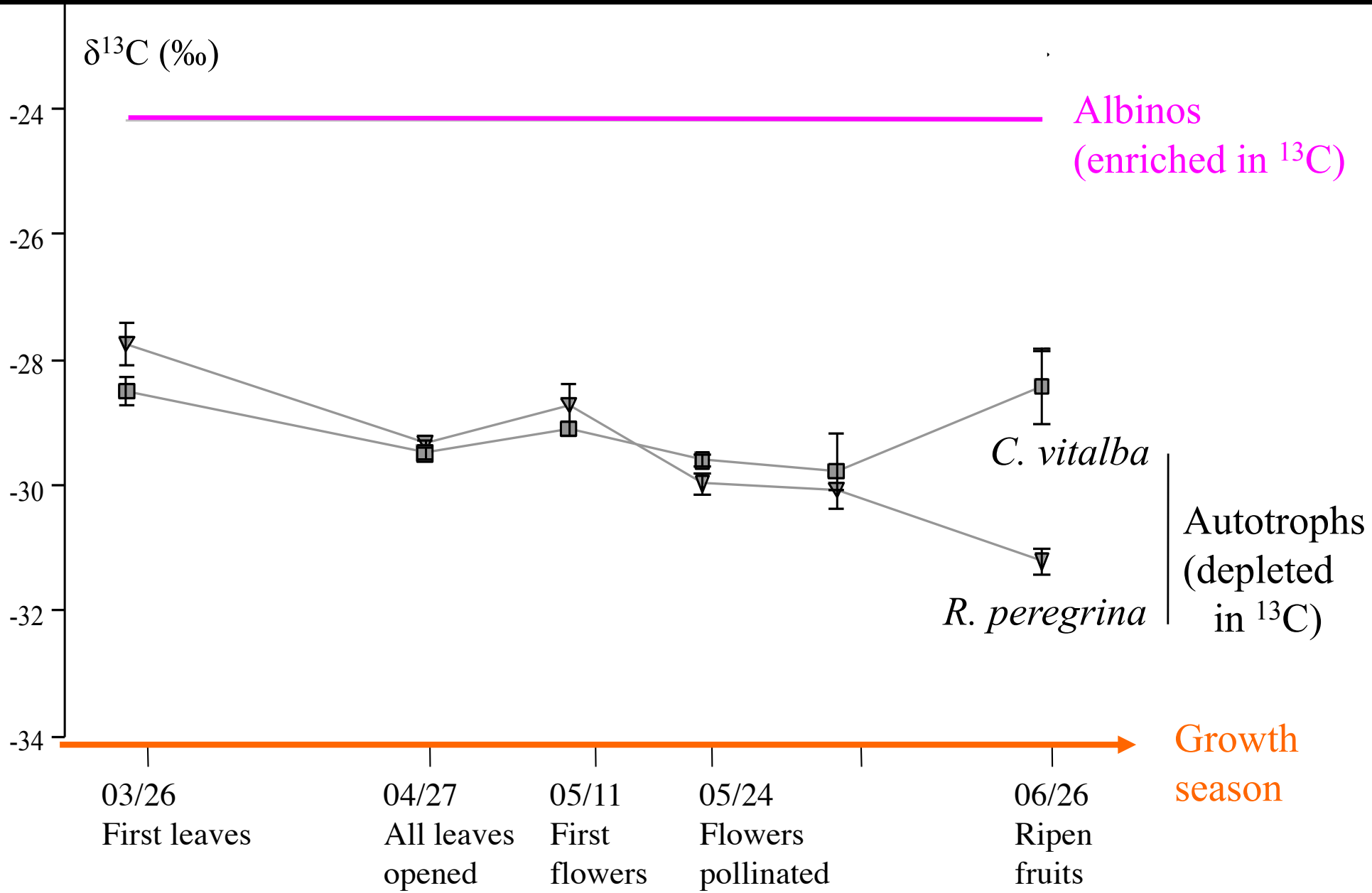
based on $\delta^{13}C$

(and N content)

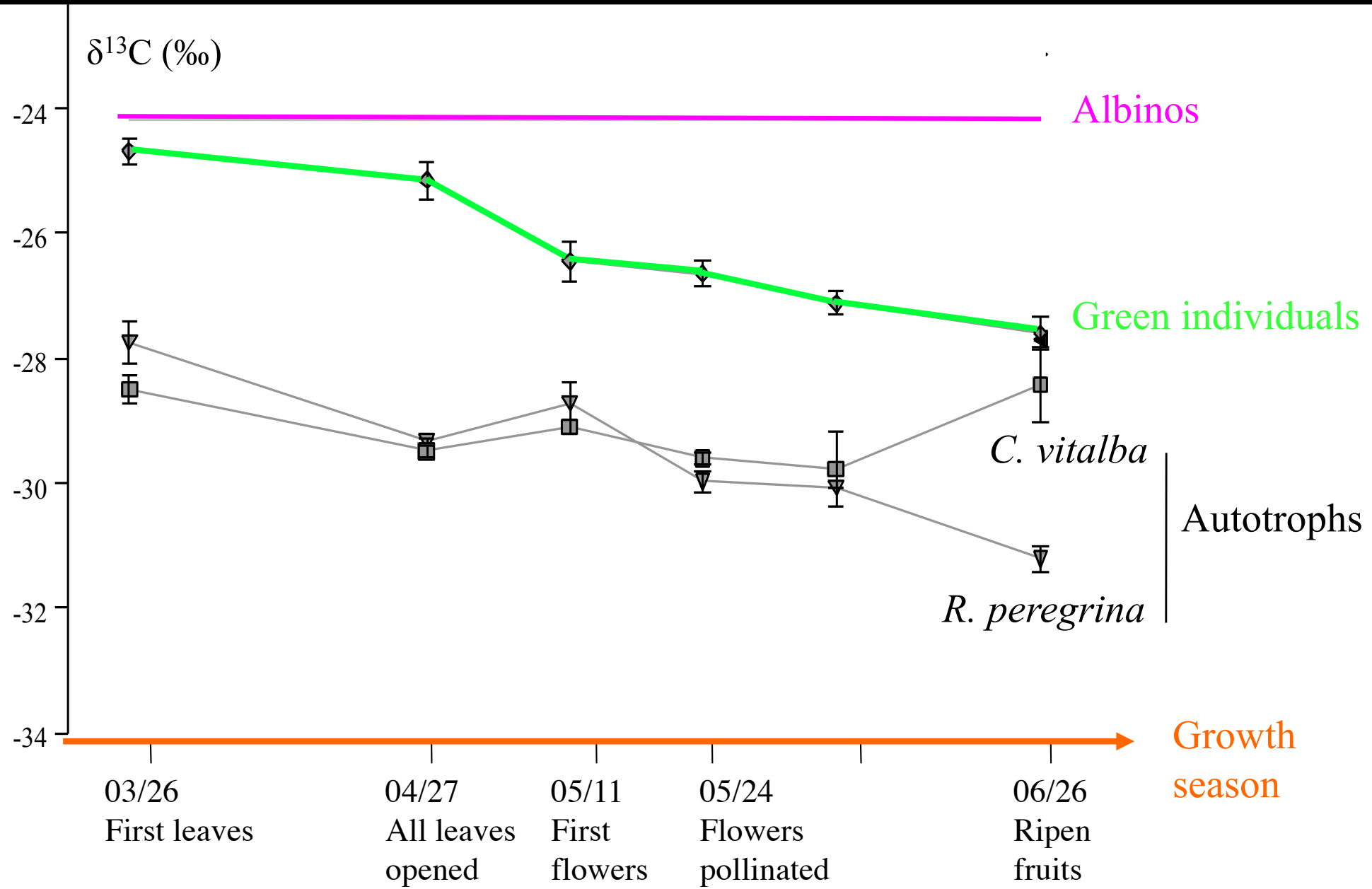
Allocation of fungal *versus* photosynthetic C

In shoots

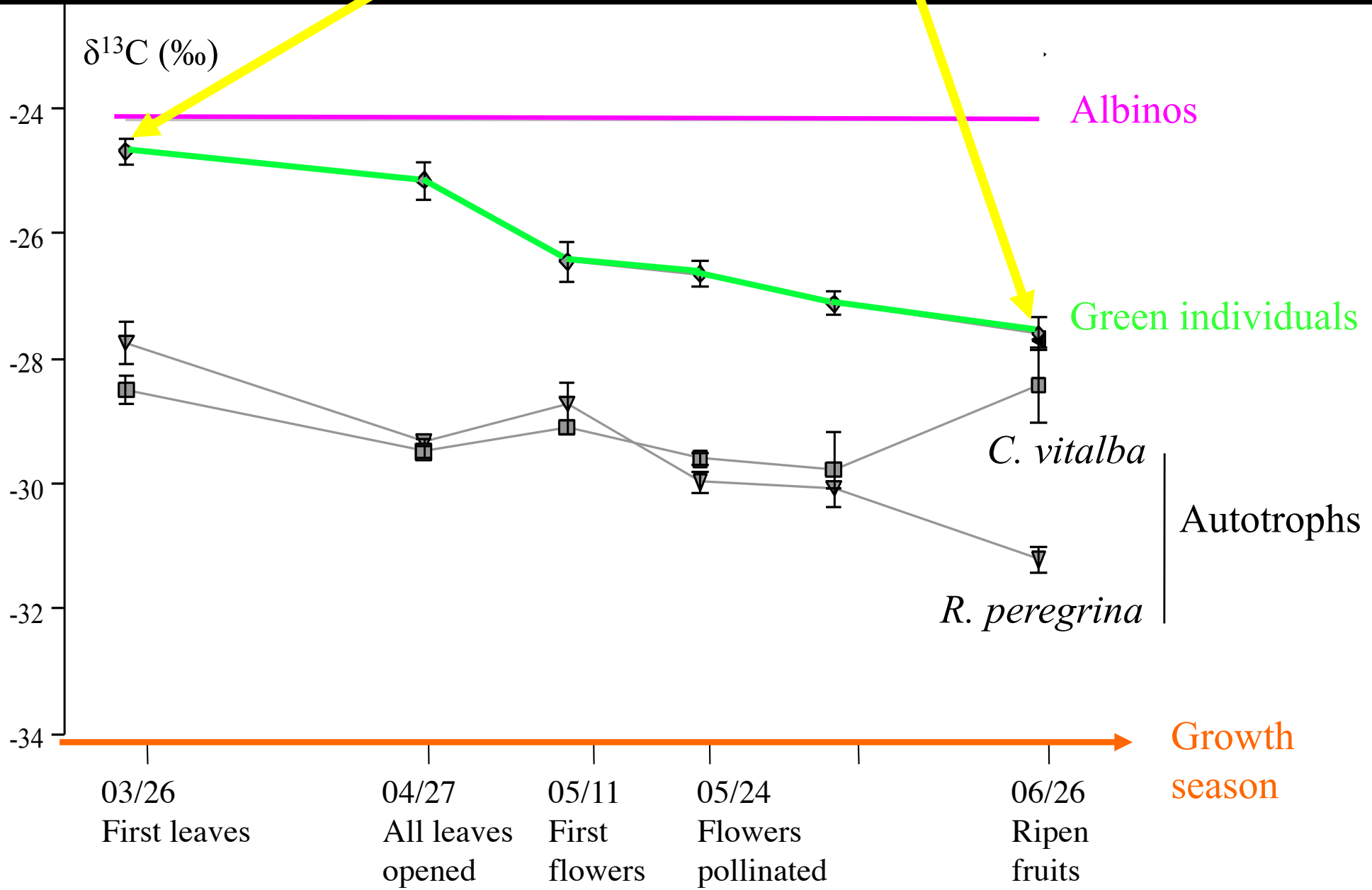
Shoot C nutrition over the growth season in *C. damasonium*



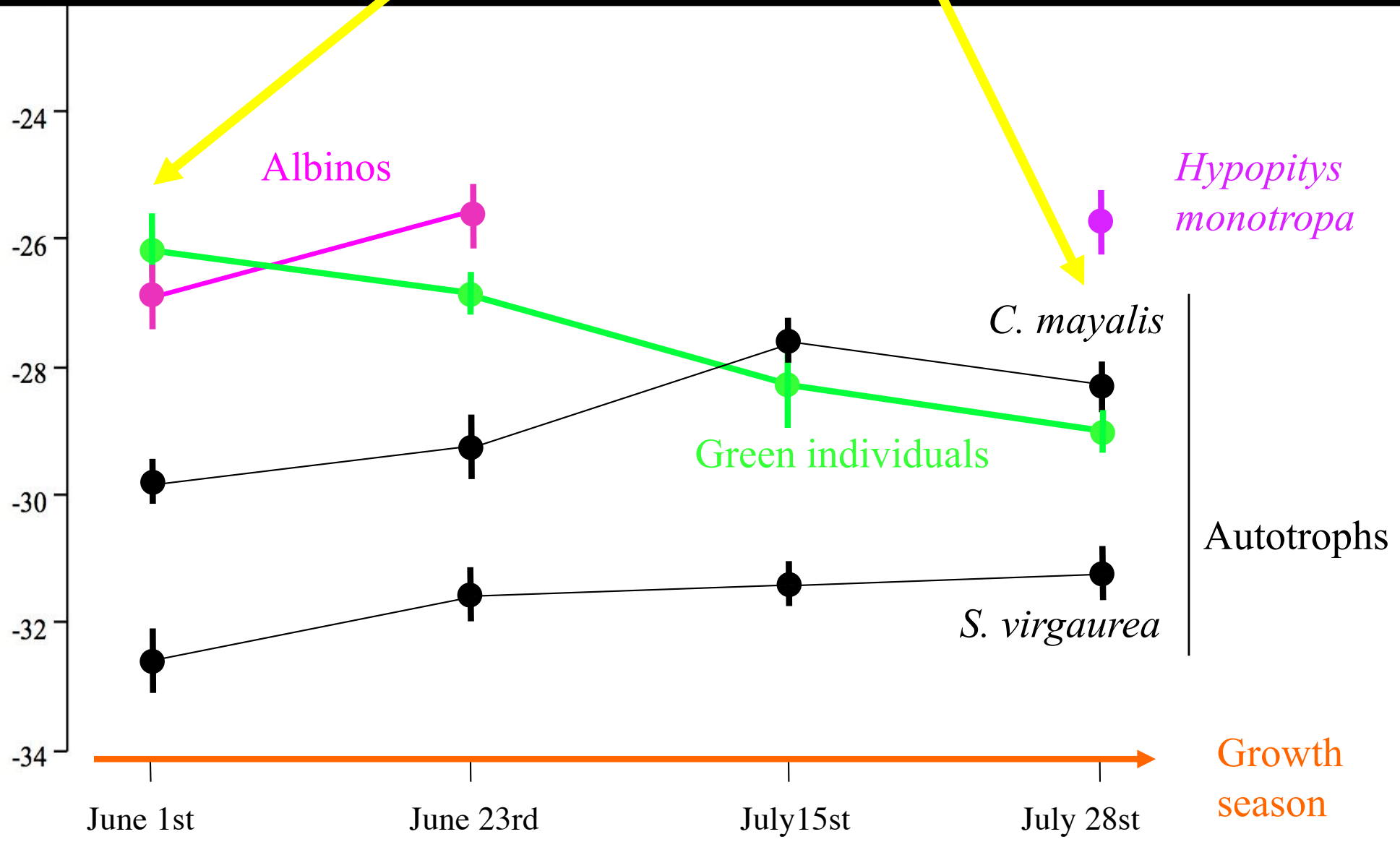
Shoot C nutrition over the growth season in *C. damasonium*



A shift from **80%** heterotrophic to **20%** at fruiting!

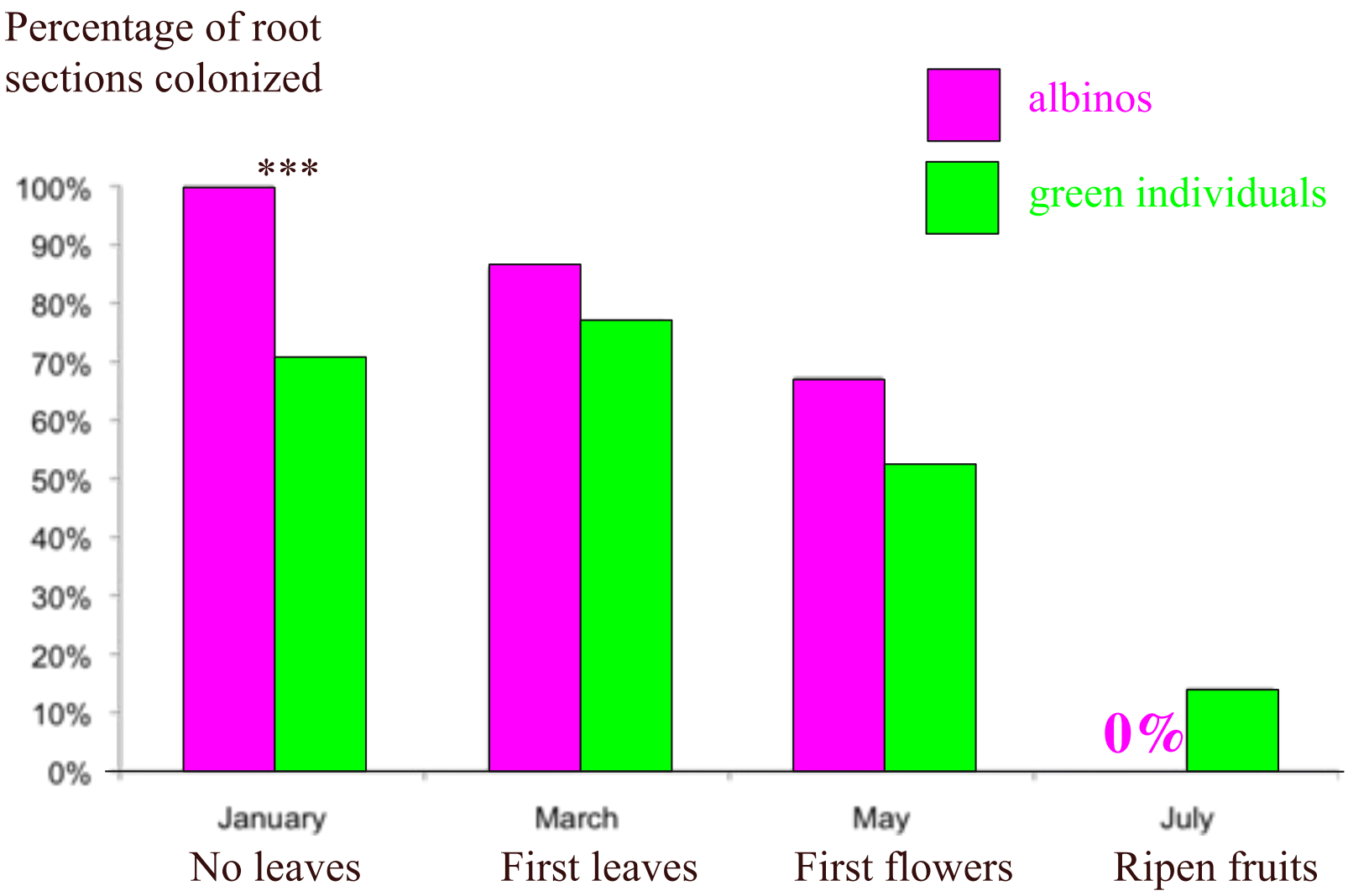


A shift from **100%** heterotrophic to **20%** in *E. helleborine*



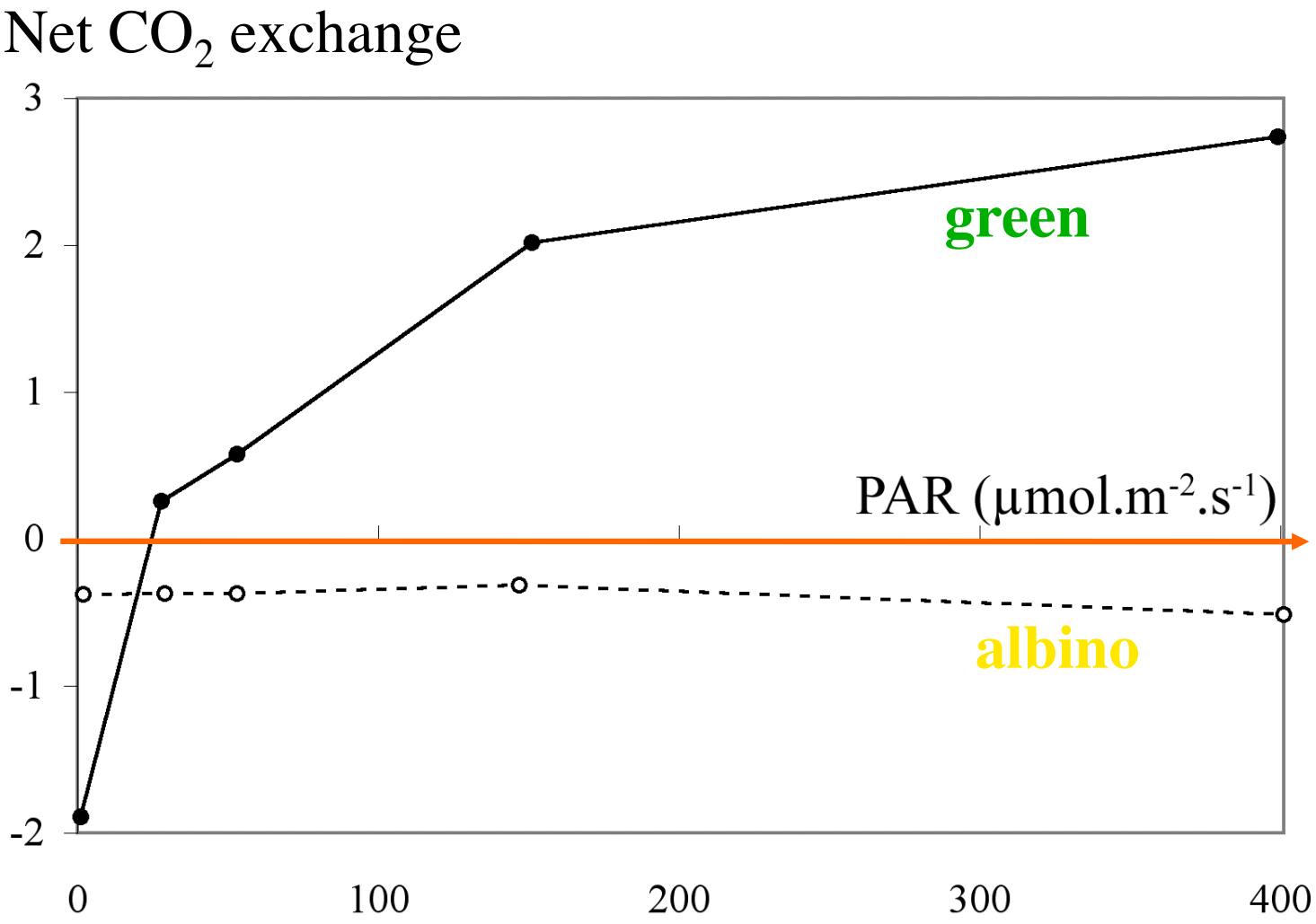
Gonneau *et al*. 2014, *J. Ecol*., in press

A decrease of mycorrhizal colonization at fruiting in *C. damasonium*



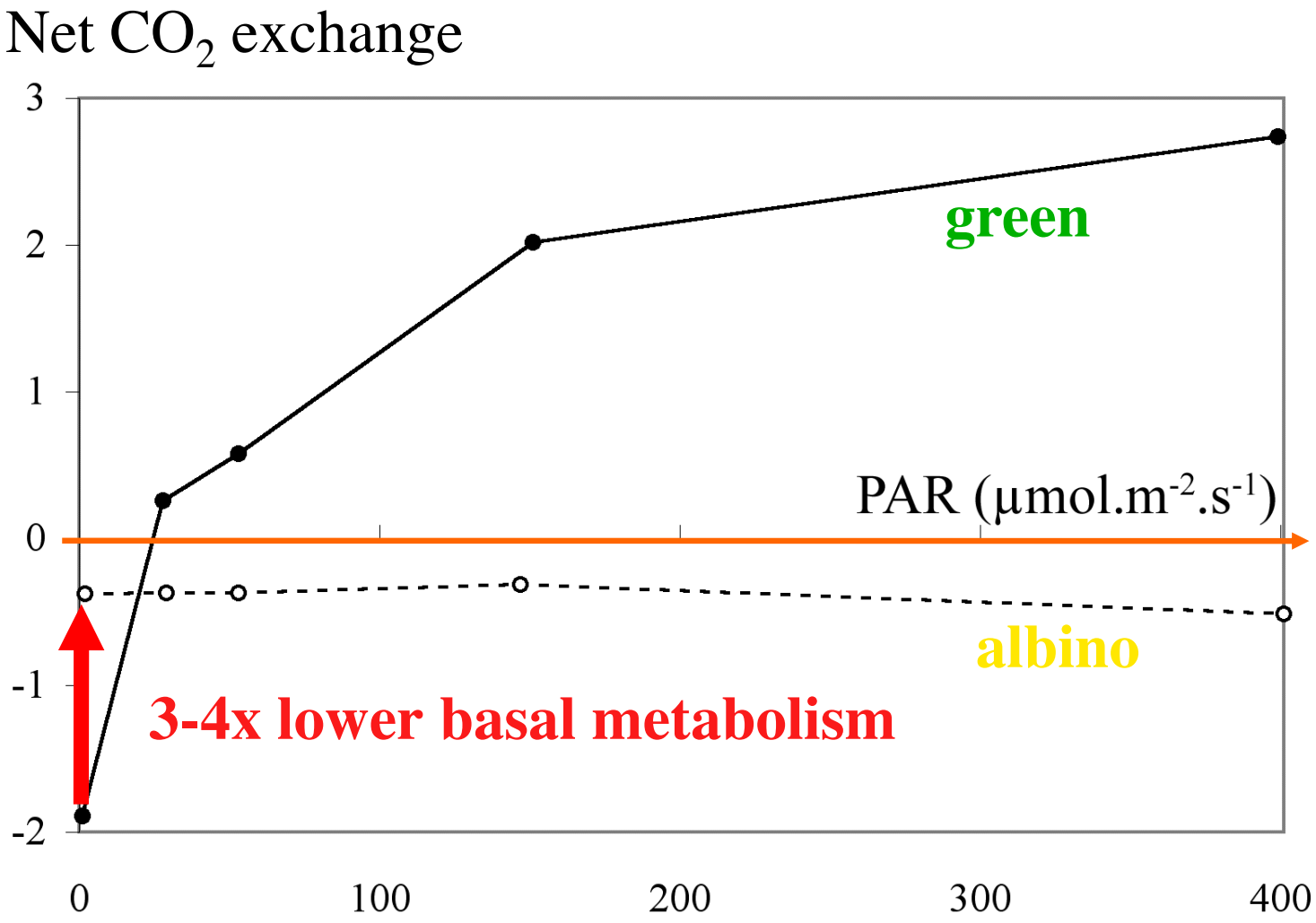
Roy *et al*. 2013, *Ecol. Monographs*

Gaz exchange in *C. damasonium*



Julou *et al.*, 2005, *New Phytol.*

Gaz exchange in *C. damasonium*



… a carbon limitation ?

Julou *et al.*, 2005, *New Phytol.*

CONCLUSIONS

- Shoot autotrophy increases over the growth season.

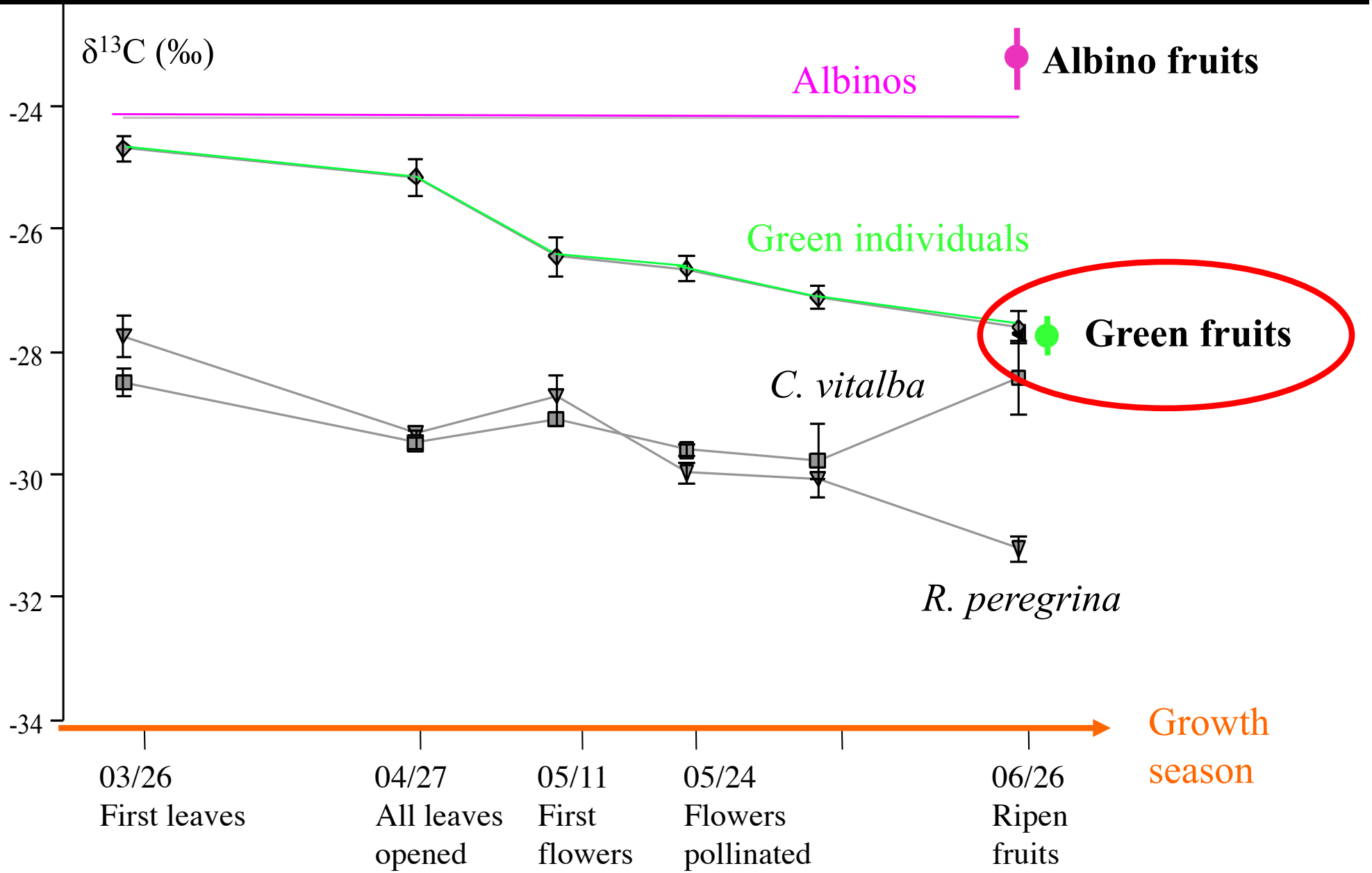
- Albinos have lower basal metabolism, and especially lack photosynthetic and fungal C at fruiting.

Allocation of fungal versus photosynthetic C

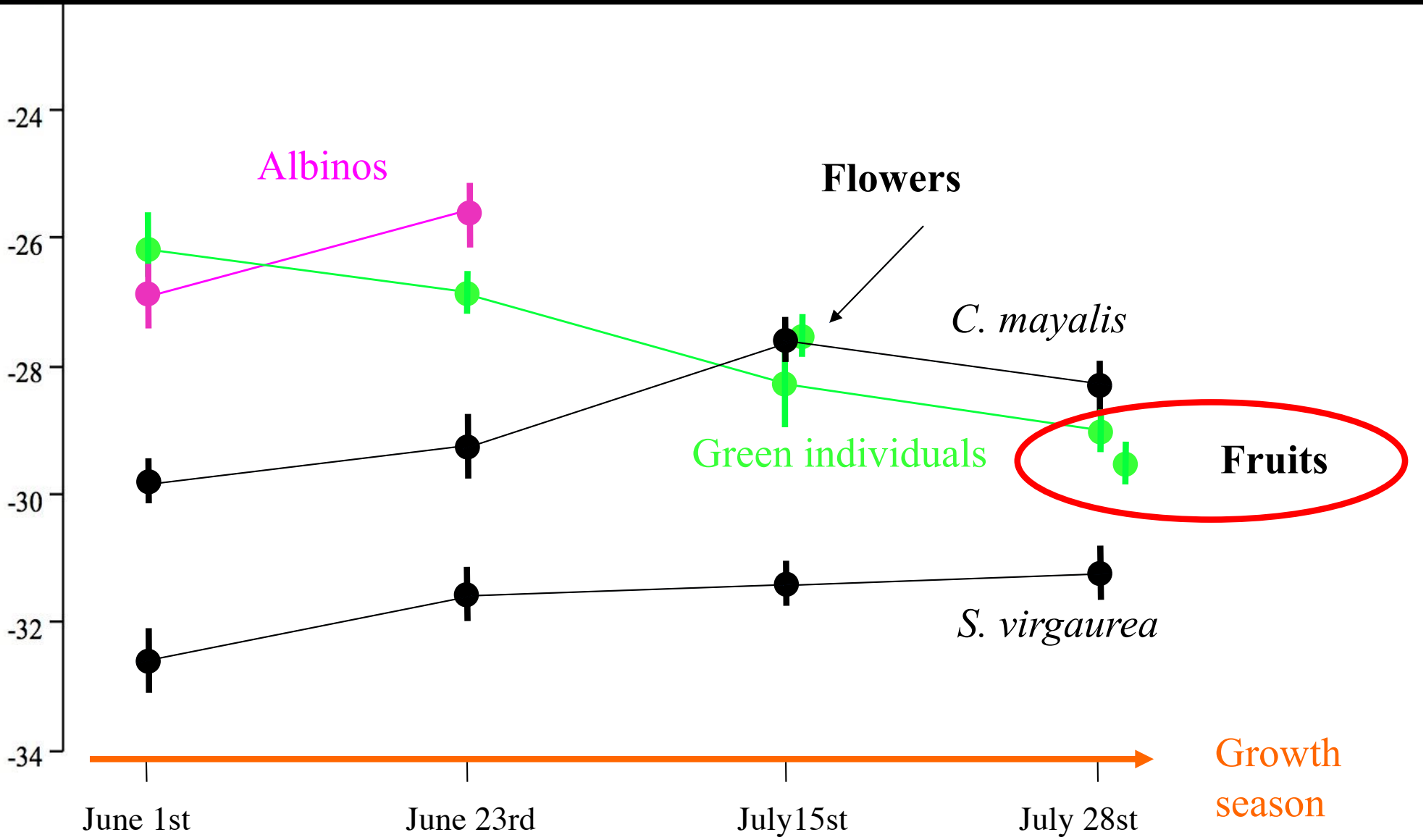
In shoots

In fruits

Fruit C nutrition in *Cephalanthera damasonium*



Fruit C nutrition in *Epipactis helleborine*



Gonneau *et al*. 2014, *J. Ecol*., in press

TESTING THE ROLE OF FUNGAL C

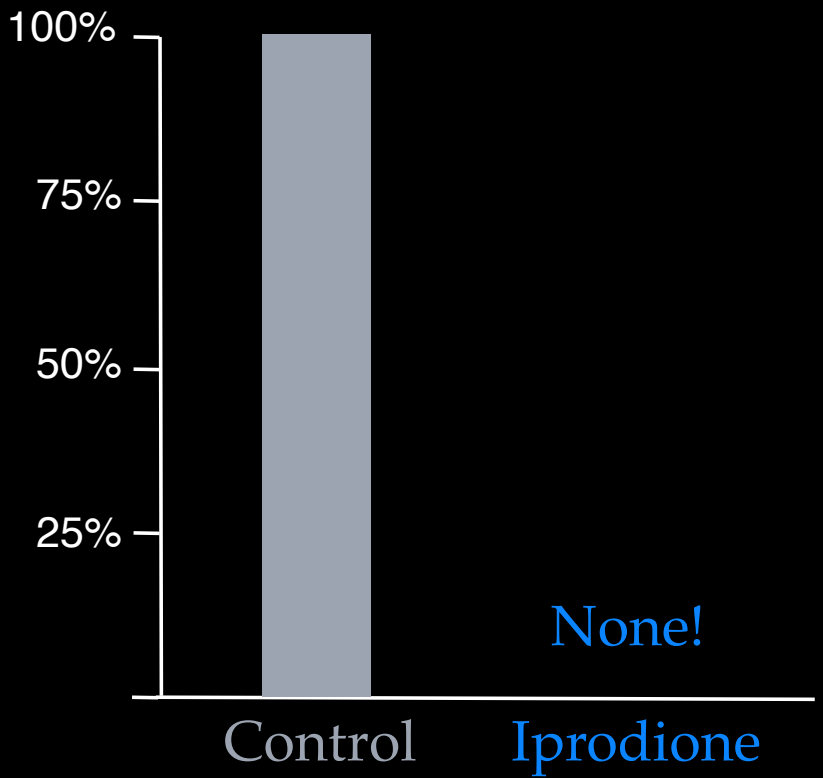
Limodorum abortivum, control *vs*. treated with iprodione

Bellino *et al.*, 2014
Oecologia **175**: 875-885

TESTING THE ROLE OF FUNGAL C

Limodorum abortivum, control *vs*. treated with iprodione twice, during and after anthesis

In situ root of *L. abortivum* with fungus at fruiting



TESTING THE ROLE OF FUNGAL C

Limodorum abortivum, control *vs*. treated

	Control	Iprodione	
Fruit length (mm)	25.7 ± 2.3 ***a***	26.7 ± 3.4 ***a***	(*n*=42)
Fruit diam. (mm)	8.4 ± 0.3 ***a***	9.0 ± 0.5 ***a***	(*n*=42)
Seed (mm^2)	0.26 ± 0.06 ***a***	0.28 ± 0.07 ***a***	(*n*=713)
Fruit $\delta^{13}C$ (‰)	-25.06 ± 0.08 ***a***	-25.50 ± 0.17 ***b***	(*n*=21)

No impact on seed set, full compensation by photosynthesis

CONCLUSIONS

- Shoot autotrophy increases over the growth season.

- Albinos have lower basal metabolism, and especially lack photosynthetic and fungal C at fruiting.

- Fruits use photosynthates, even if fungal C may help (a bit).

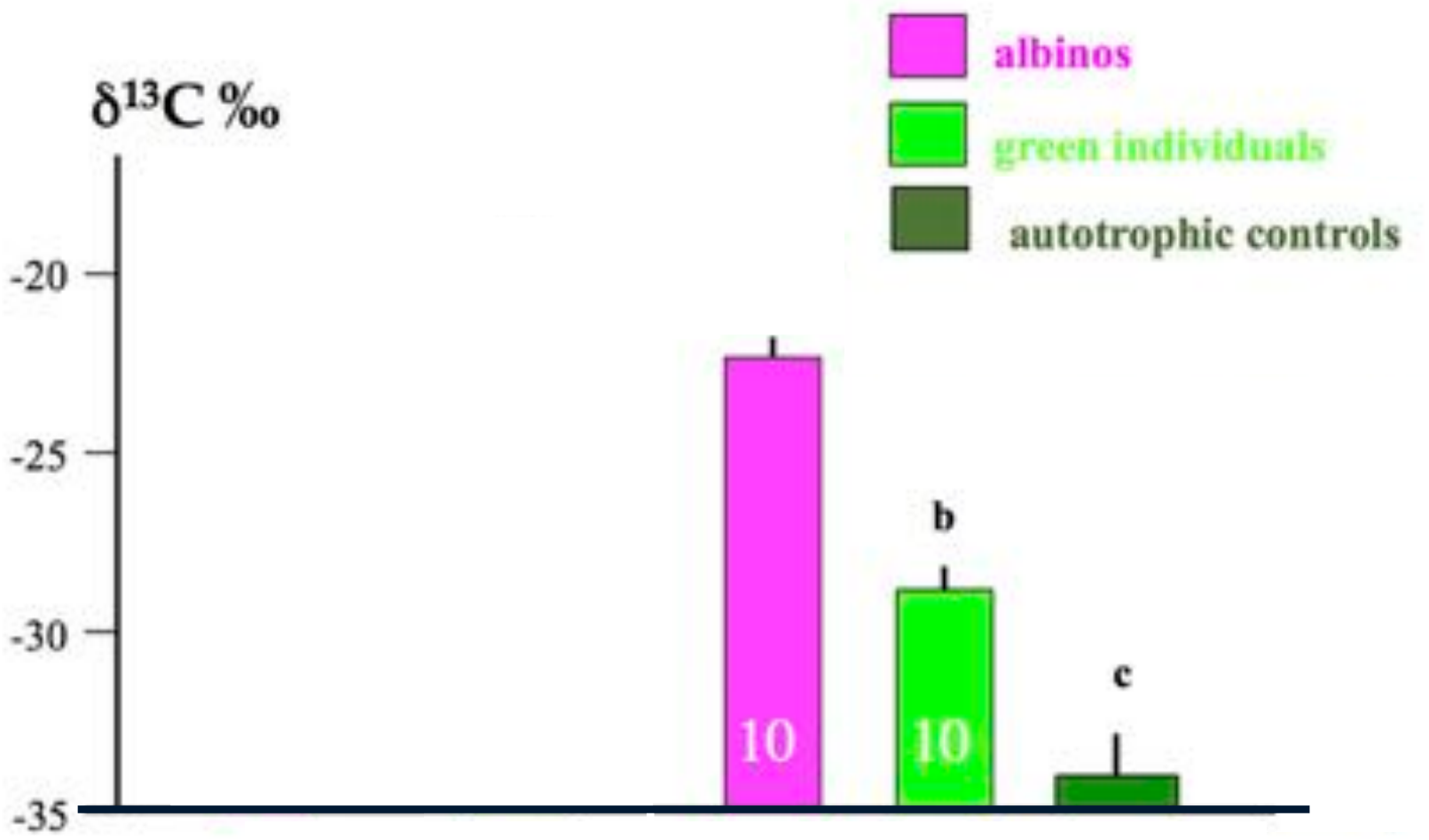
Allocation of fungal *versus* photosynthetic C

In shoots

In fruits

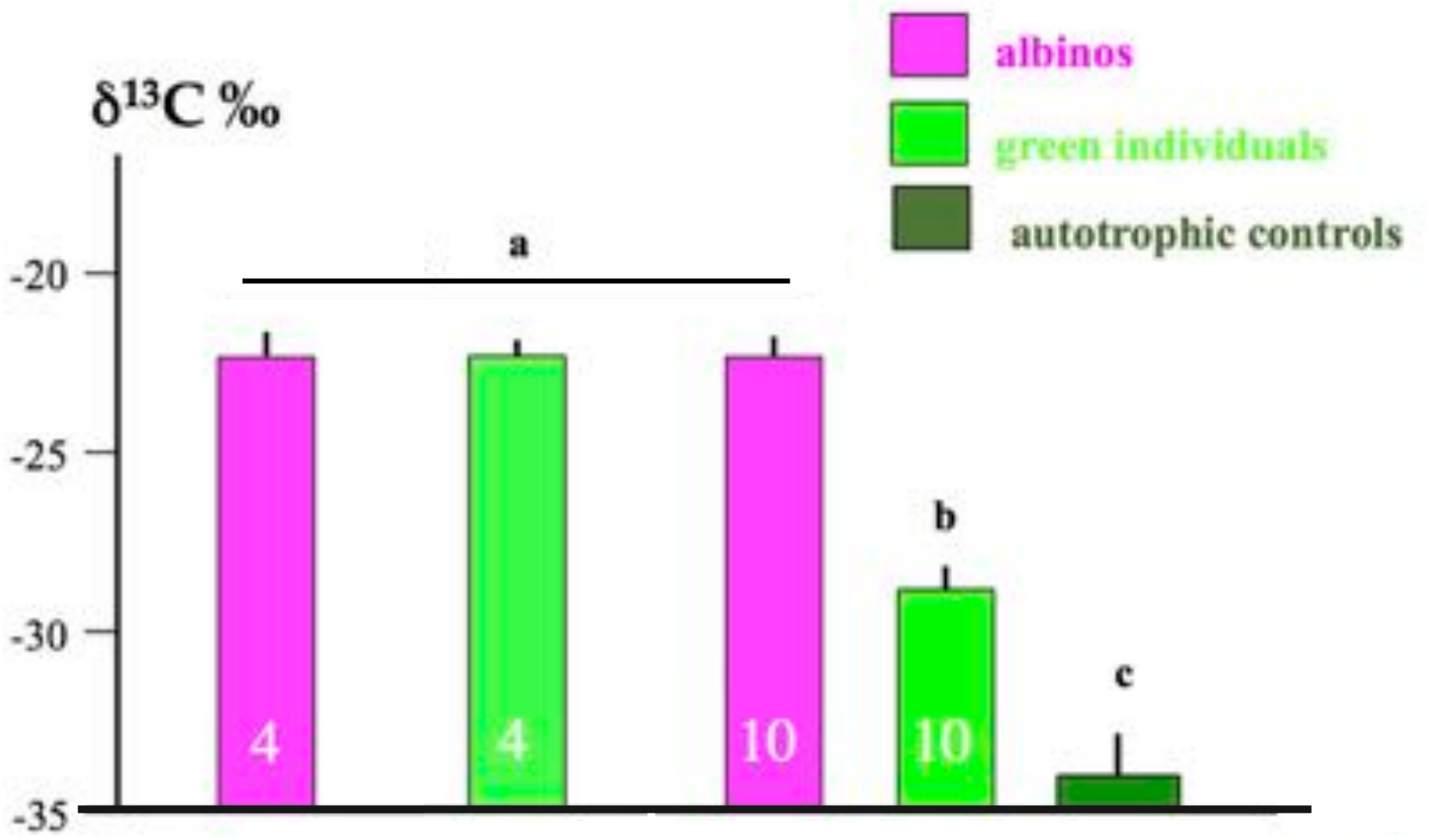
In underground parts and emerging shoots

RHIZOME FEED ON FUNGAL C



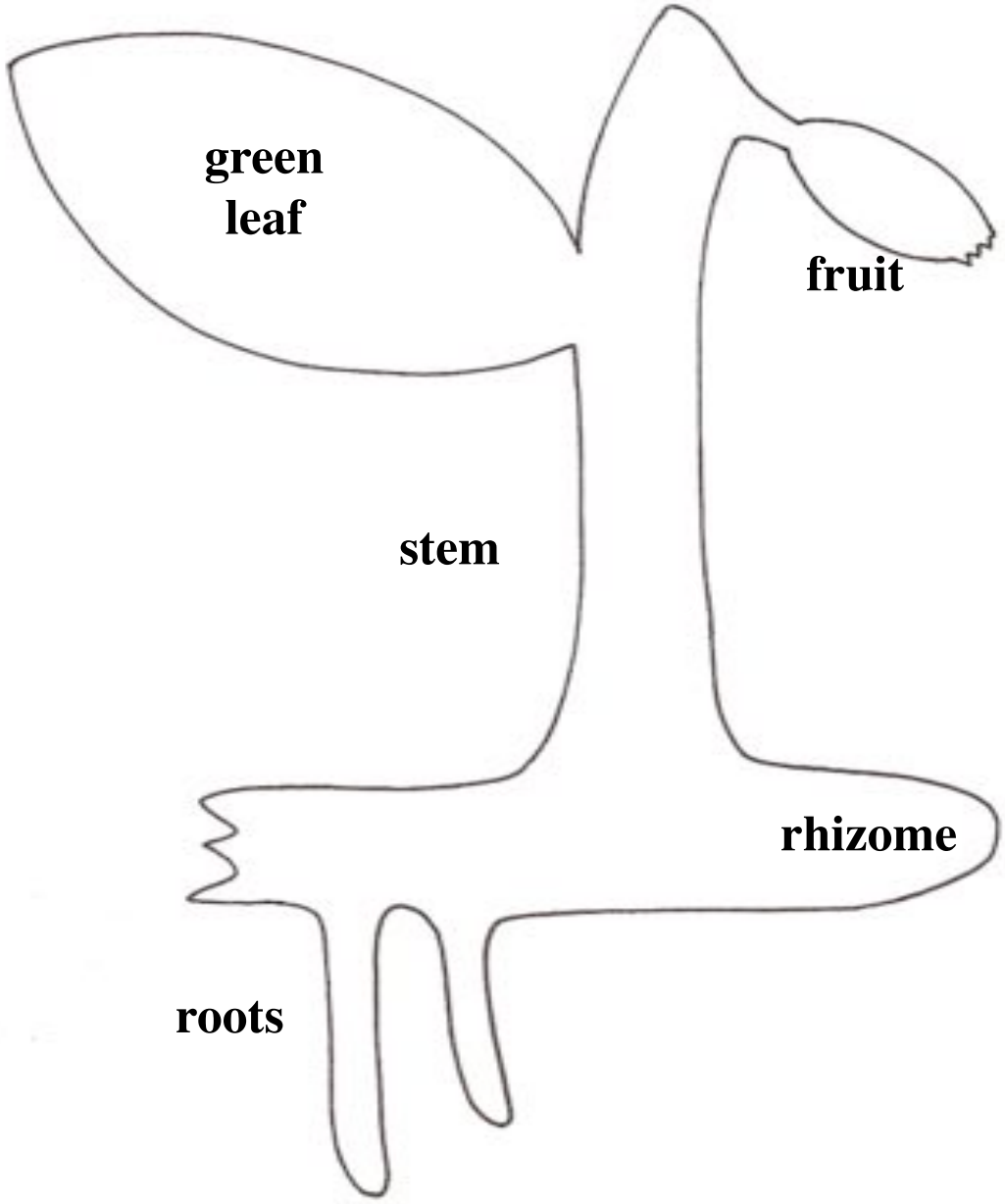
Gonneau *et al*. 2015

RHIZOME FEED ON FUNGAL C



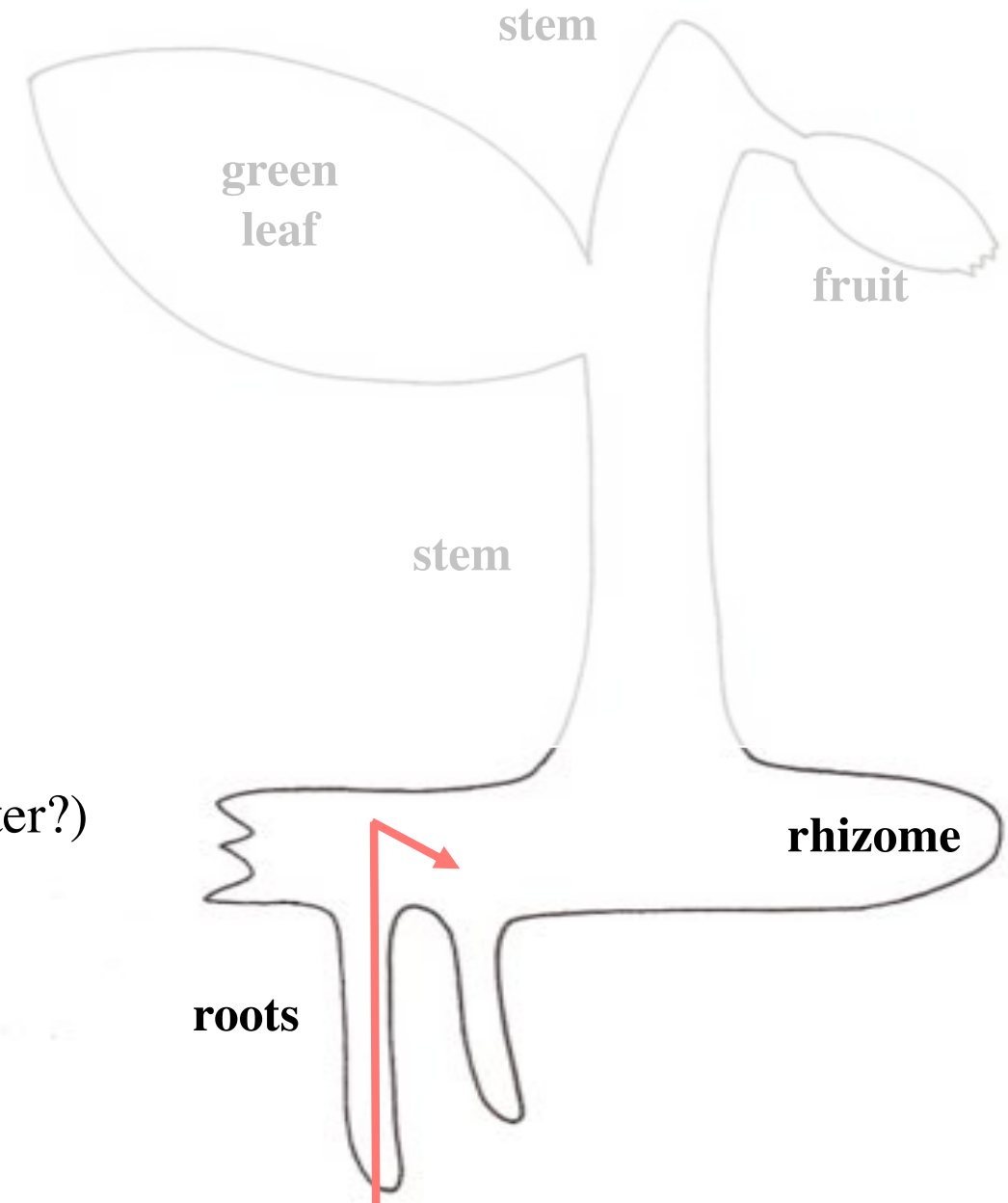
Gonneau *et al*. 2015

PHOTOSYNTHESIS



MYCOHETEROTROPHY

PHOTOSYNTHESIS

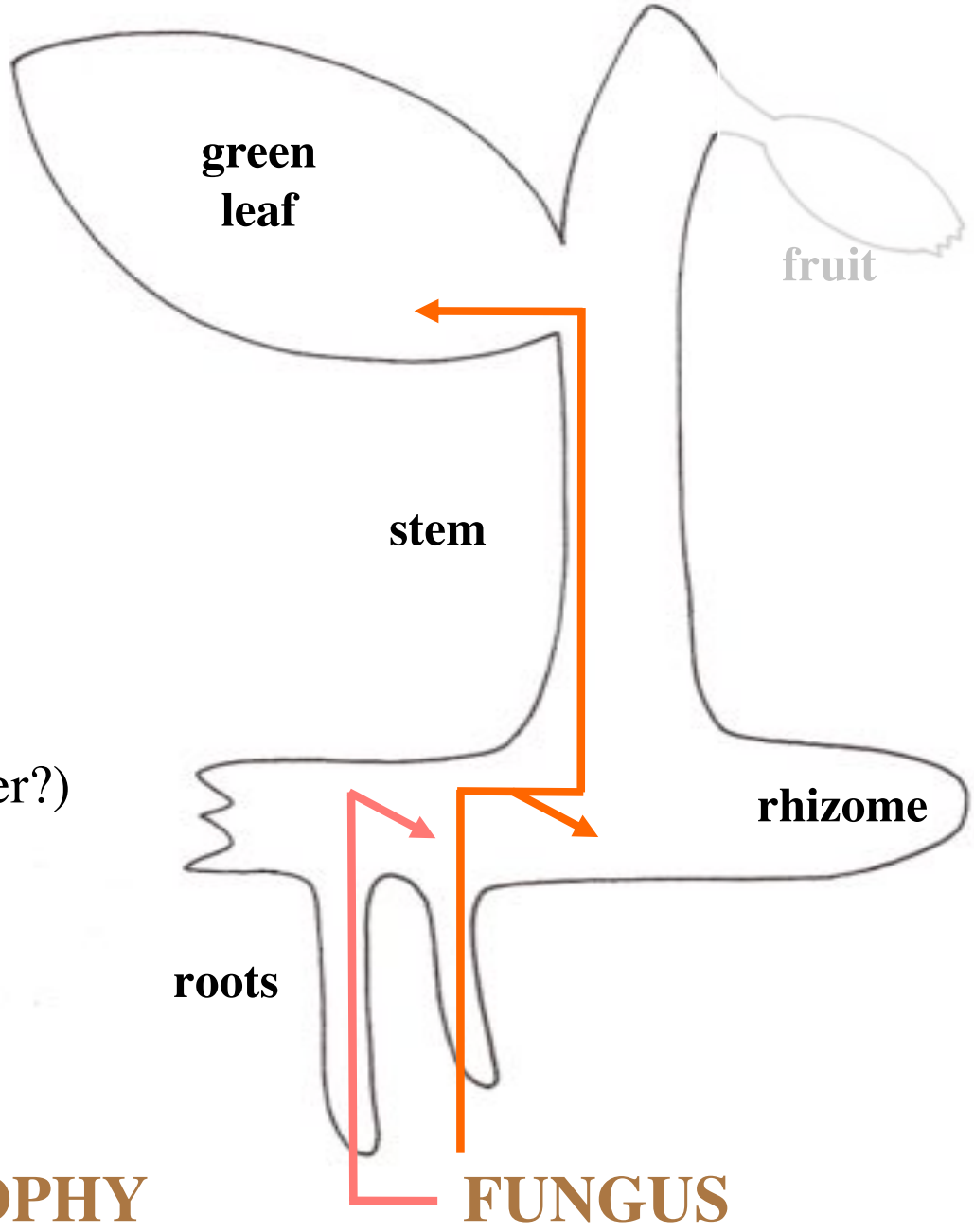


Fungal C

— dormancy (& winter?)

MYCOHETEROTROPHY **FUNGUS**

PHOTOSYNTHESIS



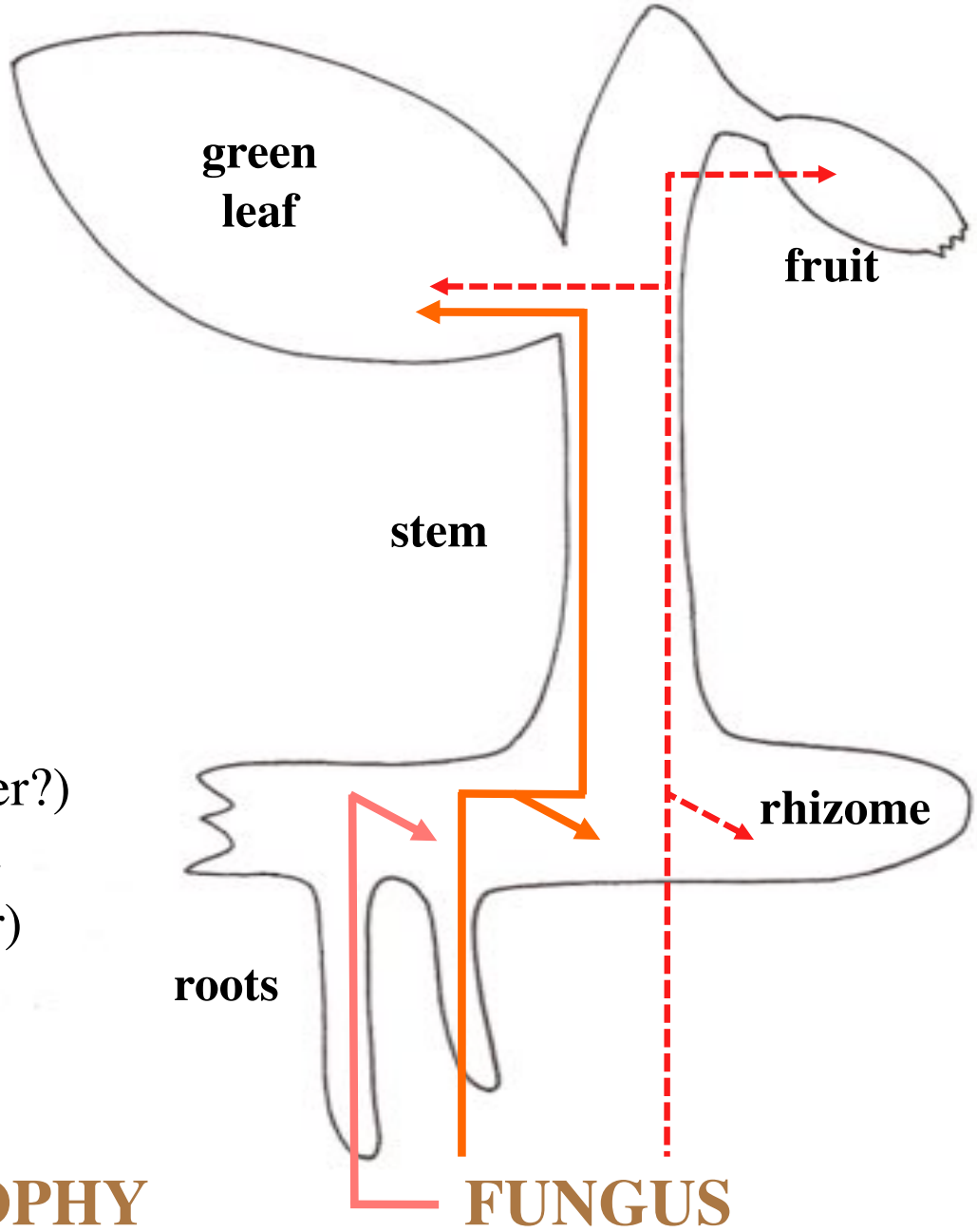
Fungal C

dormancy (& winter?)

at shoot emergence

MYCOHETEROTROPHY **FUNGUS**

PHOTOSYNTHESIS



Fungal C

- dormancy (& winter?)
- at shoot emergence
- at fruiting (summer)

MYCOHETEROTROPHY **FUNGUS**

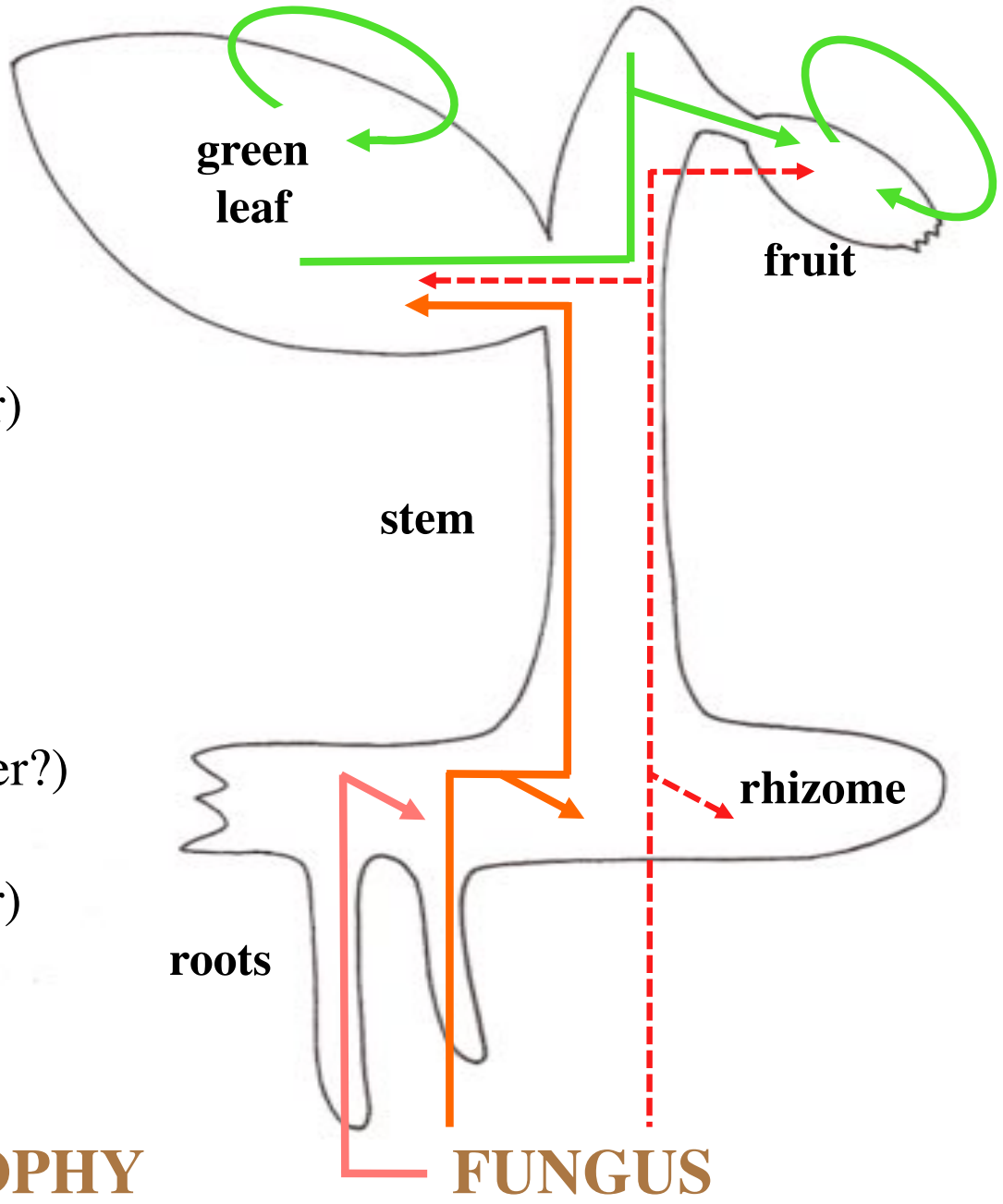
PHOTOSYNTHESIS

Plant C

— at fruiting (summer)

Fungal C

— dormancy (& winter?)
— at shoot emergence
— at fruiting (summer)

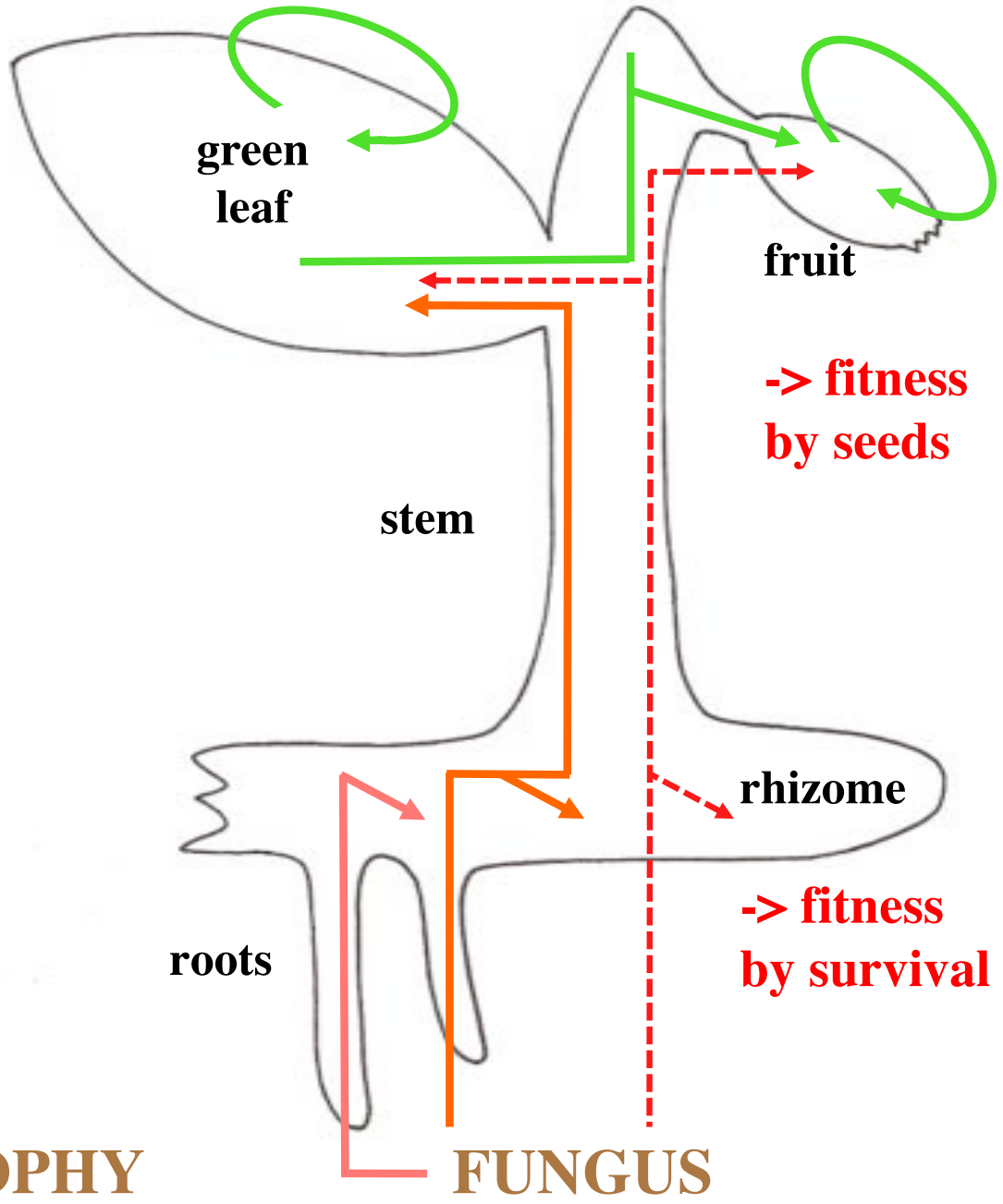


MYCOHETEROTROPHY

FUNGUS

PHOTOSYNTHESIS

Plant C



Fungal C

MYCOHETEROTROPHY

FUNGUS

CONCLUSIONS

- Fruits use mostly photosynthates

- Underground tissues use mostly fungal C

- The resulting optimization of the use of fungal and photosynthetic C is problematic for albino fruiting.

CONCLUSIONS

- Fruits use mostly photosynthates

- Underground tissues use mostly fungal C

- The resulting optimization of the use of fungal and photosynthetic C is problematic for albino fruiting.

… due to this fatal addiction to light of mixotrophic plants, you cannot lose photosynthesis in one step!

CONCLUSIONS

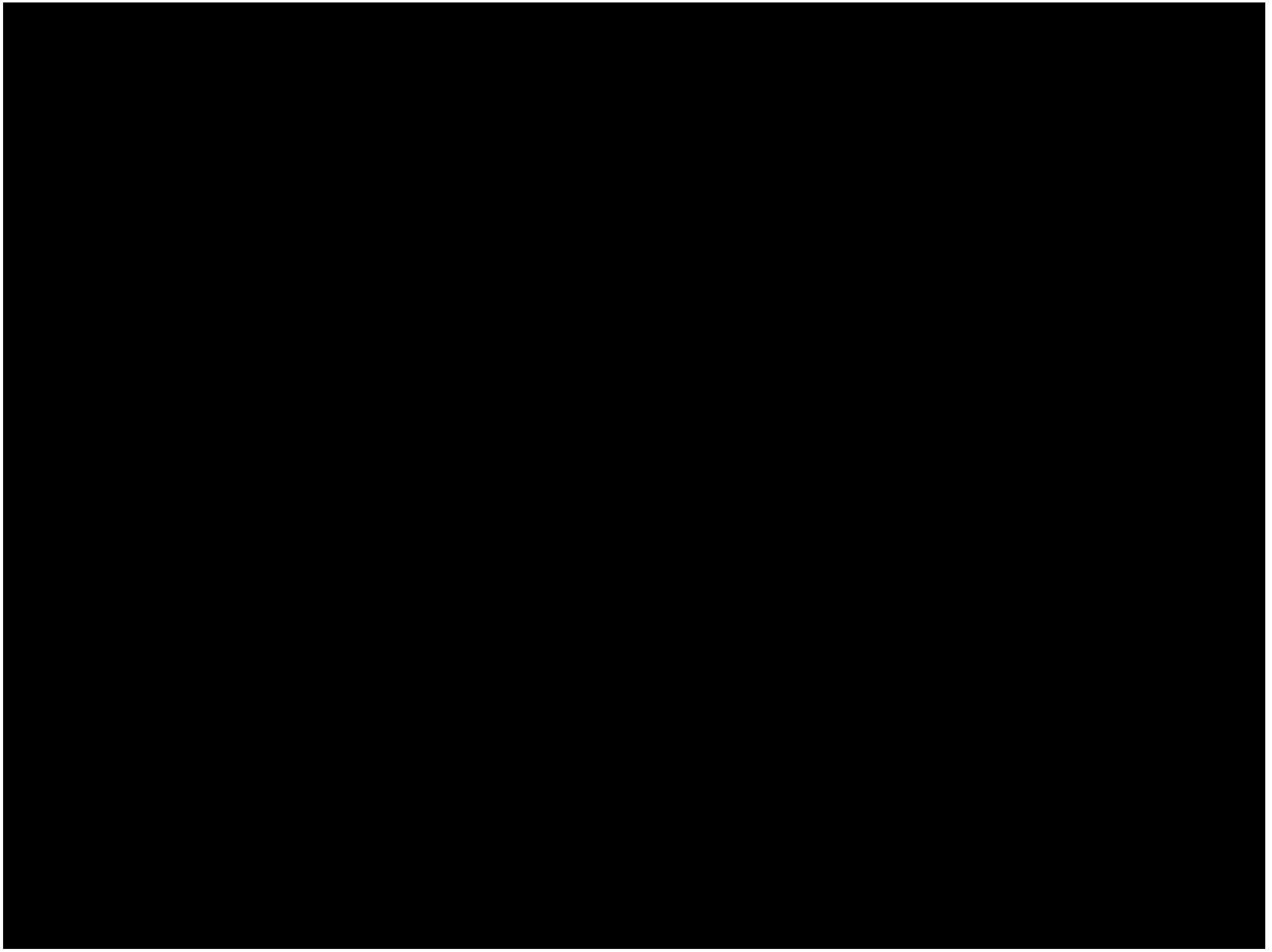
- Fruits use mostly photosynthates

- Underground tissues use mostly fungal C

- The resulting optimization of the use of fungal and photosynthetic C is likely fatal to albino seed production.

The evolutionary emergence of pure C sinks in mycorrhizal networks is a complex process,

… and mixotrophy is metastable in evolution



My partner network…

Mélanie Roy, Cédric Gonneau

Soc. Française d'Orchidophilie: J.-P. Amardeihl, C. Blanchon, F. Dusak, G. Joseph, J. Koenig, P. Pernot, C. & J. Péternel, D. Prat, G. Scappaticci, R. Souche, J. Villeret

Univ. Salerno: A. Bellino, A. Alfani, D. Baldantoni

Univ. Ceske-Budejovice: J. Jersakova, T. Malinova, T. Hajcek

Univ. Turin: P. Bonfante, A. Faccio, M. Girlanda, S. Perotto

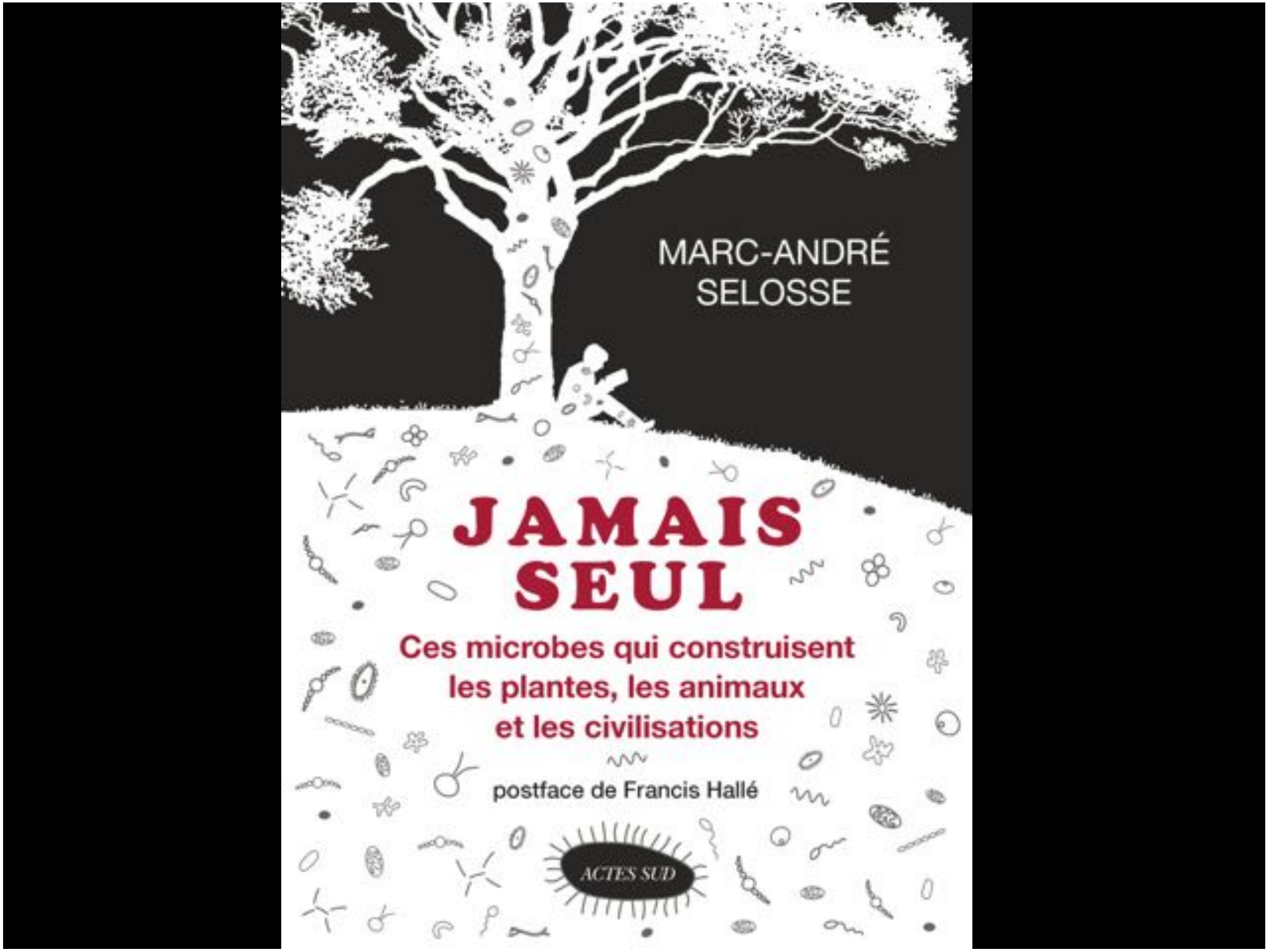
Univ. Tartu: U. Koljalg, L. Tedersoo, U. Püttsepp, M. Öpik

Acad. Science of Russia: M. Logacheva

Univ. Pointe-à-Pitre: A. Ba, M. Dulorme, A. Rousteau

Univ. Basel: P.-E. Courty, T. Boller, F. Walder, A. Wiemken

… all papers online on ISYEB website


MARC-ANDRÉ
SELOSSE
JAMAIS
SEUL
Ces microbes qui construisent
les plantes, les animaux
et les civilisations
postface de Francis Hallé
ACTES SUD