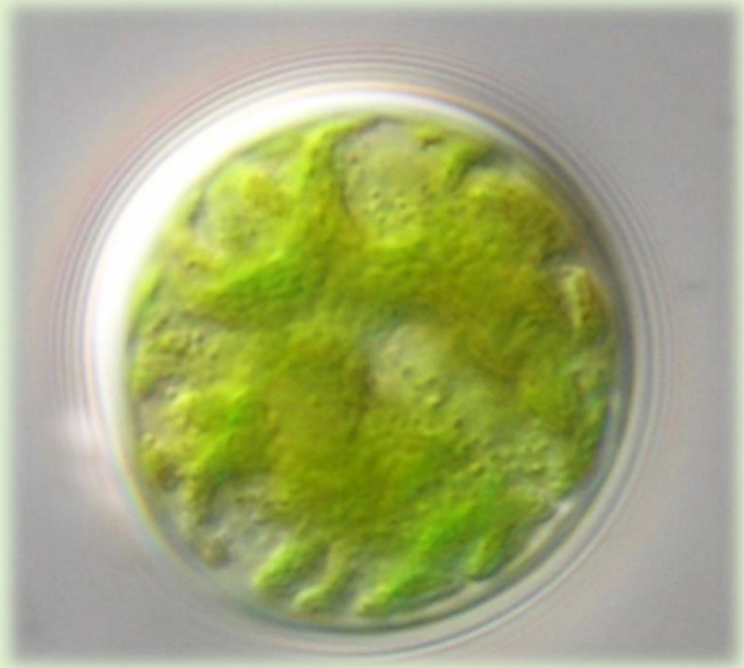
How to find the best partner:
Insights into the mysterious world of symbiotic algae

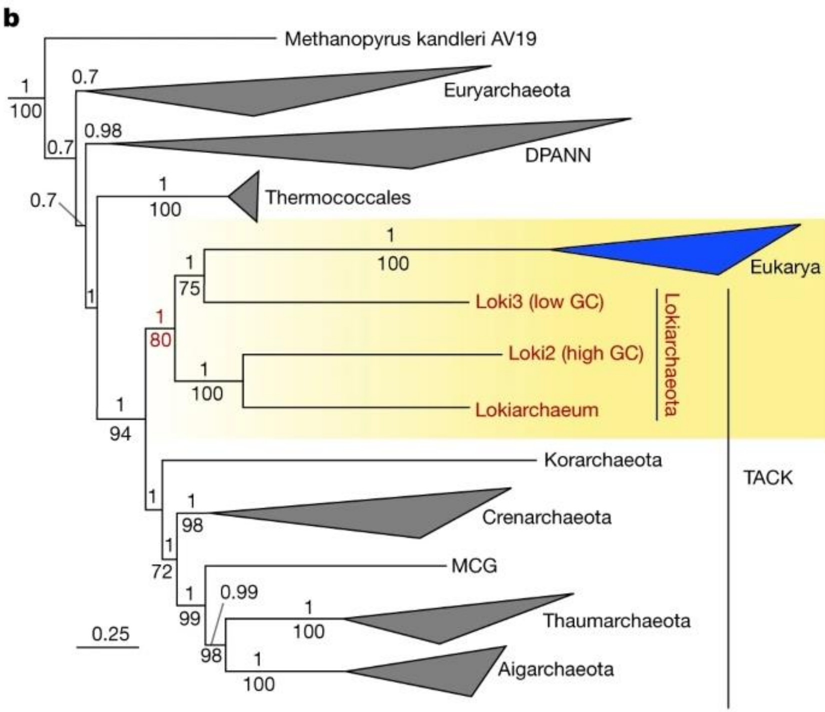



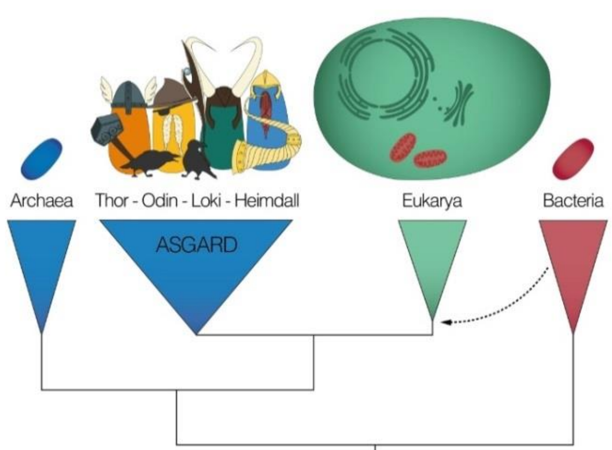
Pavel Škaloud

FACULTY OF SCIENCE
Charles University

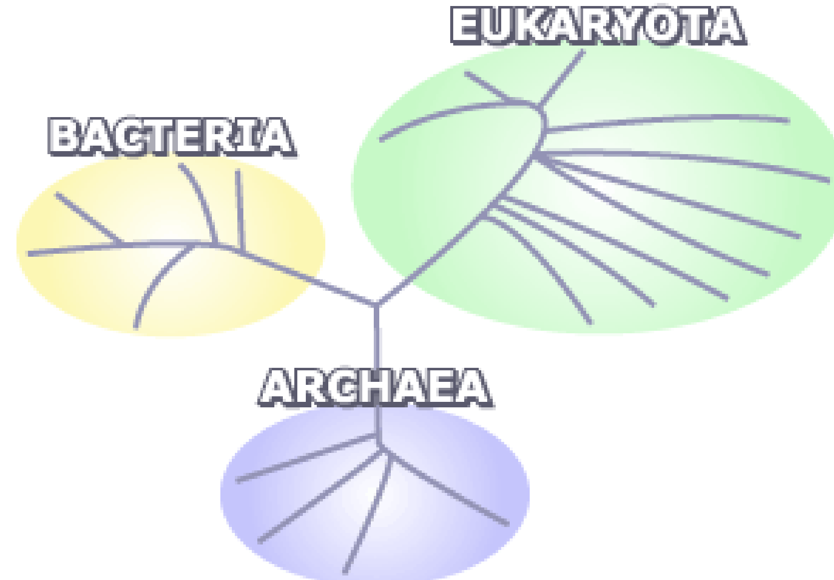
Algal speciation & evolution lab

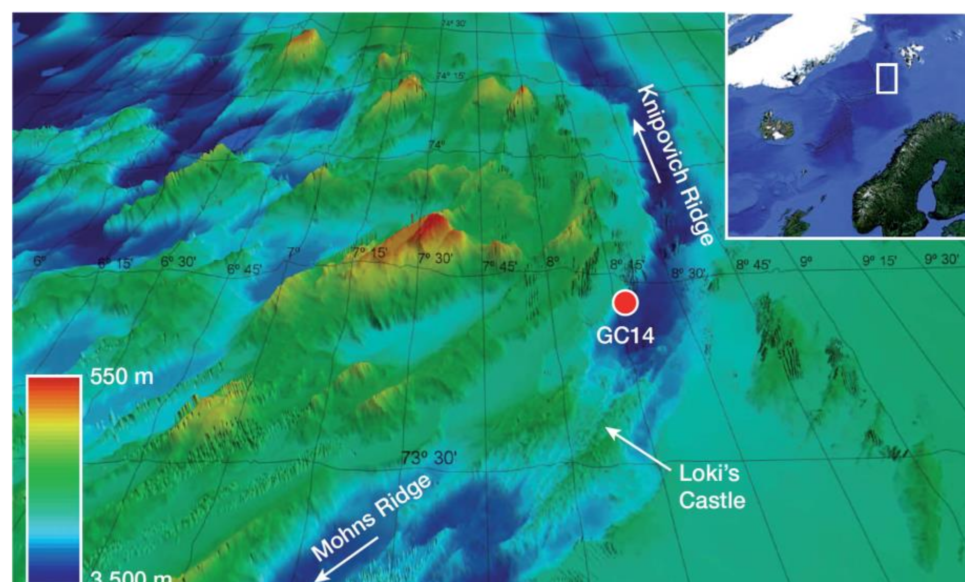
Symbiosis - Eukaryogenesis





Zaremba-Niedzwiedzka et al. (2017): Nature

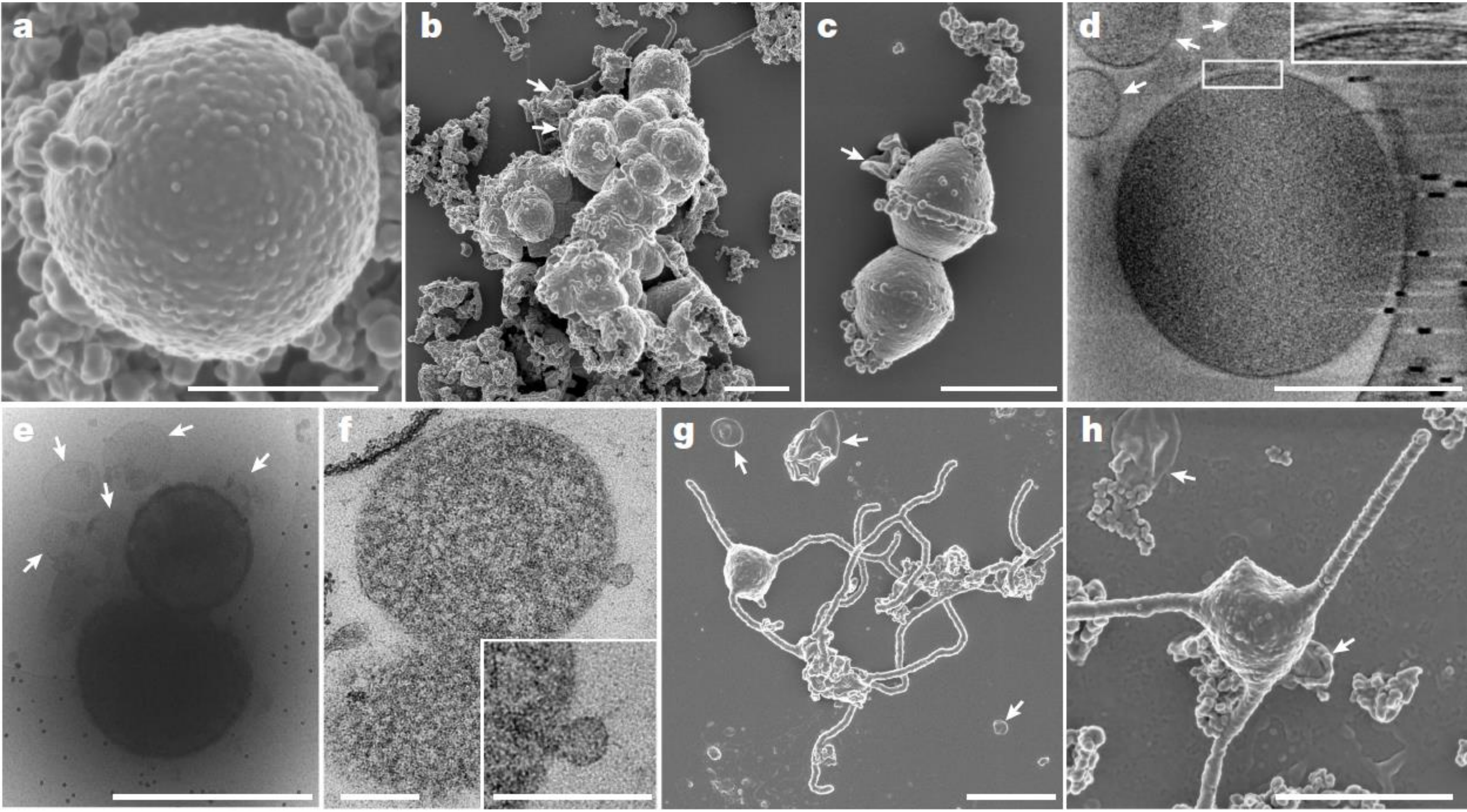




Spang et al. (2015): Nature

Symbiosis - Eukaryogenesis

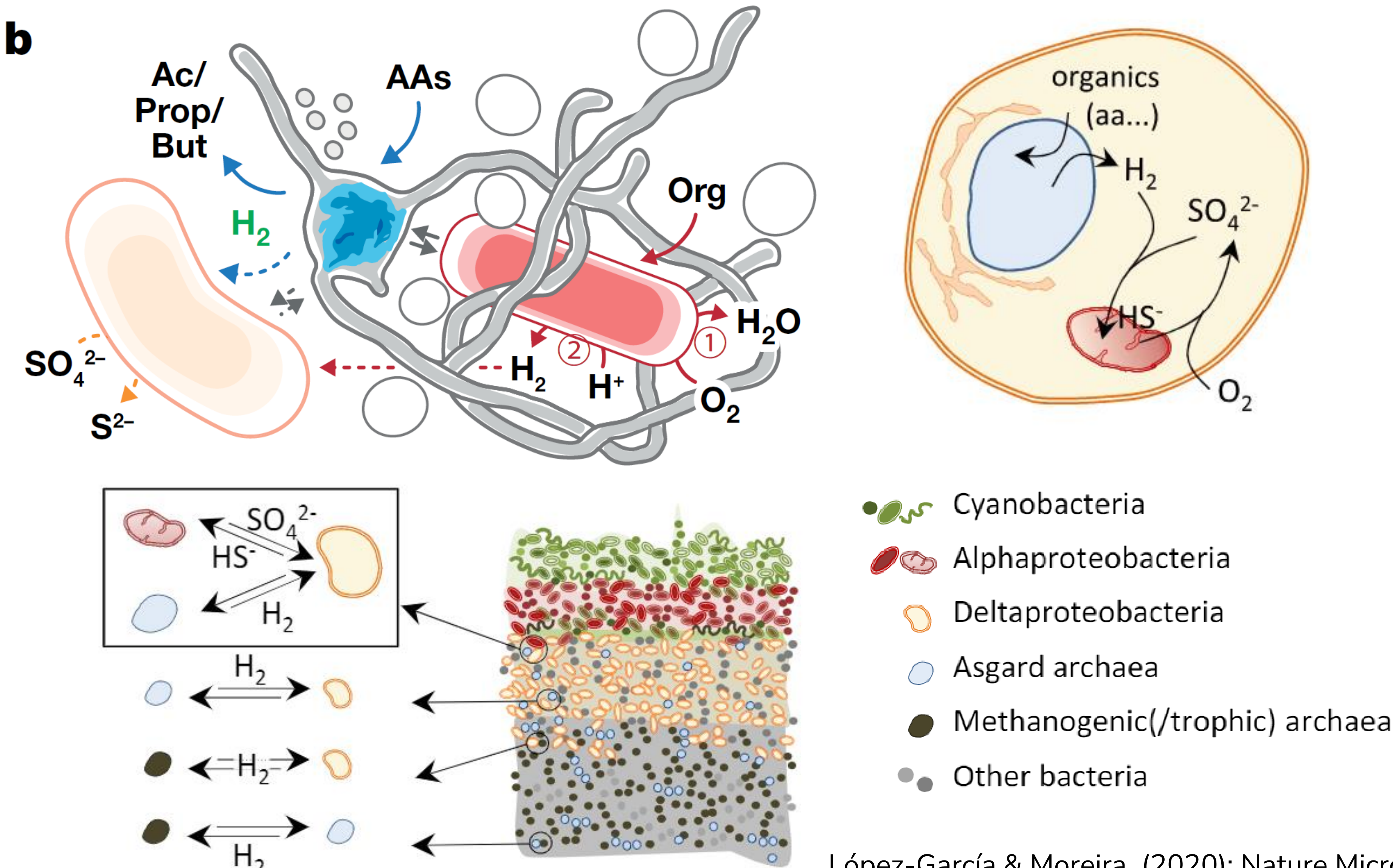
- *Prometheoarchaeum syntropicum*



Imachi et al. (2020): Nature

Symbiosis - Eukaryogenesis

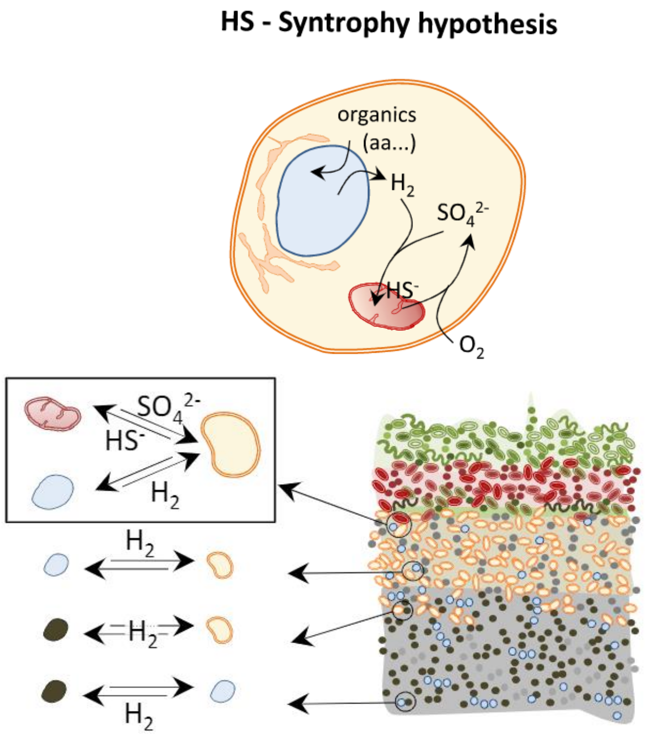
- *Prometheoarchaeum syntropicum*, syntrophy hypothesis

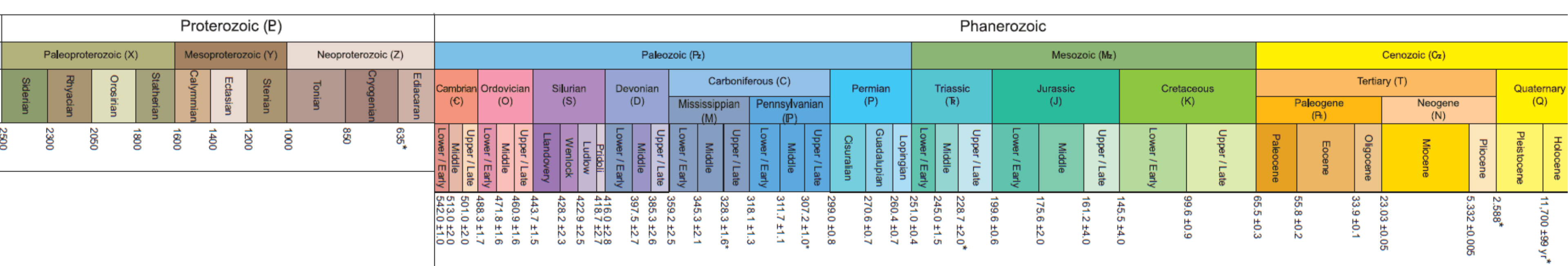


López-García & Moreira (2020): Nature Microb.

Symbiosis

- Central driver for evolution across the entire tree of life



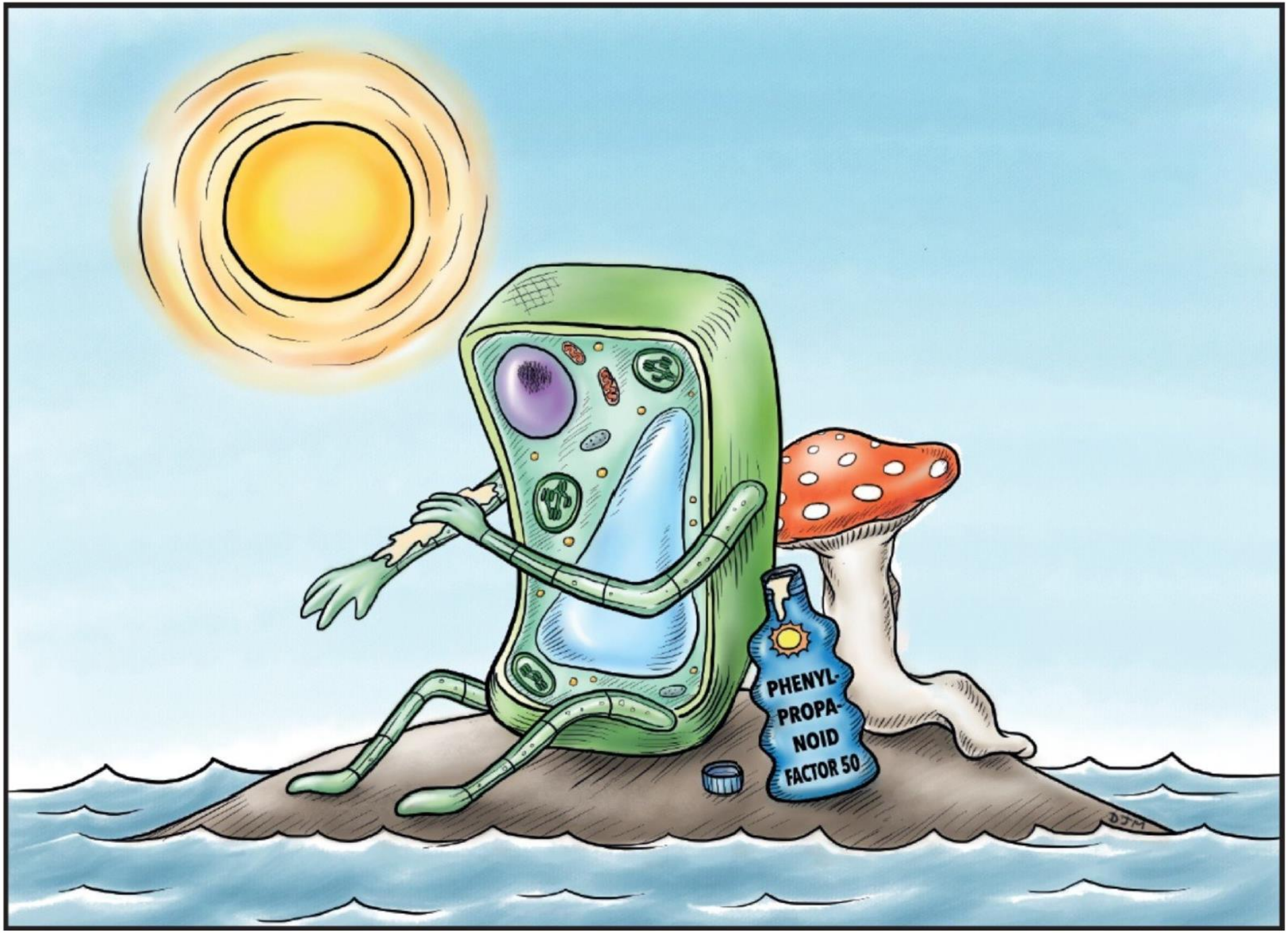


Symbiosis – first land plants

- *Cooksonia barrandei*

© Emiliano Troco

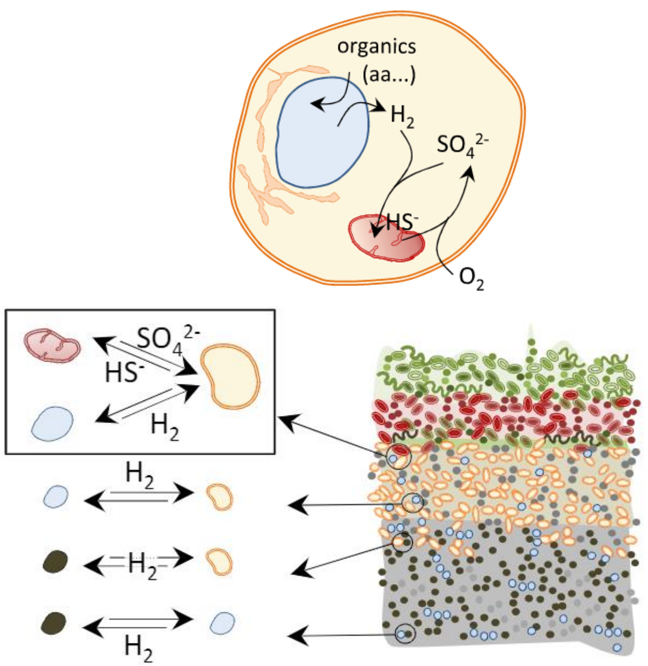
Symbiosis – first land plants

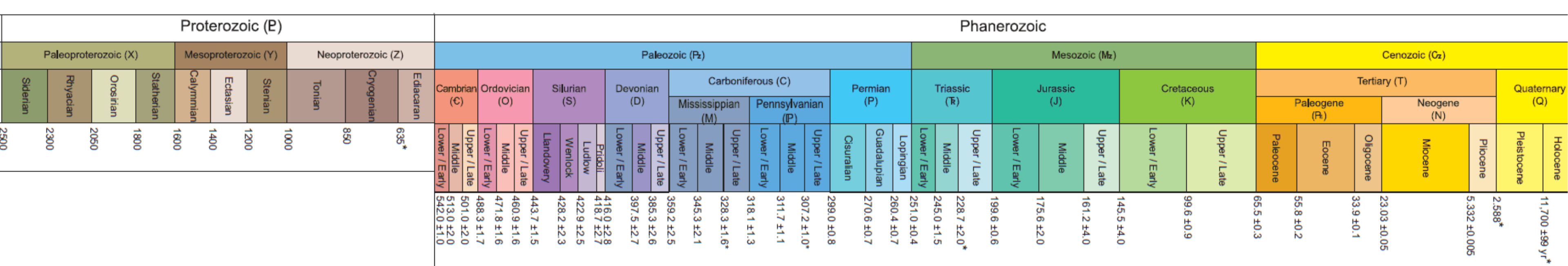


Symbiosis

- Central driver for evolution across the entire tree of life

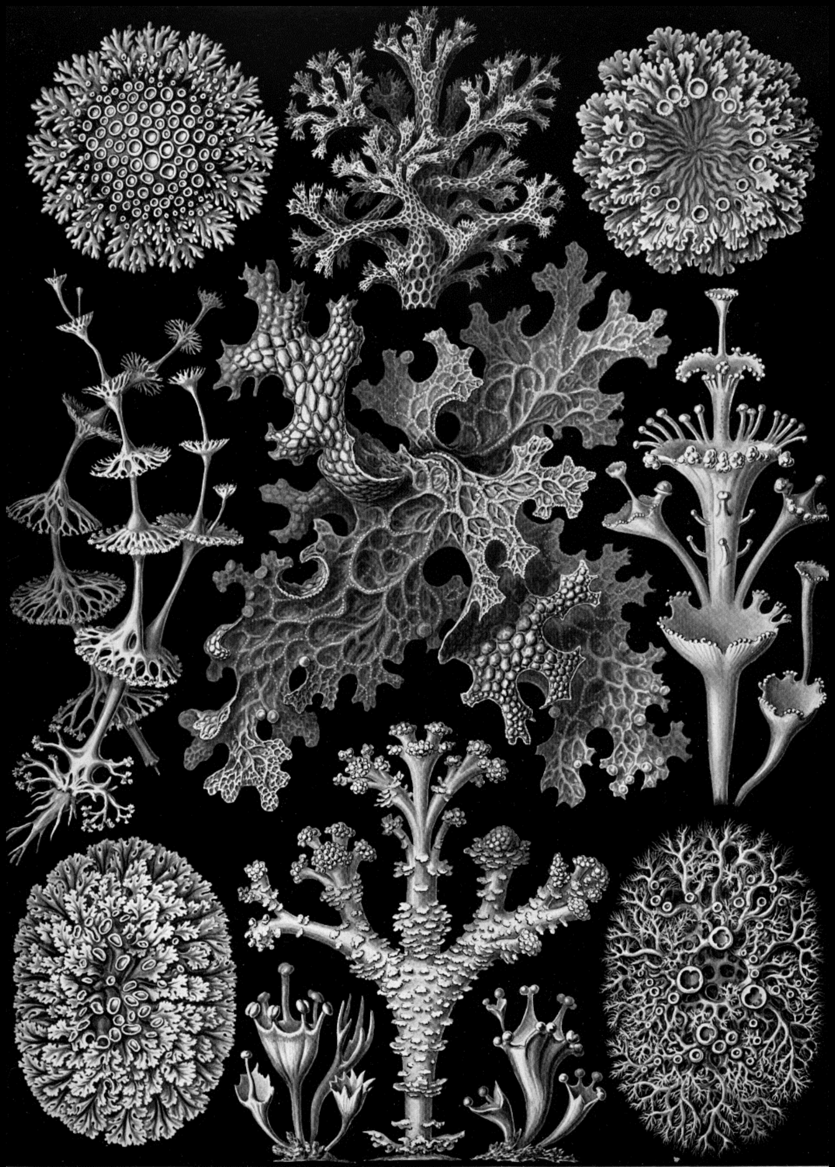
HS - Syntrophy hypothesis

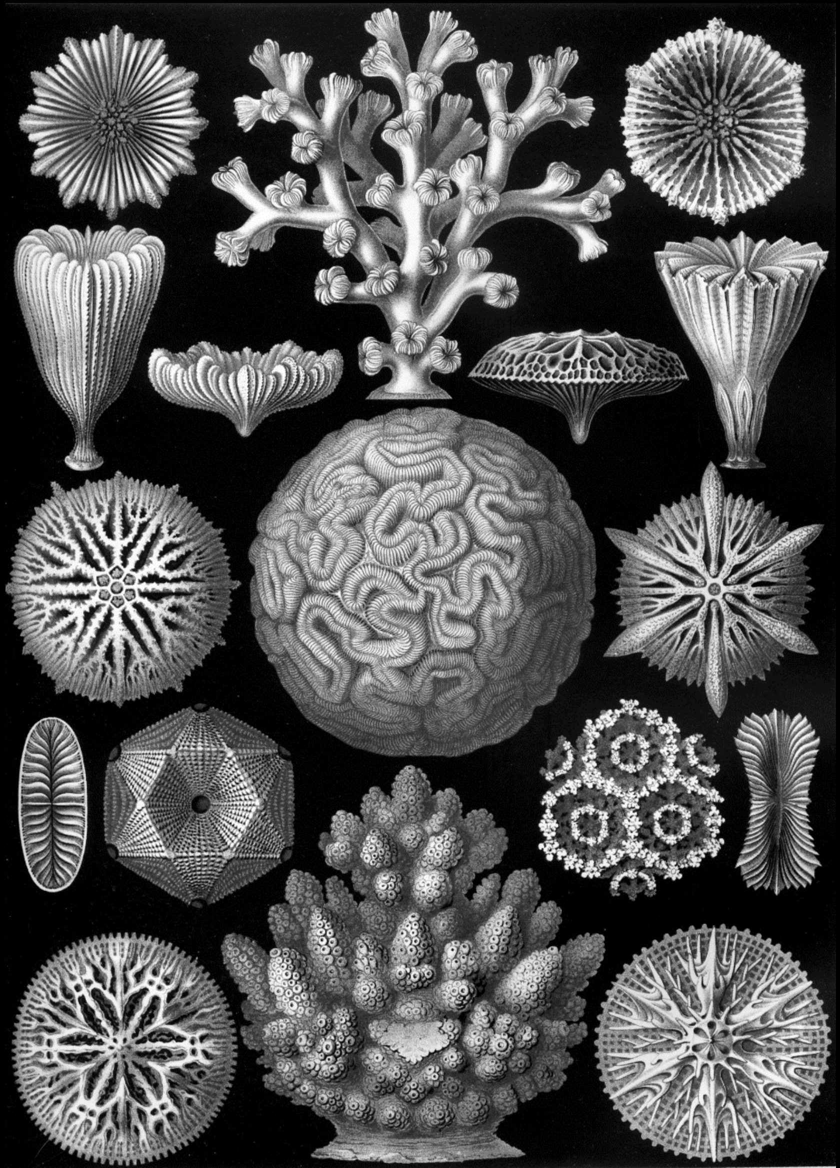




Phototrophic symbioses

- Generally macroscopic hosts nutritionally dependent on microscopic endosymbionts providing organic carbon produced by the photosynthesis

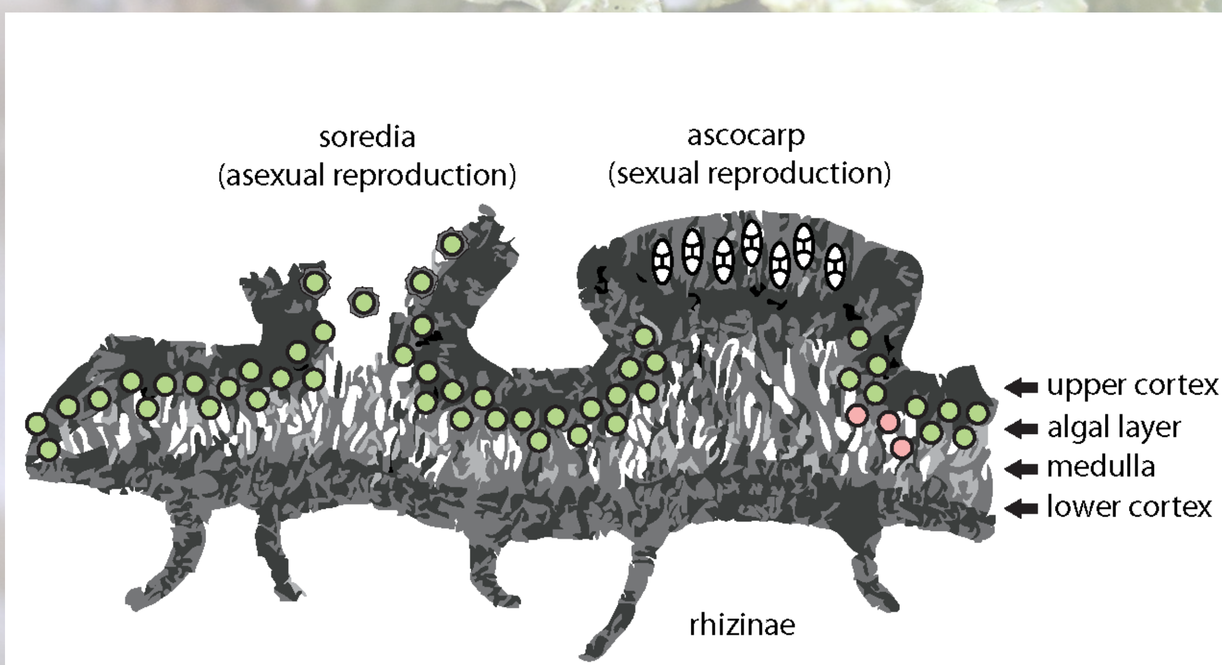


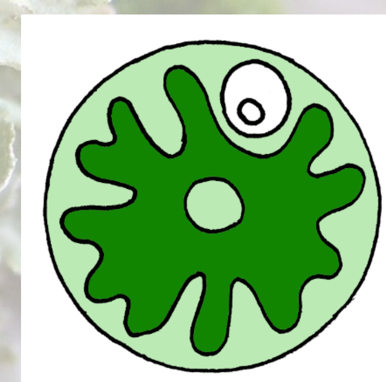


Haeckel (1904)

Phototrophic symbioses

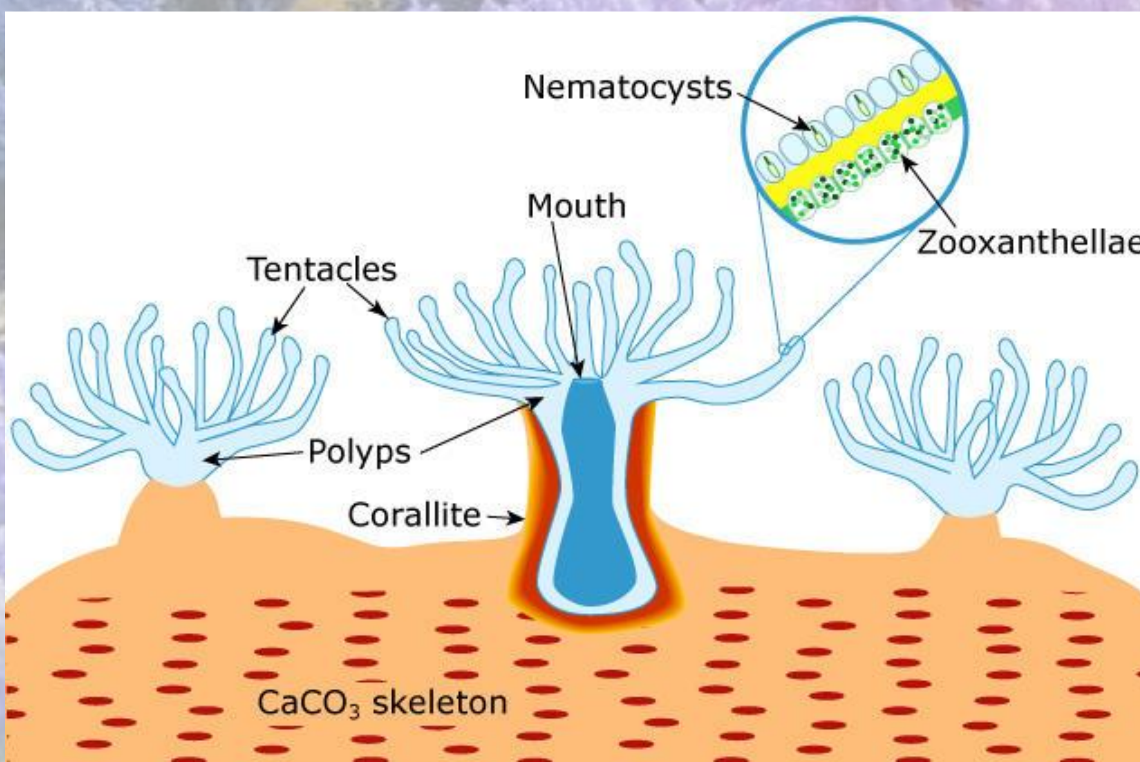
- Lichens
  - Dominate 8% of the Earth's land surface
  - Impacting global fluxes of carbon and nutrients
  - Soil stabilization and development

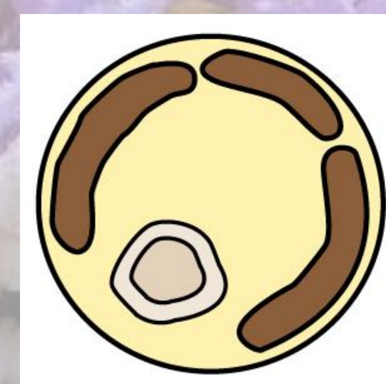




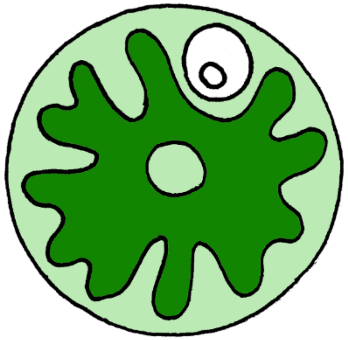
Phototrophic symbioses

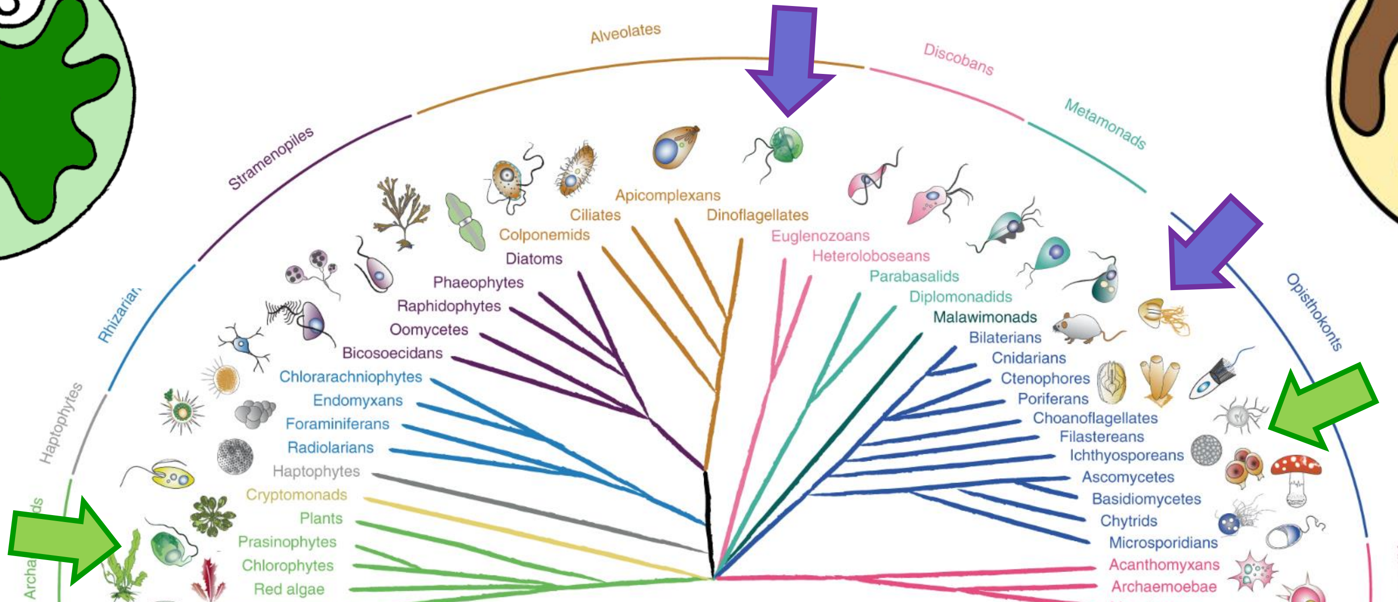
- Corals
  - Cover 0.17% of the ocean surface
  - Coral reefs as important planetary biodiversity hotspots





Phototrophic symbioses



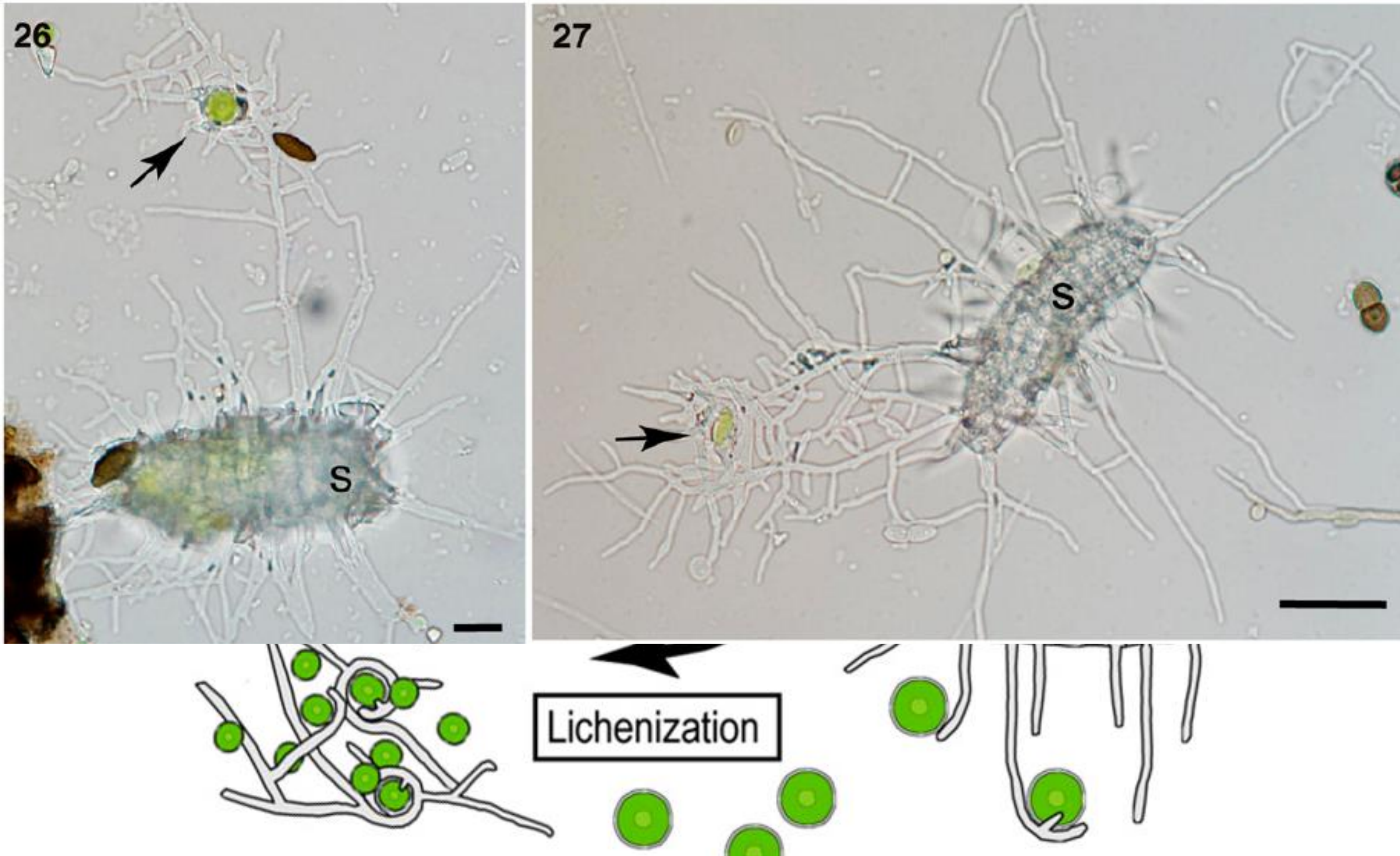


Faktorová (2020): Nat. Methods

nytimes.com

Horizontal transmission

- The majority of heterotrophic hosts disperse without their symbionts by sexually propagated offspring, and thus have to re-establish the symbiotic state at each reproductive cycle



Sanders et al. (2014): Am. J. Bot.

Horizontal transmission

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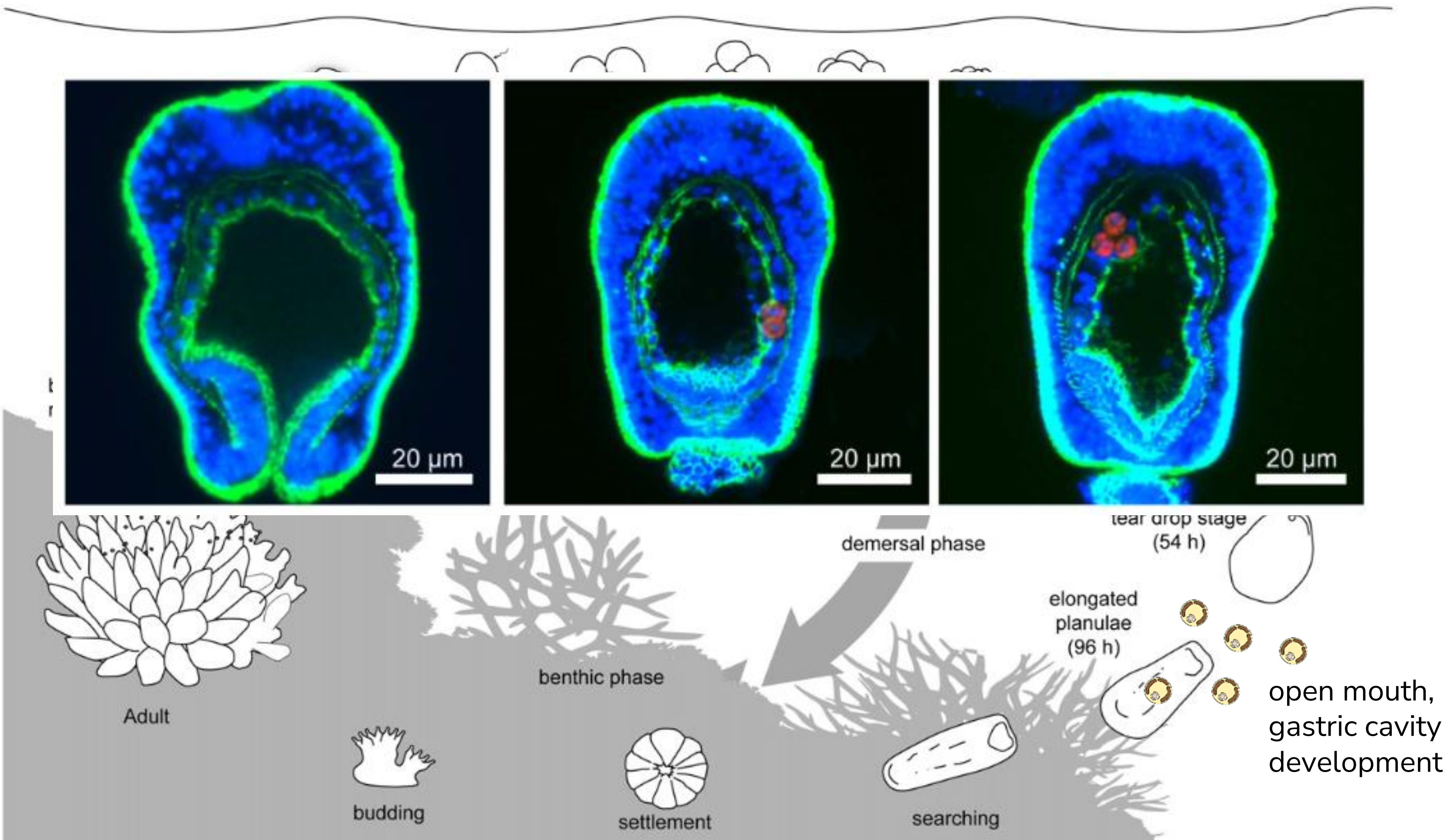
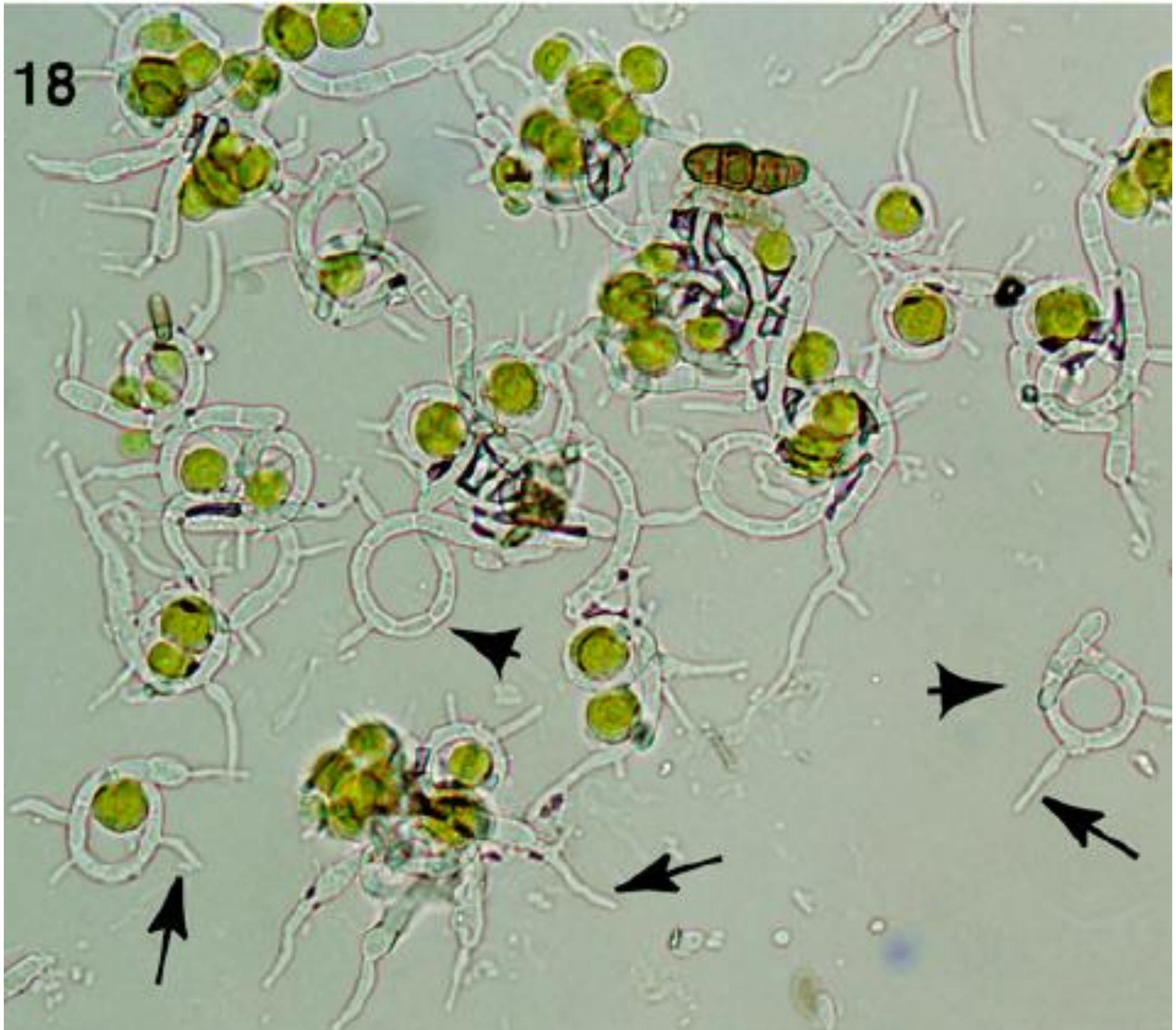


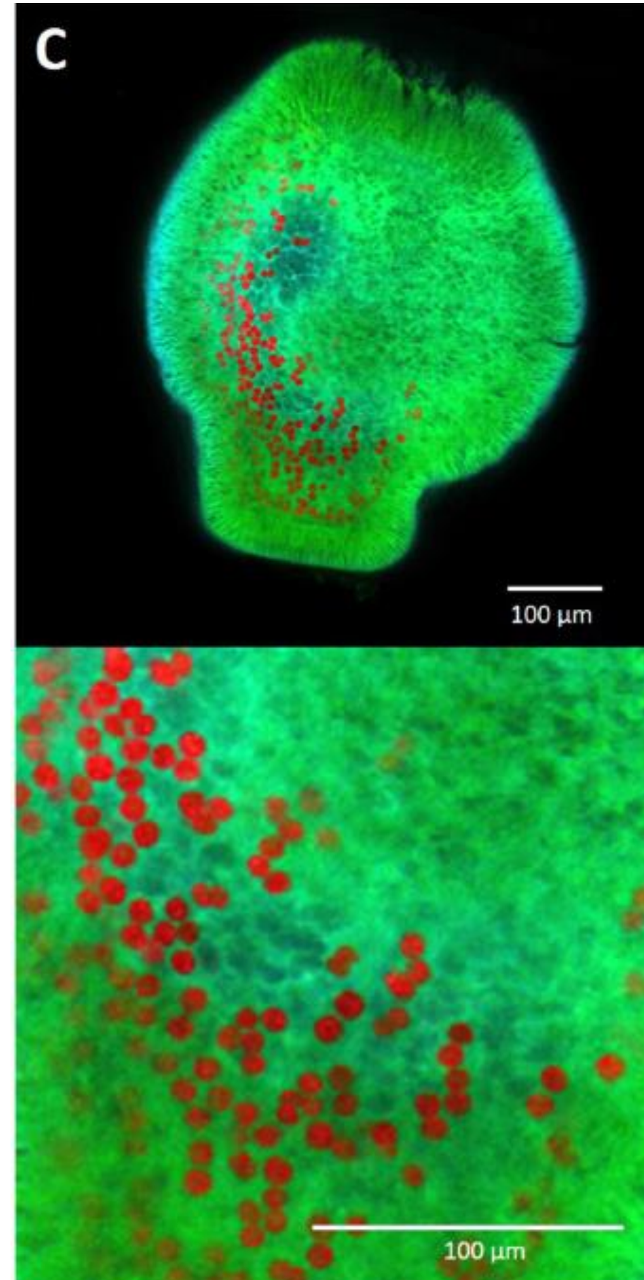
Bucher et al. (2016): Sci. Rep.

Jones et al. (2015): Mar. Poll. Bul.

Vertical transmission

- Co-dispersal of both symbionts



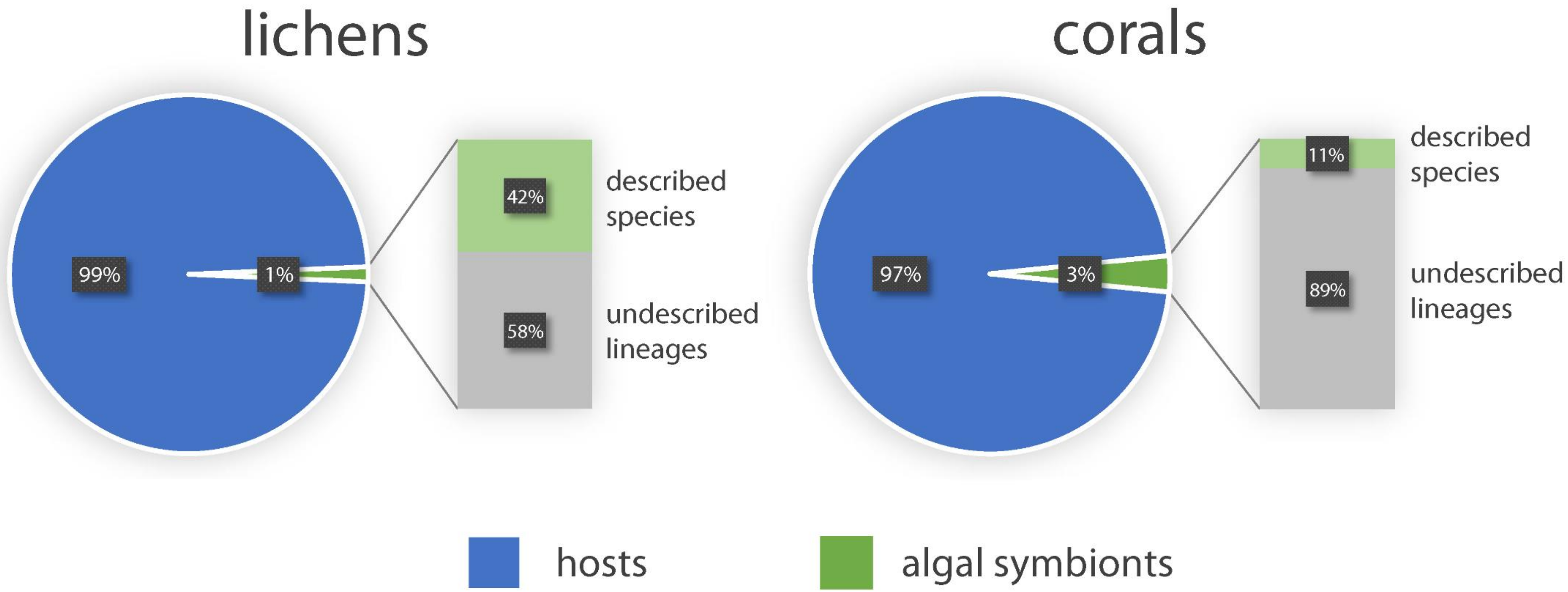


Sanders (2014): Am. J. Bot.

Chakravarti et al. (2019): Front. Microbiol.

Enormous disparity in species richness

- Lichens:
  - ~ 17,000 host species
  - ~ 233 algal symbiotic lineages
- Corals:
  - ~ 6,000 host species
  - ~ 200 algal symbiotic lineages



High specialization of symbionts

- Strong algal host specificity

Bongaerts et al. (2013) BMC Evol. Biol.

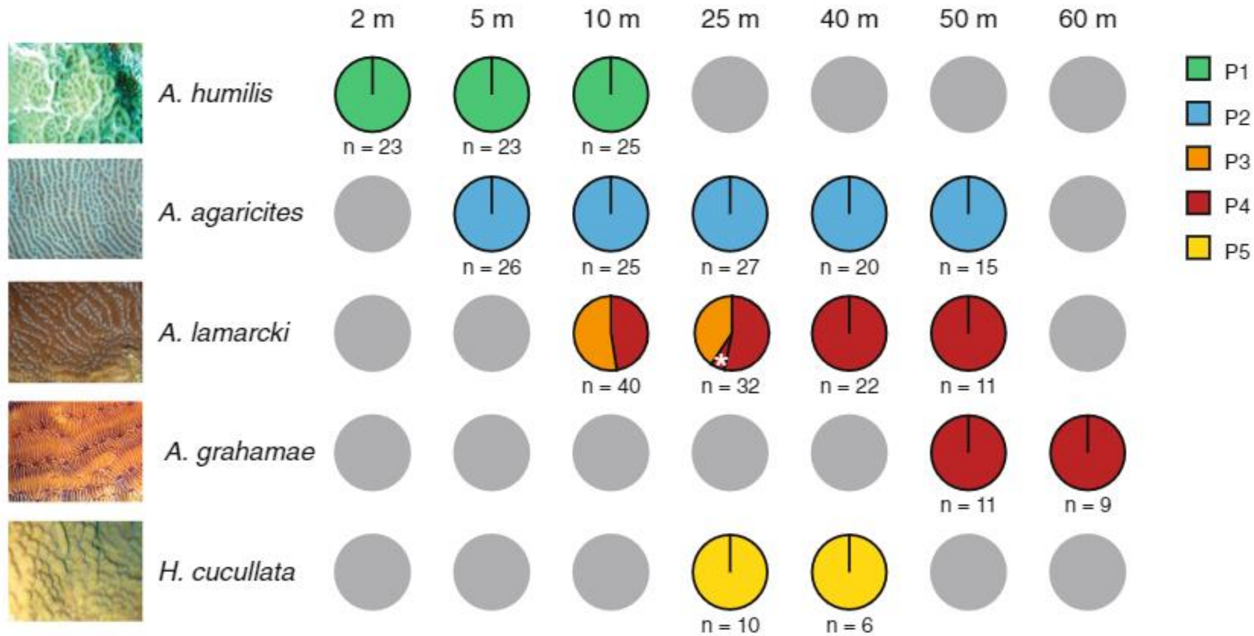
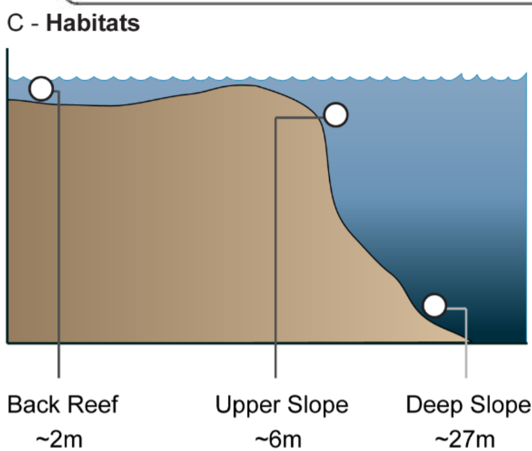
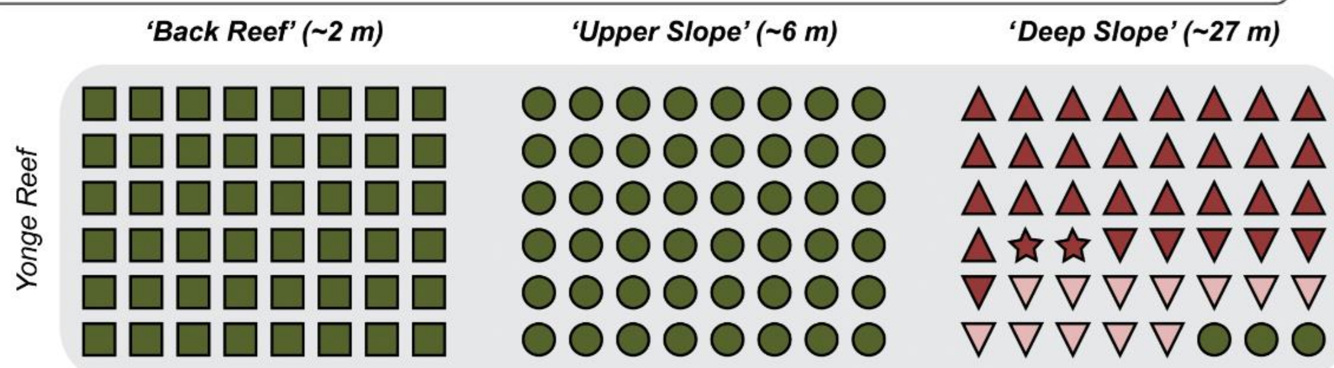


Figure 2 Distribution of *Symbiodinium* ITS2 profiles across the five agariciid host species and depths. Each pie chart represents the sampled population of a host species at a certain depth. Asterisk (*) indicates a P4 profile that had an additional C1 band. Figure legend text.

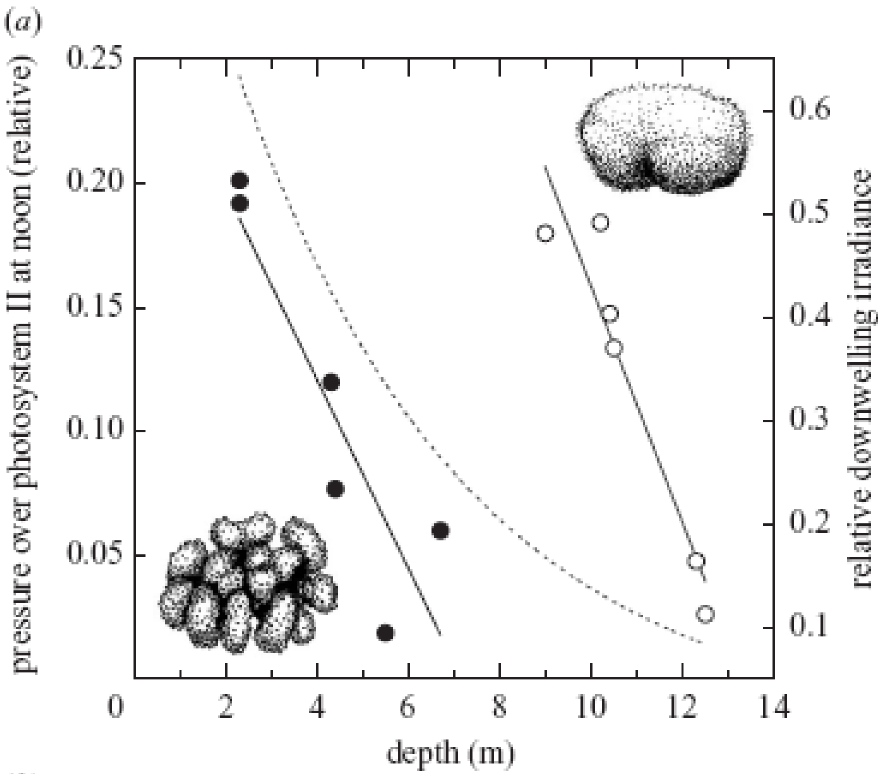


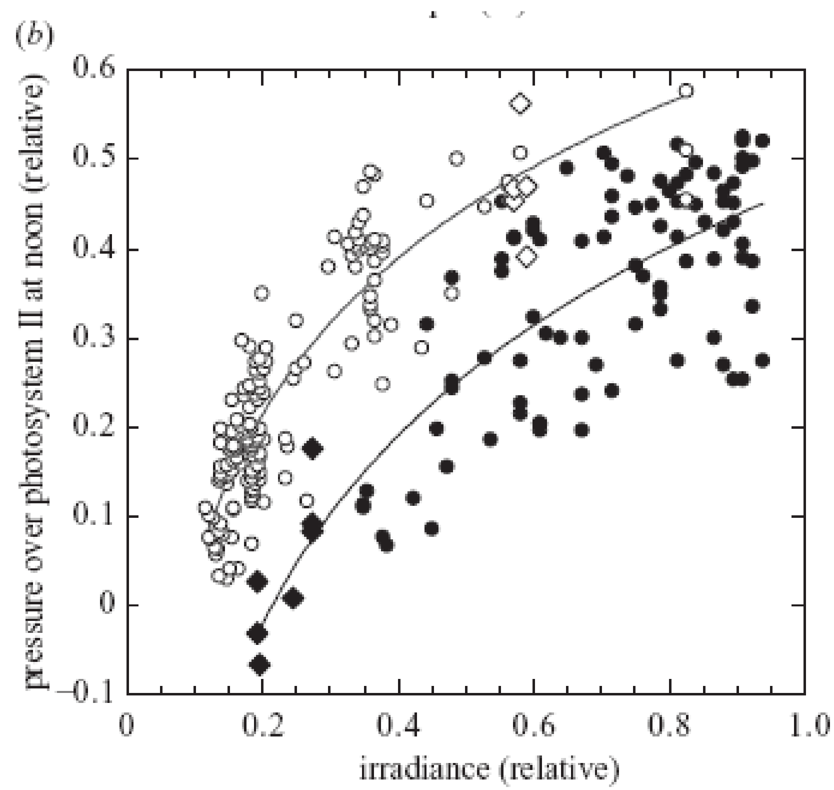


Bongaerts et al. (2010) Plos ONE

High specialization of symbionts

- Narrow ecological niches of algal symbionts





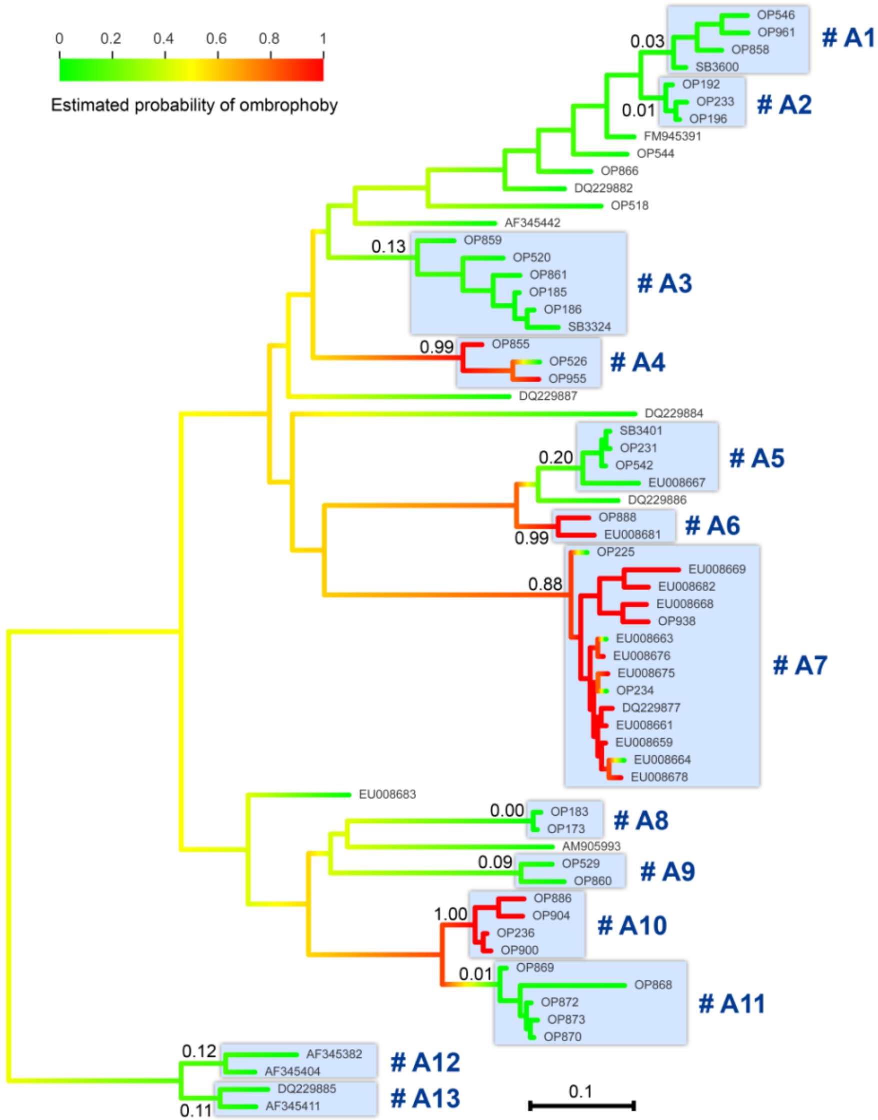
Pocillopora

Pavona

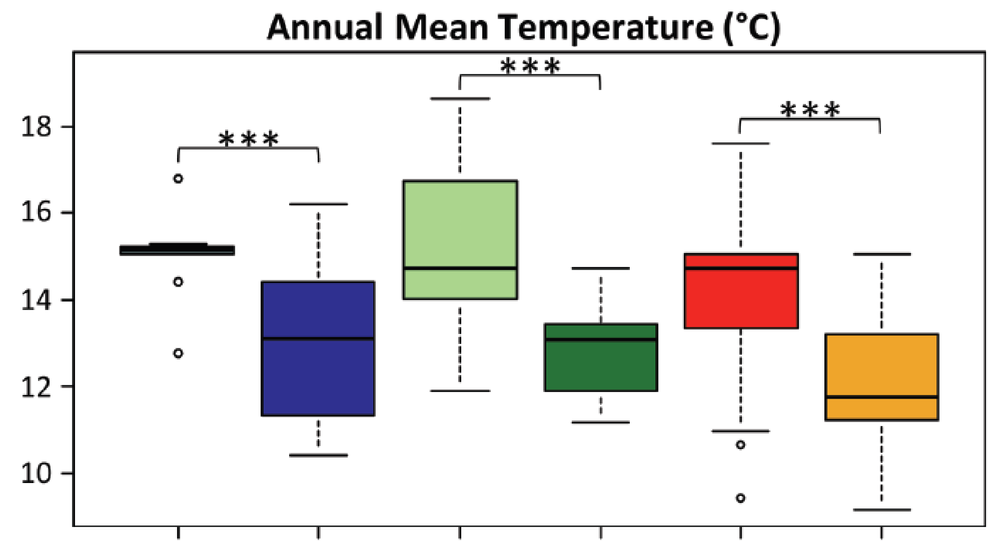
Iglesias-Prieto et al. (2004): Proc. R. Soc. Lond. B

High specialization of symbionts

- Strong algal host specificity

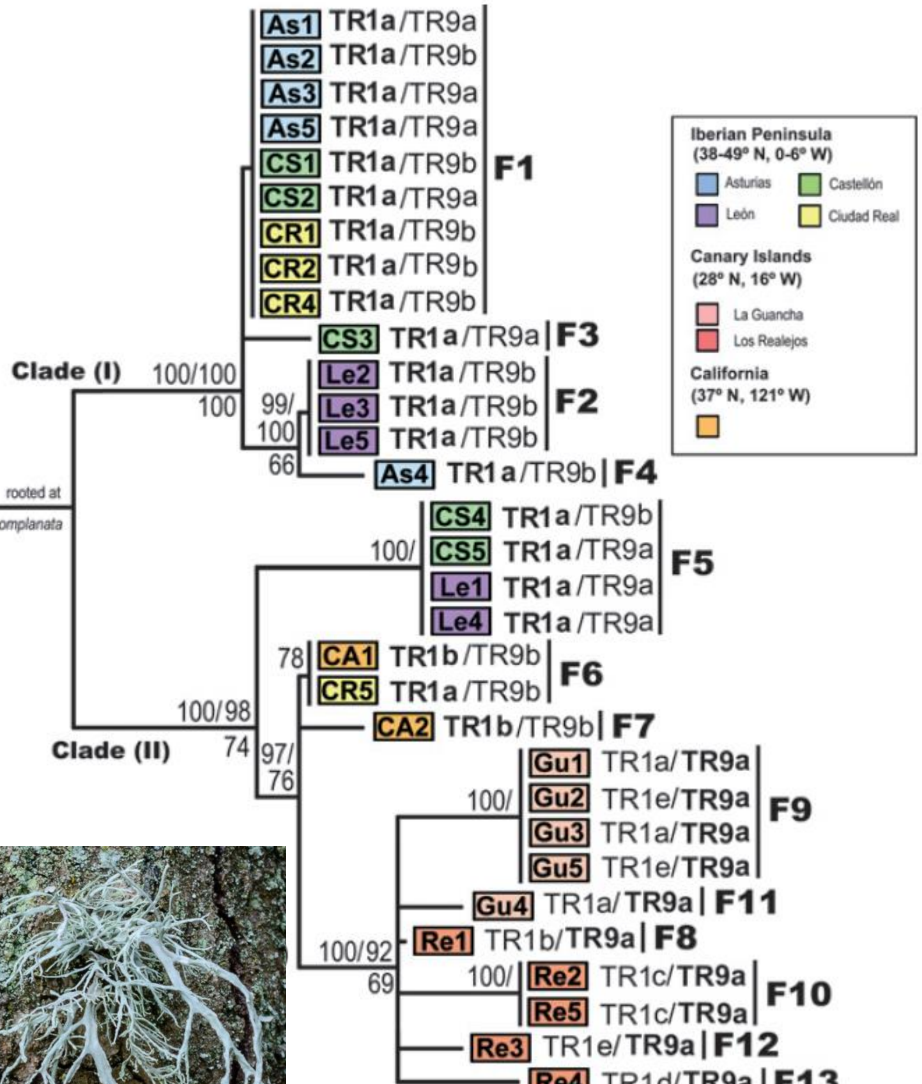


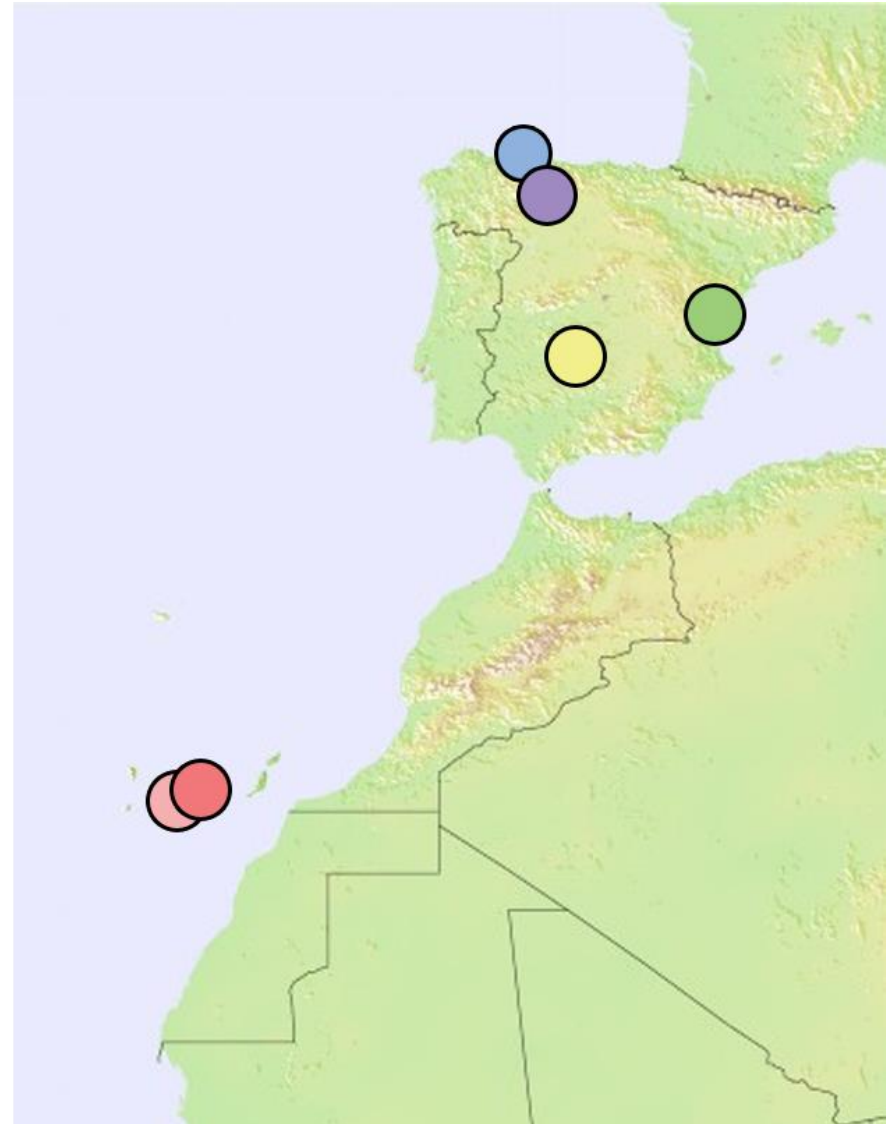
Peksa & Škaloud (2011): Mol Ecol 20: 3936-3948.



Vančurová et al. (2021): Frontiers Microb 12: 769304.

Multiple symbionts

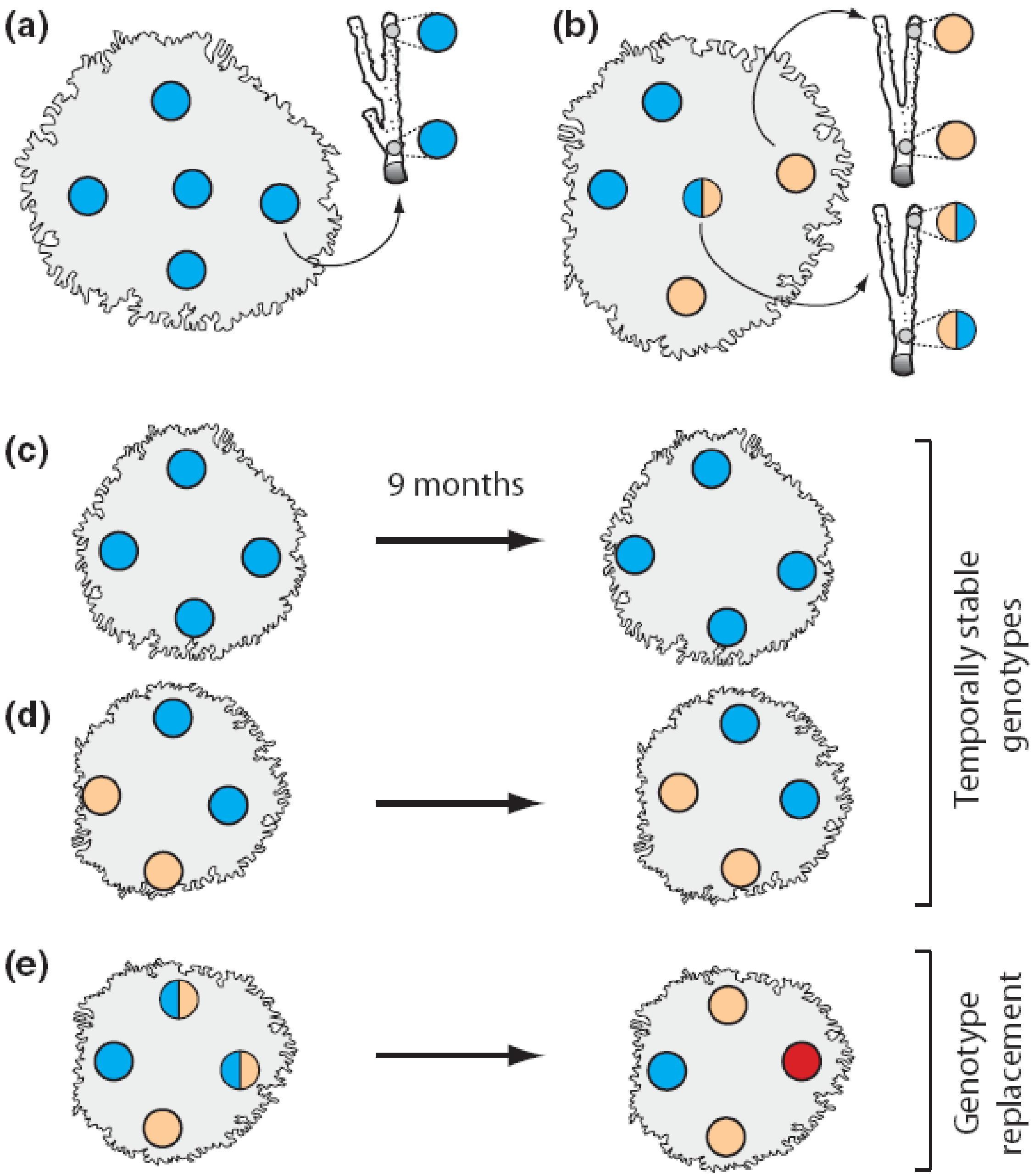




Ramalina farinacea

del Campo et al. (2012): FEMS Microbiol. Ecol.

Multiple symbionts

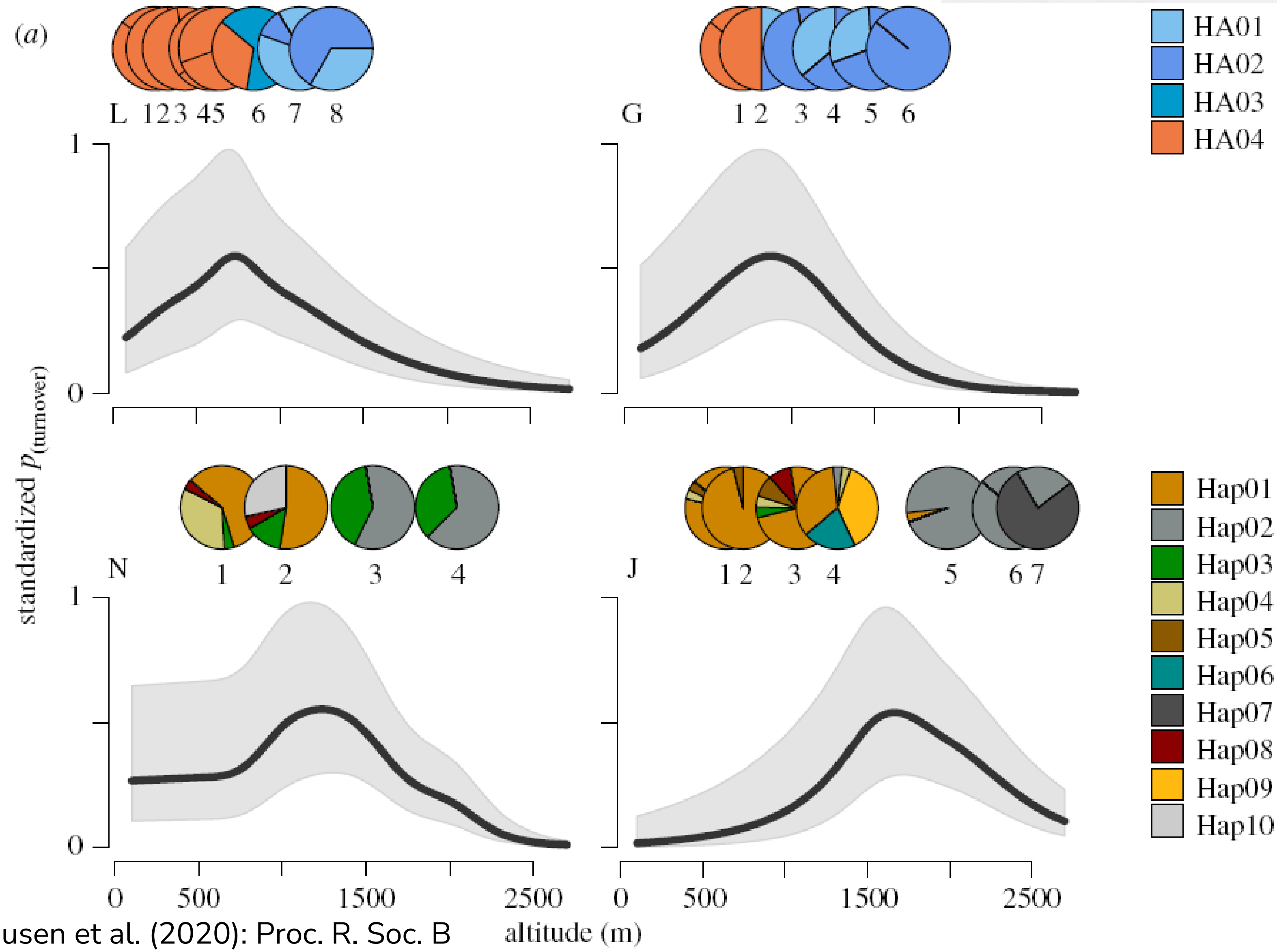


Pocillophora

Pettay et al. (2011): Mol. Ecol.

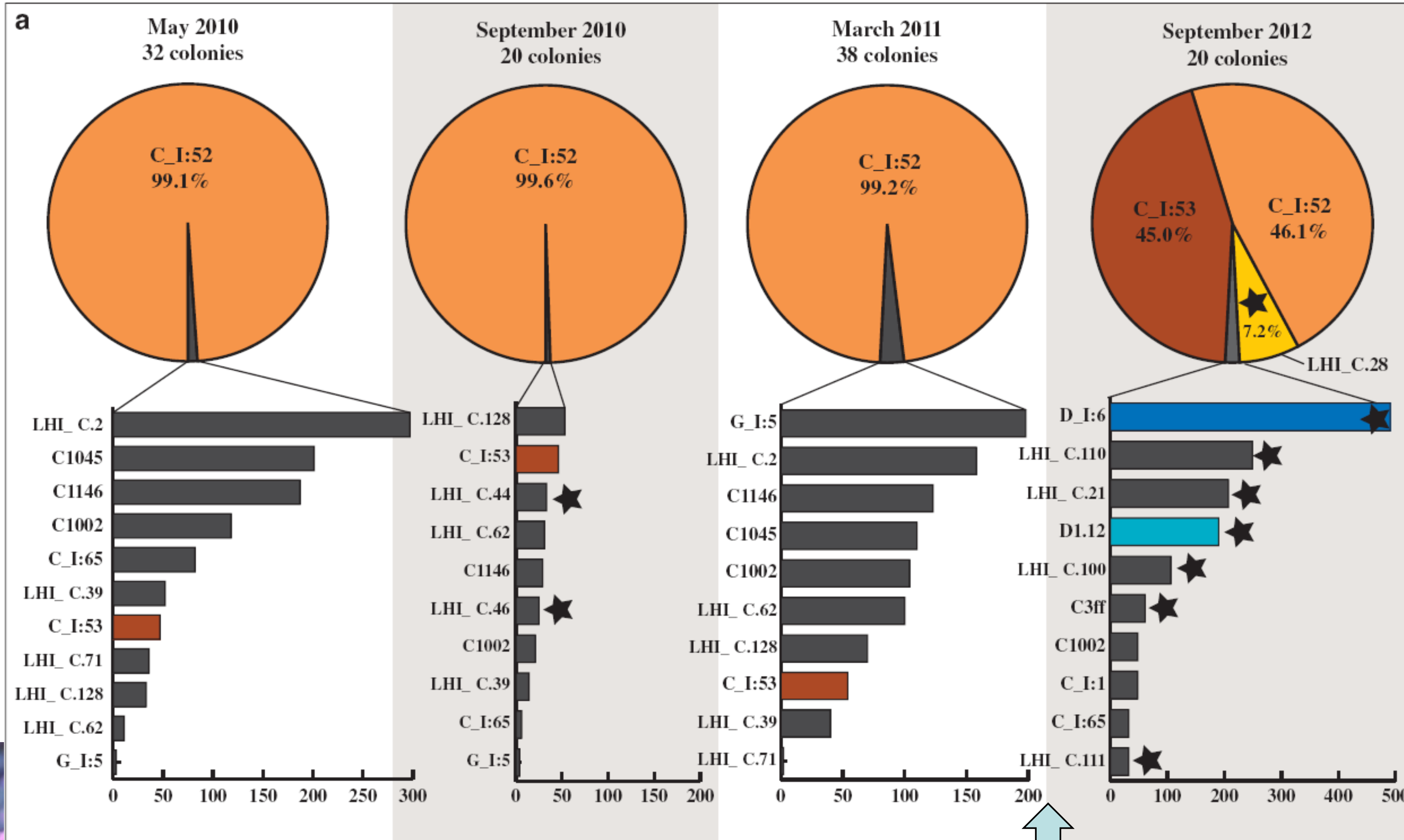
Symbiont switching

Lasallia

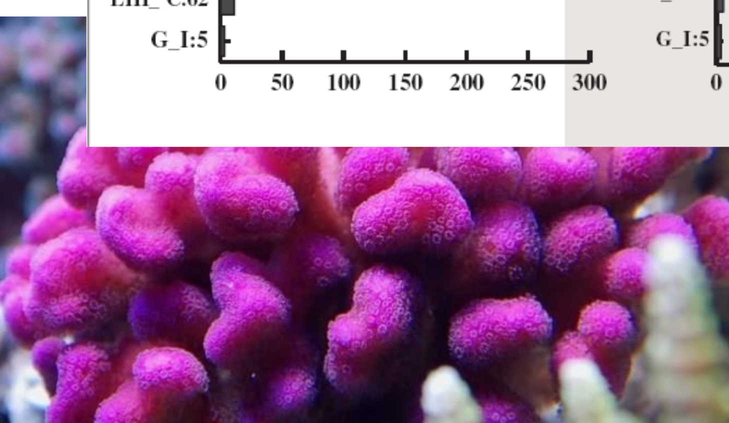


Rolshausen et al. (2020): Proc. R. Soc. B

Symbiont switching



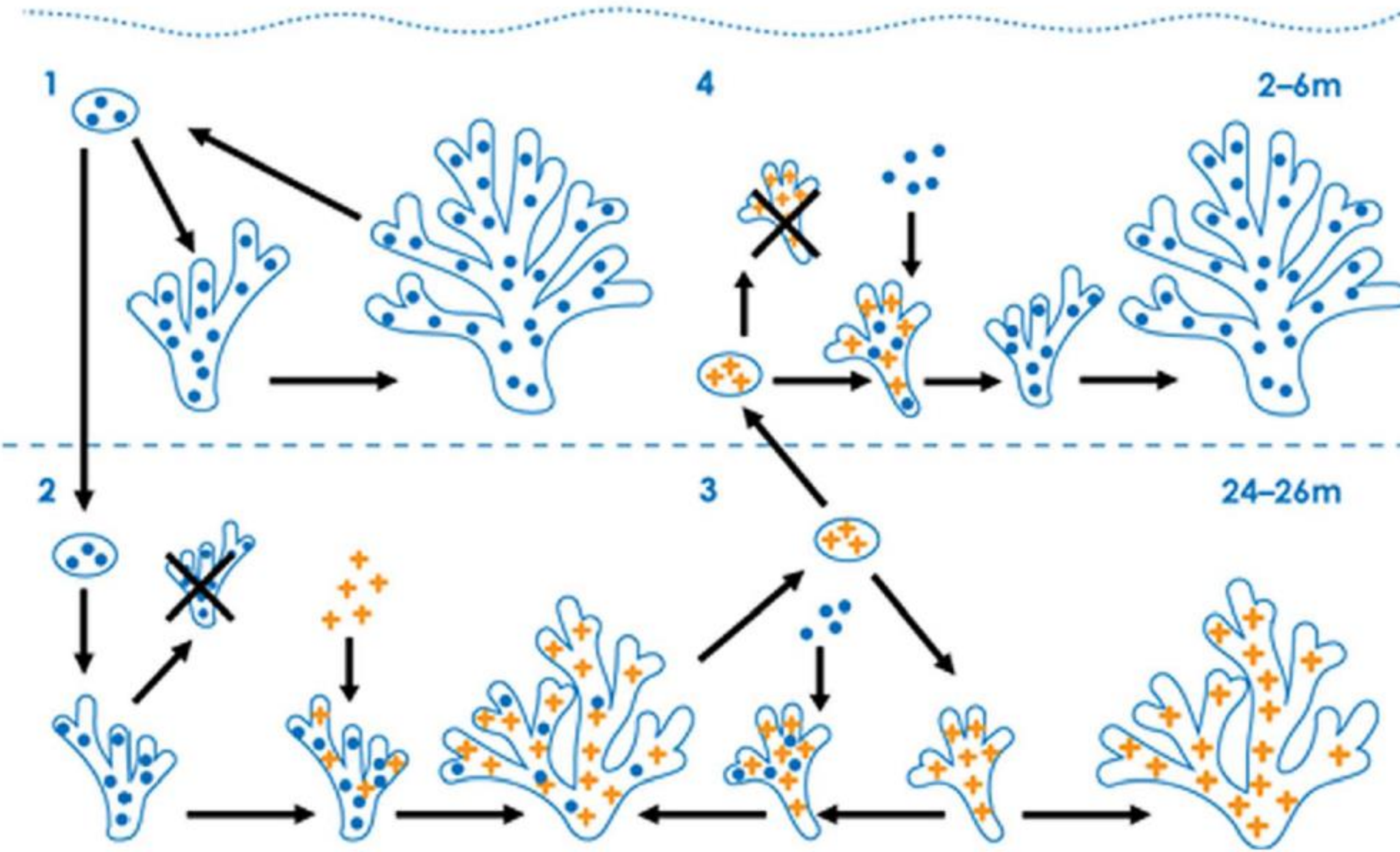
bleaching event



Stylophora pistillata

Boulotte et al. (2016): ISME J

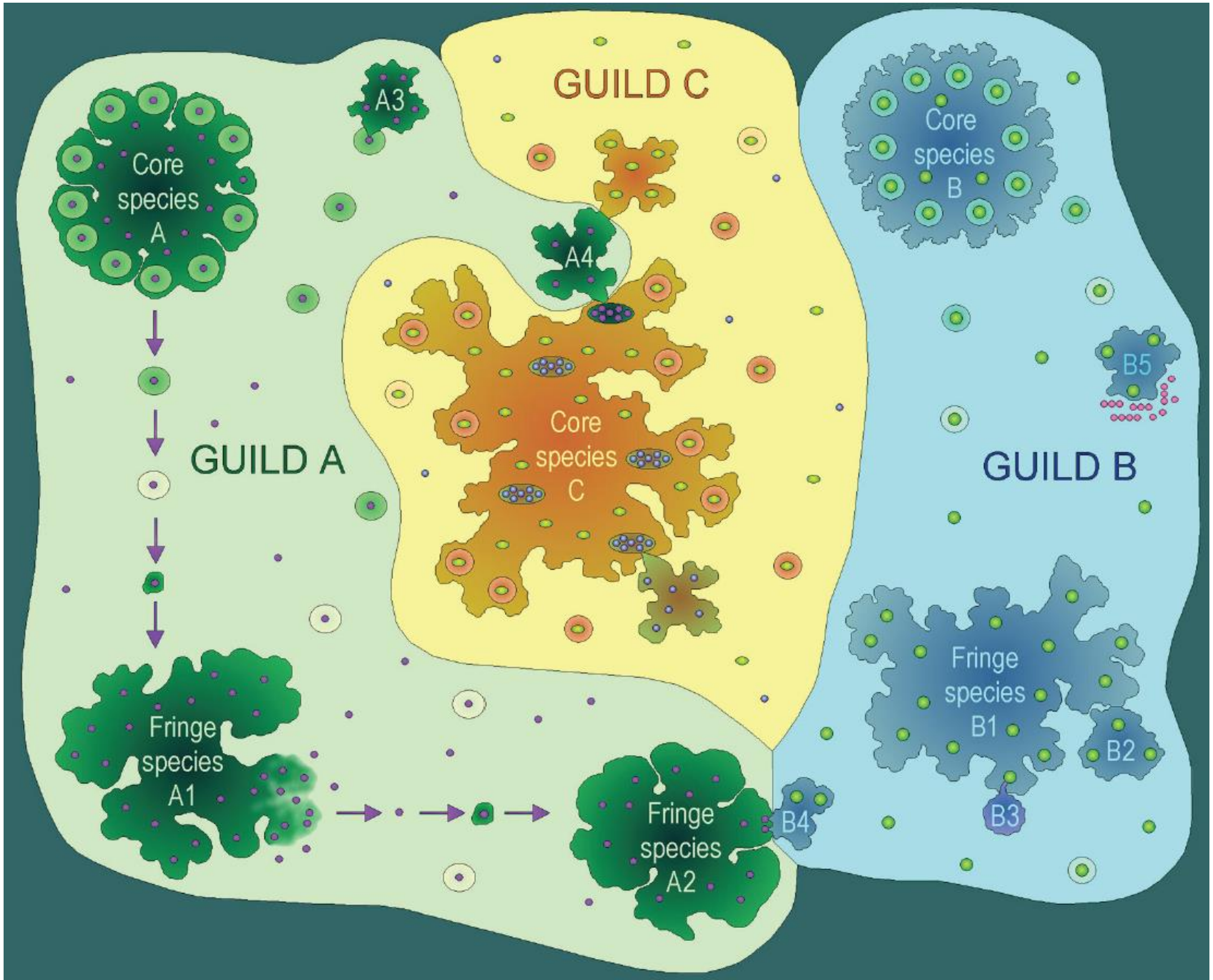
Habitat adapted symbiosis



Byler et al. (2013): Plos ONE

Habitat adapted symbiosis

- Core species (vertical transmission) act as symbiont distributors for fringe species (horizontal transmission)
- A widely adopted concept in cyanolichens. What about green algae?

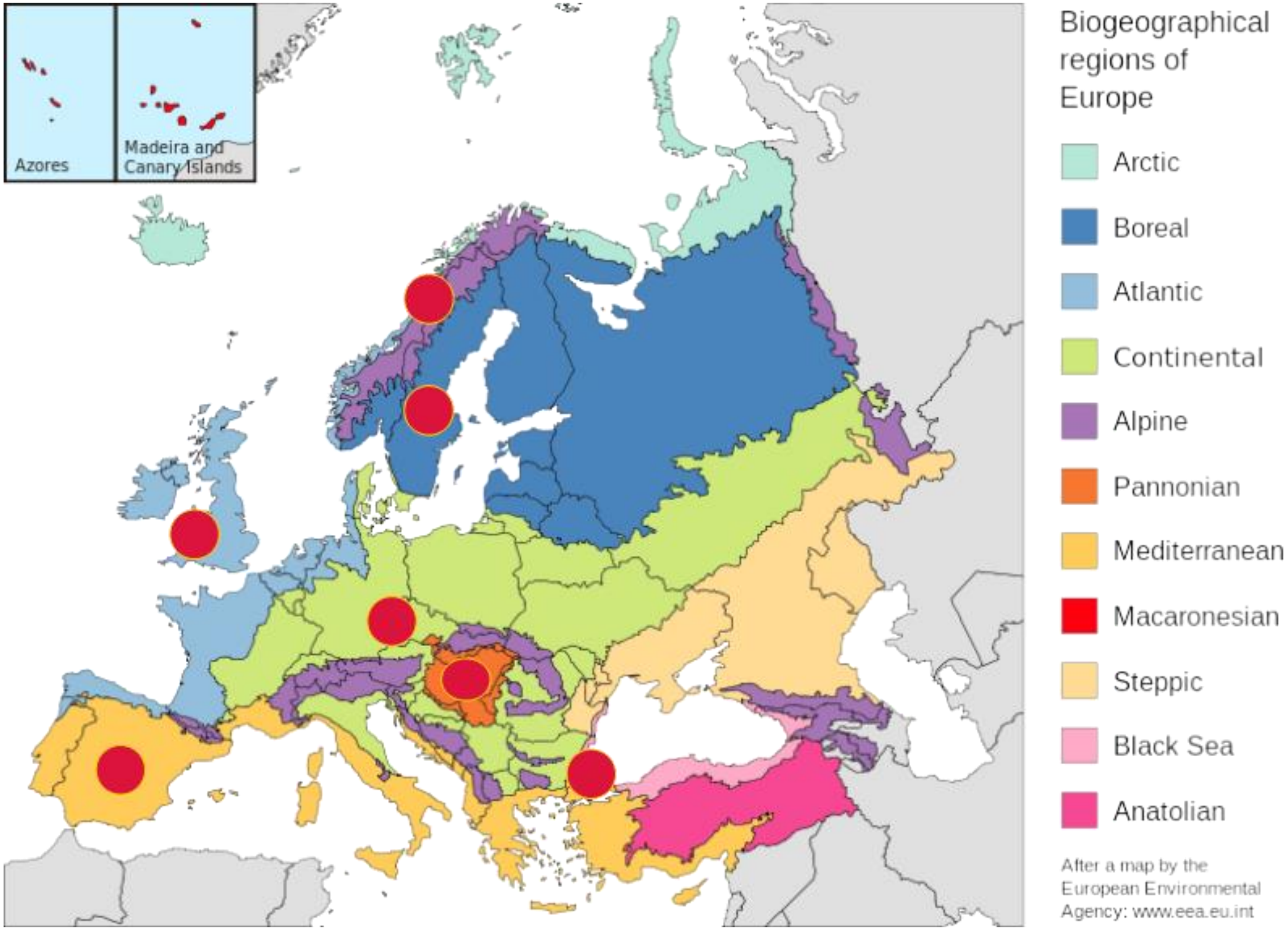


Rikkinen (2013): MycoKeys

Lichen guilds

- Which factors shape the associations between the lichen symbiotic partners?

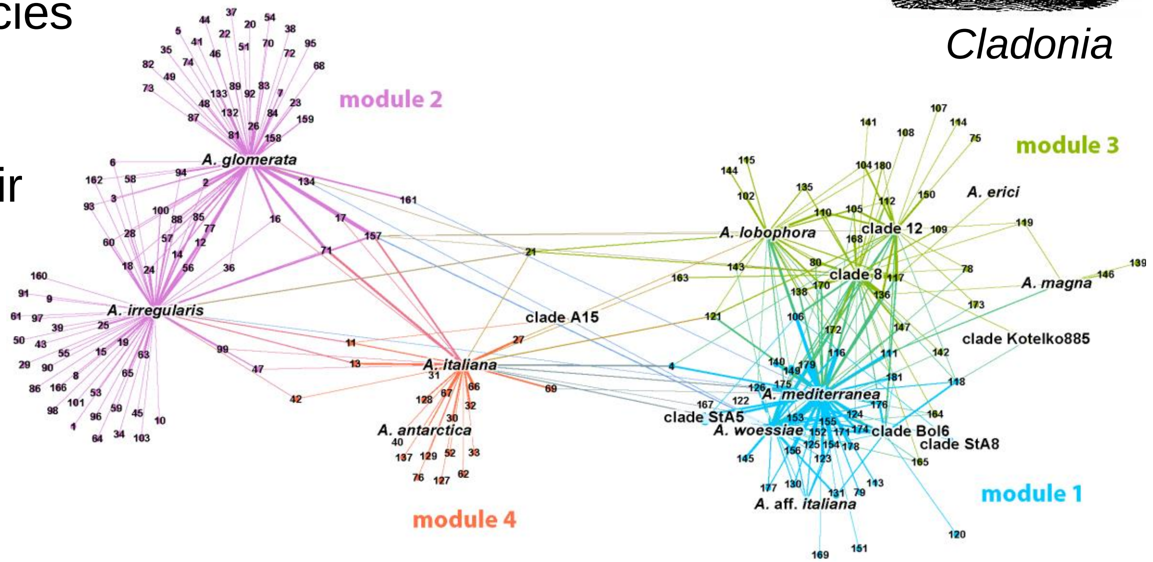
Cladonia

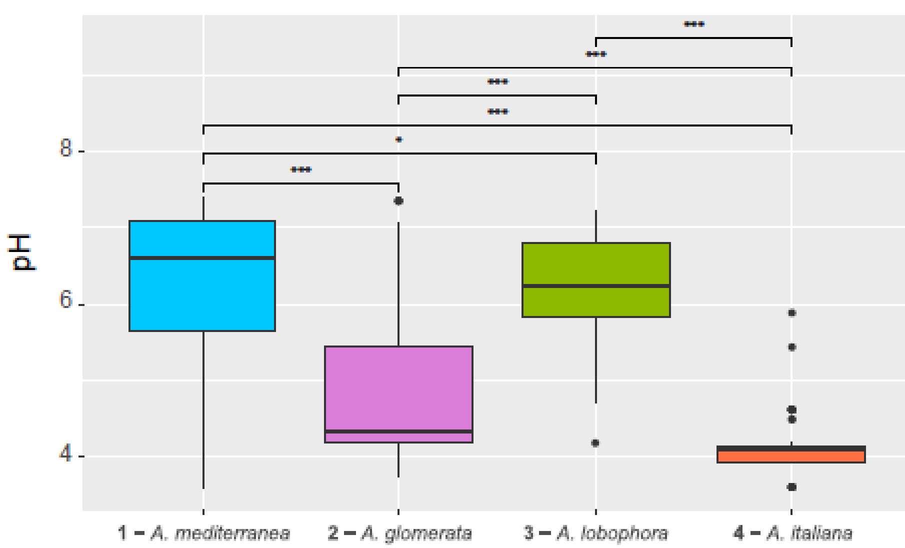


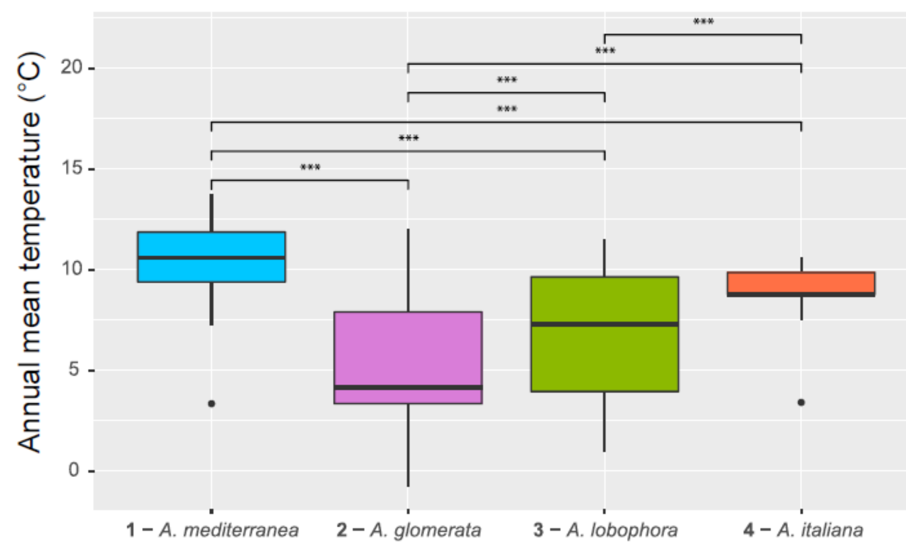
Lichen guilds

Cladonia

- The host choice of the symbiotic partner is limited to those species belonging to the same guild
- The guilds can be clearly distinguished according to their preferences for soil chemistry and climatic conditions
- Fungi therefore have only a limited ability to increase their ecological niche through algal switching





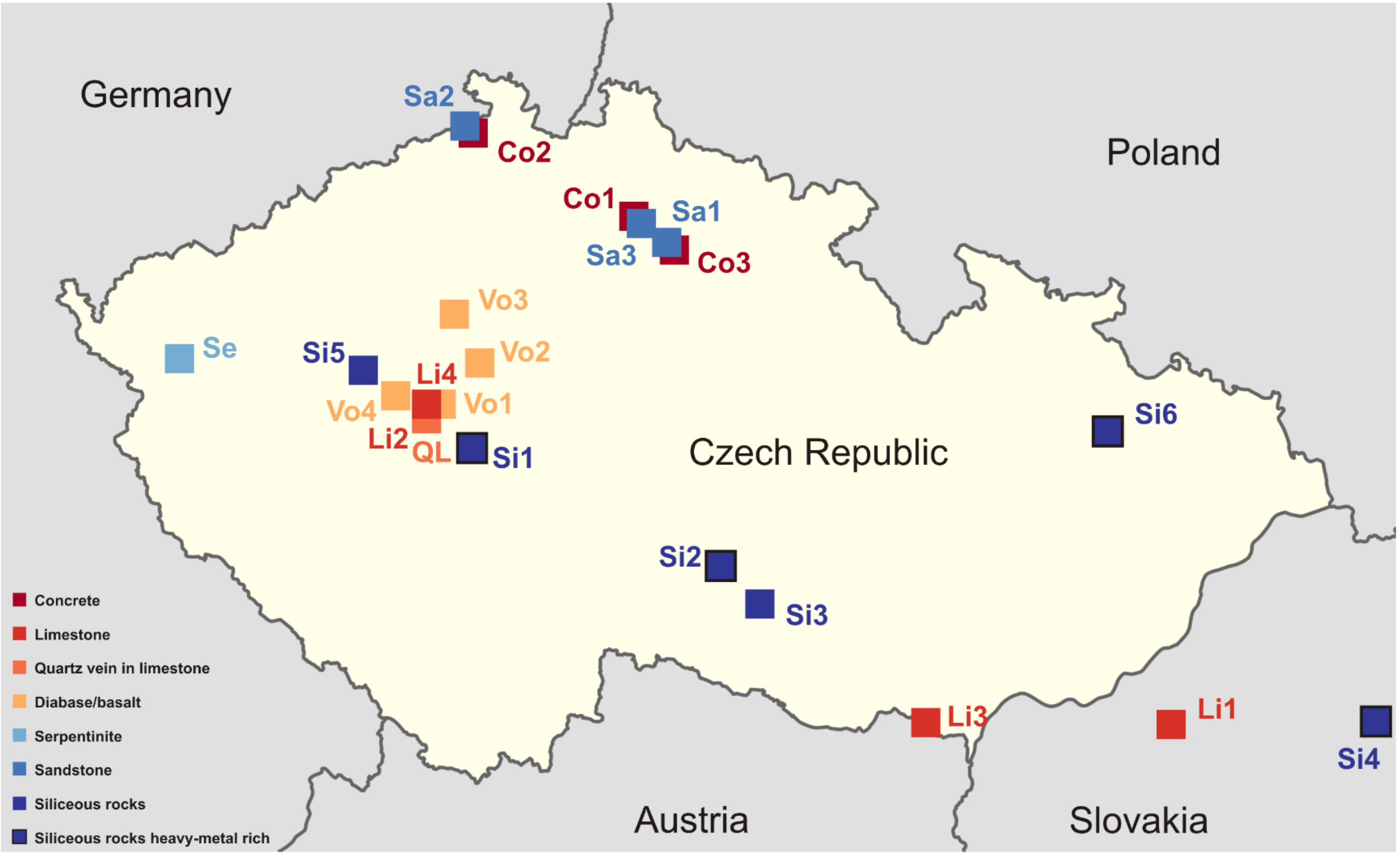


Skvorová et al. (2022): Frontiers Microb 12: 781585.

Lichen guilds

- Do green algal lichens form the guilds mediated by photobionts?
- Do lichens reproducing by symbiotic propagules (core species) fulfil the role of photobiont distributors in mycobiont assemblages?

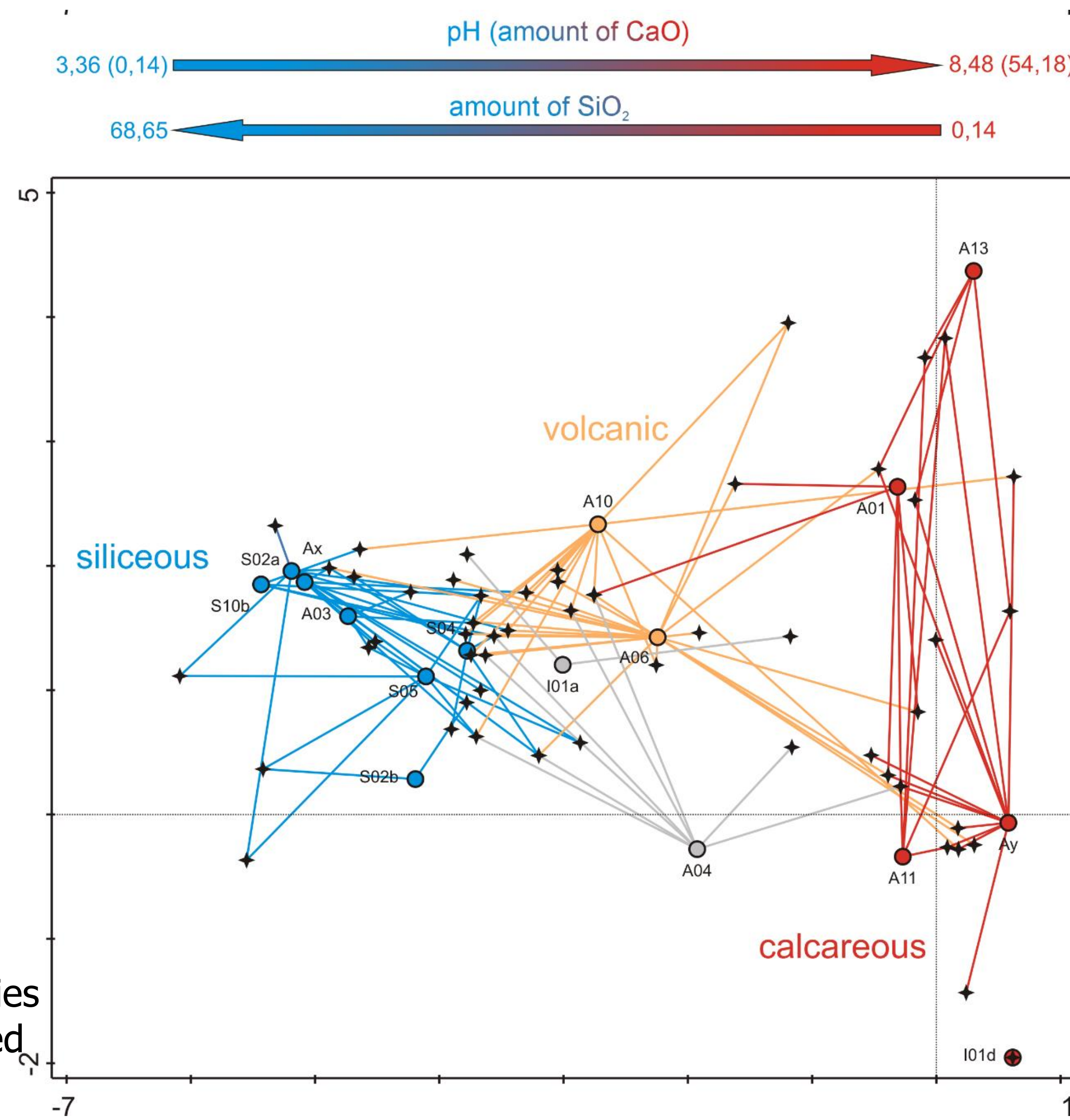
- *22 saxicolous lichen communities, 250 sequenced lichen photobionts*



Lichen guilds

- The fungal assemblages exhibited distribution influenced by photobionts which formed three clearly separated groups

- Three photobiont-mediated guilds were detected, conditioned by substrate chemistry (pH).

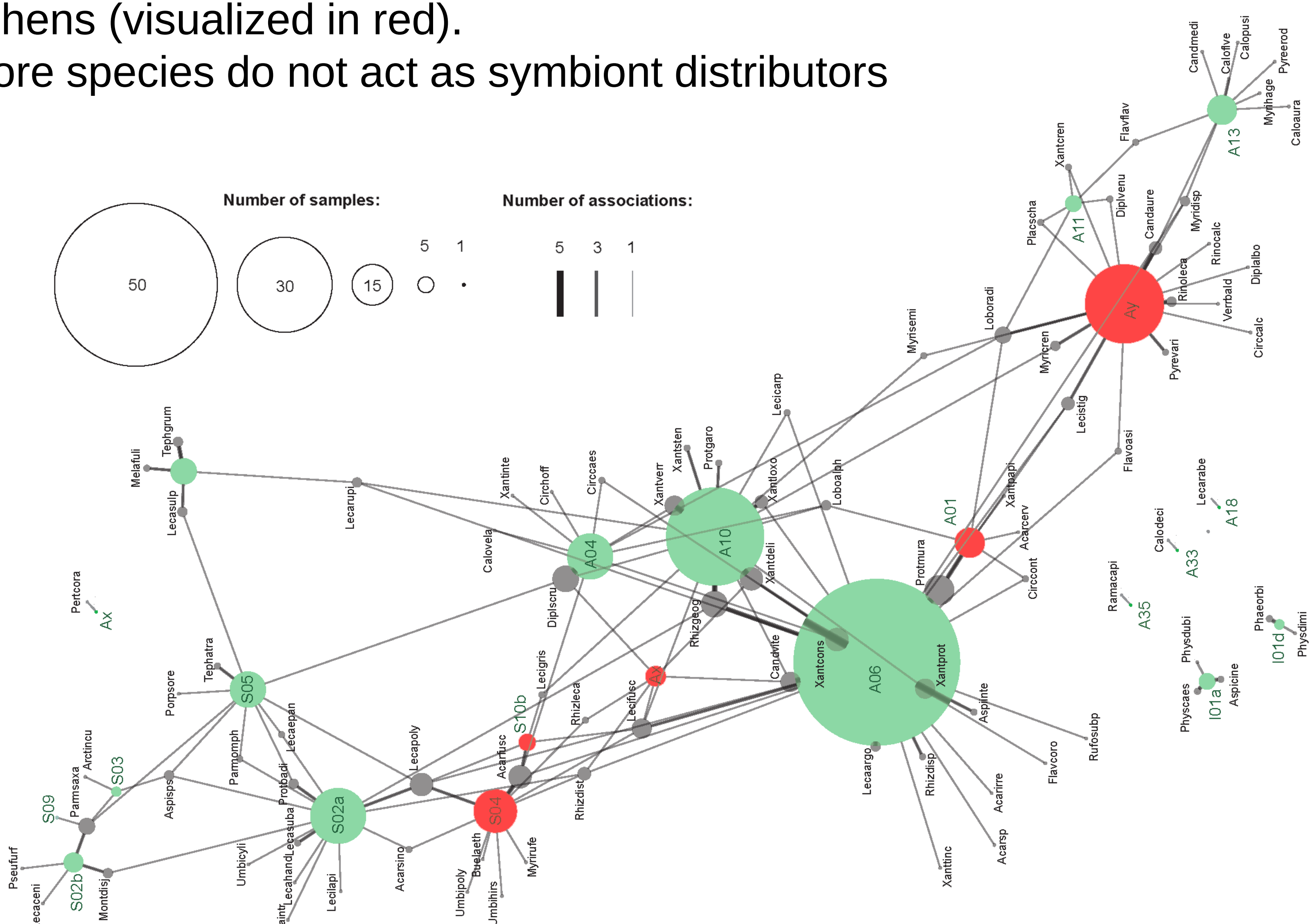


Detrended correspondence analysis (DCA) of saxicolous lichen communities with three main rock types highlighted in color. A network of photobiont-mycobion associations is visualized.

Peksa et al. (2022): FEMS Microbiol Ecol 98: 1-17.

Lichen guilds

- A number symbionts were found exclusively in horizontally-dispersed (fringe) lichens (visualized in red).
- Core species do not act as symbiont distributors



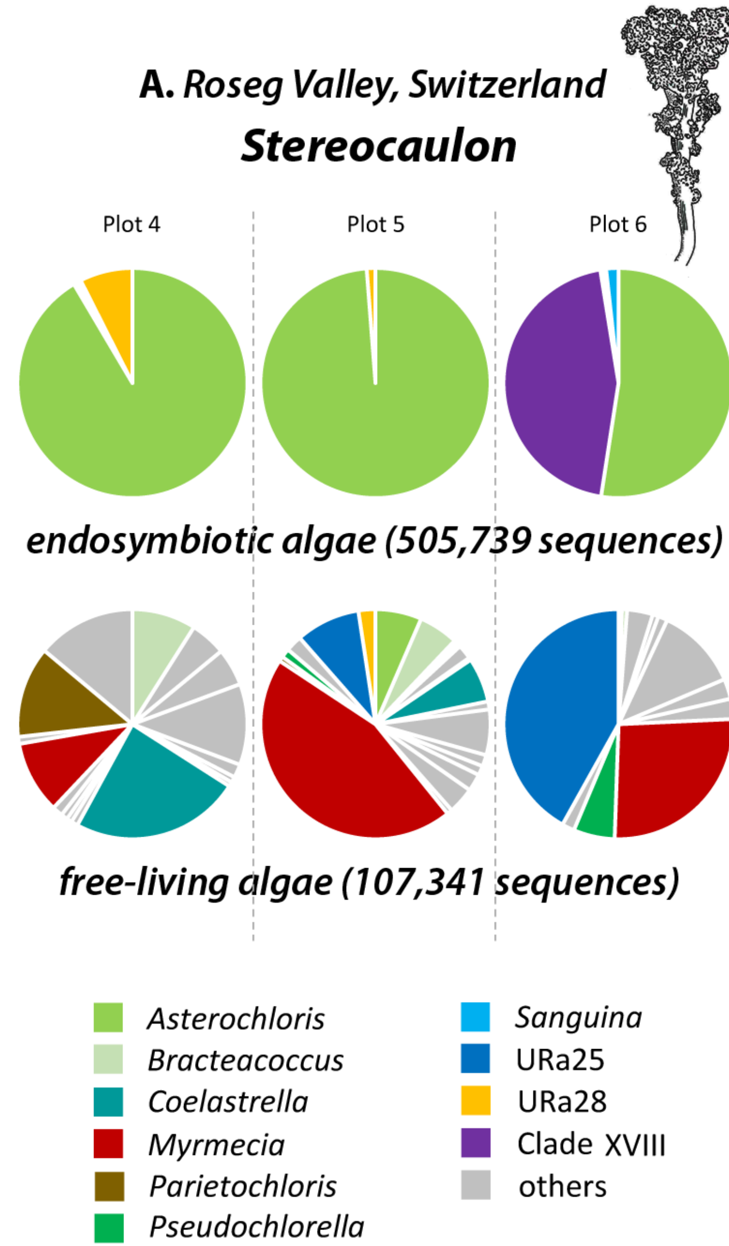
Species network uncovering relationships between lichen-forming fungi (grey circles) and their photobionts (green/red circles)

Peksa et al. (2022): FEMS Microbiol Ecol 98: 1-17.

Symbiont acquisition

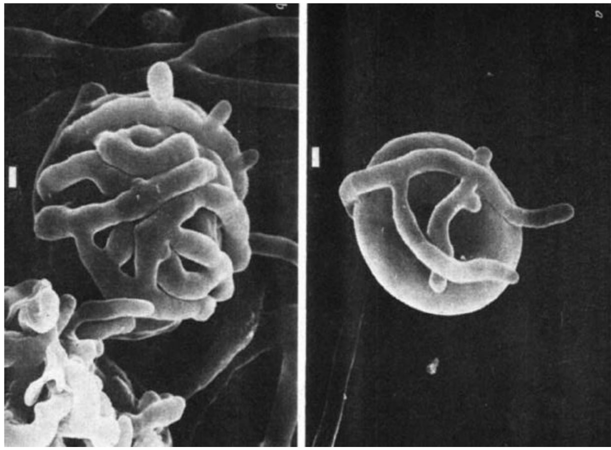
- Symbiosis dynamics on river gravel bars
- Selected plots - sequencing all endosymbiotic and free-living algae
- **Host symbionts are physically absent in the environment**

Vančurová et al. (2020): Algal Res. 51: 102062

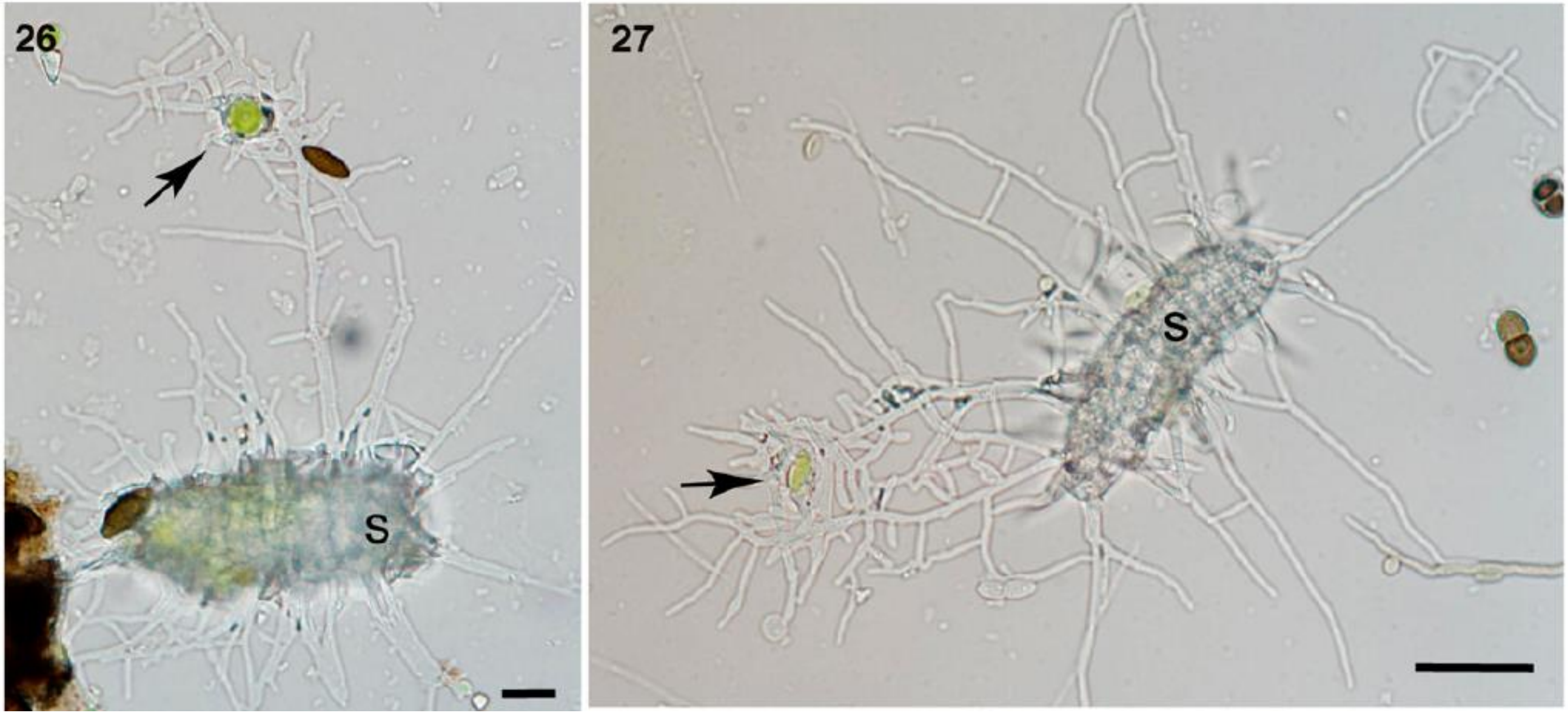


Symbiont acquisition

- How do hosts acquire their symbionts from environment?
  – Young lichen hosts are extremely unspecific towards their symbionts, their hyphae even encircle glass beads in the same manner as algal cells



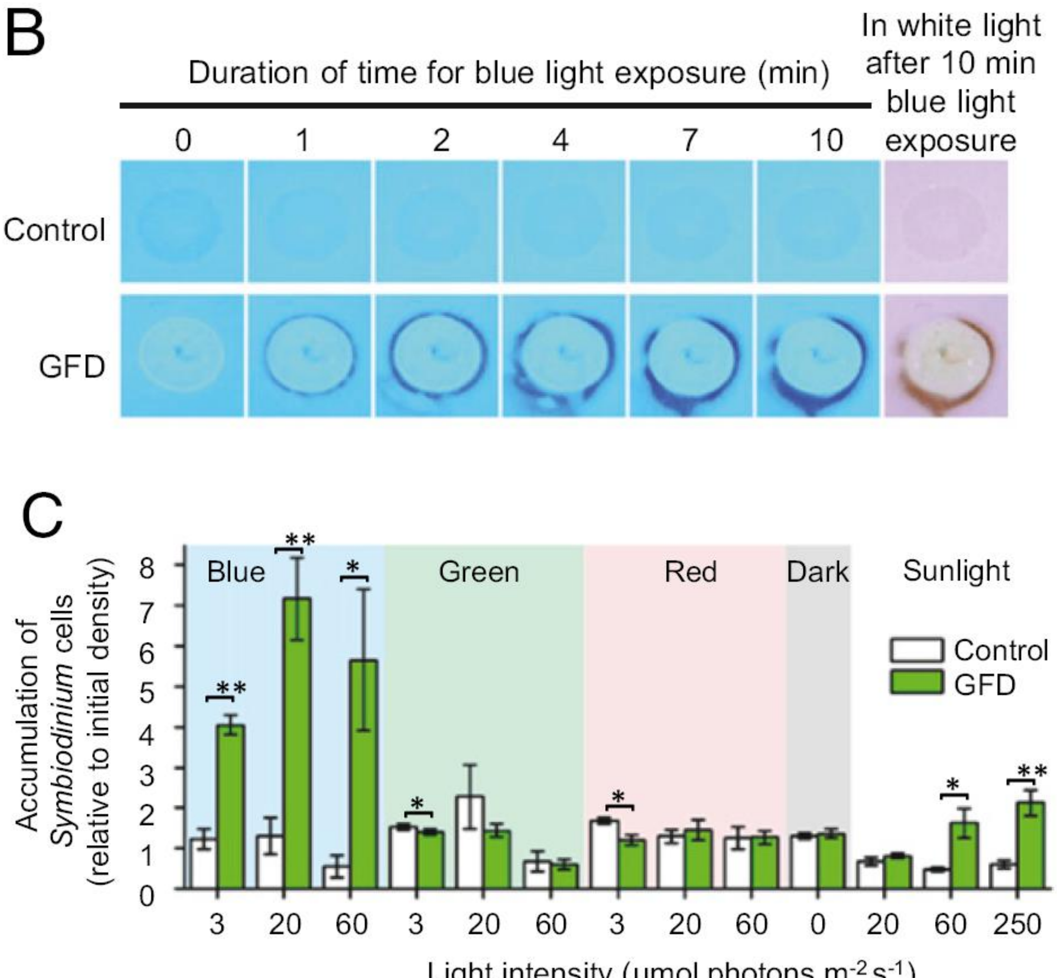
Ahmadjian & Jacobs (1981): Nature

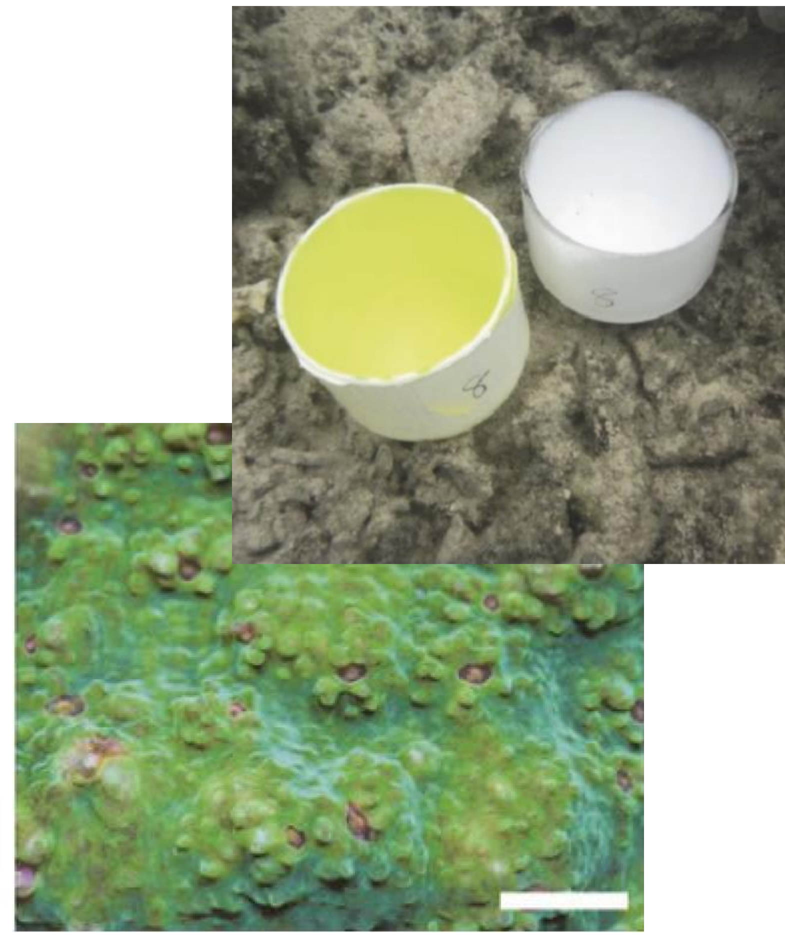


Sanders et al. (2014): Am. J. Bot.

Symbiont acquisition

- How do hosts acquire their symbionts from environment?
  - Young corals may attract algal symbionts by emitting green fluorescence under daylight conditions (strong blue light), using GFP





Aihara et al. (2019): PNAS

Conclusions

- Lichens and corals are unexpectedly similar in their nature of symbiotic interactions

- The guilds of lichens are shaped by substrate chemistry (pH)

- The fungal hosts are frequently forming symbiotic associations with algal partners, which are
    - physically absent in the environment
    - not co-dispersed with their host
    - absent in co-occurring vertically-dispersed lichens (so called core species)

Ondřej Peksa

Jana Steinová

Lucie Vančurová

Ivana Černajová

Zuzana Škvorová

Tereza Gebouská

Helena Bestová

Patricia Moya

Thank you for your attention

https://botany.natur.cuni.cz/skaloud

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