Partnerský život symbiontů: výprava do světa lišejníků a korálů

Pavel Škaloud

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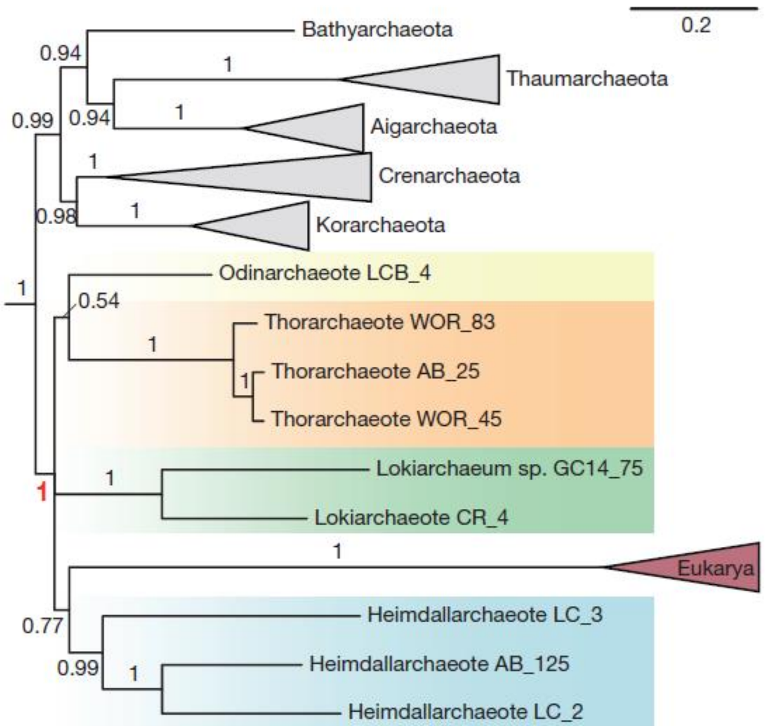
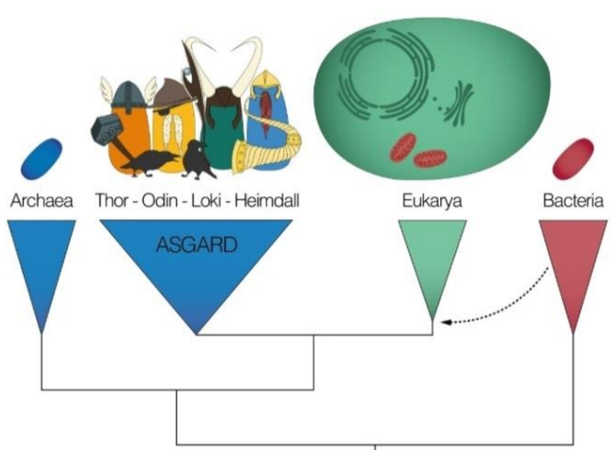
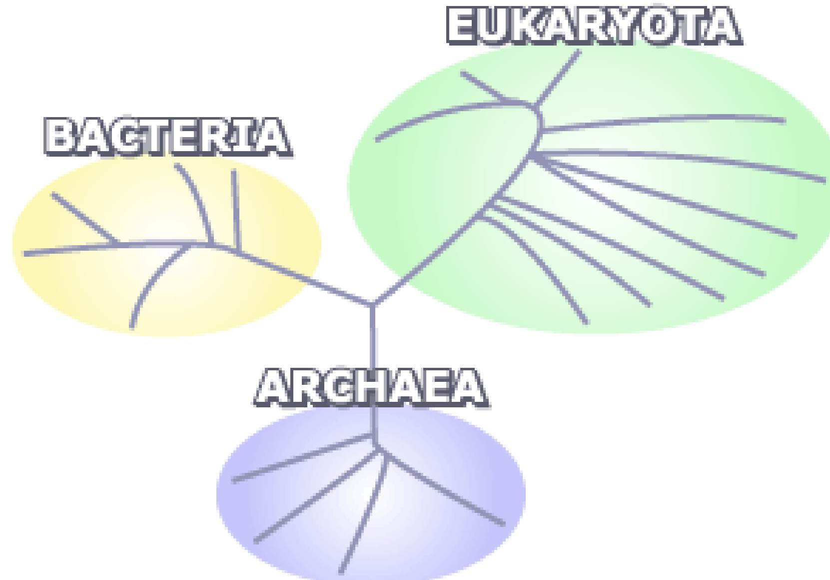
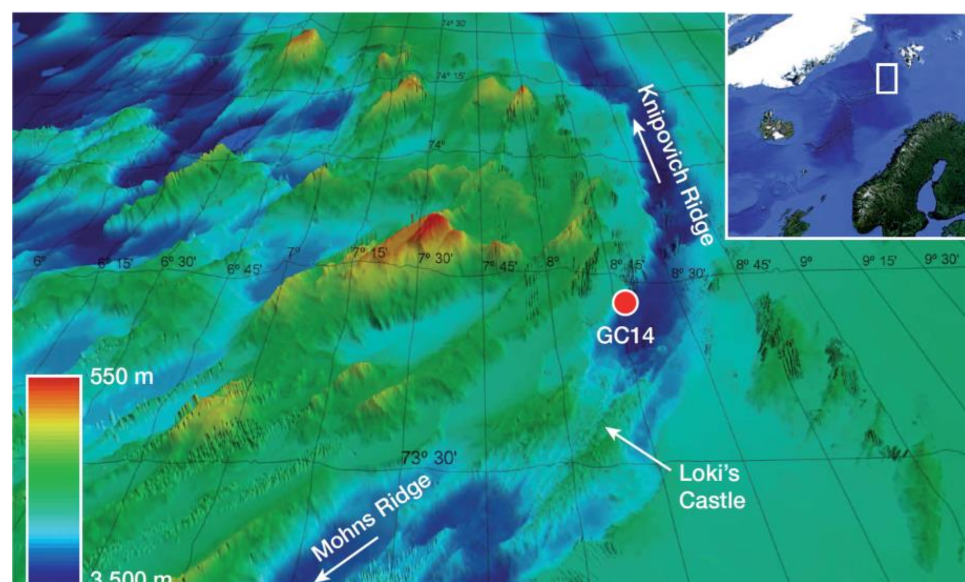
Symbiosis - Eukaryogenesis





Zaremba-Niedzwiedzka et al. (2017): Nature

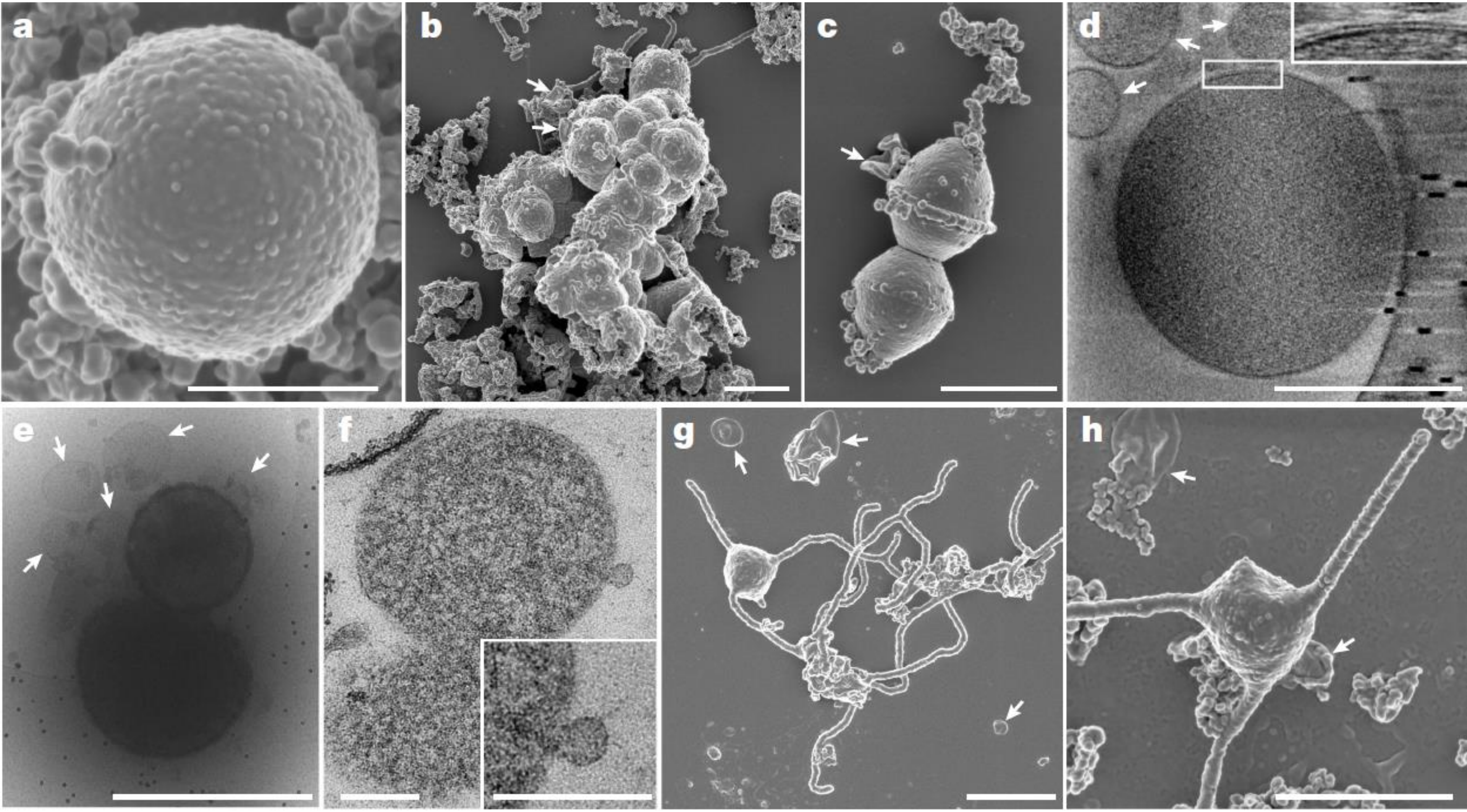




Spang et al. (2015): Nature

Symbiosis - Eukaryogenesis

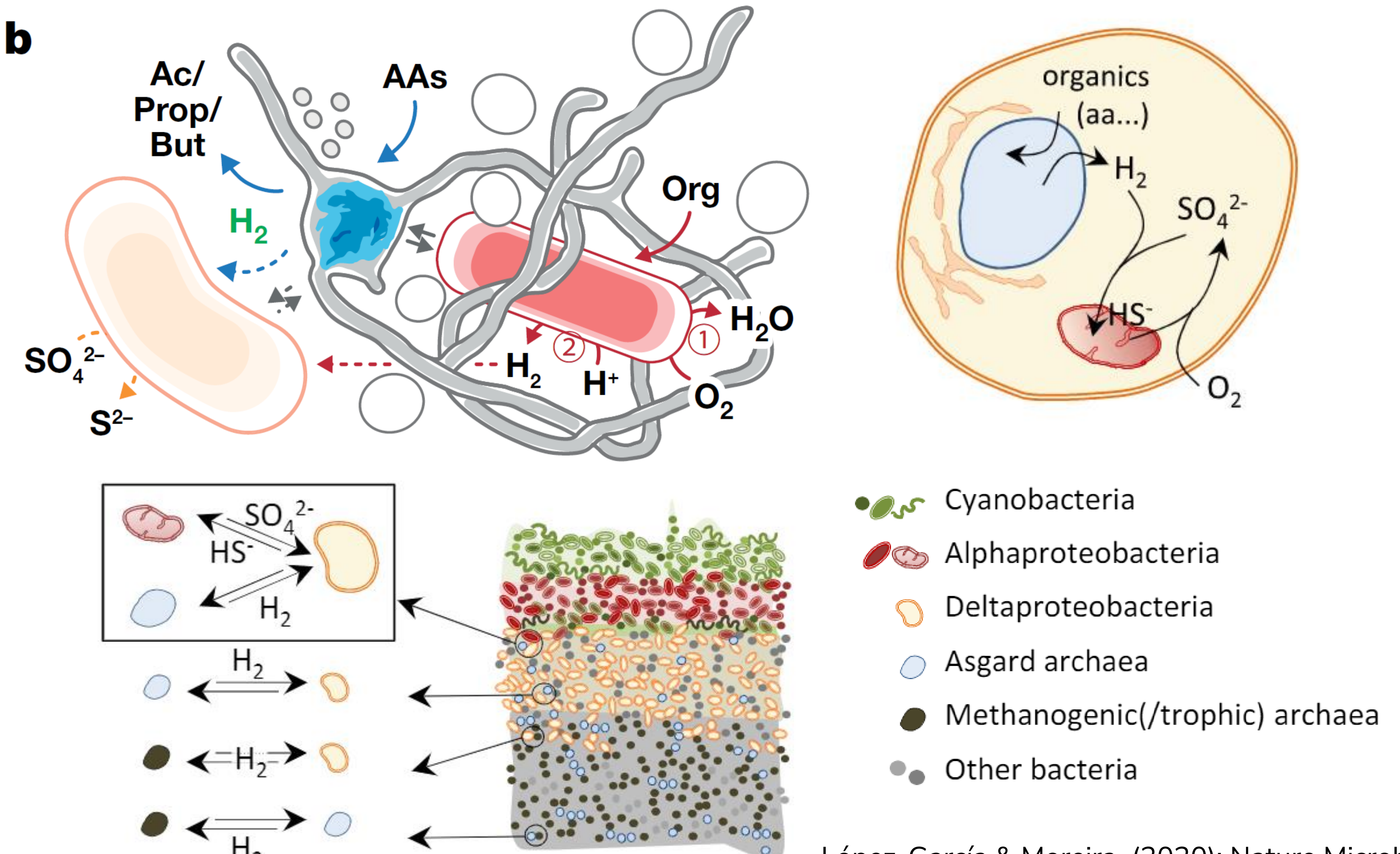
- *Prometheoarchaeum syntropicum*



Imachi et al. (2020): Nature

Symbiosis - Eukaryogenesis

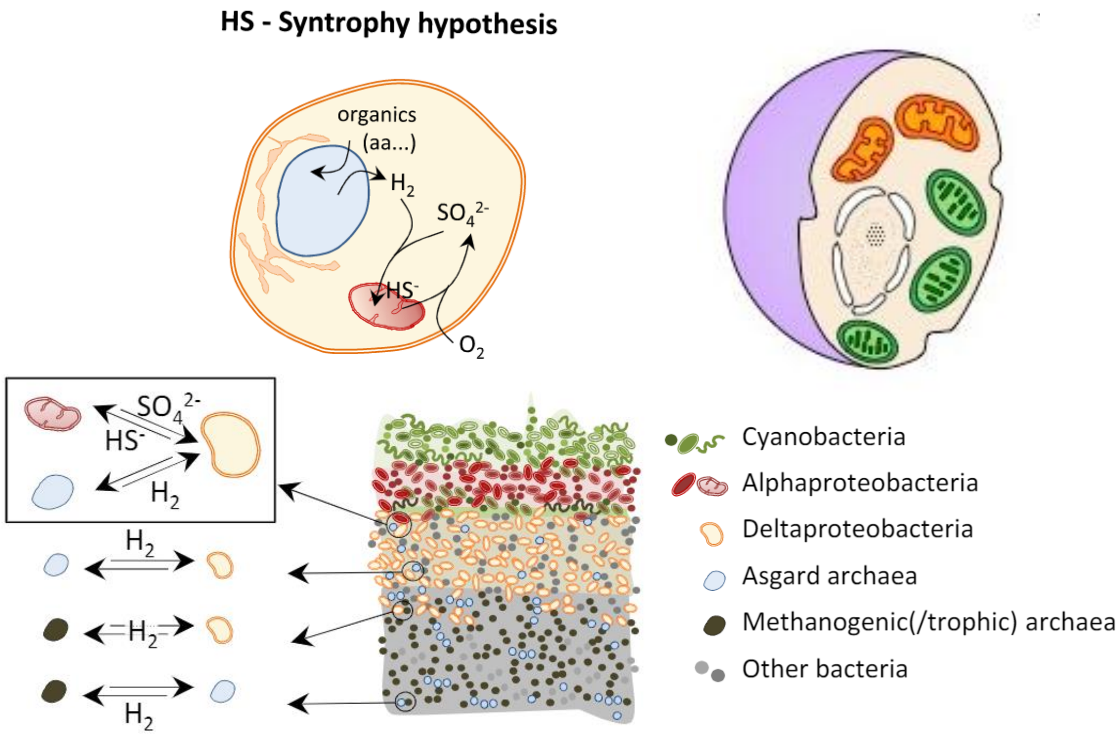
- *Prometheoarchaeum syntropicum*, syntrophy hypothesis

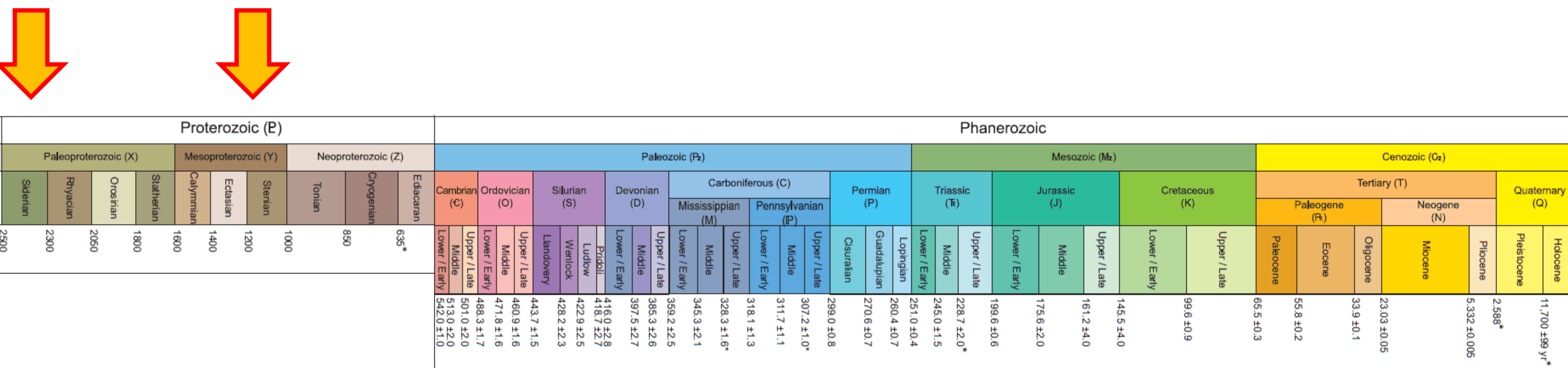


López-García & Moreira (2020): Nature Microb.

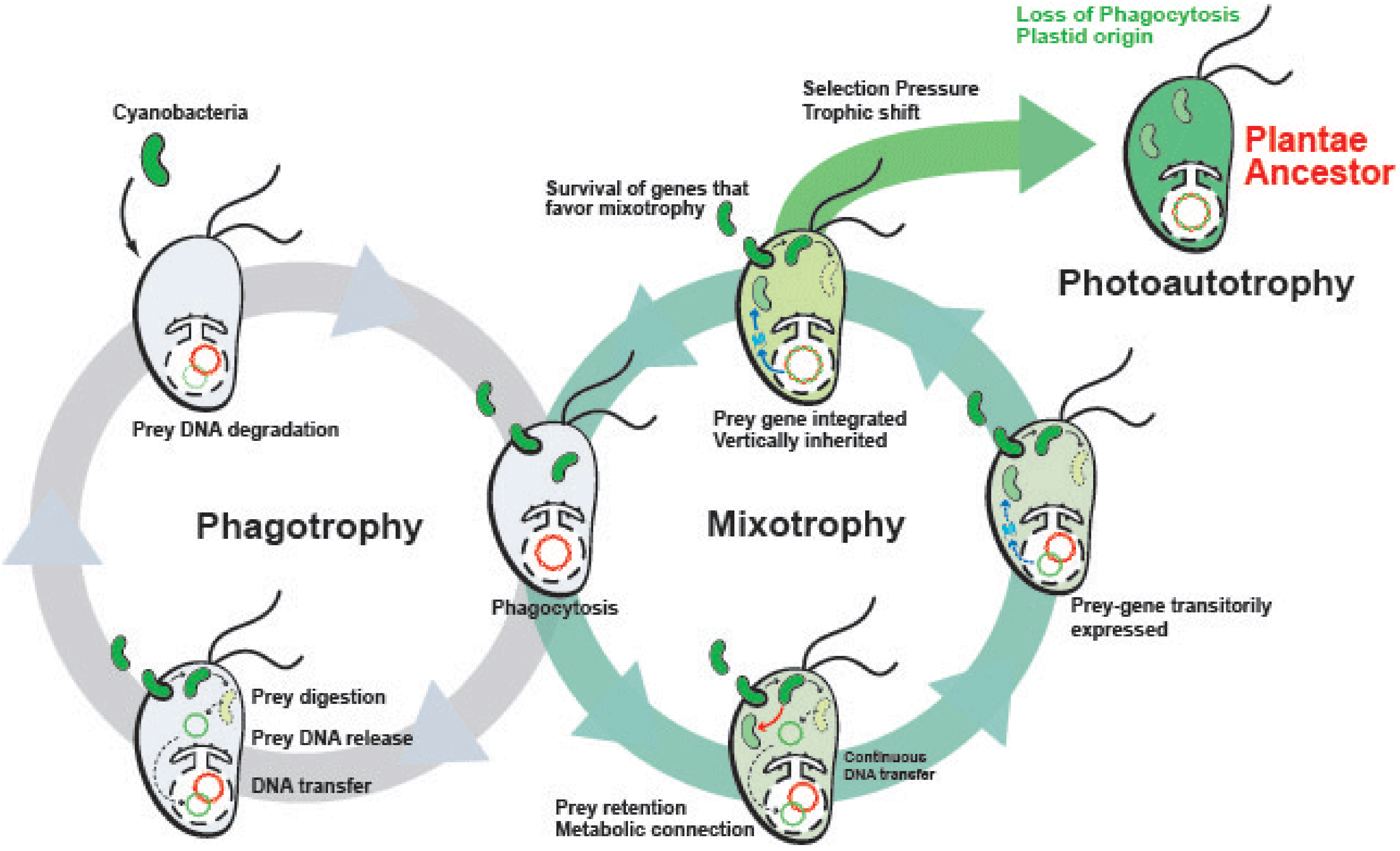
Symbiosis

- Central driver for evolution across the entire tree of life





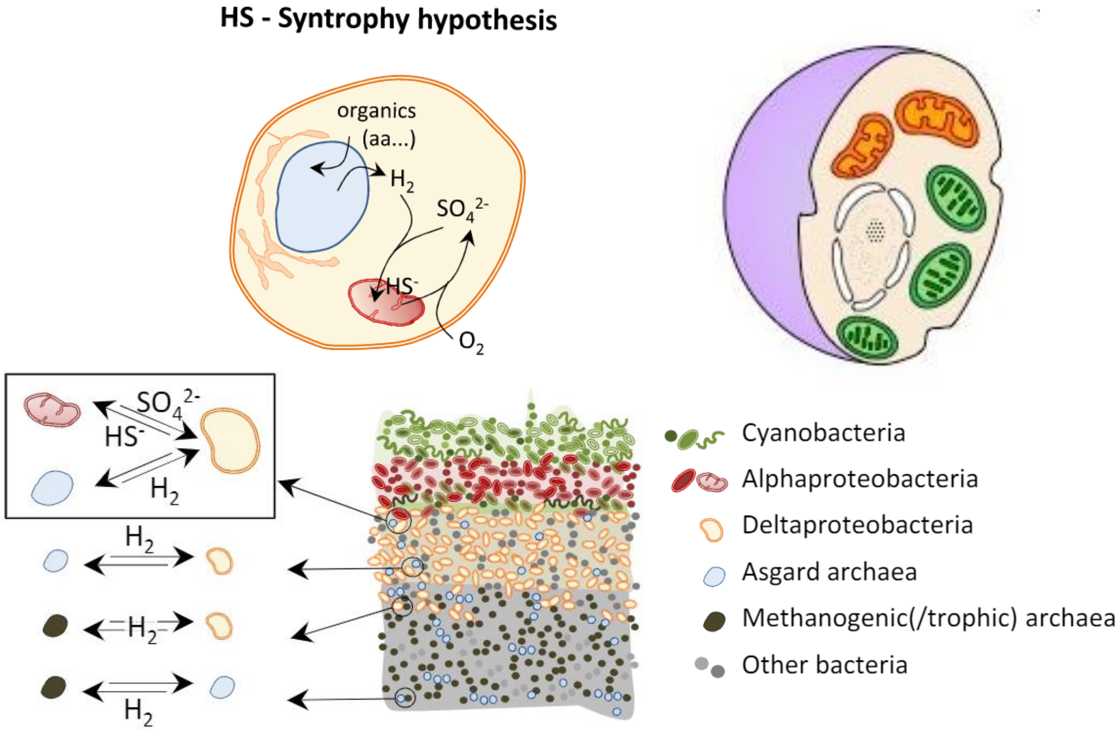
Symbiosis – primary endosymbiosis

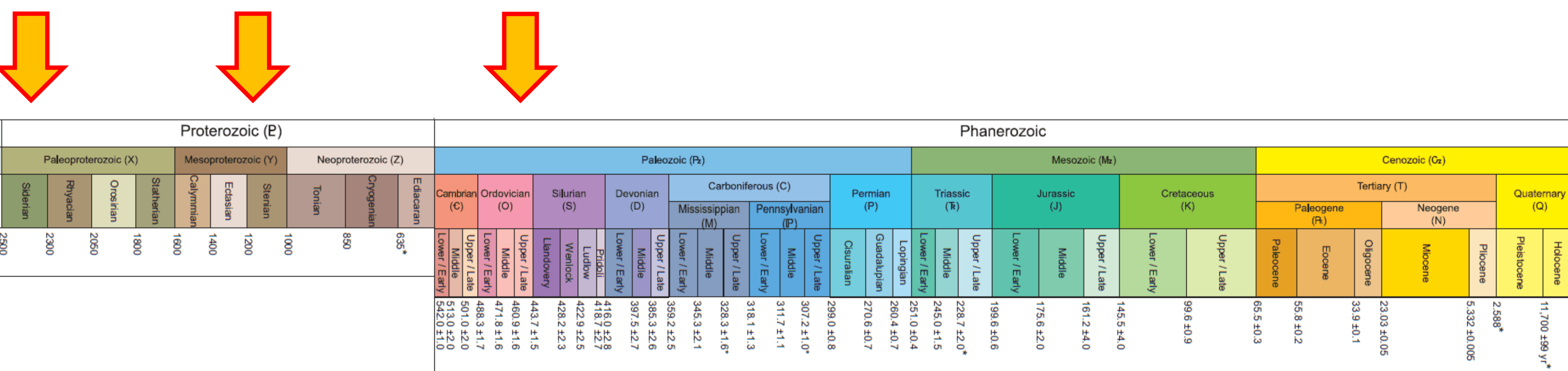


Yoon et al. (2006): Curr. Biol.

Symbiosis

- Central driver for evolution across the entire tree of life





Symbiosis – first land plants

- *Cooksonia barrandei*

ibertín et al. (2018): Nature Plants

Symbiosis – first land plants

- *Cooksonia barrandei*

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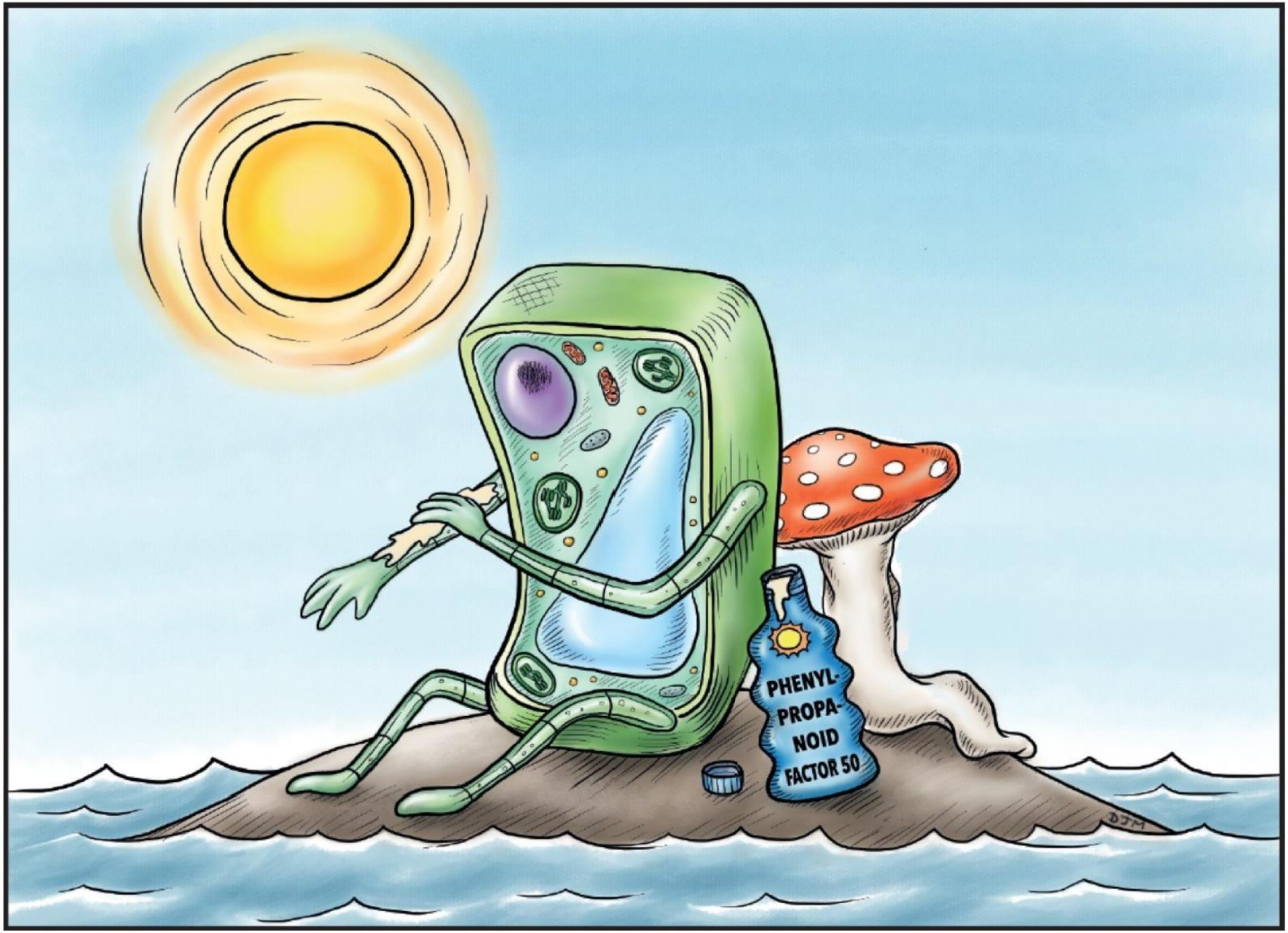
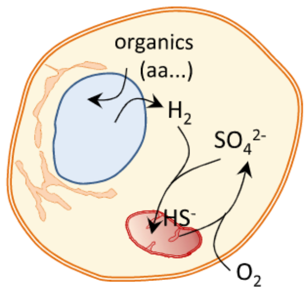
Symbiosis – first land plants

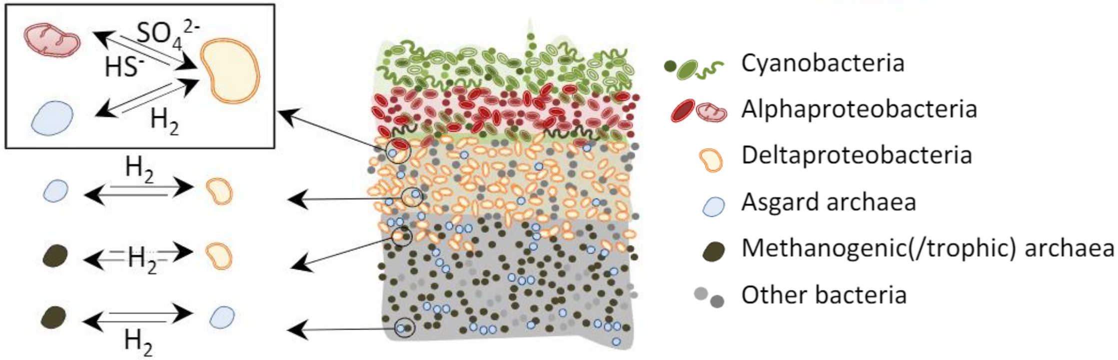


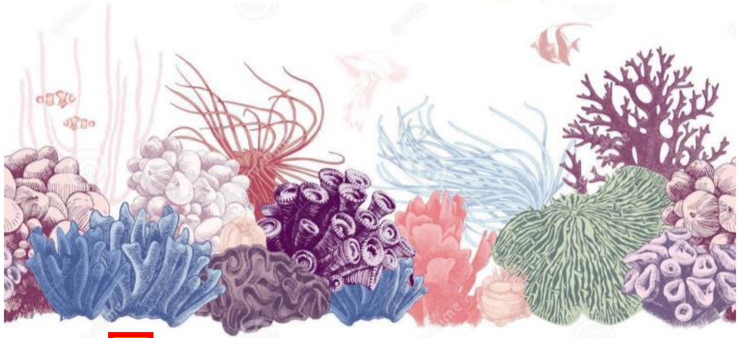
Symbiosis

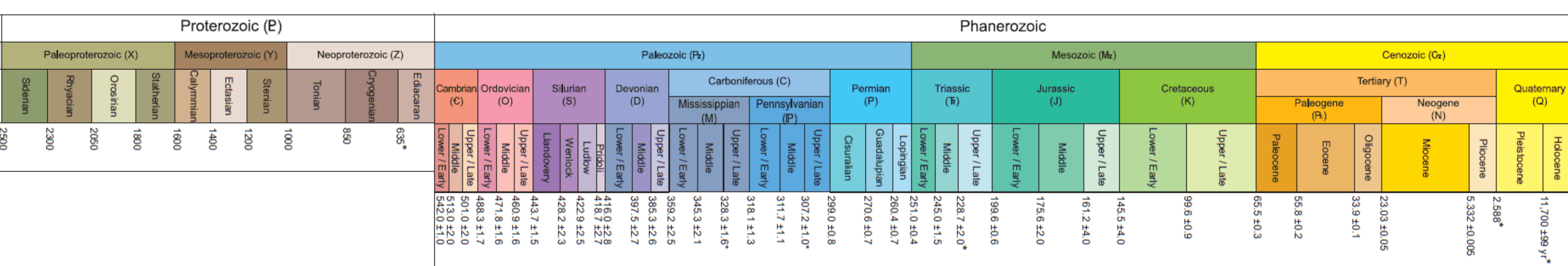
- Central driver for evolution across the entire tree of life

HS - Syntrophy hypothesis



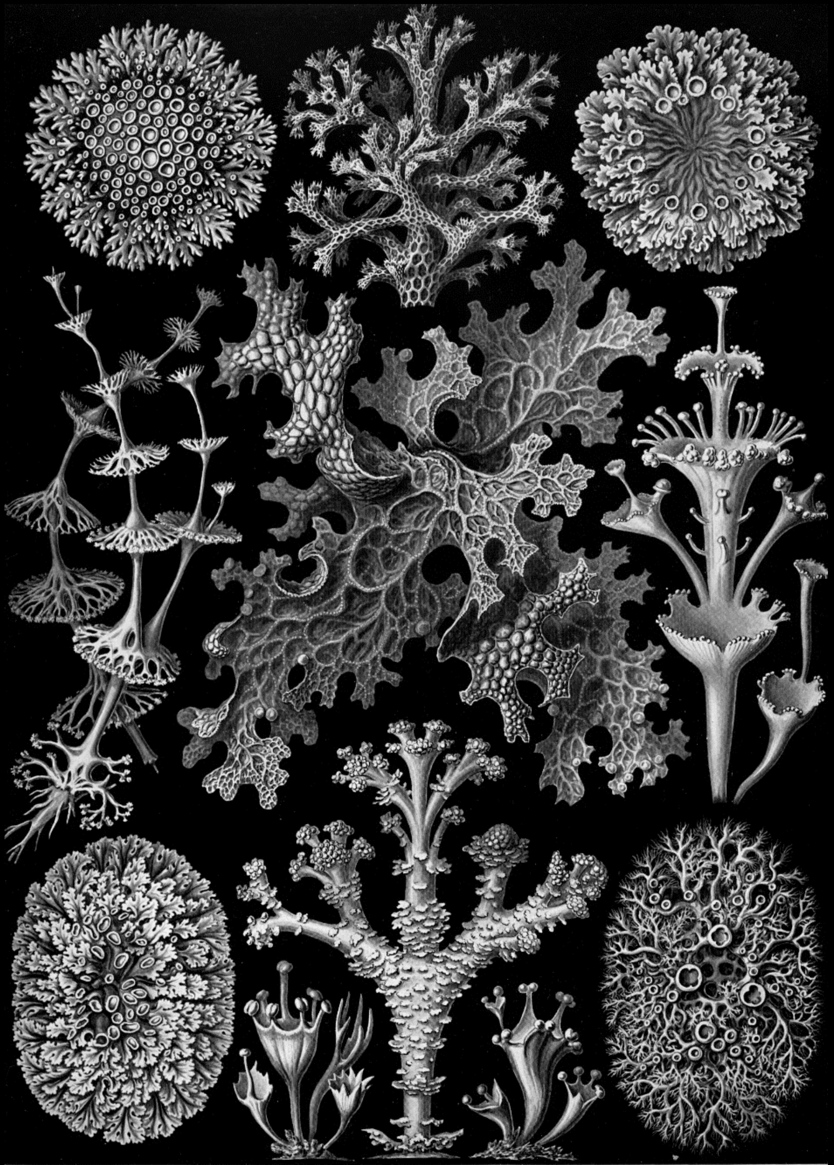


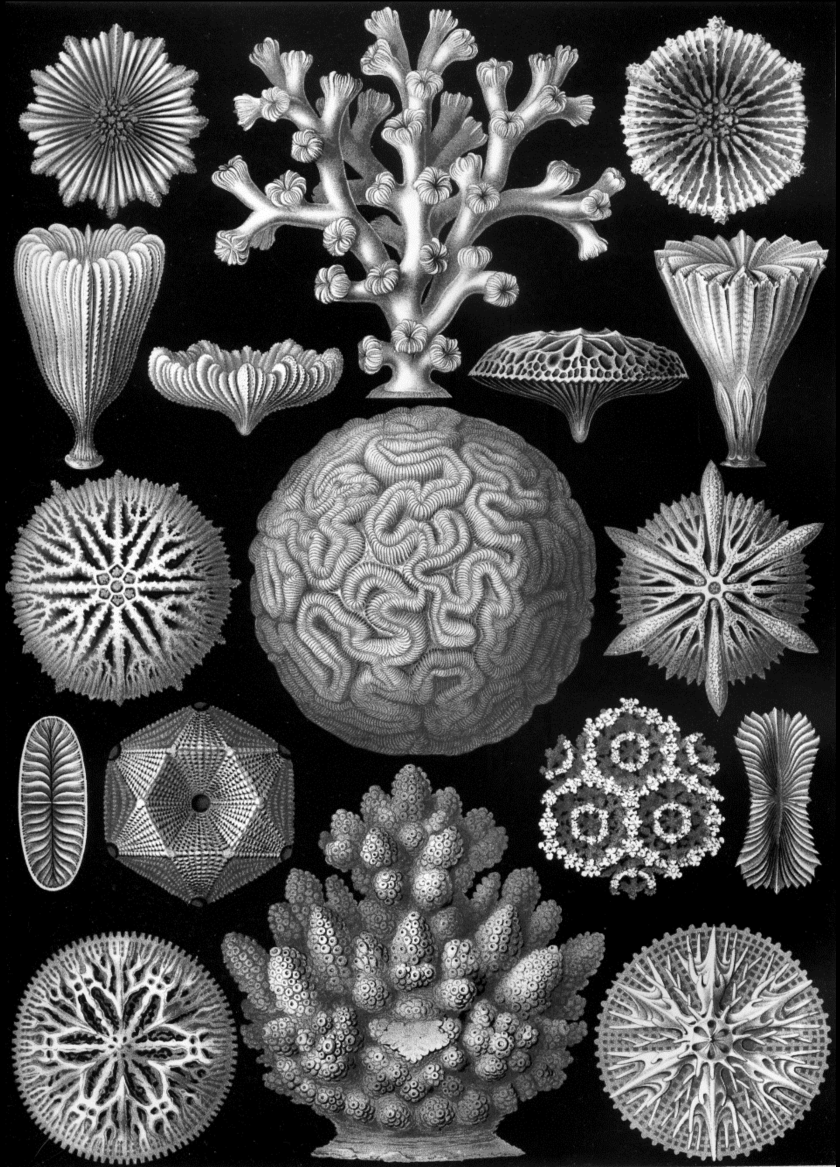




Phototrophic symbioses

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

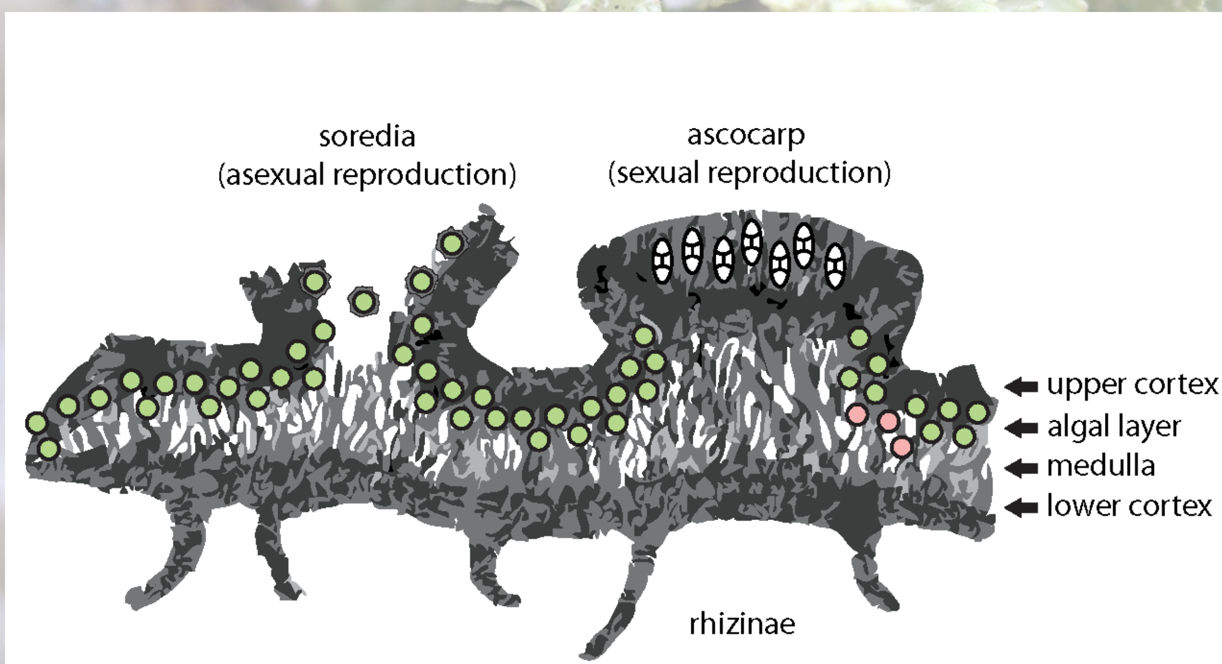


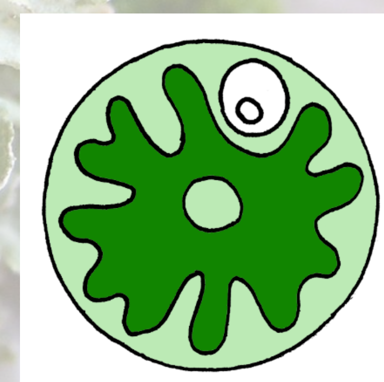


Haeckel (1904)

Phototrophic symbioses

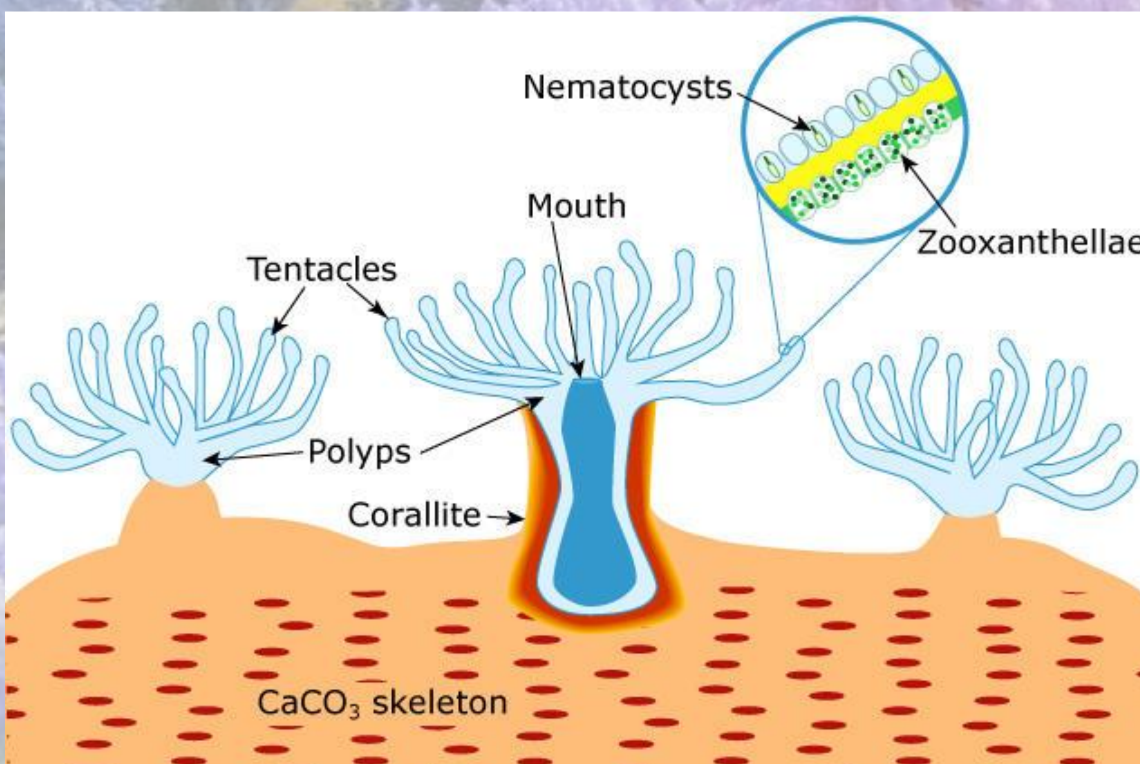
- Lichens
  - Dominate 8% of the Earth's land surface
  - Impacting global fluxes of carbon and nutrients
  - Soil stabilization and development

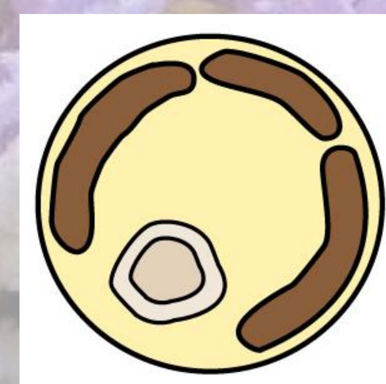




Phototrophic symbioses

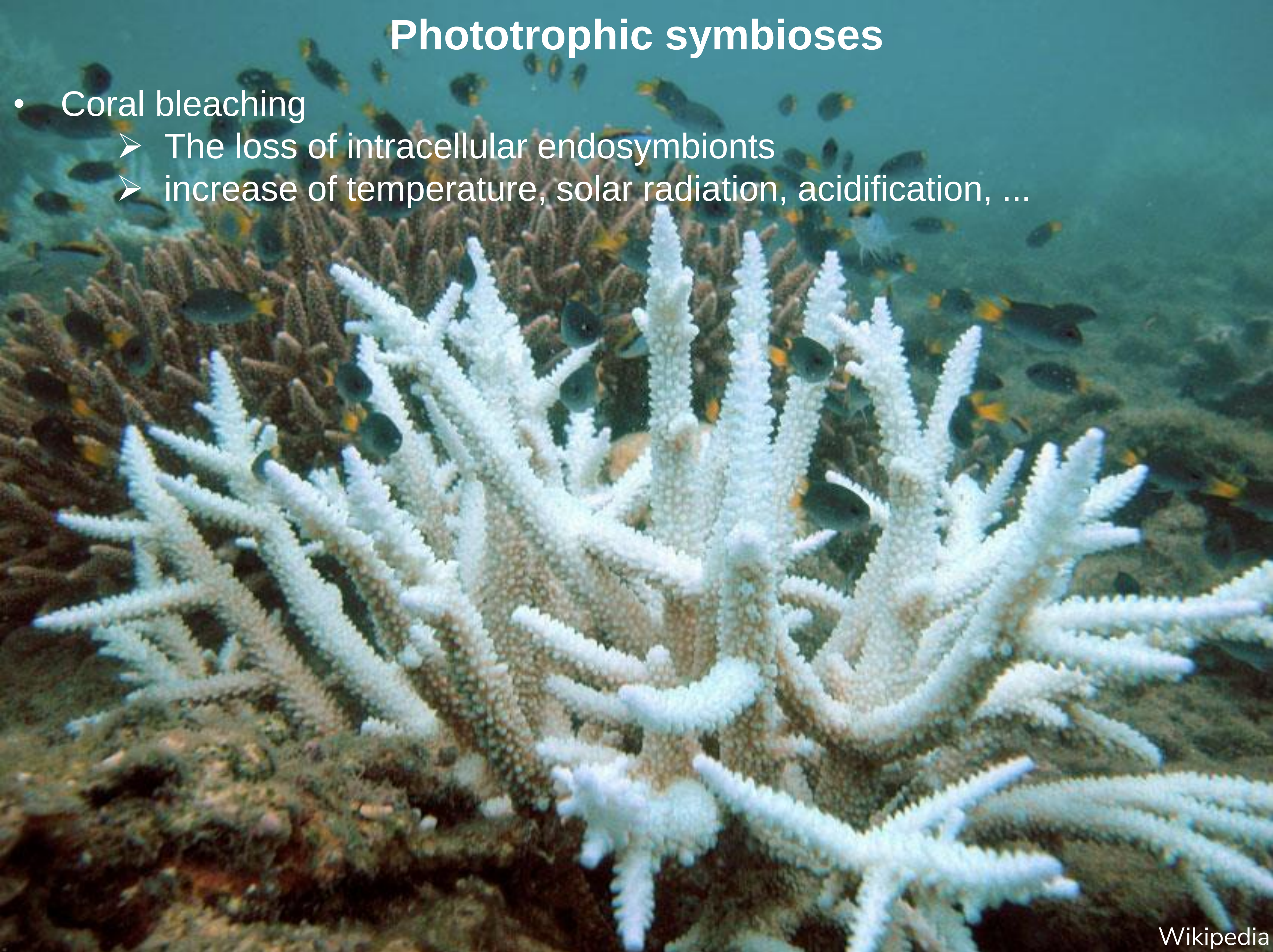
- Corals
  - Cover 0.17% of the ocean surface
  - Coral reefs as important planetary biodiversity hotspots





Phototrophic symbioses

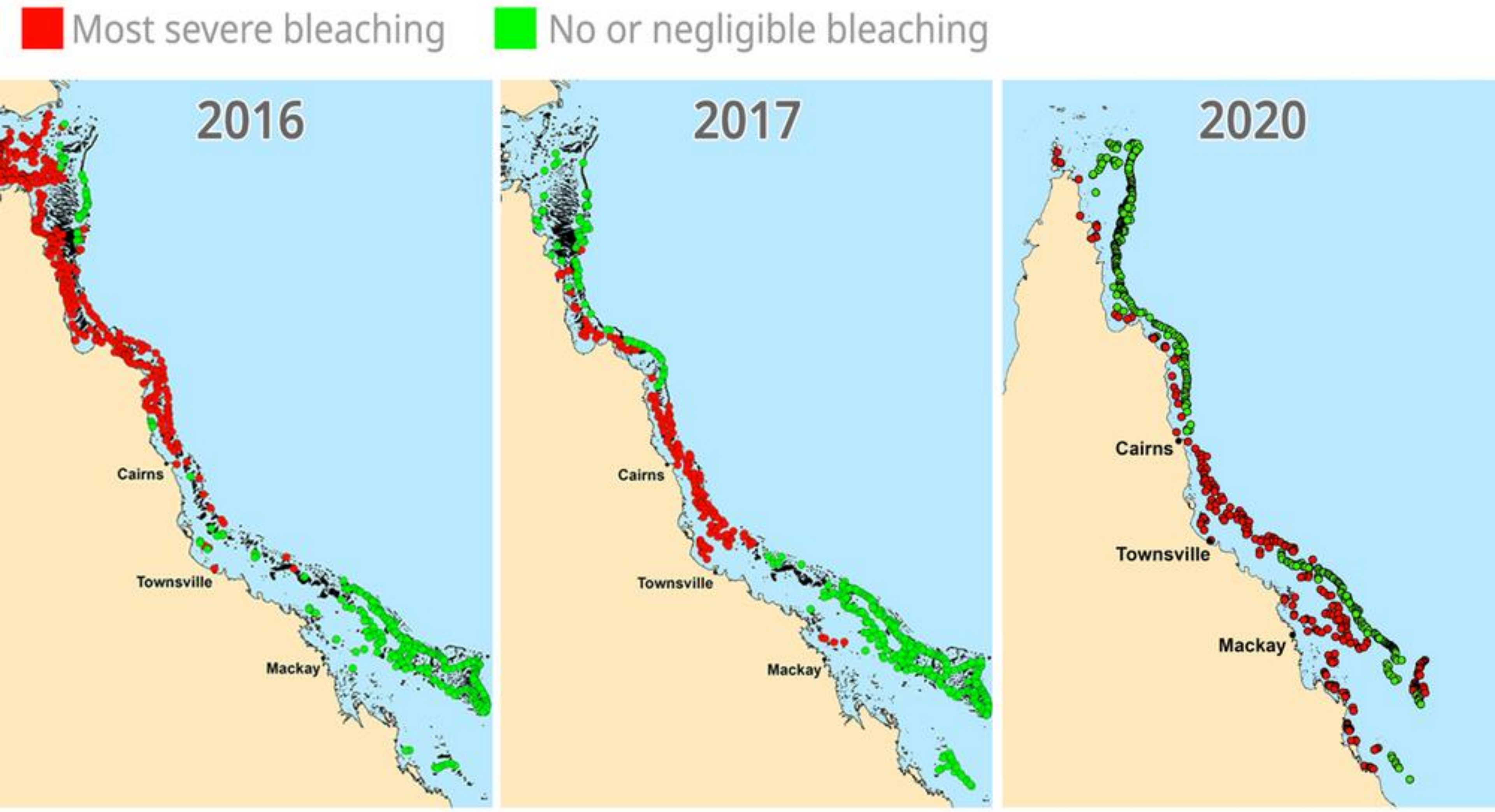
- Coral bleaching
  - The loss of intracellular endosymbionts
  - increase of temperature, solar radiation, acidification, ...



Wikipedia

Phototrophic symbioses

- Coral bleaching
  - Great Barrier Reef – five massive bleaching events
  - The number of corals has declined by more than 50% since the 1990s



Source: ARC Centre of Excellence for Coral Reef Studies

Phototrophic symbioses

- Decrease of lichens in Arctic ecosystems, climatic changes
  - Dramatic decline in reindeer populations in recent years

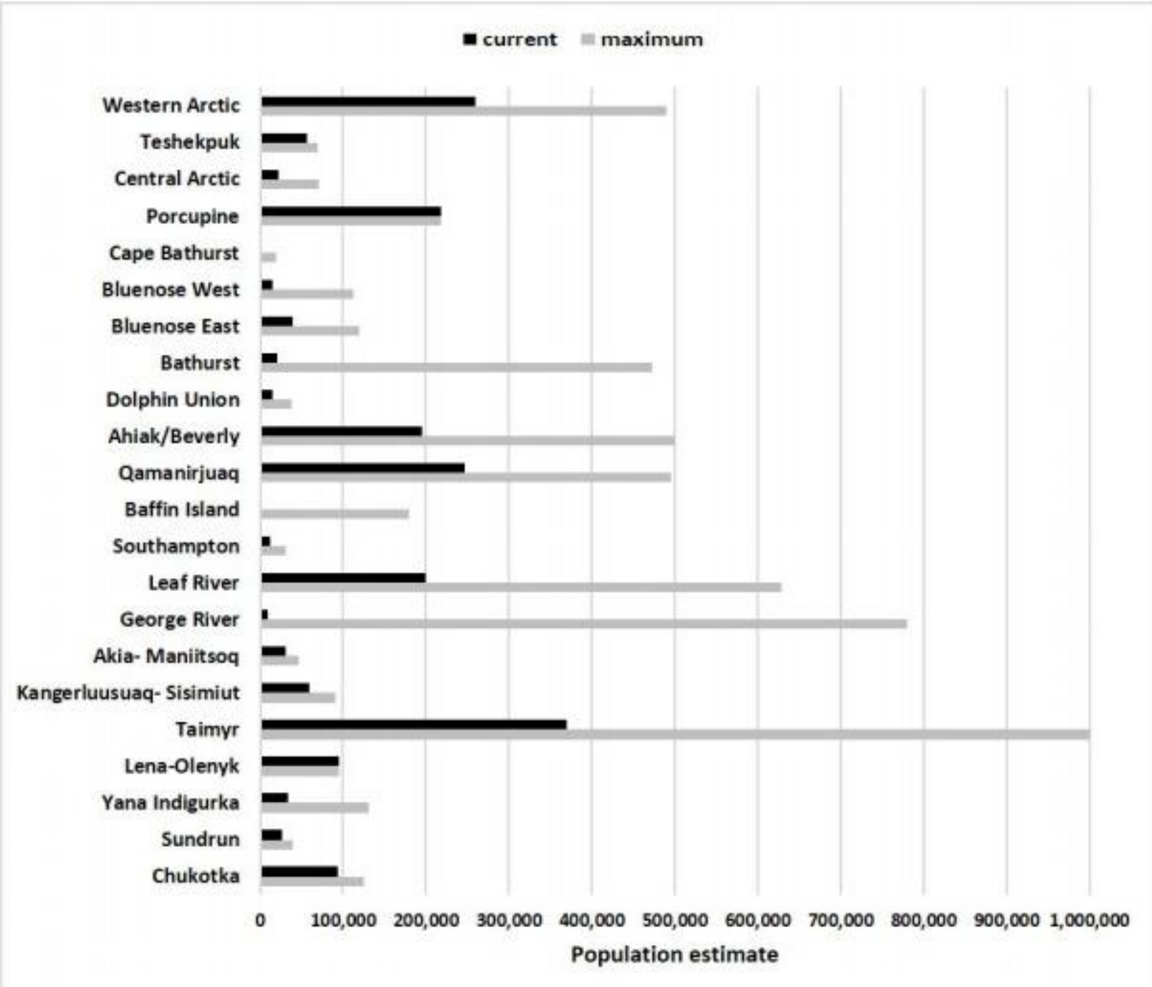
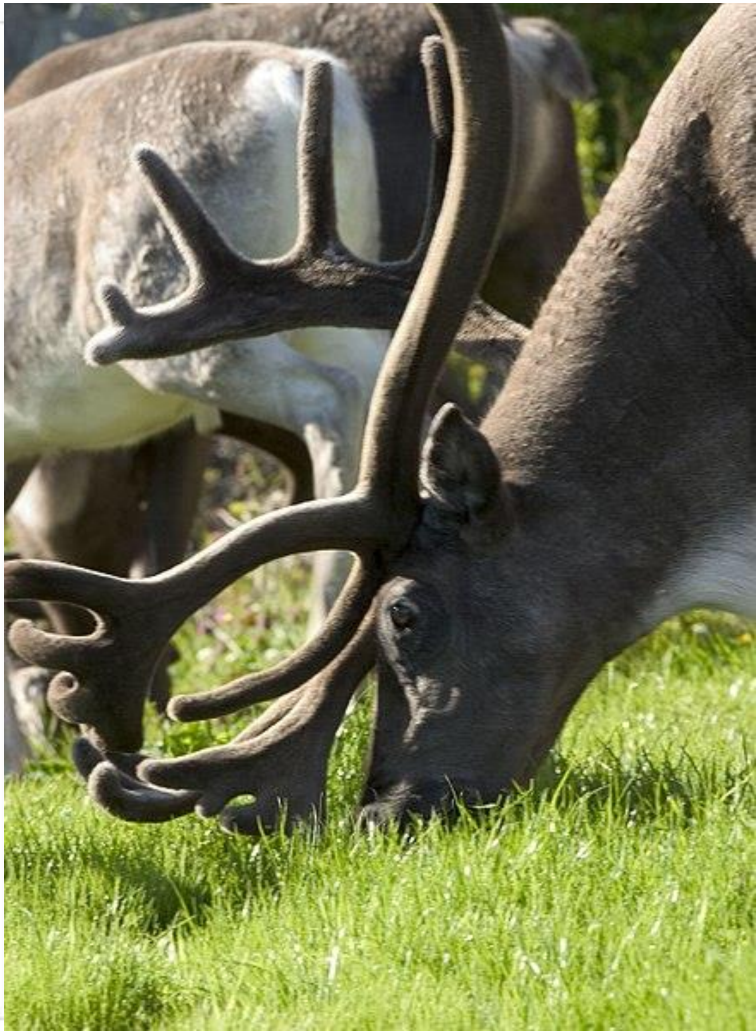


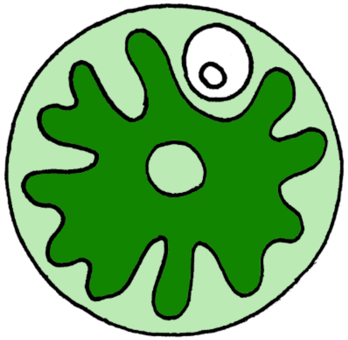
Figure 2. The current and peak estimates for migratory tundra wild reindeer/caribou herds for the 22 herds with at least three censuses. Data from CARMA's population database and covers population estimates from 1970-2017. Herds are ordered from west to east, starting in western Alaska.

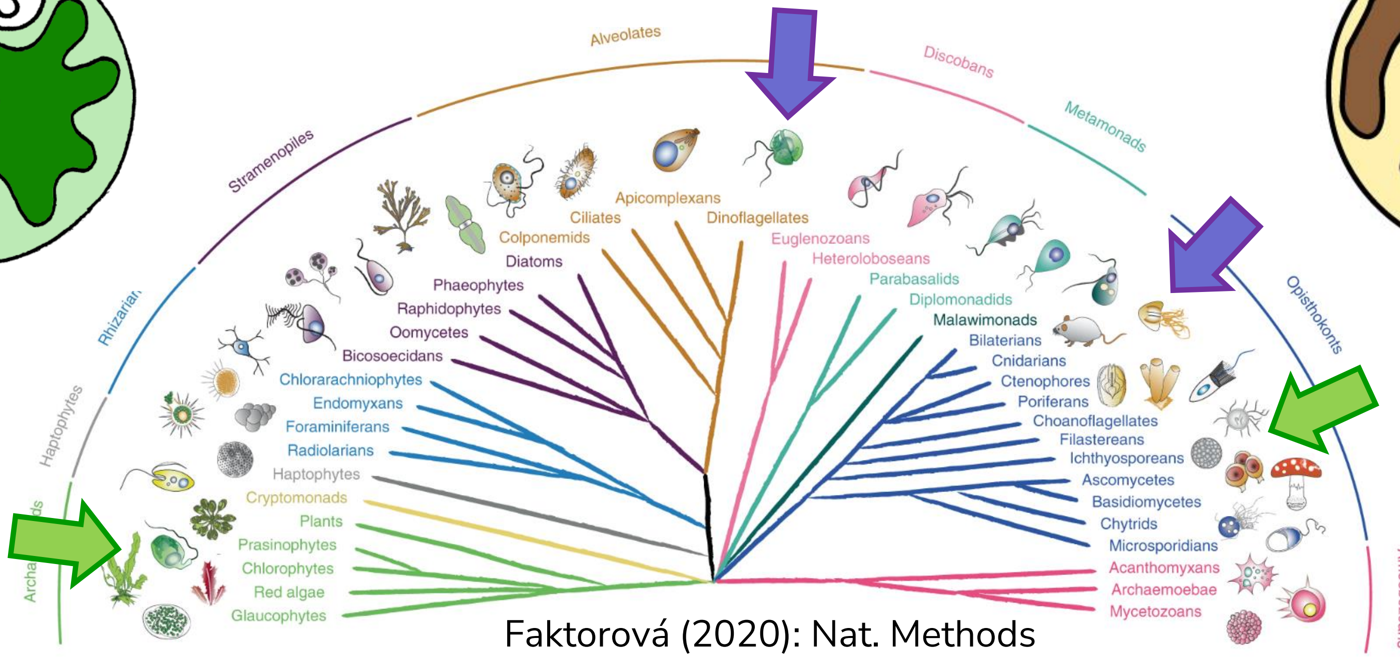


Arctic Report Card/NOAA

https://www.statnews.com/2016/12/09/suicide-sweden-sami-mental-health/

Phototrophic symbioses



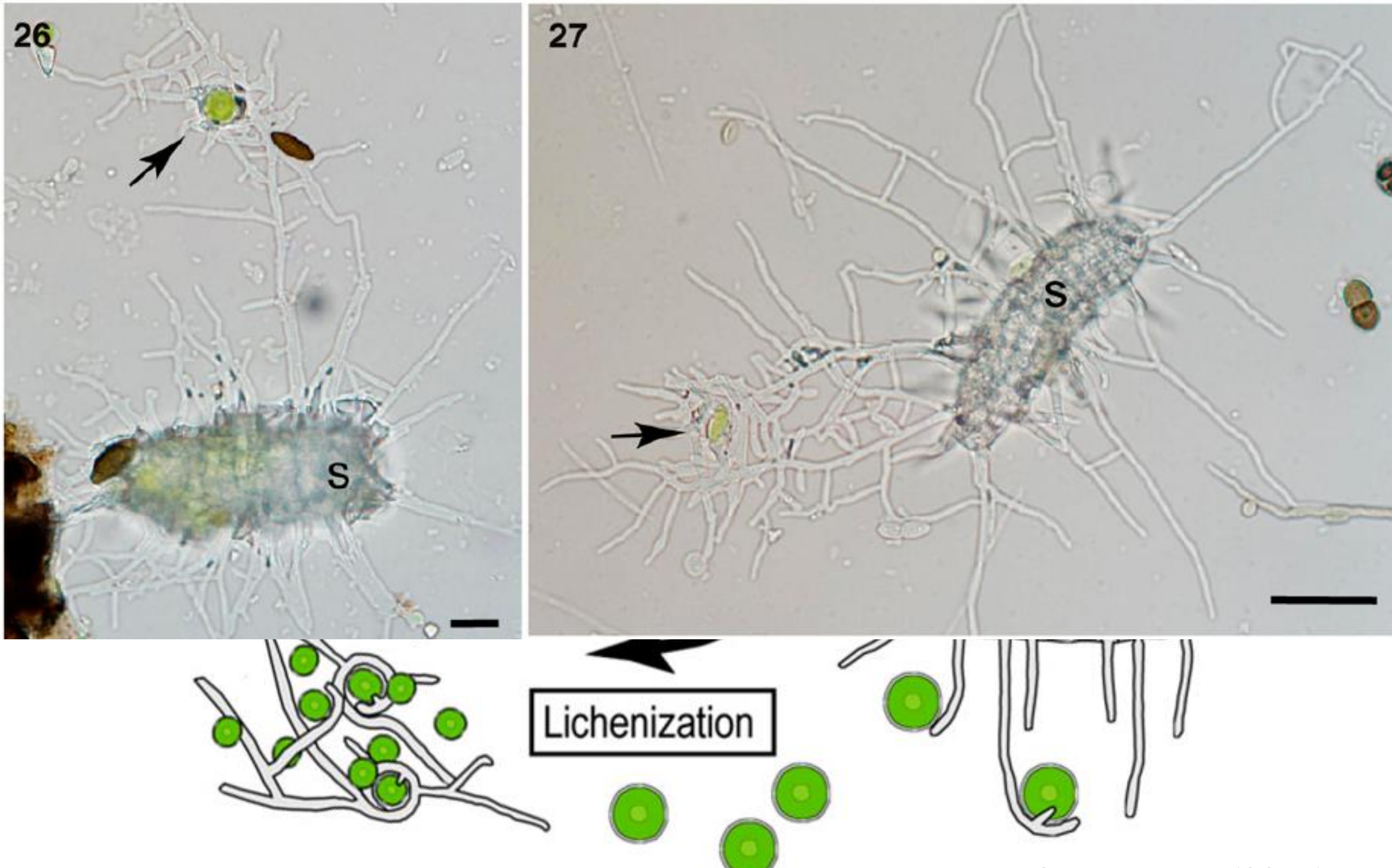


Faktorová (2020): Nat. Methods

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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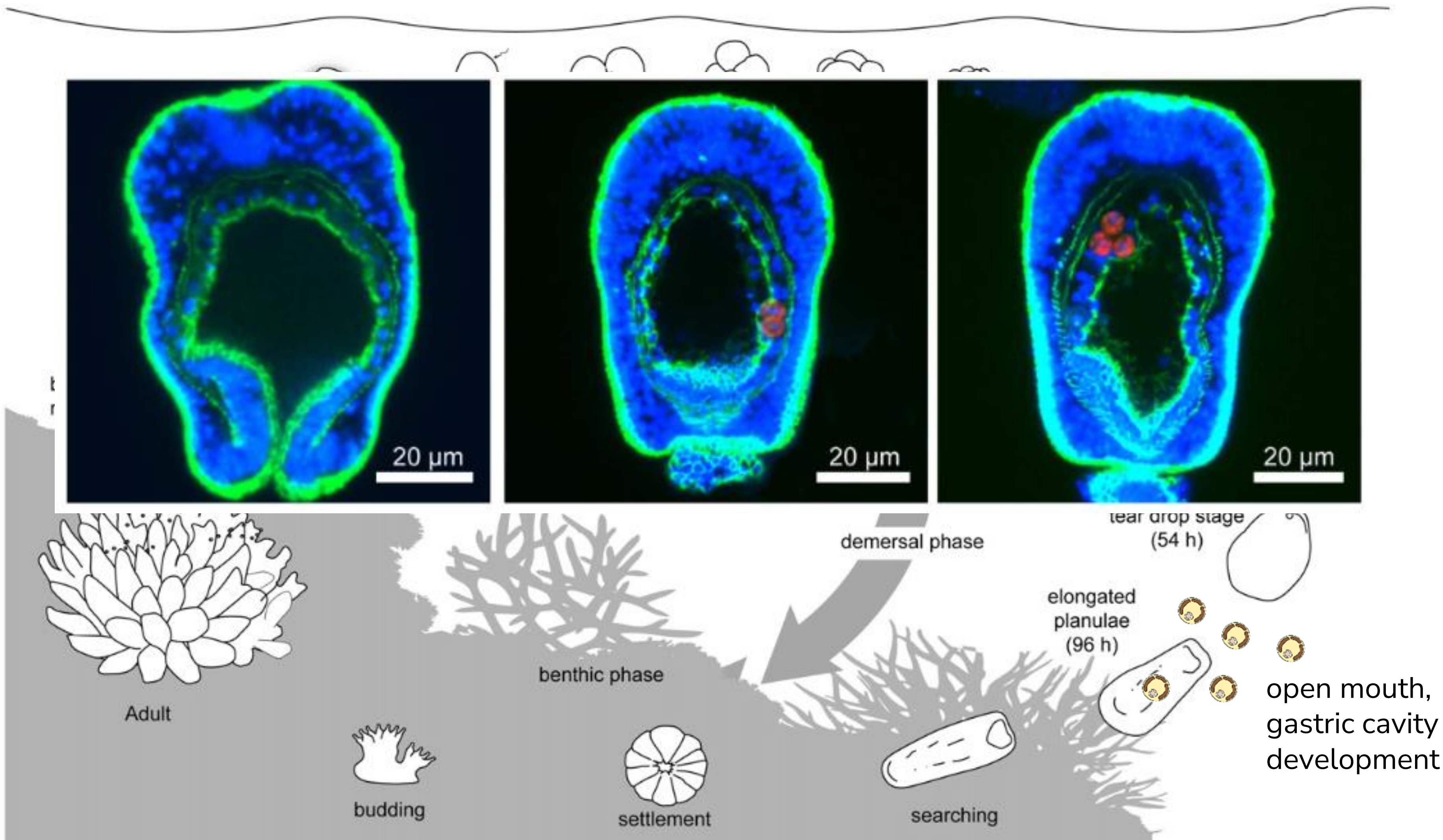
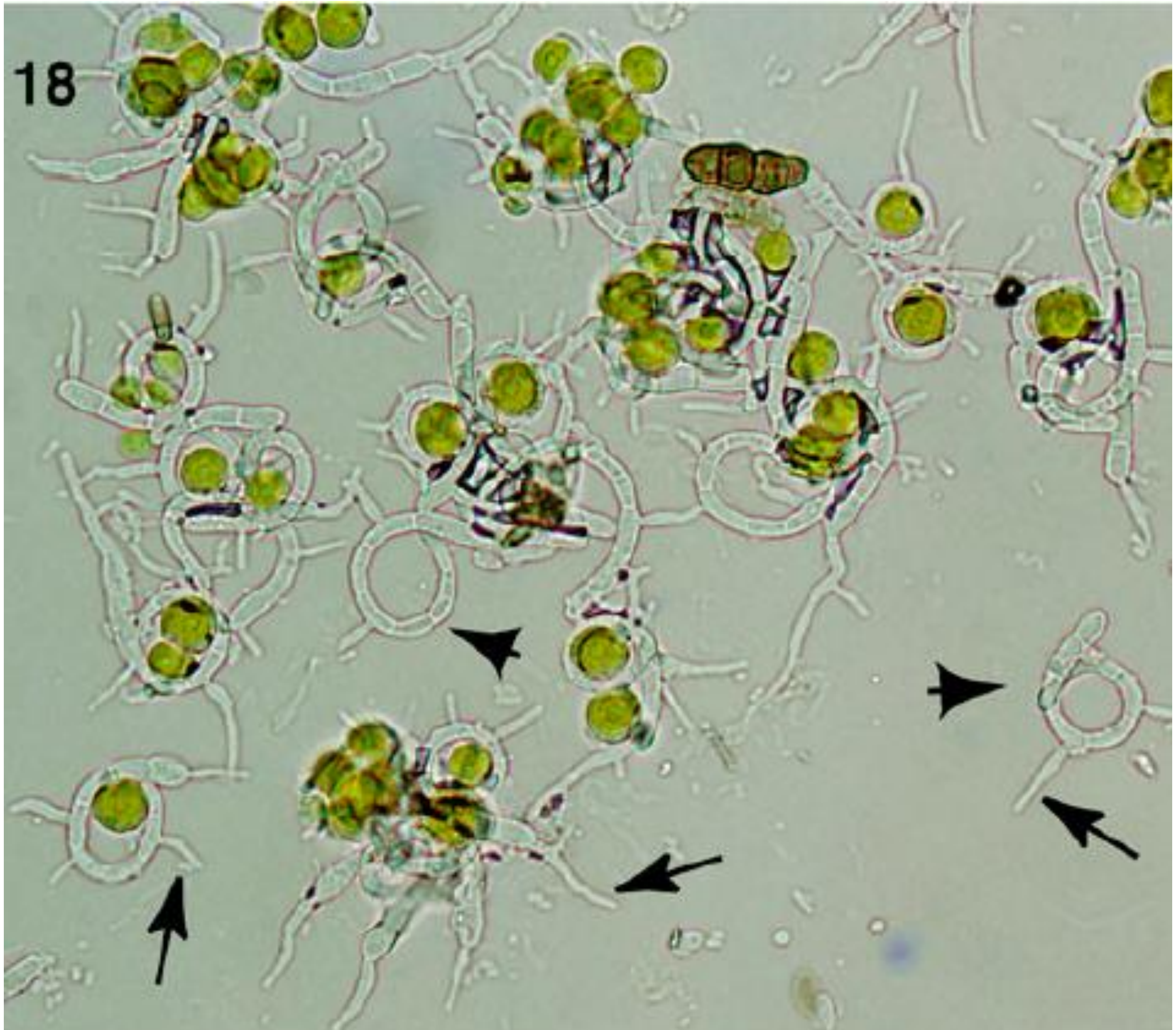


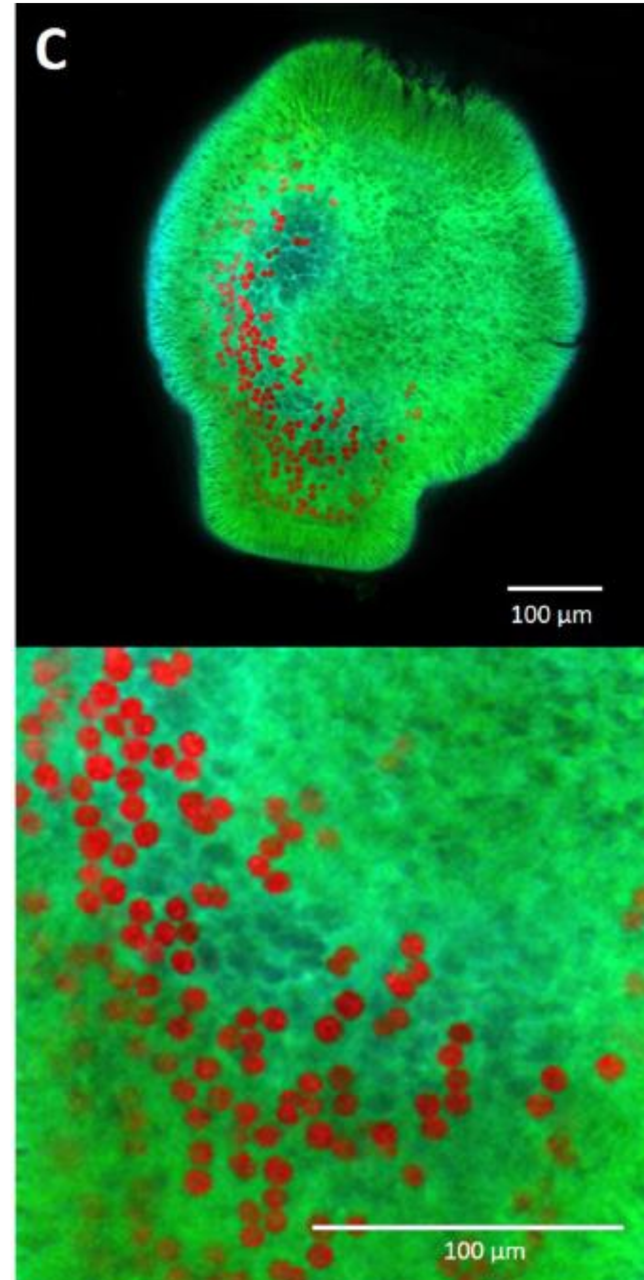
Bucher et al. (2016): Sci. Rep.

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

Vertical transmission

- Co-dispersal of both symbionts

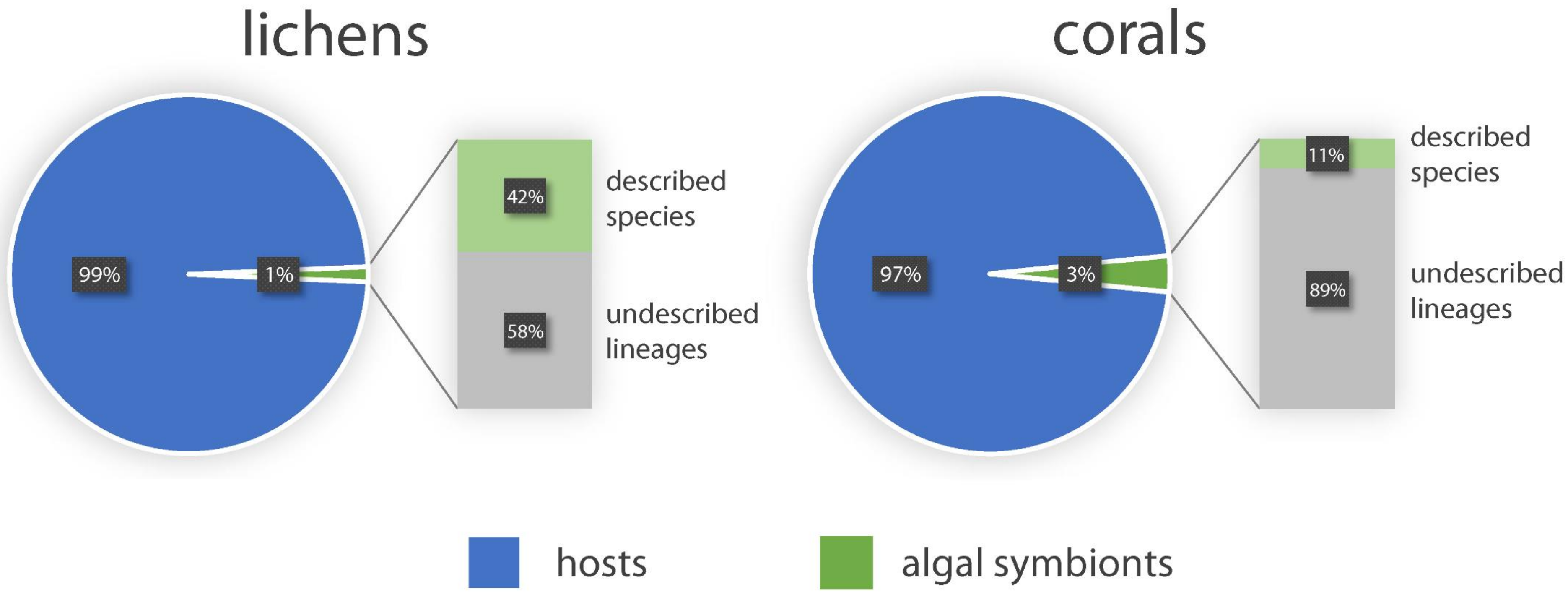




Sanders (2014): Am. J. Bot. Chakravarti et al. (2019): Front. Microbiol.

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.

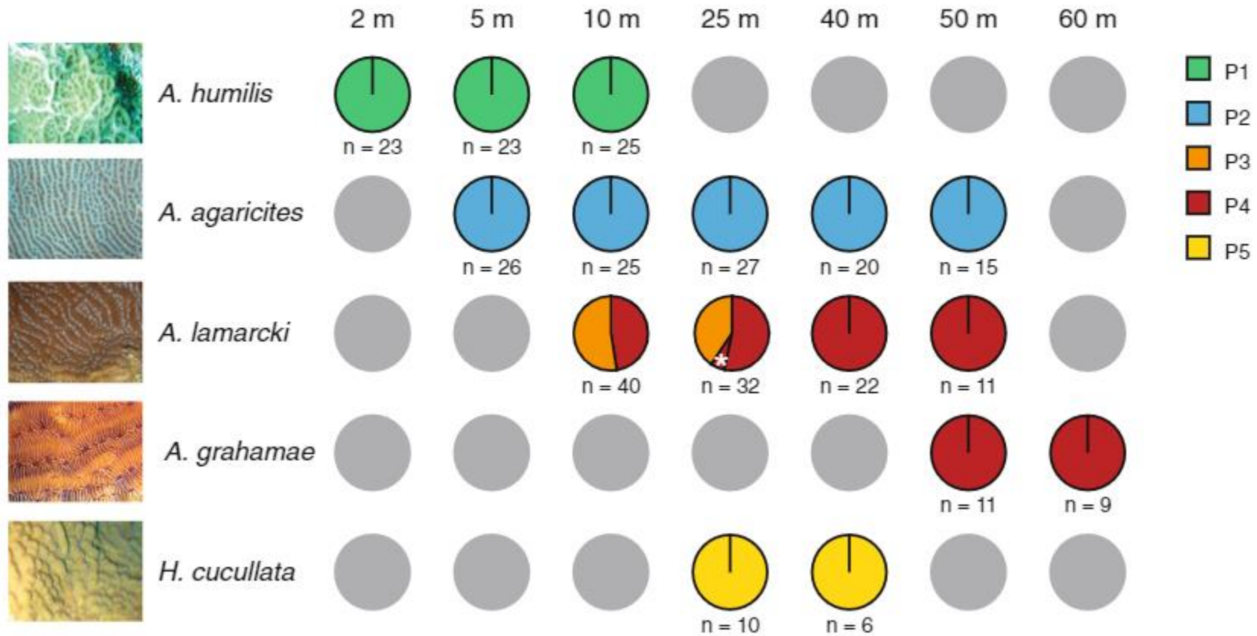
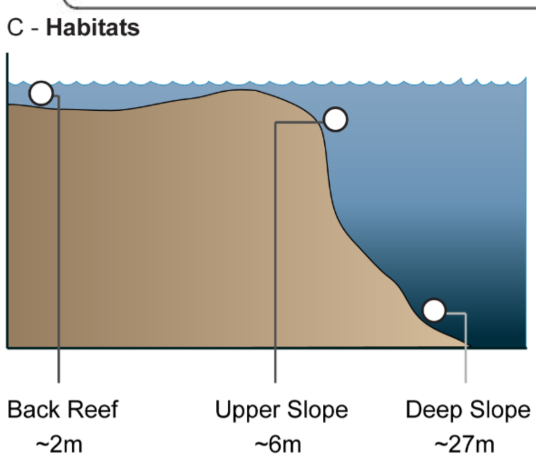
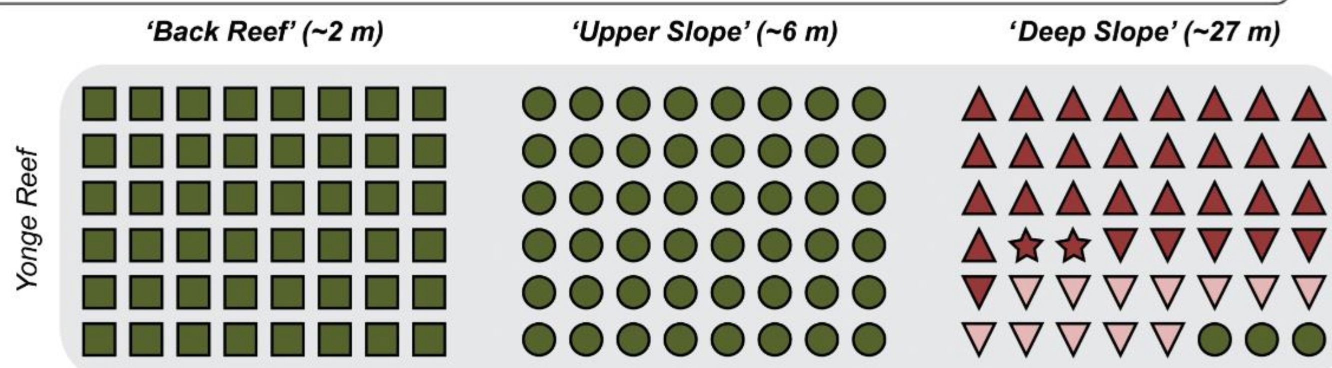


Figure 2 Distribution of *Symbiodinium* ITS2 profiles across the five agariciid host species and depths. Each pie chart represents the sampled population of a host species at a certain depth. Asterisk (*) indicates a P4 profile that had an additional C1 band. Figure legend text.

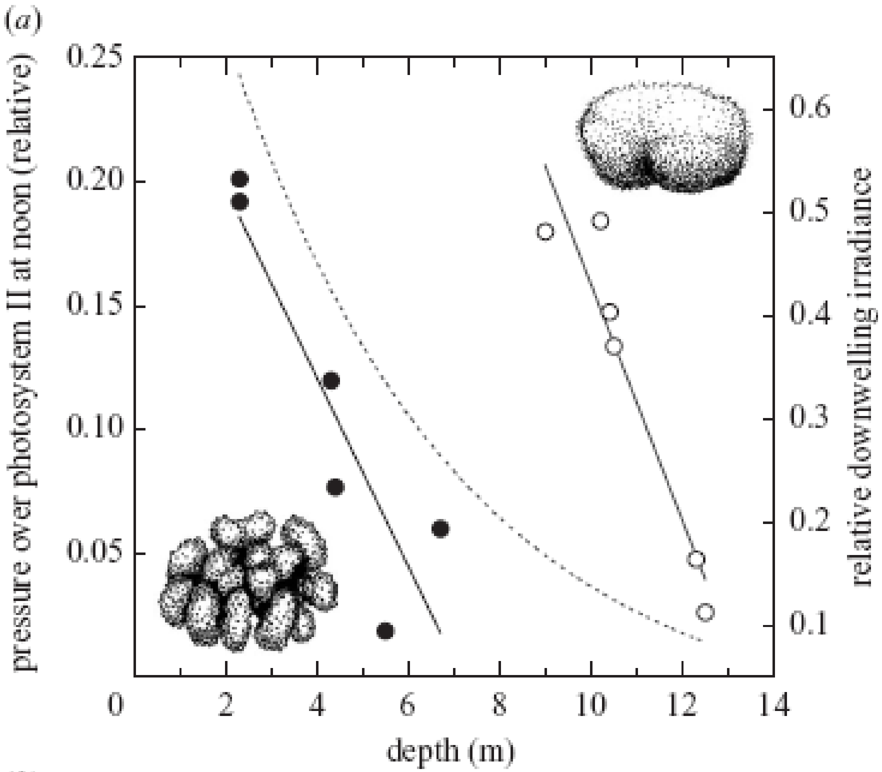


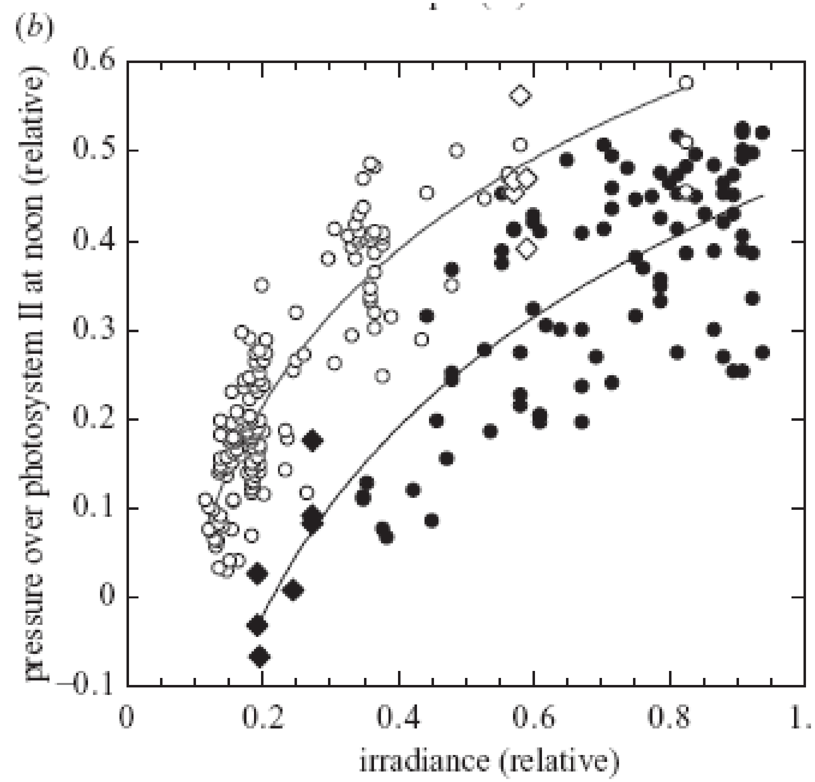


Bongaerts et al. (2010) Plos ONE

High specialization of symbionts

- Narrow ecological niches of algal symbionts





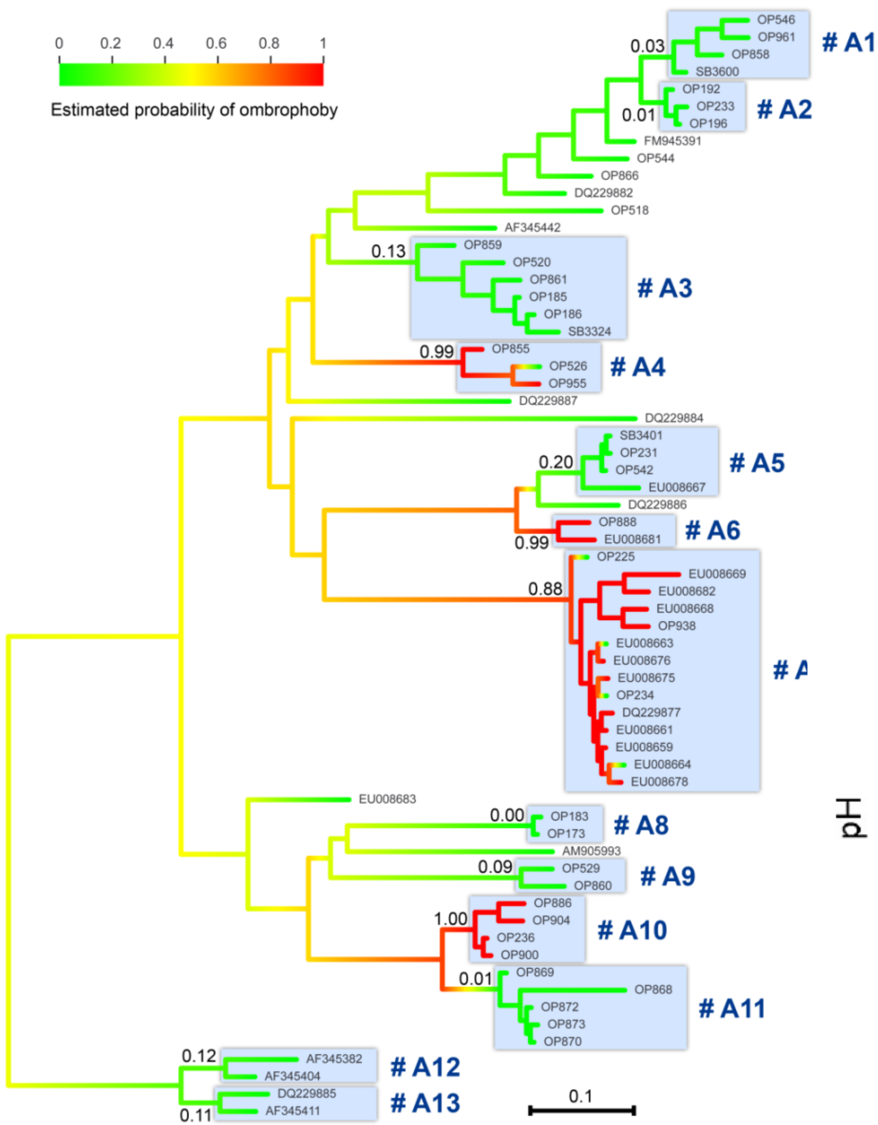
Pocillopora

Pavona

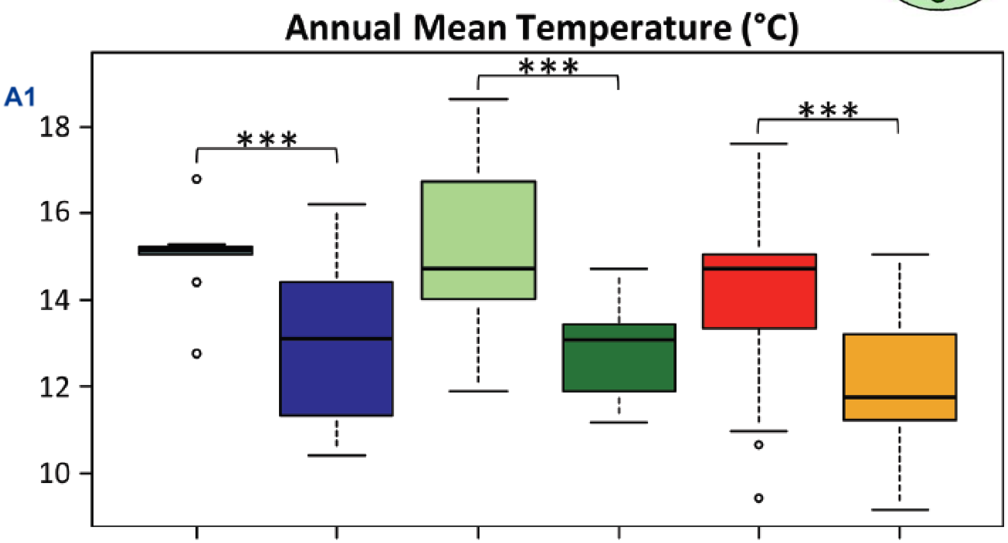
Iglesias-Prieto et al. (2004): Proc. R. Soc. Lond. B

High specialization of symbionts

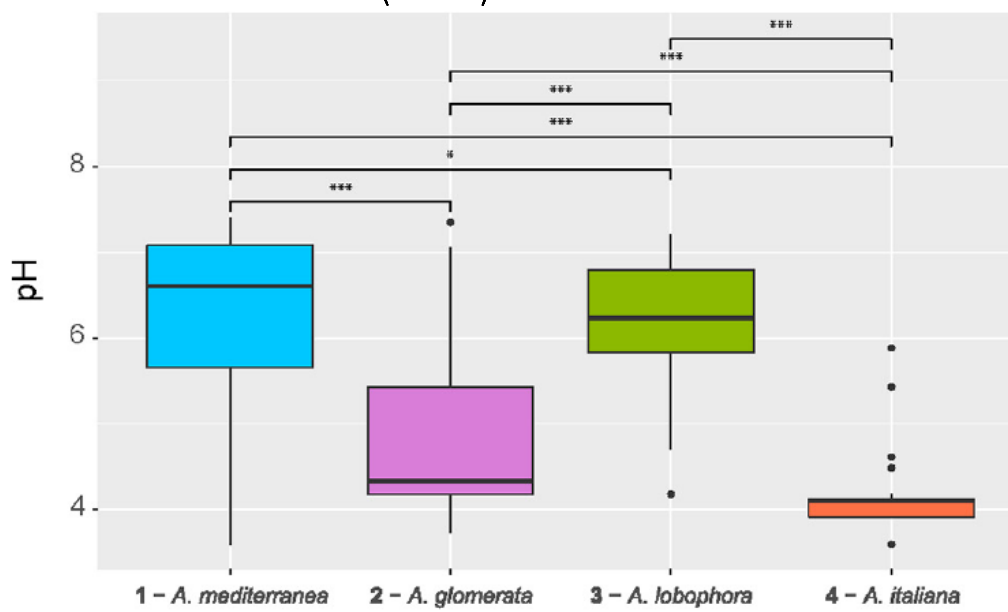
- Strong algal host specificity



Peksa & Škaloud (2011): Mol. Ecol.

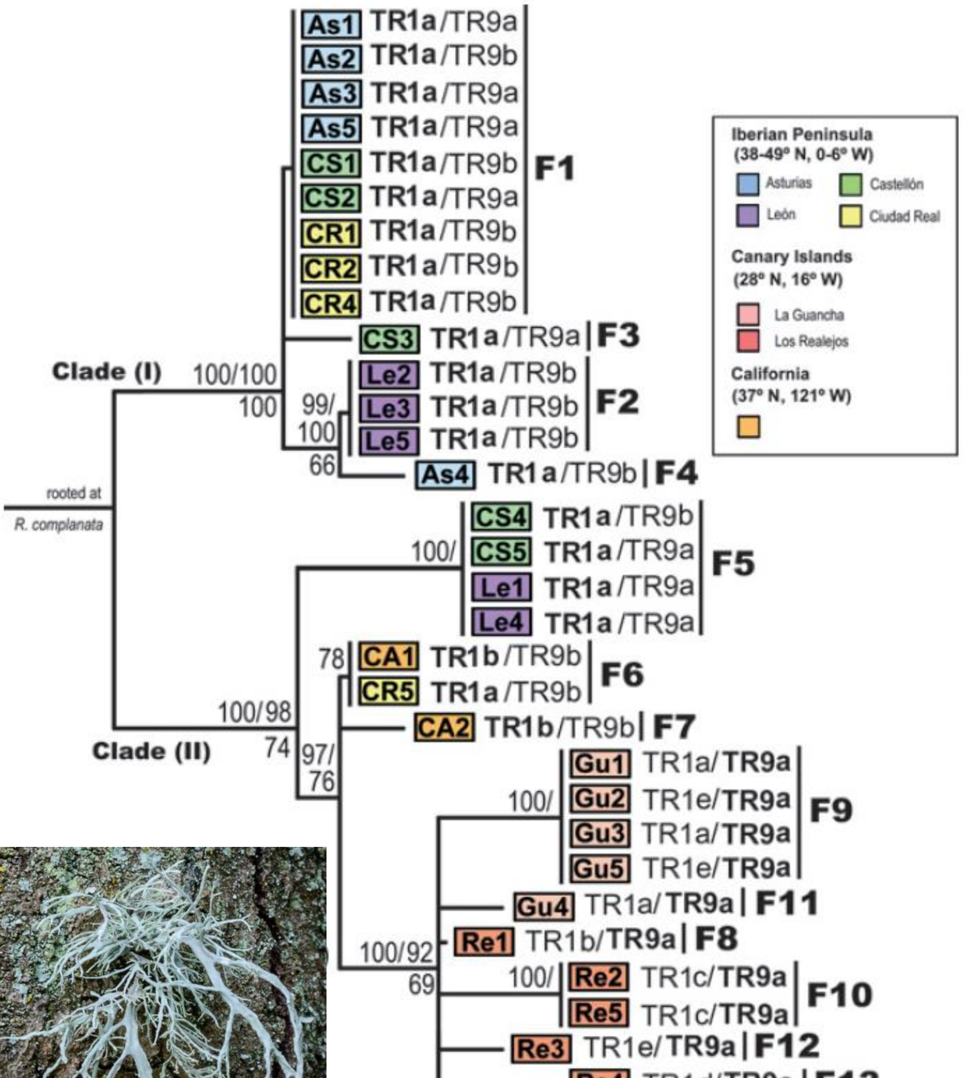


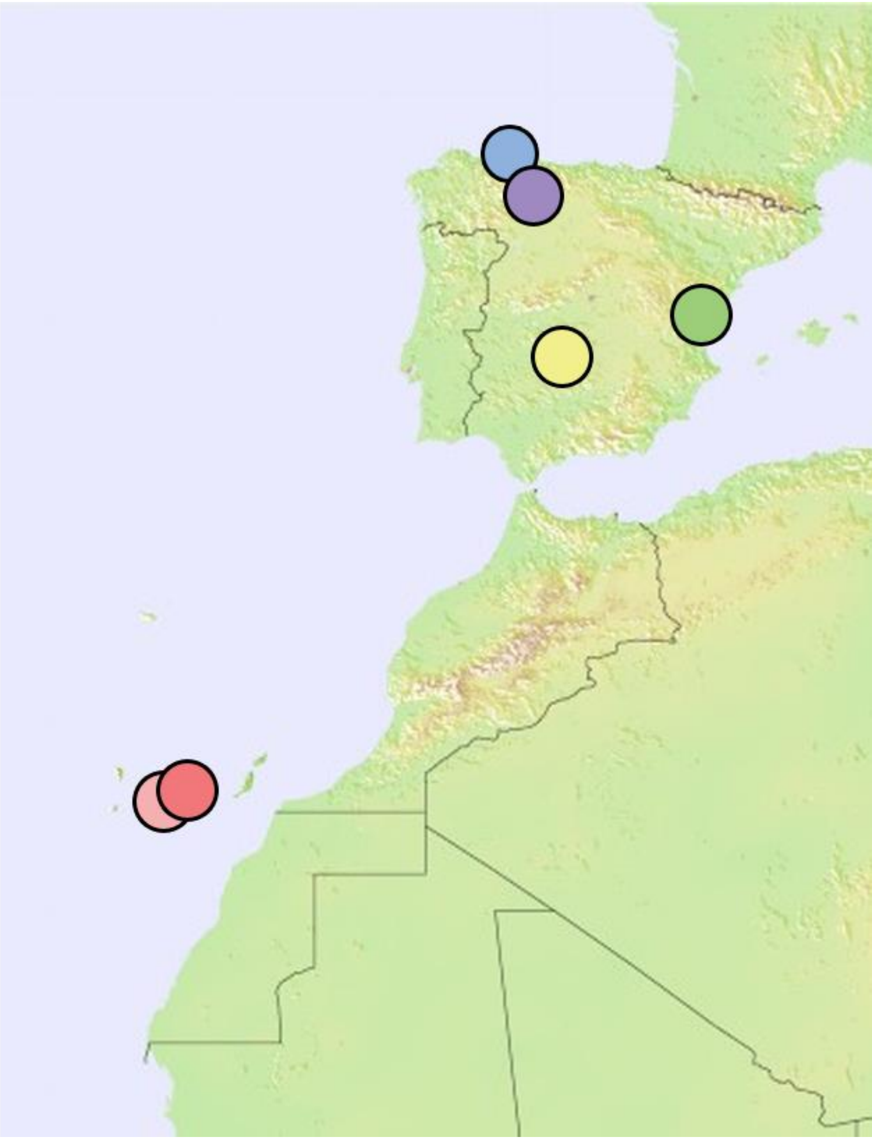
Vančurová et al. (2021): Frontiers Microb.



Škvorová et al. (2022): Frontiers Microb.

Multiple symbionts

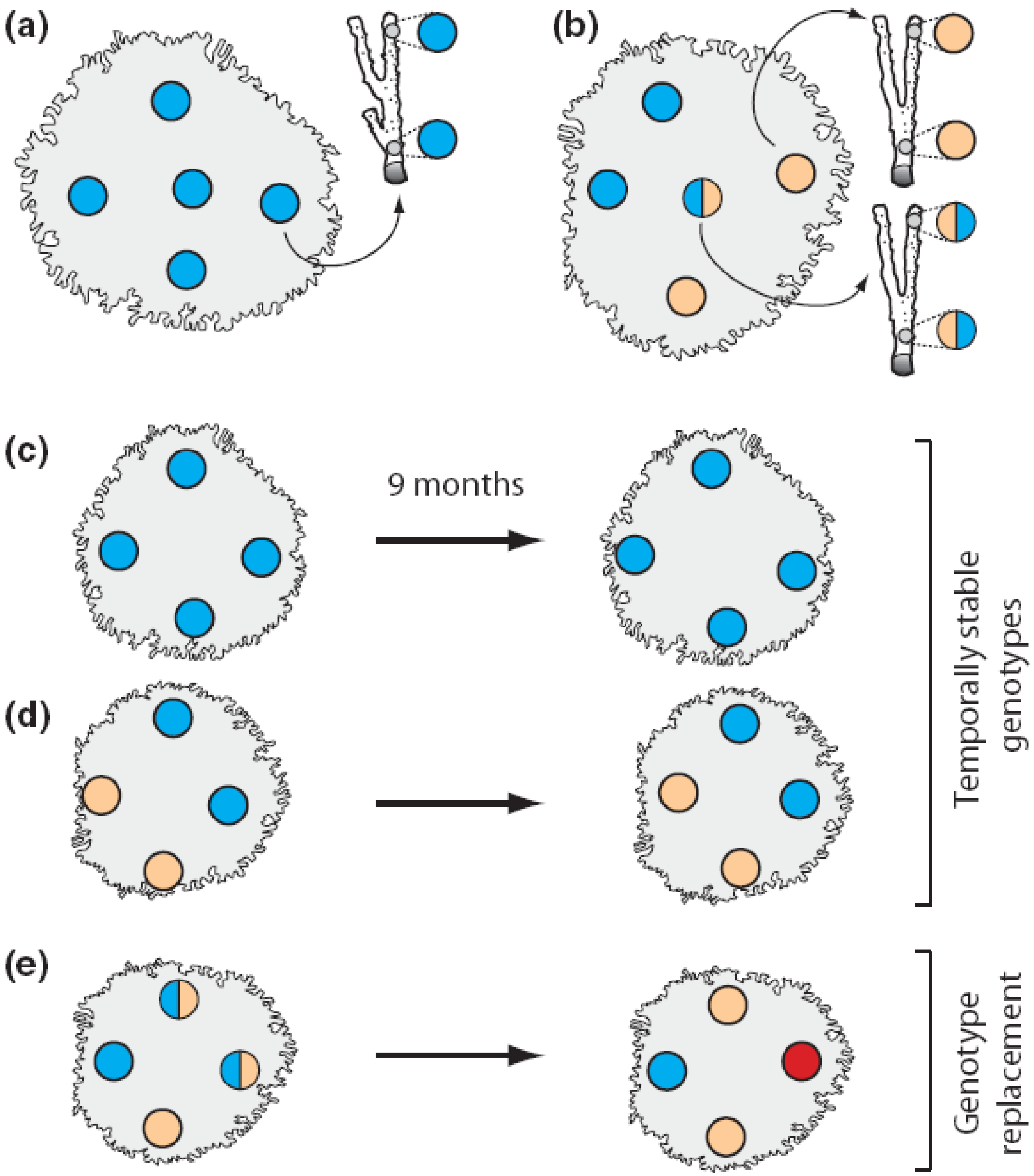




Ramalina farinacea

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

Multiple symbionts

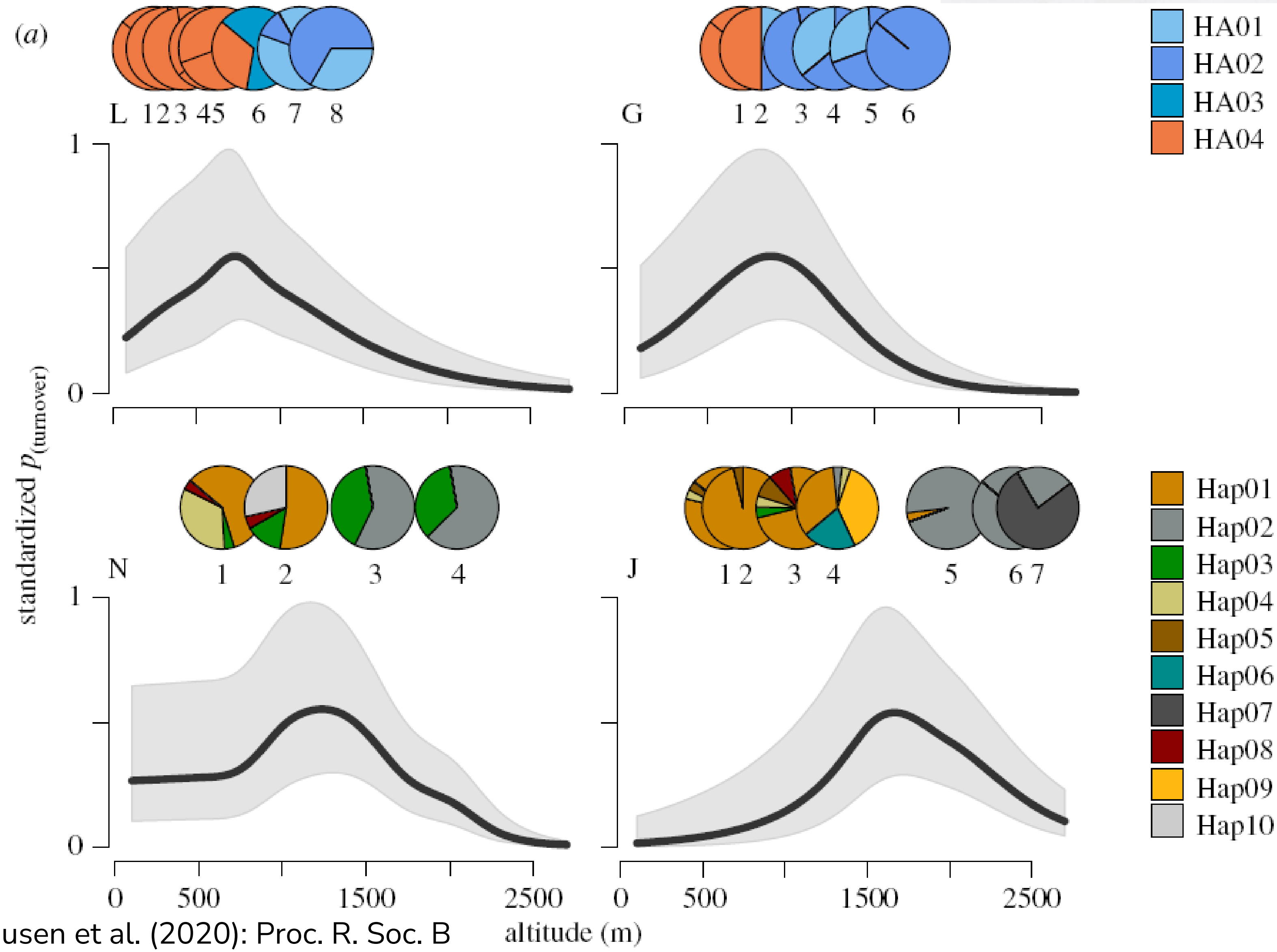


Pocillophora

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

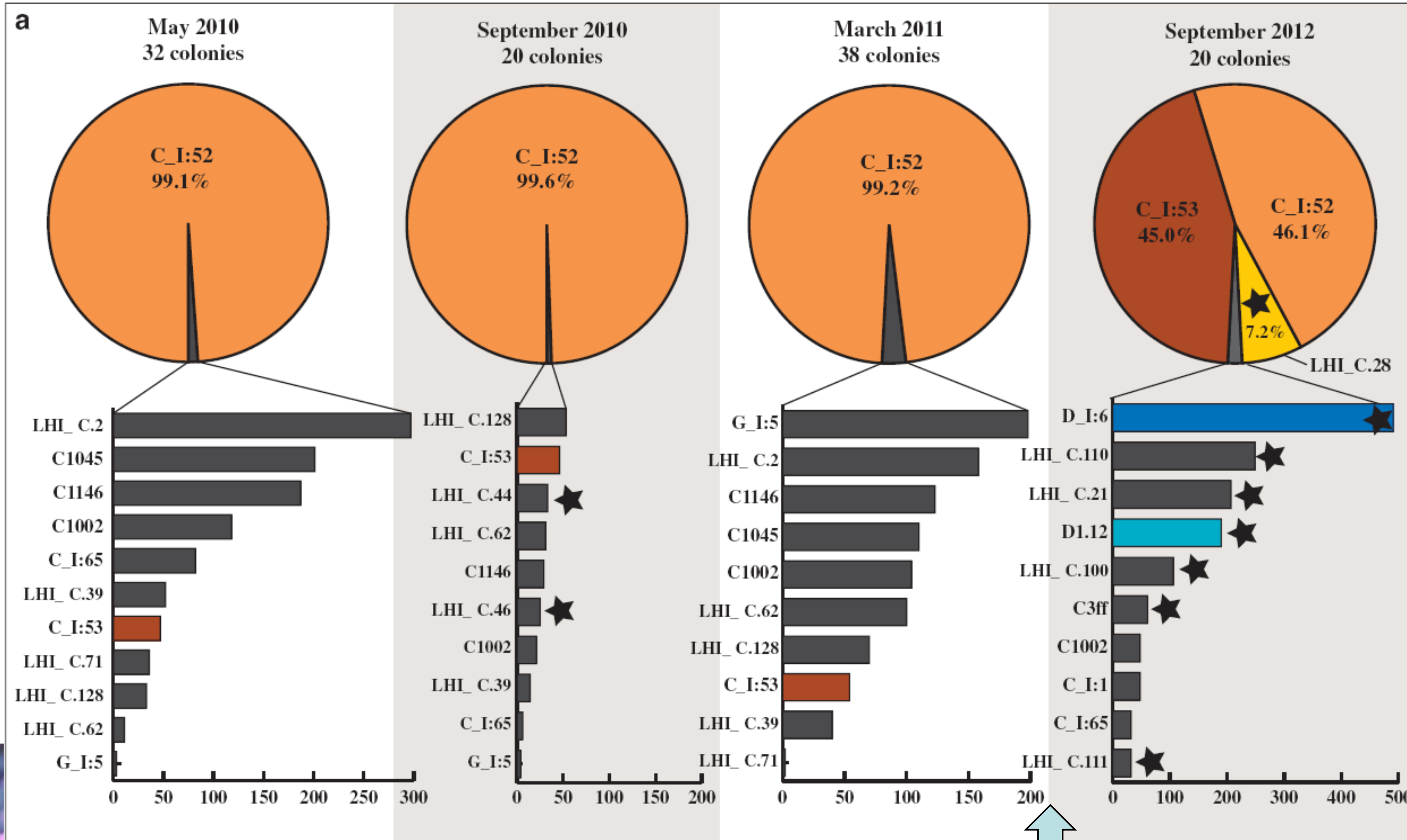
Symbiont switching

Lasallia

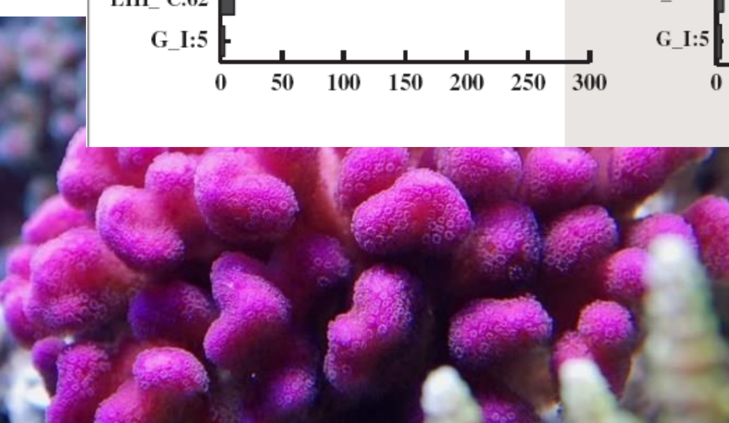


Rolshausen et al. (2020): Proc. R. Soc. B

Symbiont switching



bleaching event

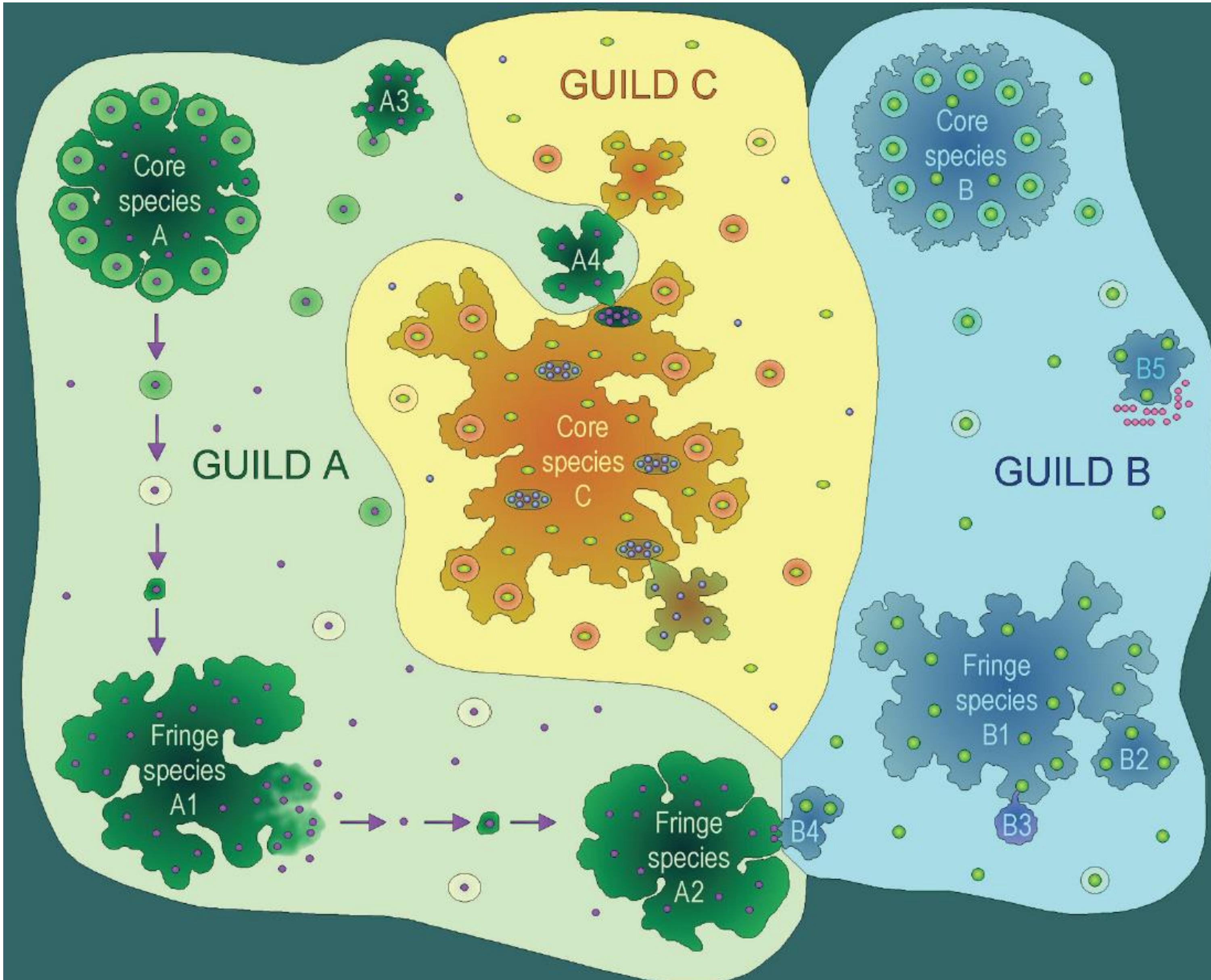


Stylophora pistillata

Boulotte et al. (2016): ISME J

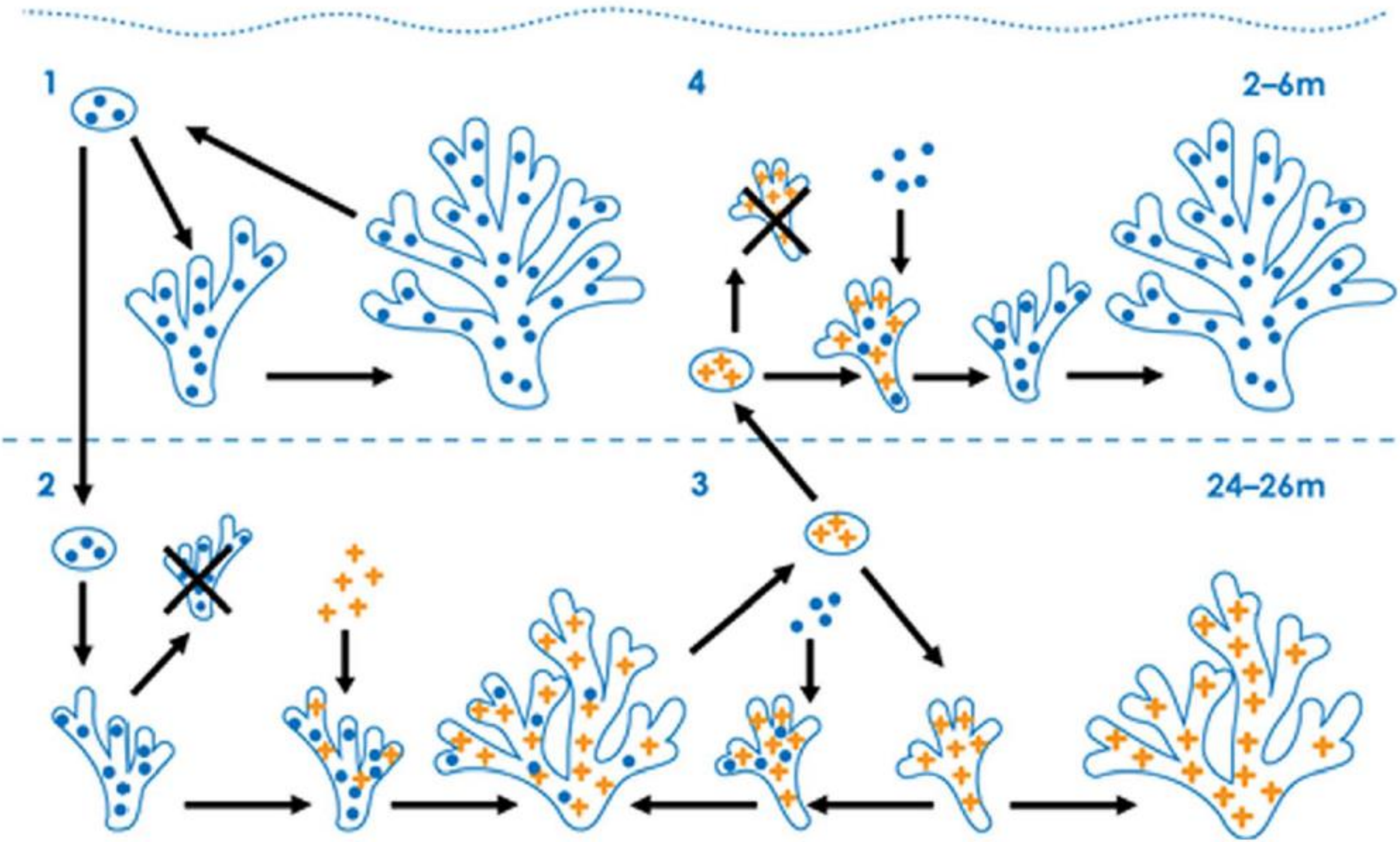
Habitat adapted symbiosis

- Core (vertical transmission) and fringe (horizontal transmission) species



Rikkinen (2013): MycoKeys

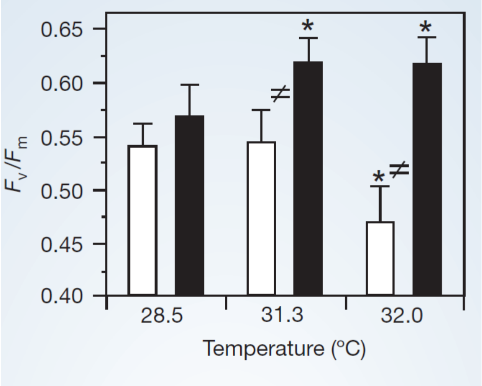
Habitat adapted symbiosis



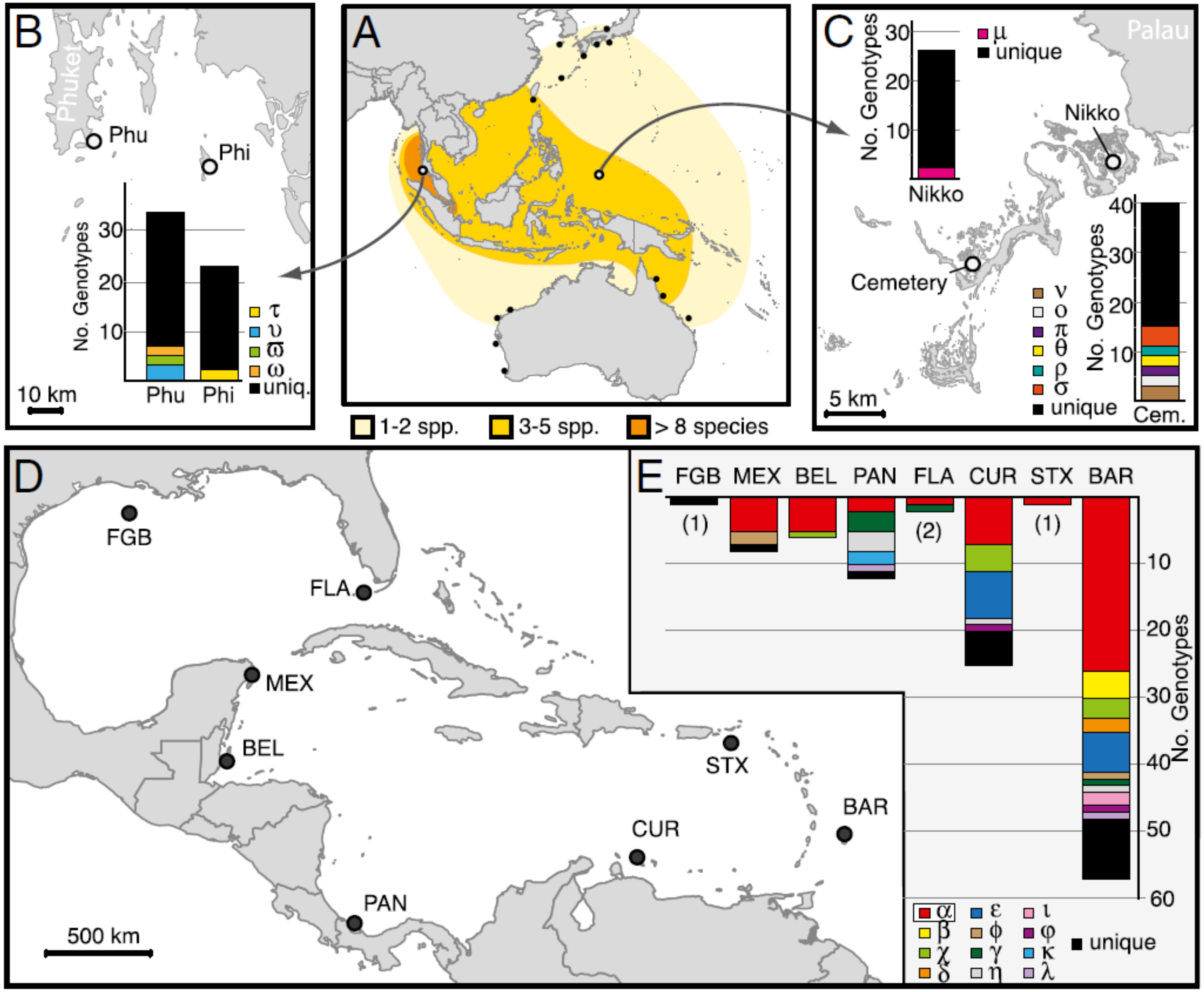
Byler et al. (2013): Plos ONE

Habitat adapted symbiosis

- Avoiding coral bleaching by a symbiont switch?
  - ➢ Invasion of the Caribbean, heat-tolerant symbiont in the Gulf of Mexico



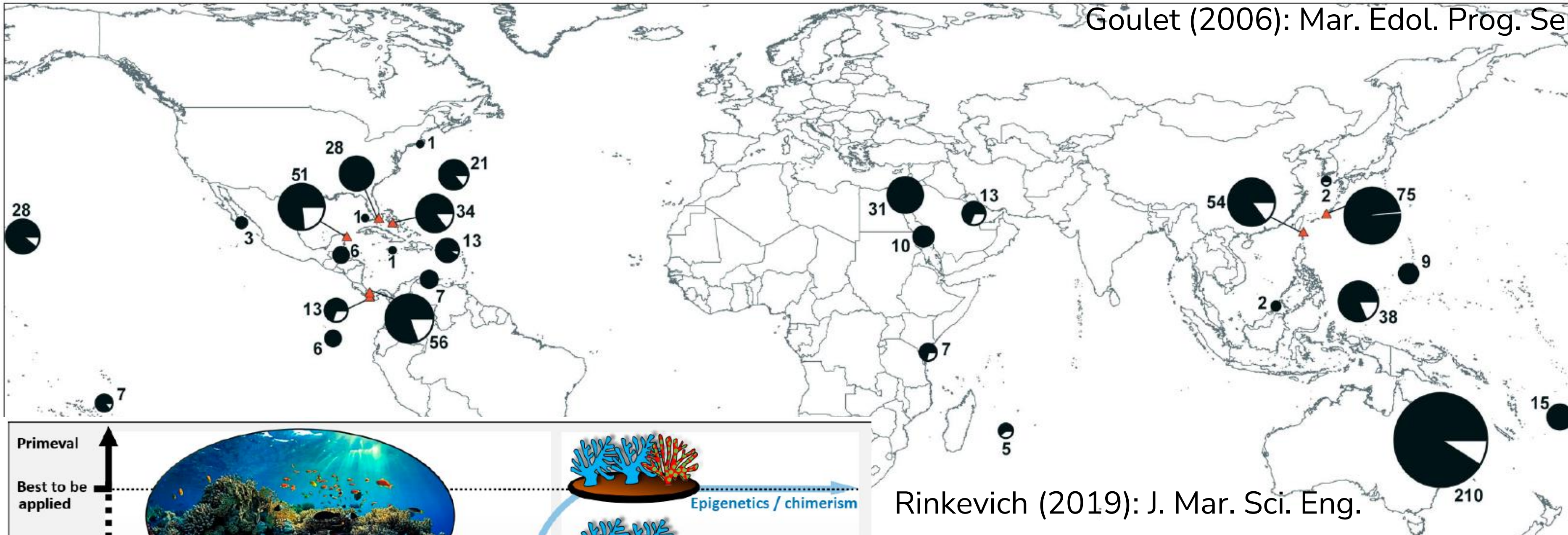
Rowan (2004): Nature



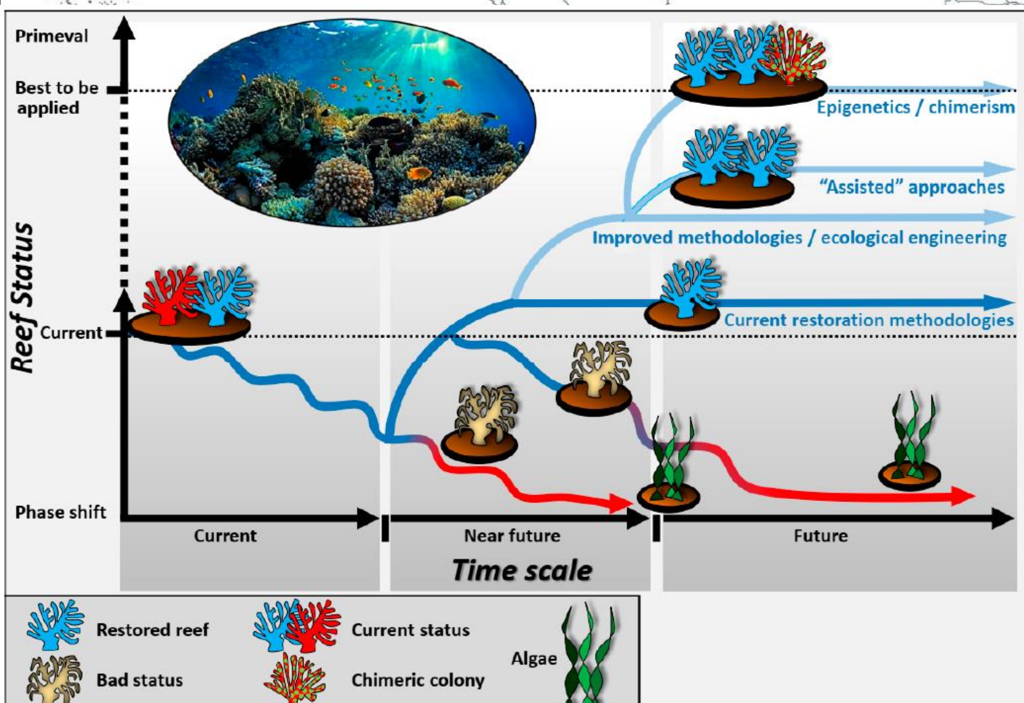
Pettay et al. (2015): PNAS

Habitat adapted symbiosis

- Only 23% of coral species host multiple symbions



Goulet (2006): Mar. Edol. Prog. Ser.

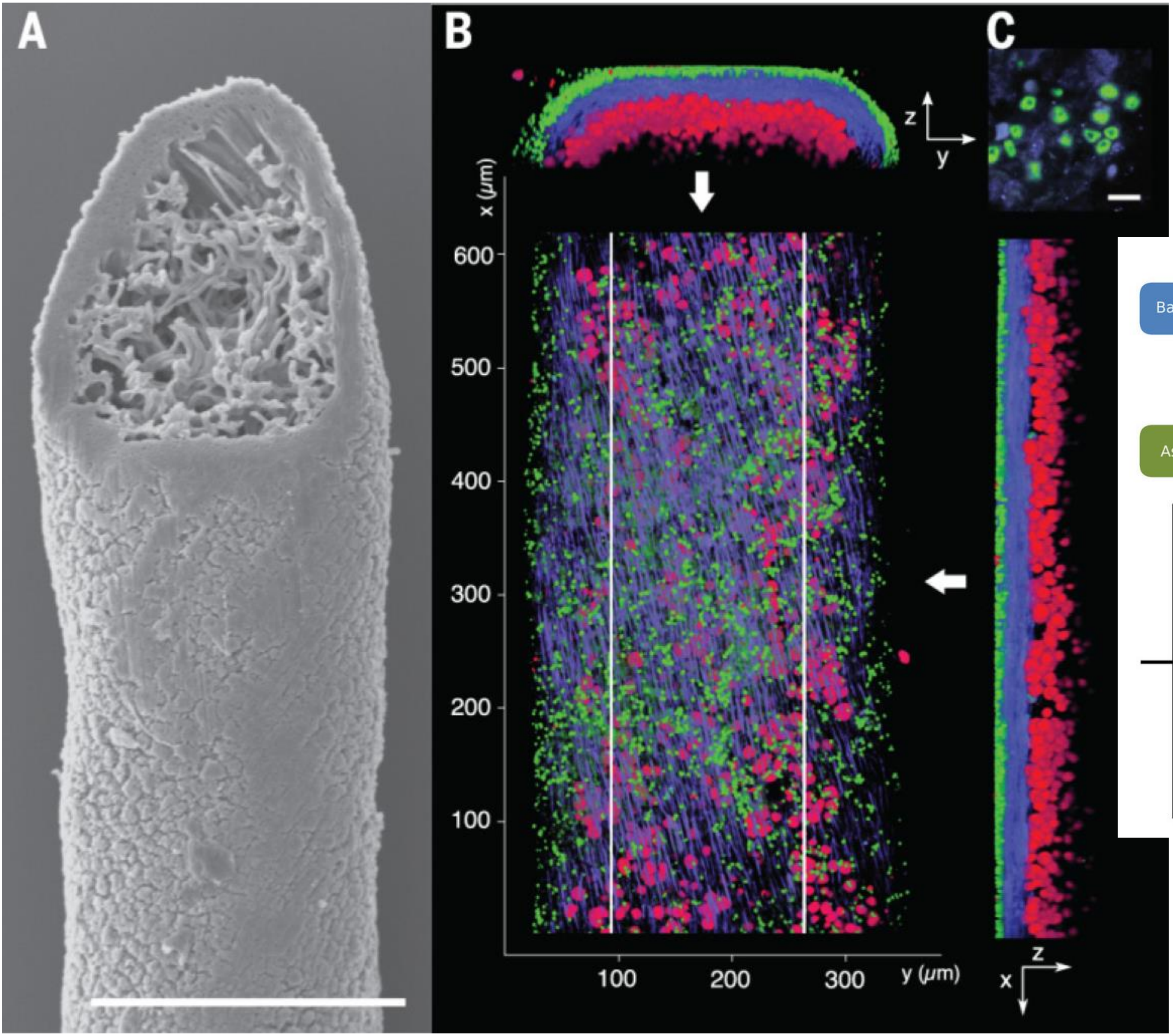


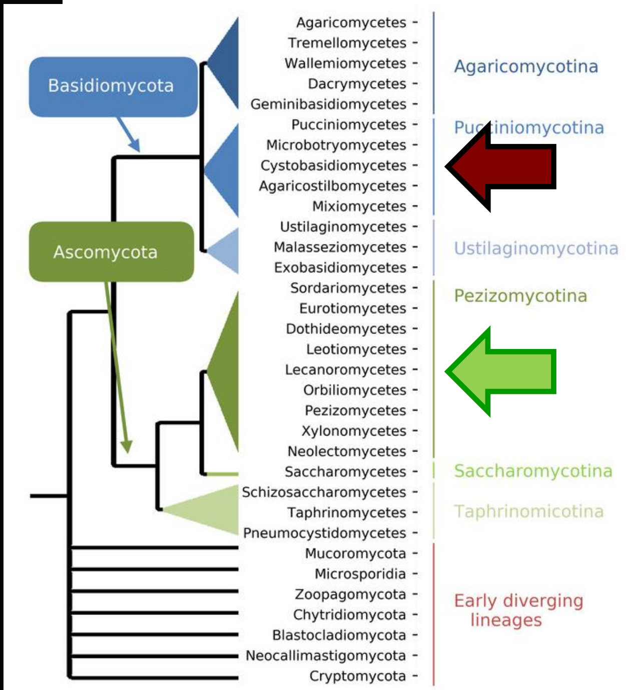
Rinkevich (2019): J. Mar. Sci. Eng.

The University of Hong Kong

Revolution in symbiosis research

- Basidiomycete yeasts as a third partner in lichen symbiosis?

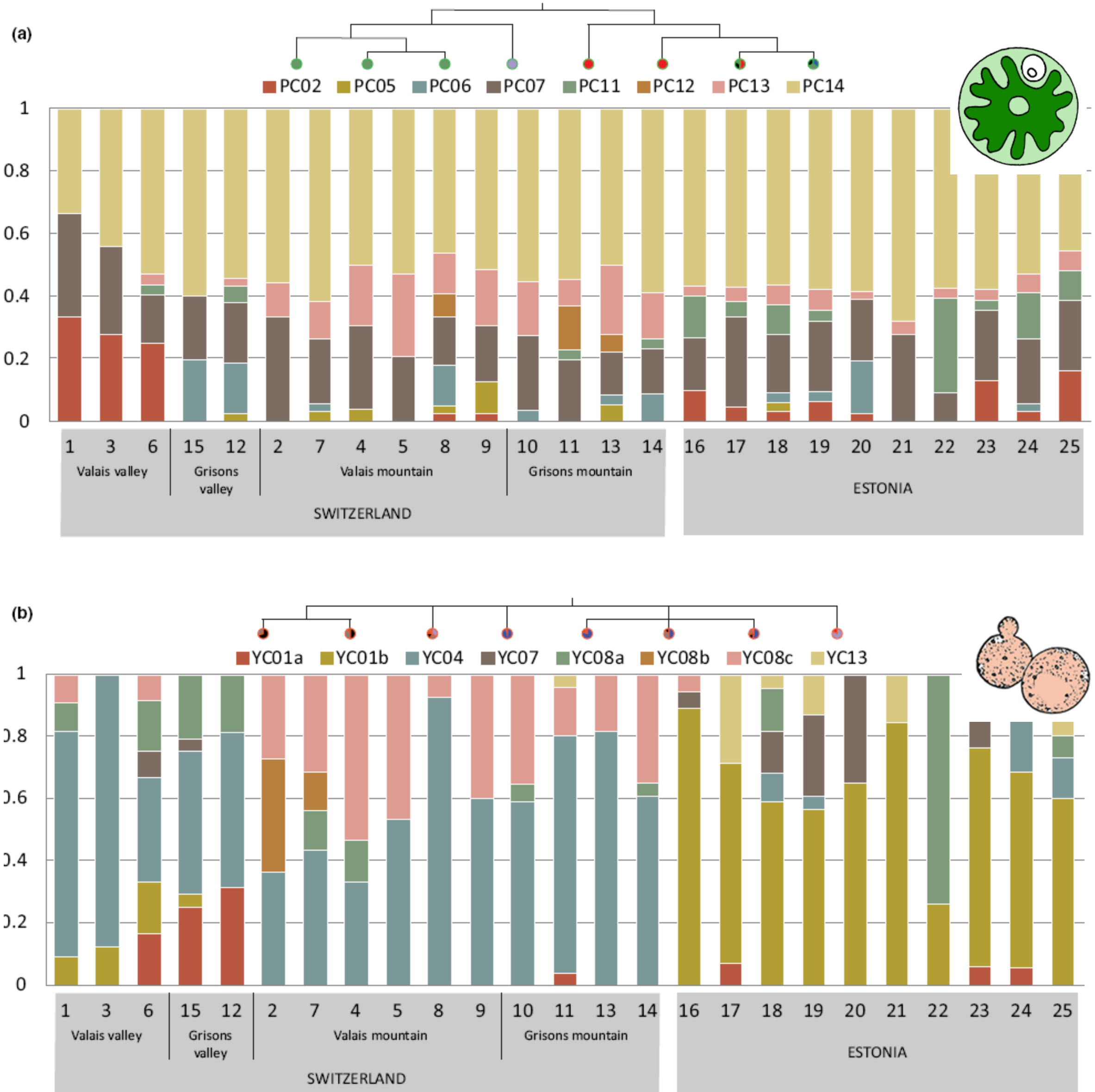


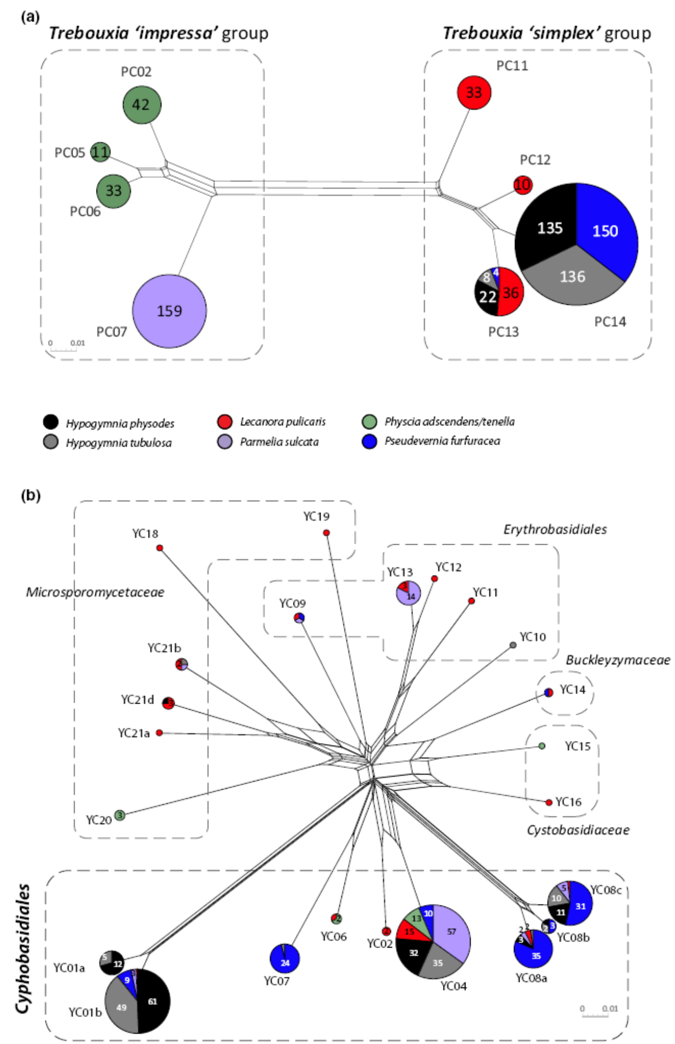


Spribille et al. (2016): Science

Revolution in symbiosis research

- Yeasts not omnipresent, much less lichen-specific than the included algae

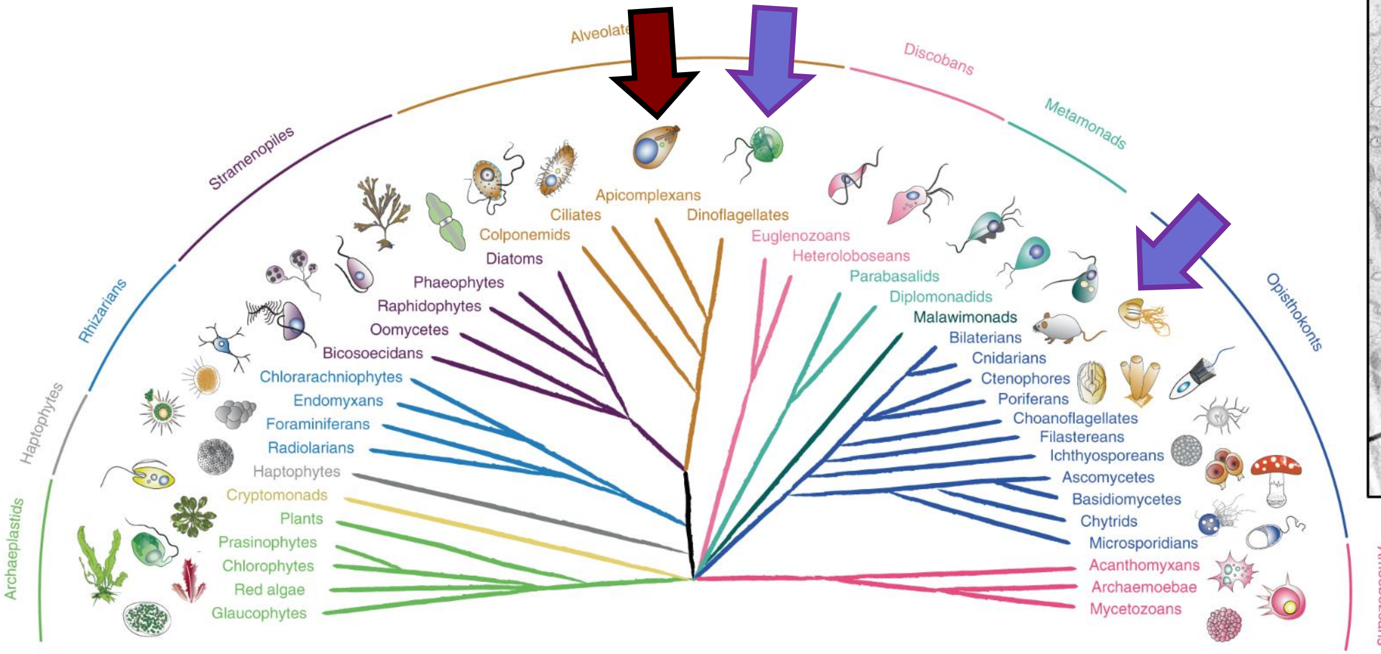


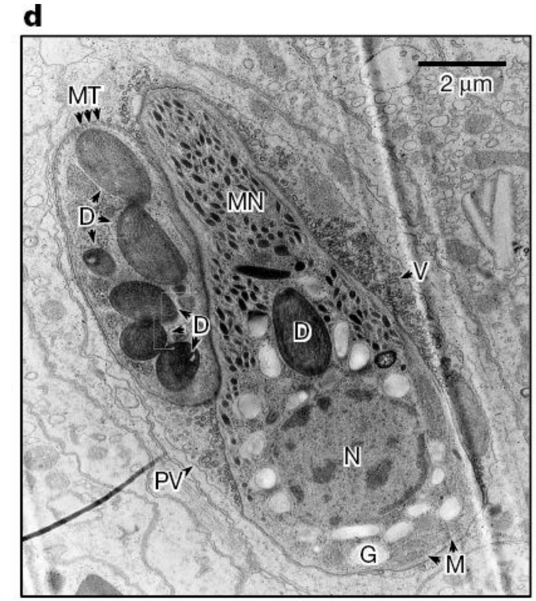


Mark et al. (2020): New Phytol.

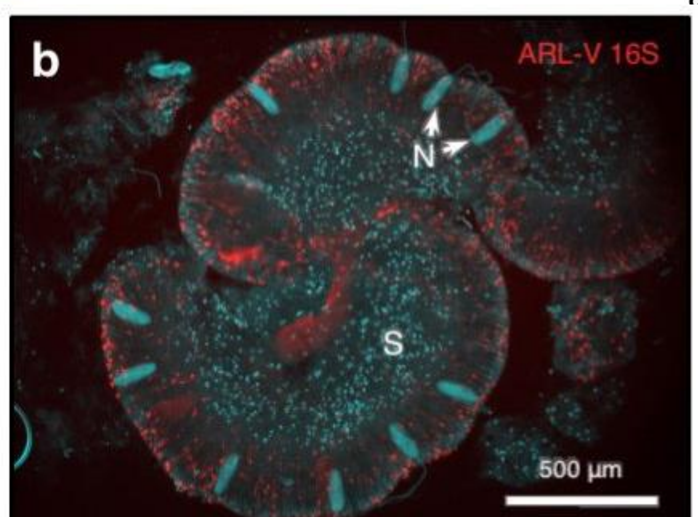
Revolution in symbiosis research

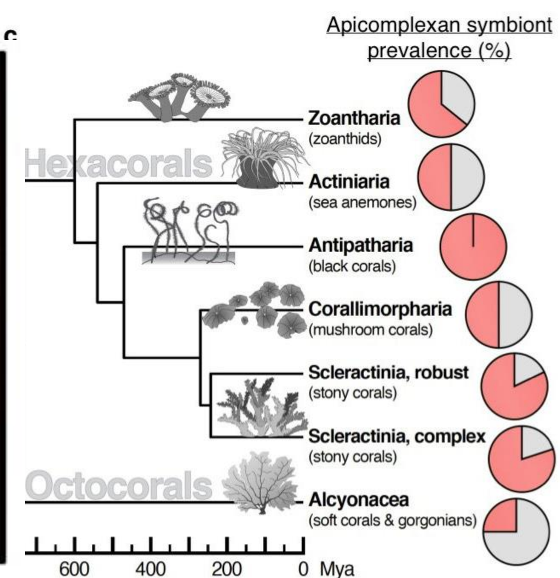
- Corallicolids – a third partner in coral symbiosis?





Kwong et al. (2019): Nature

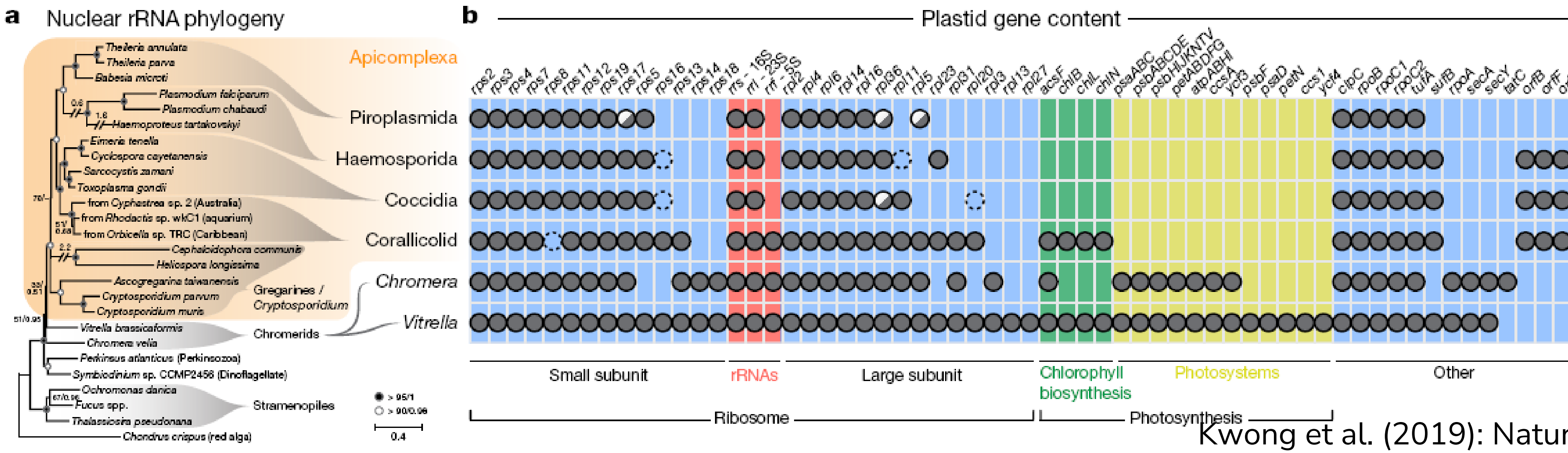




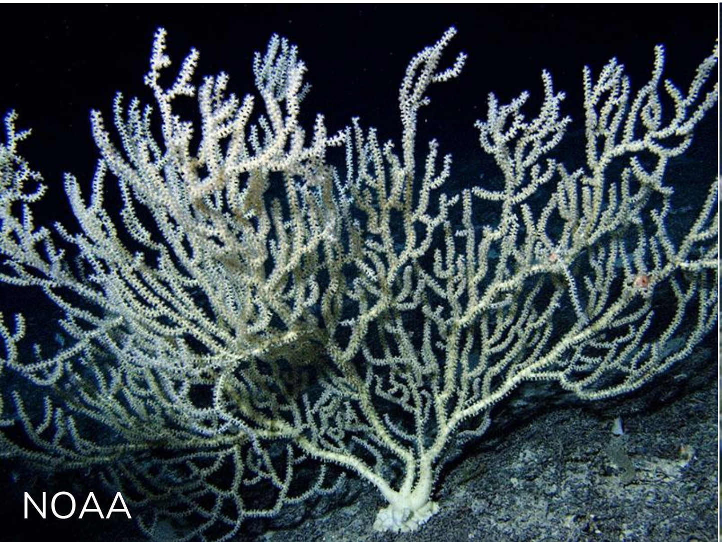
Revolution in symbiosis research

- Corallicolids – a third partner in coral symbiosis?
  - ➢ Chlorophyll genes with unknown function (survival at low-oxygen environments?)

Vohsen et al. (2020): Microbiome



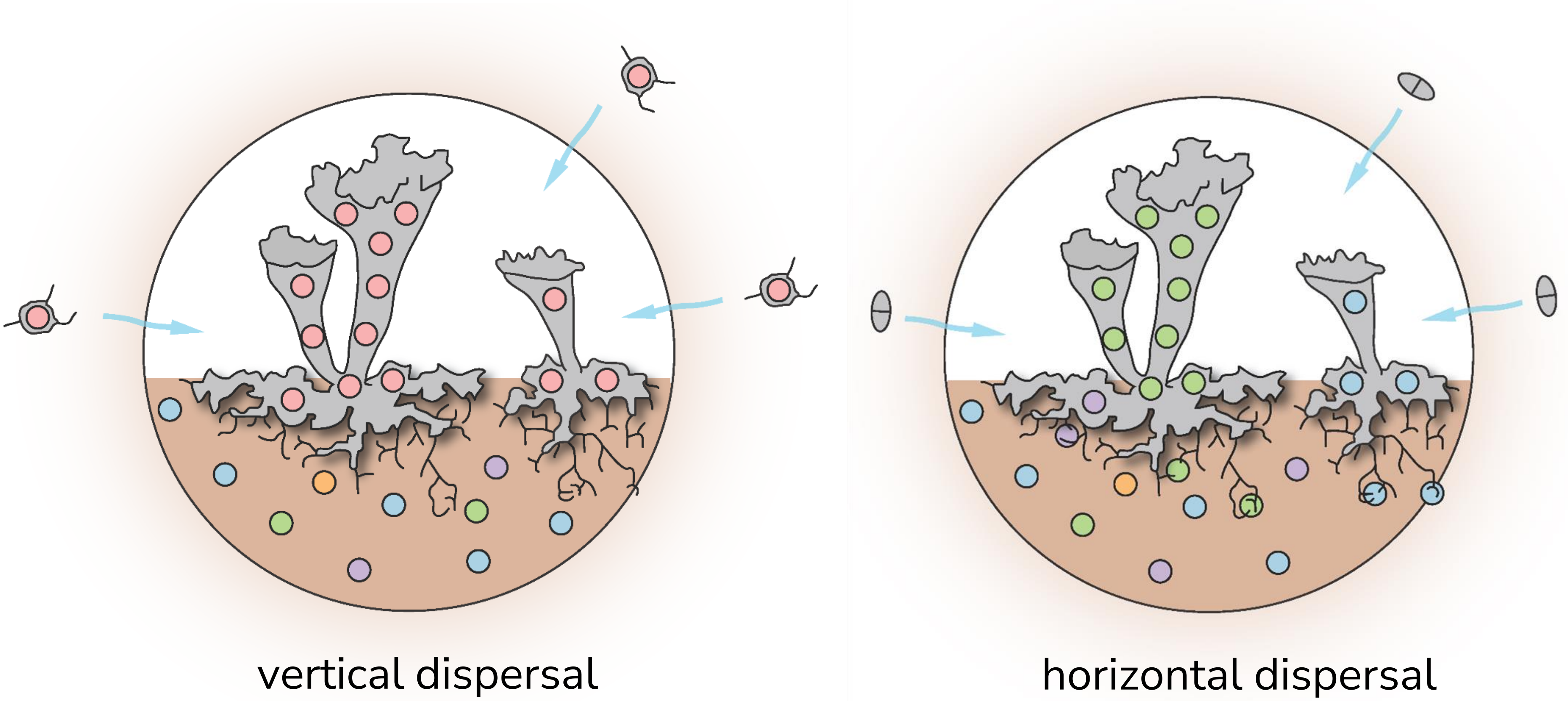
Kwong et al. (2019): Nature



Paradox I.

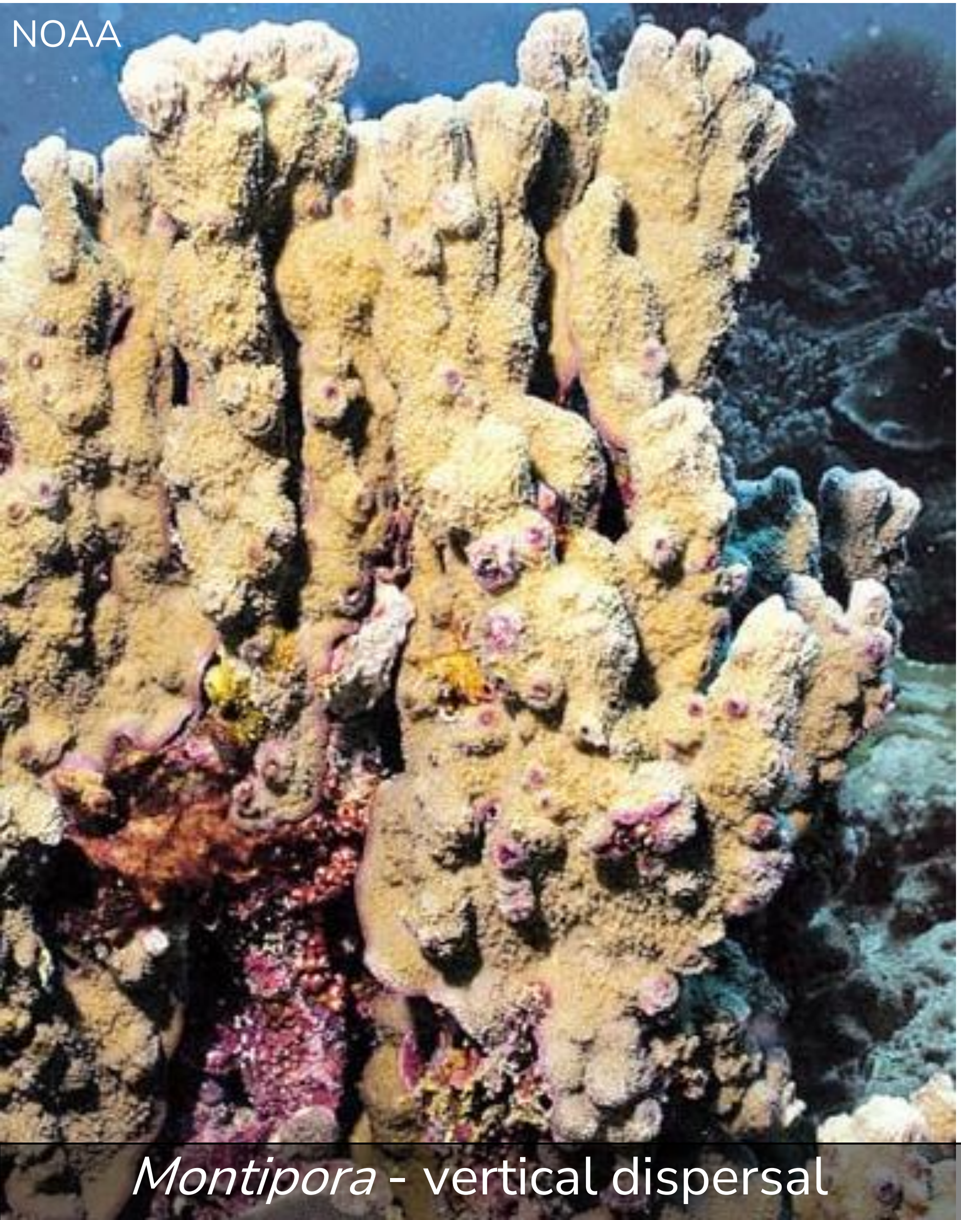
Contrasting diversity of differently dispersed symbionts?

- Hosts that maternally transfer symbionts to their offspring (vertical dispersal) might be expected to contain less diverse symbionts than hosts which are required to obtain them environmentally (horizontal dispersal).



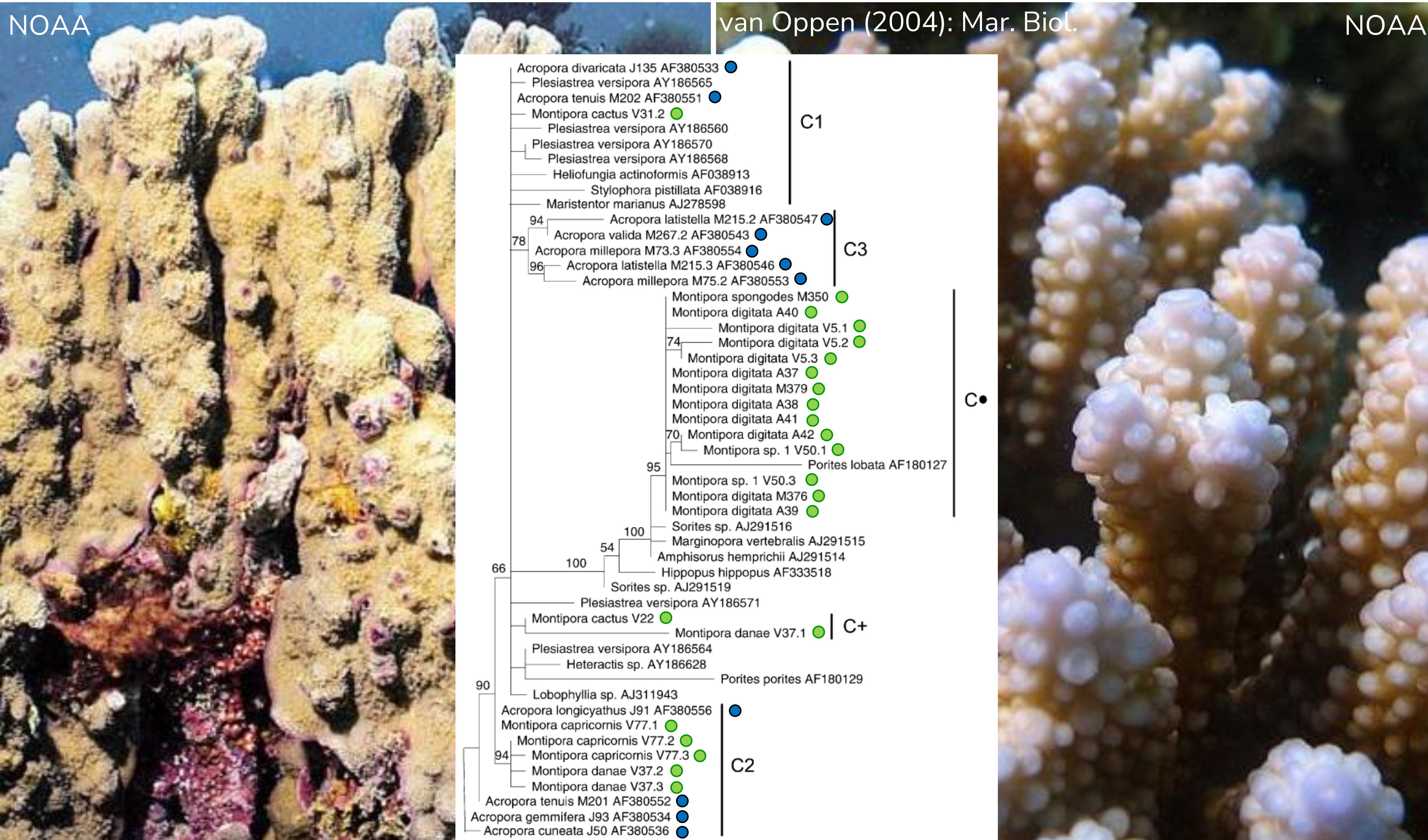
Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity



Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity

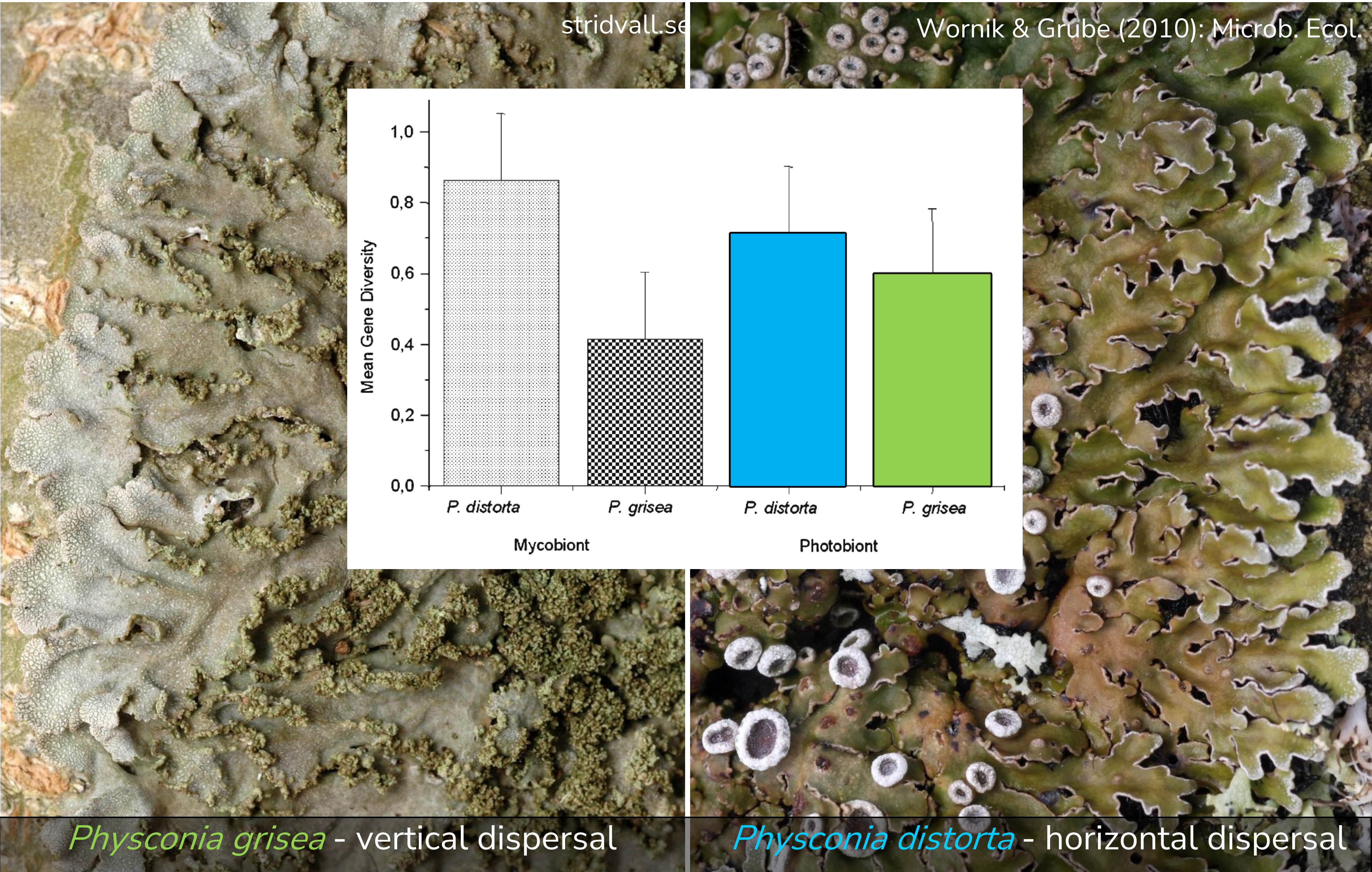


Montipora - vertical dispersal

Acropora - horizontal dispersal

Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity

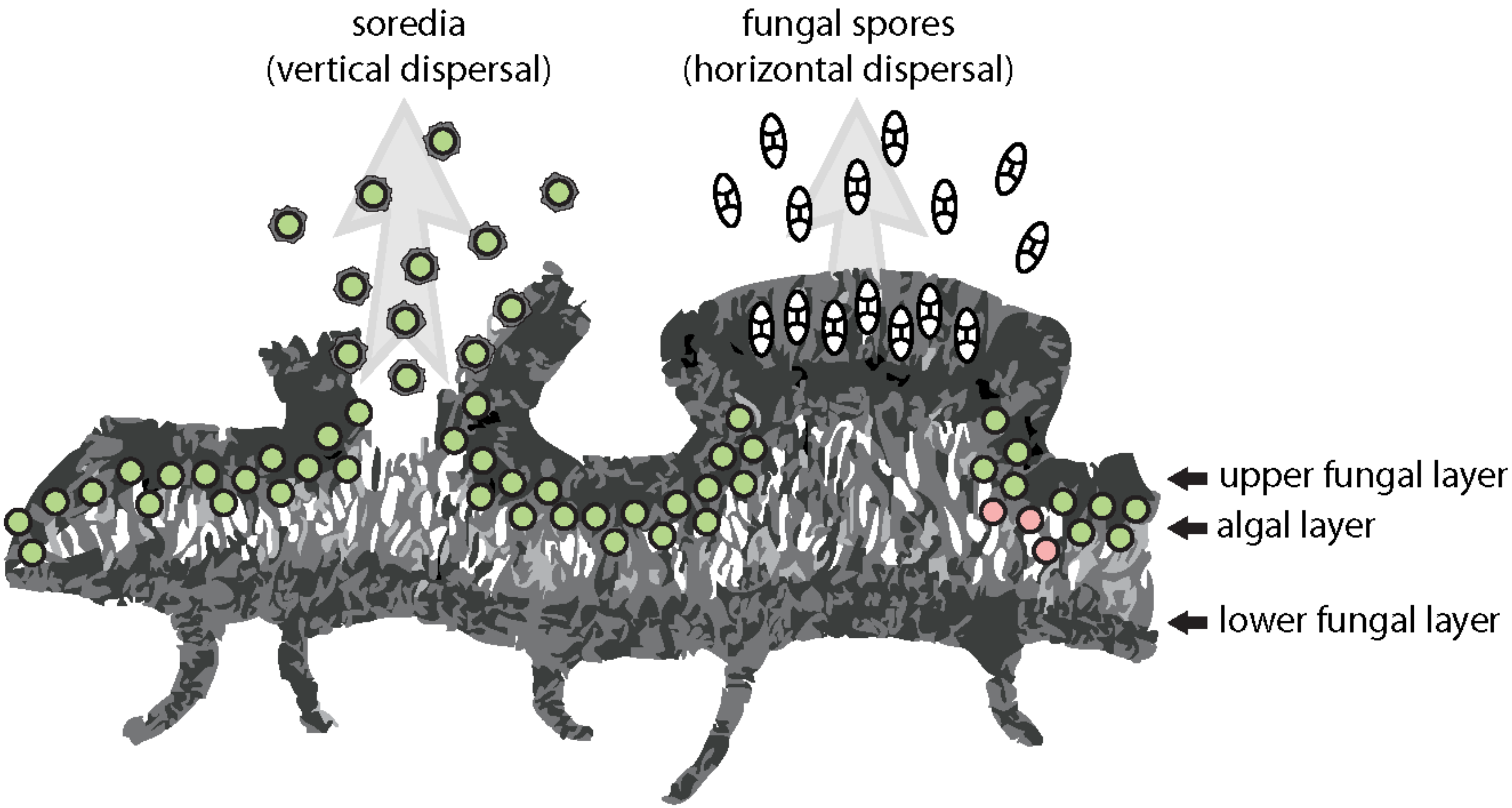


Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity

- Why do hosts maintain vertical dispersal of symbionts?

  - Need to convince the symbiont to travel with the host
  - Need to form specialized structures
  - The propagules are heavy, produced in less quantities in comparison with sexual offspring



Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity

- Why do hosts maintain vertical dispersal of symbionts?

  - To win the battle against other symbionts in a local space

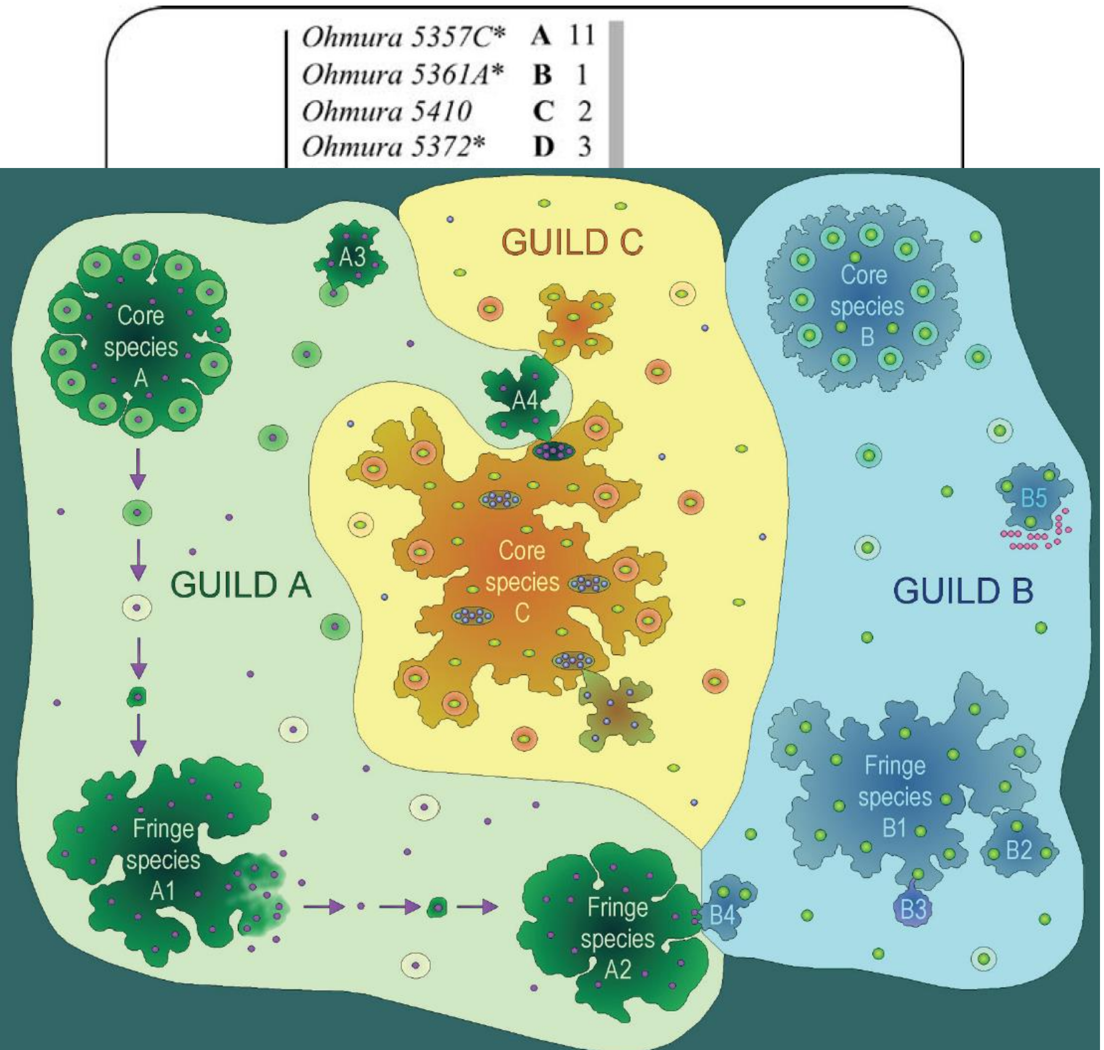
Paradox I.

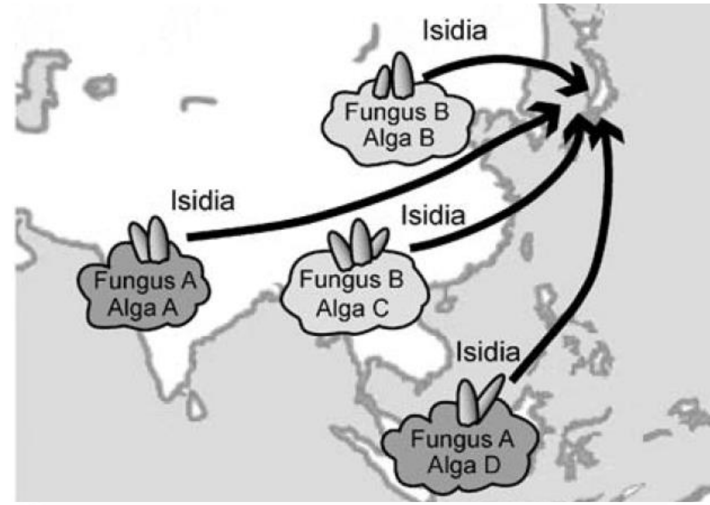
The mode of symbiont dispersal does not affect symbiont diversity

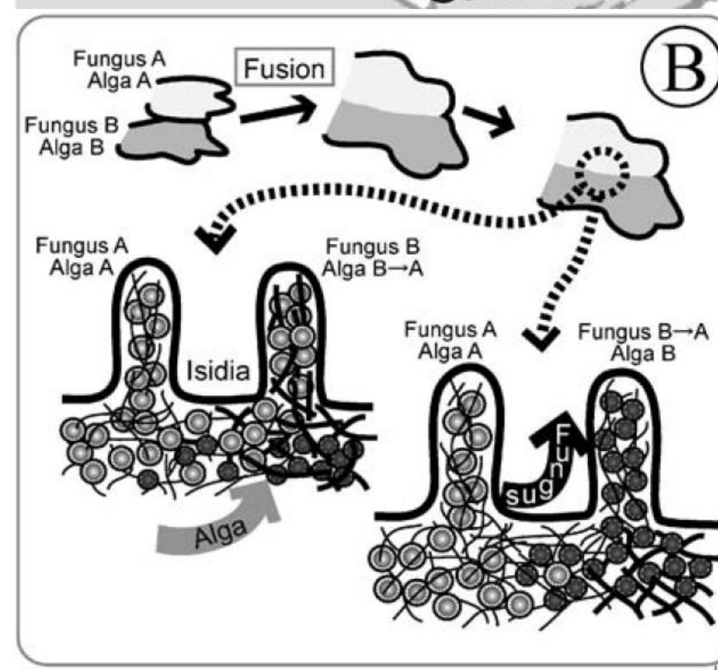
Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity

- Exceptionally high diversity of symbionts for a vertically-dispersed lichen (23 genotypes)
- Long dispersal? Fungal fusion?



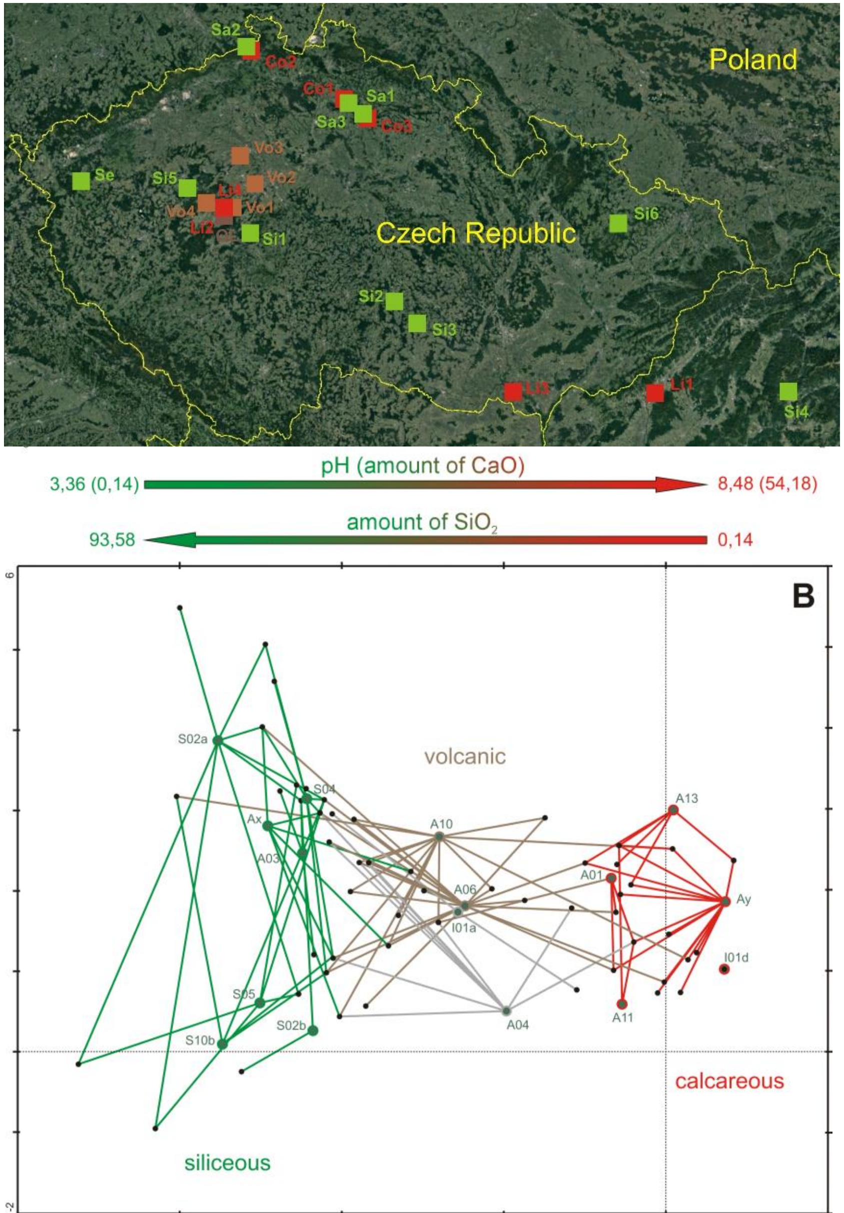


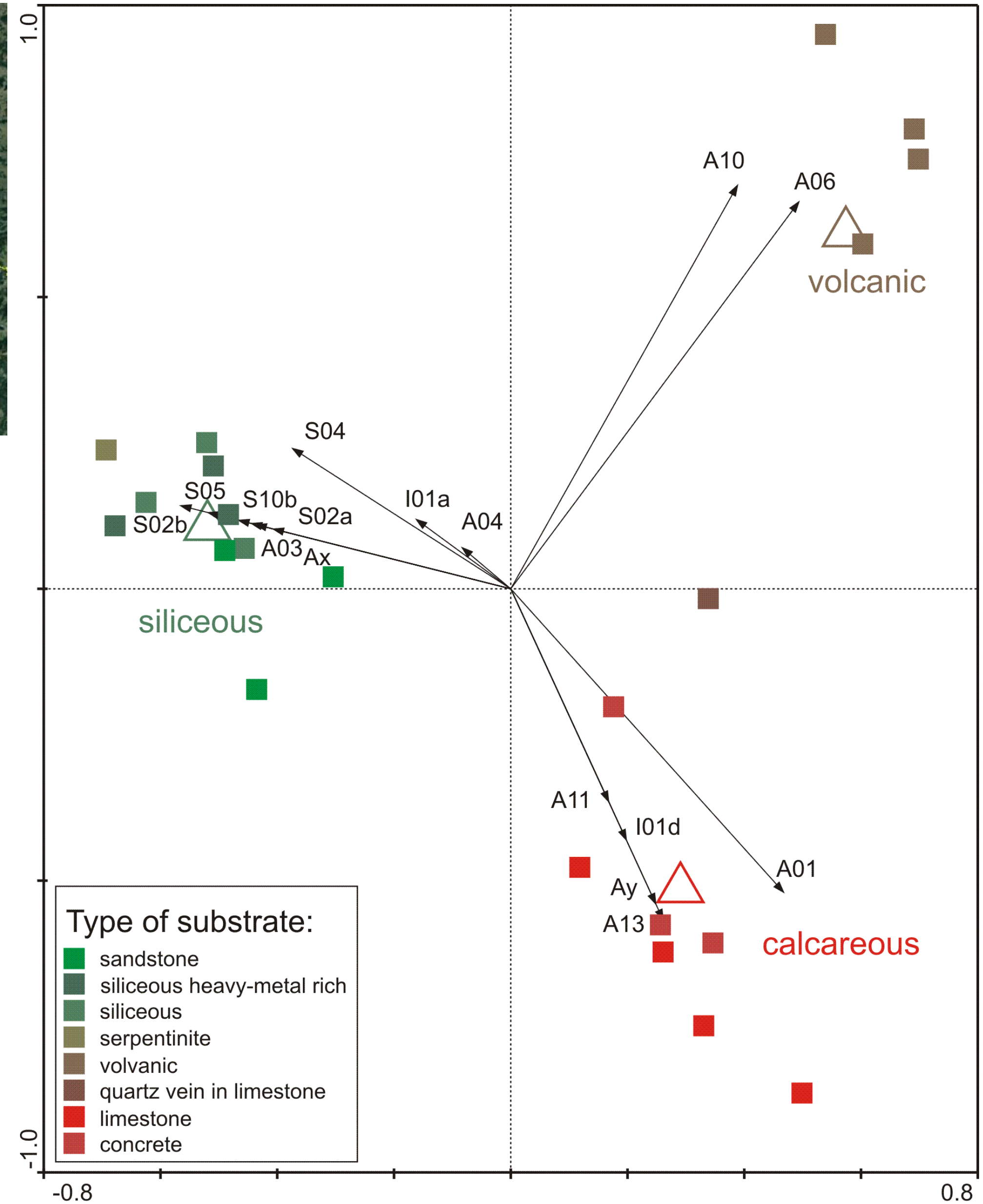


Ohmura et al. (2006): Bryologist

Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity



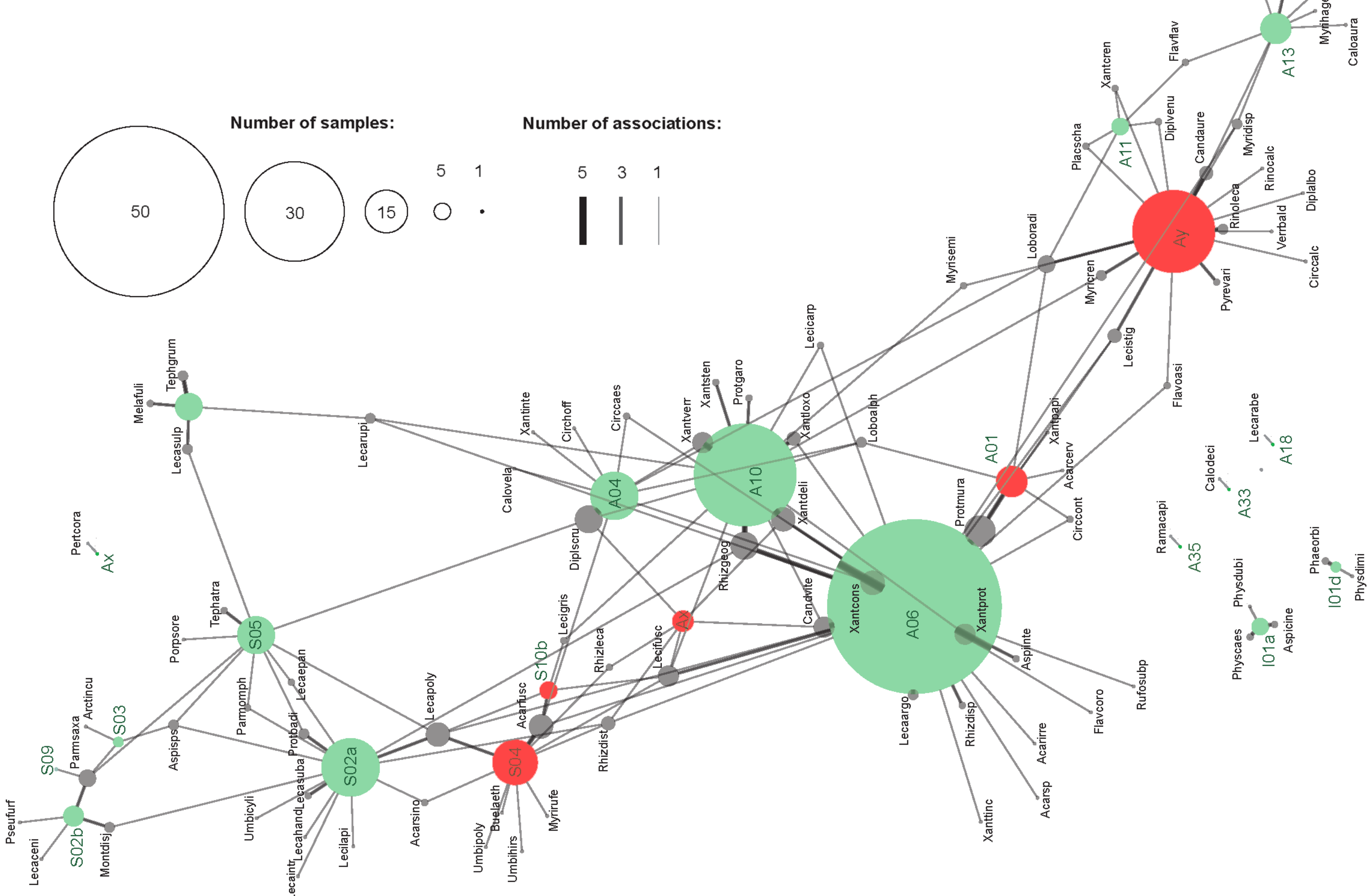


Peksa et al. (2022): FEMS Microb. Ecol. (*in press*)

Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity

- A number symbionts were found exclusively in horizontally-dispersed lichens!
- Core species do not act as symbiont distributors
- Rejecting the fungal fusion theory

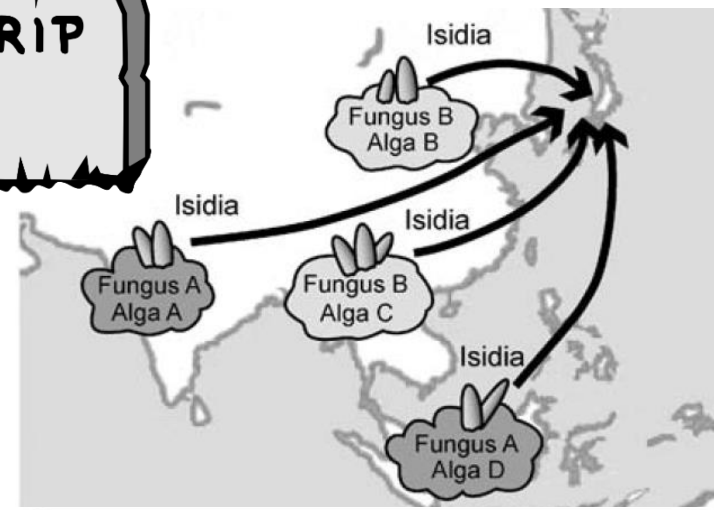


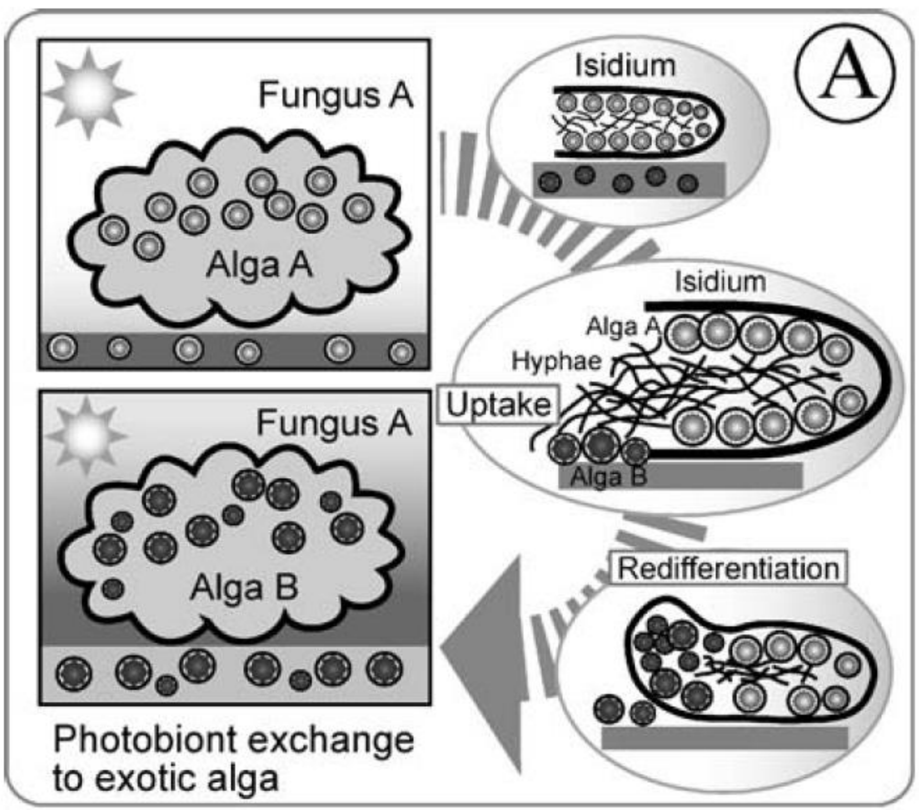
Peksa et al. (2022): FEMS Microb. Ecol. (*in press*)

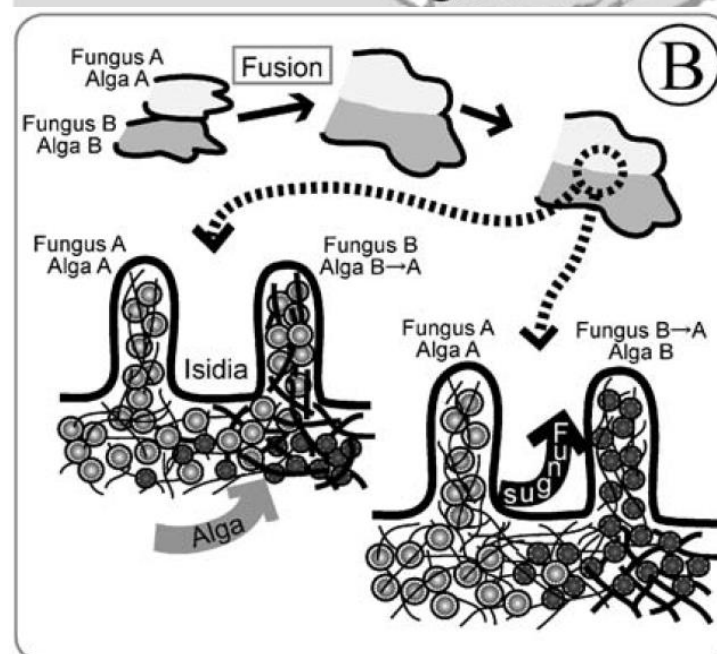
Paradox I.

The mode of symbiont dispersal does not affect symbiont diversity

- No long dispersal
- No fungal fusion
- **Symbiont switch to locally-adapted alga!**





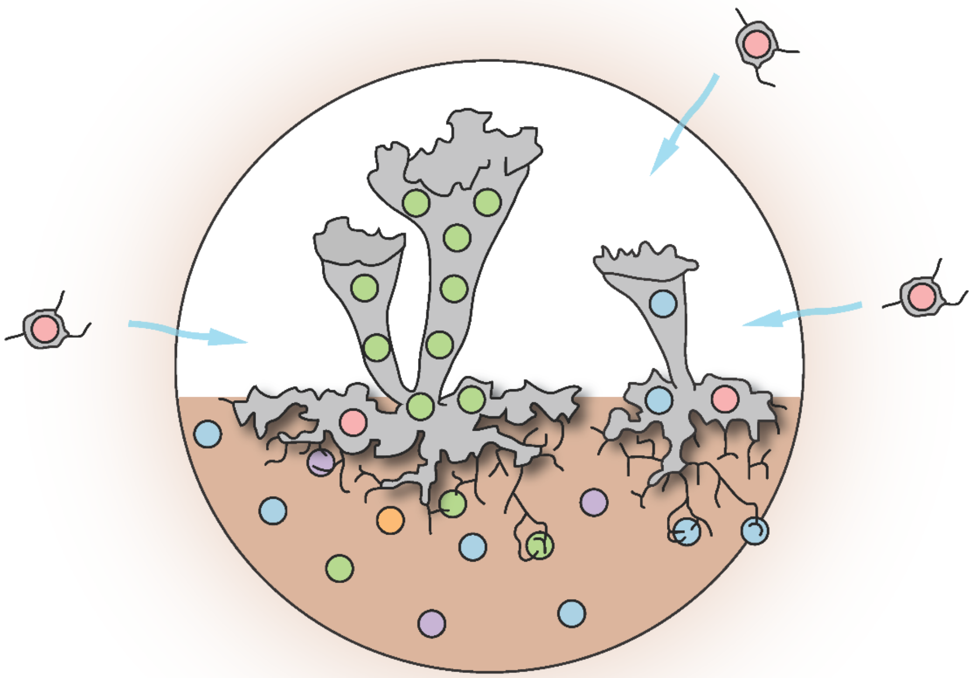


Ohmura et al. (2006): Bryologist

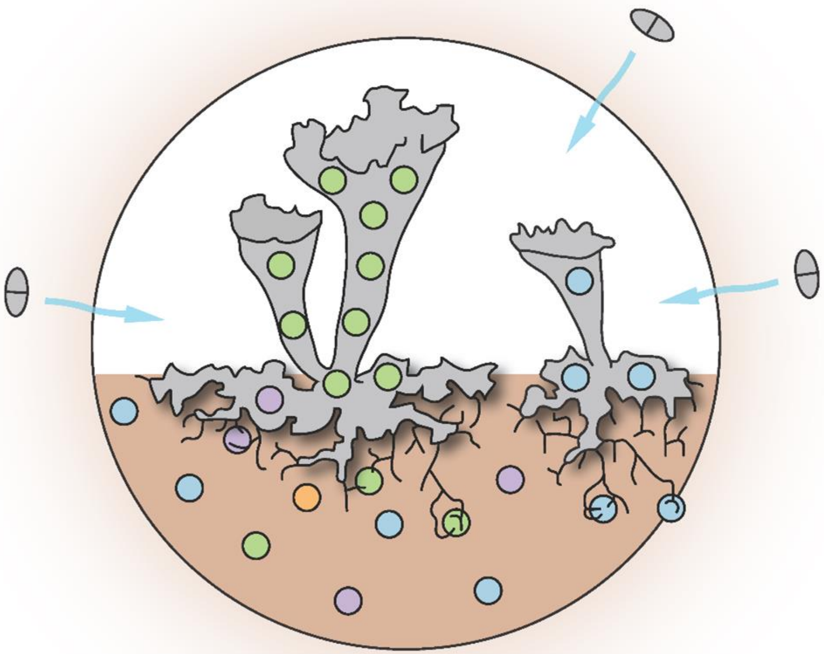
Paradox II.

Symbiont switch to locally-adapted alga?

- Hosts are selecting their algal symbionts from a regional pool of free-living algae, preferring well adapted local genotypes



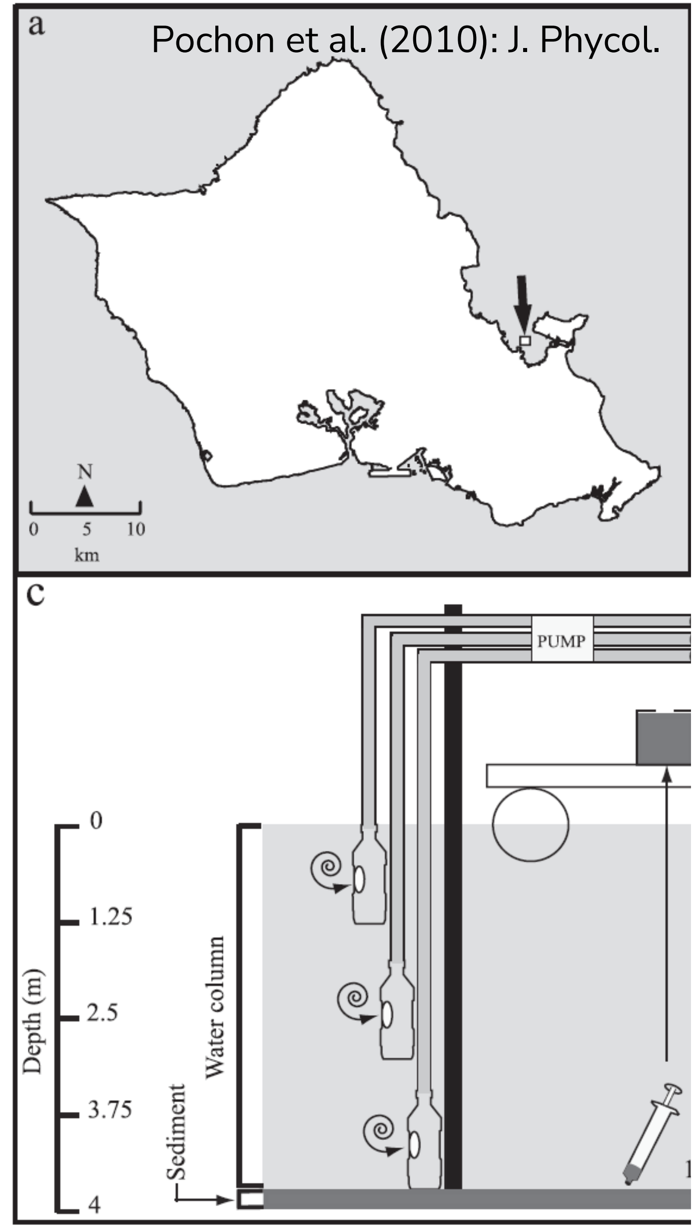
vertical dispersal



horizontal dispersal

Paradox II.

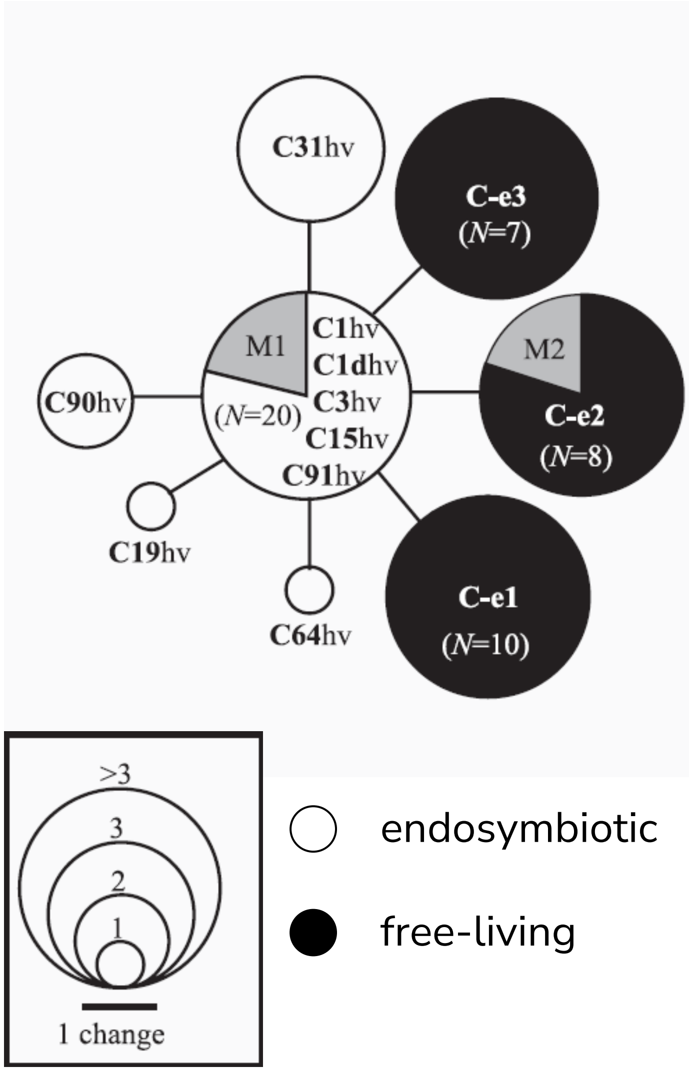
Host symbionts are physically absent in the environment



Paradox II.

Host symbionts are physically absent in the environment

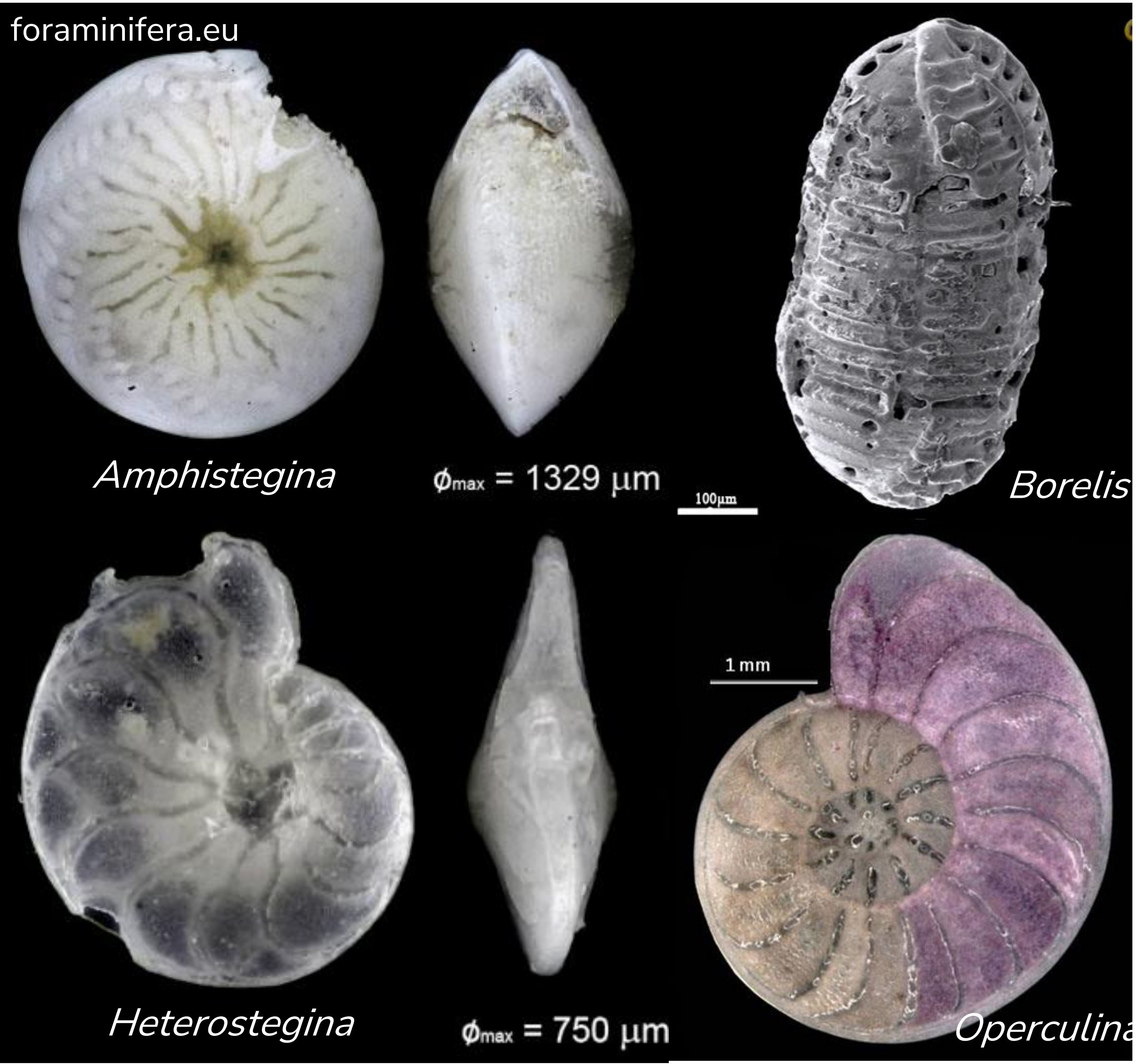
- No overlap between endosymbiotic and free-living communities of symbionts

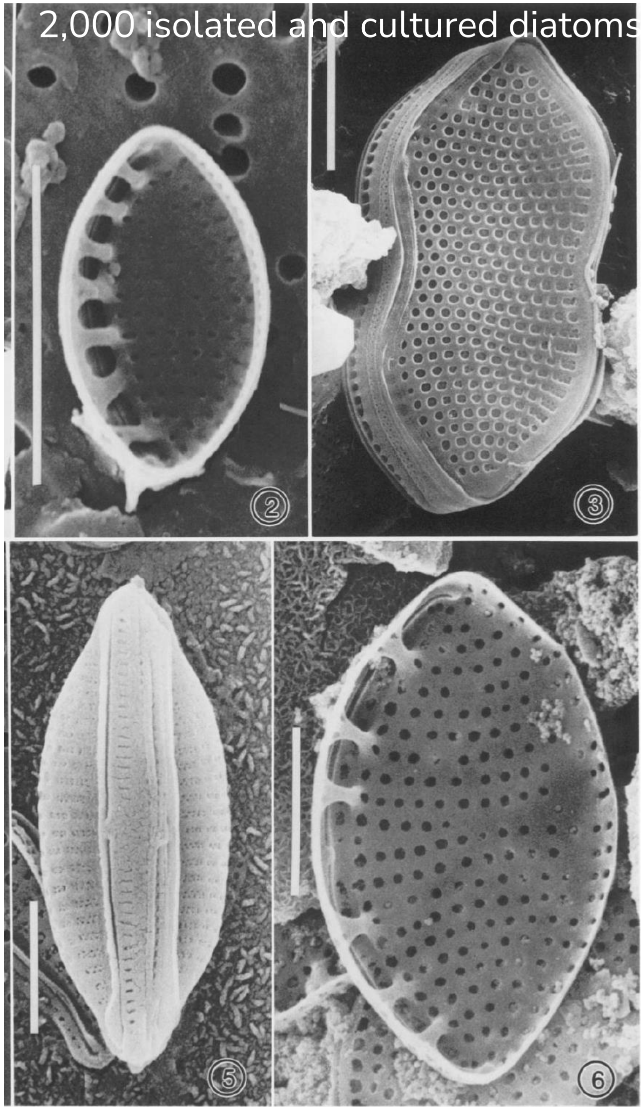


Pochon et al. (2010): J. Phycol.

Paradox II.
Host symbionts are physically absent in the environment

- Foraminifera endosymbiotic diatoms were extremely rare in the nearby habitat (<0.5%)





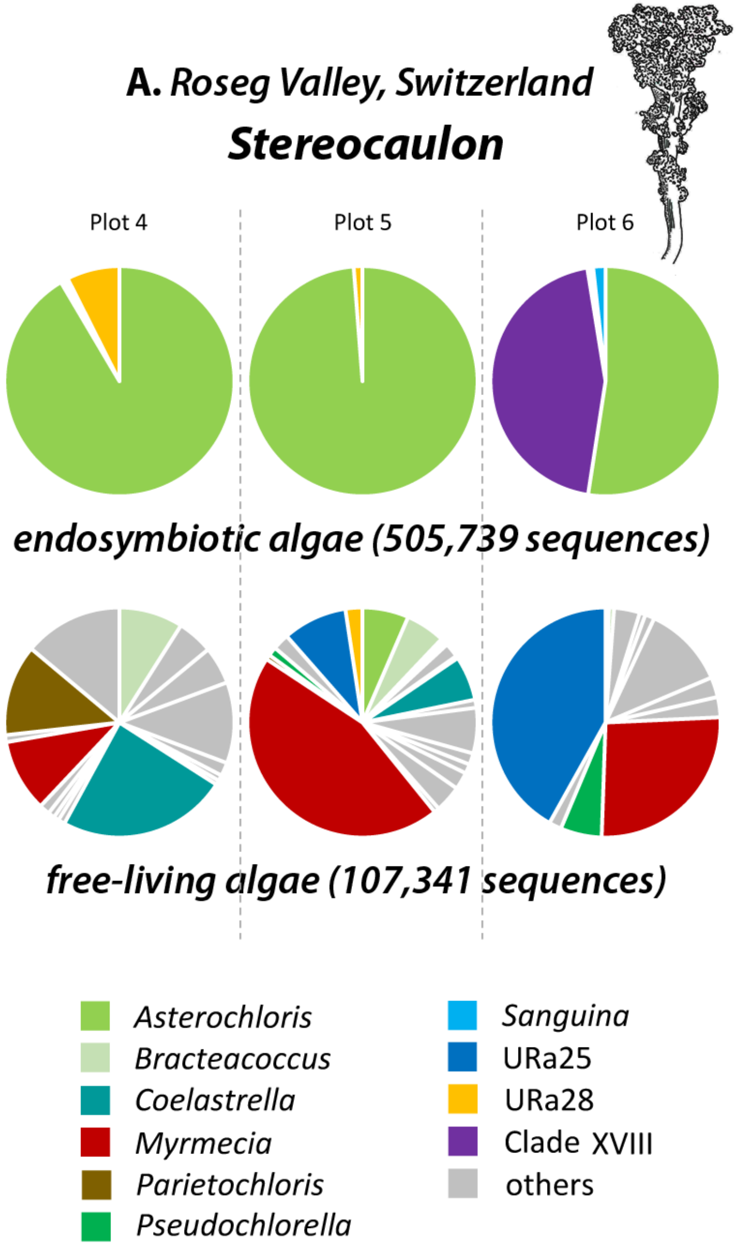
Lee et al. (1989): Micropaleontology

Paradox II.

Host symbionts are physically absent in the environment

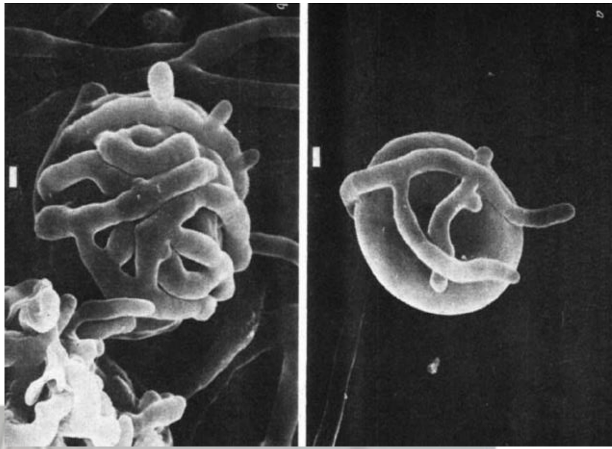
- Symbiosis dynamics on river gravel bars
- Selected plots - sequencing all endosymbiotic and free-living algae

Vančurová et al. (2020): Algal Res.



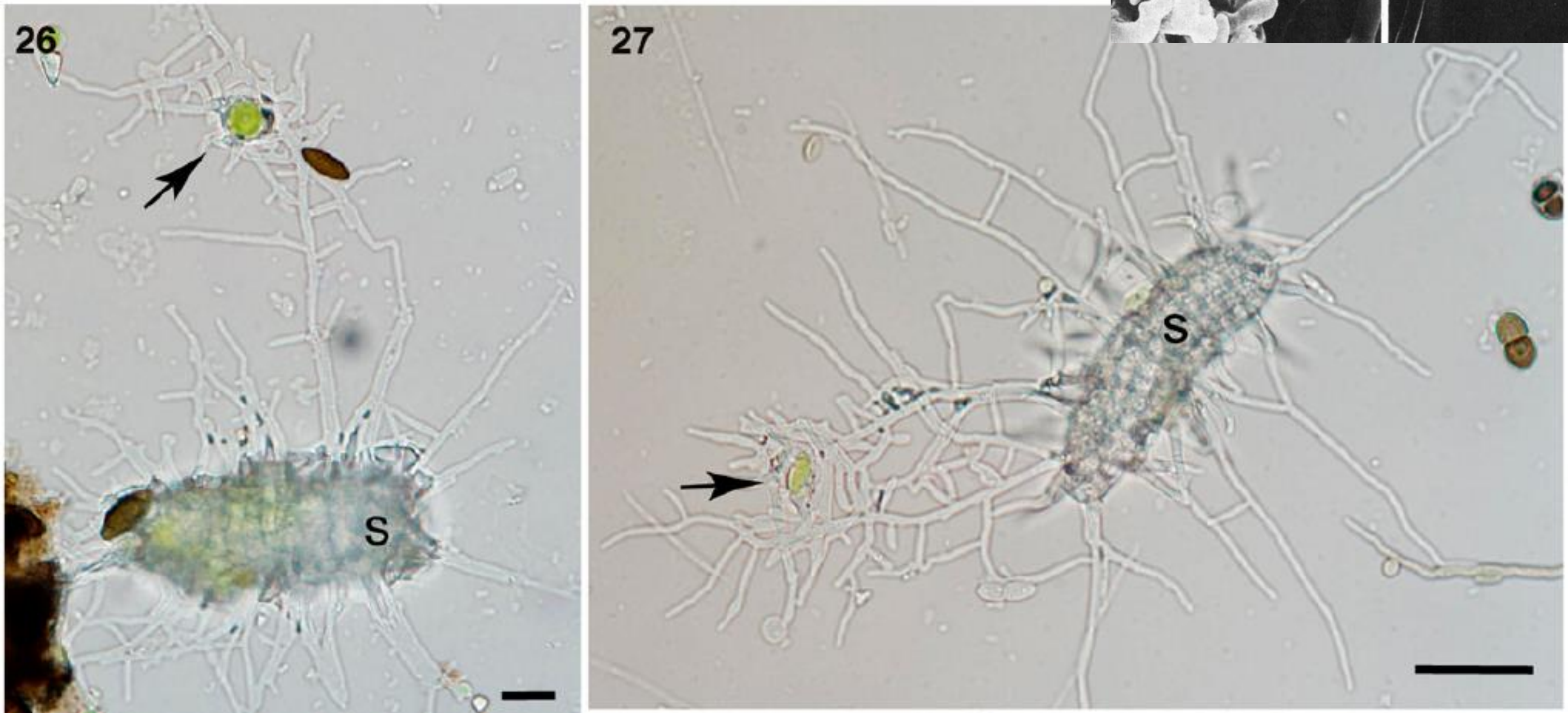
Paradox II.

Host symbionts are physically absent in the environment



- 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

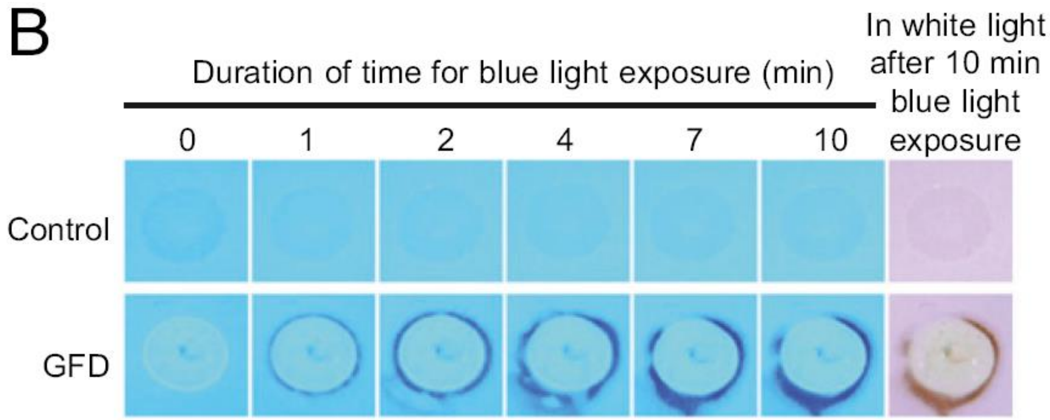


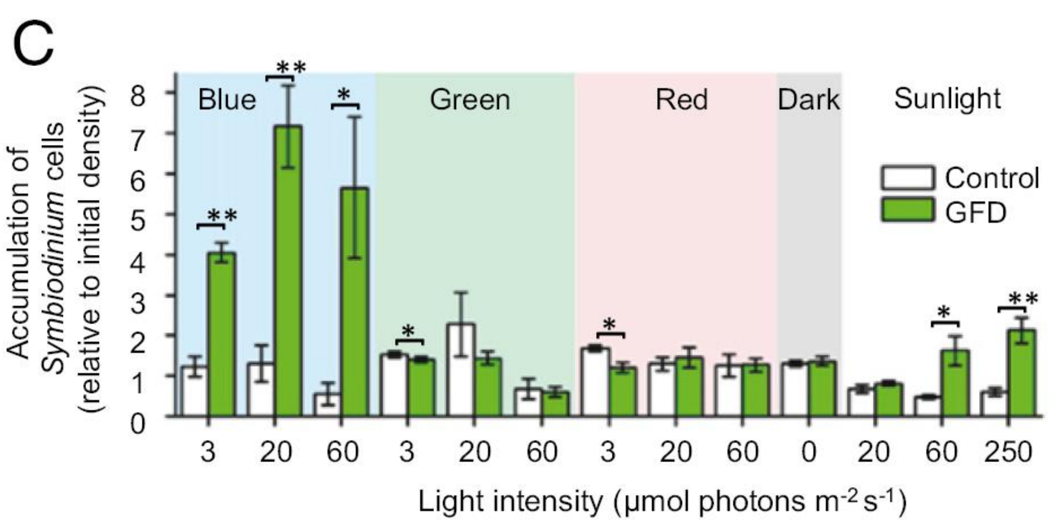
Sanders et al. (2014): Am. J. Bot.

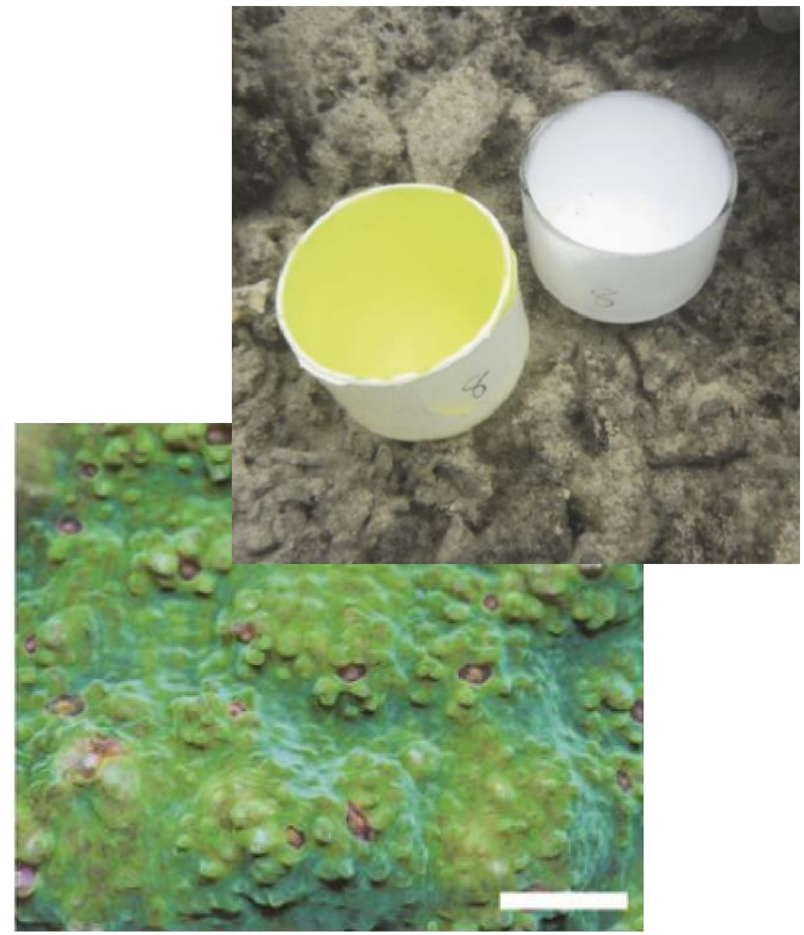
Paradox II.

Host symbionts are physically absent in the environment

- 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

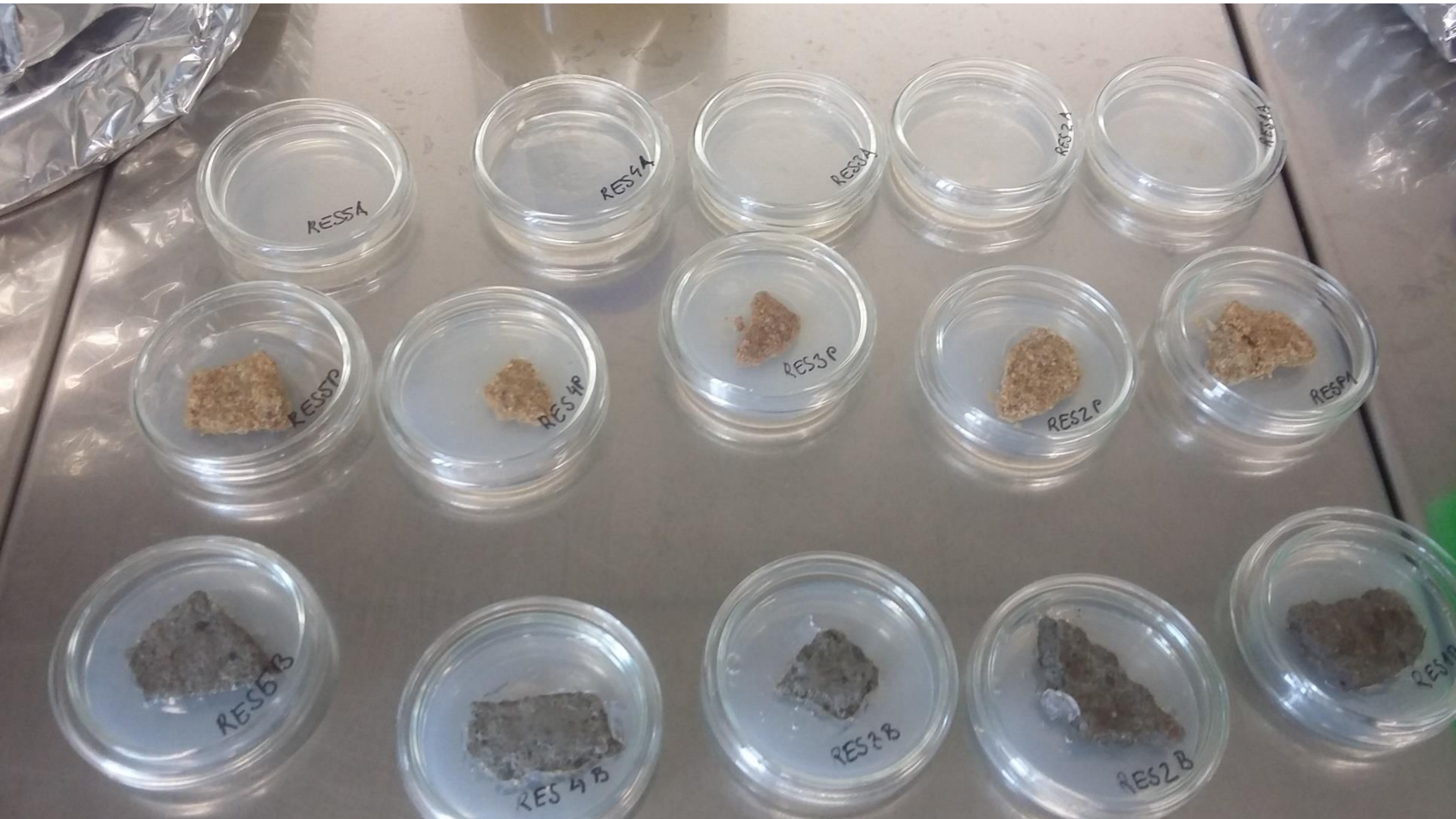
Paradoxes of lichen symbiosis

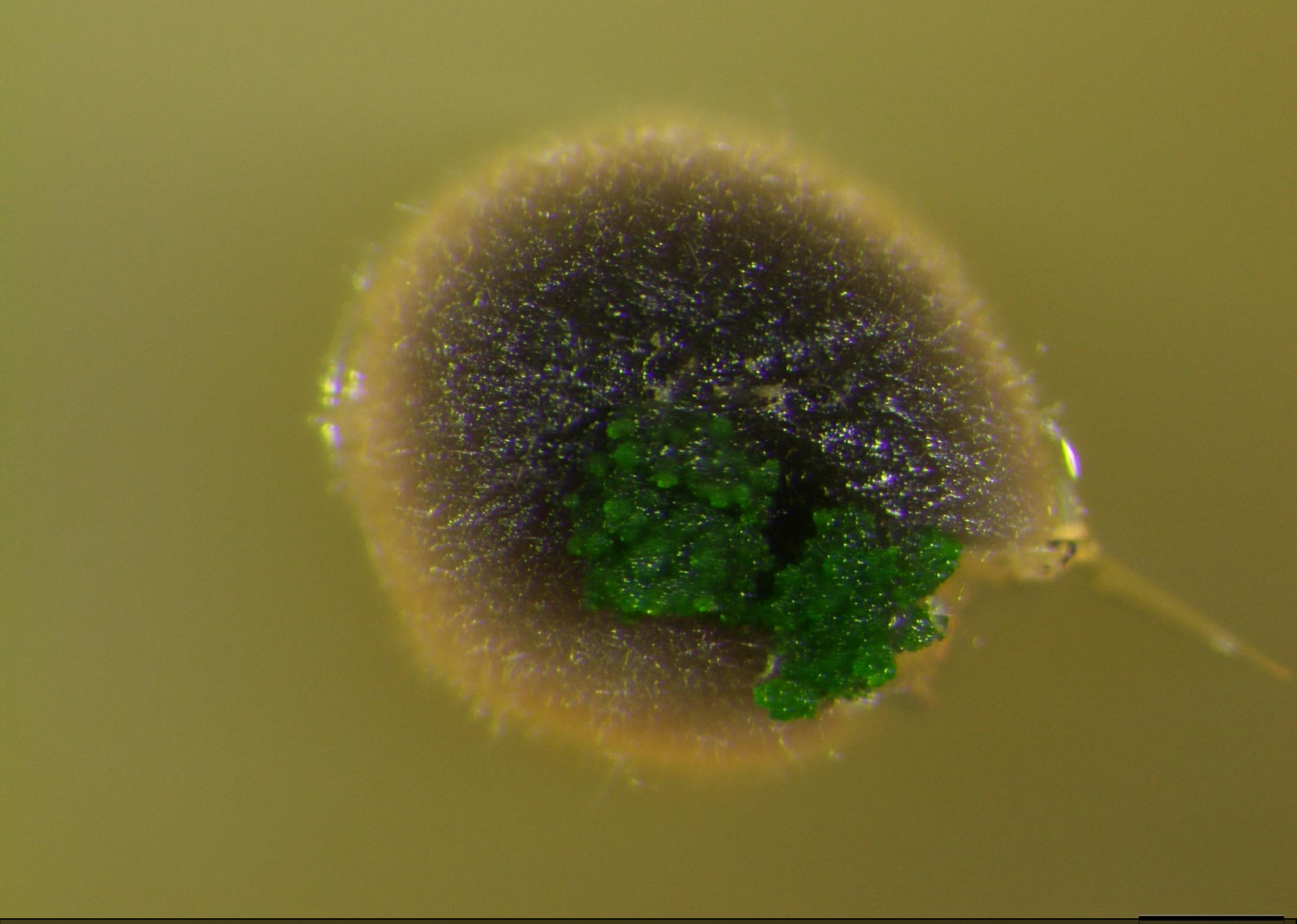
- Lichens have two types of dispersal propagules, one of them not being used for dispersal

- 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)

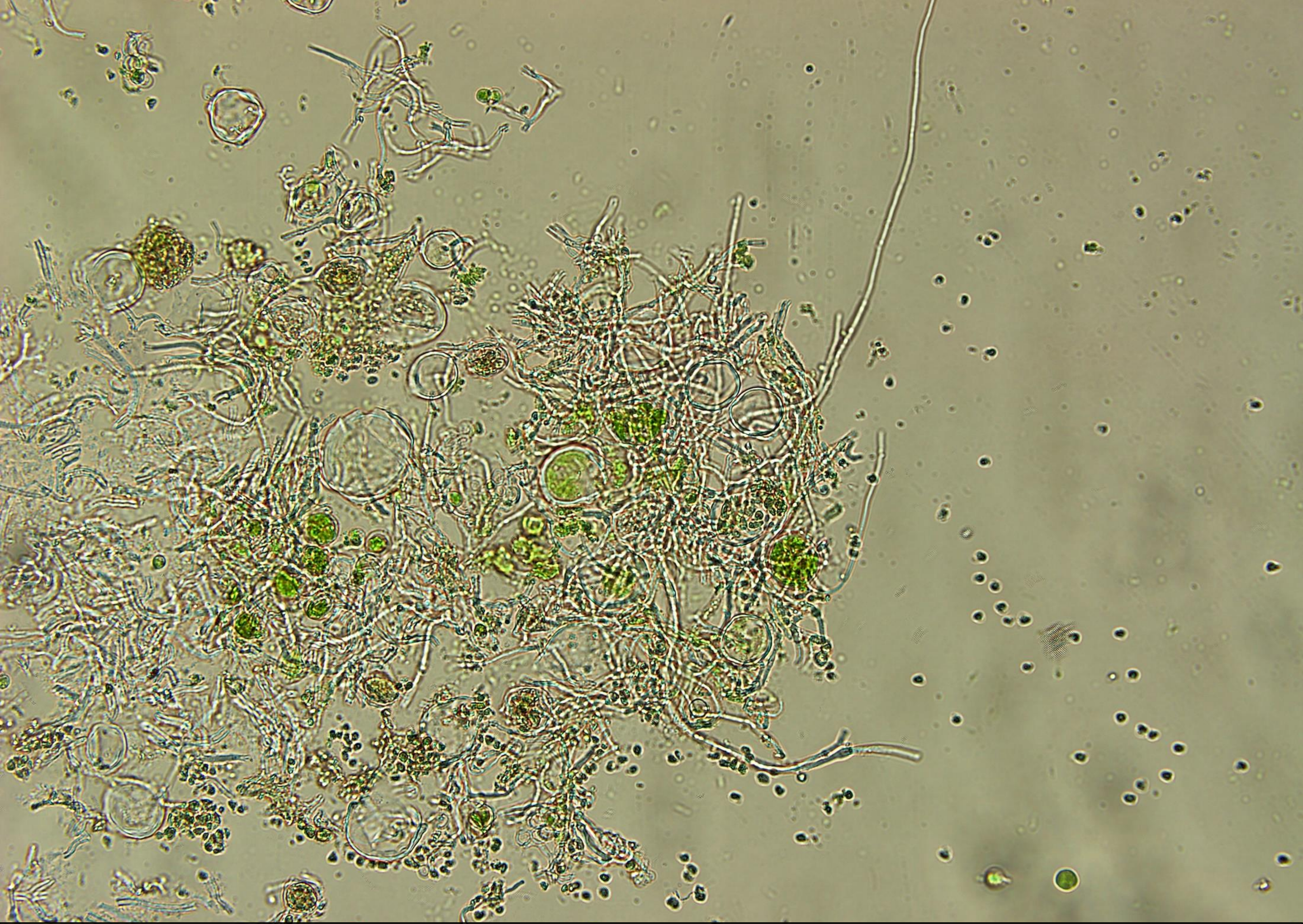
Let‘s build a lichen!

- Artificial lichen synthesis using pure fungal and algal cultures



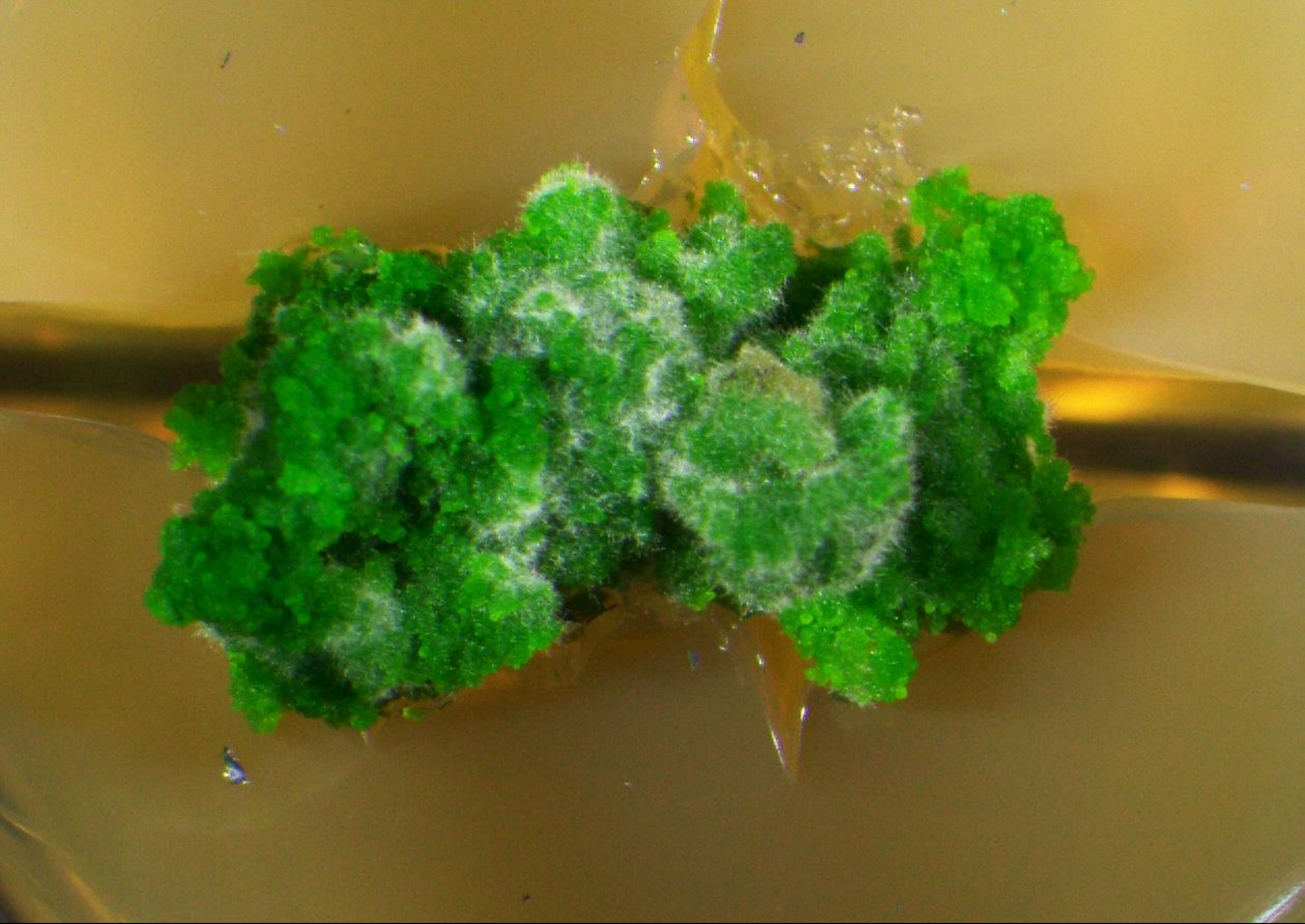


Fungal and algal pure cultures

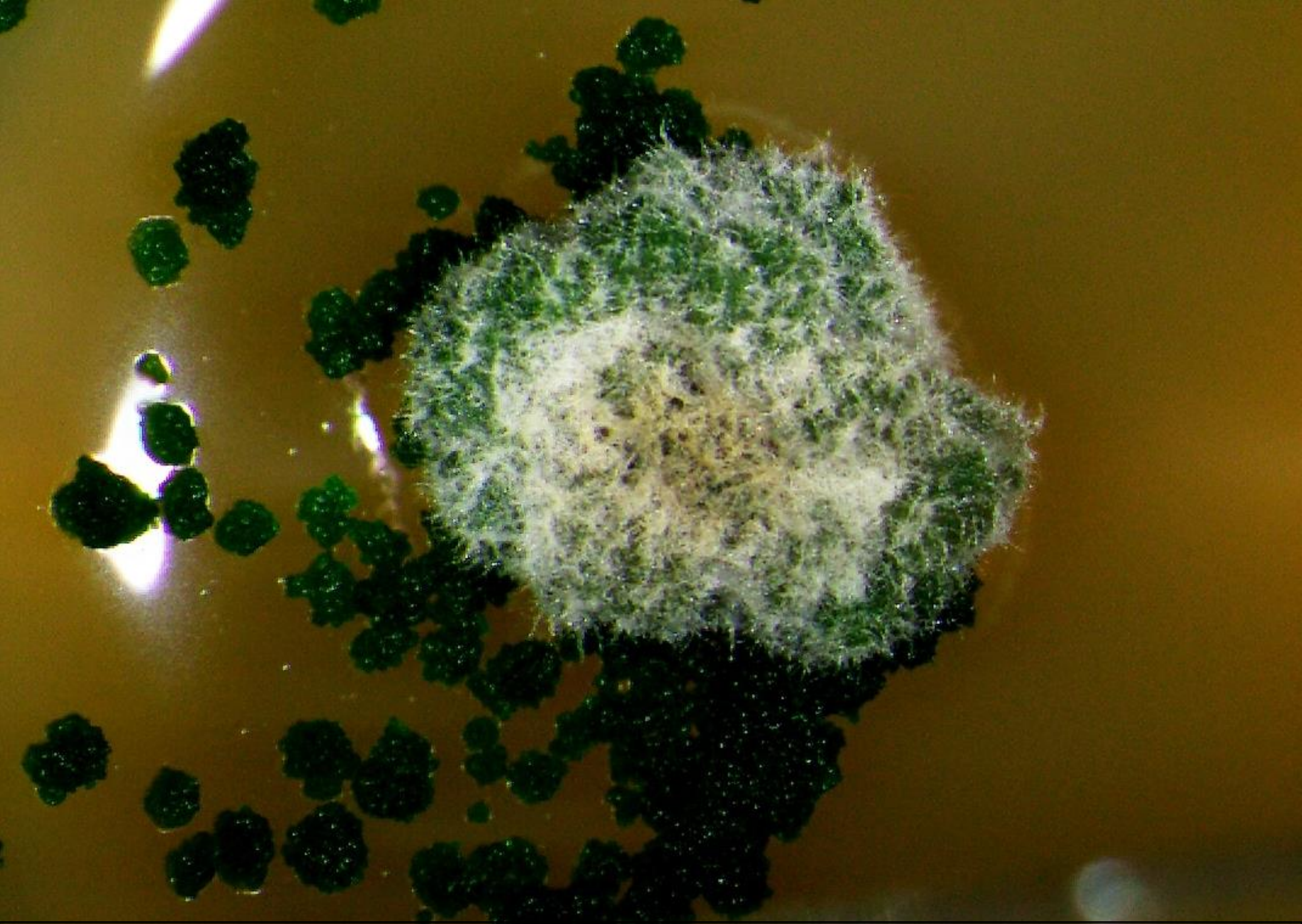


Fungus encircling algal cells

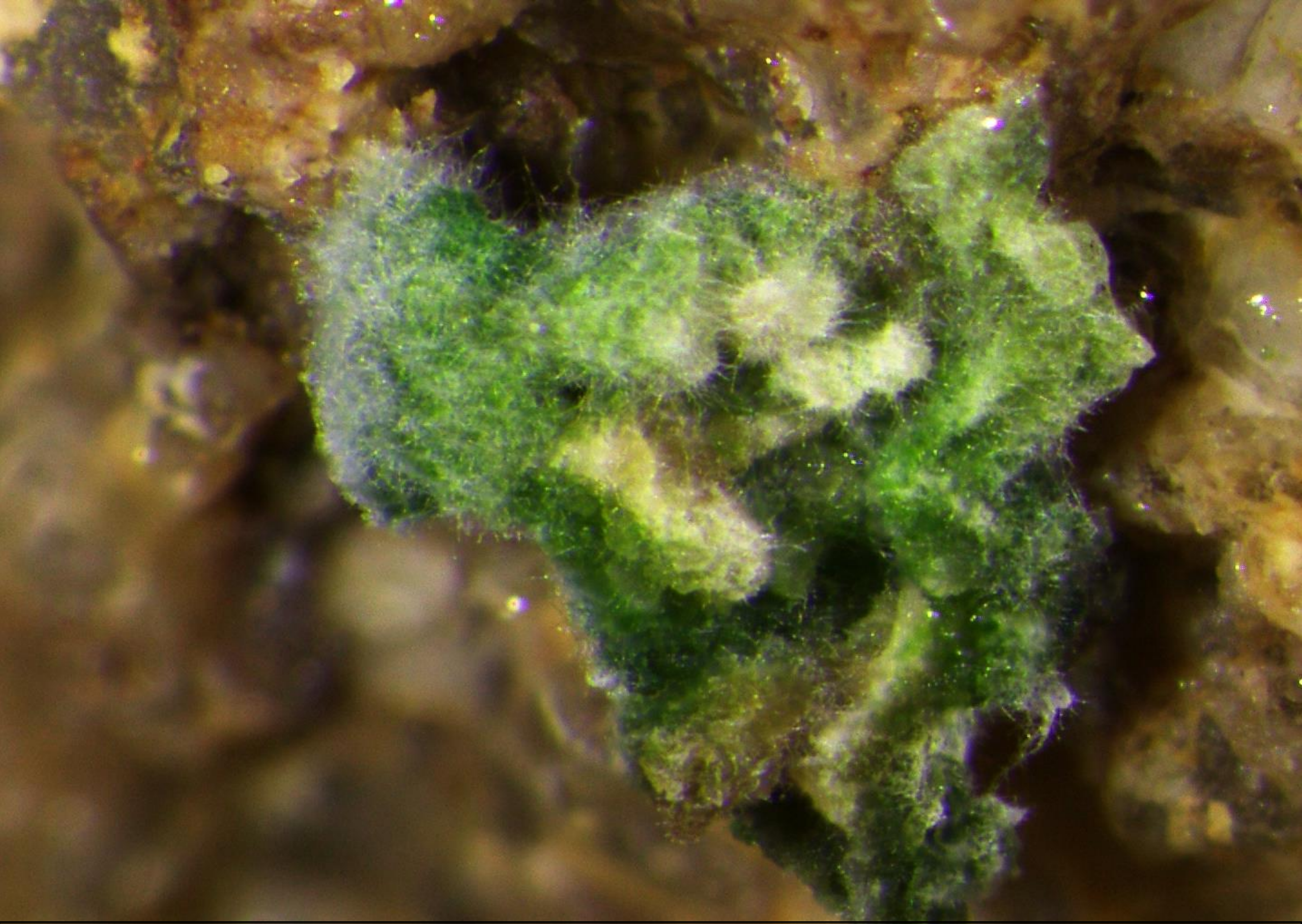
A mass of predominantly algal cells with a few interwoven fungal hyphae



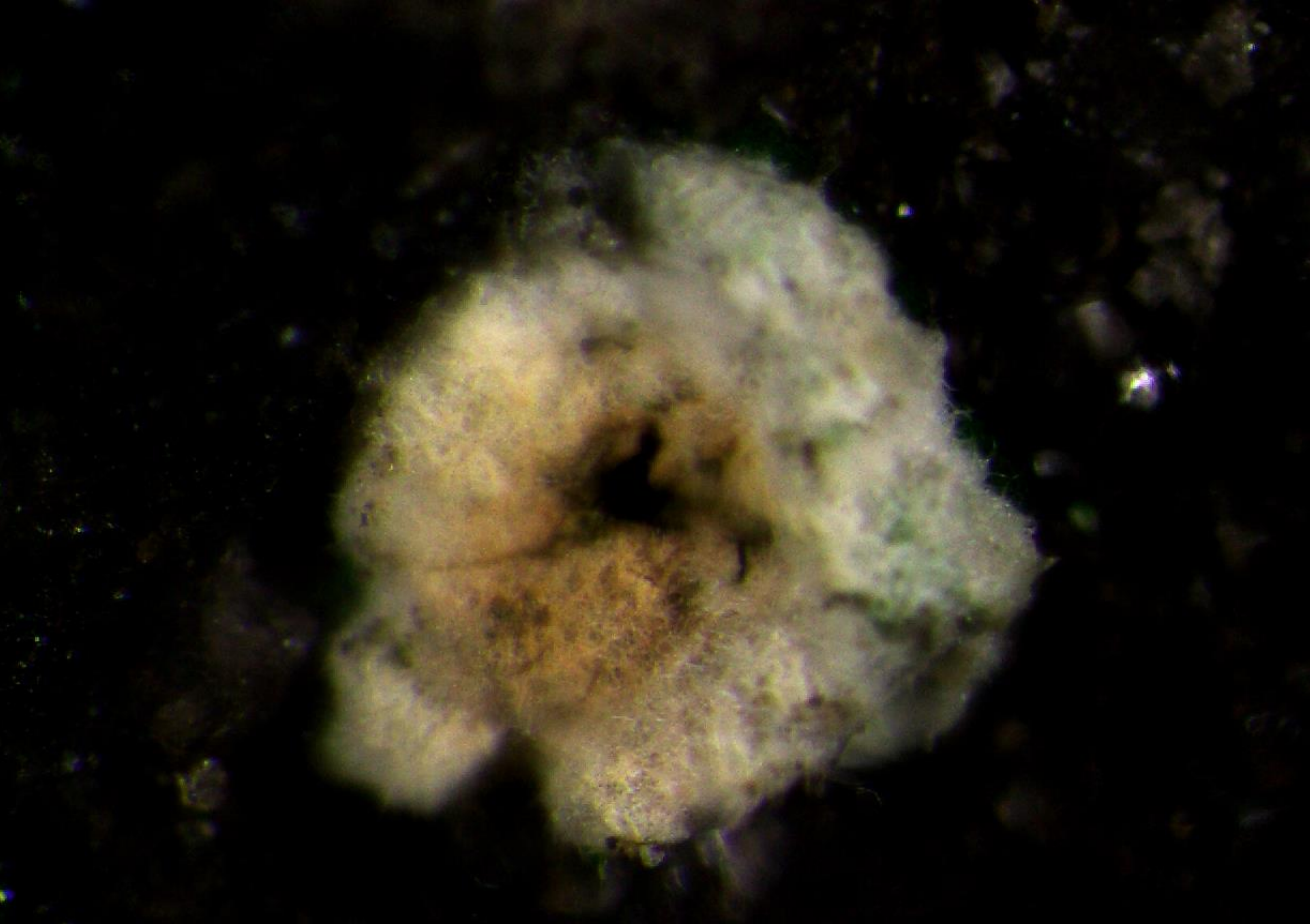
Fungus starts to take over



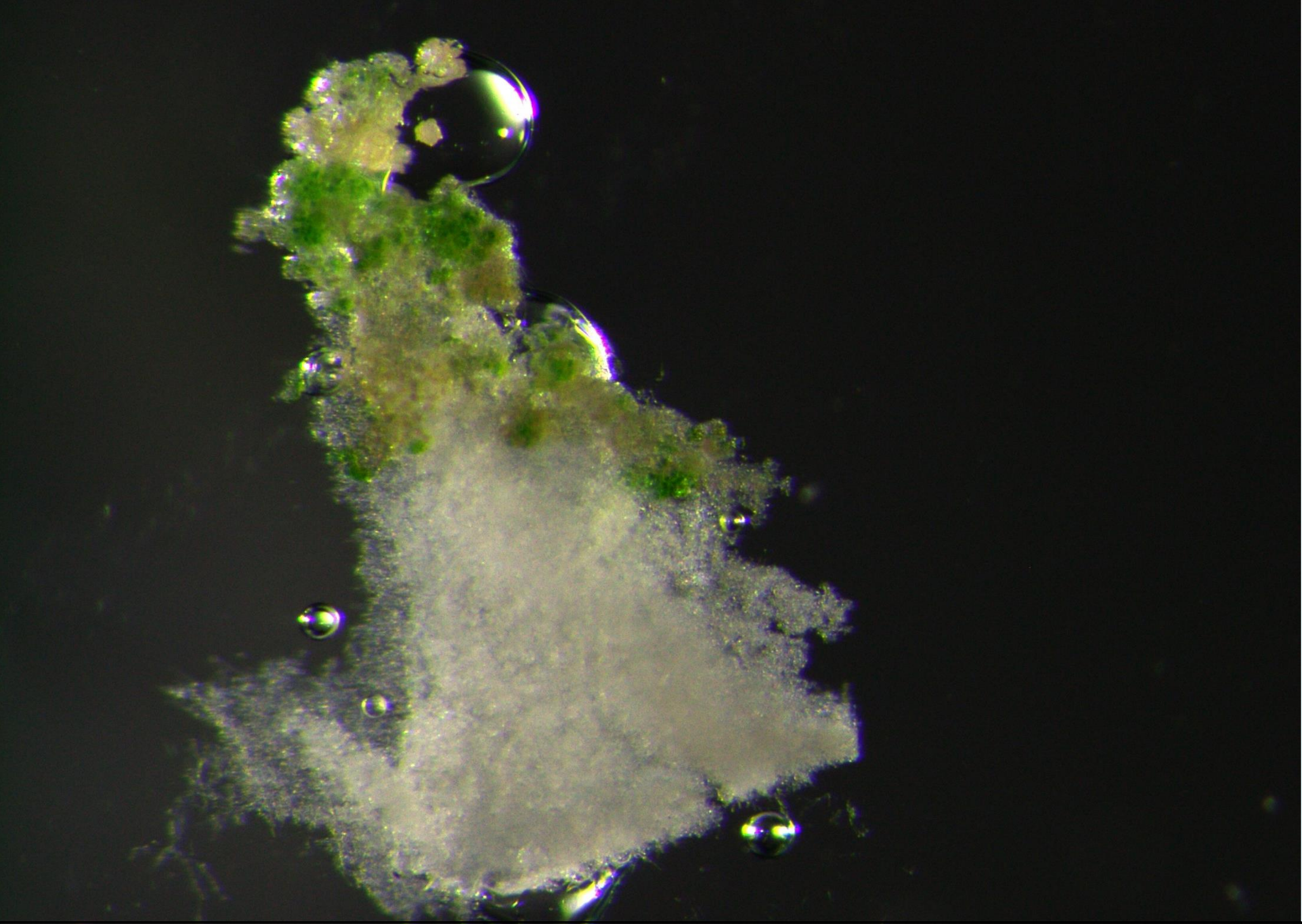
Fungus forms a superficial layer enclosing the algae inside 1 mm



Transfer on the soil, development of rhizine-like structures



A young lichen – fungus completely enclosed the algae



A young lichen (cross section) – fungal and algal layers are developed

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Helena Bestová

Thank you for your attention

Patricia Moya

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CHARLES UNIVERSITY

Primus Research Programme