How to live in a microcosm

Hidden diversity, speciation, and evolution of protists

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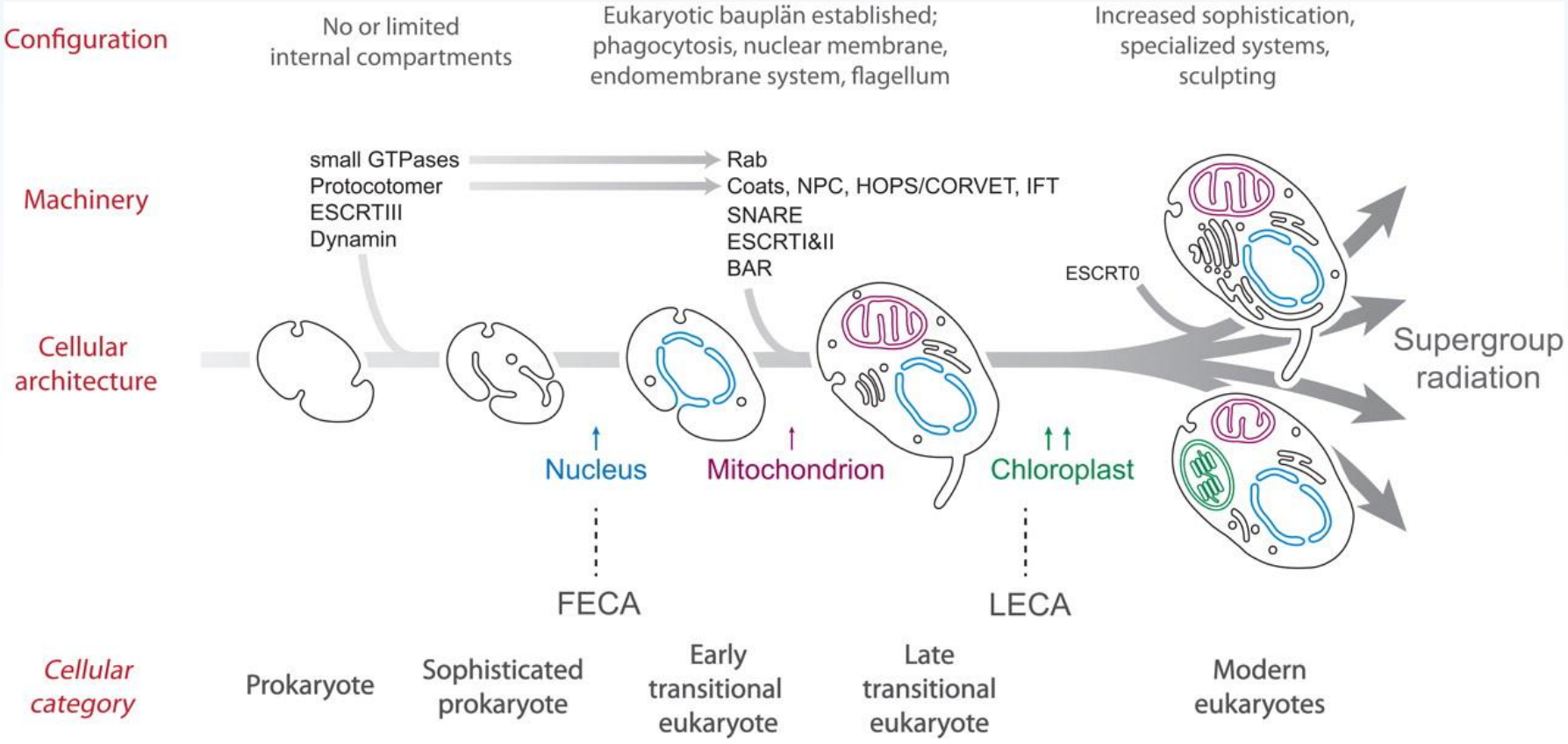
Protists

- Eukaryotic microorganisms with simple thalli (unicellular, colonial or filamentous).

Finlay 2002, Science

Protists

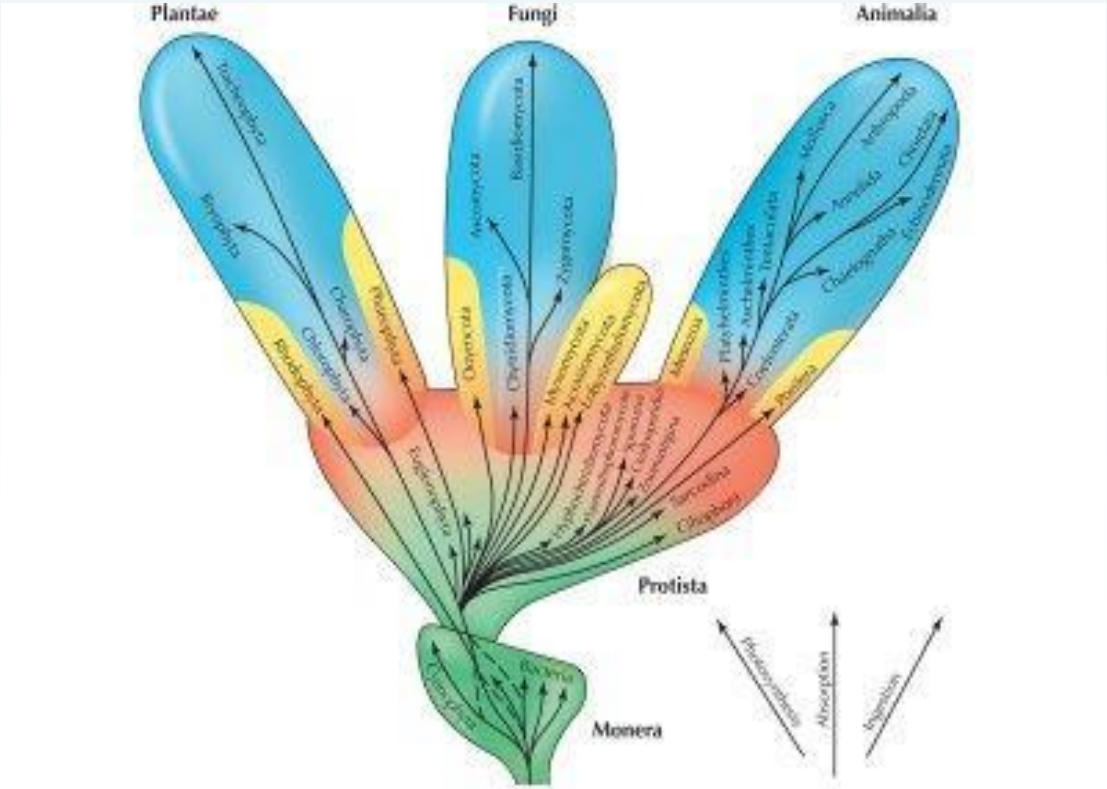
- Age of protists – 1.2 – 3.5 billion years
- Last common eukaryotic ancestor (LECA) – ca 1 billion years



Field et al. 2011, JCB

Protists

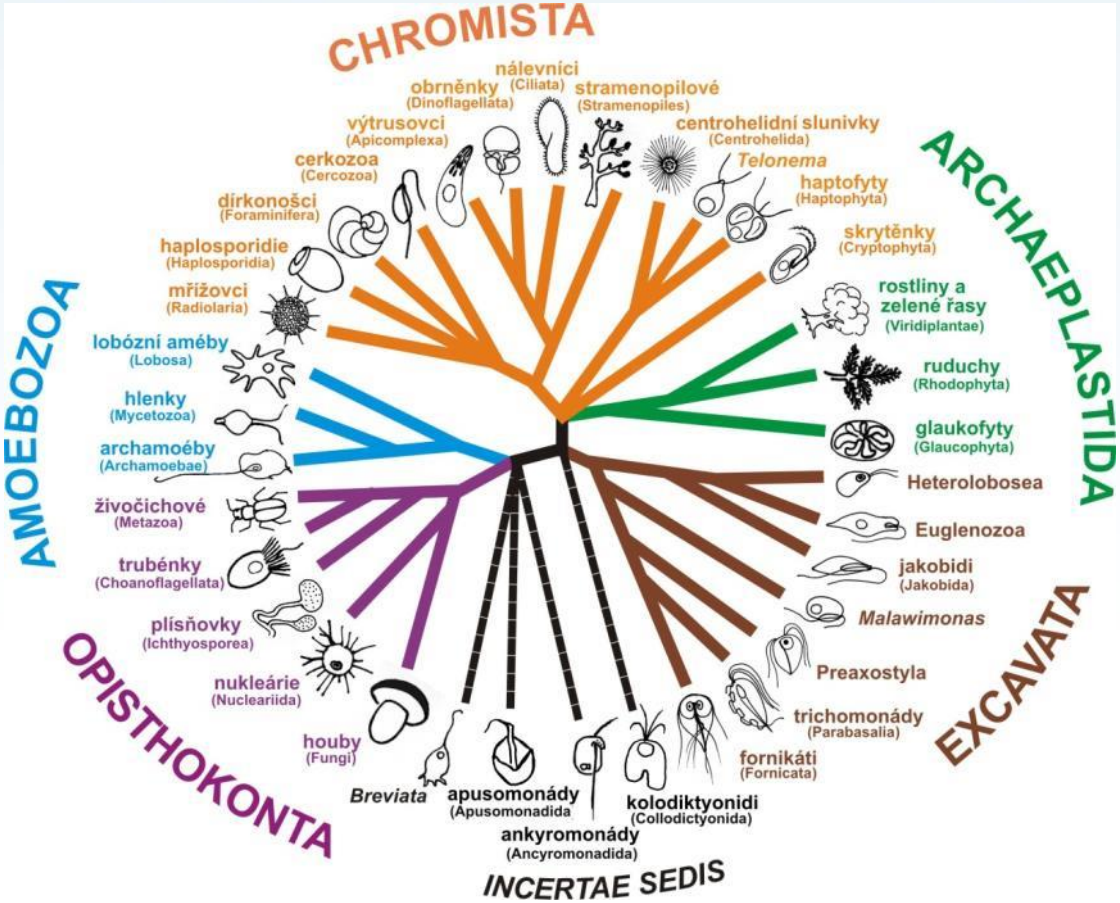
- Traditionally classified to the supergroup Protista (concept of 5 kingdoms)



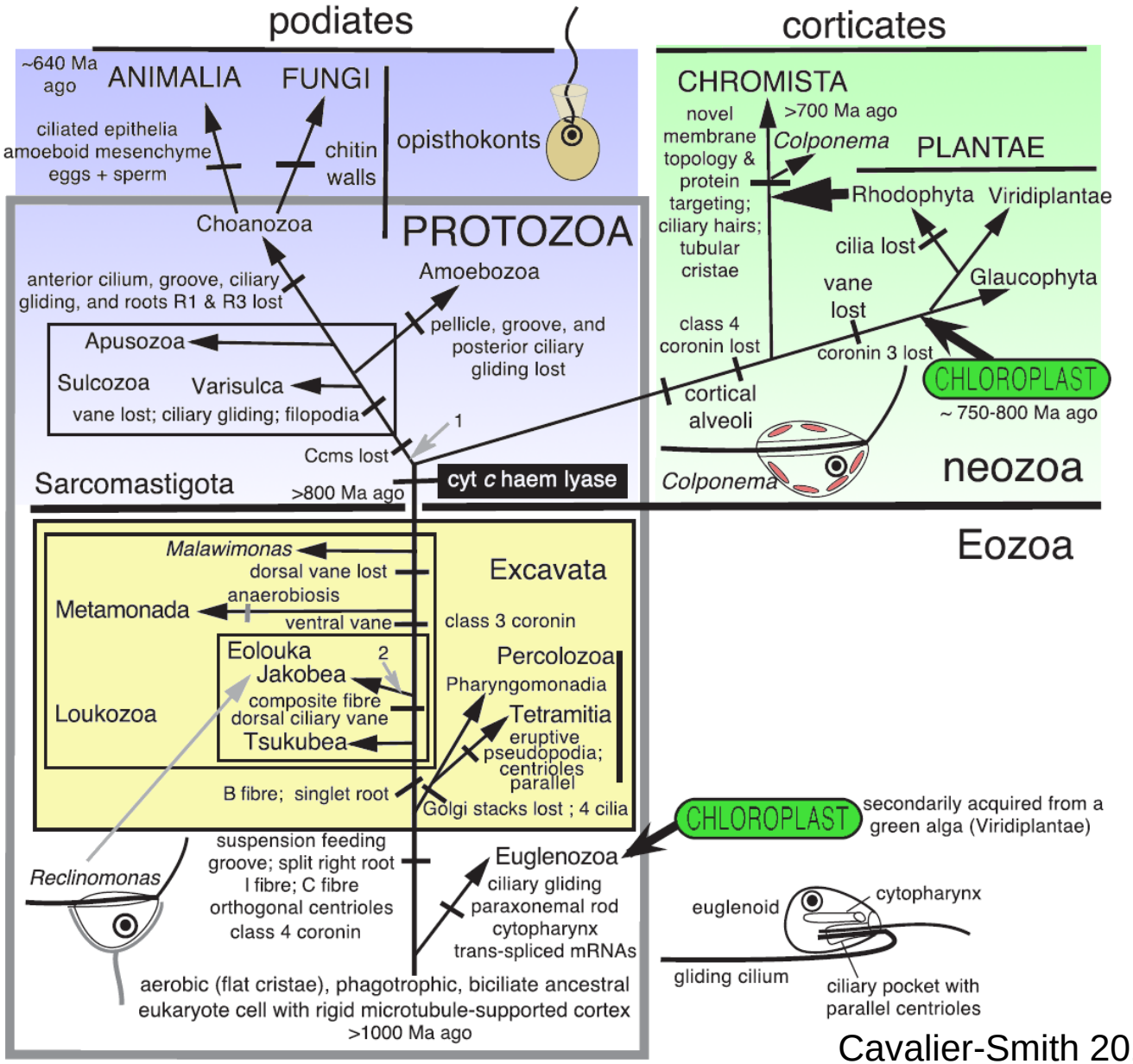
Whittaker 1969, Science

Protists

- Current systematics of 5 kingdoms
- A major portion of eukaryotic diversity is comprised by protist organisms



Protists



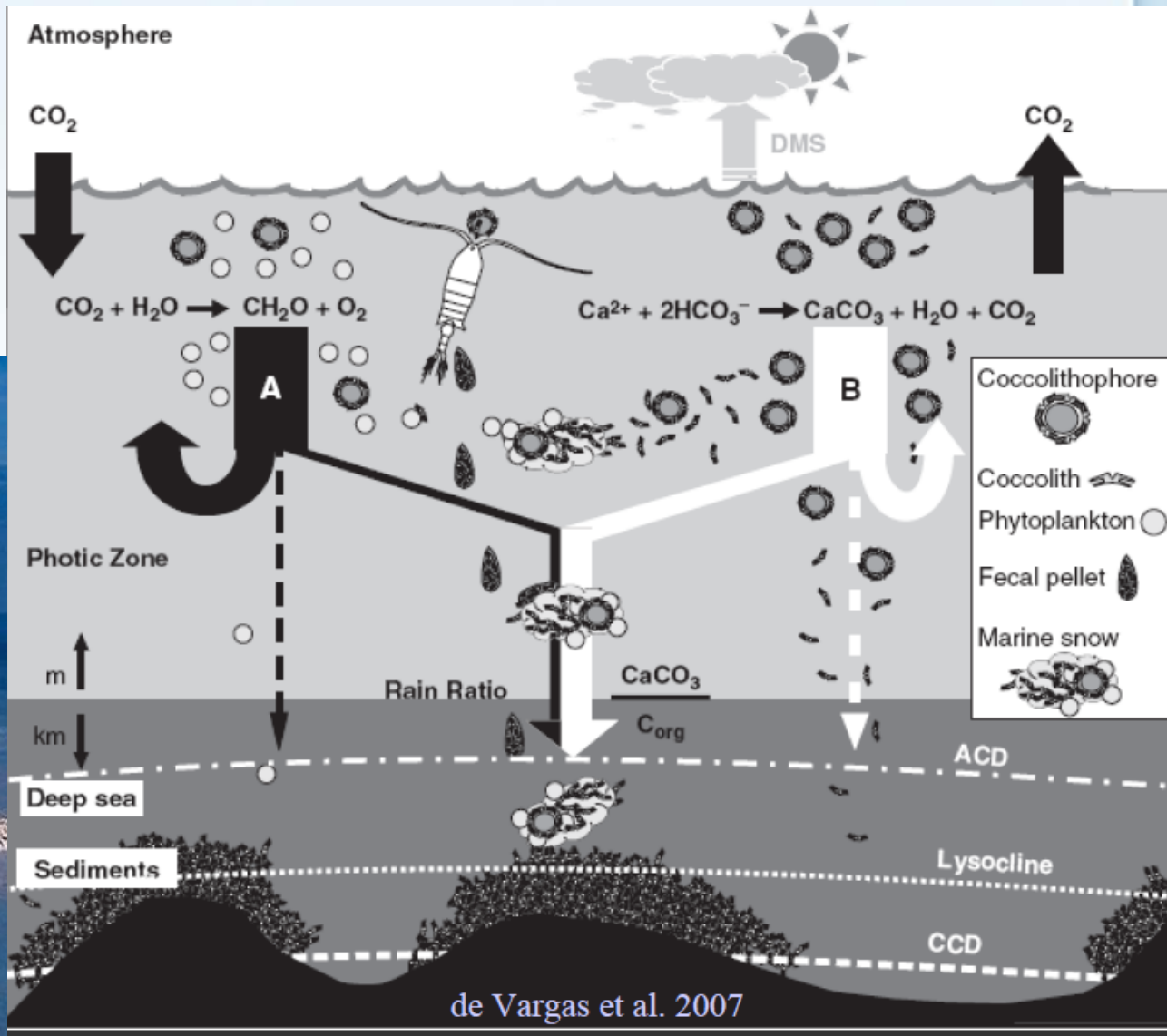
Cavalier-Smith 2012, Eur. J. Prot.

Global importance of protists

- *Emiliania*

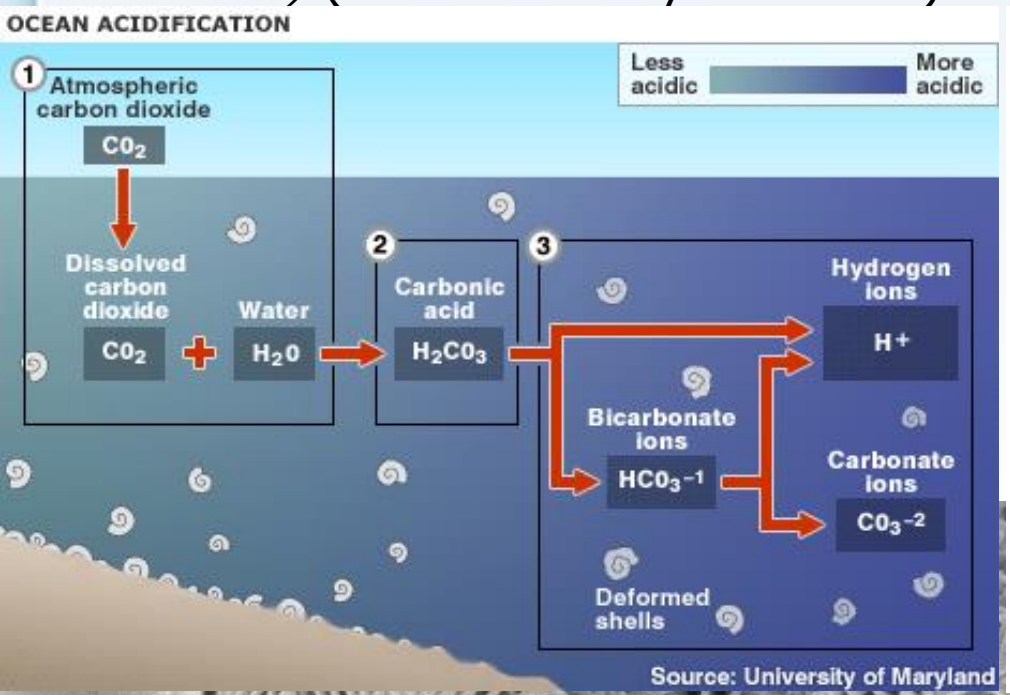
Global importance of protists

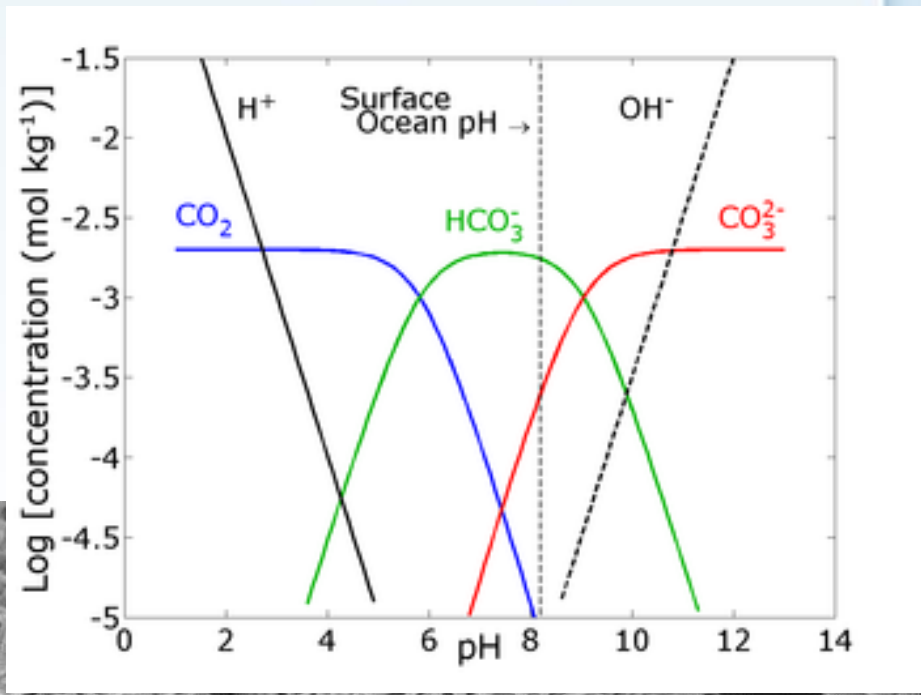
- *Emiliania huxleyi* – coccolithes $Ca + 2HCO_3 \dashrightarrow CaCO_3 + H_2O + CO_2$
- Strong influence of global Earth climate
- Limestones (Dover cliffs)

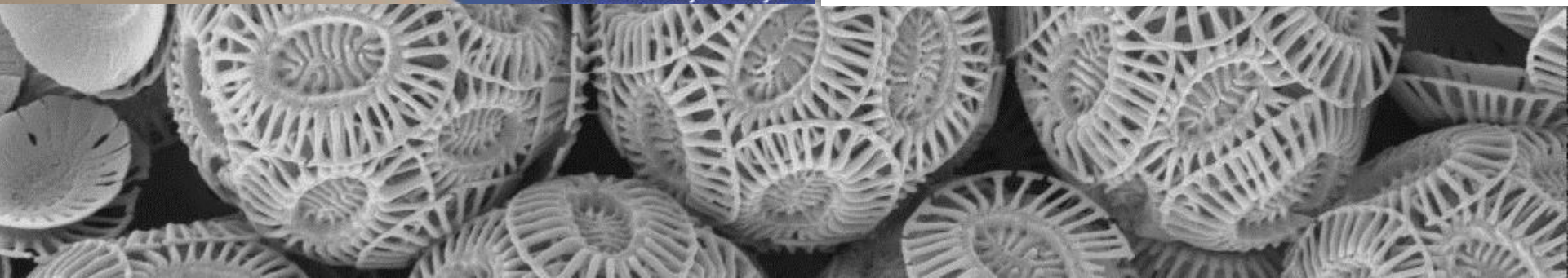


Global importance of protists

- *Emiliania huxleyi*
  - Sea acidification: carbon dioxide decreases pH of sea water, changing the balanced state of its three soluble forms in favour of CO_2 (not utilized by *Emiliania*)








AMERICAN ENERGY
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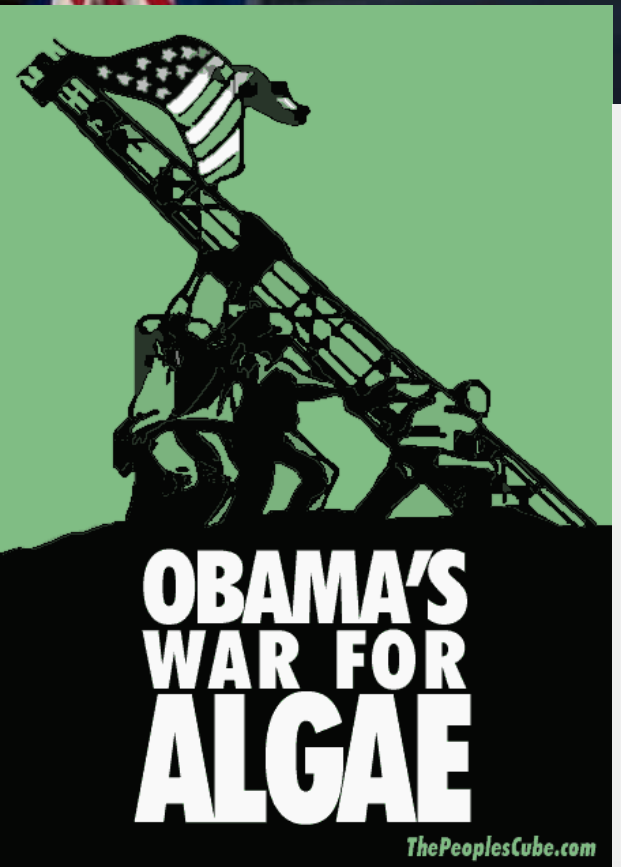
WE DON'T NEED TO DRILL, DAMMIT, WE'VE GOT ALGAE !
Alinsky's Rule #5
Ridicule is man's most potent weapon...


OBAMA'S WAR FOR ALGAE
ThePeoplesCube.com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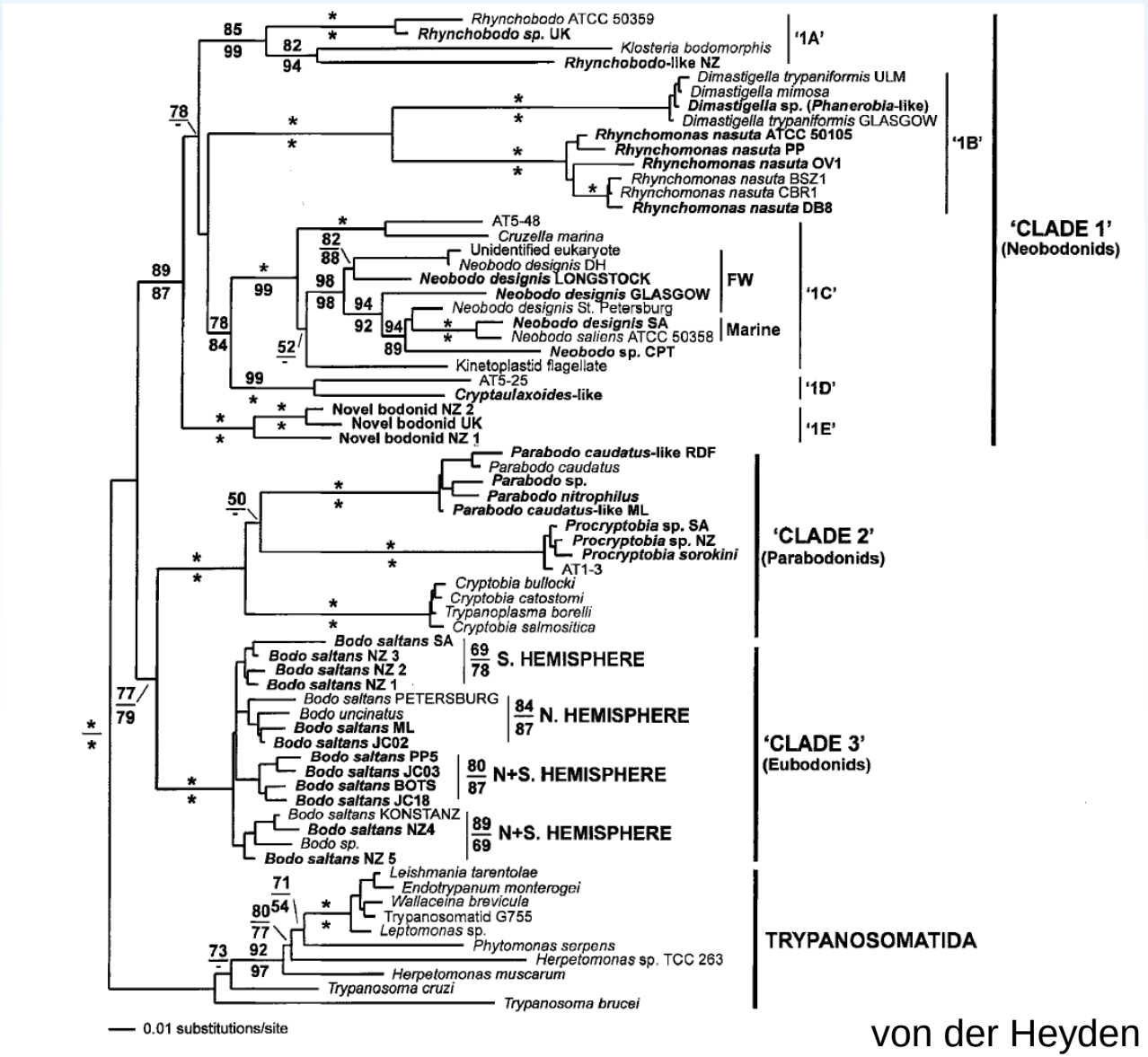
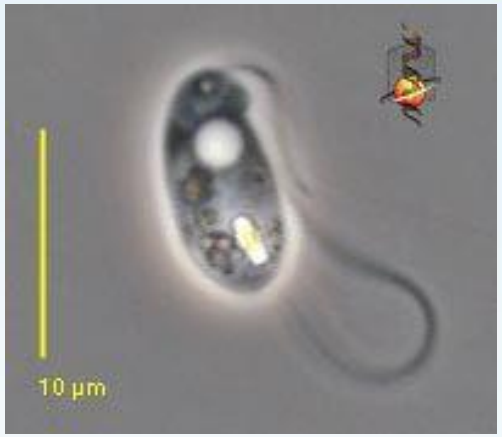
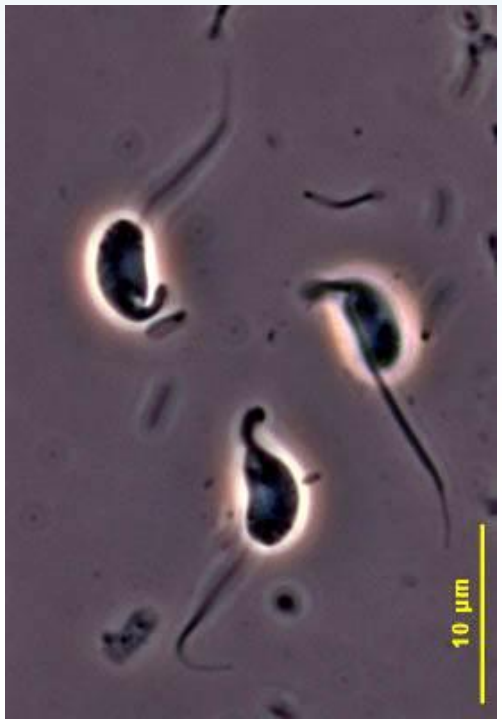
Hidden diversity of protists

- Genetic diversity of bodonids (Kinetoplastida)



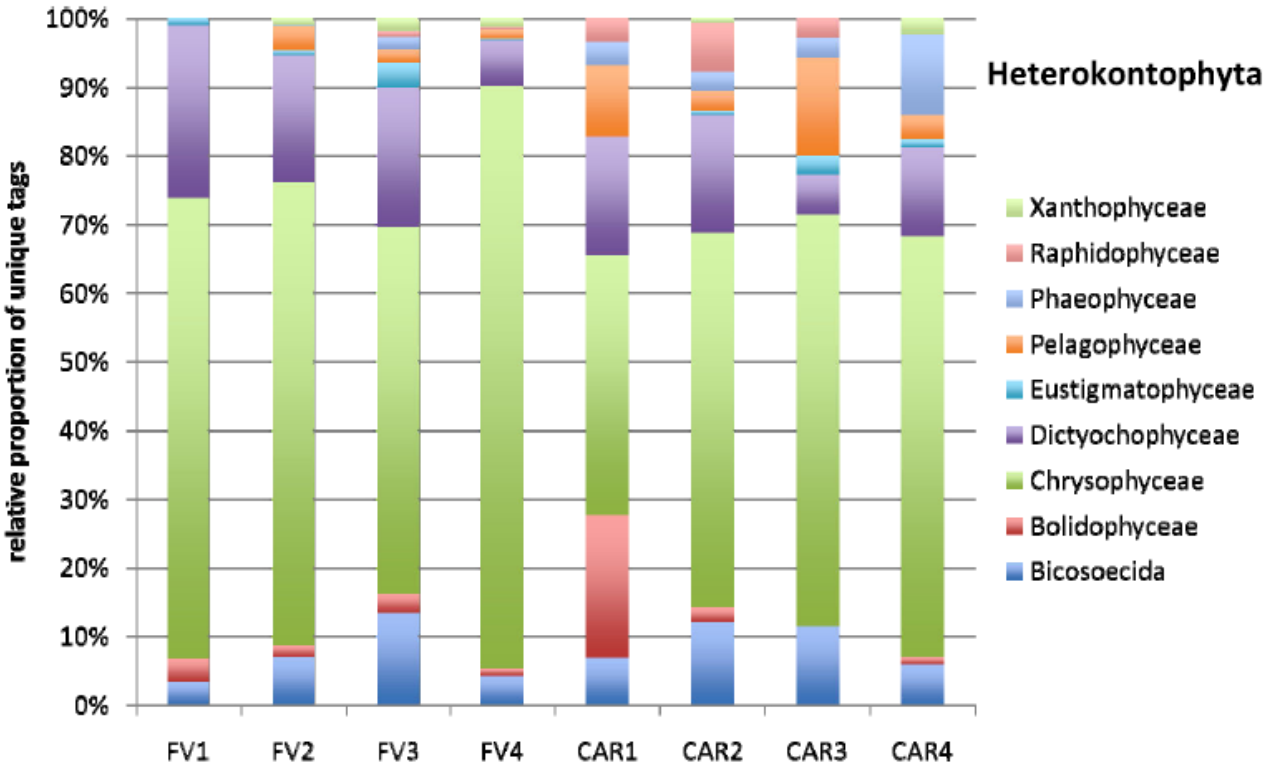




von der Heyden et al. 2004, J. Euk. Microb.

Hidden diversity of protists

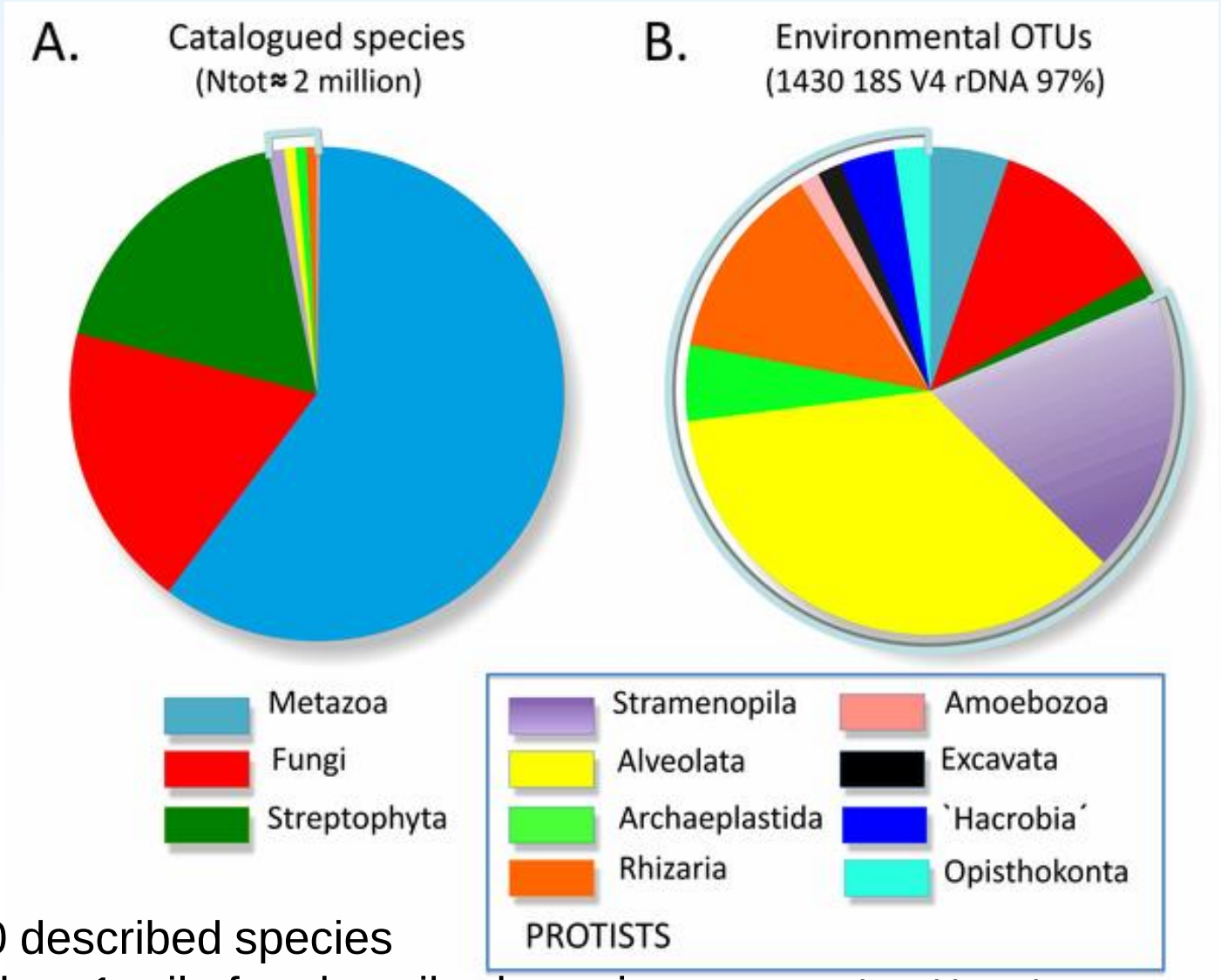
- Diversity of protists in marine benthos (454 sequencing)



Stoeck et al. 2009, BMC Biology

Hidden diversity of protists

- Great proportion of undescribed protist species (genotypes)



Protists:

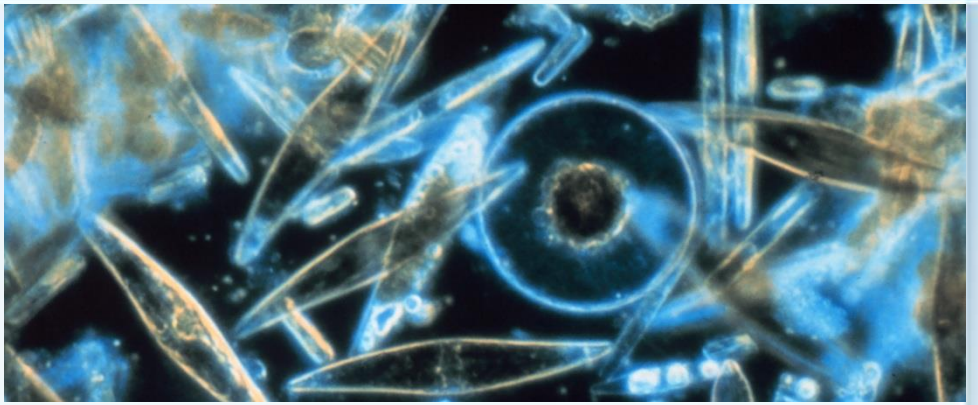
- 43 000 described species
- more than 1 mil of undescribed species

Pawlowski et al. 2012, PLOS Biology

Specificity of protist organisms

Finlay & Fenchel

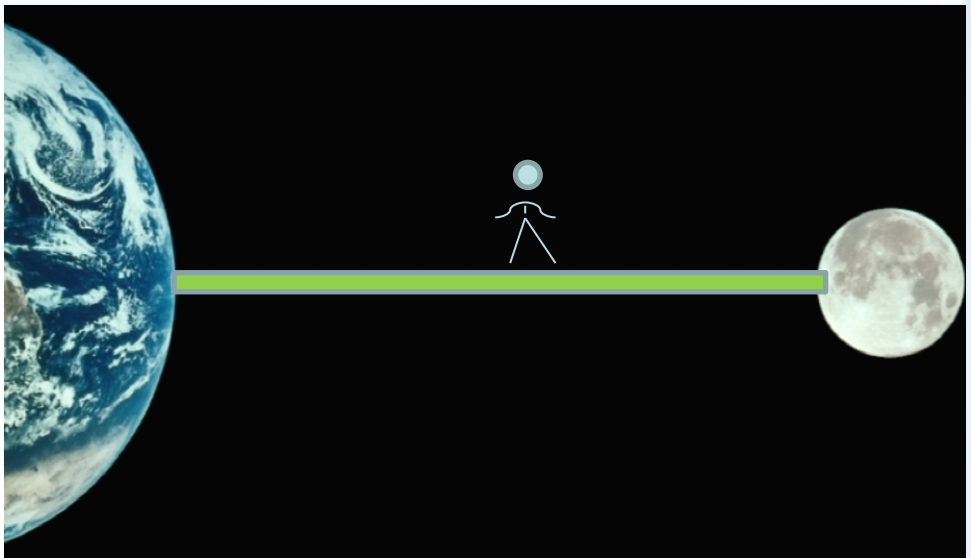
- Short generation time
- Enormous population sizes
- Unlimited distribution & gene flow



- Marine phytoplankton – 10^{25} of cells
- Average cell size – 2 μm
- A pavement 30 cm wide and 8 cm thick (150 000 x 40 000 cells)

Unlike the macroorganisms:

- Ubiquitous distribution
- Very low speciation rate
- Absence of population differentiation



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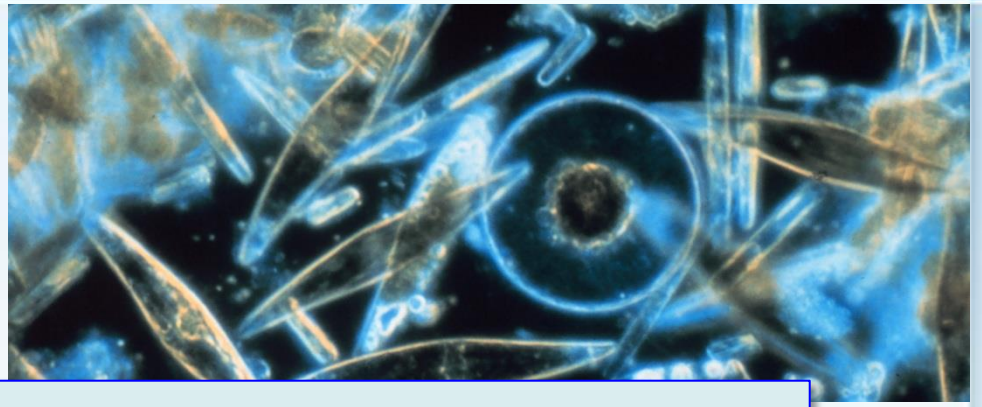


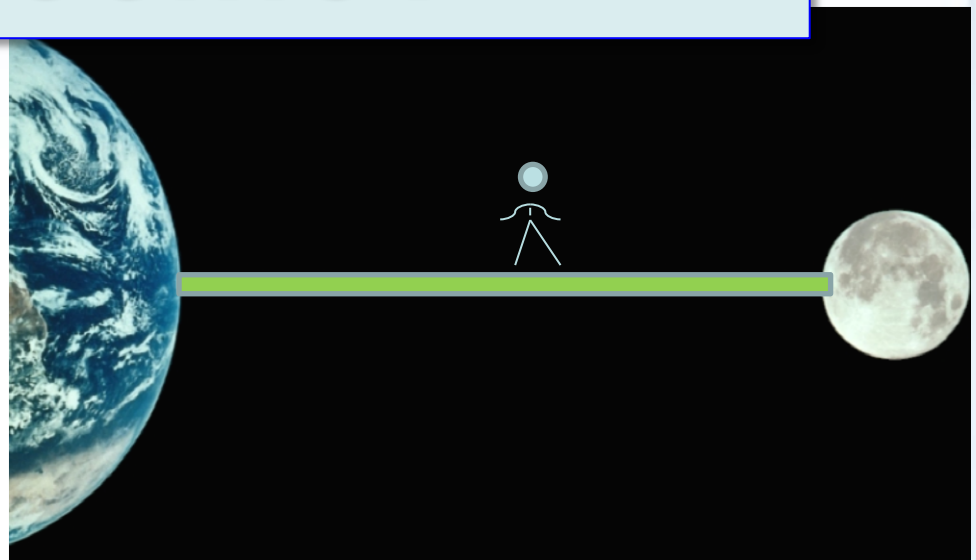
Are the protists really so specific?

lls

thick

Unlike

- Ubiquitous distribution
- Very low speciation rate
- Absence of population differentiation

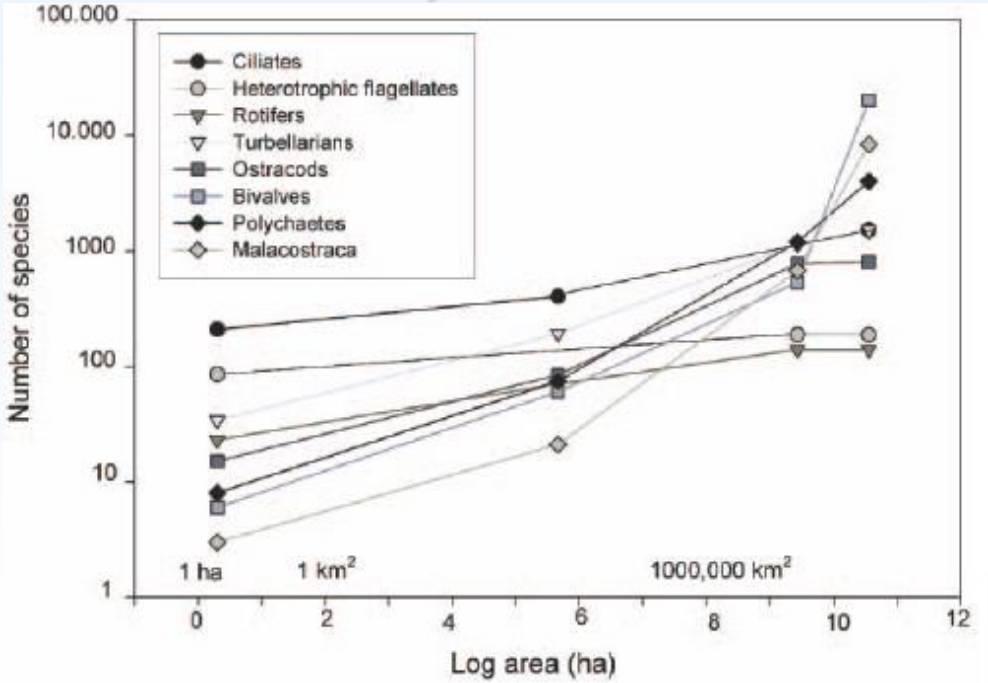


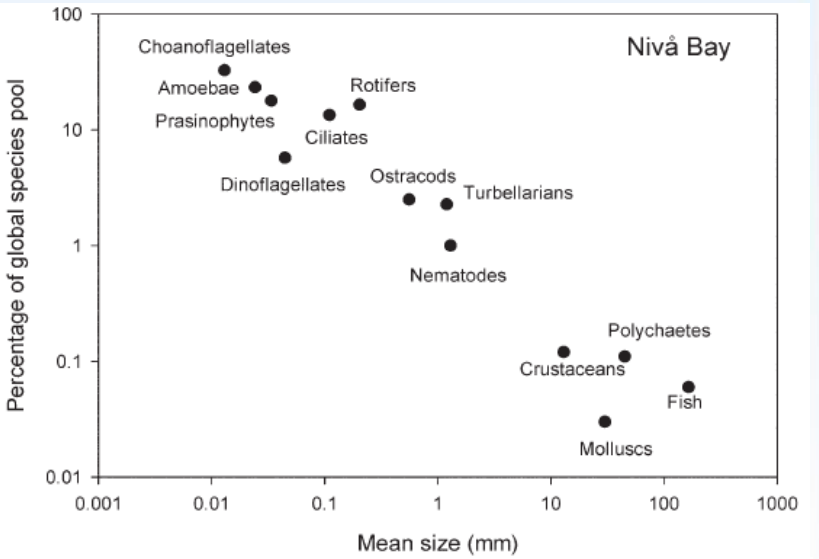
Specificity of protist organisms

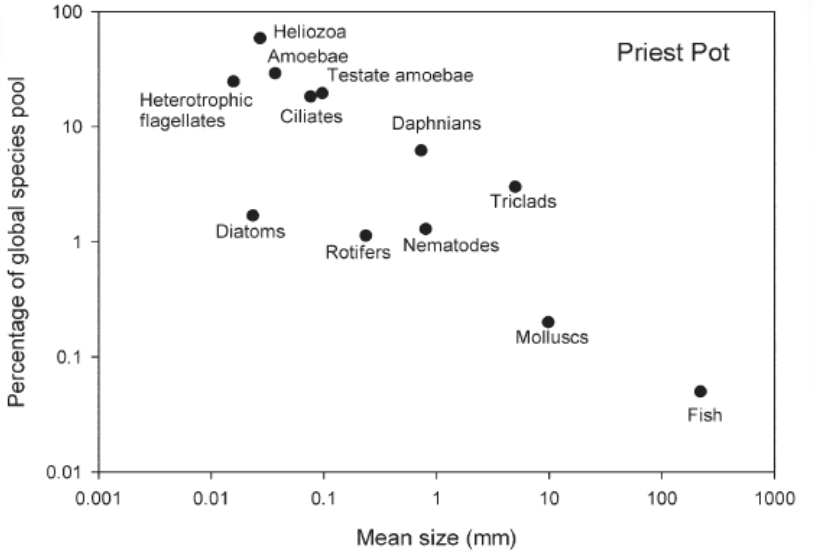
- Are the “hidden“ protist species real?
- Are the protists ubiquitous?
- Could they form different populations?
- How do the protists speciate?

Species diversity

- Comparable global and local diversity
  - ➡ Globally low number of species







Fenchel & Finlay 2004, BioScience

Species diversity

- The most important is the functional (incl. phenotypic) species differentiation in nature, we are confused by molecular data

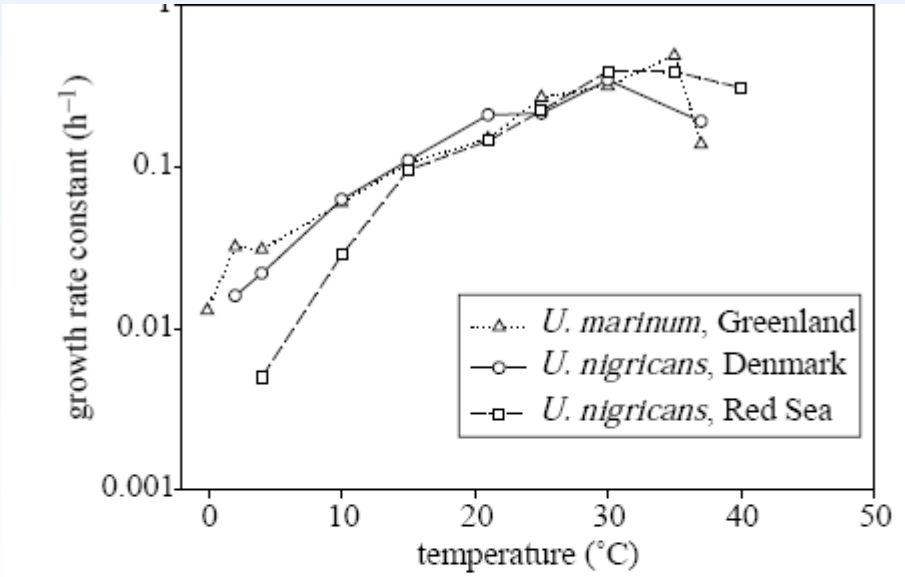
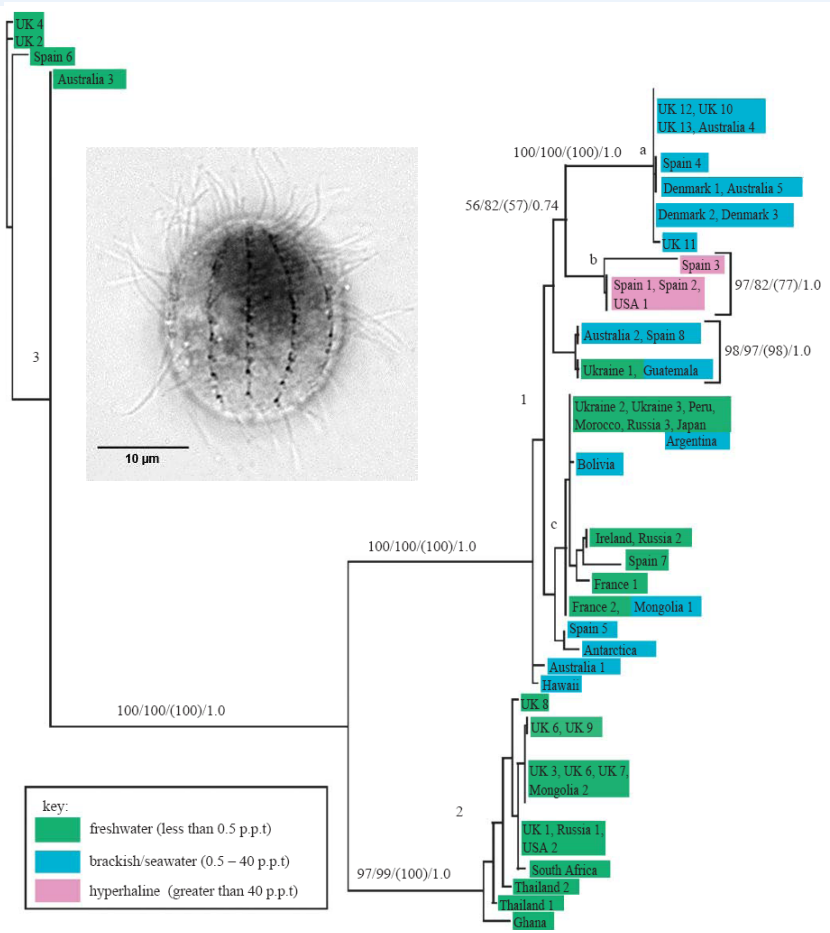


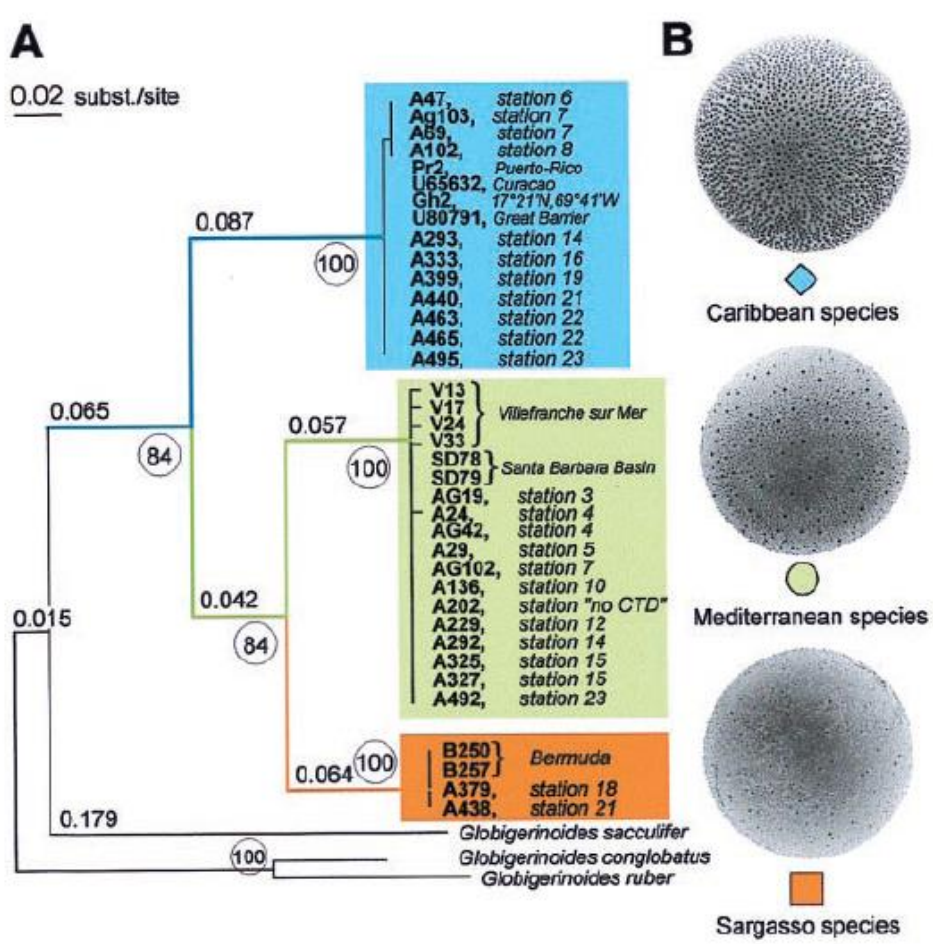
Figure 1. Maximum growth rate constants of the ciliates *Uronema marinum* isolated from the east coast of Greenland and *Uronema nigricans* isolated from the Red Sea (Eilat) and from Denmark, as a function of temperature. The tropical isolate grows significantly slower at temperatures below 10°C, but it is more striking that all three strains show balanced growth within a temperature range that far exceeds that of the habitats from which they were isolated (T. Fenchel, unpublished data).



Fenchel & Finlay 2006, Phil. Trans. R. Soc. B

Species diversity

- Functional differentiation of cryptic species
  - *Orbulina universa* – slight ecological and morphological differences



De Vargas et al. 1999, PNAS

Species diversity

- Functional differentiation of cryptic species
  - *Sellaphora pupula* – morphological differentiation of hidden species

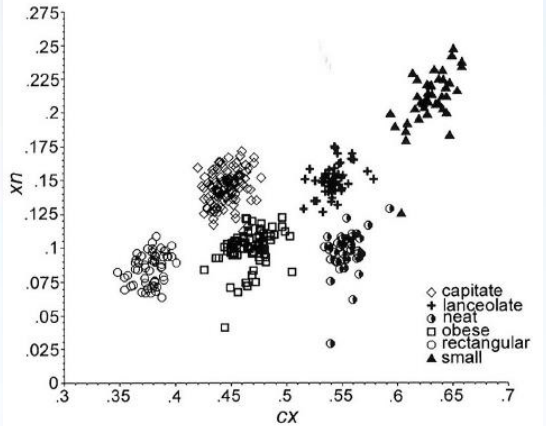
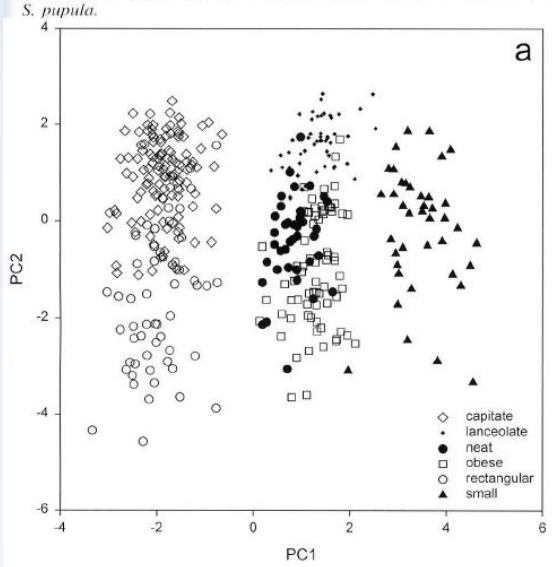
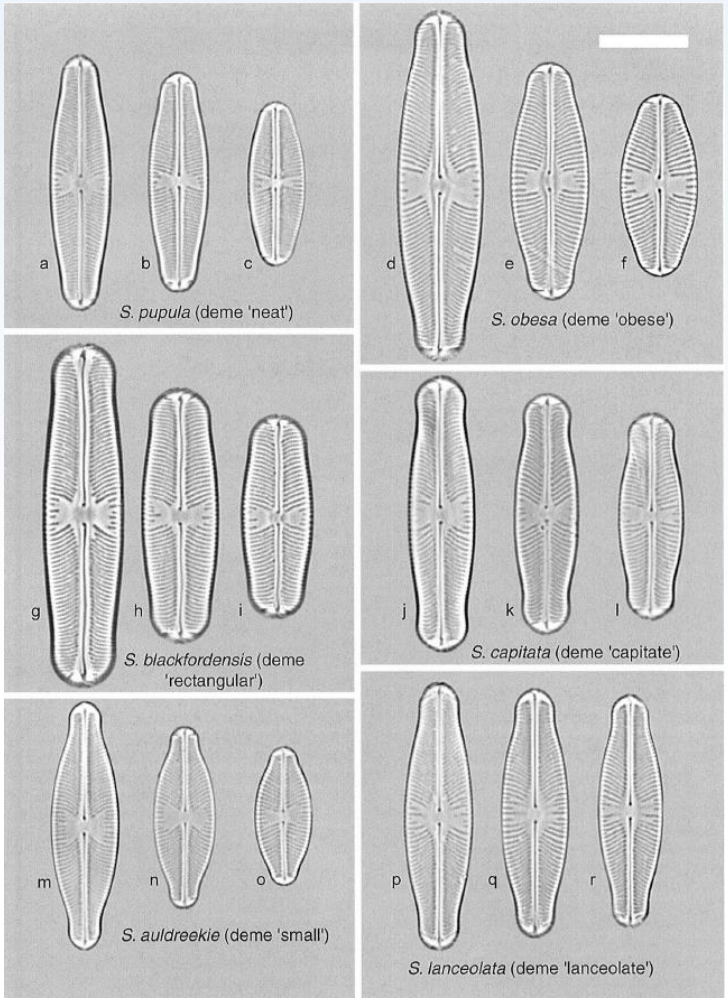
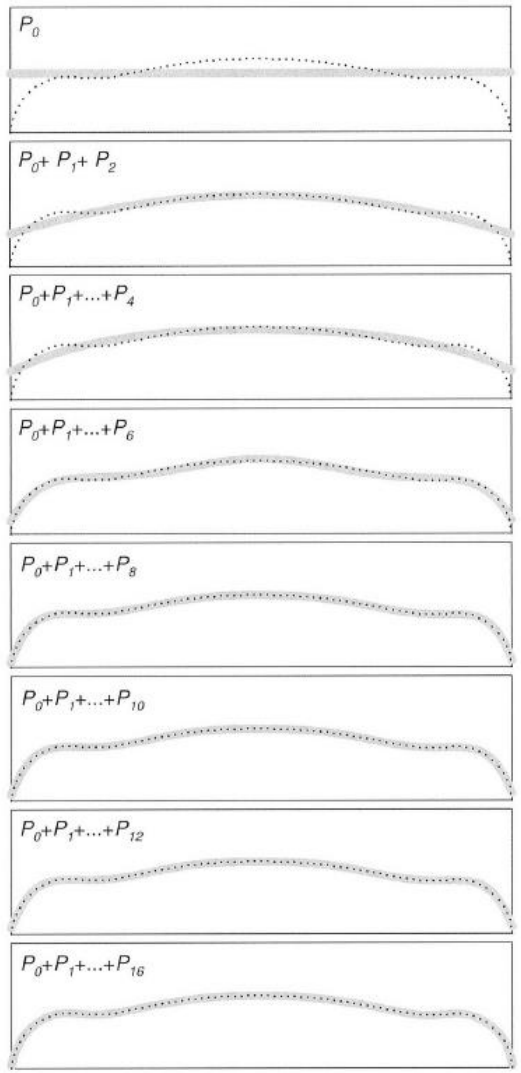


Fig. 16. Contour segment analysis: maximum curvature of all contour points (*cx*) plotted against the maximum of all segment minimum curvatures (*xn*), giving six clusters corresponding to the six demes of *S. pupula*.



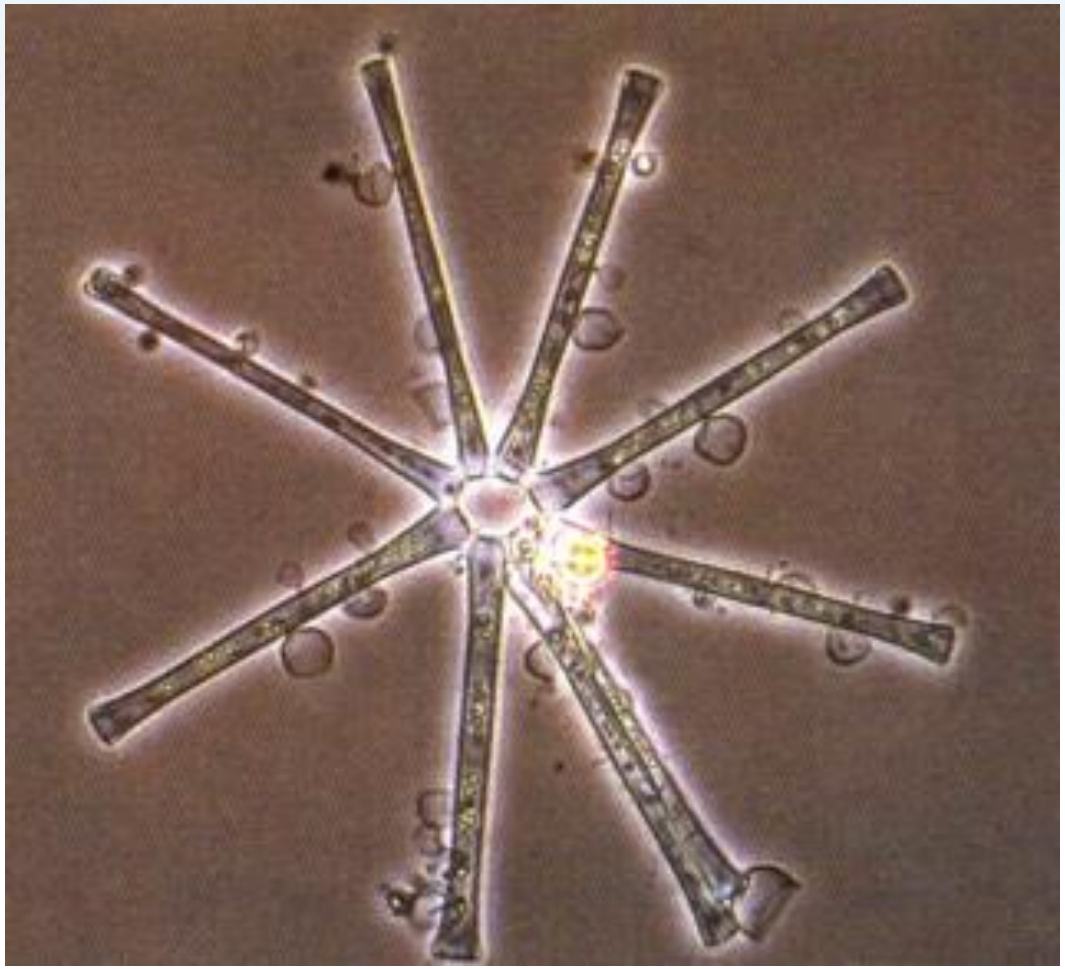


Mann et al. 2004, Phycologia



Species diversity

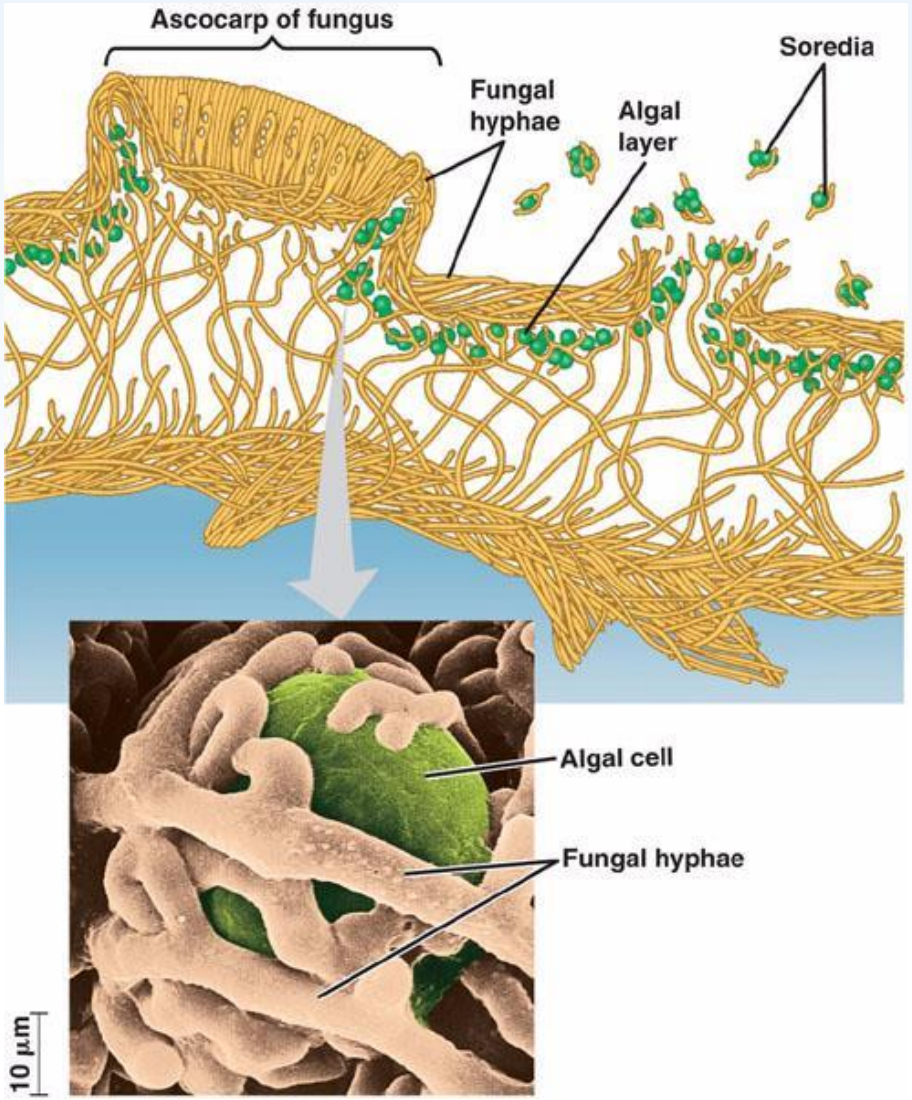
- Functional differentiation of cryptic species – fungal parasites
  - *Asterionella formosa* – genetically different strains are infected by specific parasite genotypes



De Bruin et al. 2004, J. Phycol.

Species diversity

- Lichen photobionts
  - Lichen association: 15 000 fungal species + 100 algal species



Species diversity

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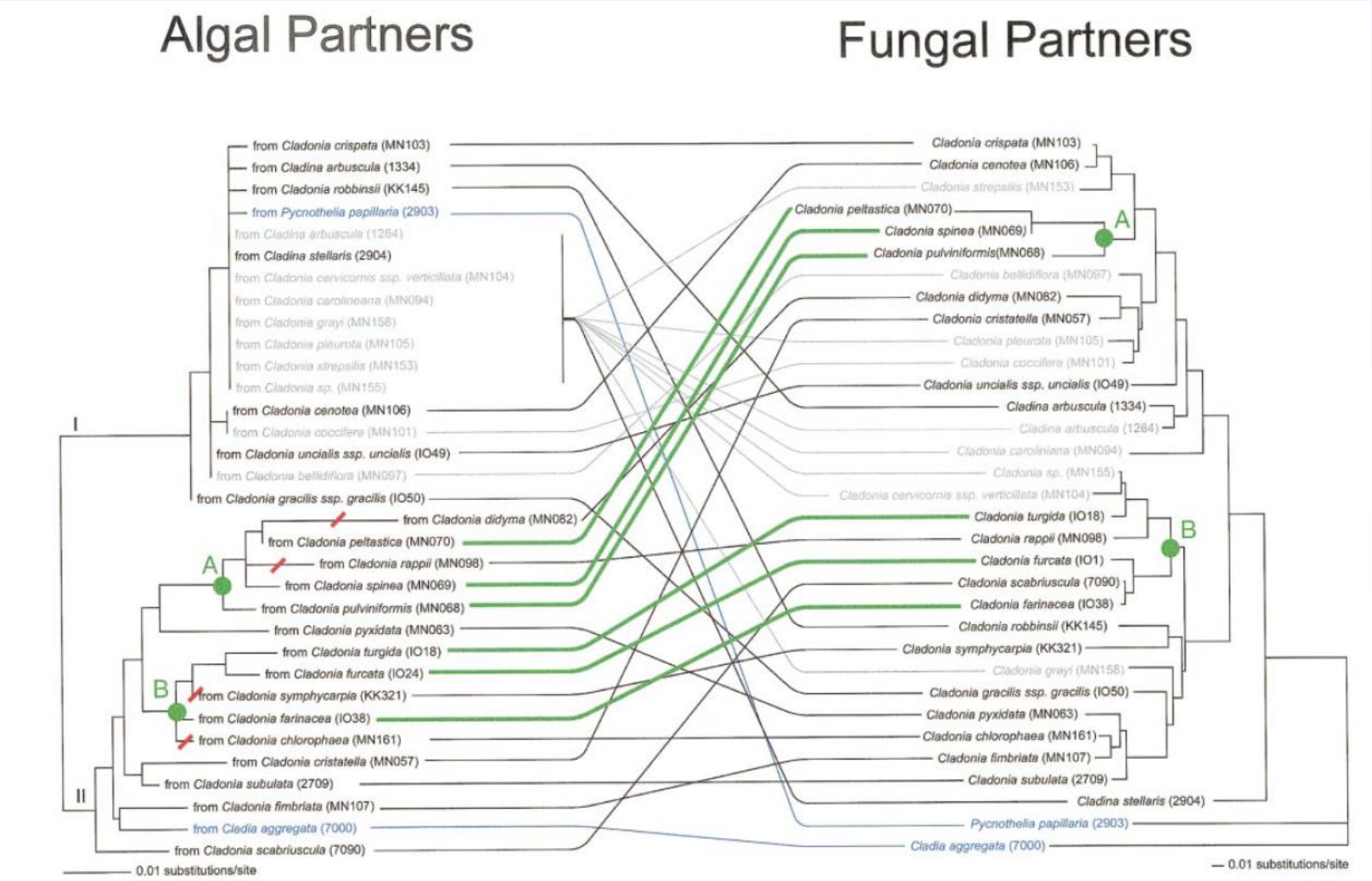


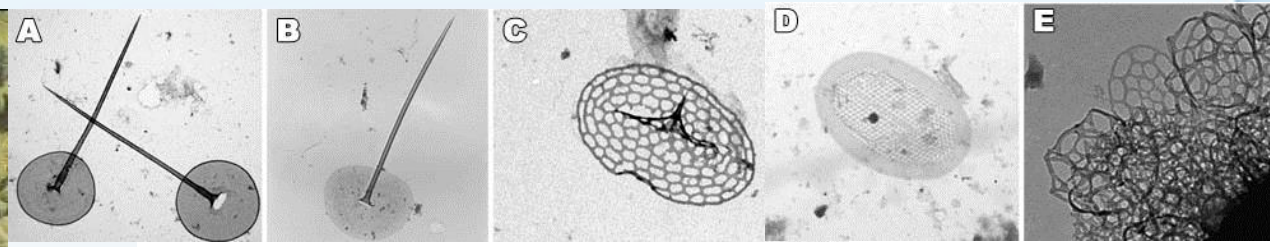
Piercey-Normore & DePriest 2001, Am. J. Bot.

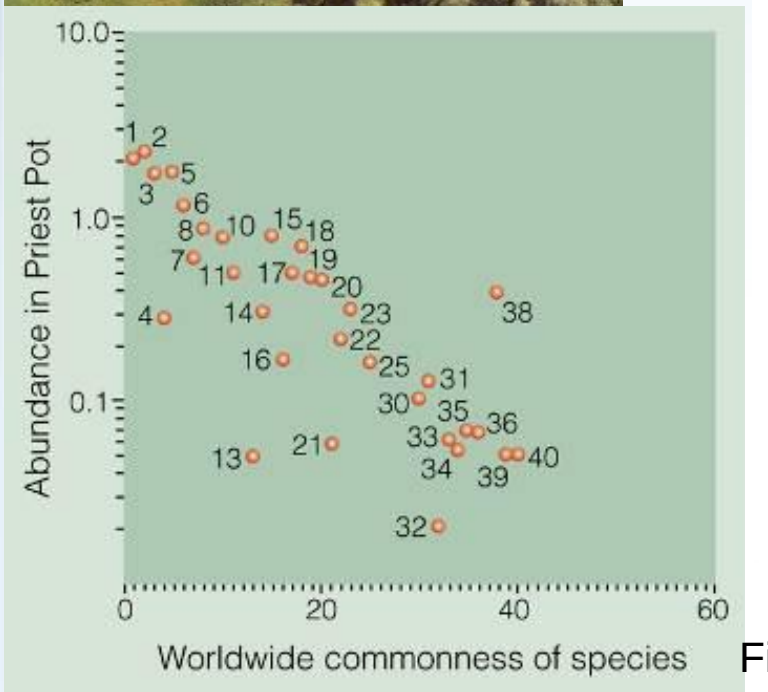
Specificity of protist organisms

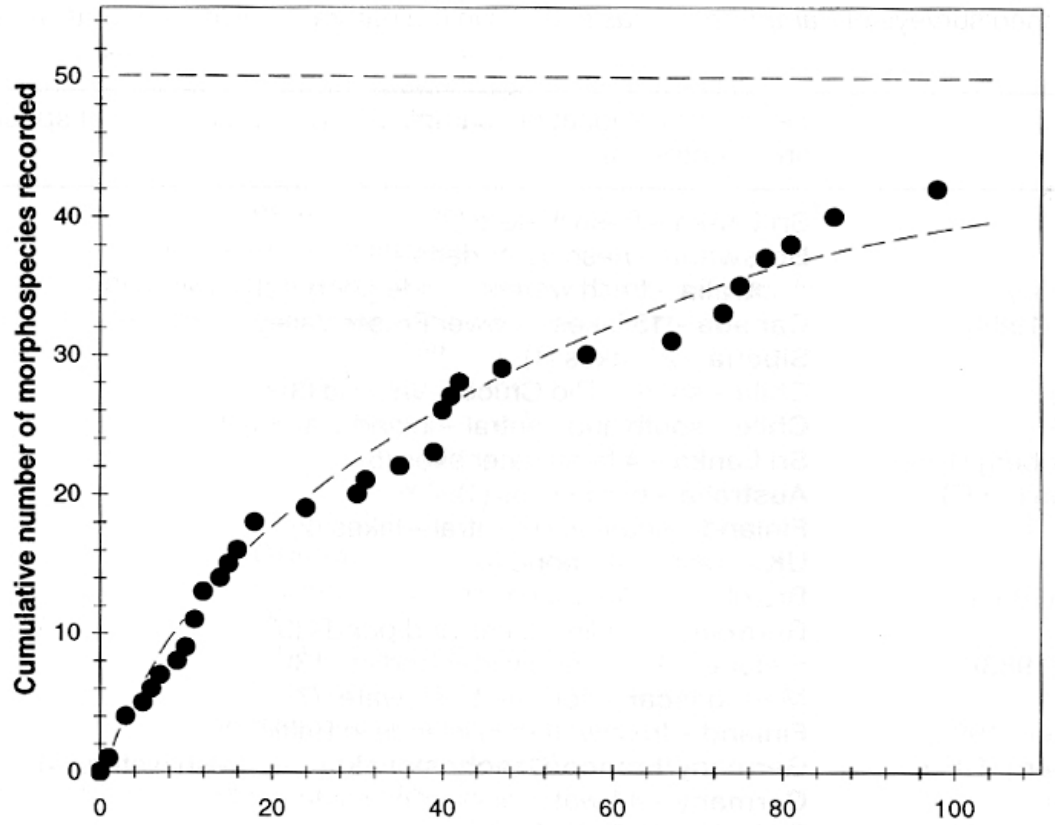
- Are the “hidden“ protist species real?
- **Are the protists ubiquitous?**
- Could they form different populations?
- How do the protists speciate?

Biogeography

- Finlay & Fenchel – neutral theory of ubiquitous protist distribution





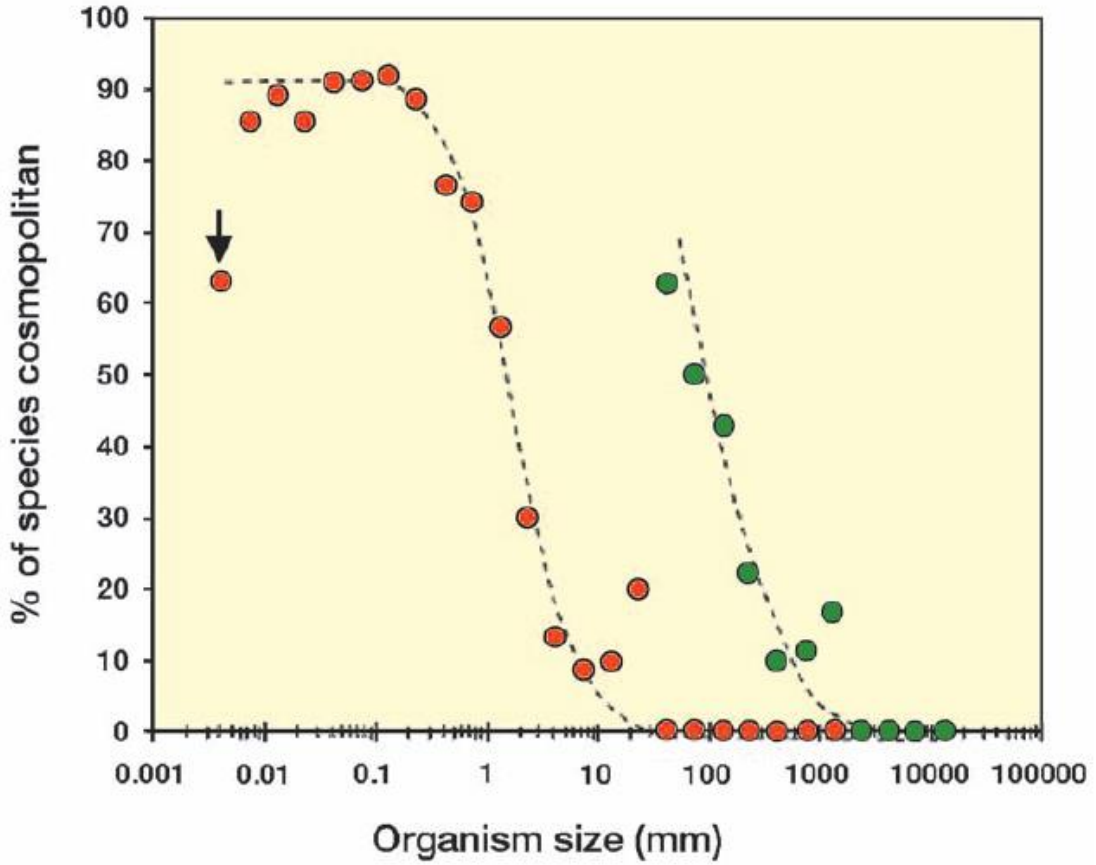


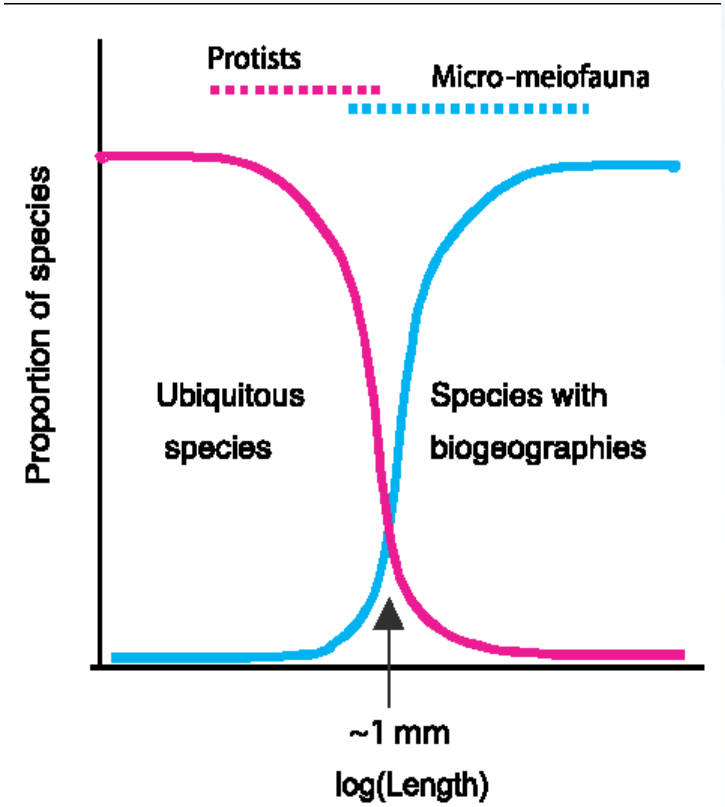
Finlay & Clarke 1999, Protist

Finlay 1999, Nature

Biogeography

- Finlay & Fenchel – neutral theory of ubiquitous protist distribution
  - Everything is everywhere, but many species are extremely rare (enormous populations with unlimited dispersal)
  - Conservation of protists is not needed, the diversity could be investigated in the closest available locality





Finlay & Fenchel 2004, Protist

Biogeography

- Foissner – moderate endemicity model
  - Even if many species are qbiquitous, one third of known species have limited distribution

Table 5.3 Percentages of dispersal routes of protists. Based on the calculation of Foissner (2008) that one-third of ciliates possibly have restricted distribution.

Dispersal routes	Amount (%)
Cosmopolitan distribution due to step-by-step dispersal and human introductions	35
Cosmopolitan distribution due to geological processes, euryoecious lifestyle and others	30
Restricted distribution due to morphological and physiological peculiarities of the resting cysts, break-up of Pangaea and insufficient time to disperse in young species	35

Foissner 2011, Biogeography of Microscopic Organisms

Biogeography

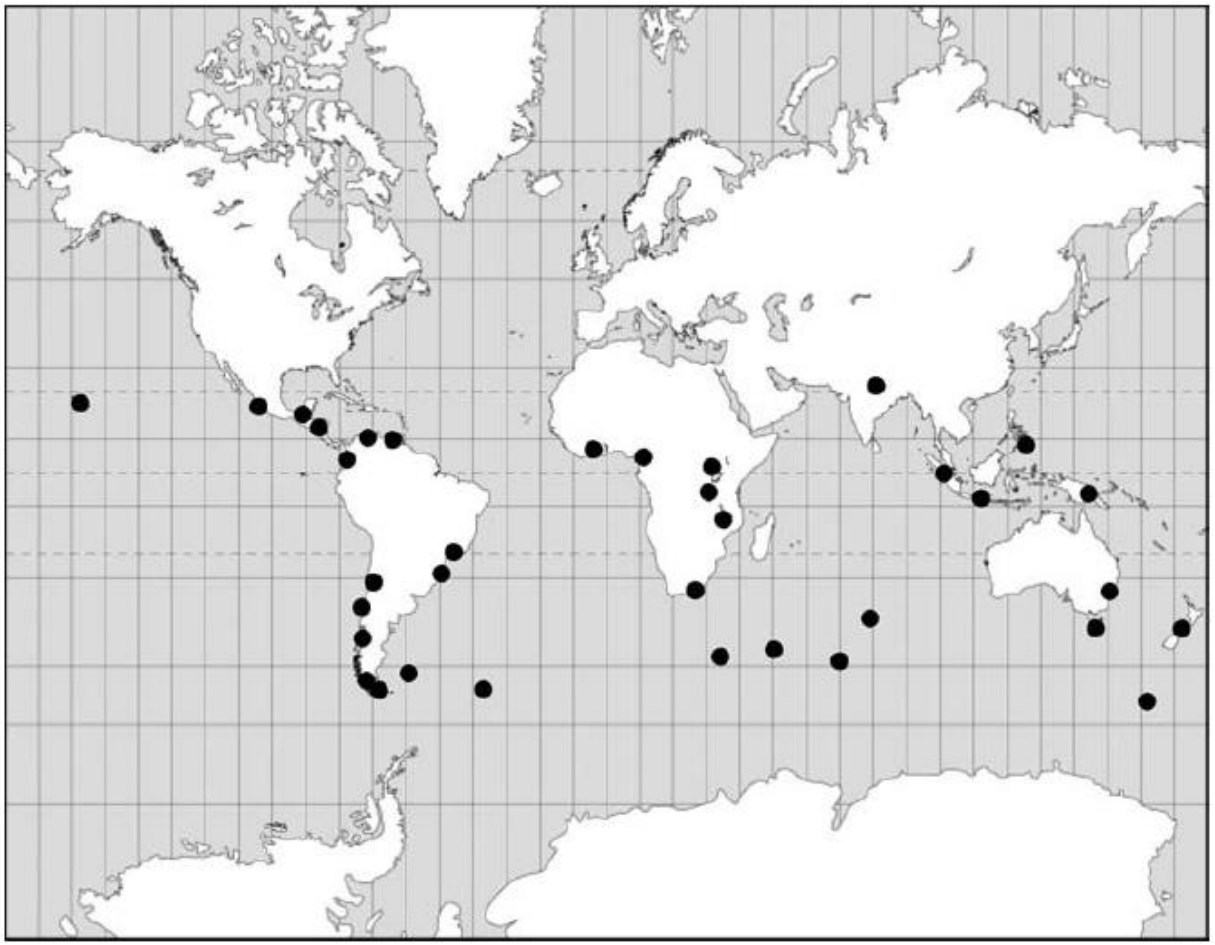
- Foissner – moderate endemicity model
  - Flagship species

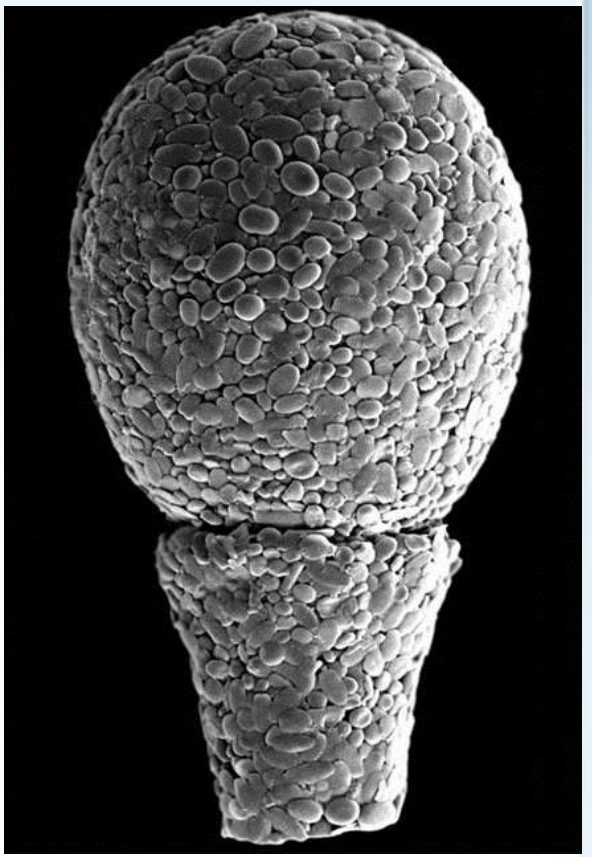
Micrasterias hardyi - Australia

Maristentor dinoferus – *S* America

Biogeography

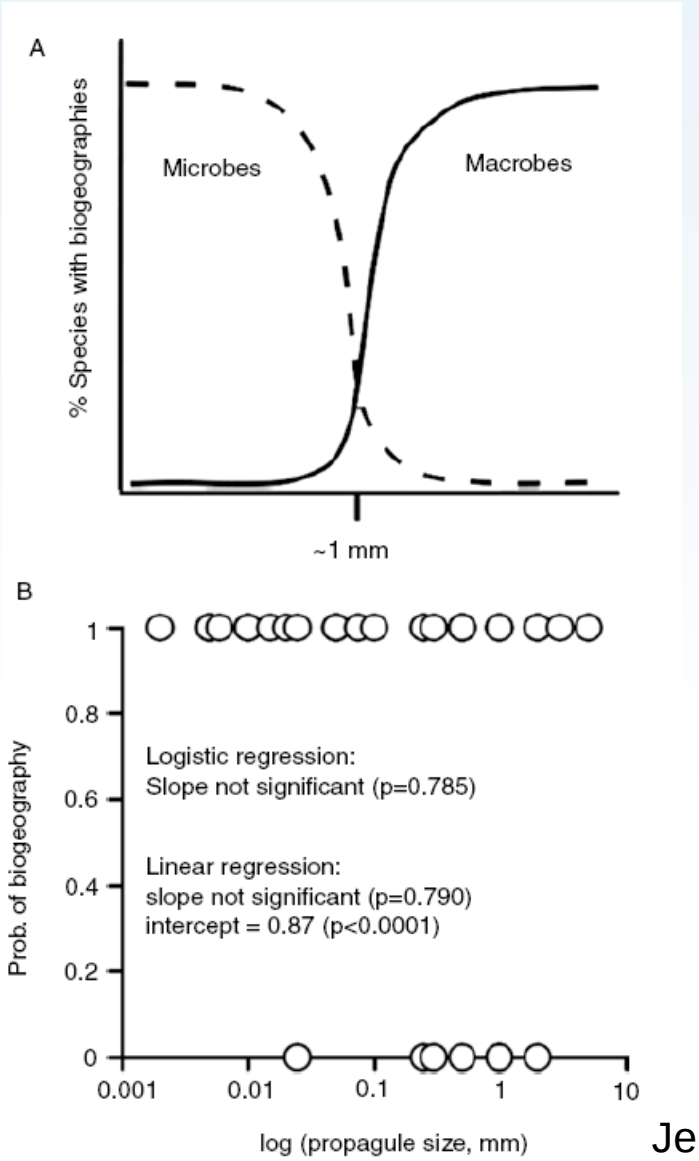
- Foissner – moderate endemicity model
  - *Apodera vas* – Gondwanan distribution

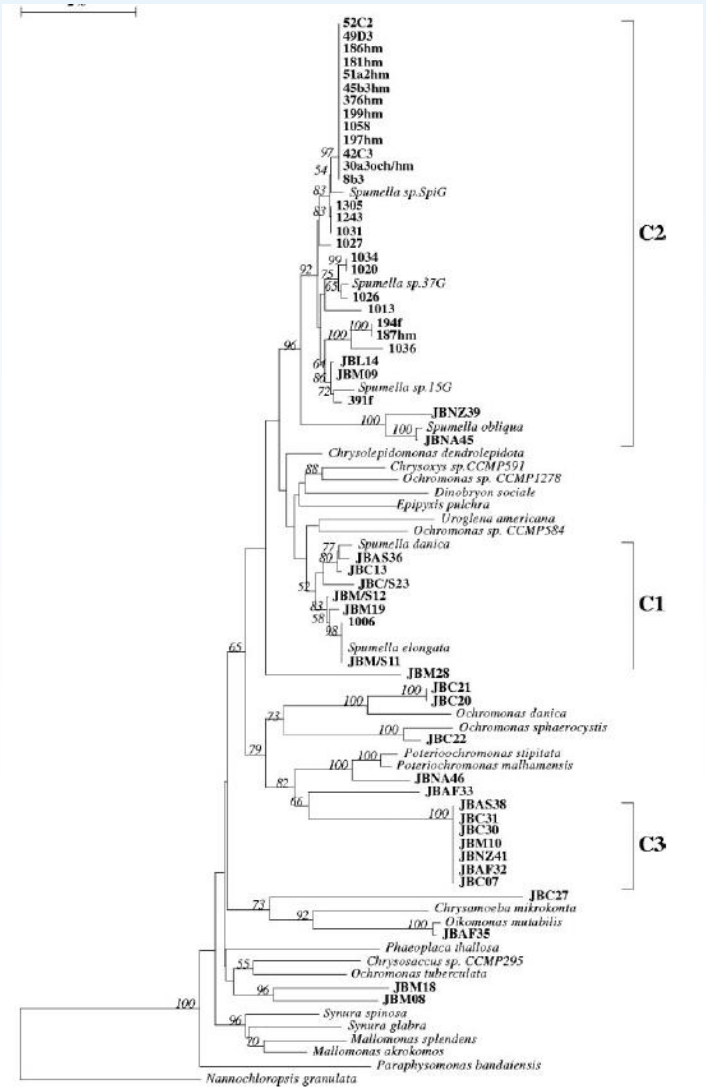




Biogeography

- Testing the ubiquity theory on 51 phylogeographic studies

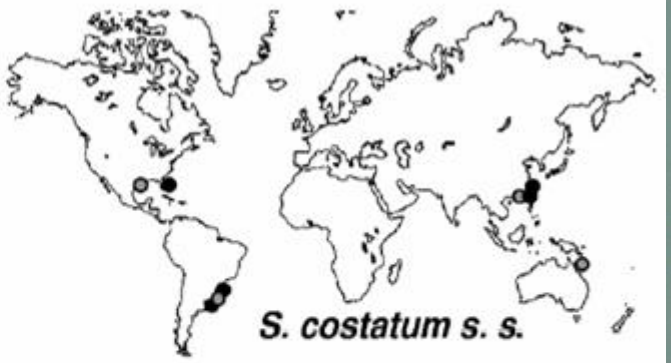


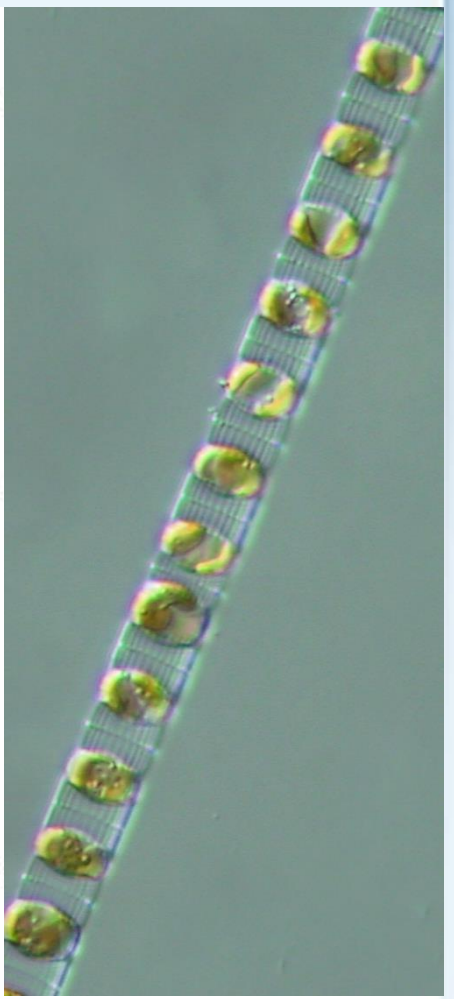


Jenkins et al. 2011, Biogeography of Microscopic Organisms

Biogeography

- Phylogeography – endemic species within the genus *Skeletonema*

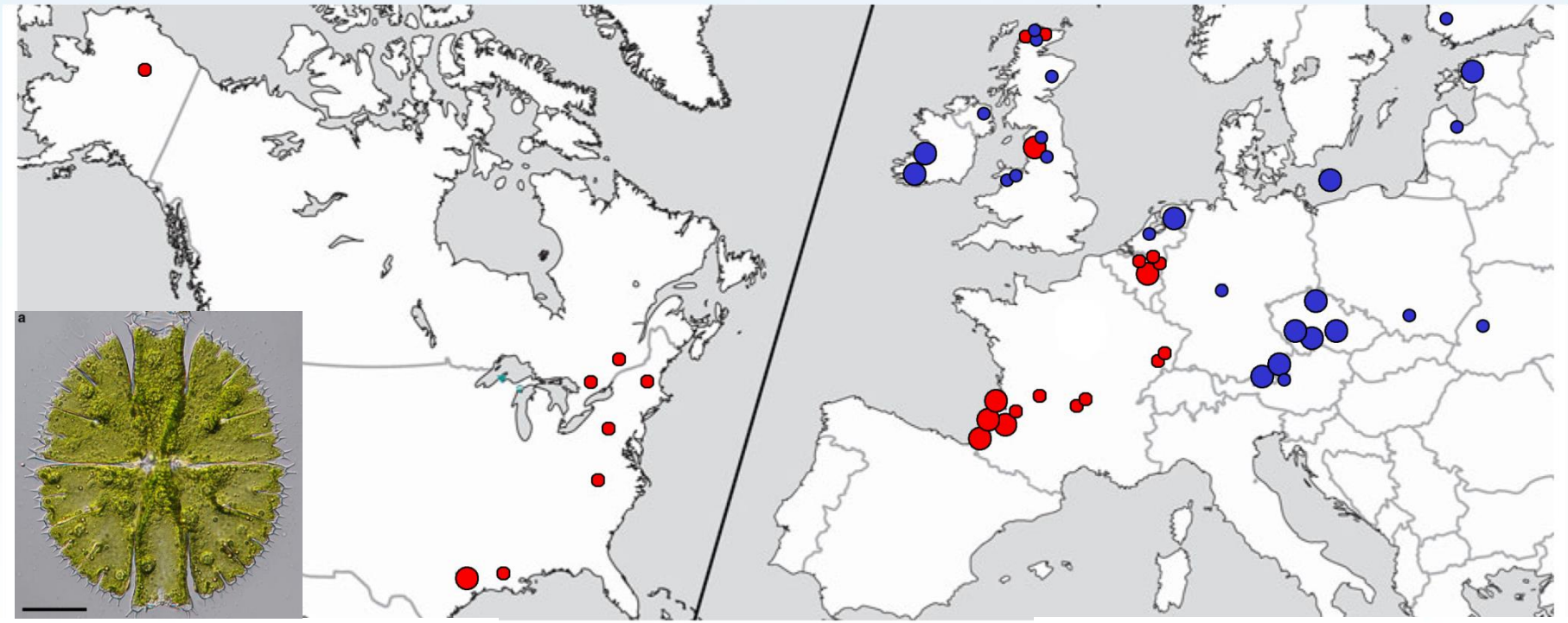




Kooistra et al. 2007, Protist

Biogeography

- Phylogeography – distinct biogeography of two cryptic desmid species



Neustupa et al. 2011, Hydrobiologia

Specificity of protist organisms

- Are the “hidden“ protist species real?
- Are the protists ubiquitous?
- **Could they form different populations?**
- How do the protists speciate?

Genetic structure of protist populations

- Very few studies
- Finlay – unlimited dispersal and continuous gene flow imply the absence of differentiated populations

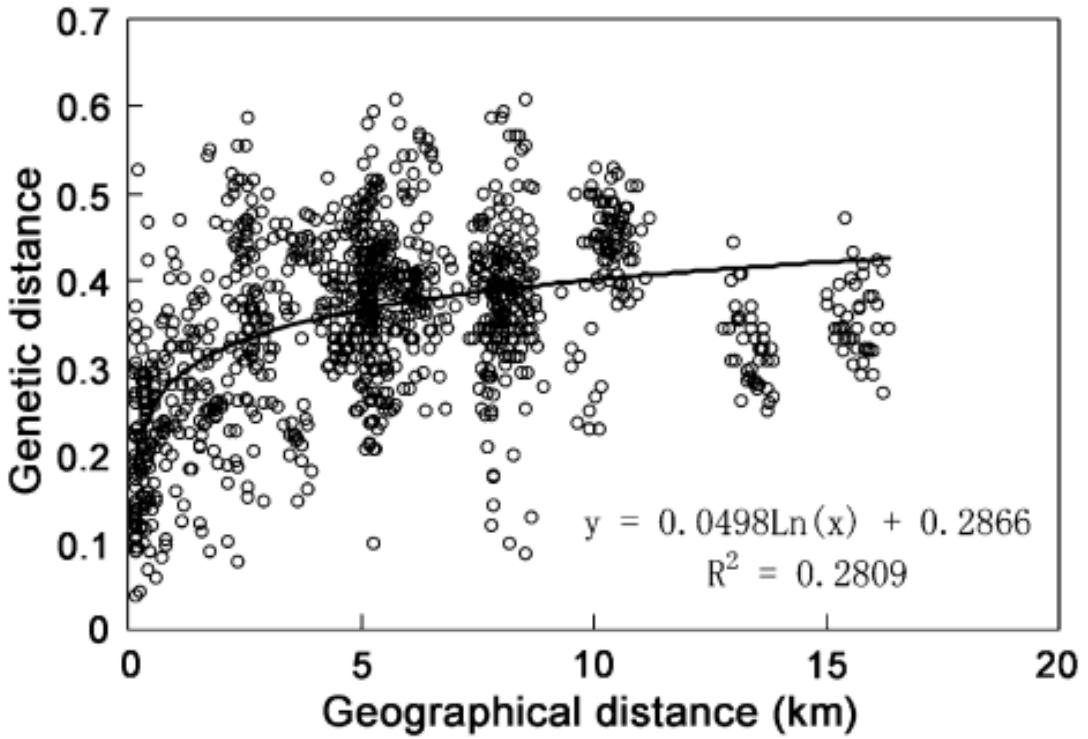
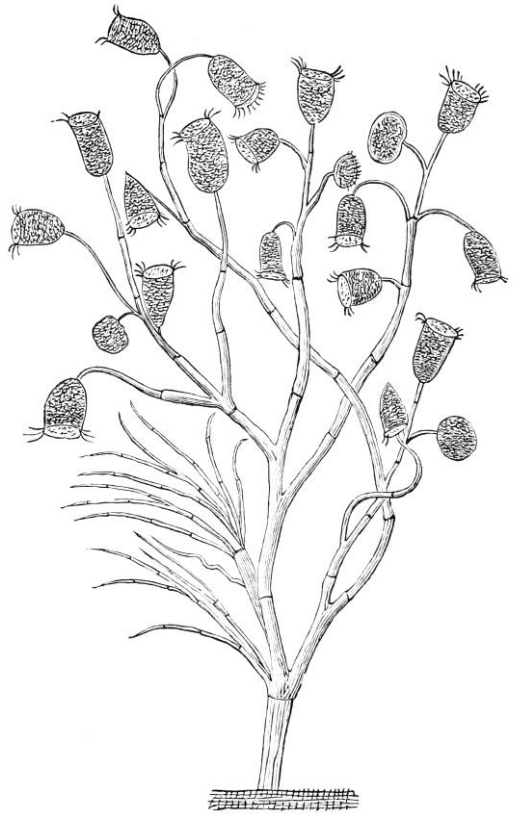


Fig. 5. Logarithmic correlation between genetic distance (Nei and Li 1979) and geographical distance ($r = 0.5300$, $P < 10^{-6}$).



Carchesium polypinum

Zhang et al. 2006, J. Eukar. Microbiol.

Genetic structure of protist populations

- Spatial population structure – *Pseudo-nitzschia pungens*

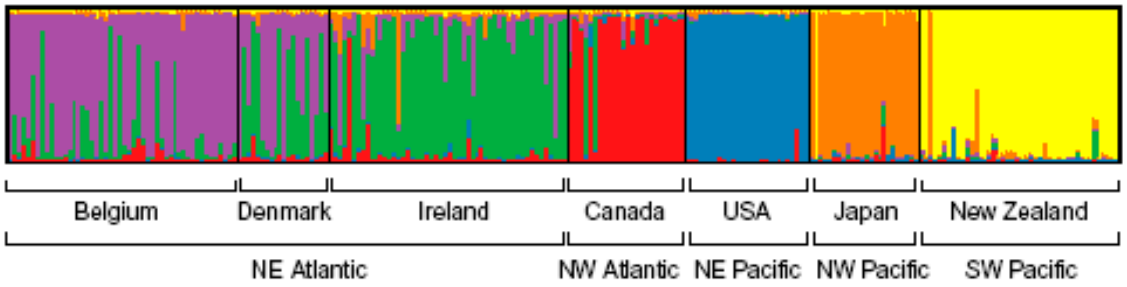


Fig. 3. Structure plot for $K = 6$. Each individual is depicted by a vertical line that is partitioned into K colored sections, with the length of each section proportional to the estimated membership coefficient (q_{ind}) of the isolate to each cluster.

Fig. 4. Principal component analysis of pairwise F_{ST} values among the seven predefined populations of *P. pungens* clade I. The first and second principal components account for 59.47% and 24.58% of the total variation, respectively.

Casteleyn et al. 2010, PNAS

Genetic structure of protist populations

- Spatial population structure – *Scrippsiella hangoei*

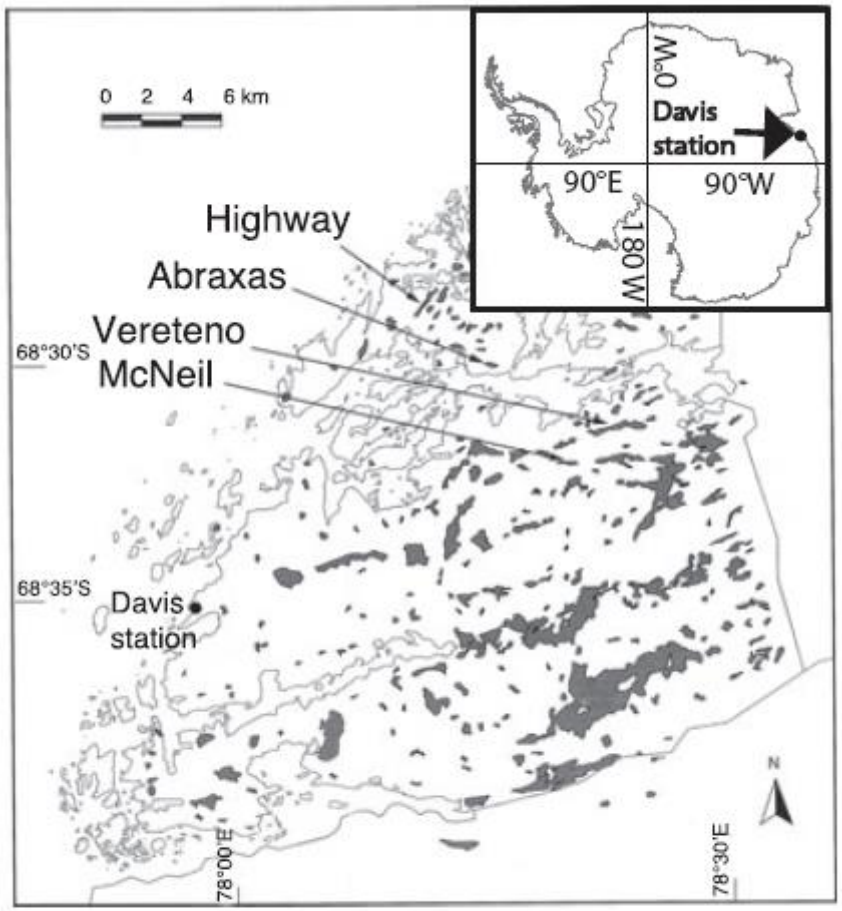


Fig. 1. Map of Vestfold Hills showing location of study lakes and Davis Station.

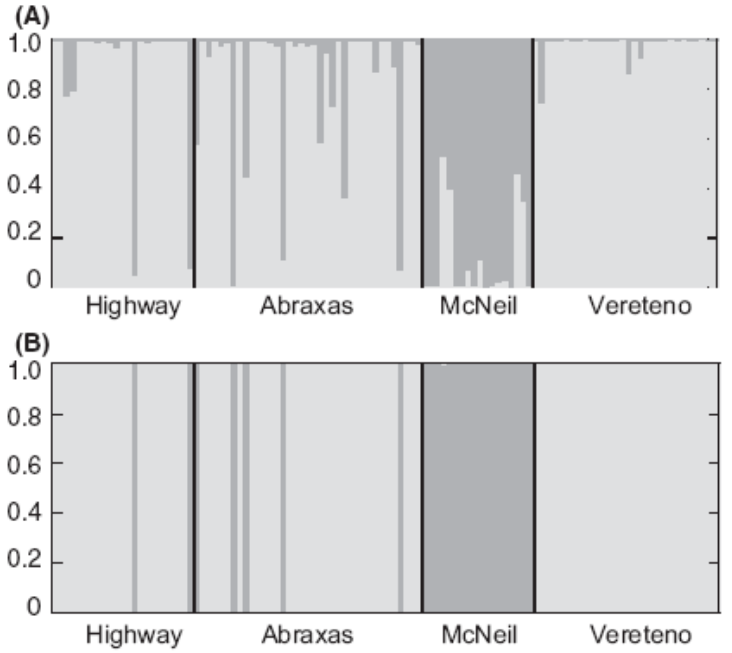
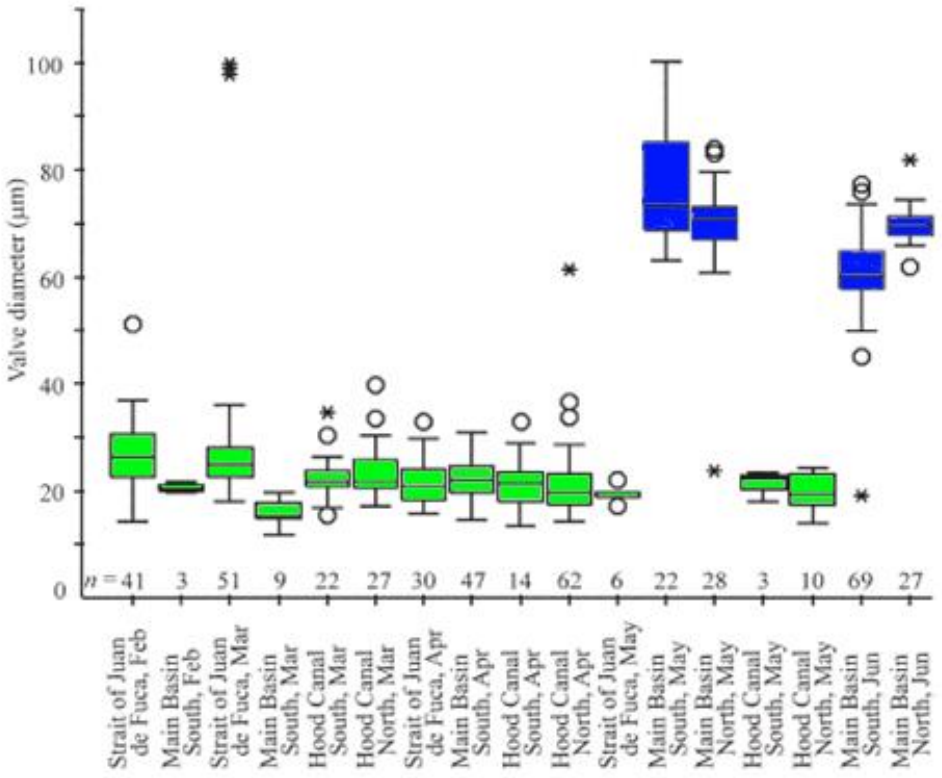


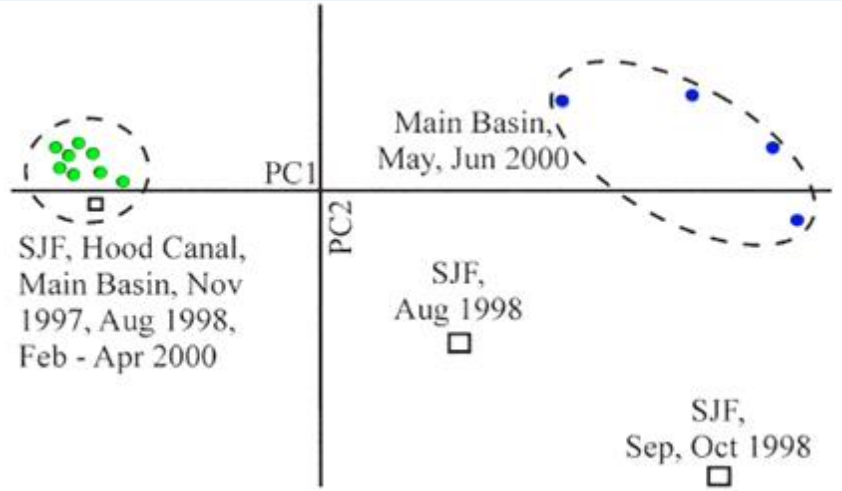
Fig. 3. Population analyses results from STRUCTURE shown as bar plots. Only the models showing the highest likelihood

Rengefors et al. 2012, Mol. Ecol.

Genetic structure of protist populations

- Temporal population structure – *Ditylum brightwellii*
- *Annual change of two blooms*





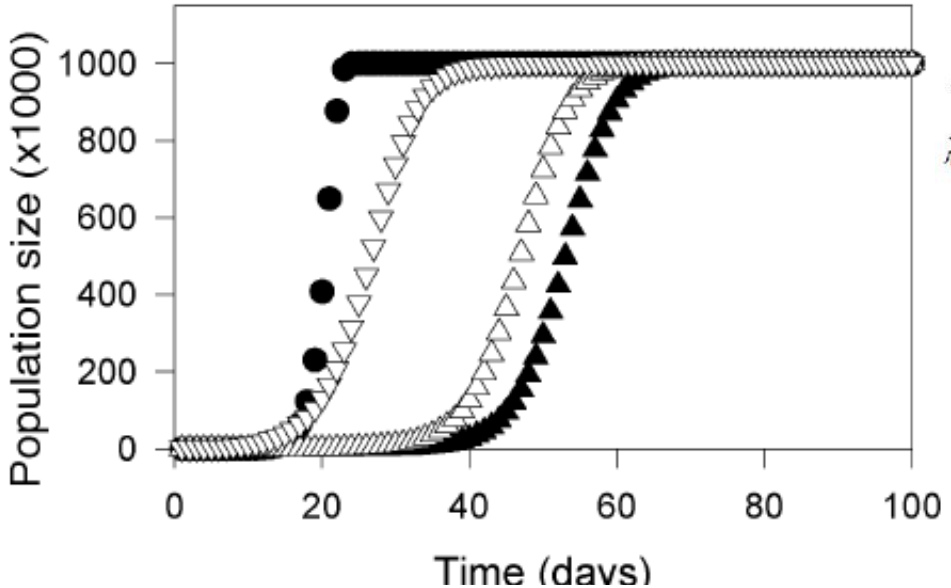
Rynearson et al. 2006, Limnol. Oceanogr.

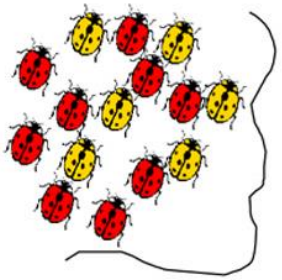
Specificity of protist organisms

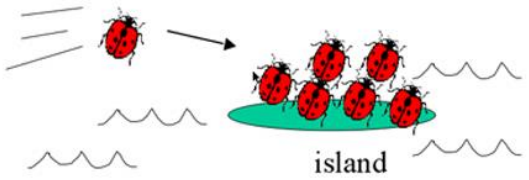
- Are the “hidden“ protist species real?
- Are the protists ubiquitous?
- Could they form different populations?
- **How do the protists speciate?**

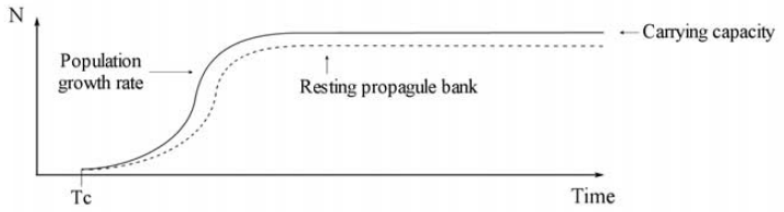
Protist speciation

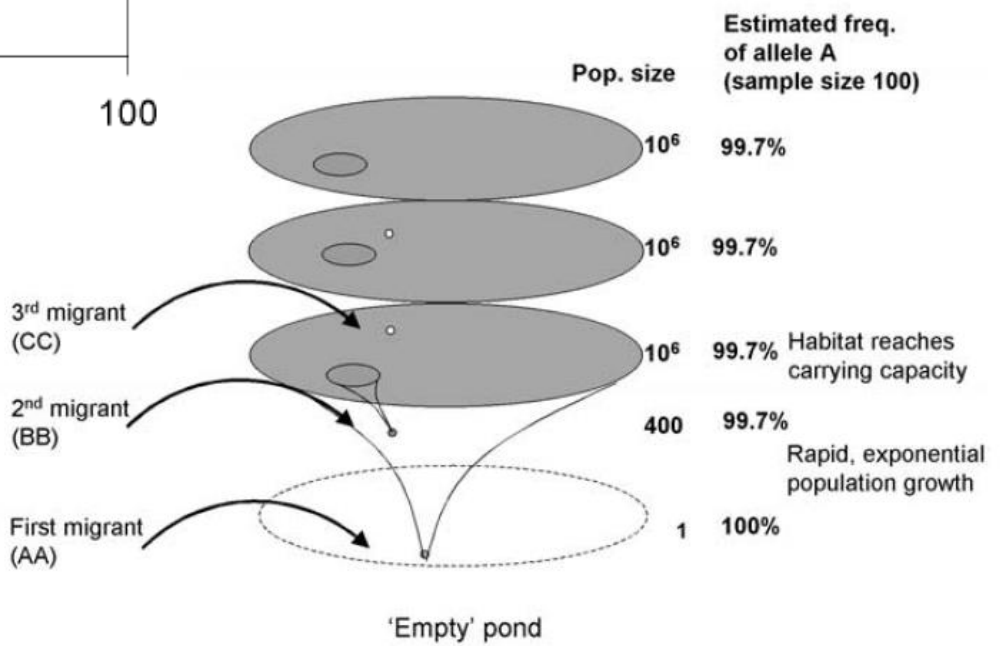
- Monopolisation hypothesis – founder efect (bank of dormant cysts)
  - Rapid adaptation to local environmental conditions







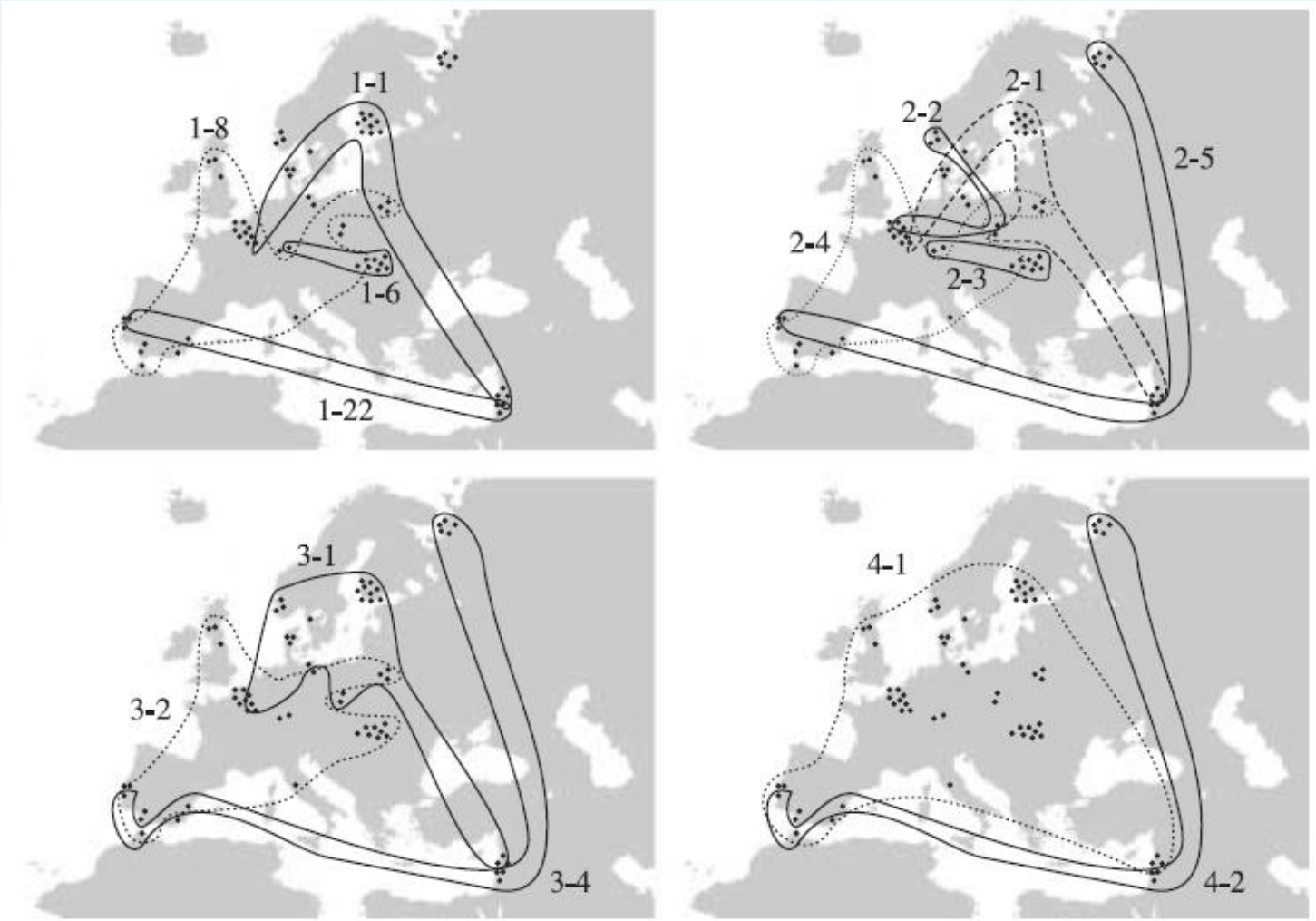




De Mesteer et al. 2002, Acta Oecol.

Protist speciation

- Monopolisation hypothesis
  - *Mosaic populations in Daphnia = allopatric speciation*

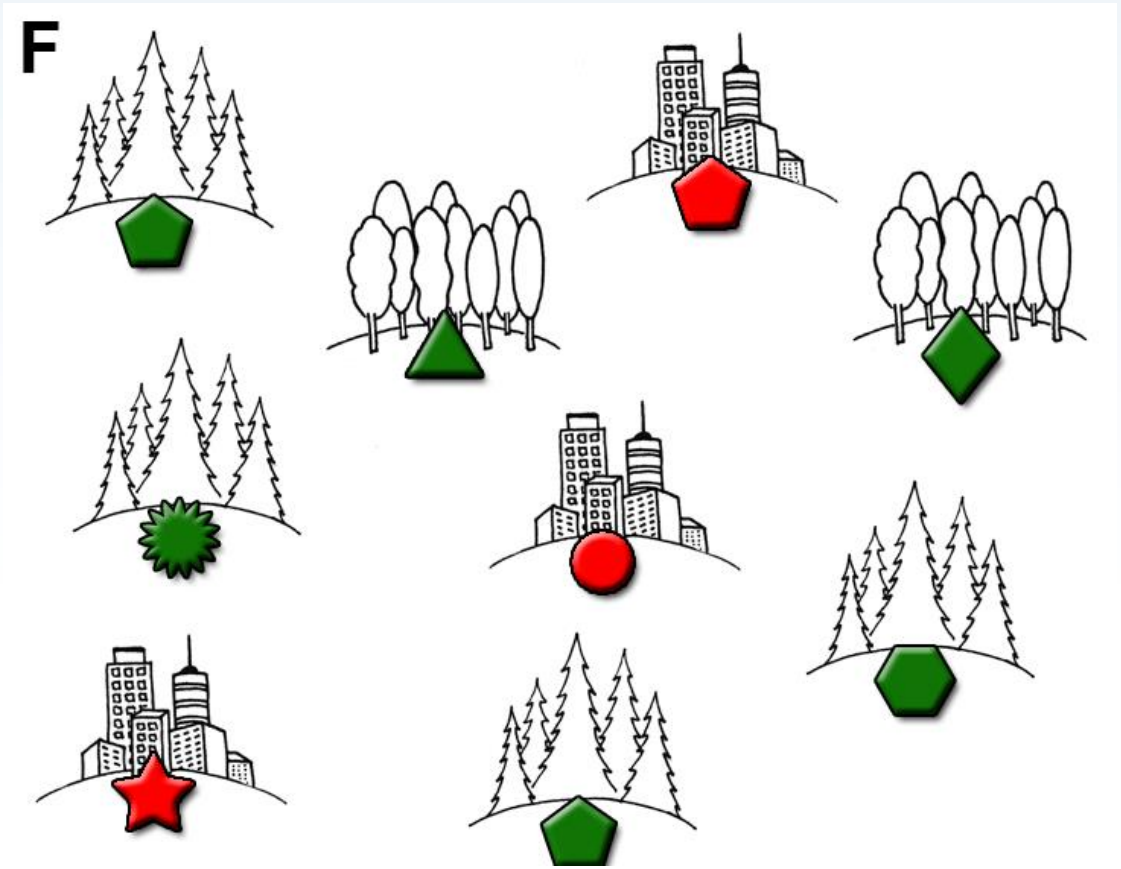


De Gelas & De Meester 2005, Mol. Ecol.

Protist speciation

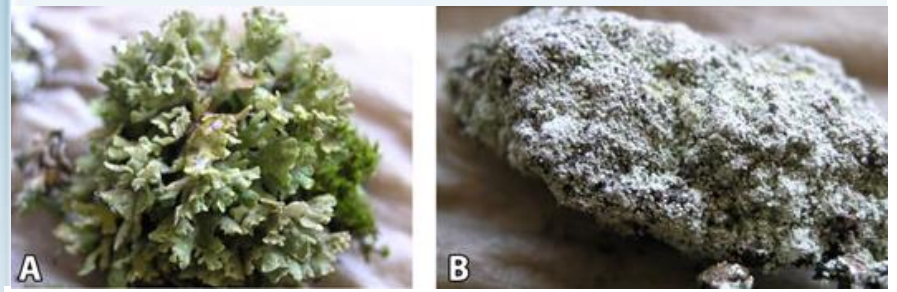
- Monopolisation hypothesis – founder efect (bank of dormant cysts)
  - Rapid adaptation to local environmental conditions

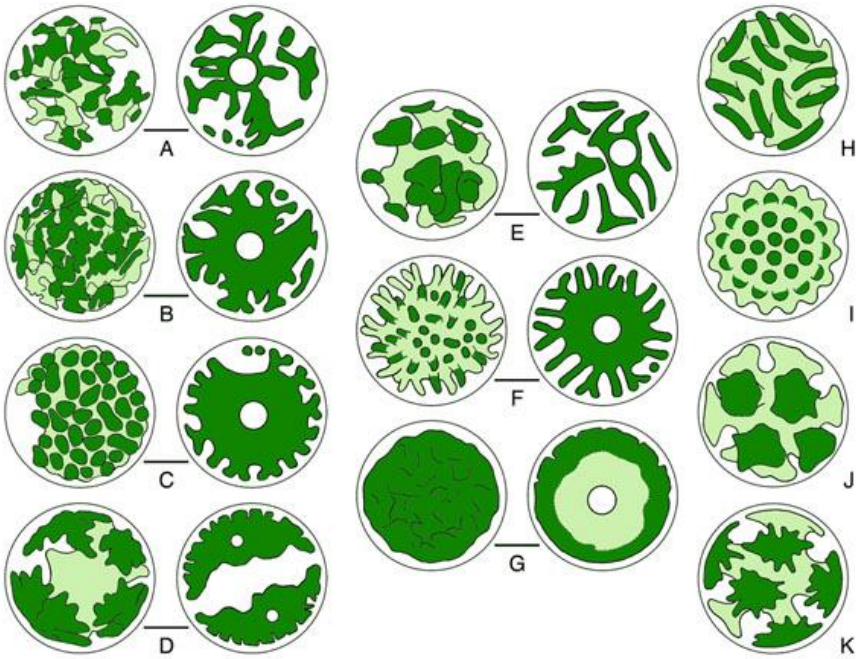
⇨ Ecological speciation



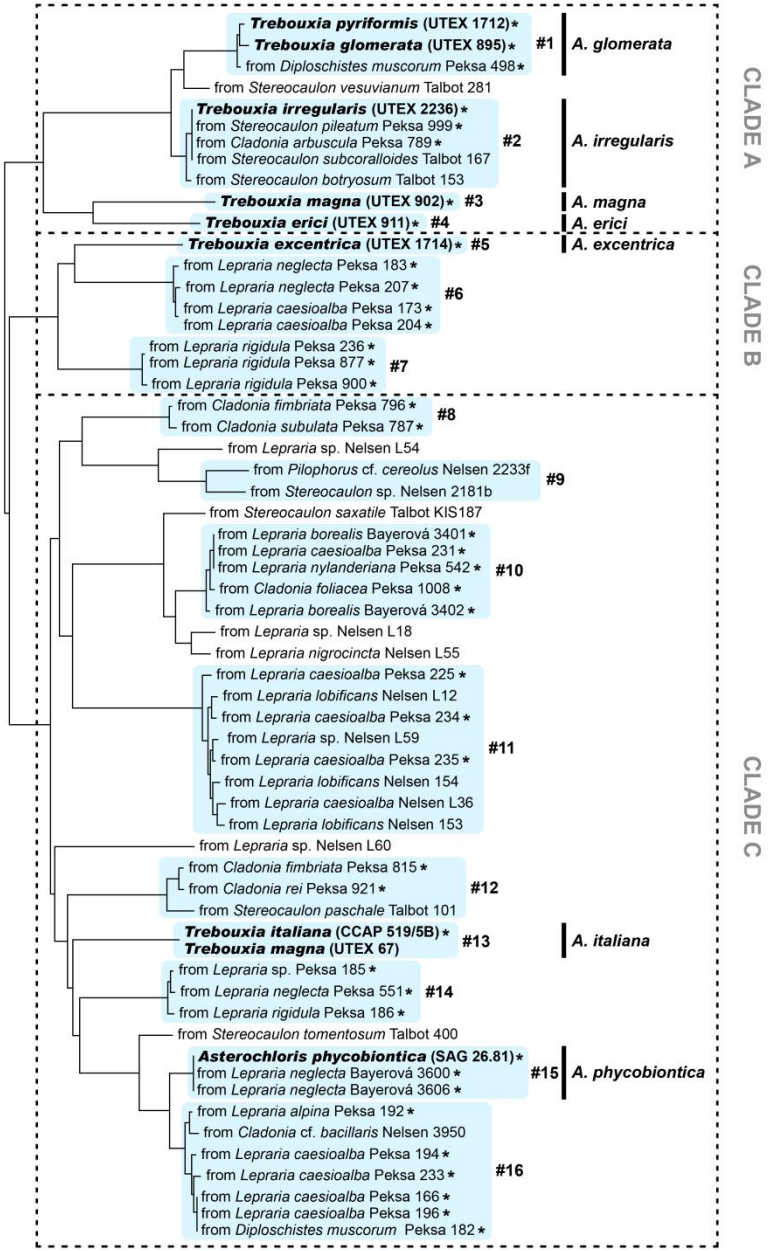
Protist speciation

- *Asterochloris*
  - Genetic diversity





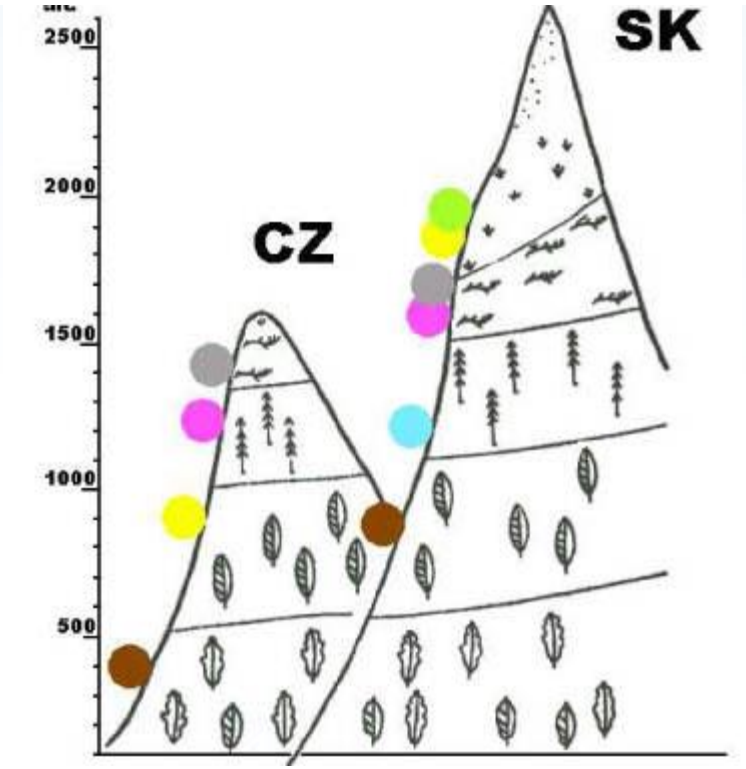
Škaloud & Peksa 2010, Mol. Phyl. Evol.

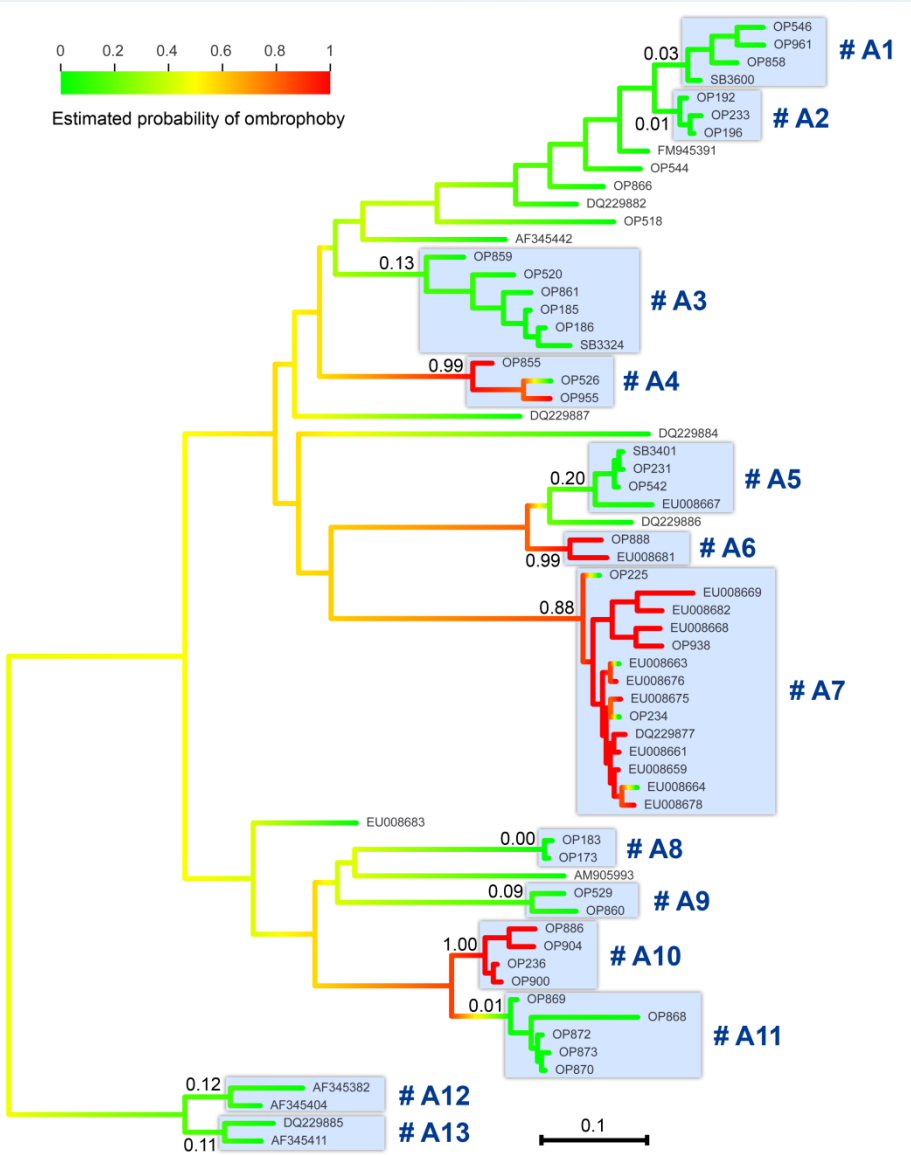


Protist speciation

- *Asterochloris*
  - Ecological speciation

Trait	Pagel's λ		
	λ	Likelihood ratio	*P*-value
Exposure to rain	0.946	1.53	<0.0001
Altitude	0.045	1.01	<0.0001
Substrate type	0.652	1.05	0.0011

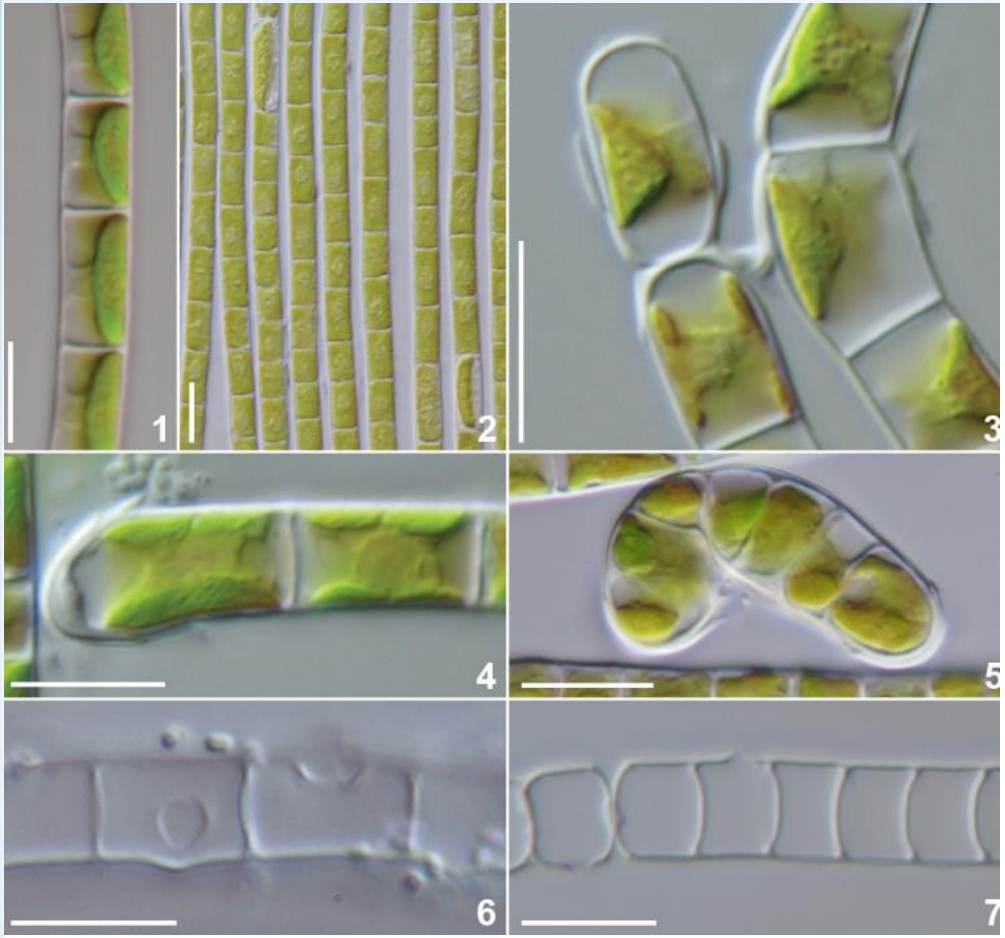


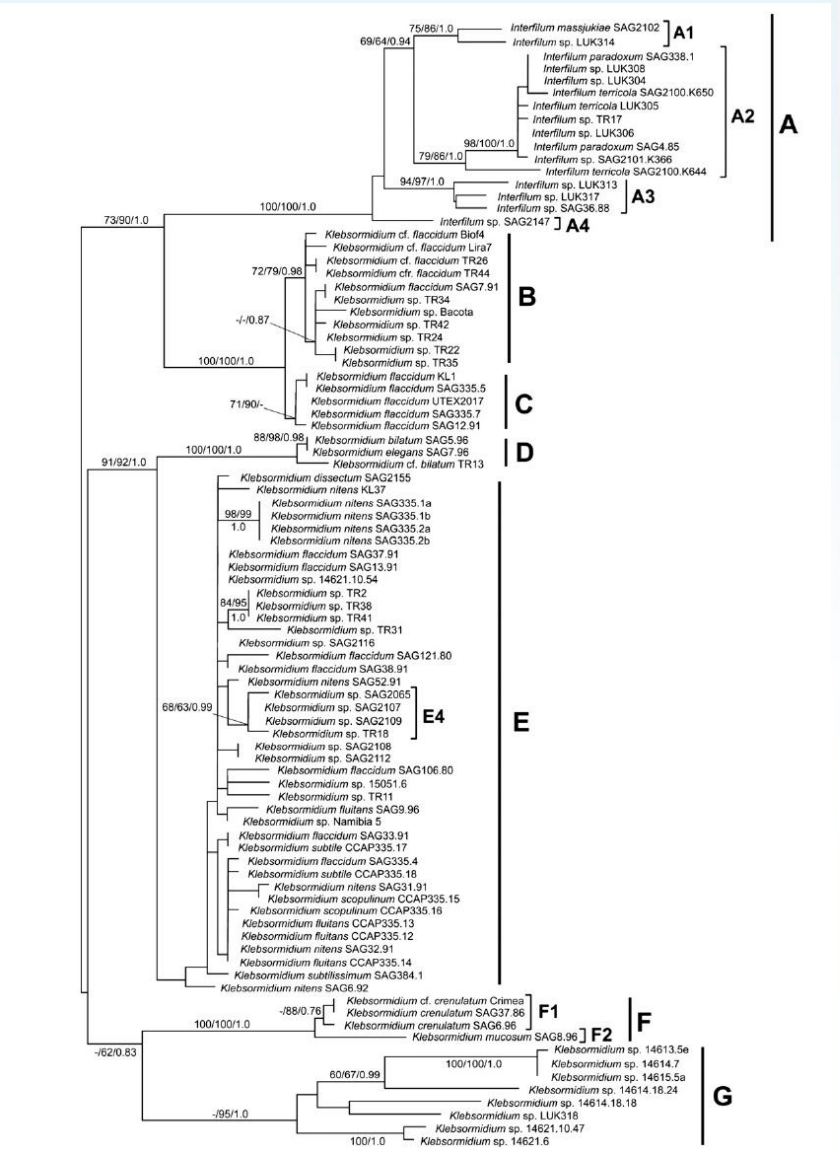


Peksa & Škaloud 2011, Mol. Ecol.

Protist speciation

- *Klebsormidium* – the high level of cryptic diversity, particular clades are morphologically indiscernable

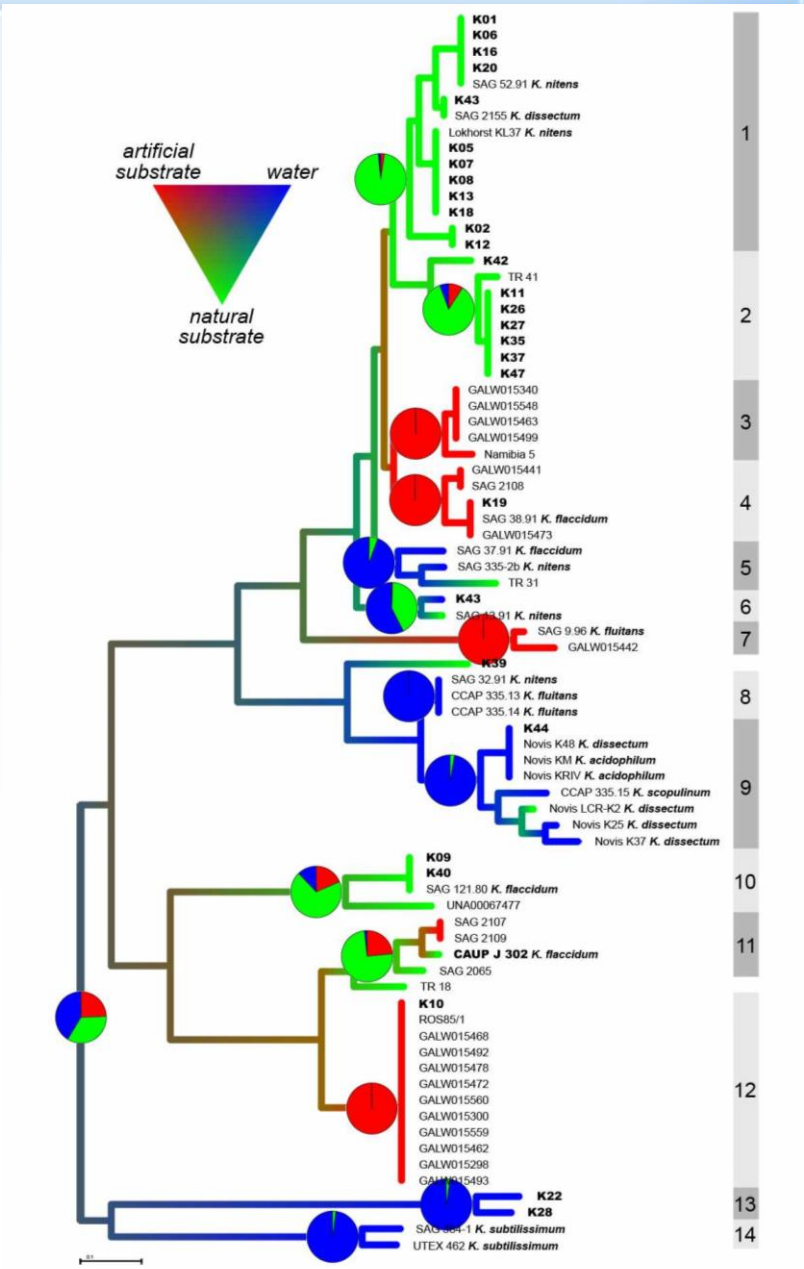




Rindi et al. 2011, Mol. Phyl. Evol.

Protist speciation

- *Klebsormidium* – ecological speciation

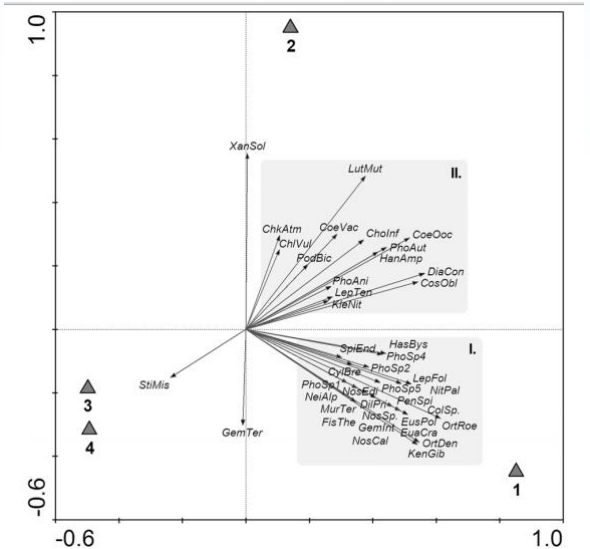


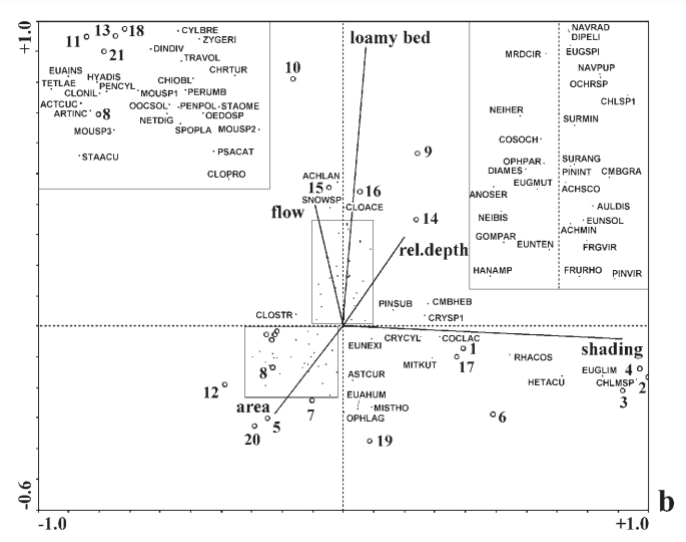
Škaloud & Rindi 2013, J. Euk. Microb., *in press*

Summary

- Protists could speciate even if they have enormous populations and unlimited dispersal
- We should keep in mind the existence of a high portion of cryptic, so far undescribed species od protists
- Species are often differentiatied by their ecological preferences

- Ekological studies based on protist morphospecies?

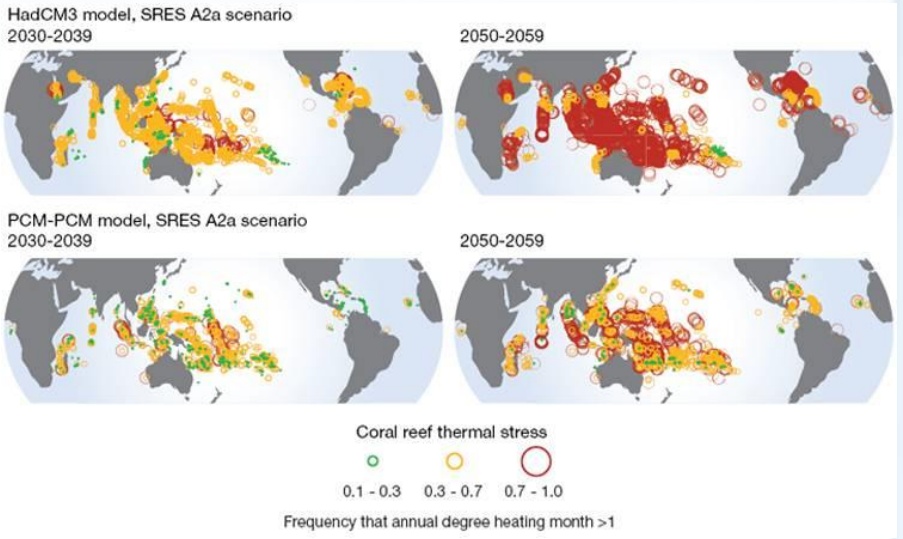




Summary

- Protists could speciate even if they have enormous populations and unlimited dispersal
- We should keep in mind the existence of a high portion of cryptic, so far undescribed species od protists
- Species are often differentiatied by their ecological preferences

- Conservation of protists – is it needed?



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Thank you for your attention