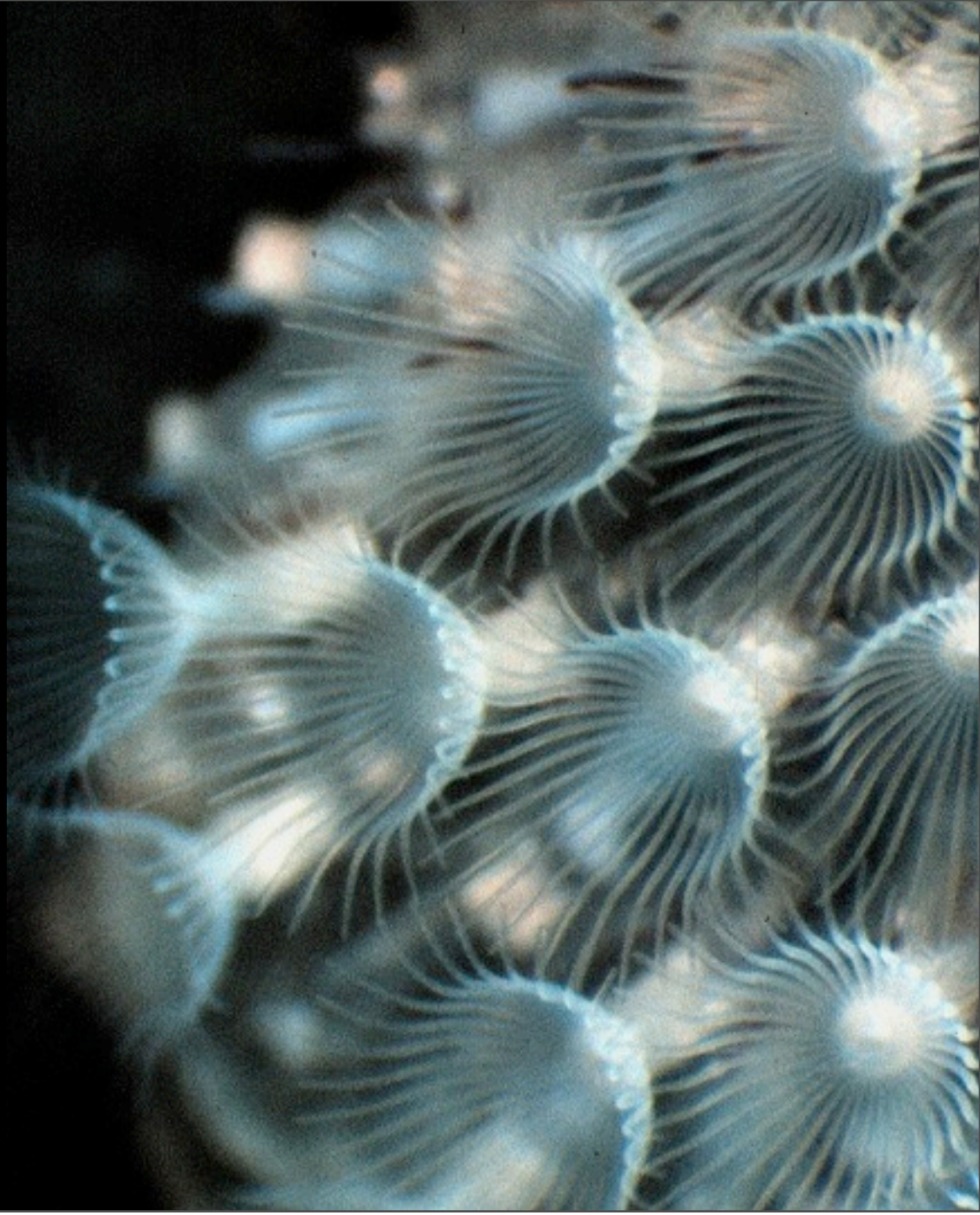
Bryozoans as palaeoenvironmental indicators

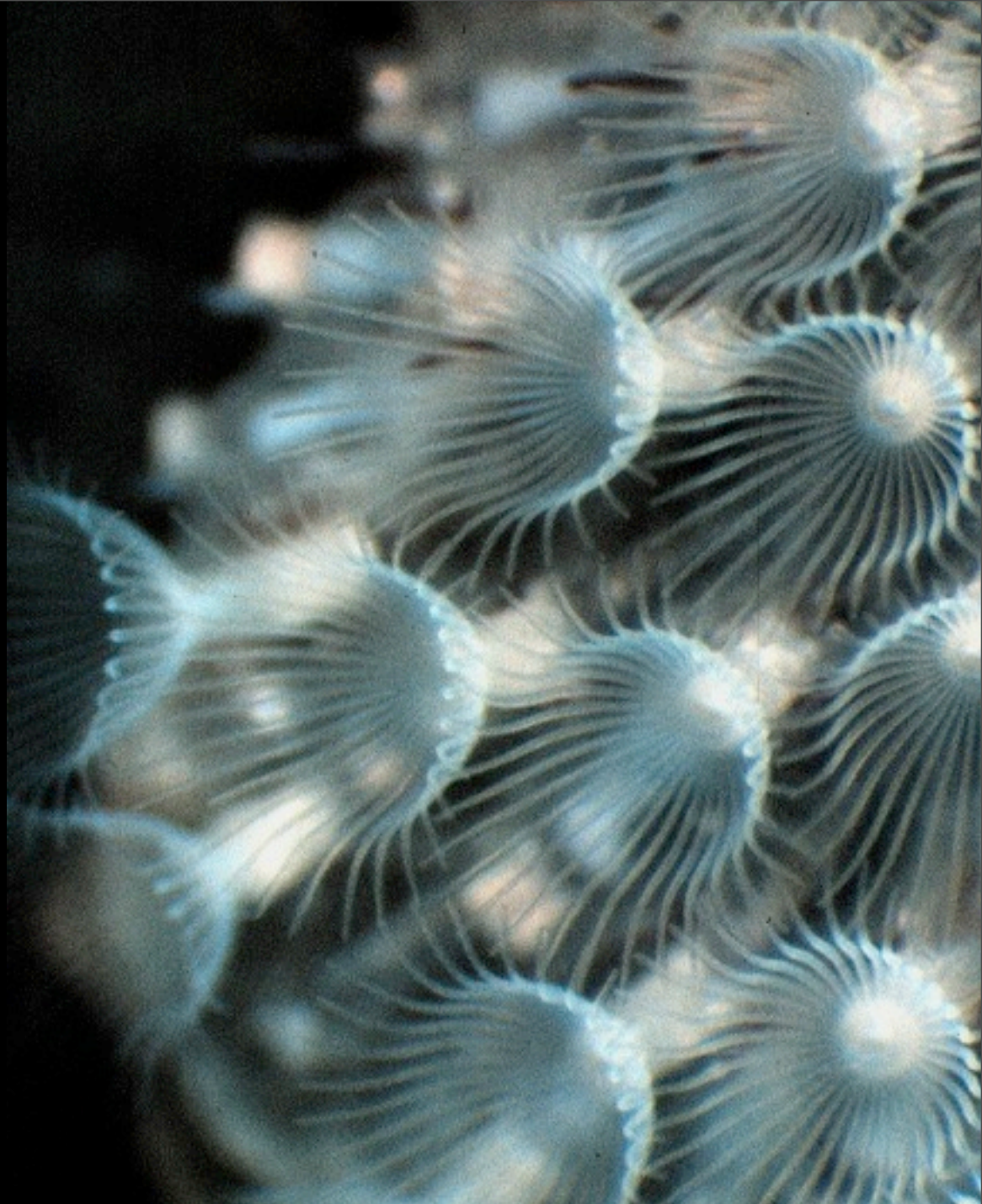
Paul D Taylor, NHM, London

What are bryozoans?



What are bryozoans?

- invertebrate phylum



What are bryozoans?

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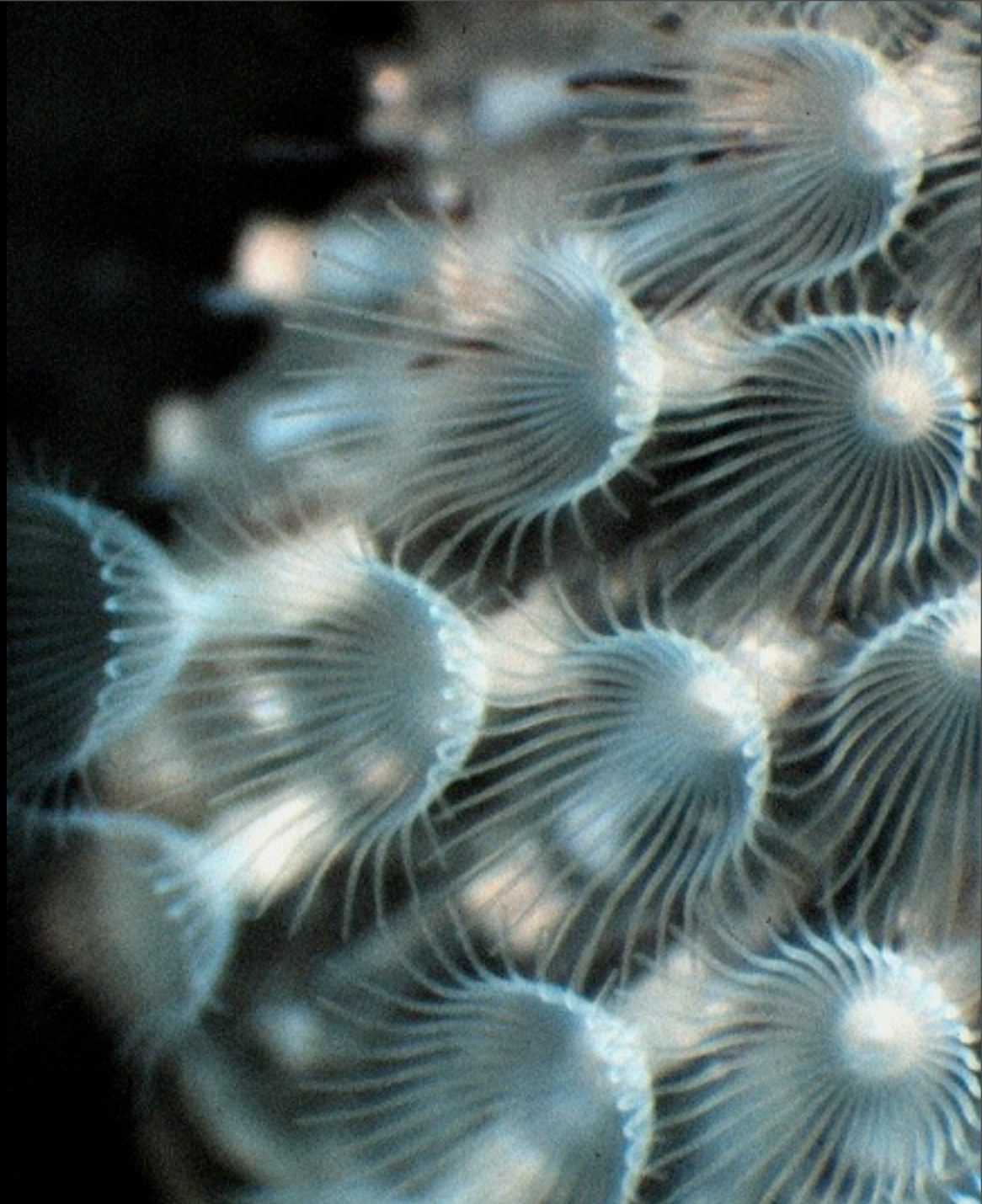

What are bryozoans?

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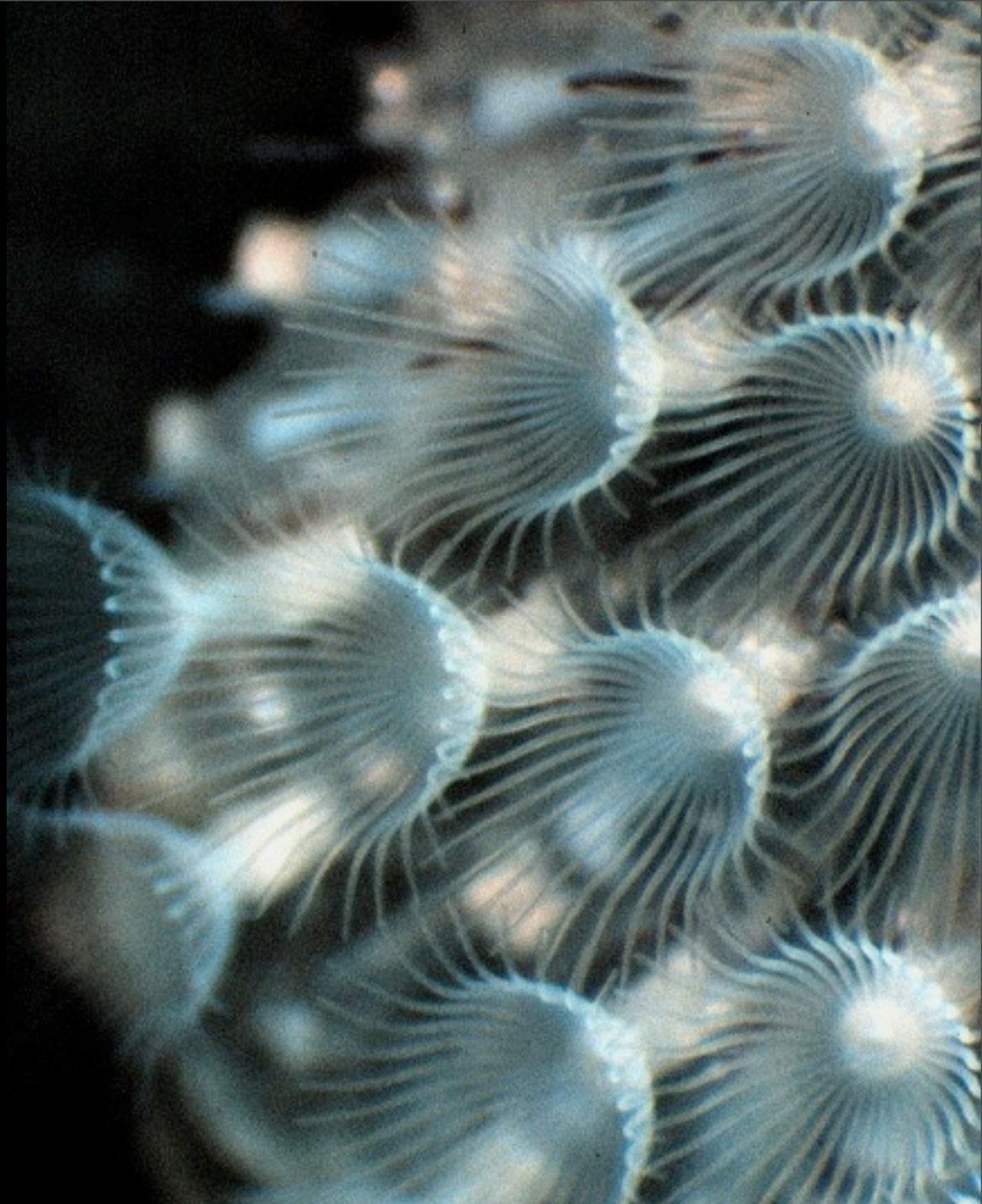
- mainly marine



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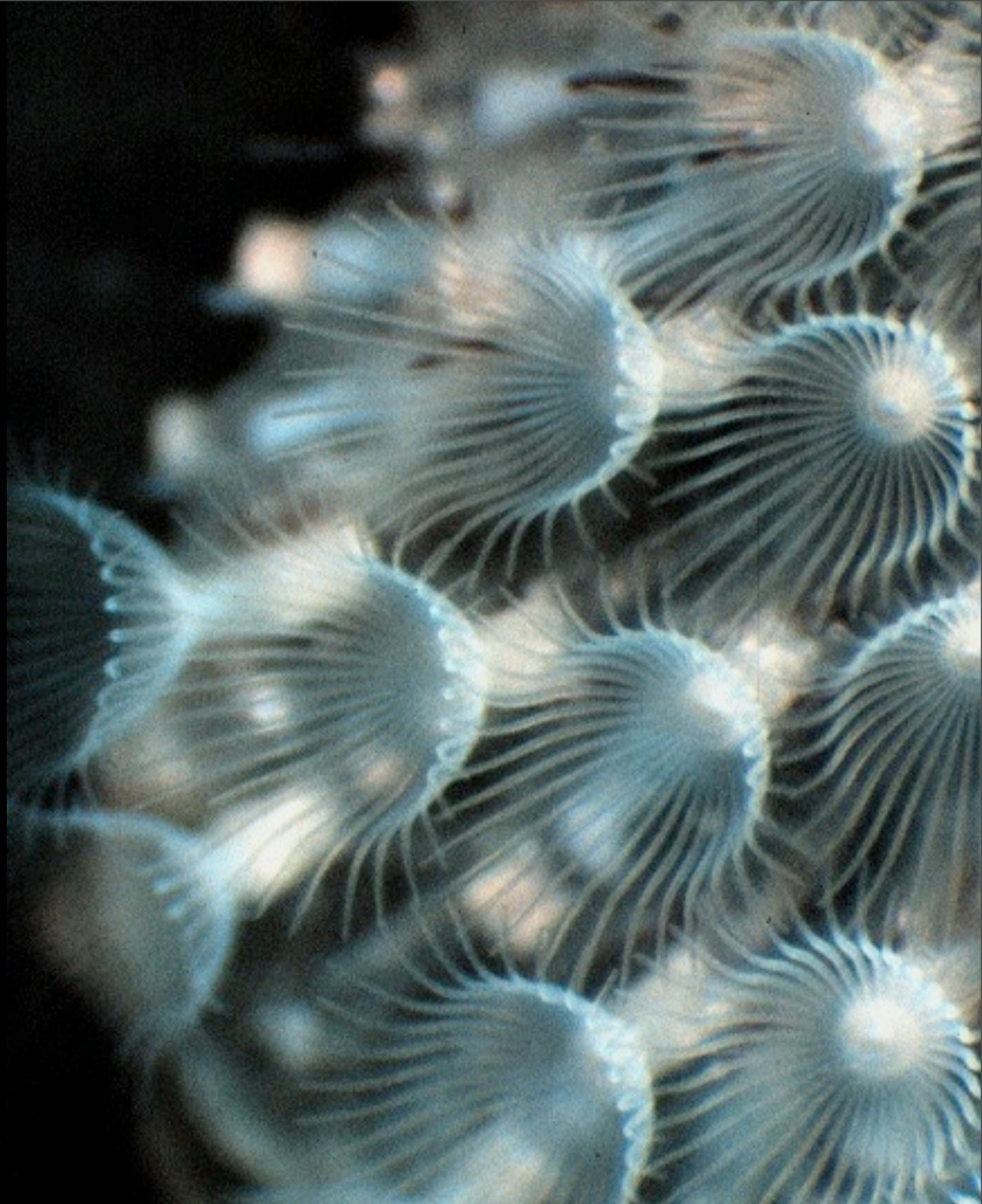

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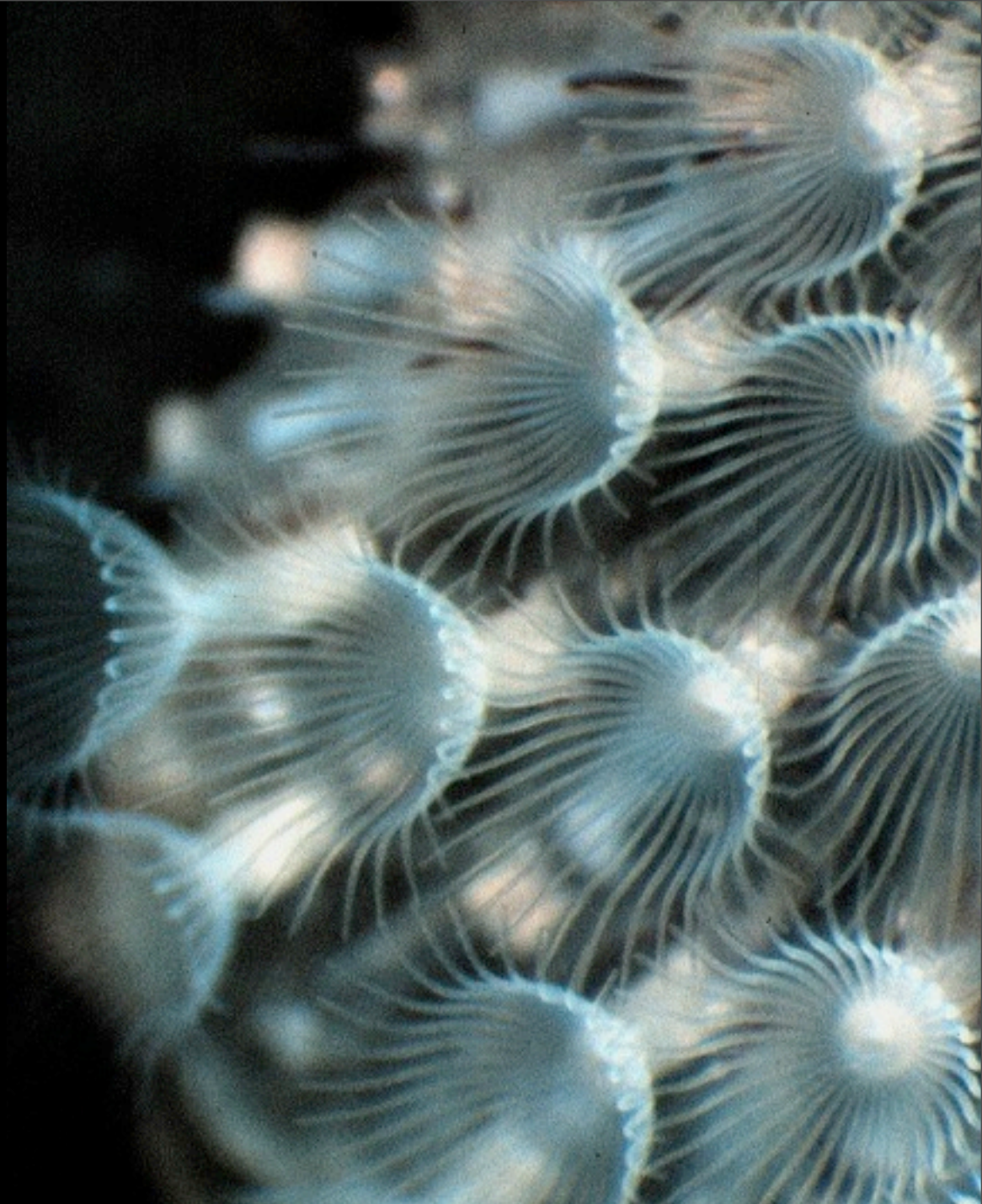

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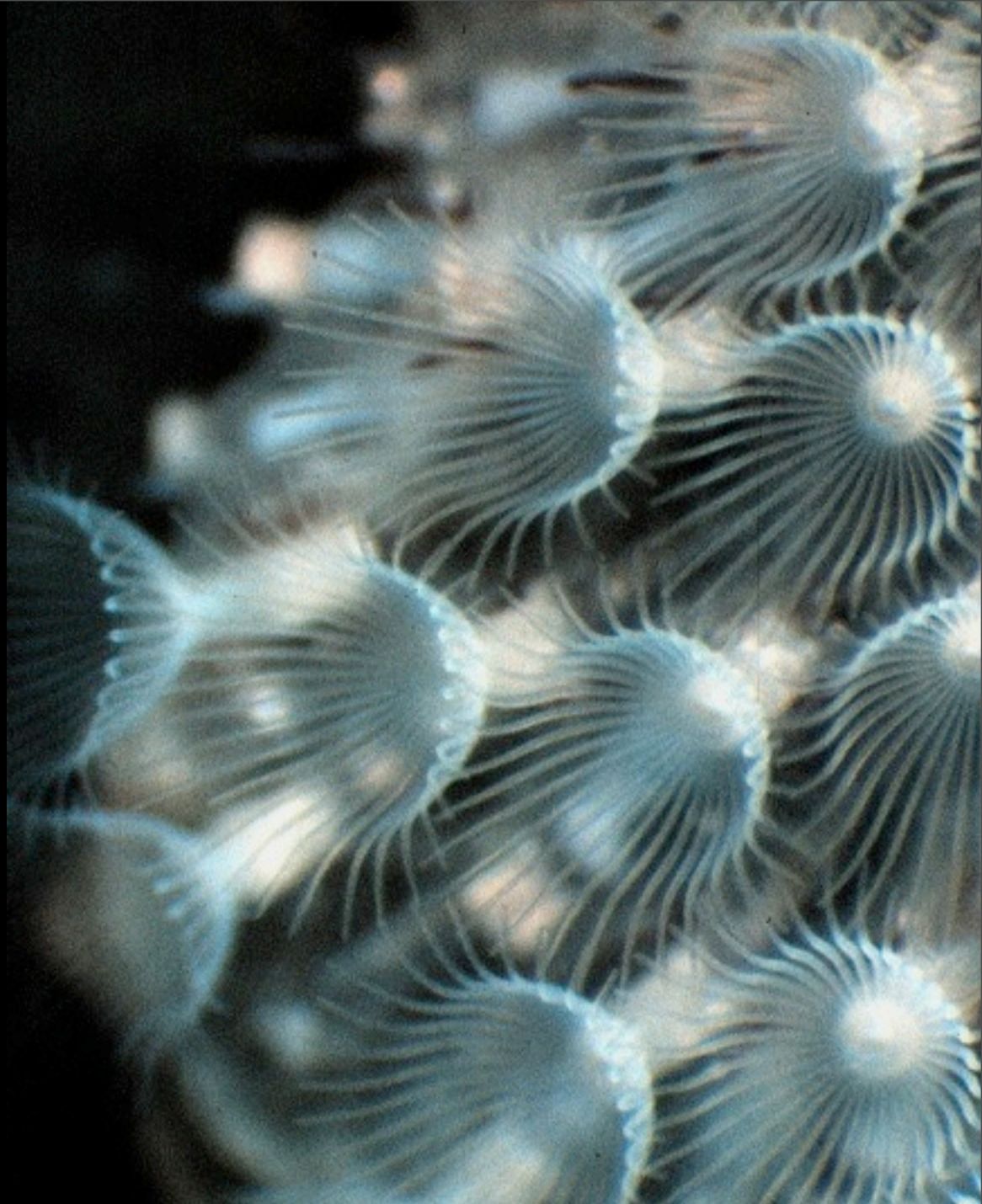
- all colonial



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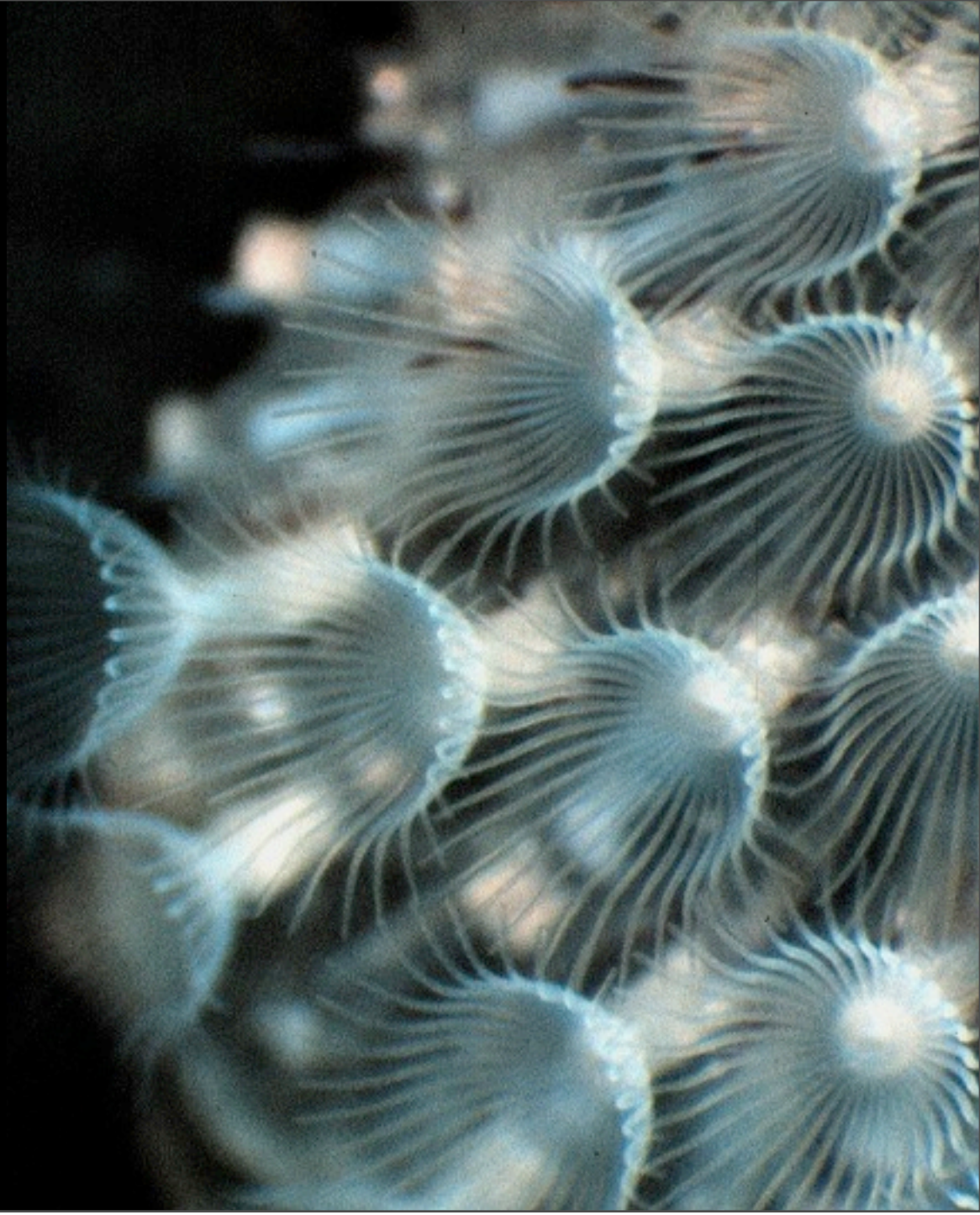

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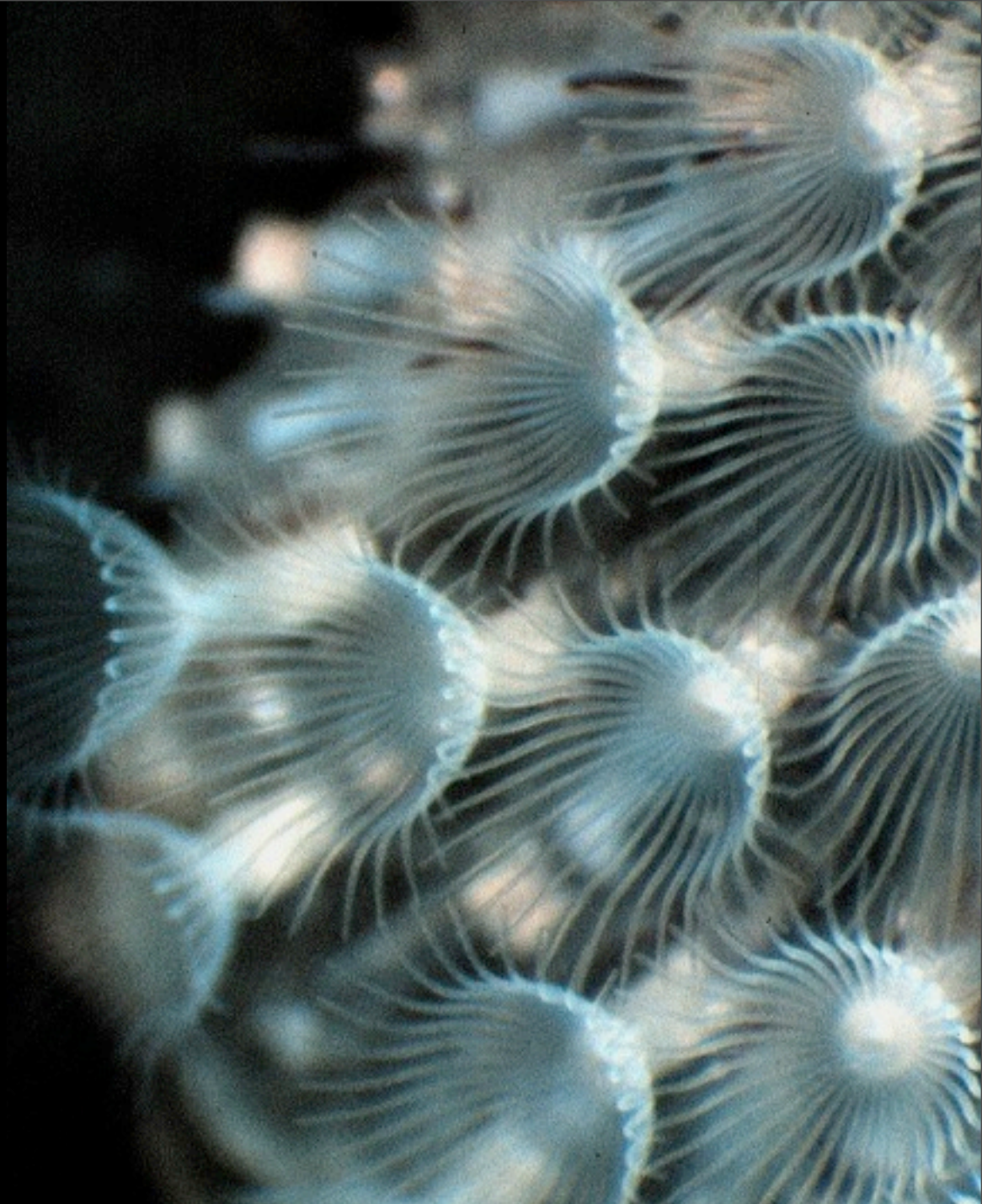

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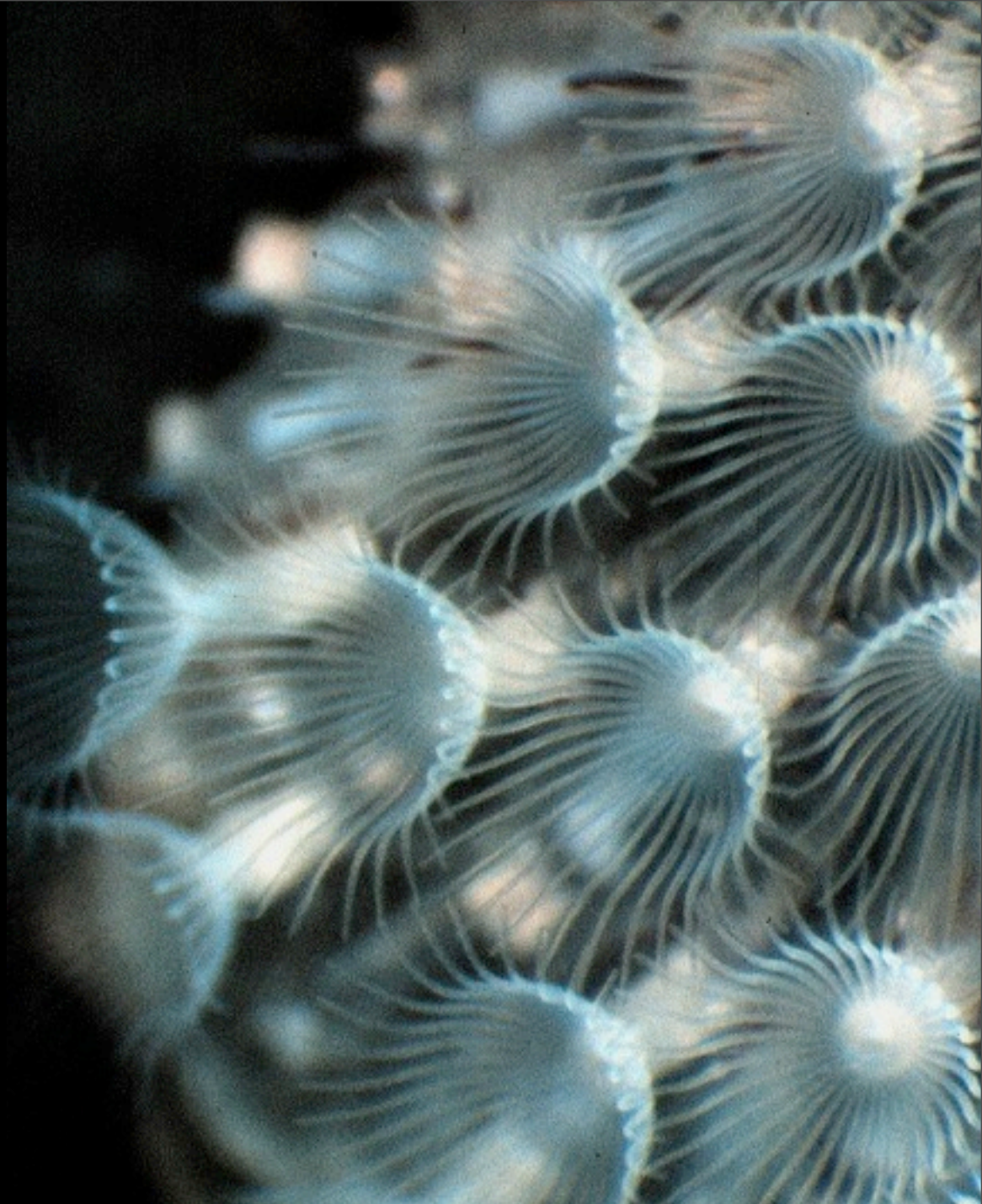
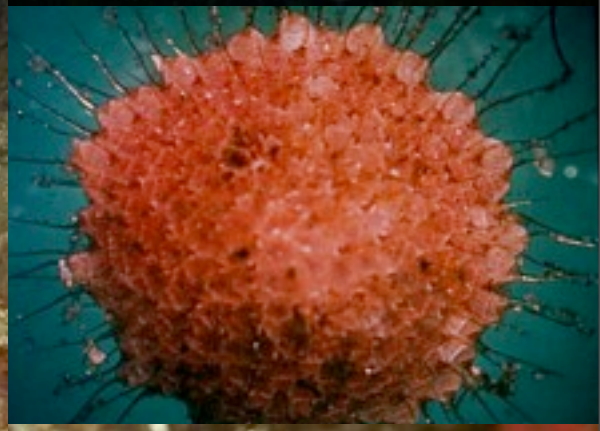
- Ordovician-Recent



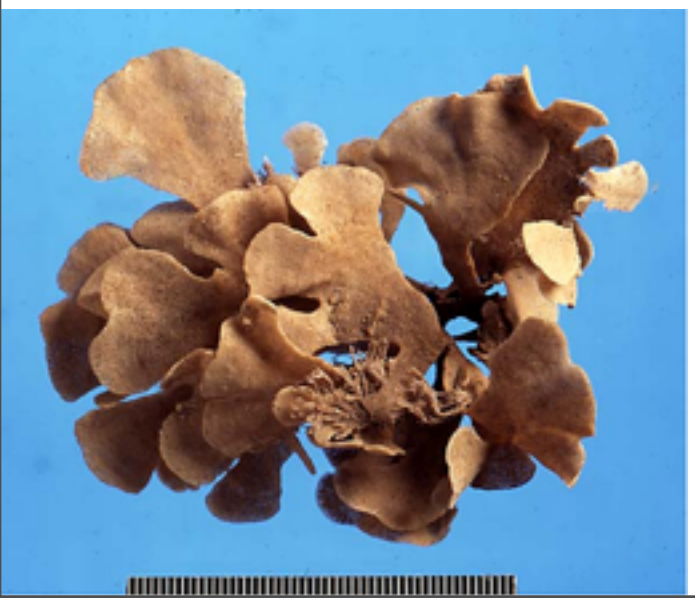
Bryozoan colony-forms

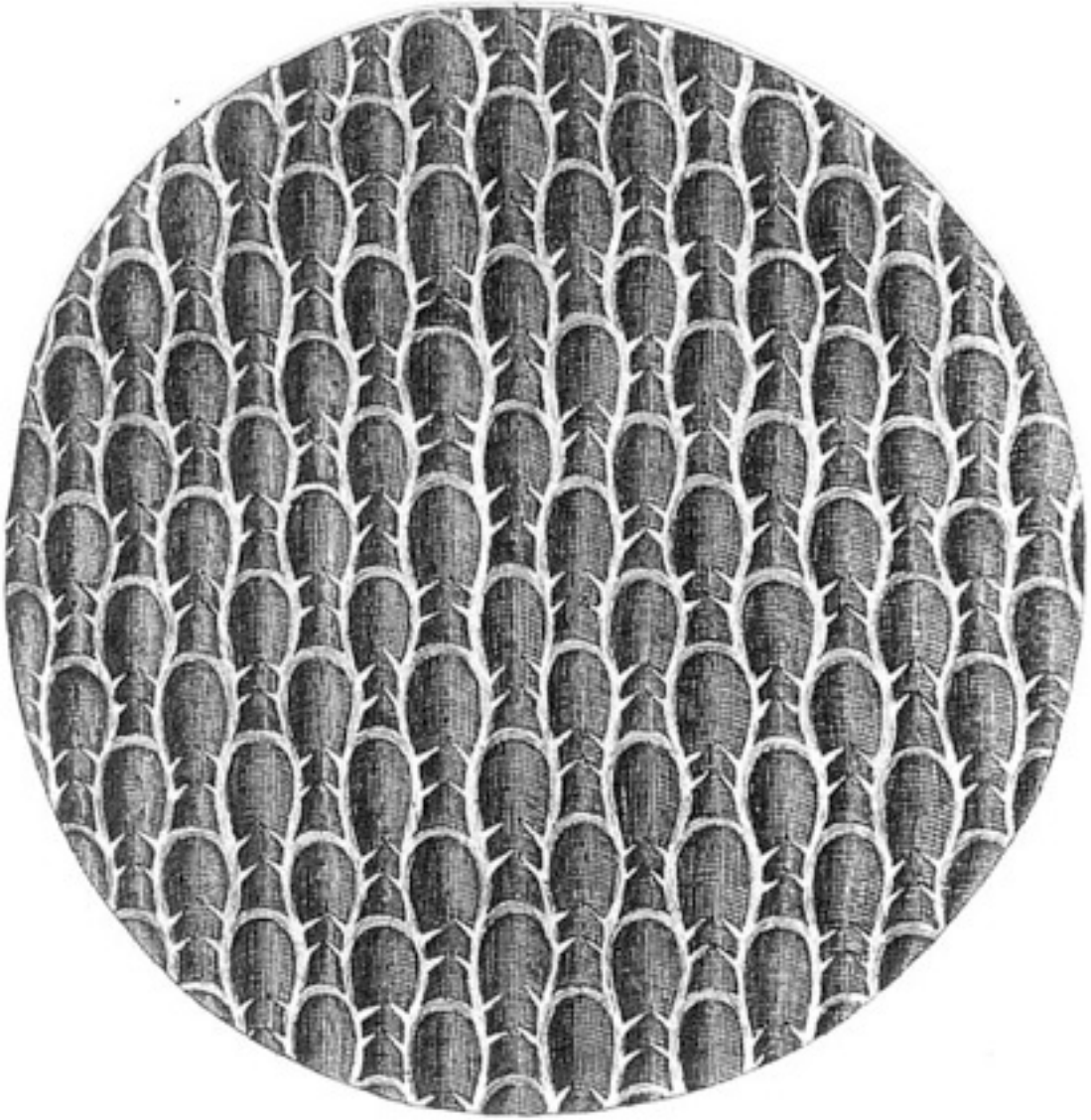


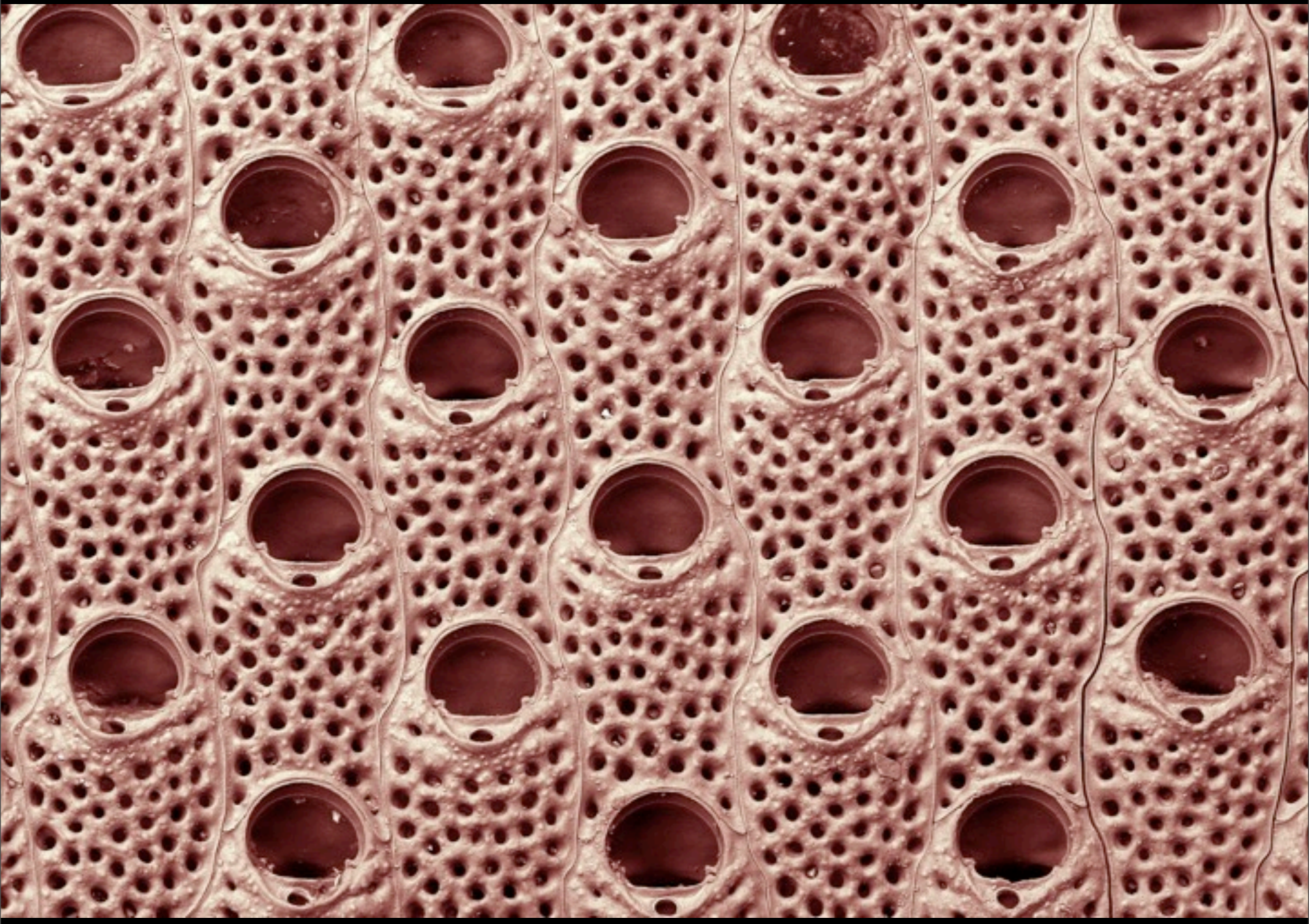


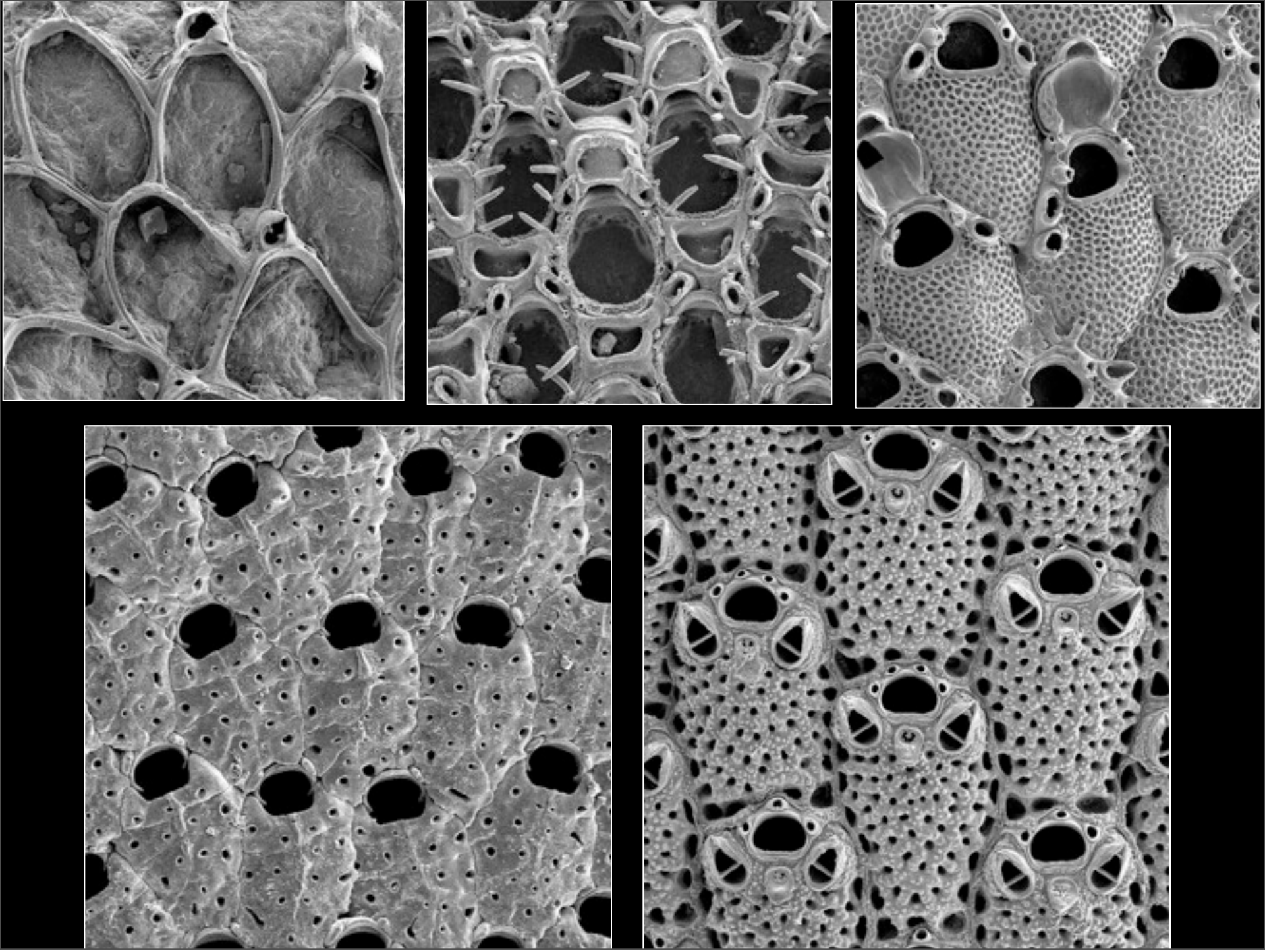



Robert Hooke's illustration of *Flustra* from *Micrographia* (1665)

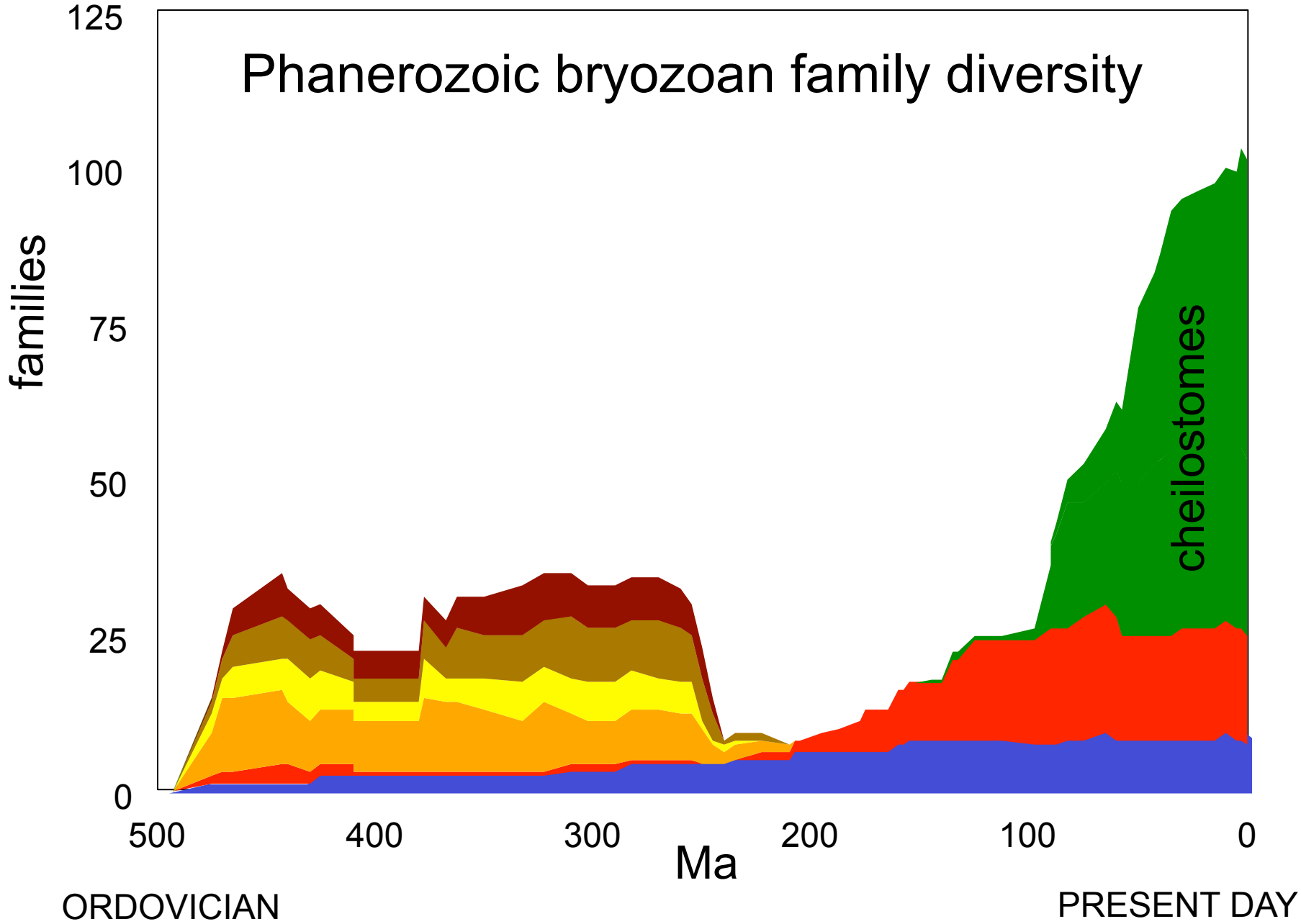


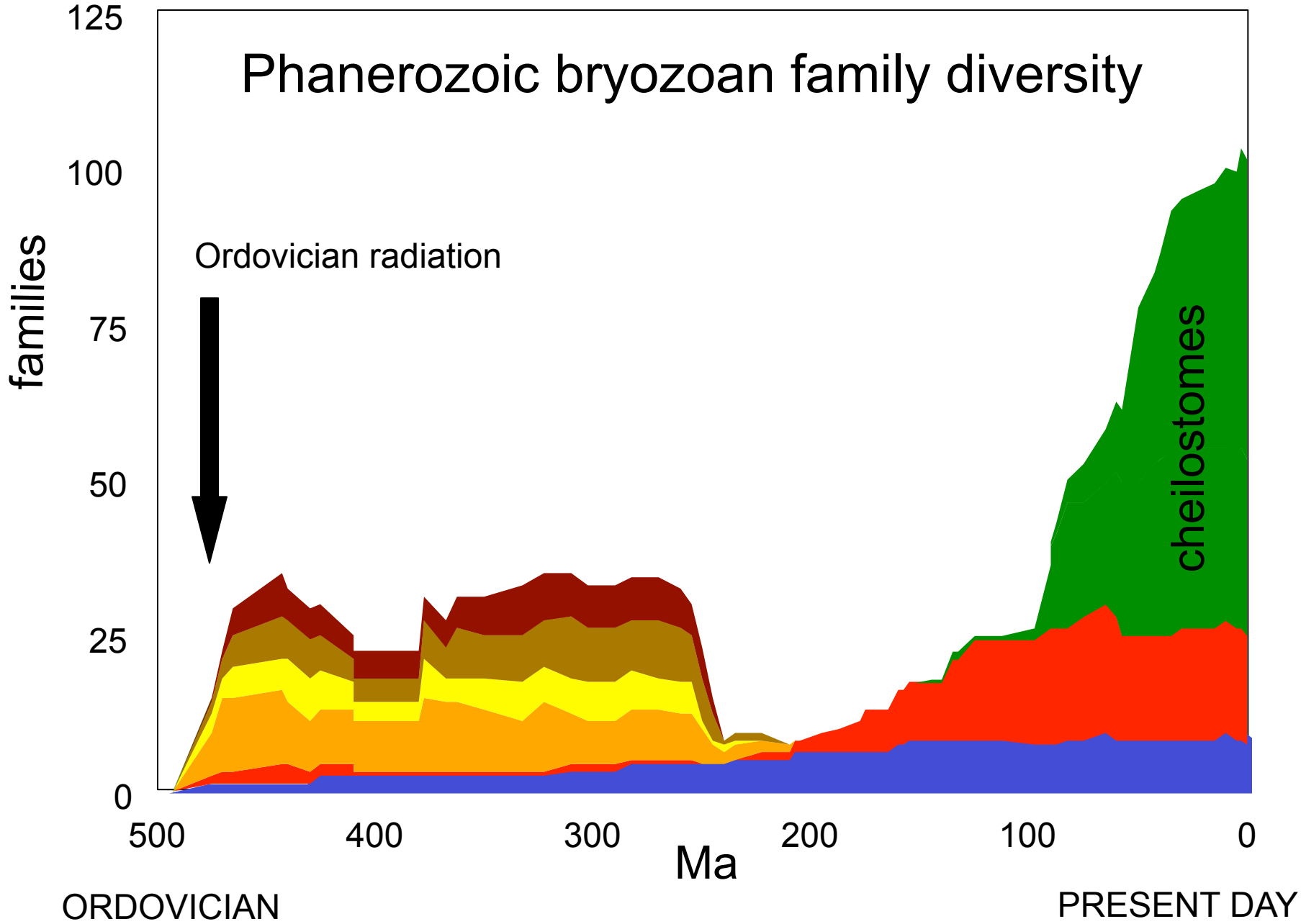






Friday, 7 October 2011


Phanerozoic bryozoan family diversity
125
100
75
50
25
0
families
cheilostomes
500
400
300
200
100
0
Ma
ORDOVICIAN
PRESENT DAY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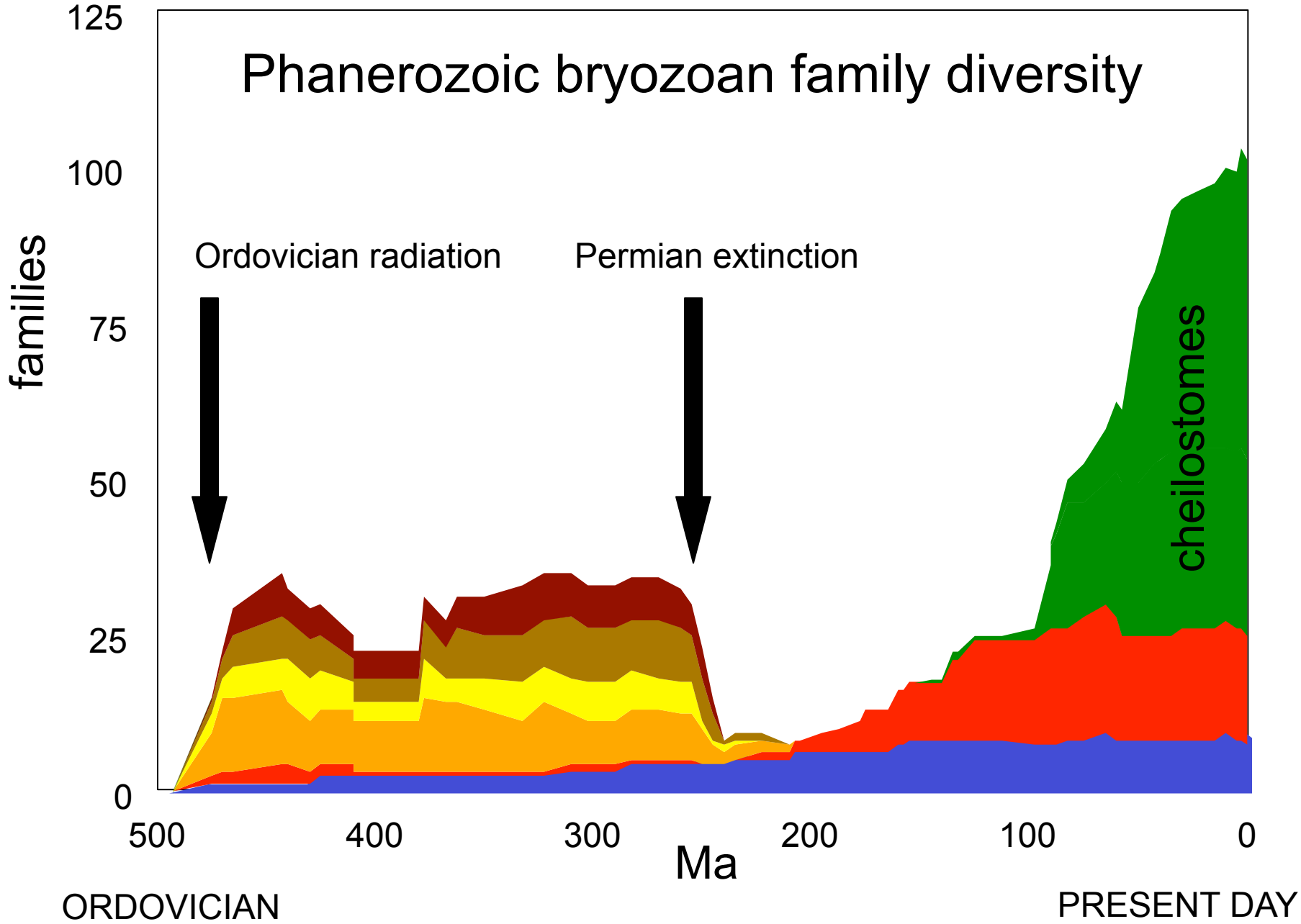
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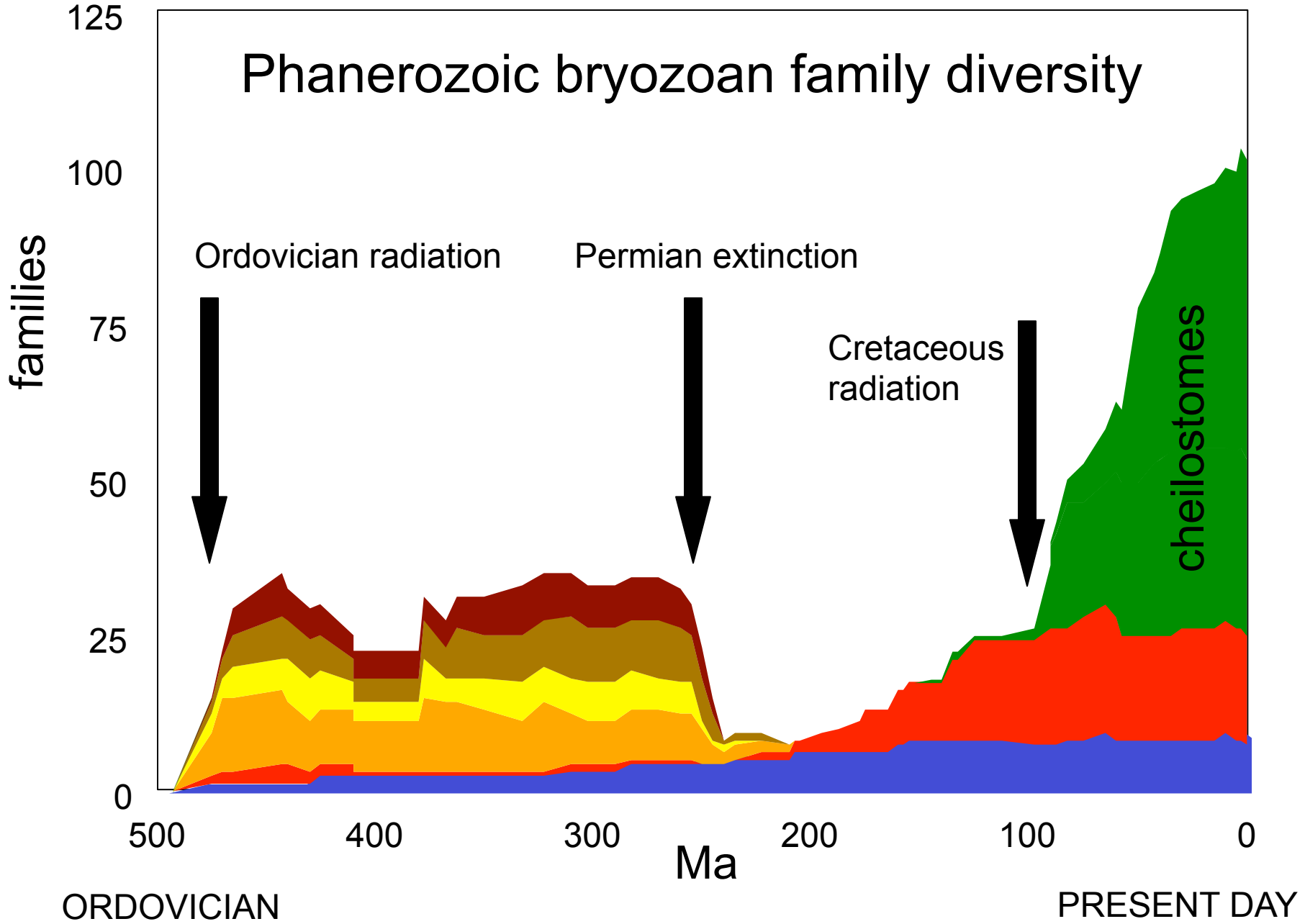
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Abundant

Upper Ordovician
Cincinnati, USA

rock-forming

Abundant

Upper Ordovician
Cincinnati, USA

rock-forming

Diverse

Upper Cretaceous
Maastricht, Netherlands

> 600 bryozoan species

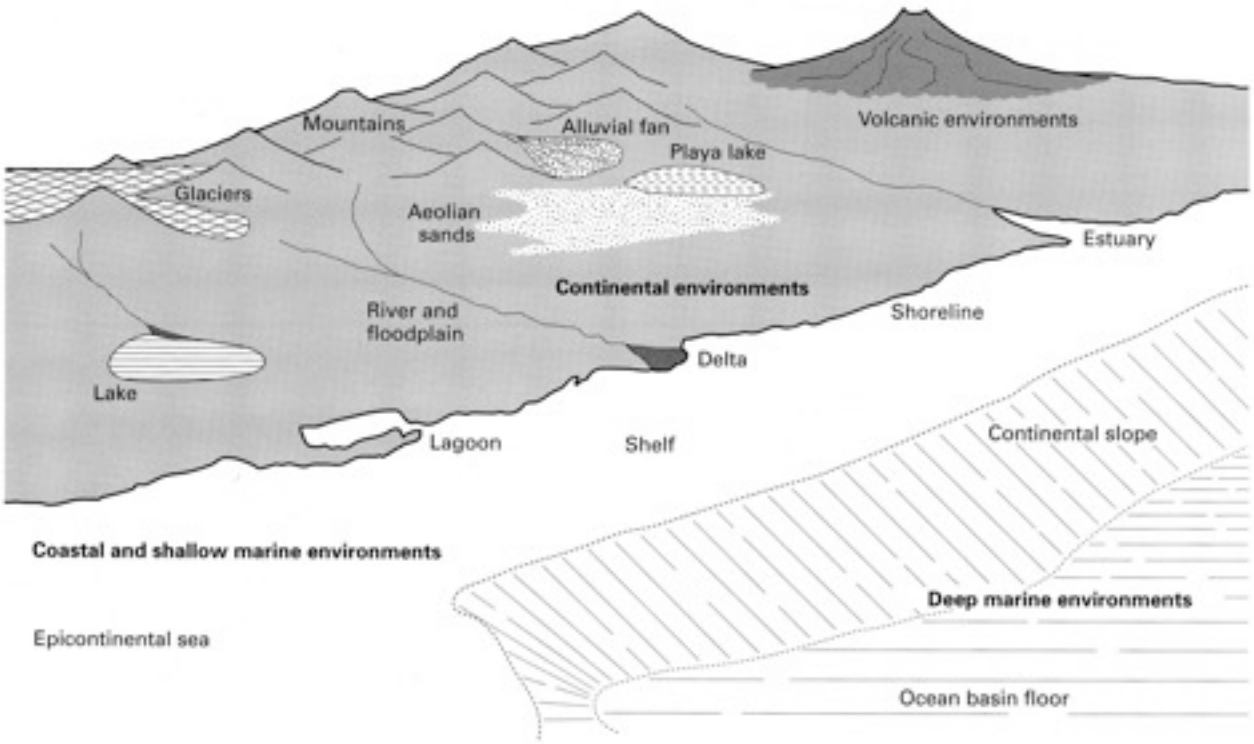
Bryozoans as palaeoenvironmental indicators

1. modern environments with bryozoans
2. colony-form analysis
3. branch diameter as a depth indicator
4. zooid size as a temperature indicator
5. palaeolatitudinal distribution of bryozoan carbonates through time

[skeletal geochemistry]

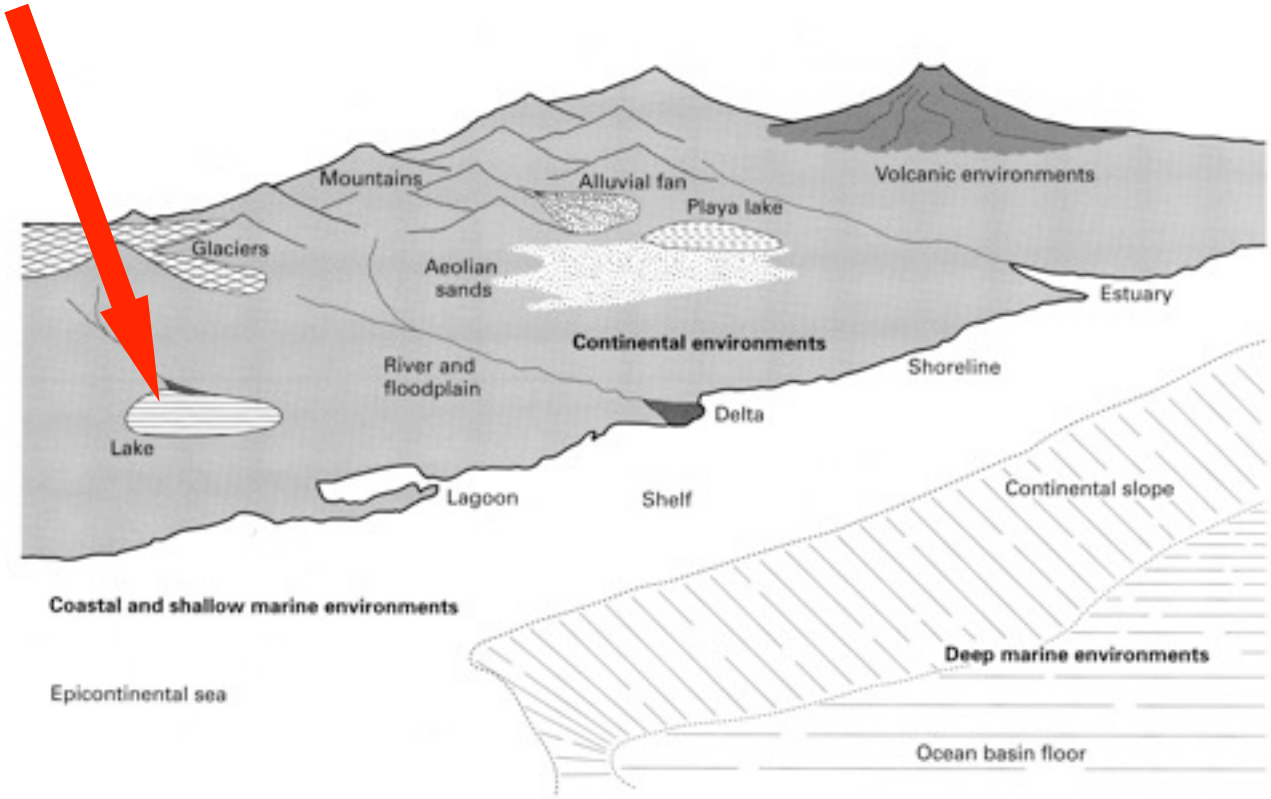
1. modern environments with bryozoans

Modern environments colonized by bryozoans



Modern environments colonized by bryozoans

Freshwater bryozoans
Low diversity
Unmineralized



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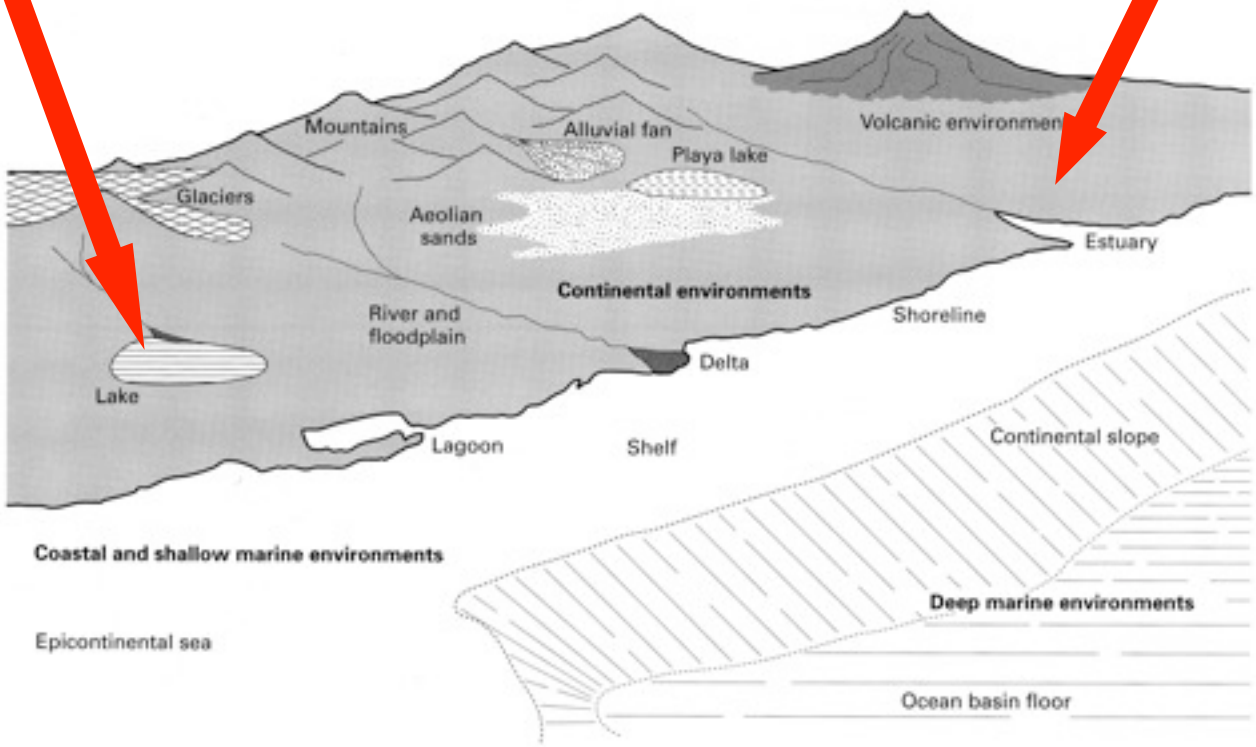
Brackish bryozoans
Low diversity
Weakly mineralized



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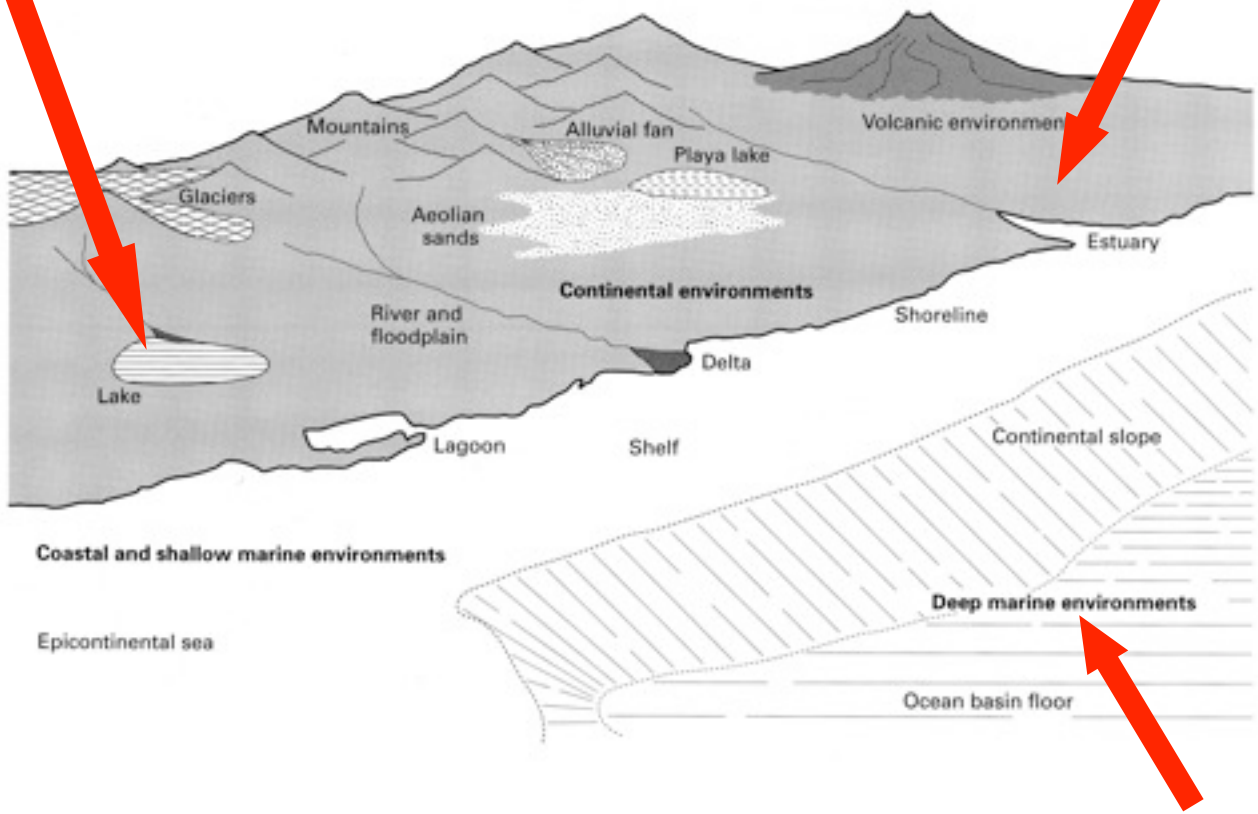

Deep sea bryozoans
Moderate diversity
Weakly mineralized

Modern environments colonized by bryozoans

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Unmineralized

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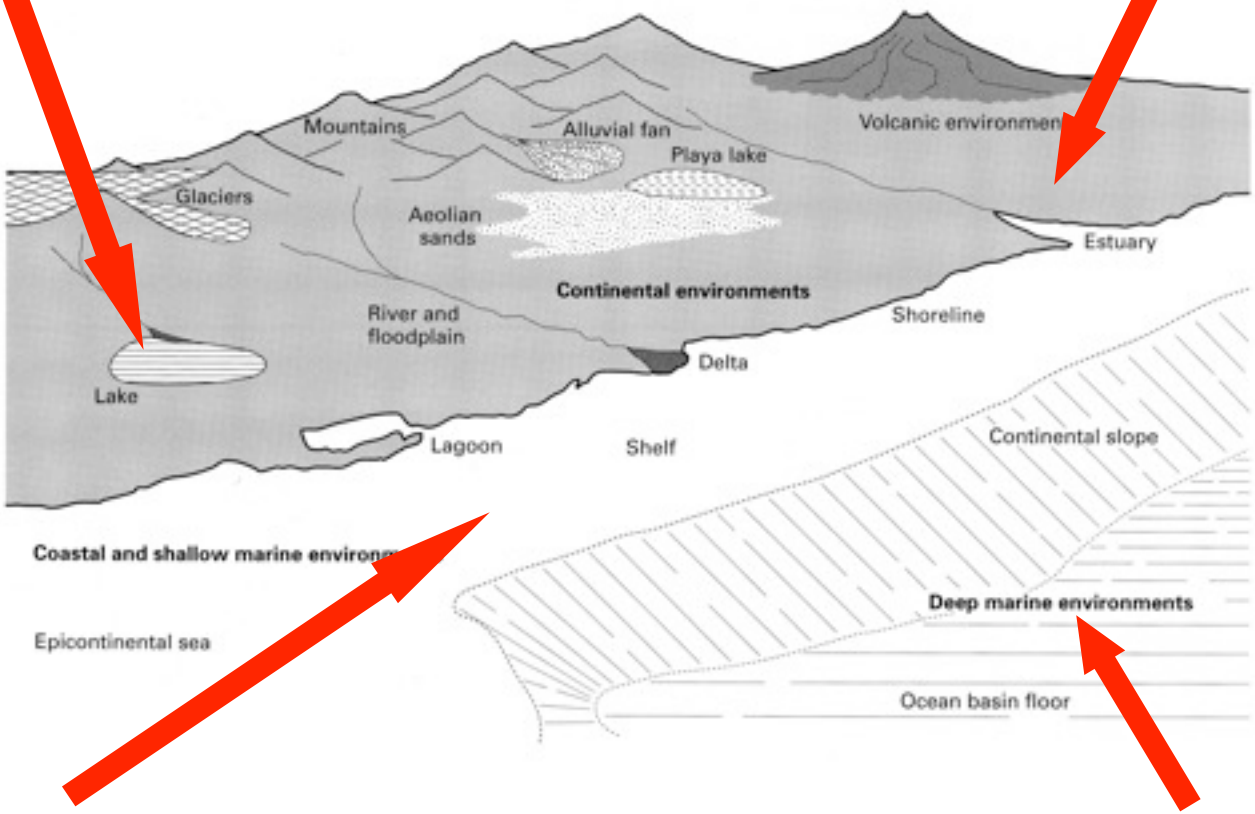
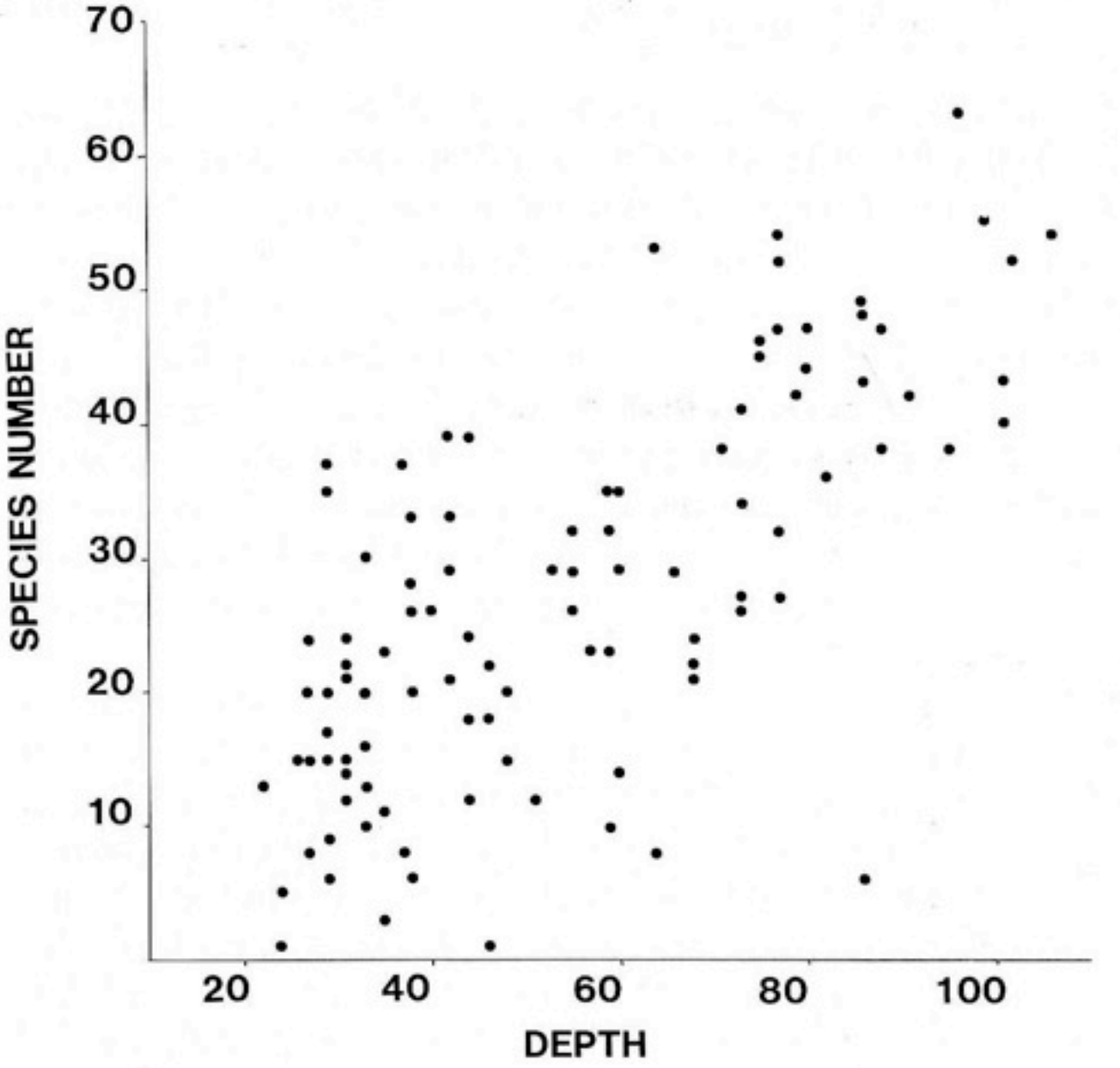


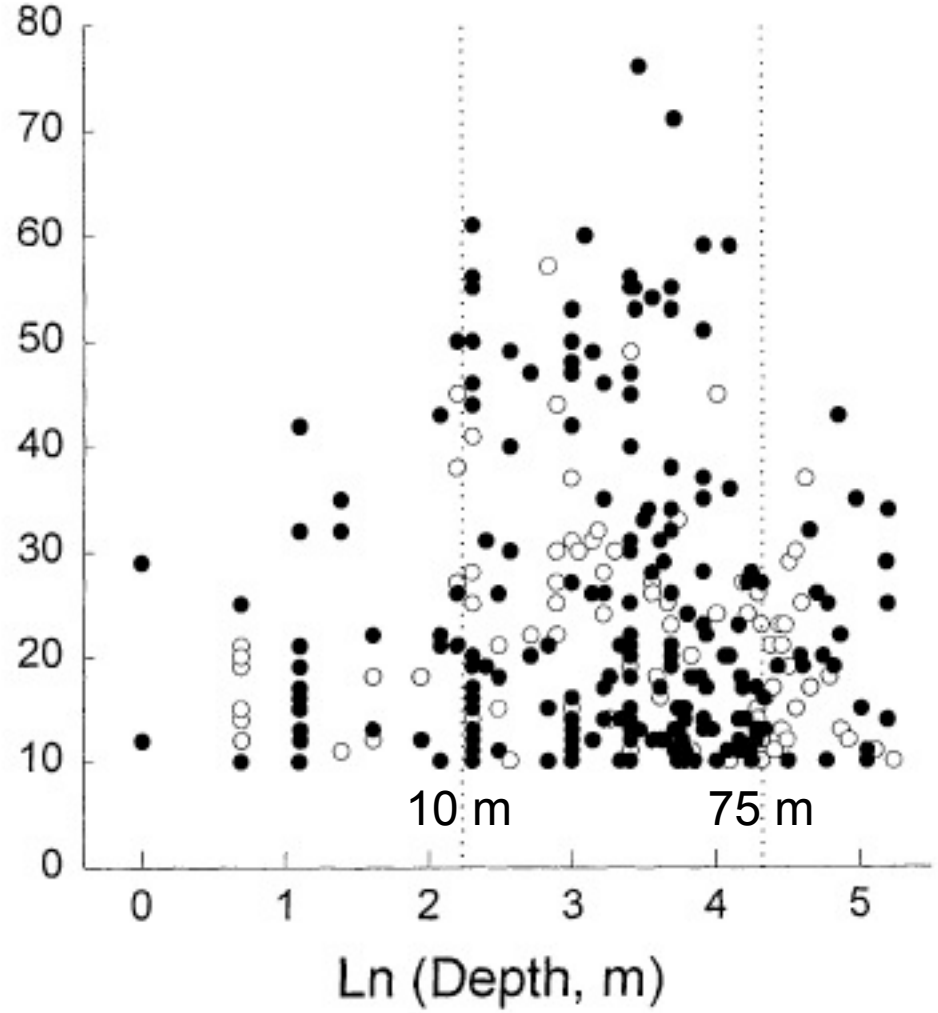
Shelf bryozoans
High diversity
Most species well-mineralized

Deep sea bryozoans
Moderate diversity
Weakly mineralized

Recent bryozoan species diversity increasing with depth
English Channel (Grant & Hayward 1985)



Bryozoan assemblage species richness vs depth in the eastern (black dots) and western (white dots) North Atlantic



Clarke & Lidgard 2000. *Journal of Animal Ecology* **69**: 799-814

2. colony-form analysis

Encrusting: *Porella*

Encrusting: *Porella*

Dome shaped: '*Dianulites*'

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Dome shaped: '*Dianulites*'

Narrow branched: *Arcanopora*

Encrusting: *Porella*

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Robust branched: *Heteropora*

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Encrusting: *Porella*

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Palmate: *Phaenopora*

Robust branched: *Heteropora*

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Encrusting: *Porella*

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Foliose: *Pentapora*

Palmate: *Phaenopora*

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Encrusting: *Porella*

Dome shaped: '*Dianulites*'

Foliose: *Pentapora*

Fenestrate: *Chasmatopora*

Palmate: *Phaenopora*

Robust branched: *Heteropora*

Narrow branched: *Arcanopora*

Encrusting: *Porella*

Dome shaped: '*Dianulites*'

Foliose: *Pentapora*

Fenestrate: *Chasmatopora*

Articulated: *Cellaria*

Palmate: *Phaenopora*

Robust branched: *Heteropora*

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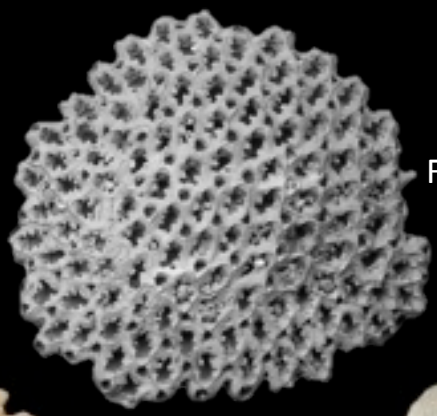

Free-living: *Cupuladria*

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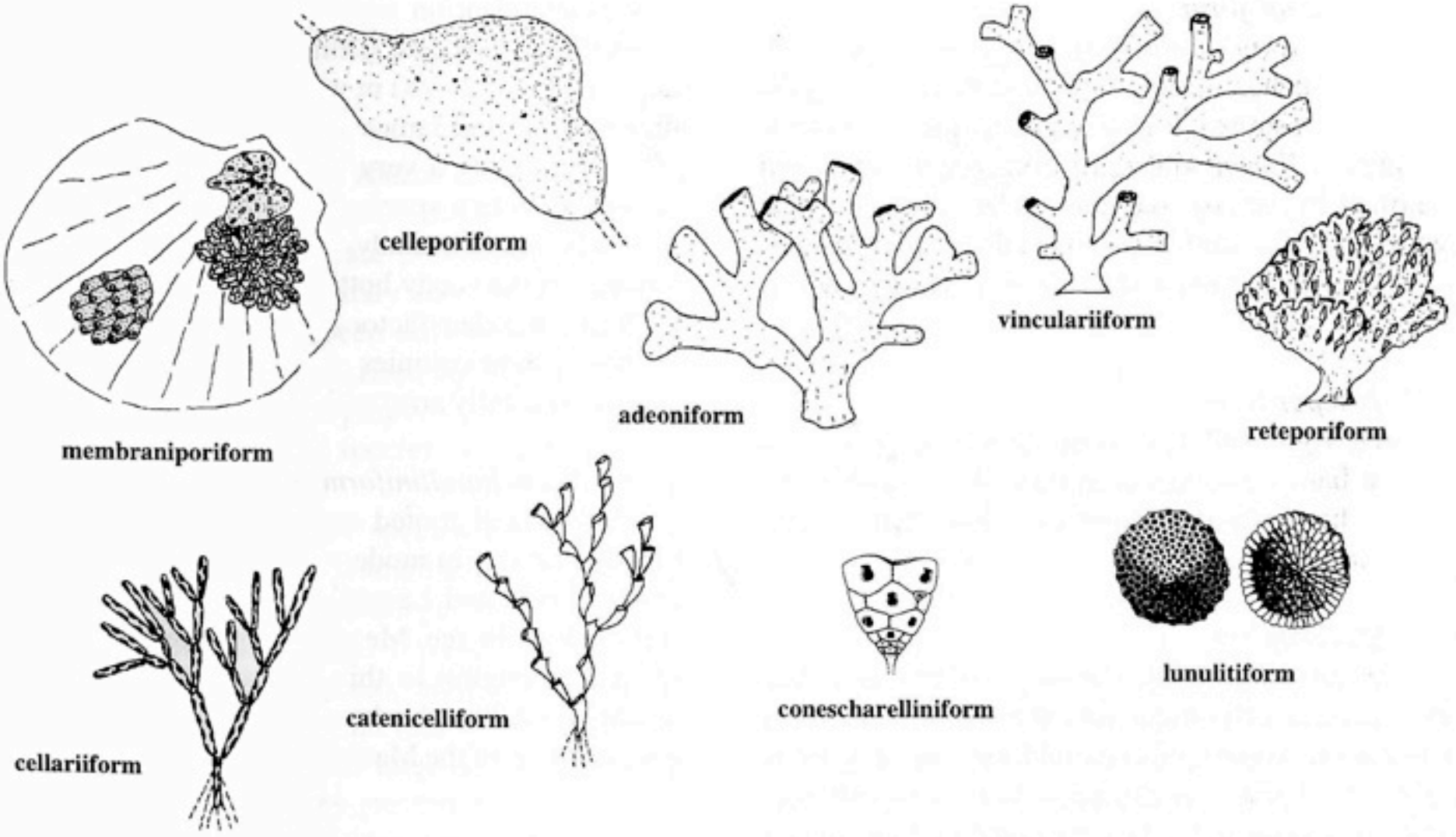
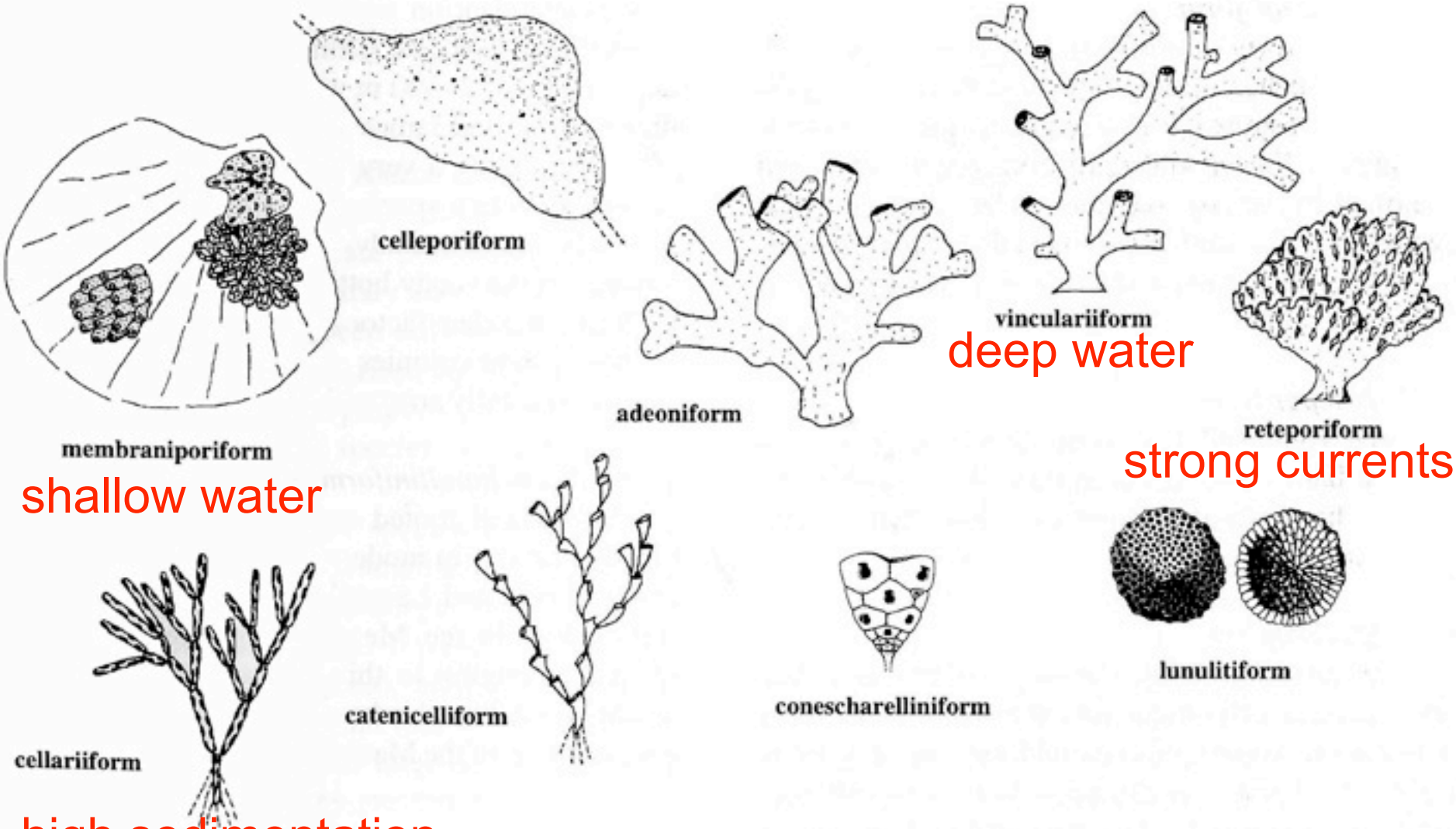
Cheilostome bryozoan colony-forms (from Moissette 2000)



can these colony-forms be used as environmental indicators?

Cheilostome bryozoan colony-forms (from Moissette 2000)



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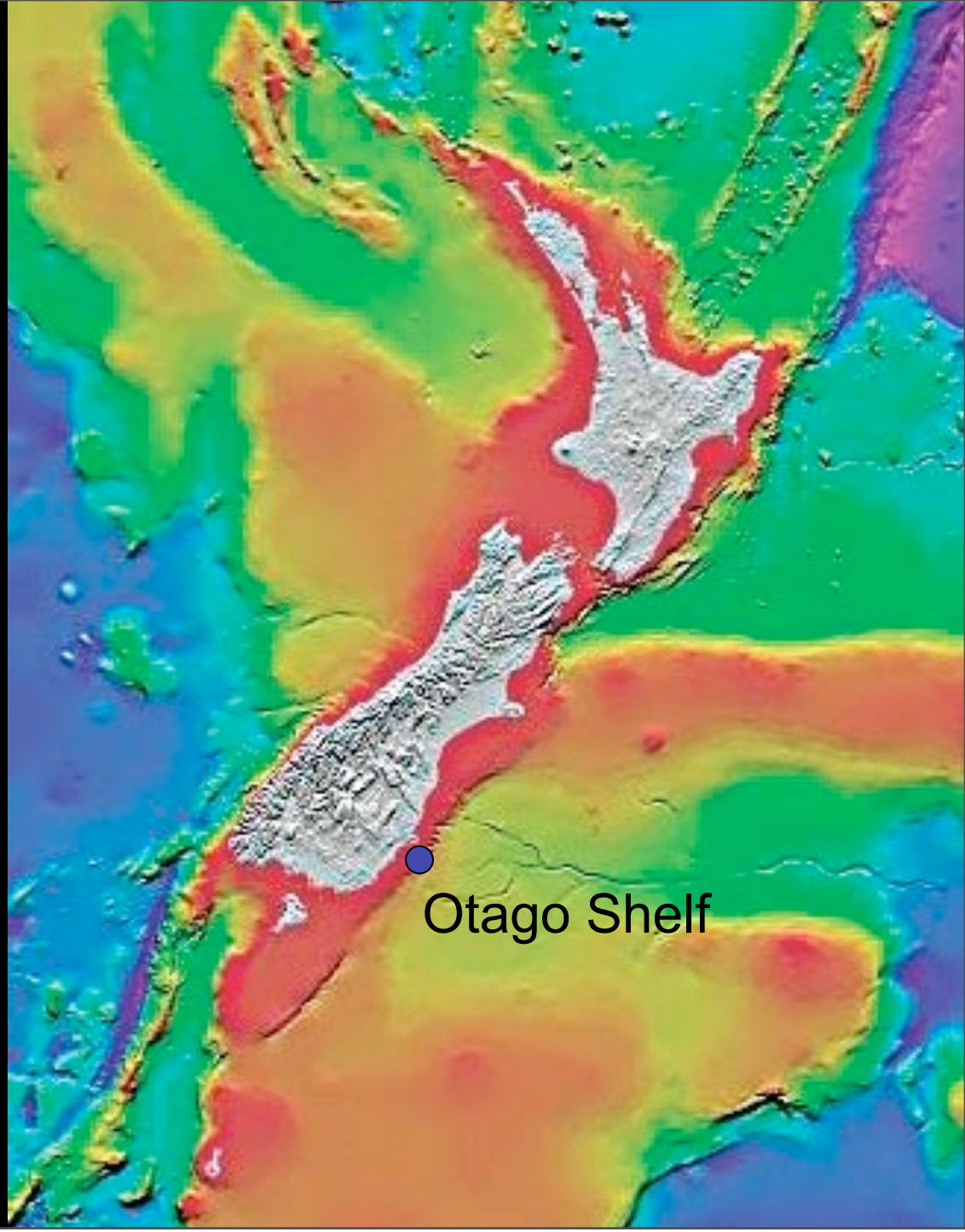
Sea-bed topography around New Zealand



bryozoan meadow, 100 metres
Otago Shelf, New Zealand

sediment from bryozoan meadow

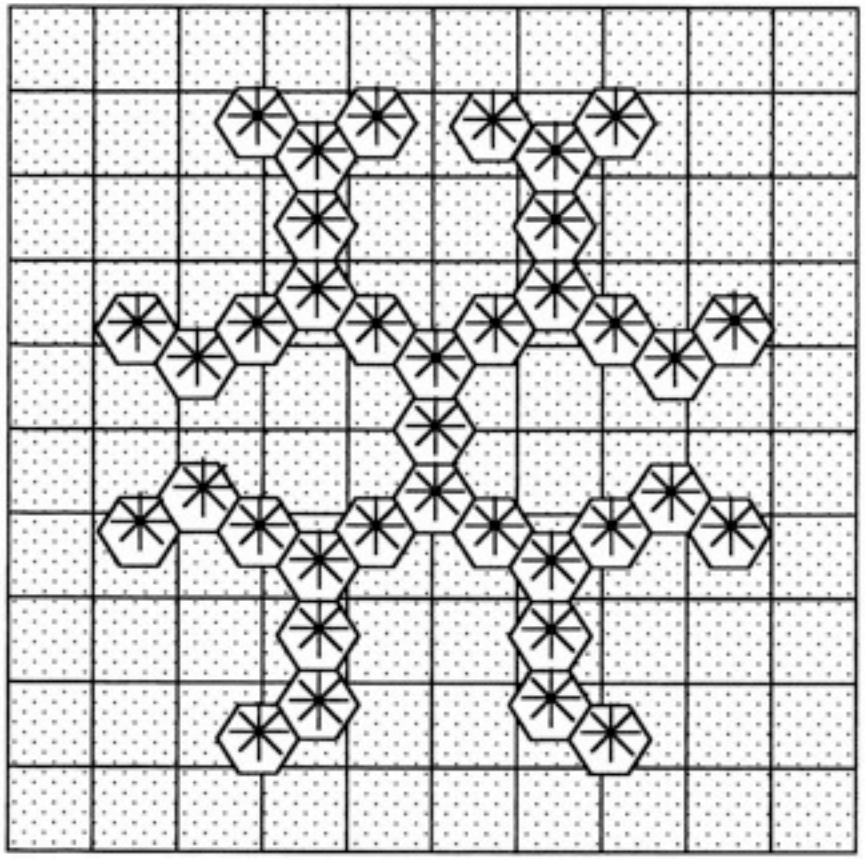
Different colony-forms represent alternative functional adaptive strategies

Encrusting colonies

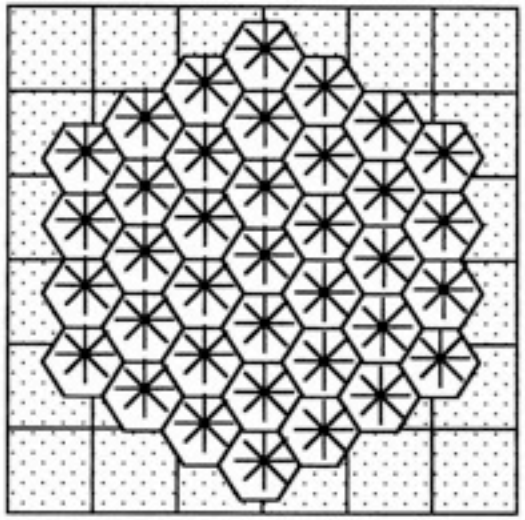
Uniserial runner

Multiserial sheet

37 zooid encrusting colonies on substrates divided into equal-sized squares

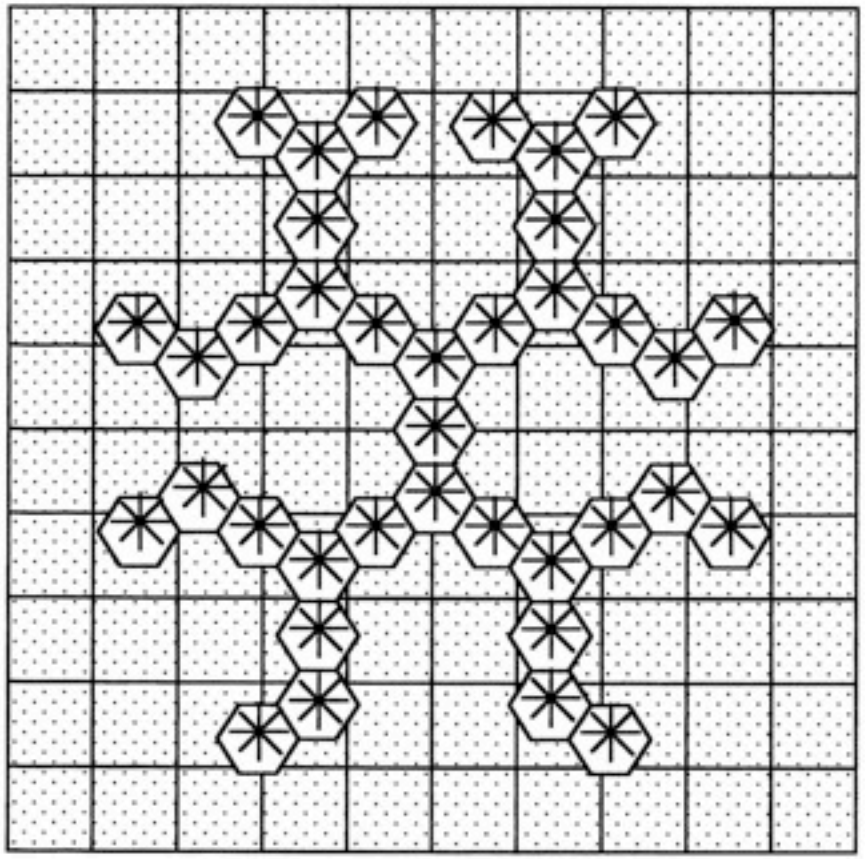


runner



sheet

37 zooid encrusting colonies on substrates divided into equal-sized squares



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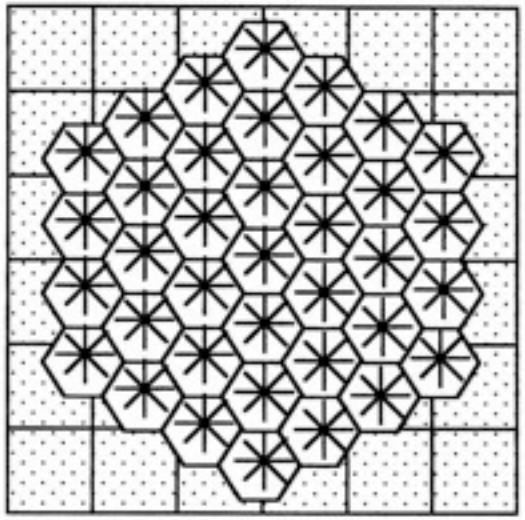
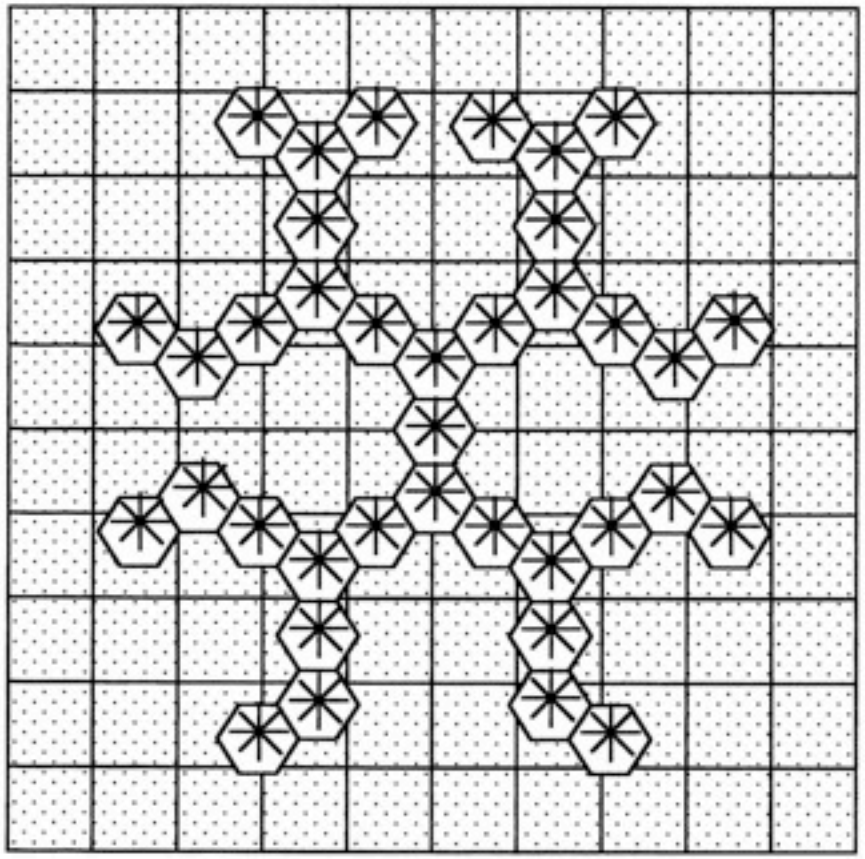


sheet

Runner ‘samples’ more squares of substrate and spreads a greater distance from origin (fugitive strategy)

37 zooid encrusting colonies on substrates divided into equal-sized squares



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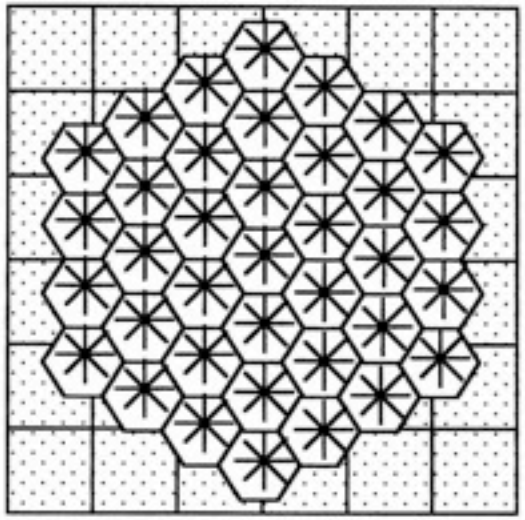


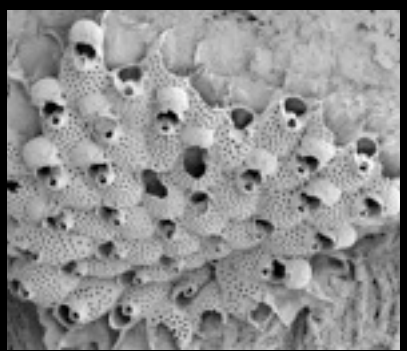
sheet

Runner ‘samples’ more squares of substrate and spreads a greater distance from origin (fugitive strategy)

Sheet is compact and better able to defend space (‘confrontational strategy’)

Percentage of colony-forms in bryozoan assemblages from shallow and deep stations in Spitsbergen

SHALLOW



DEEP (> 50 m)

?reflecting decreasing food resources with depth

Fenestrate colonies
(reteporiform)

Chasmatopora
(Ordovician, Estonia)

Cheilostome '*Sertella*'
(Oligocene, Argentina)

- 'traditionally' regarded as adaptation to strong currents
- but colonies can be found in slow flow regimes too (e.g. caves)

Articulated colonies
(cellariiform)

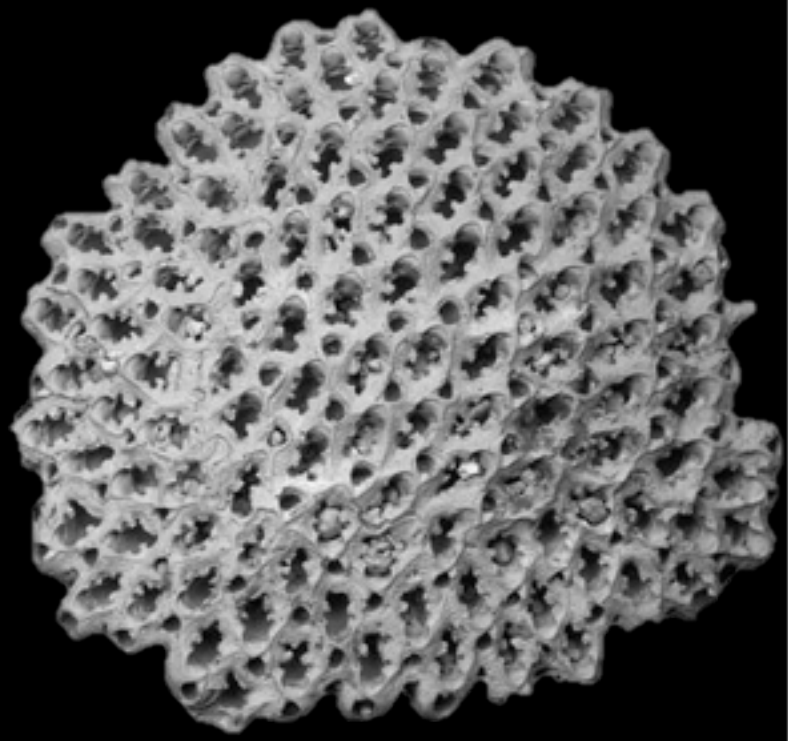
Cheilostome *Cellaria*
(Recent, Croatia)

Crisia
(Recent, Brazil)

- elastic nodes allow flexure in strong currents
- but colonies also found in areas of relatively high sedimentation and weak currents – sediment can be shaken off branches

Free living colonies
(lunulitiform)

Cupuladria
(Miocene, France)



Cupuladria
(Pliocene, England)

- able to live on fine sediments (fine sand, silt and mud) where no large substrates are present
- colonies can dig themselves out if buried

adapted for living on fine-grained, unstable substrates

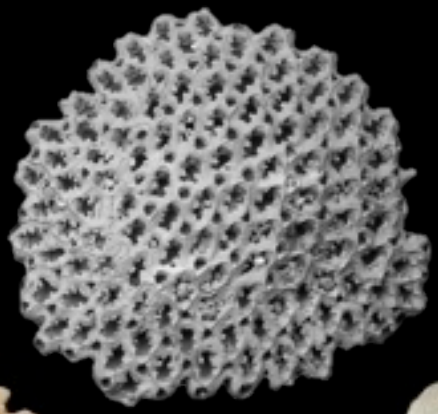
Encrusting: *Porella*

Dome shaped: '*Dianulites*'

Foliose: *Pentapora*

Fenestrate: *Chasmatopora*

Articulated: *Cellaria*



Free-living: *Cupuladria*

Palmate: *Phaenopora*

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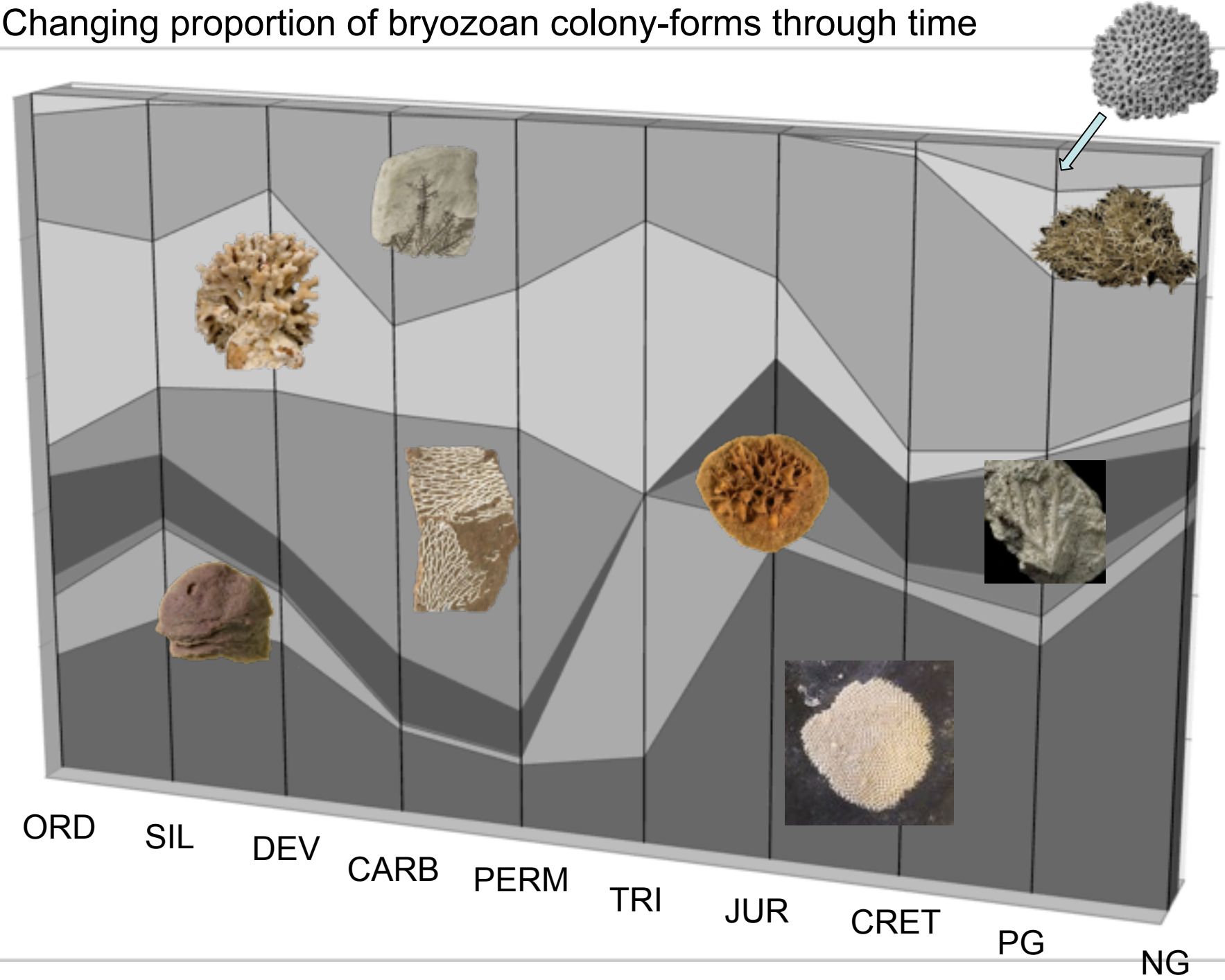
Changing proportion of bryozoan colony-forms through time



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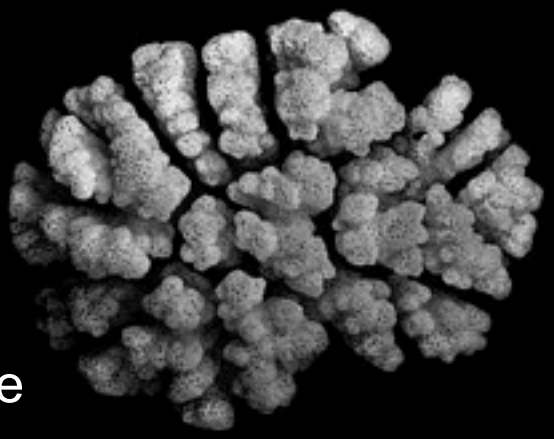
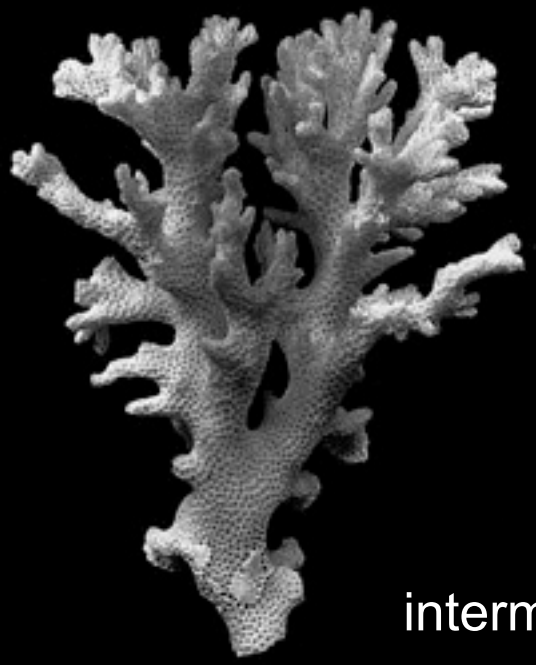
- particular colony-forms are seldom if ever restricted to one environment; sometimes almost all major colony-forms can be found together
- not enough known about factors controlling colony-forms in modern environments
- colony-forms represent alternative functional adaptive strategies that may be viable in many different environments
- representation of different colony forms has changed through the Phanerozoic

3. branch diameter as a depth indicator

Branch diameter variation within coral species as depth indicator



shallow site



intermediate site

deep site

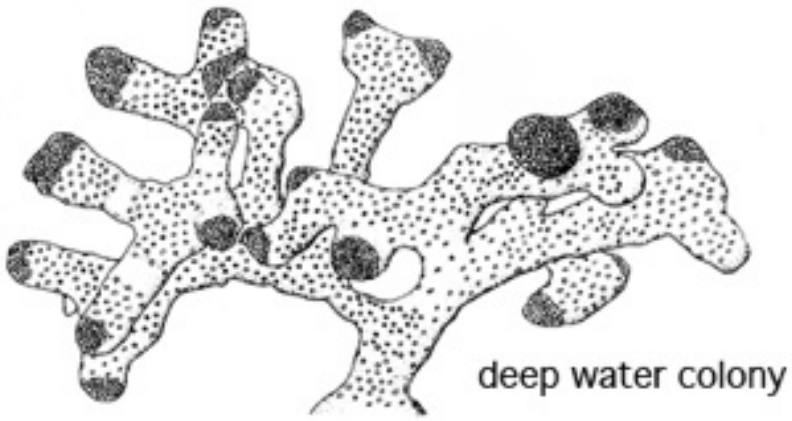
Coral

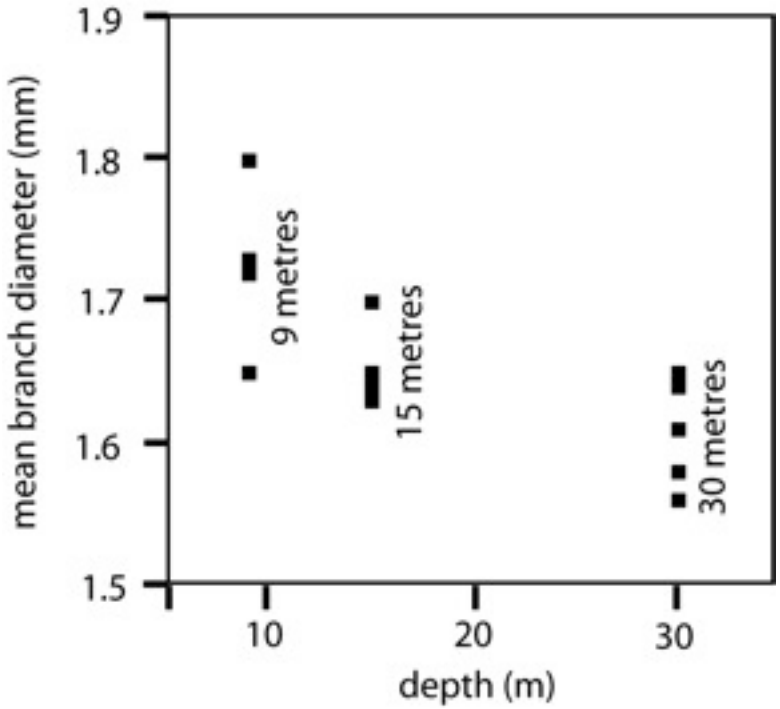
Pocillopora damicornis
(see Kaandorp 1999)

Branching bryozoans (ramose, dendroid)

Diaperoecia. Recent

Pleistocene. Setana Fm
Kuromatsunai, Japan



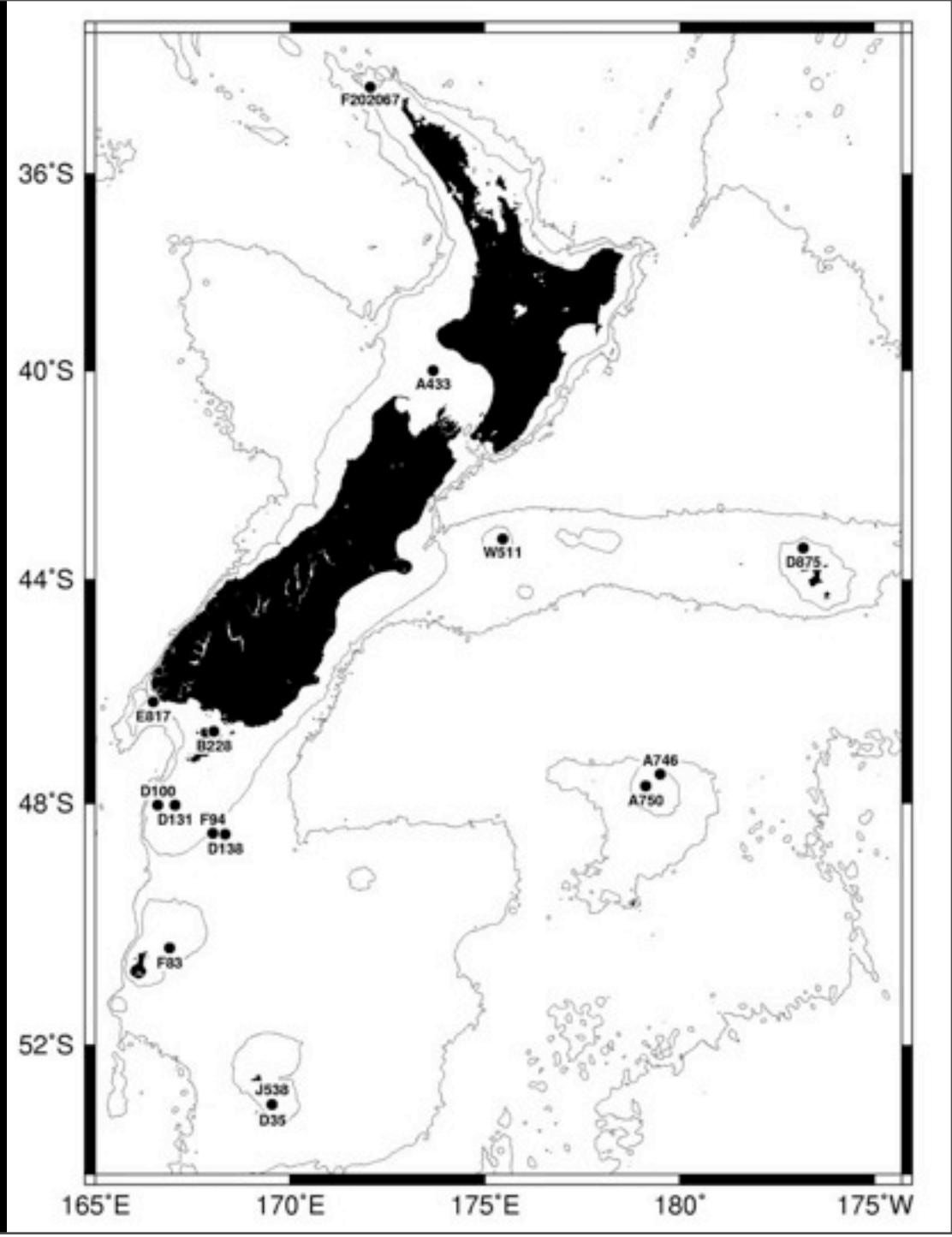


Heteropora pacifica
Puget Sound, USA
(Schopf et al. 1980)

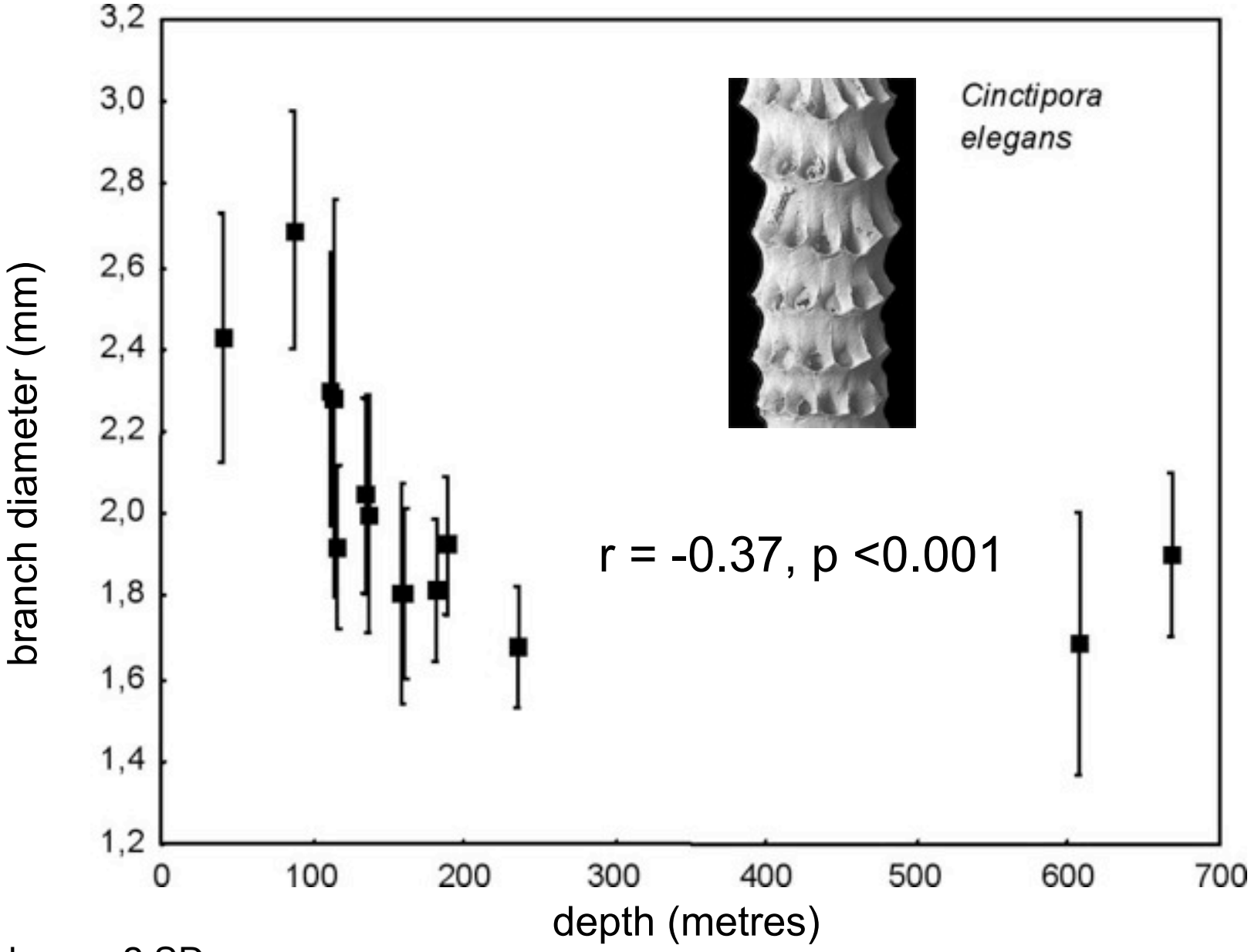
three cyclostome species:

Cinctipora elegans
Diaperoecia purpurascens
Erksonea sp.

Taylor, Kuklinski & Gordon (2007)

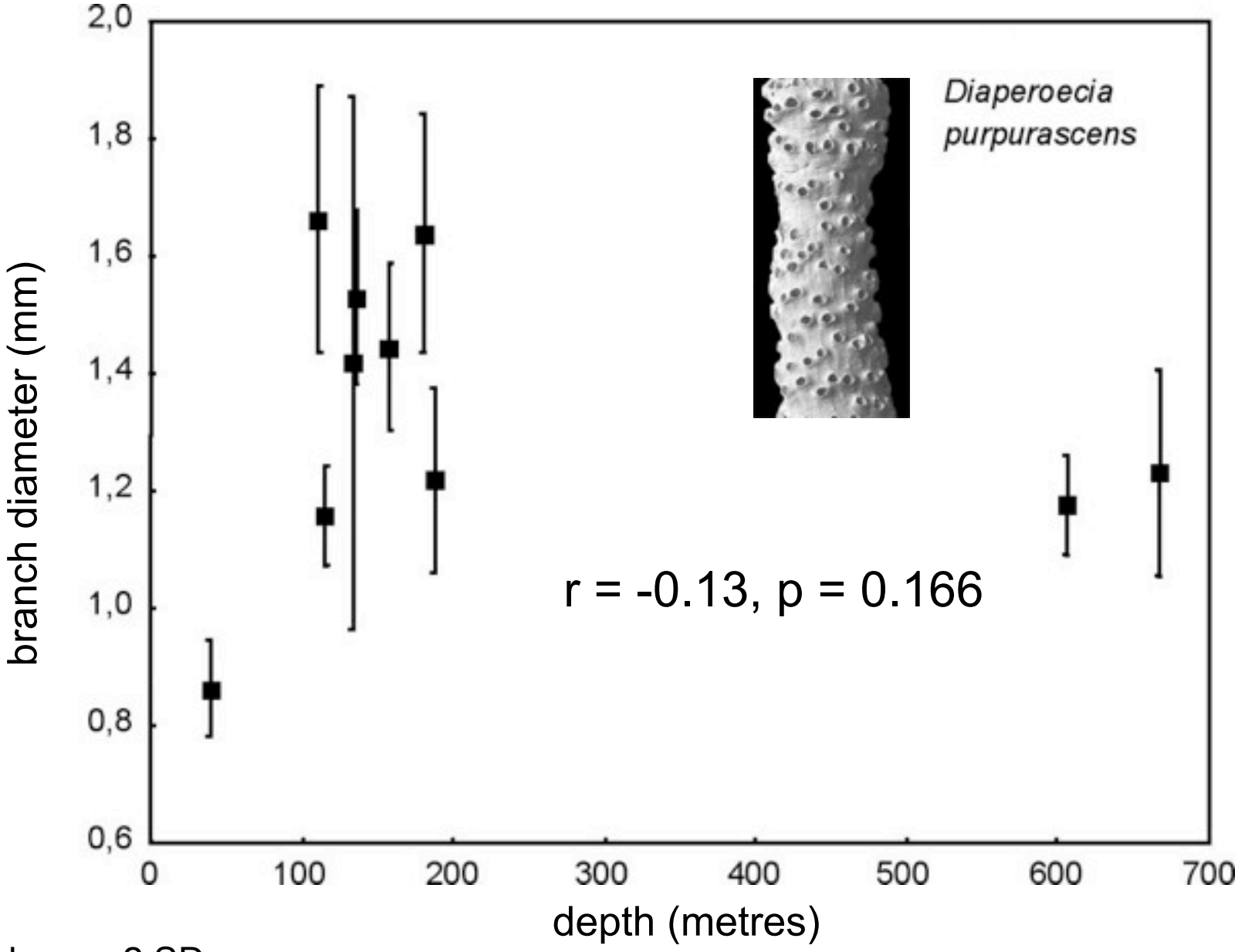


Branch diameter does correlate with depth



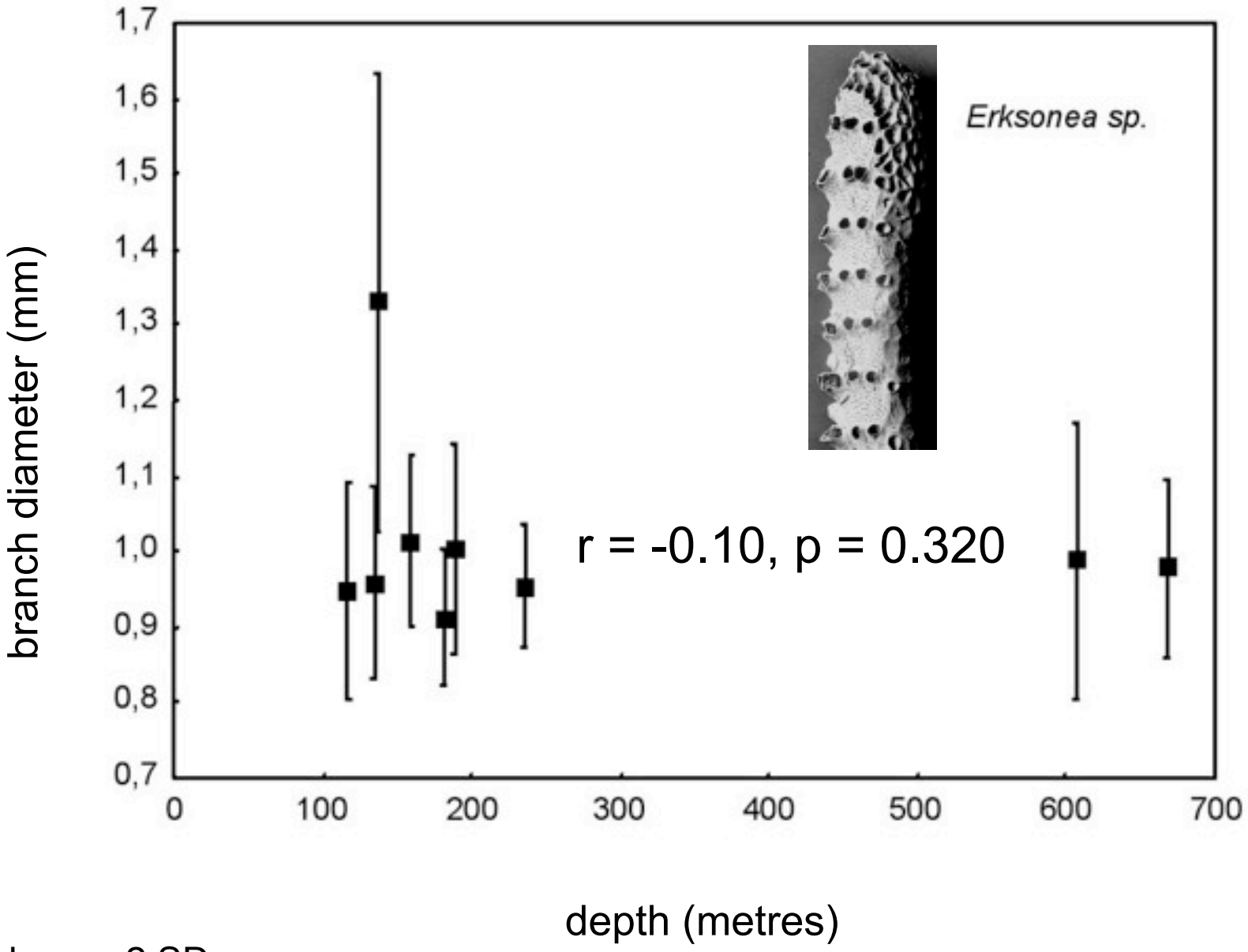
Error bars = 2 SD

Branch diameter does not correlate with depth



Error bars = 2 SD

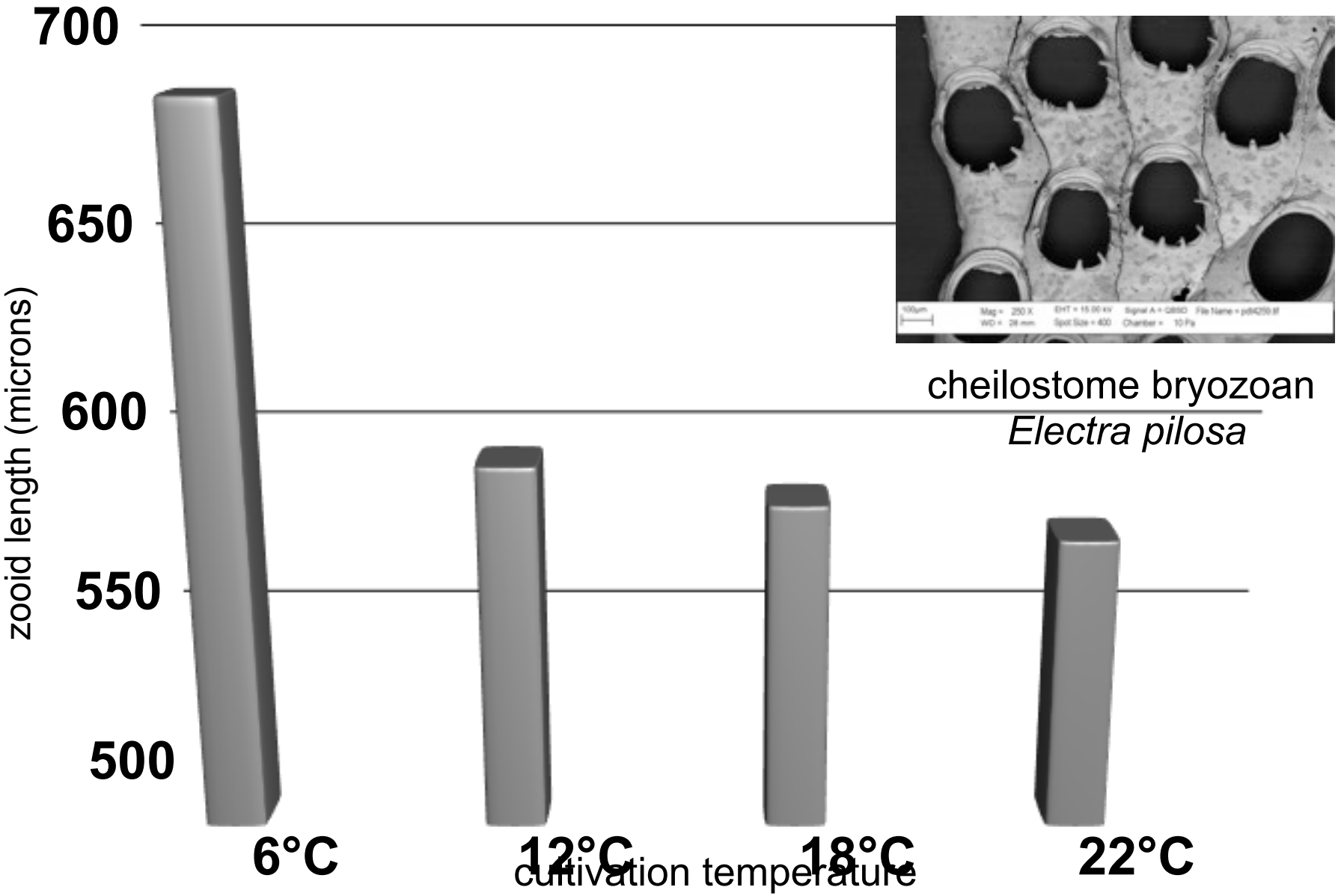
Branch diameter does not correlate with depth



Error bars = 2 SD

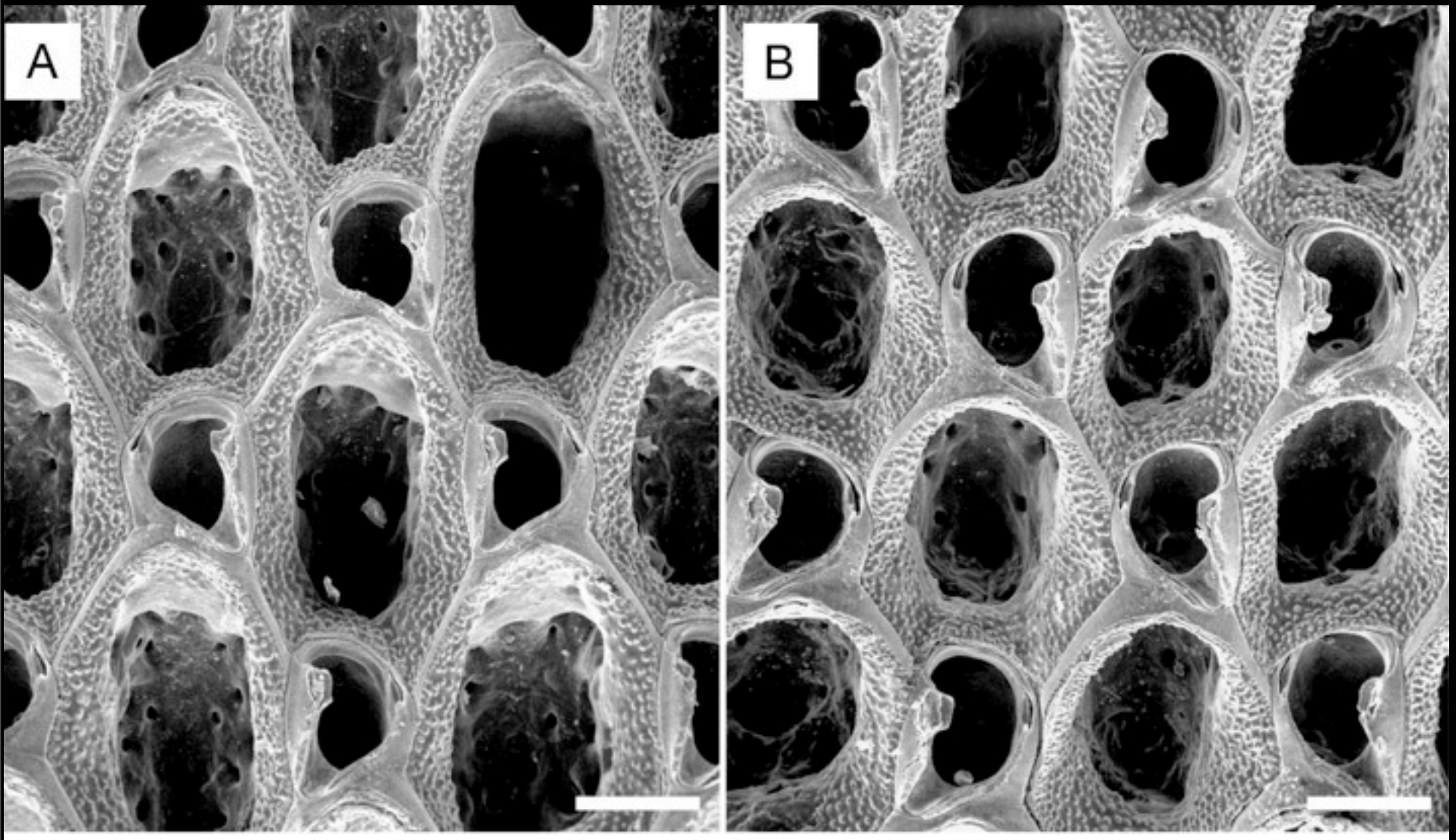
4. zooid size as a temperature indicator

Cheilostome bryozoan zooid size is inversely correlated with ambient temperature at time of budding



cheilostome bryozoan
Electra pilosa

Cupuladria exfragminis



upwelling (cold) zooids

non-upwelling (warm) zooids

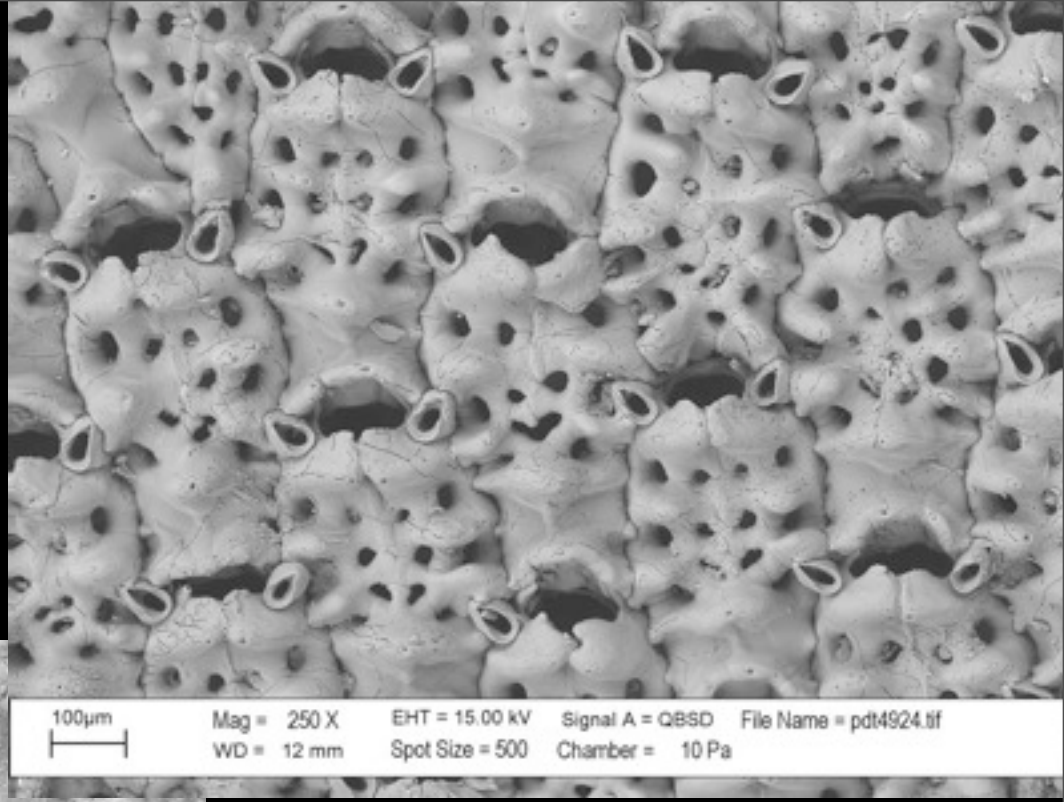
Okamura *et al*. 2011

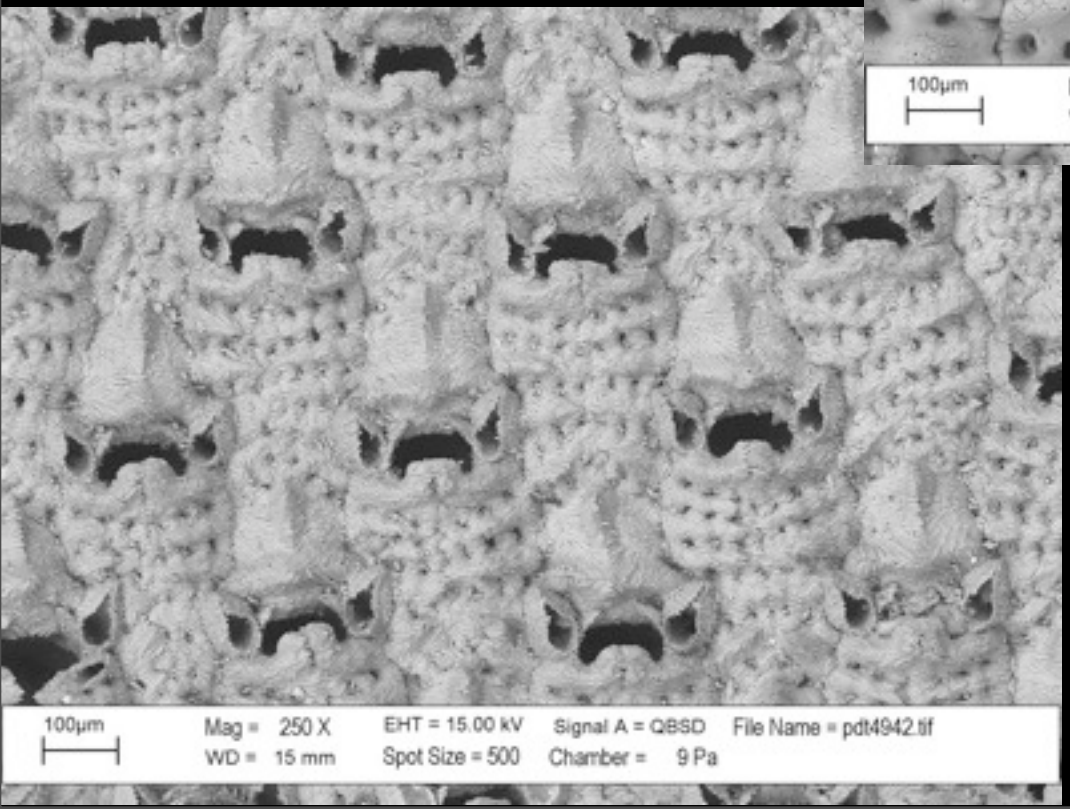
Cribrilina cryptooecium

Cold

Recent British

Large zooids





Warm

Coralline Crag (Pliocene)

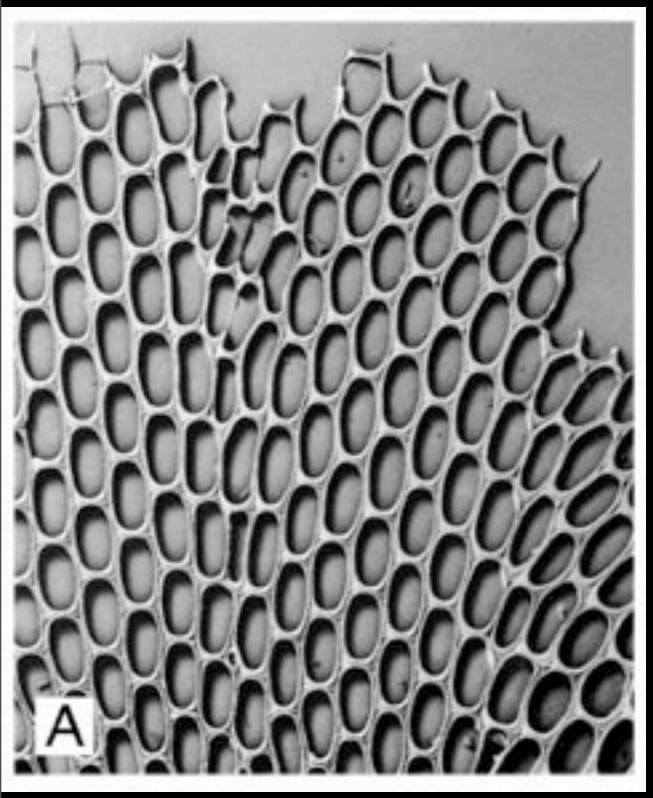
Small zooids

MART analysis using within-colony variation in zooid size

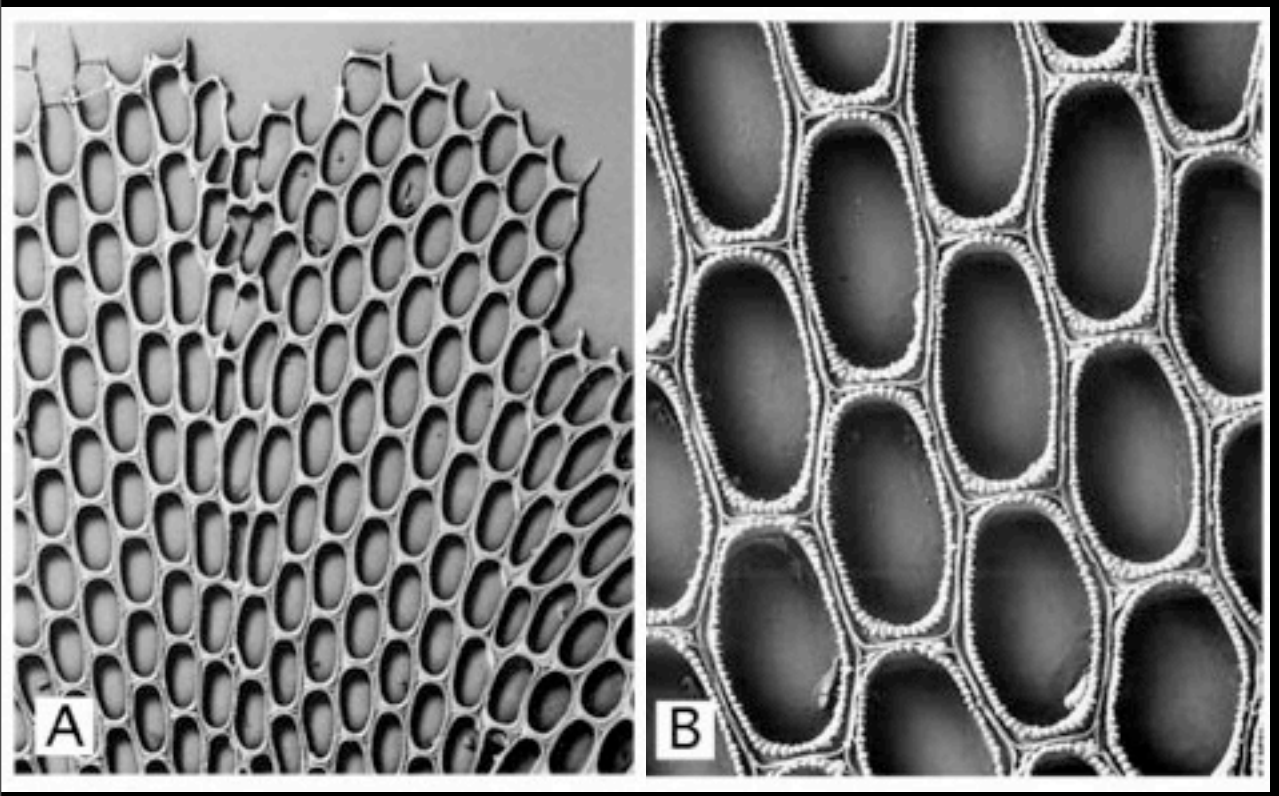
MART = mean annual range in temperature

Aaron O'Dea

Conopeum seurati
Avonmouth, England

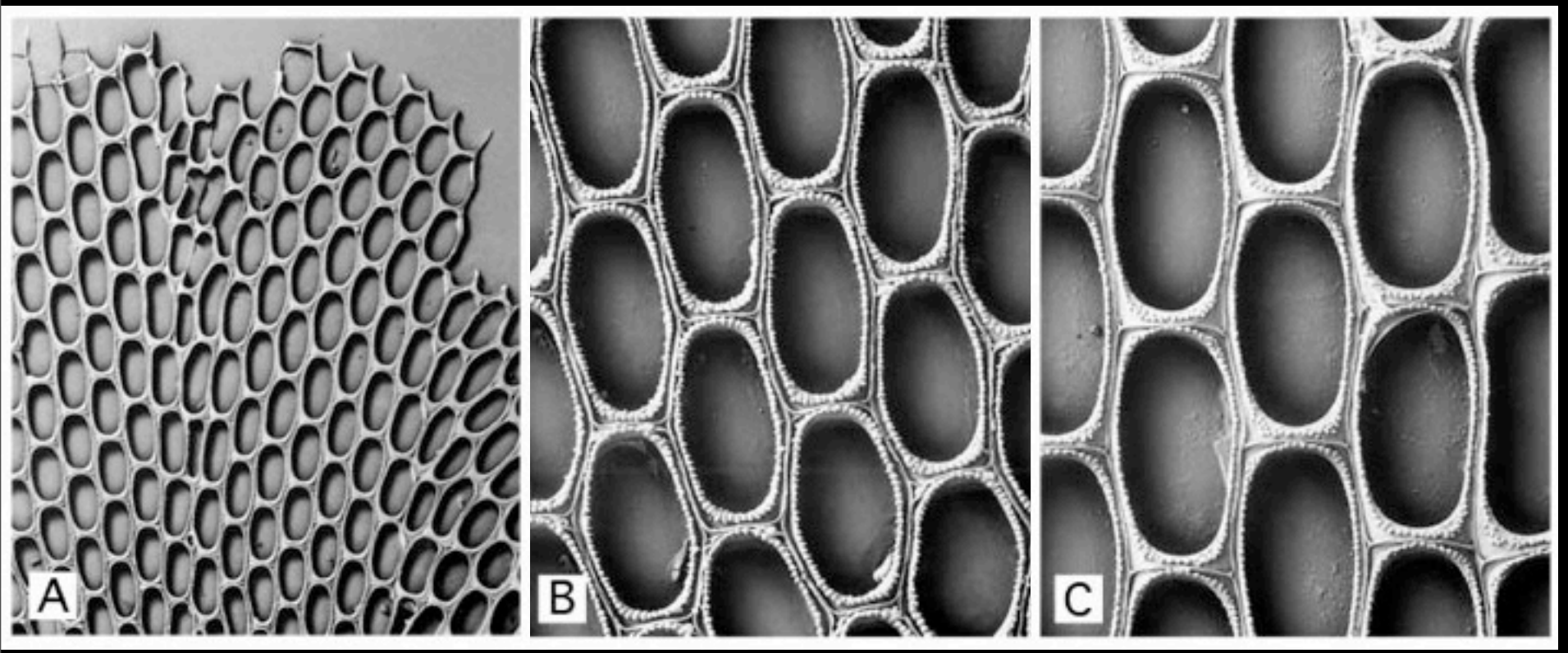


Conopeum seurati
Avonmouth, England



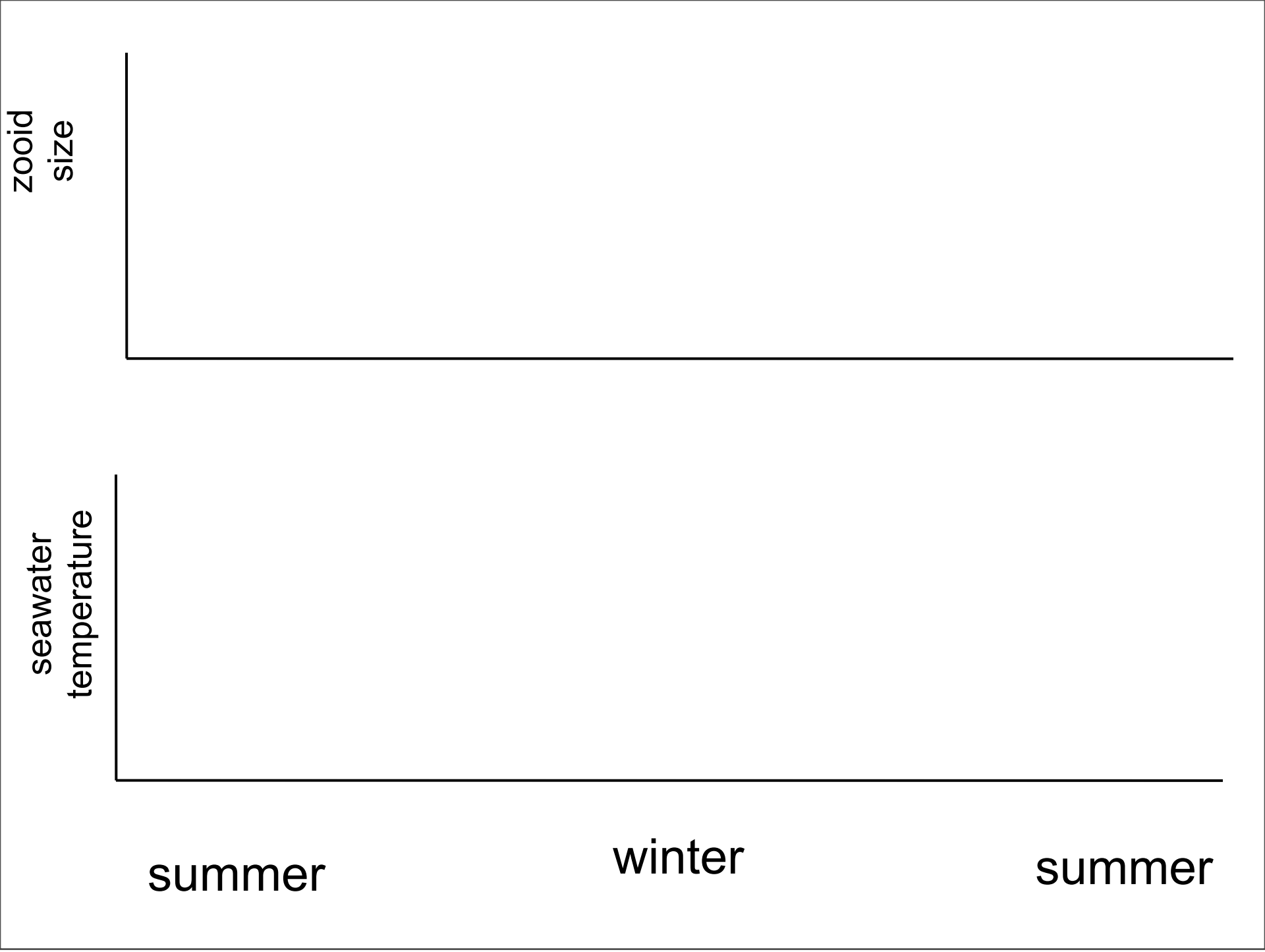
summer zooids

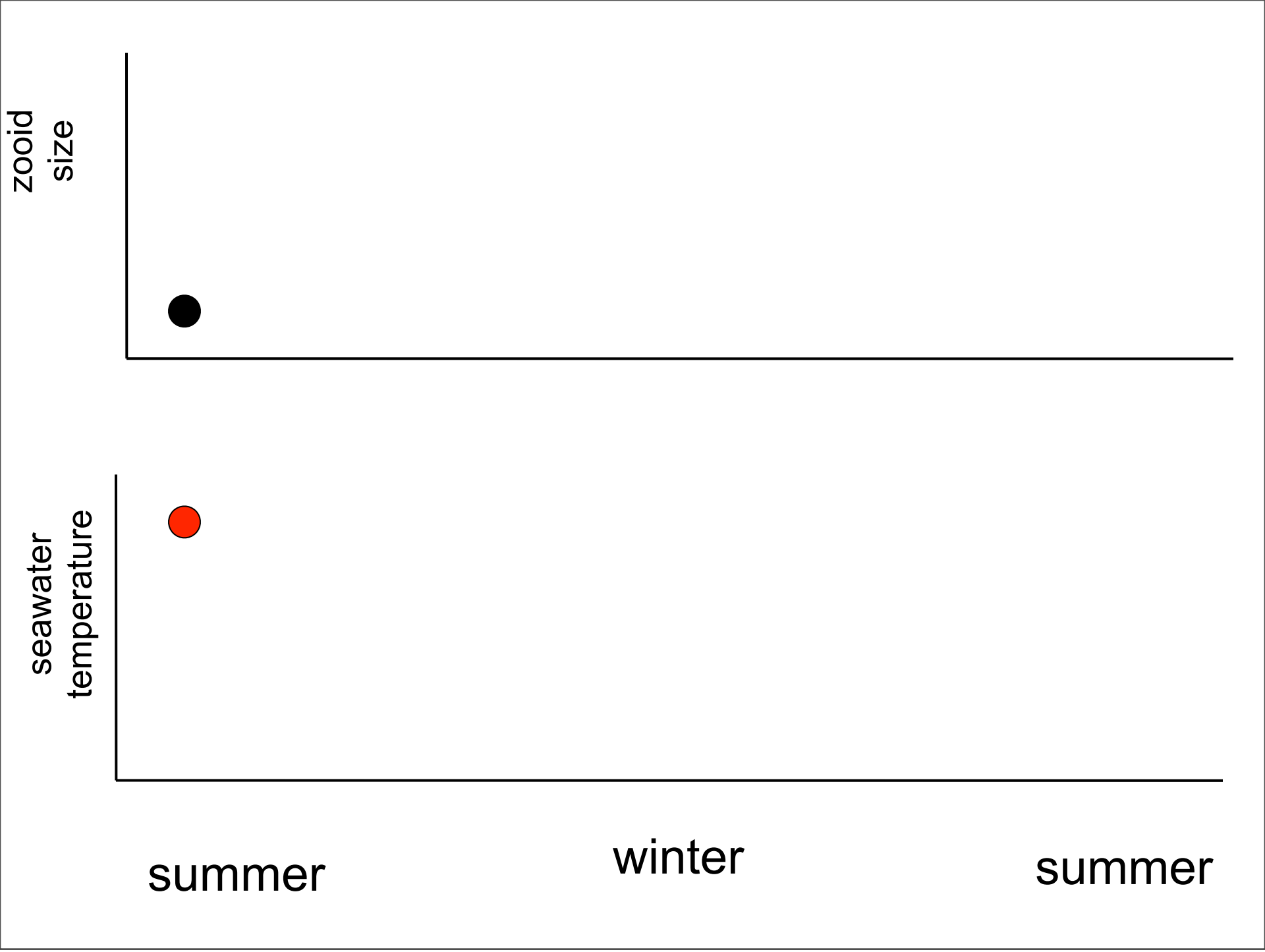
Conopeum seurati
Avonmouth, England

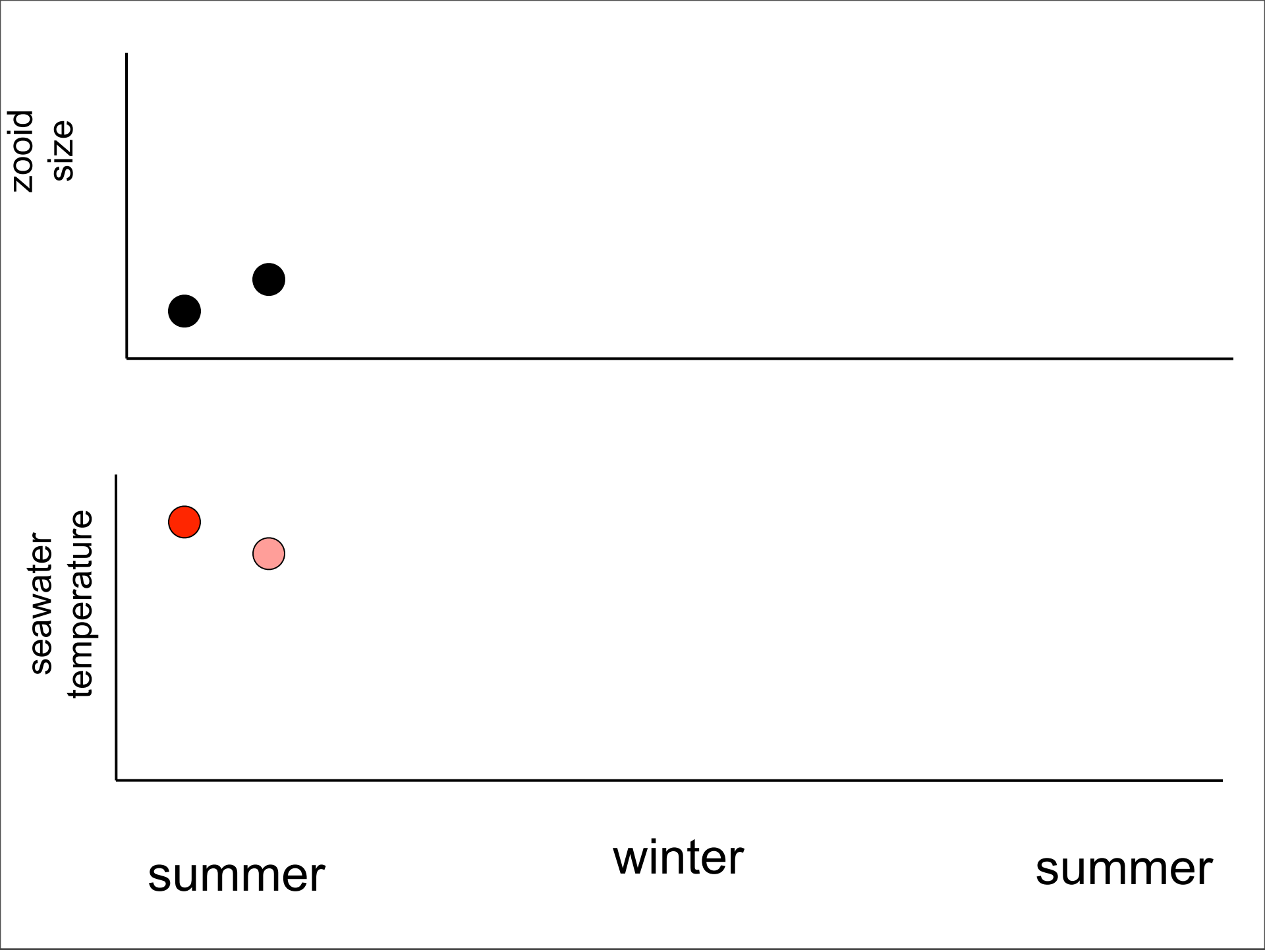


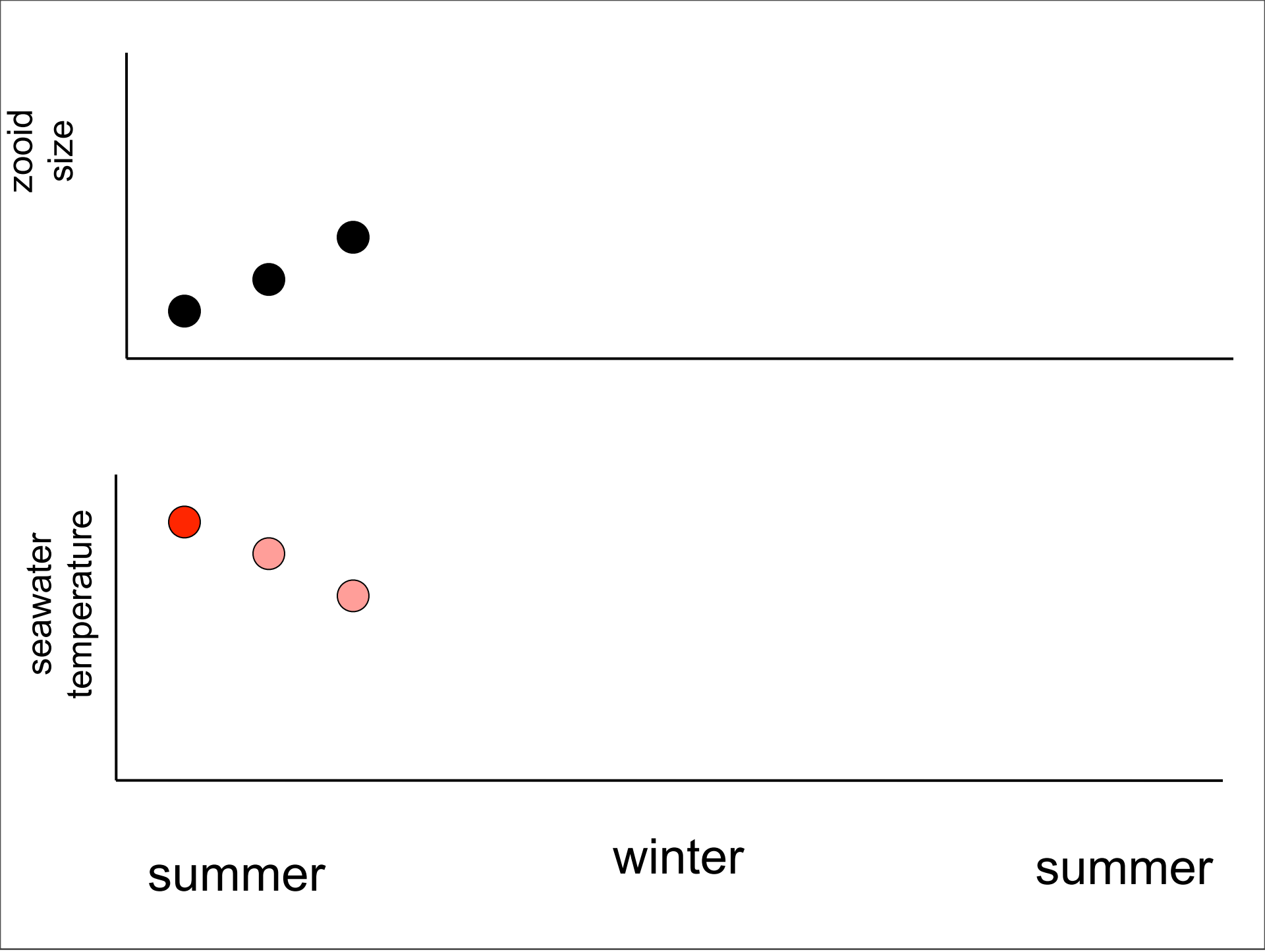
summer zooids

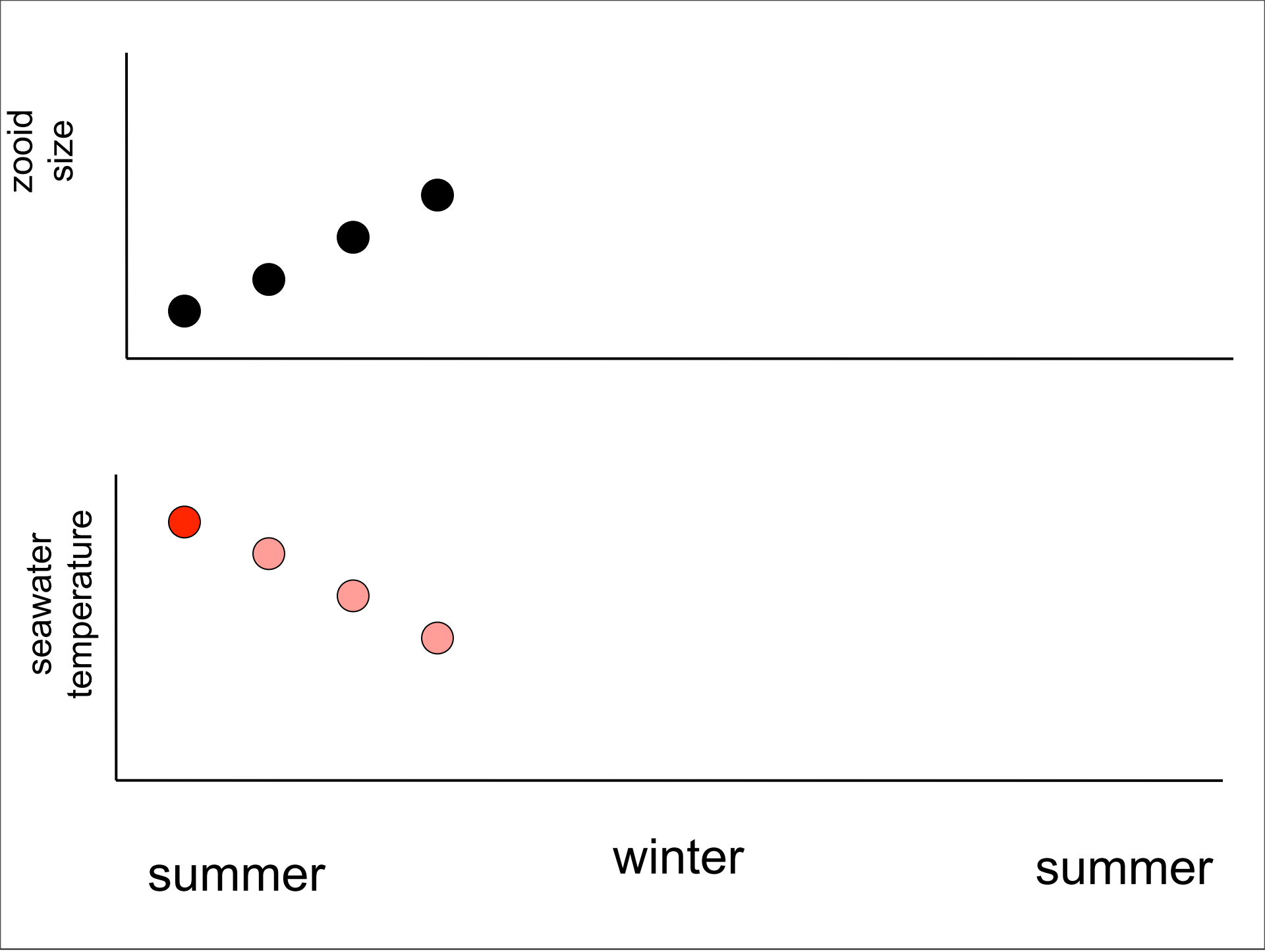
winter zooids

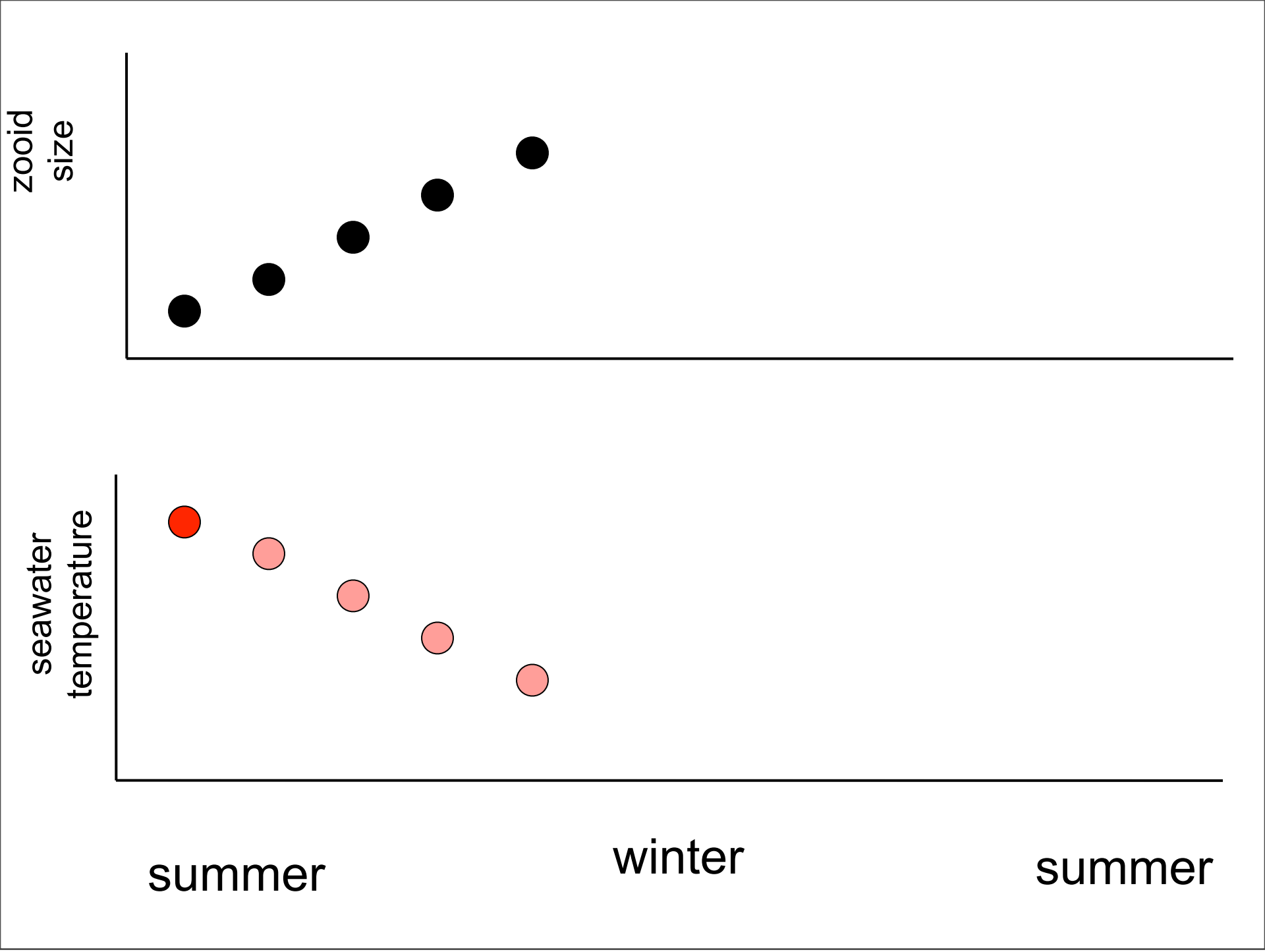

zooid
size
seawater
temperature
summer
winter
summer

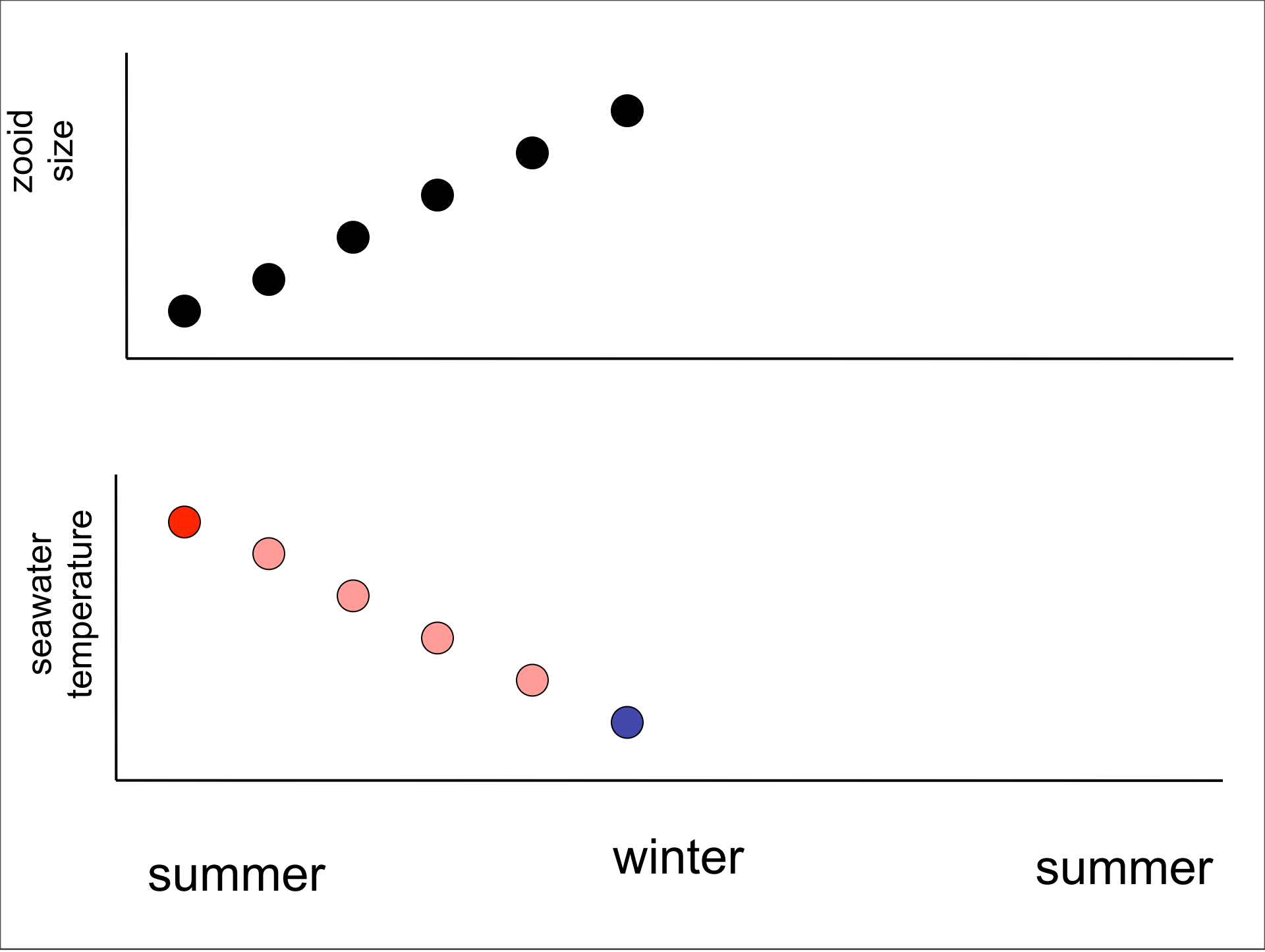

zooid
size
seawater
temperature
summer
winter
summer

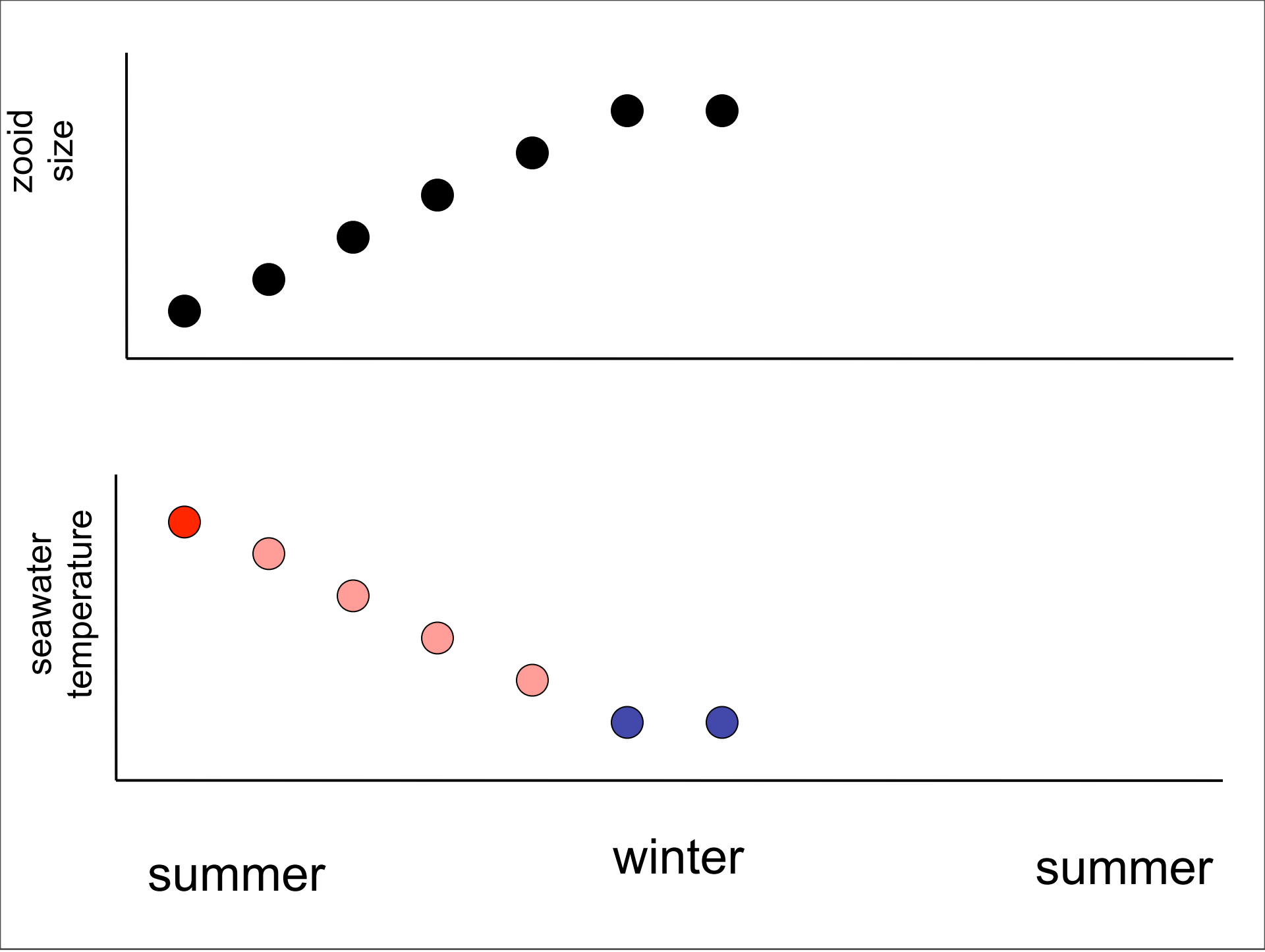

zooid
size
seawater
temperature
summer
winter
summer

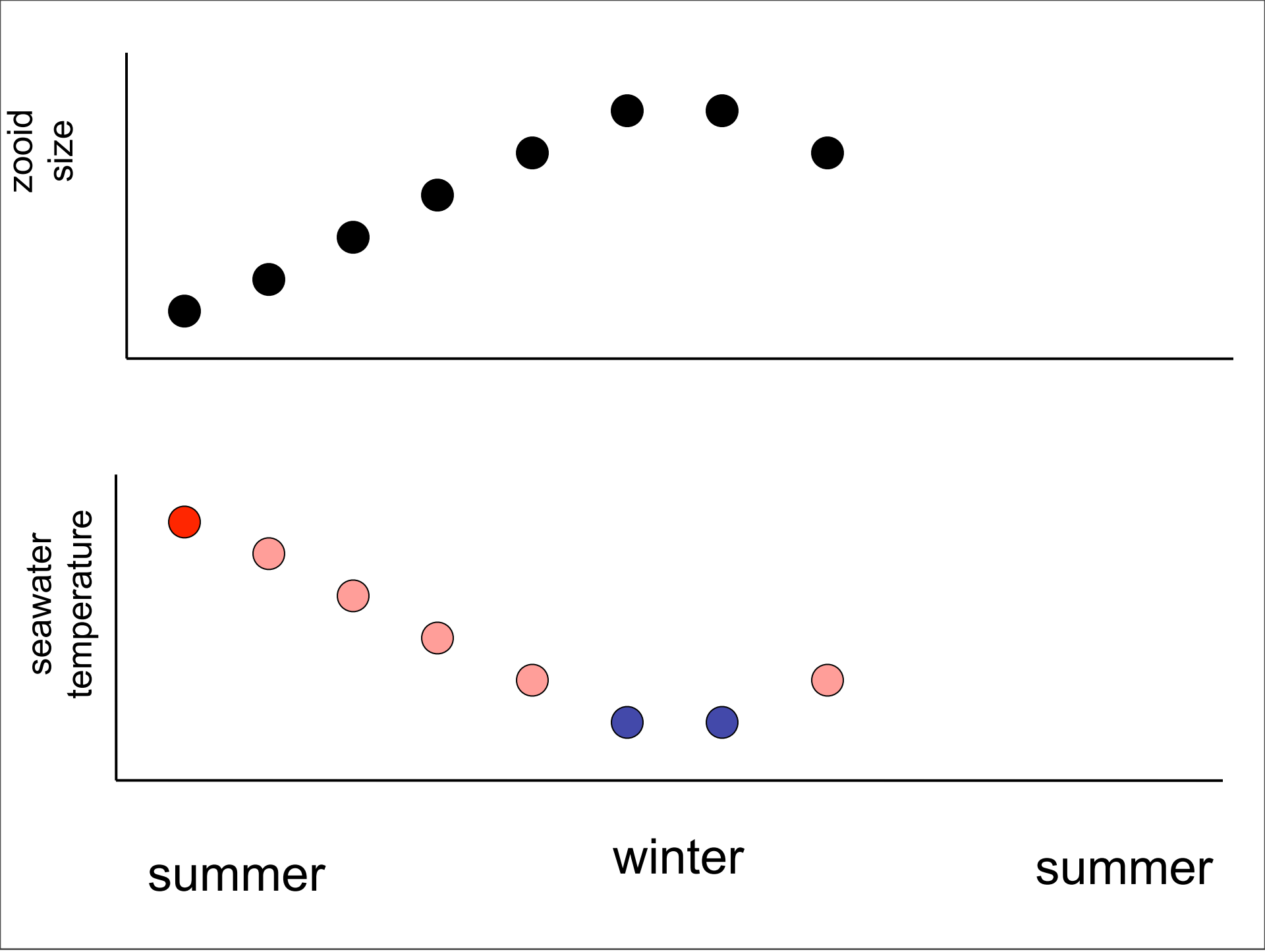

zooid
size
seawater
temperature
summer
winter
summer

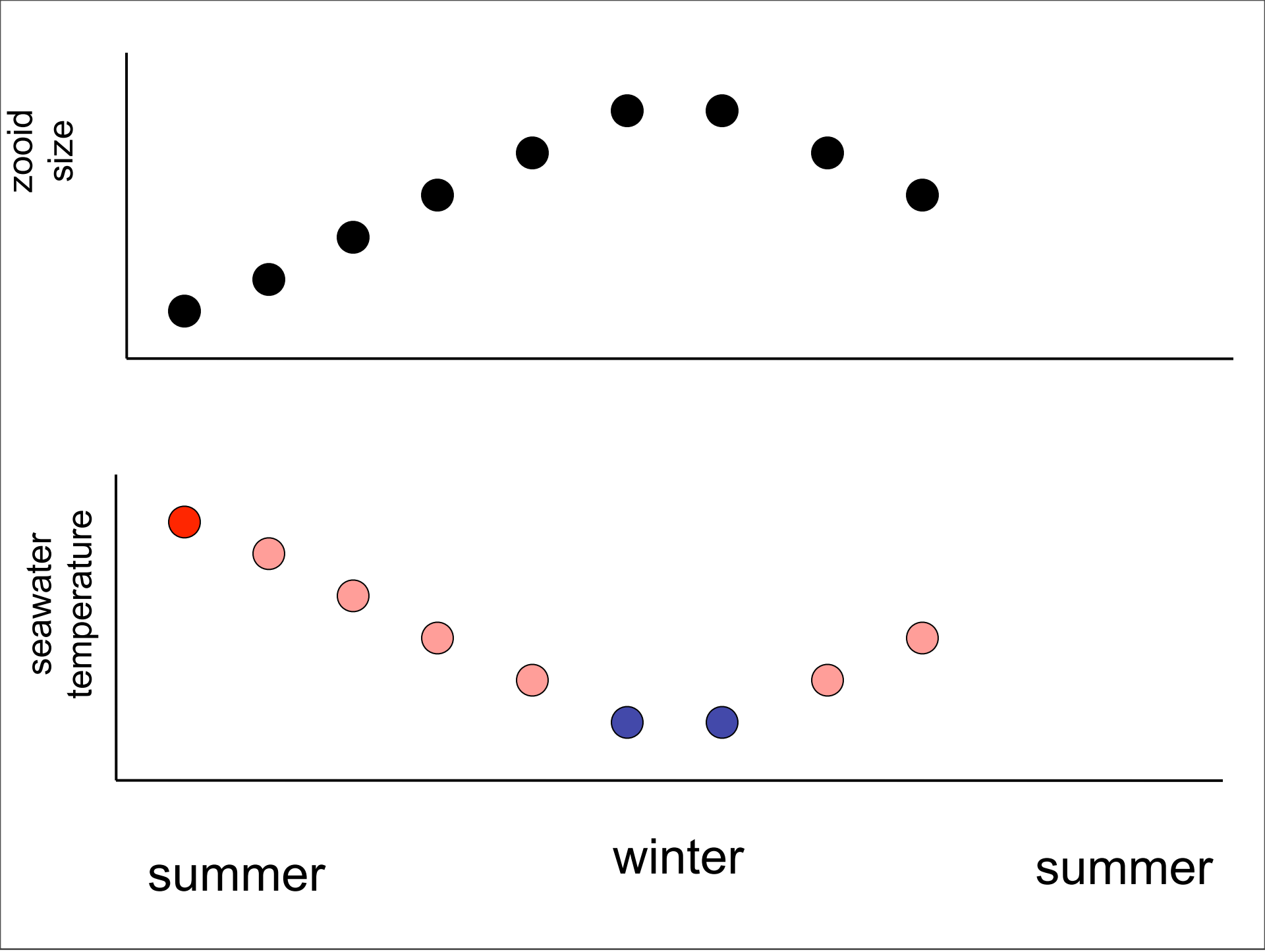

zooid size
seawater temperature
summer
winter
summer

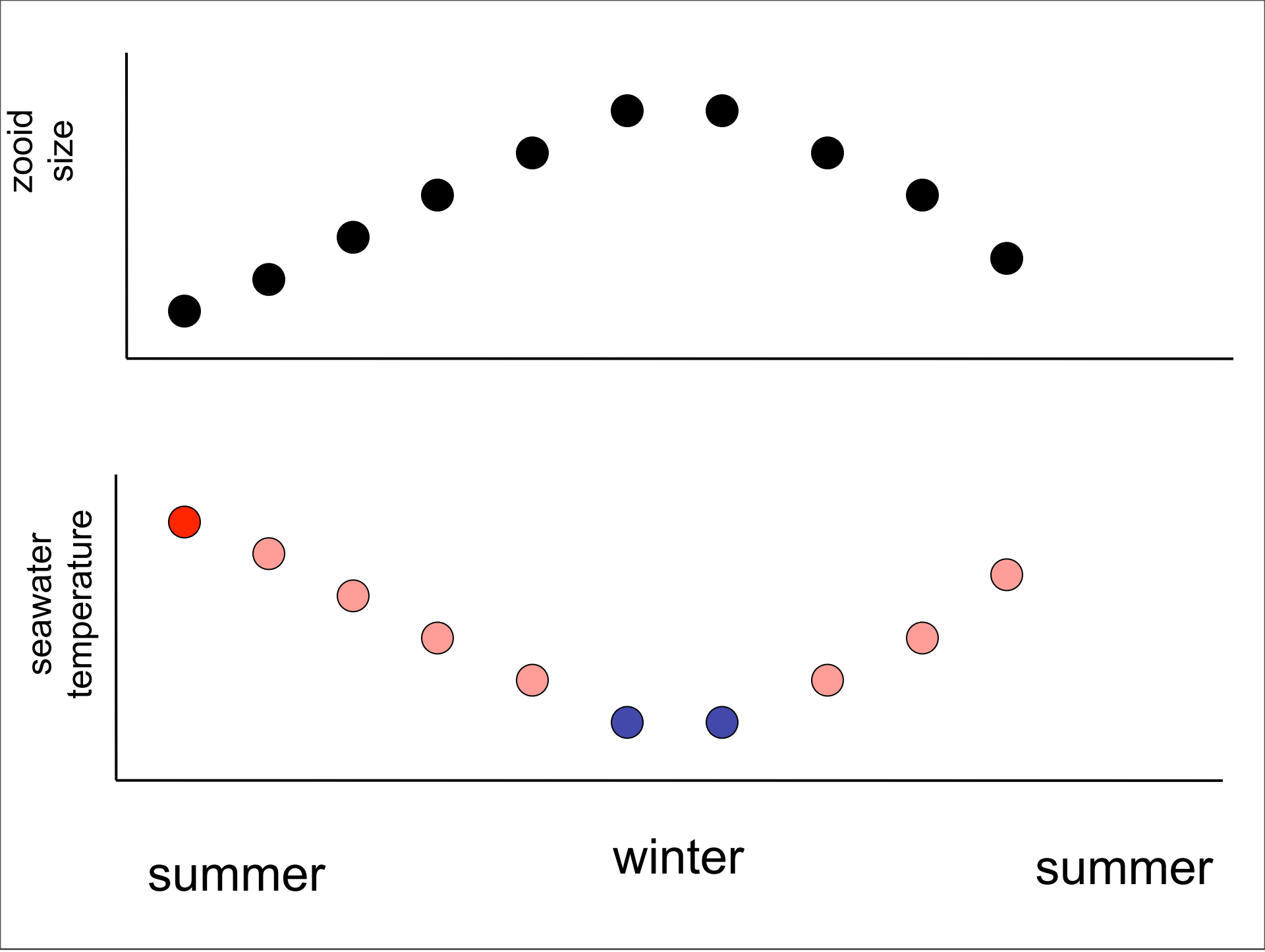

zooid size
seawater temperature
summer
winter
summer

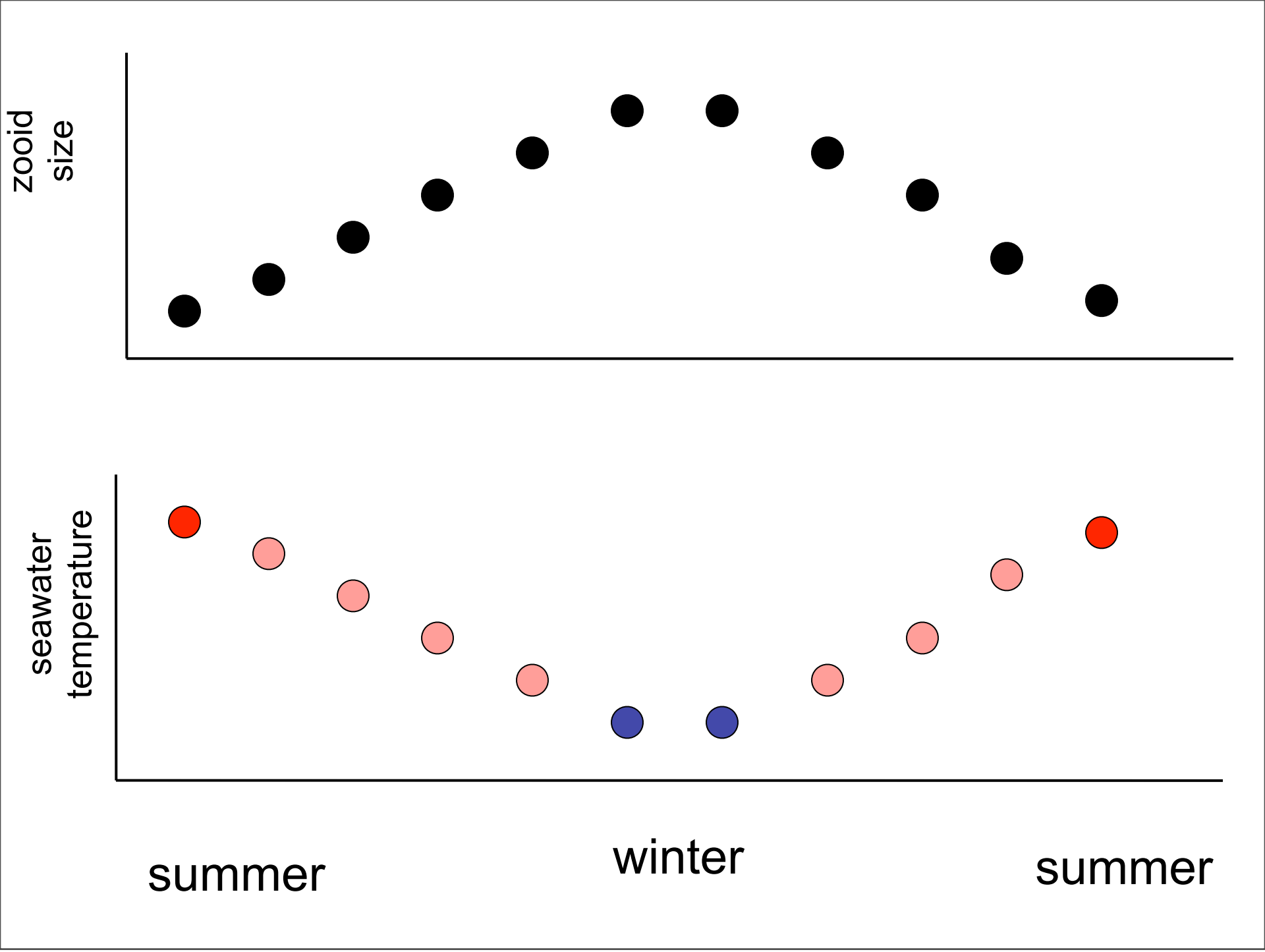

zooid size
seawater temperature
summer
winter
summer

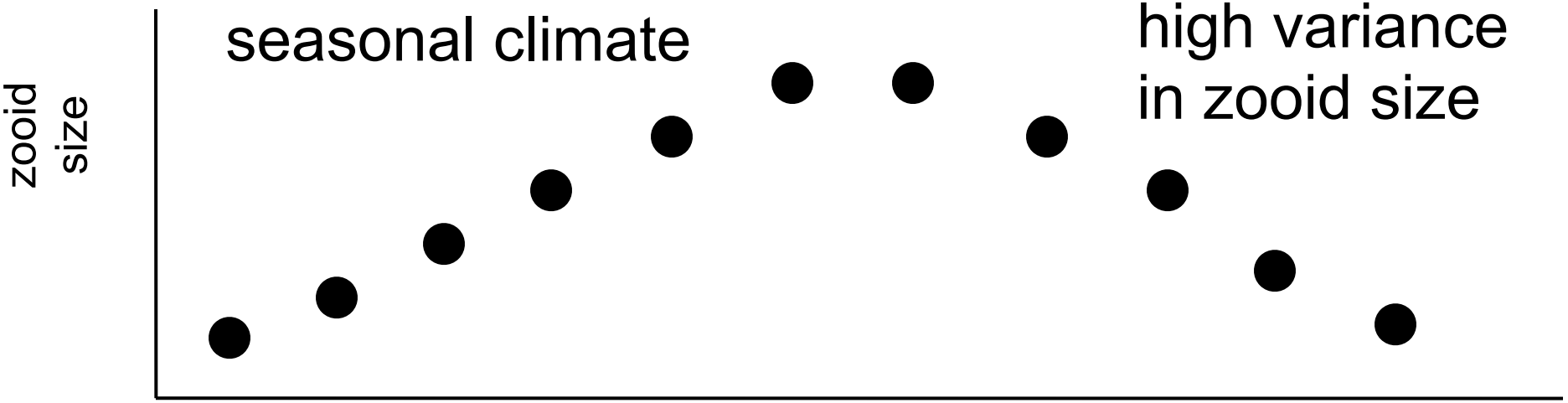

zooid size
seawater temperature
summer
winter
summer

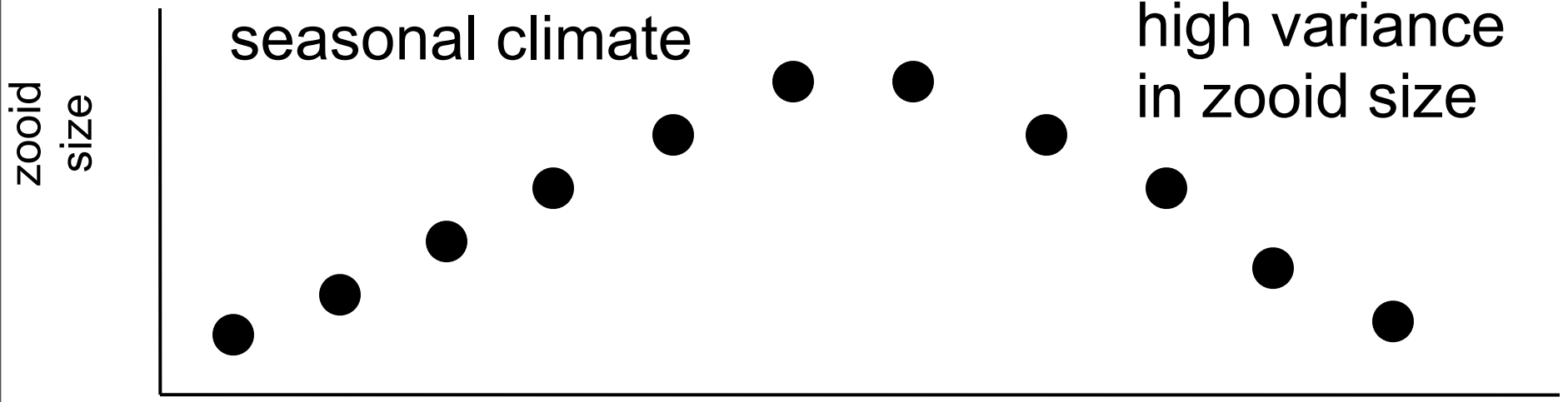

zooid size
seawater temperature
summer
winter
summer

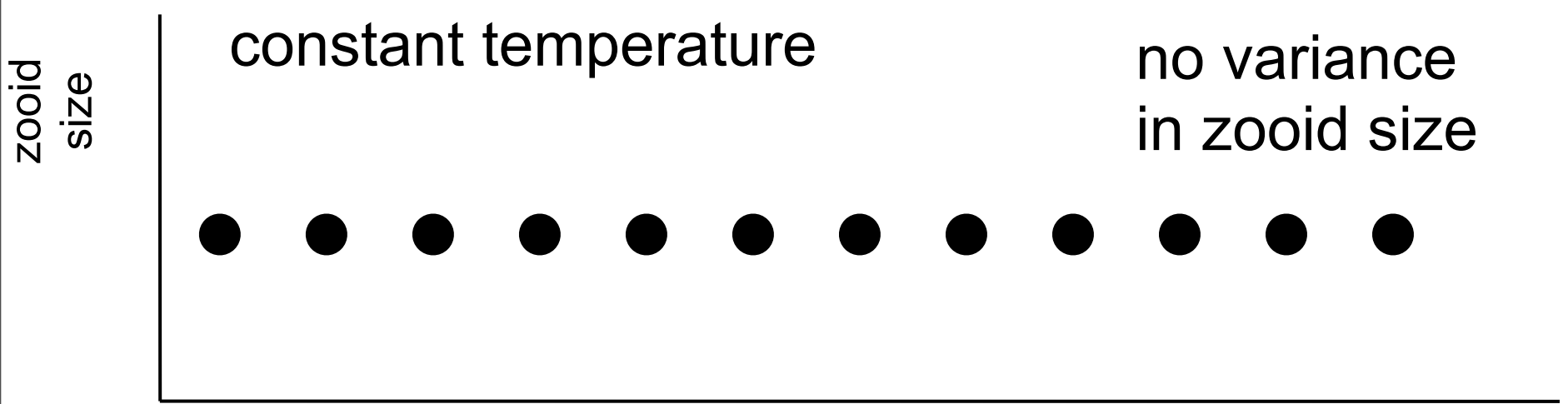

zooid size
seawater temperature
summer
winter
summer


zooid size
seawater temperature
summer
winter
summer

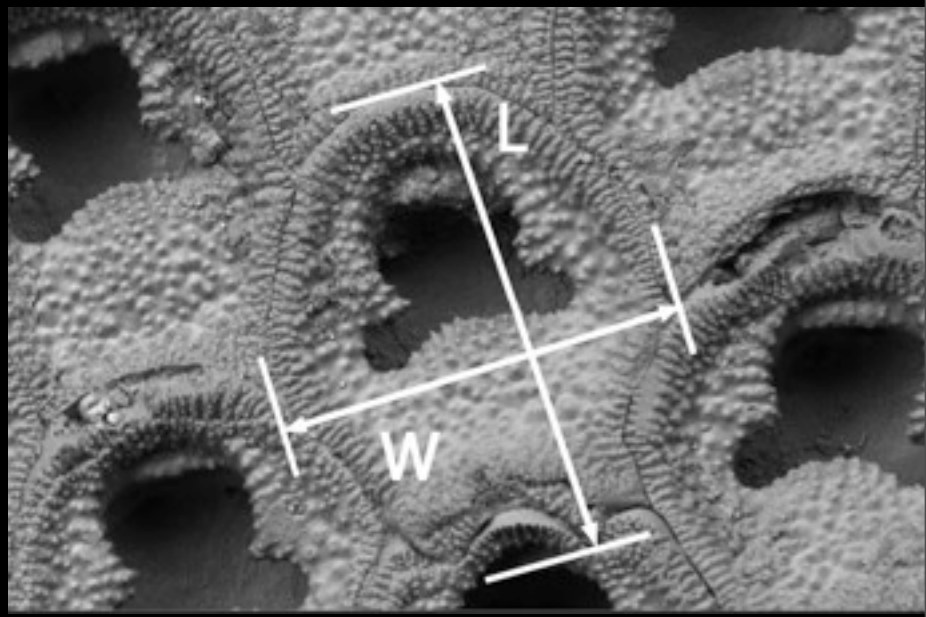

zooid size
seawater temperature
summer
winter
summer


zooid size
seasonal climate
high variance in zooid size


zooid size
seasonal climate
high variance in zooid size

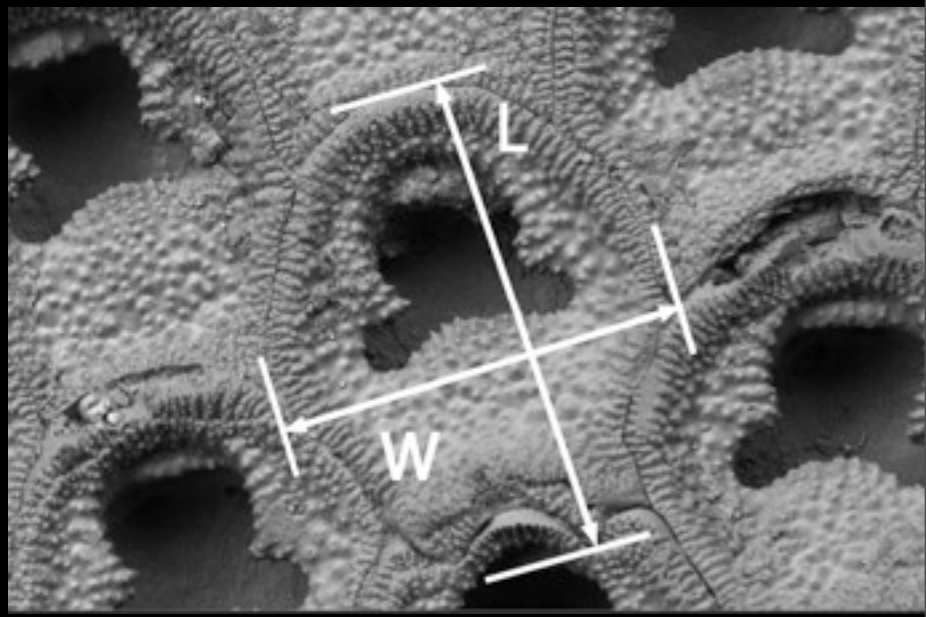

zooid size
constant temperature
no variance in zooid size

MART method



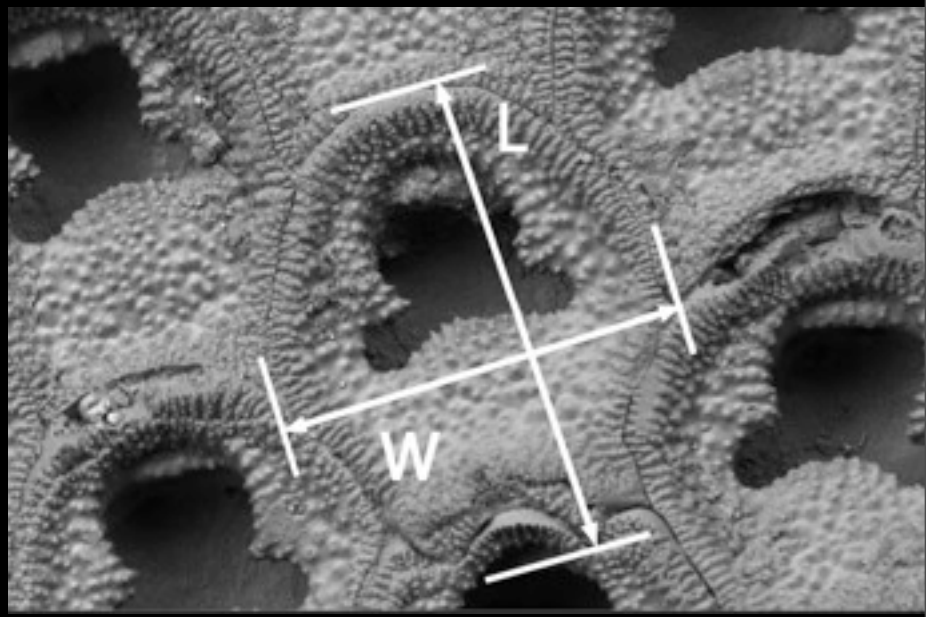
MART method

- randomly select 20 zooids



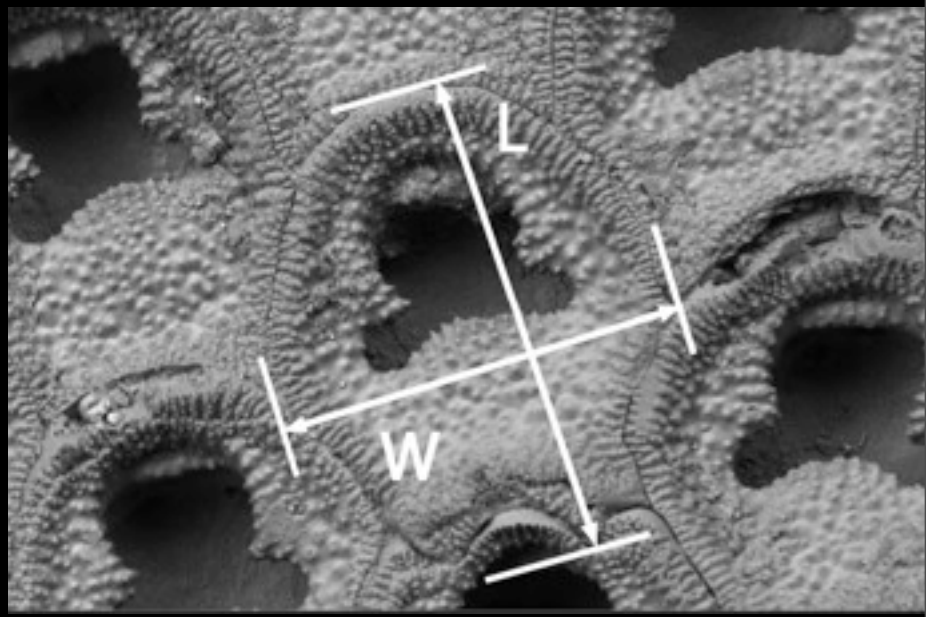
MART method

- randomly select 20 zooids
- avoid early zooids and areas of irregular growth



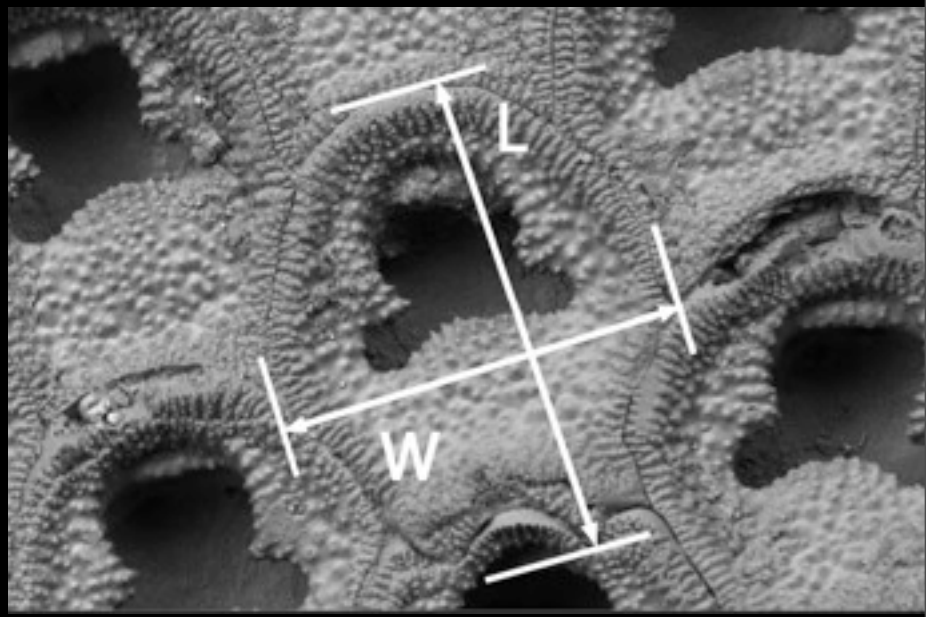
MART method

- randomly select 20 zooids
- avoid early zooids and areas of irregular growth
- measure zooid length and width



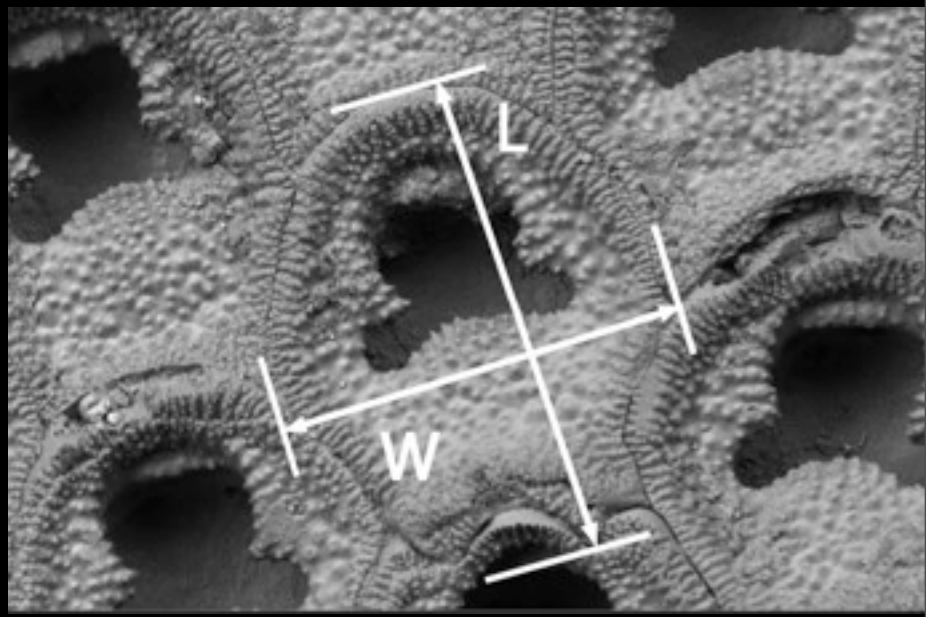
MART method

- randomly select 20 zooids
- avoid early zooids and areas of irregular growth
- measure zooid length and width
- calculate length x width (= area proxy)



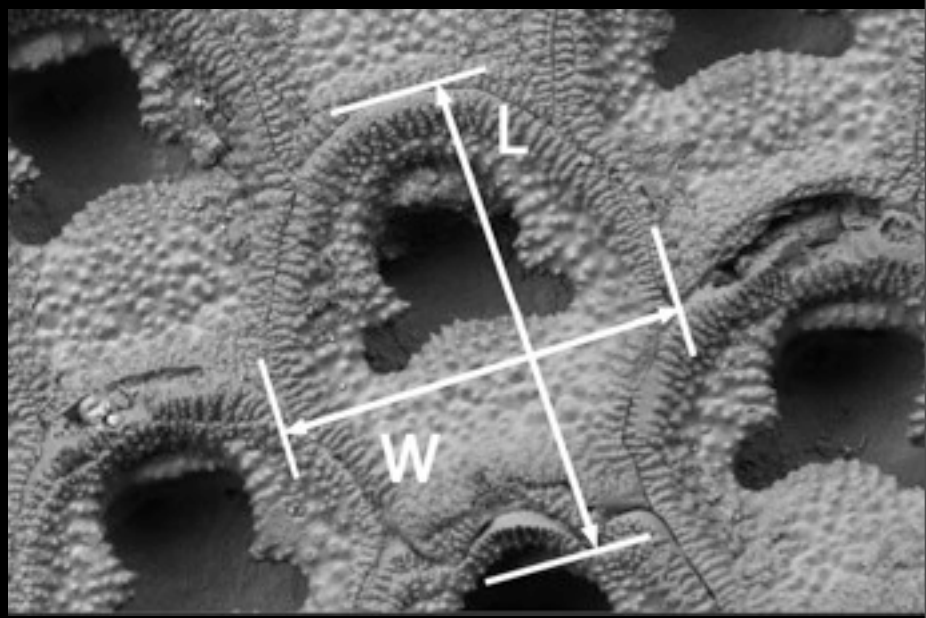
MART method

- randomly select 20 zooids
- avoid early zooids and areas of irregular growth
- measure zooid length and width
- calculate length x width (= area proxy)
- calculate CV (= SD/mean x 100)



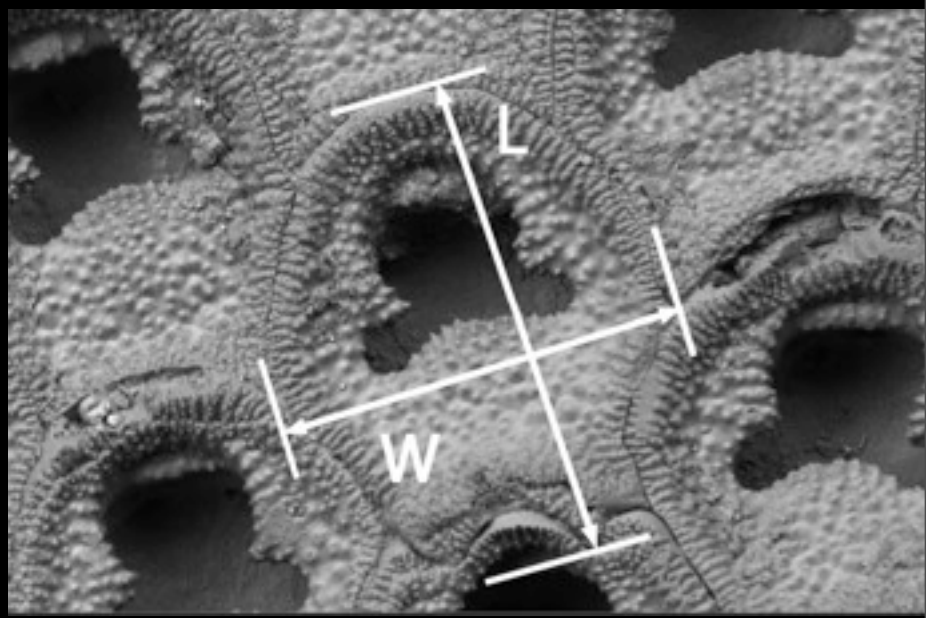
MART method

- randomly select 20 zooids
- avoid early zooids and areas of irregular growth
- measure zooid length and width
- calculate length x width (= area proxy)
- calculate CV (= SD/mean x 100)
- repeat in at least 4 more colonies



MART method

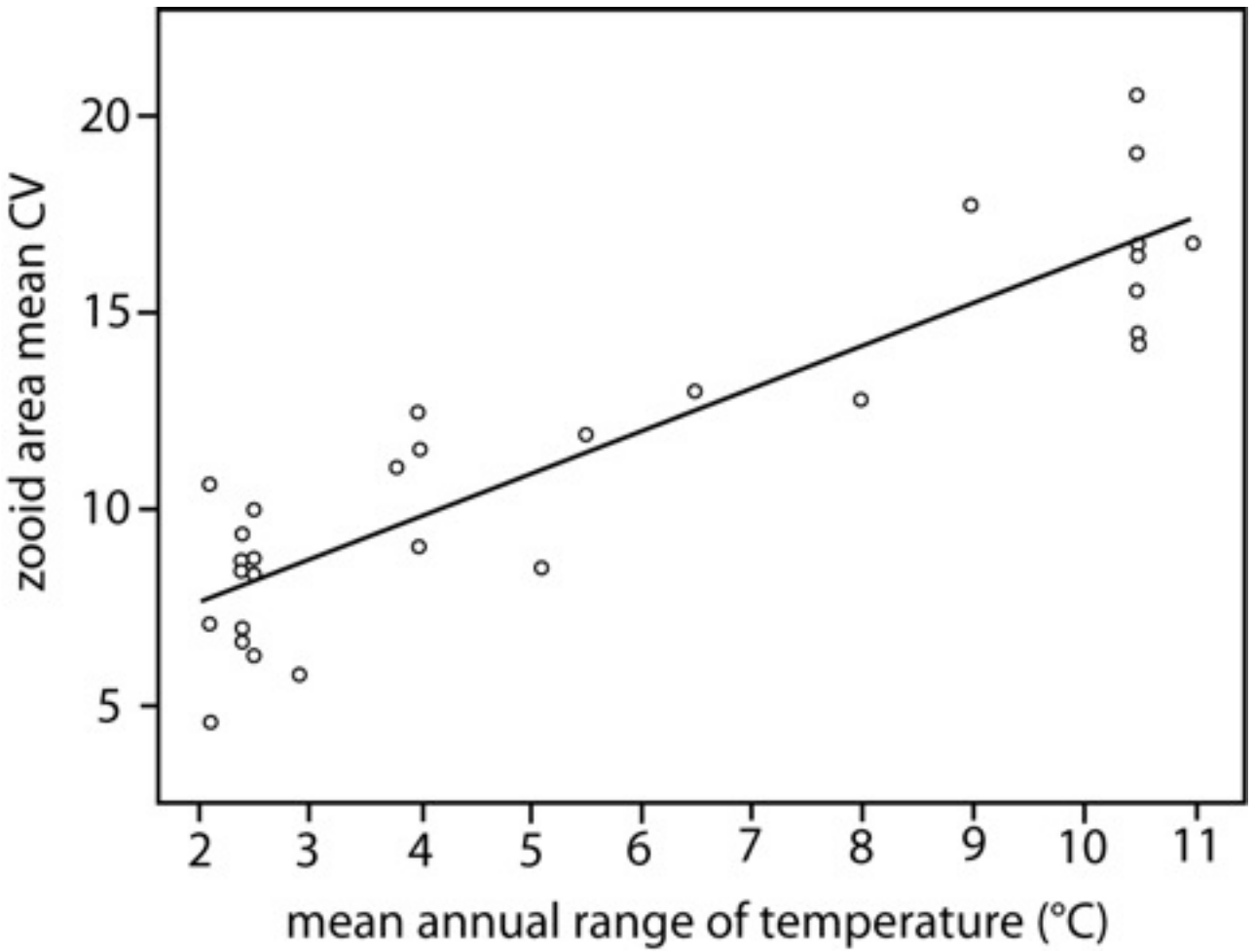
- randomly select 20 zooids
- avoid early zooids and areas of irregular growth
- measure zooid length and width
- calculate length x width (= area proxy)
- calculate CV (= SD/mean x 100)
- repeat in at least 4 more colonies

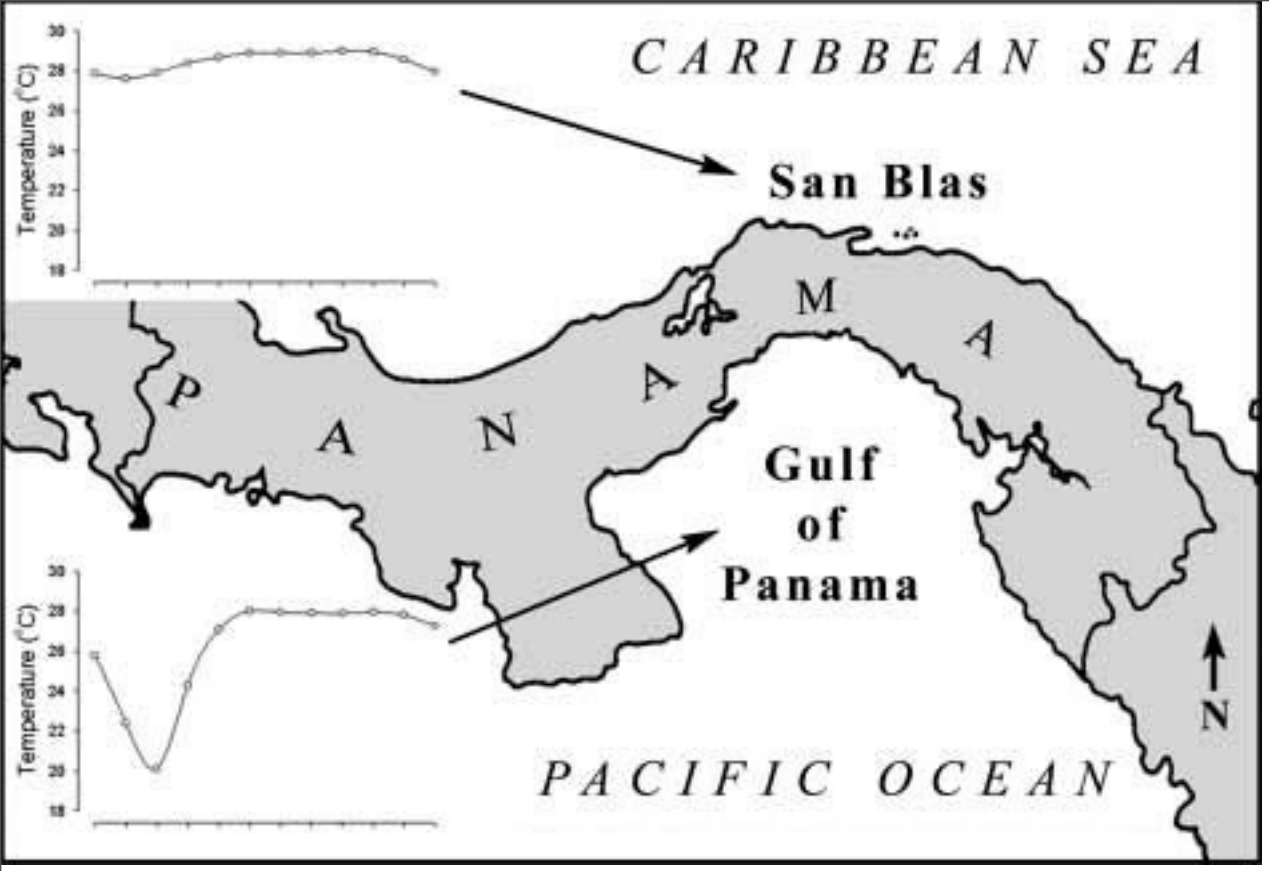


29 Recent cheilostome species

MART = -3+0.745(*b*)

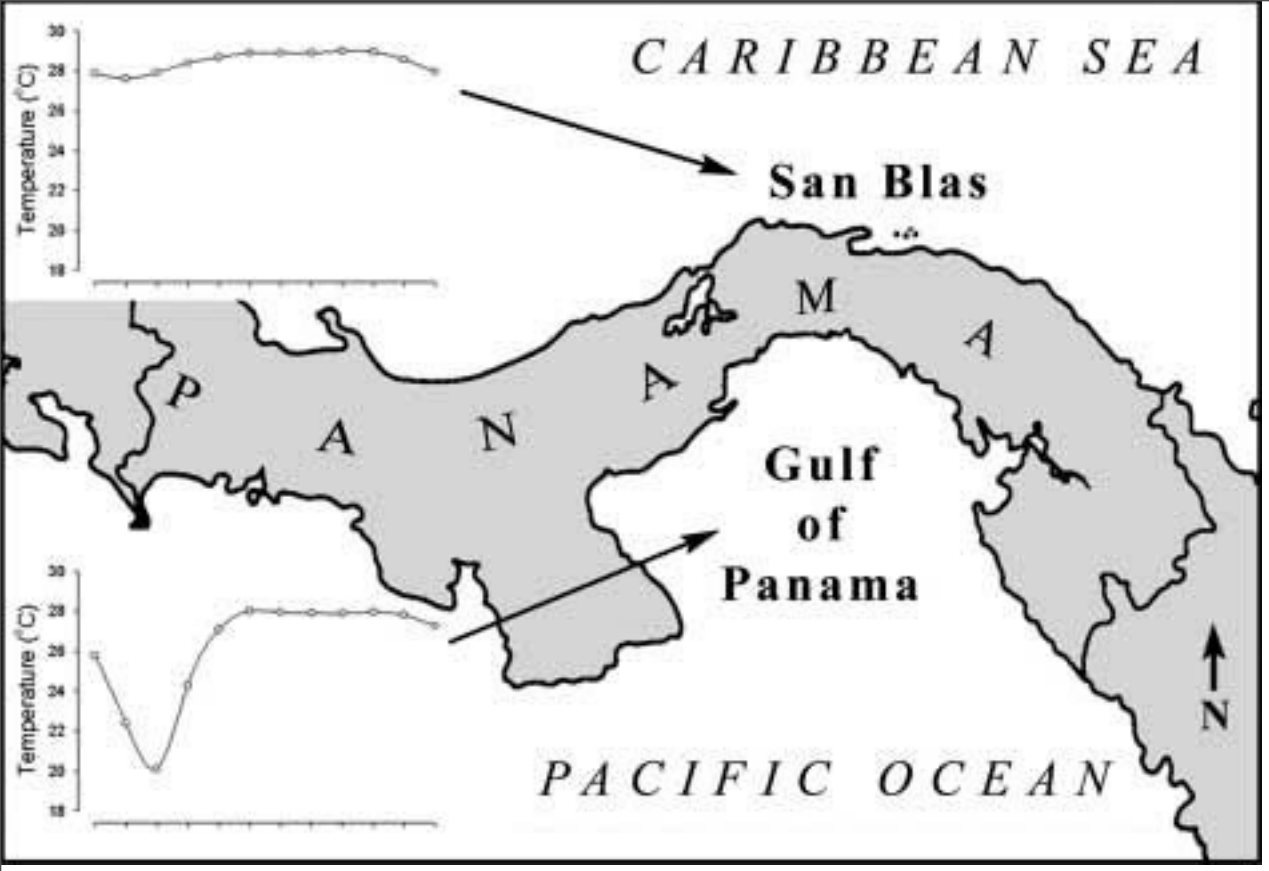
where (b) is the mean intracolony CV of frontal area (length x width)

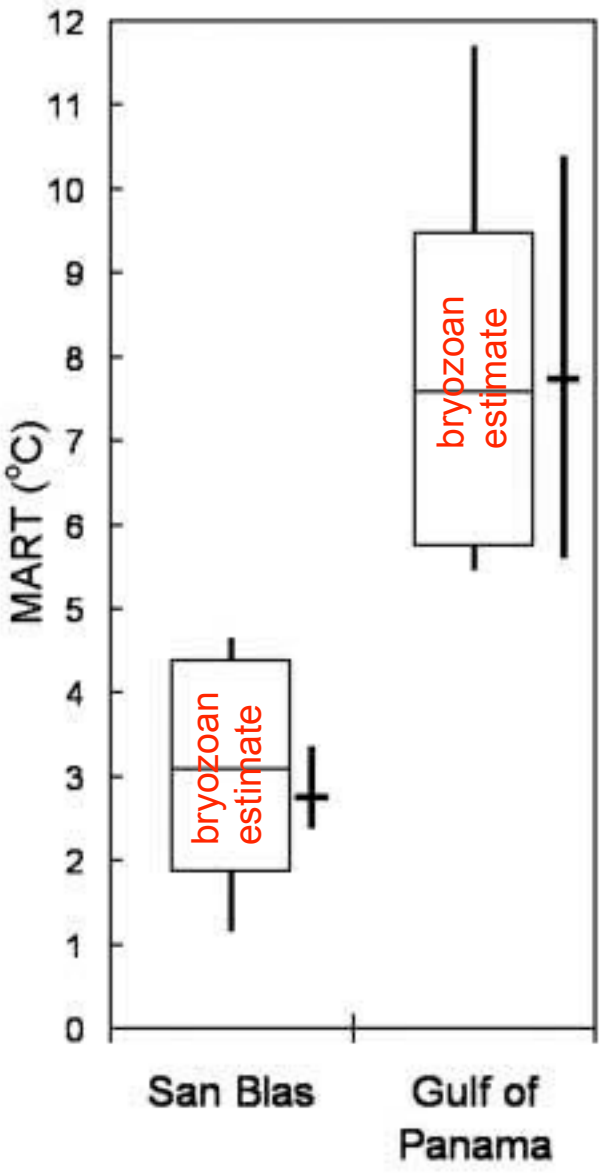




Contrasting seasonality between Caribbean and Pacific

O'Dea 2003

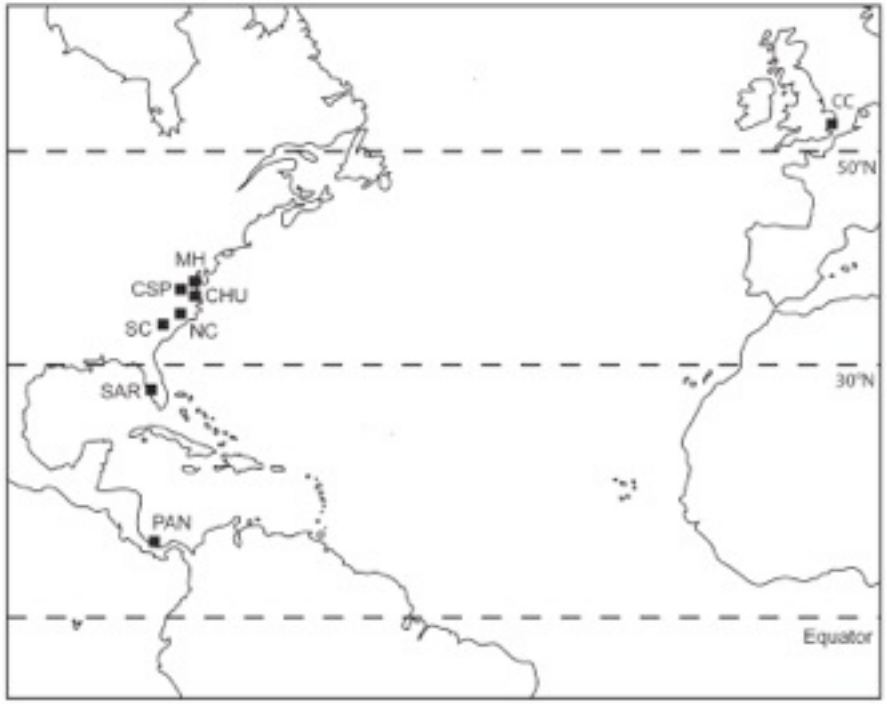




Contrasting seasonality between Caribbean and Pacific

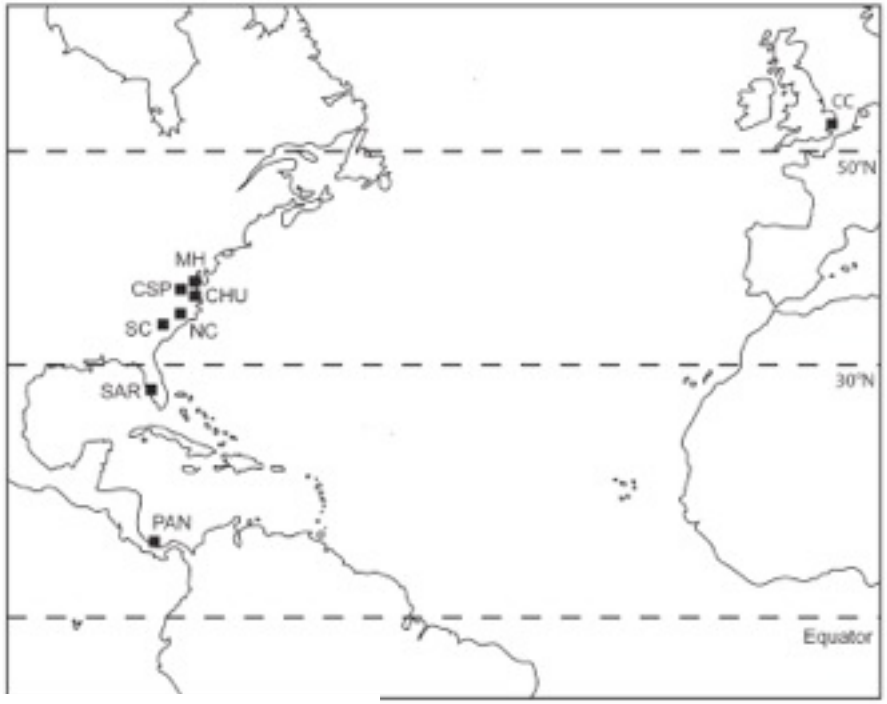
O'Dea 2003

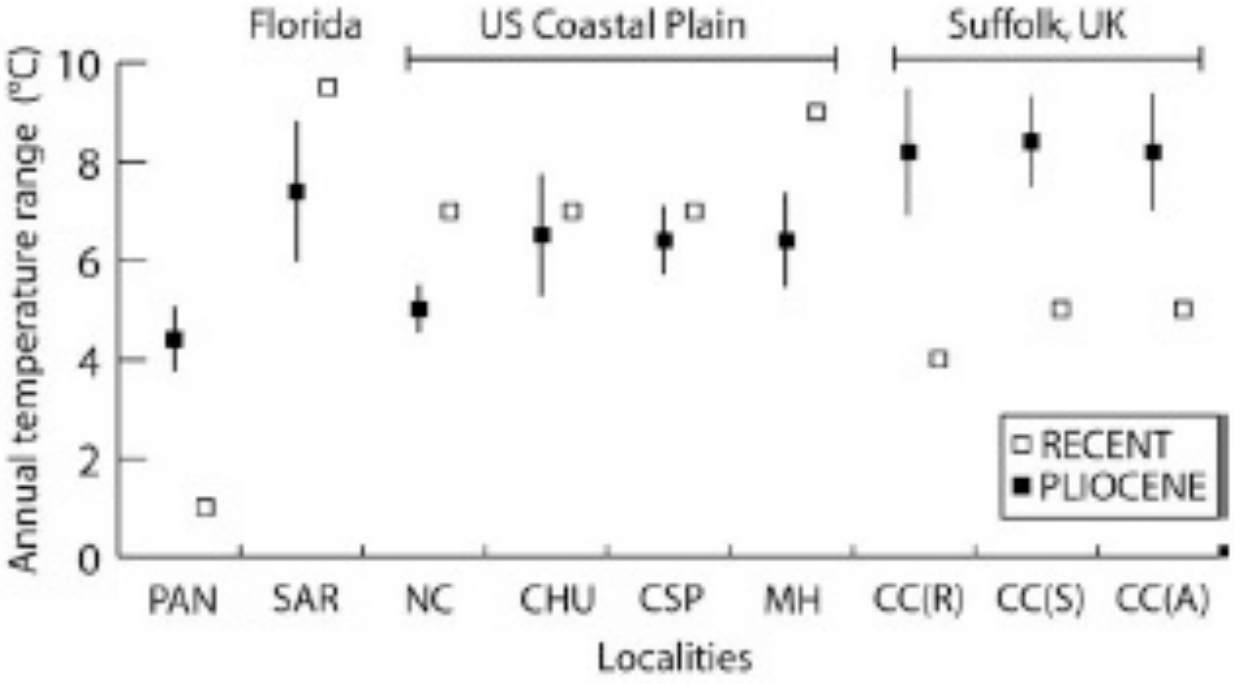
Early-Mid Pliocene
North Atlantic



Knowles *et al*. 2009

Early-Mid Pliocene North Atlantic





Knowles *et al*. 2009

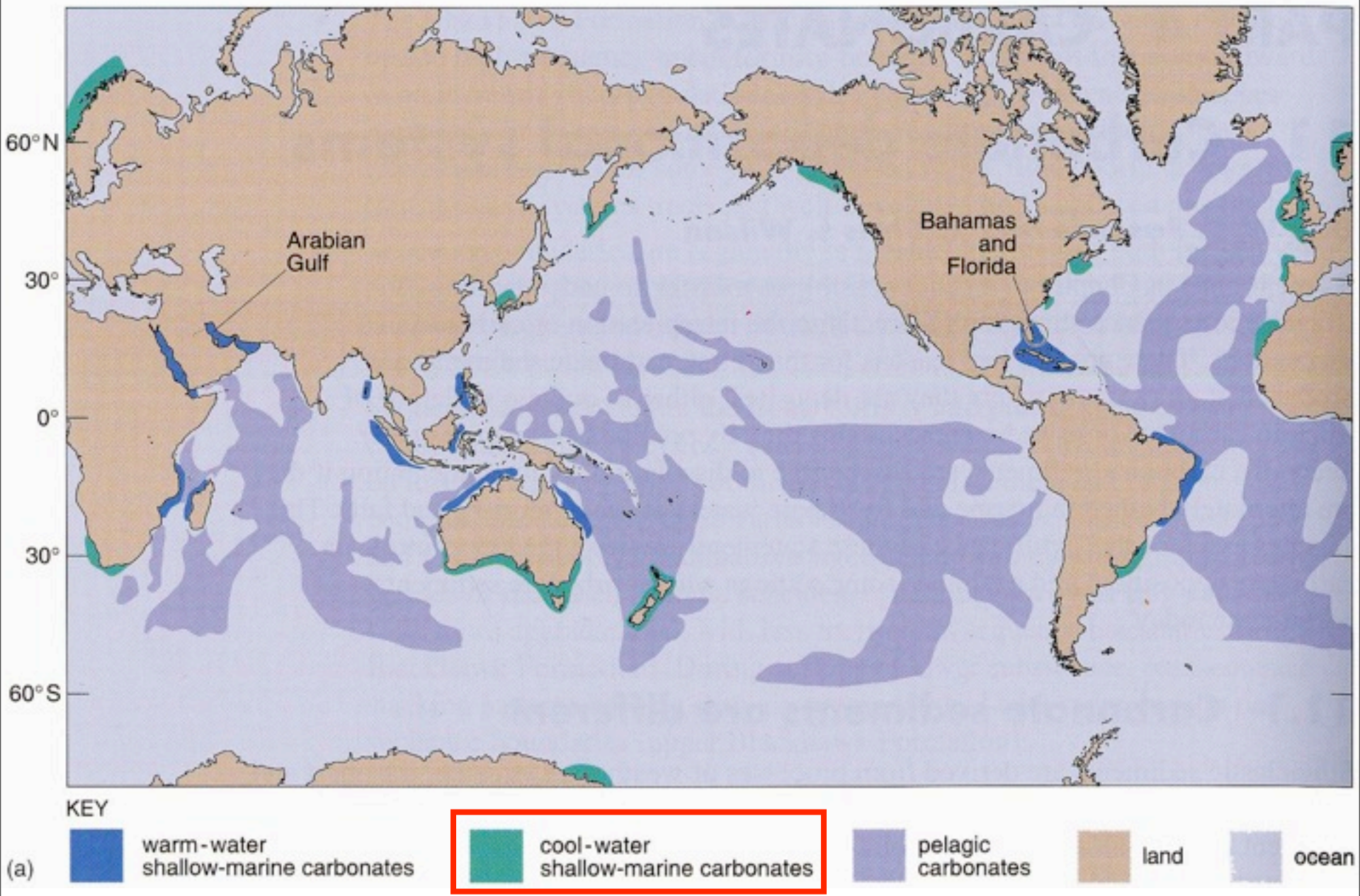
5. palaeolatitudinal distribution of bryozoan carbonates through time

Uniformitarianism

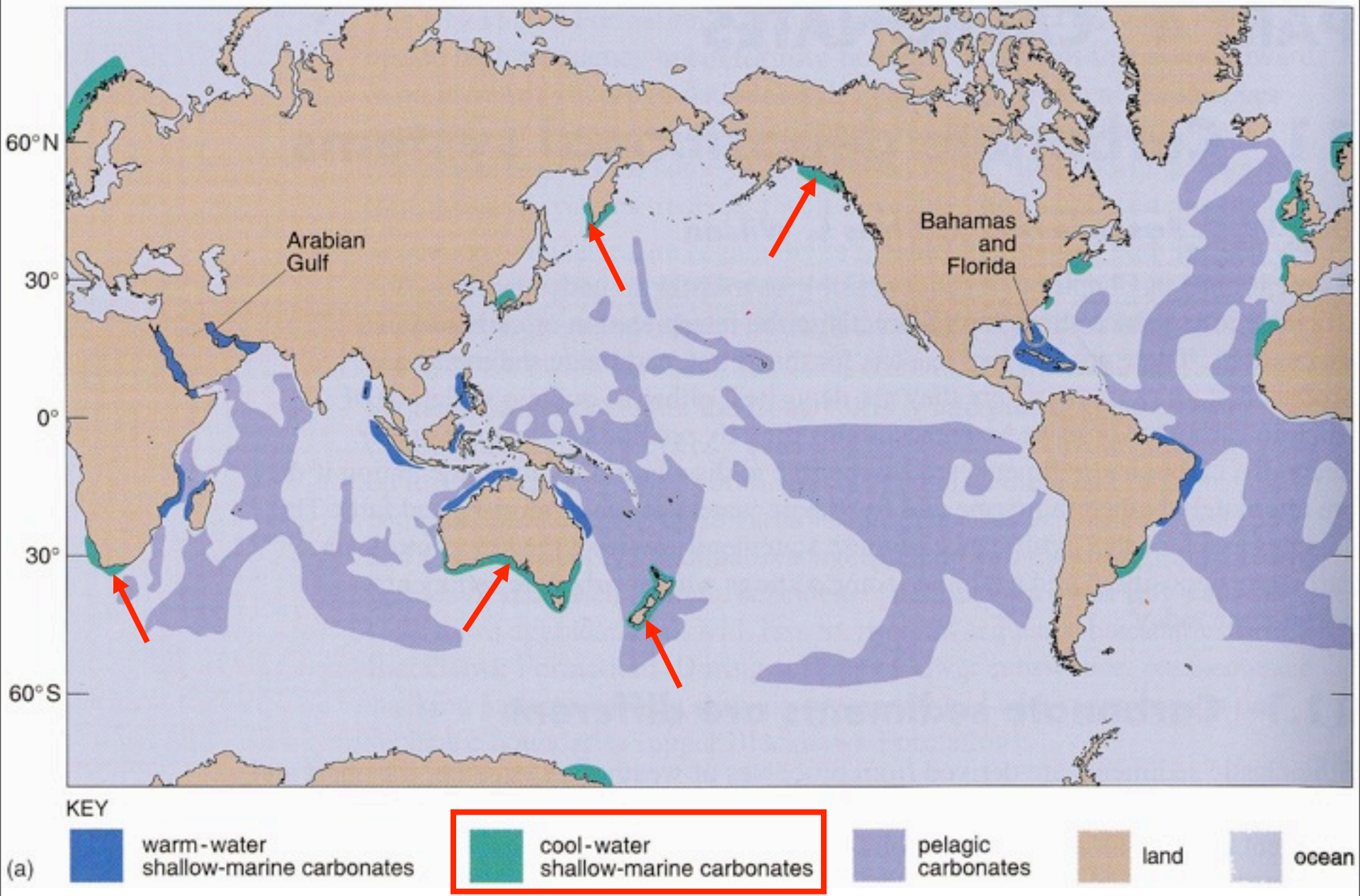
'Present is the Key to the Past'

Charles Lyell
(1797-1875)

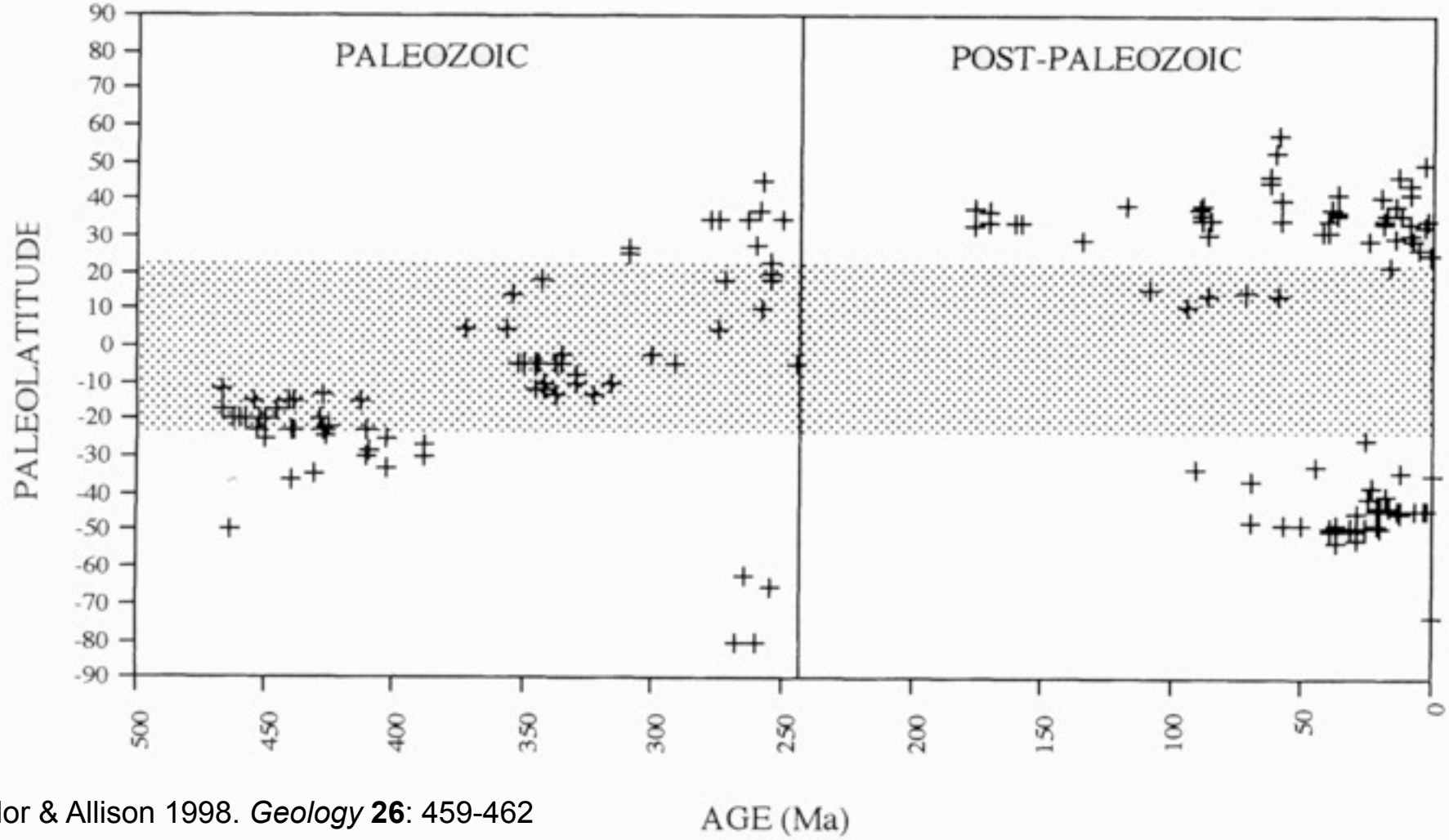
Global distribution of carbonate deposition at the present-day



Global distribution of carbonate deposition at the present-day

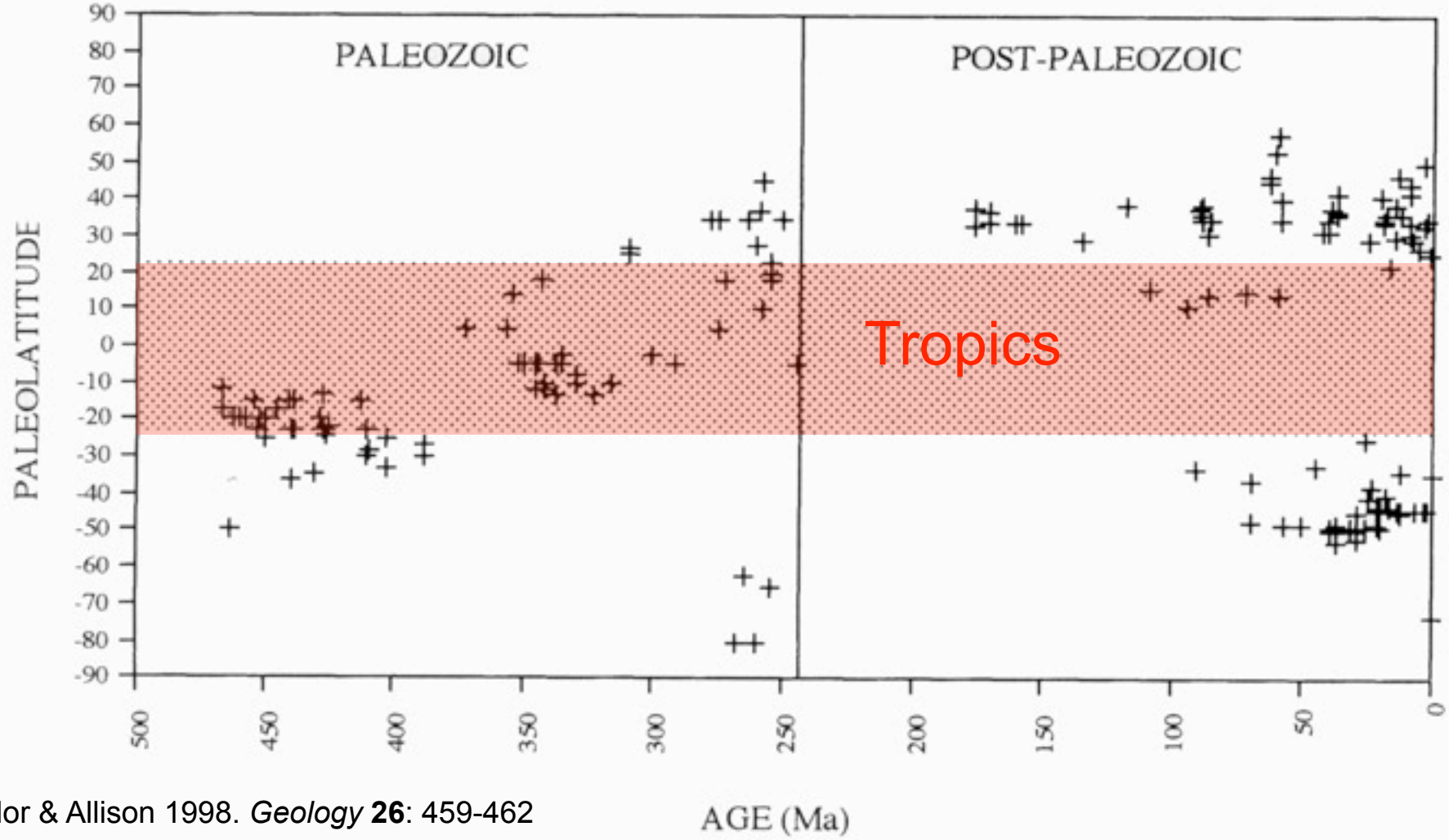


Palaeolatitudinal distribution of bryozoan-rich sediments



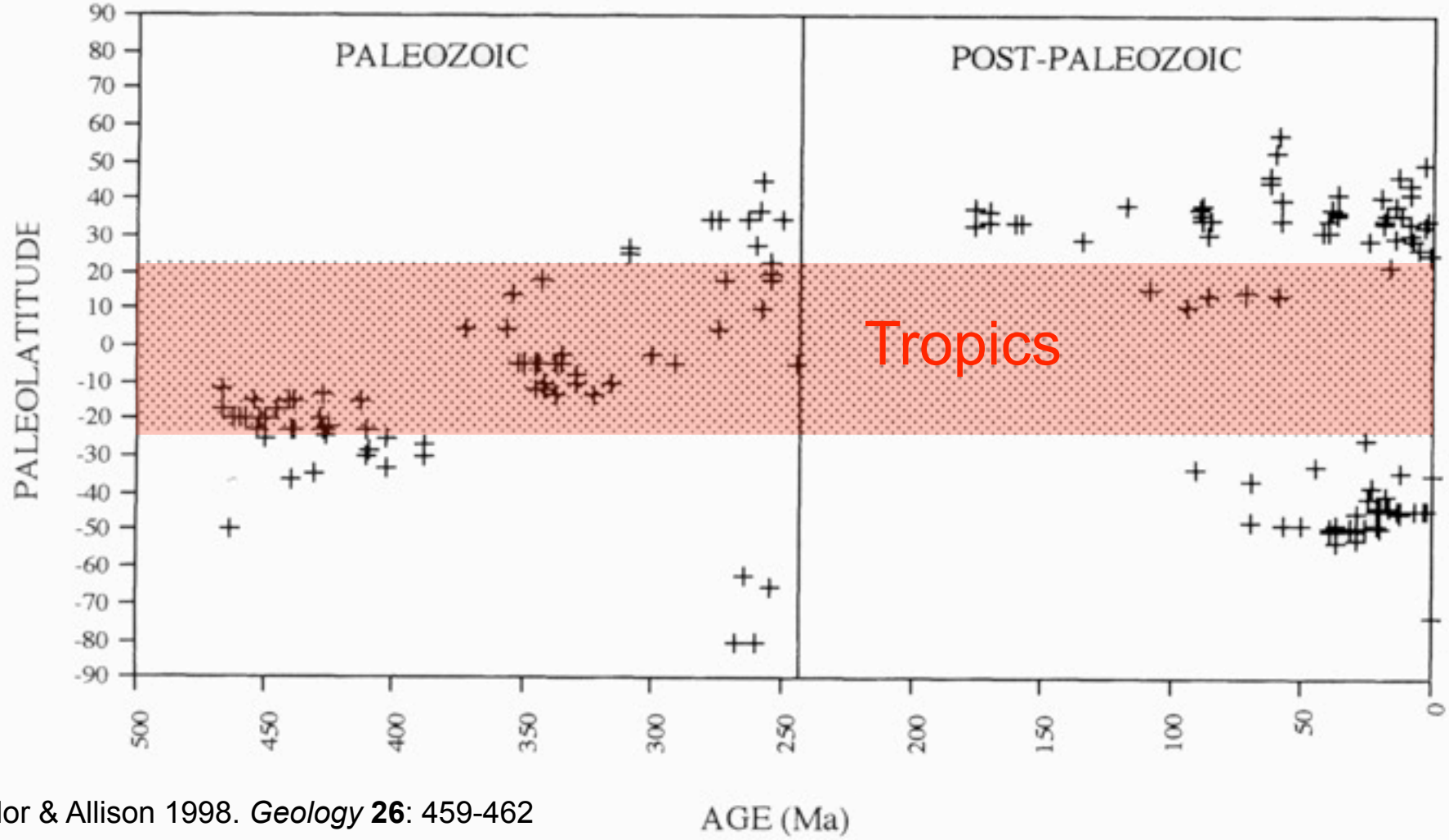
Taylor & Allison 1998. *Geology* **26**: 459-462

Palaeolatitudinal distribution of bryozoan-rich sediments



Taylor & Allison 1998. *Geology* **26**: 459-462

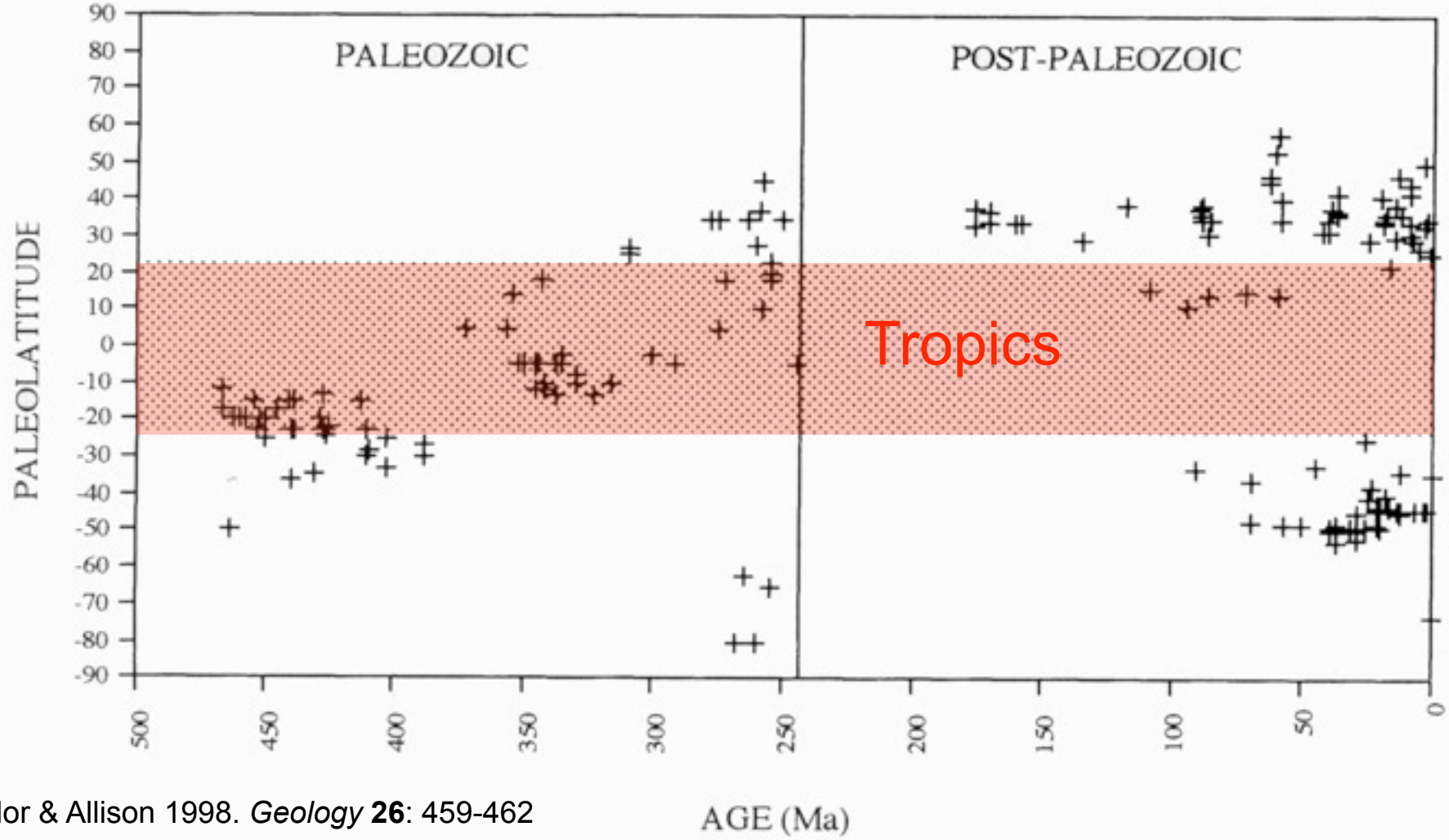
Palaeolatitudinal distribution of bryozoan-rich sediments



Taylor & Allison 1998. *Geology* **26**: 459-462

- post-Palaeozoic are nearly all non-tropical

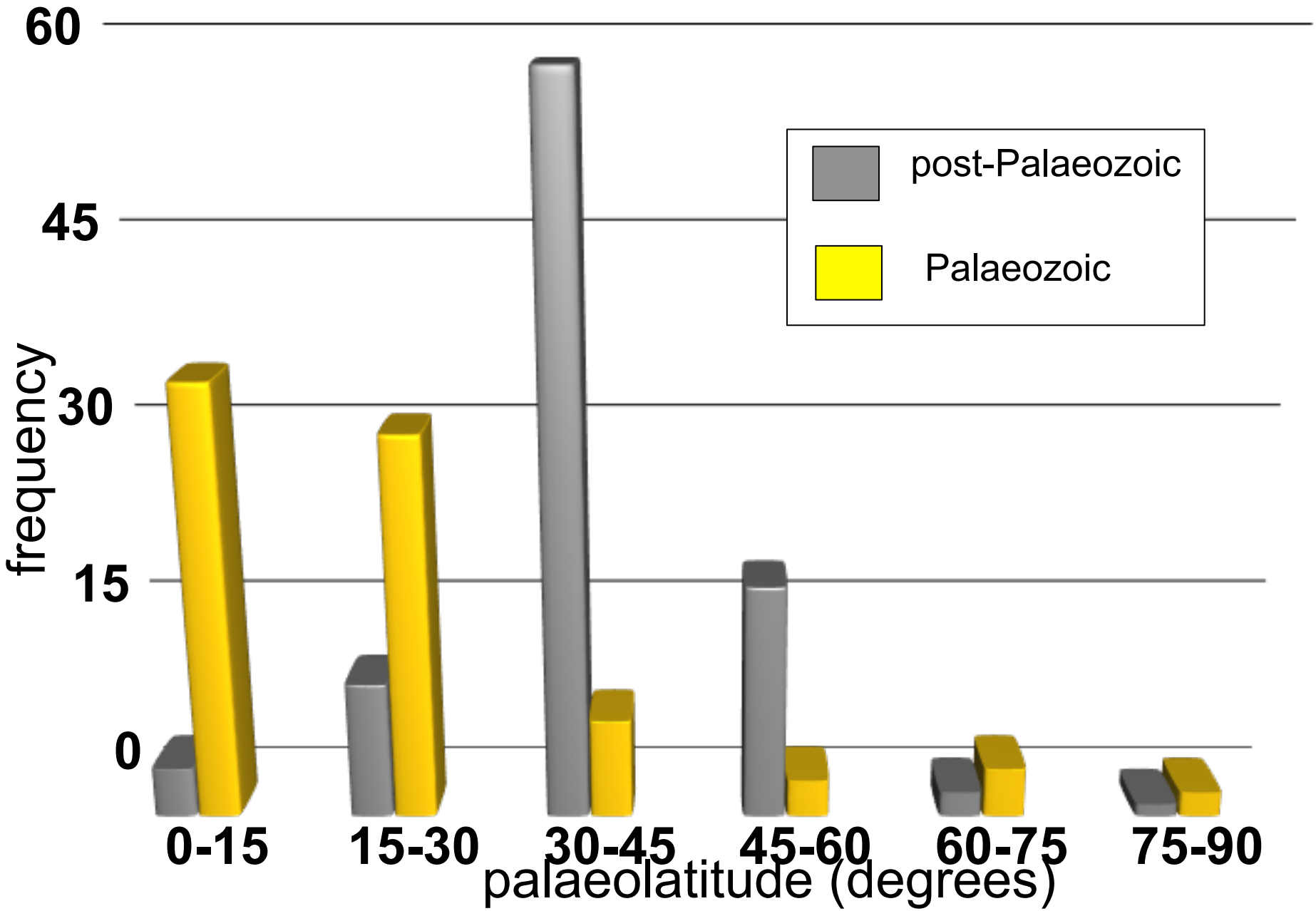
Palaeolatitudinal distribution of bryozoan-rich sediments



Taylor & Allison 1998. *Geology* **26**: 459-462

- post-Palaeozoic are nearly all non-tropical
- but Palaeozoic are pan-global

Palaeolatitudinal distribution of bryozoan-rich sediments



Palaeozoic

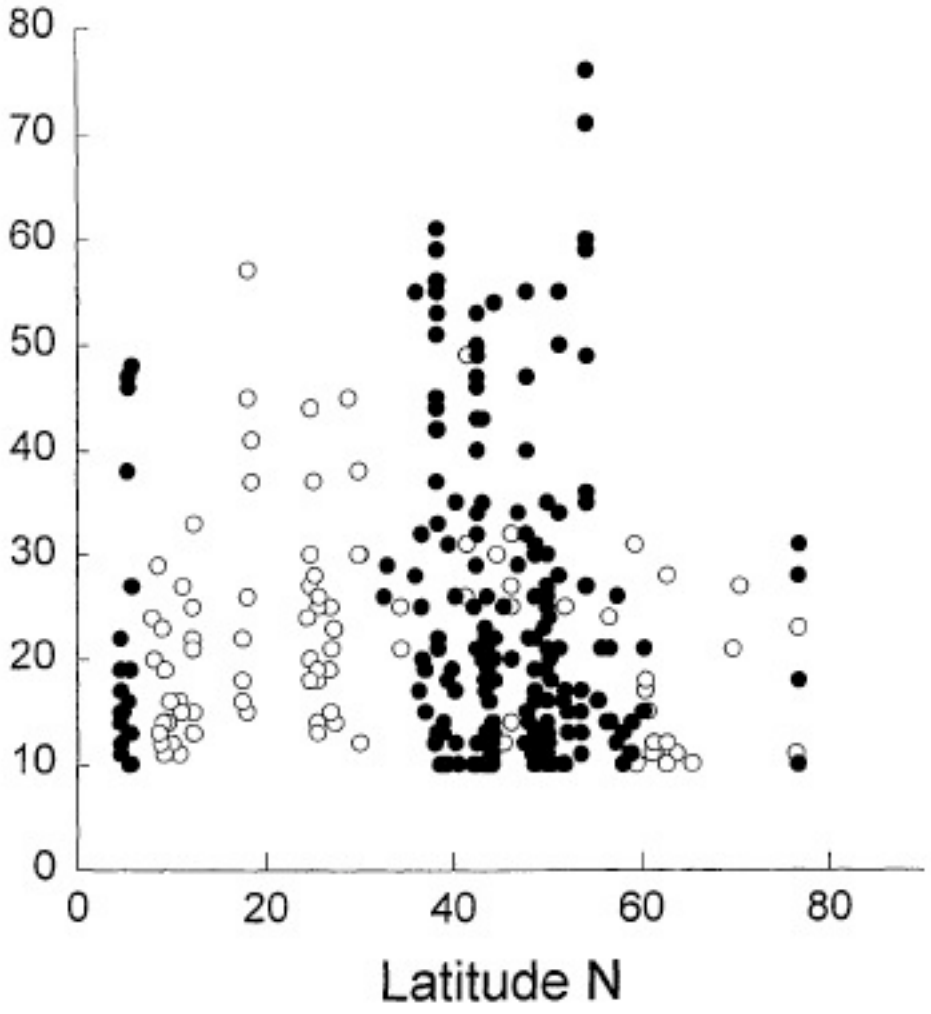
Cincinnatian Series -
Upper Ordovician, USA
Tropical carbonate

post-Palaeozoic

Coralline Crag -
Pliocene, England
Temperate carbonate

Bryozoan assemblage species richness vs latitude in the eastern (black dots) and western (white dots) North Atlantic

- no gradient of increasing species diversity into tropics (cf. many other phyla)
- bryozoans can be diverse in the tropics but have a relatively low biomass (as in Indonesian Cenozoic)



Clarke & Lidgard 2000. *Journal of Animal Ecology* **69**: 799-814

Postscript: analysis of annual growth bands as proxy for phytoplankton productivity in the Antarctic

cf. tree rings

Cellarinella
Recent
Antarctica

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- the latitudinal distribution of carbonate-producing bryozoans has changed through time