Biological Adaptations

ES 383

Colby at Bigelow, September 2019

Bigelow | Laboratory for Ocean Sciences

3 main categories of biological adaptation:

- **Physiological (=metabolism)**
- **Structural (=morphological)**
- **Behavioral**

(All 3 can be combined)

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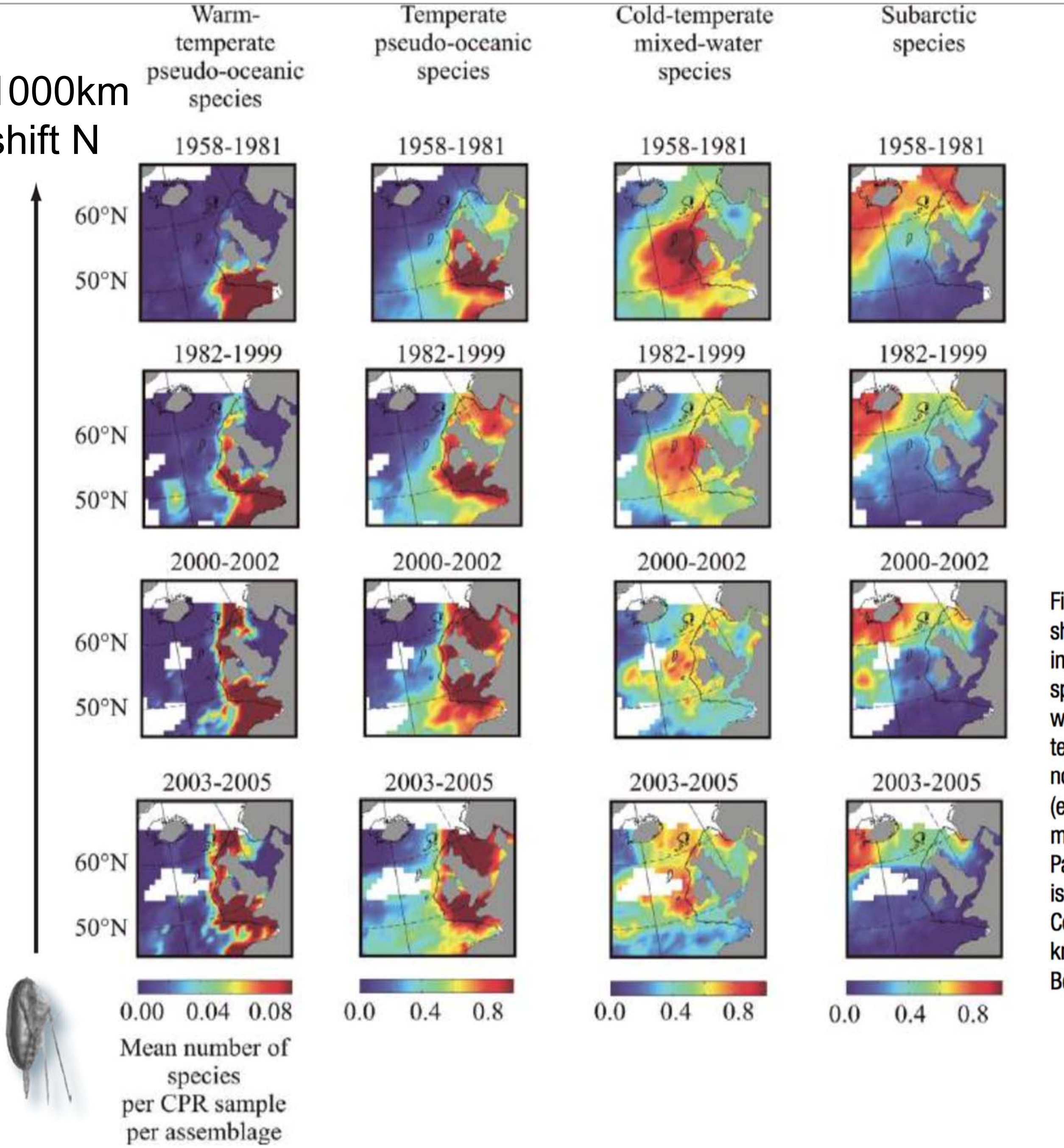
Temperature, heat capacity of SW and marine organisms

1. Metabolism and activity ↑ if T ↑ and viceversa
   – Ectothermous vs endothermous orgs.
   – Higher T better because all (bio)chemical reactions and activities are faster BUT worse as it requires more food and uses lots of O_2
2. Water T affects orgs.'s ability to cope with further environmental challenges (eg, O_2 deficiency, S change, etc.)
   - Salmon, parasites
3. Many orgs. can acclimate to slowly adjusting temperatures
   – stenothermic vs. eurythermic
4. Extreme high or low T = death, except adaptations
   – T ranges control vertical distribution, geographical extent, spawning season

1000km
shift N



The Continuous Plankton Recorder (CPR)

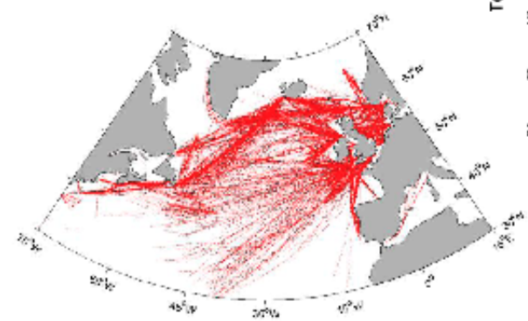


Figure 3.2.3 Biogeographical shifts: biogeographical changes in plankton assemblages spanning five decades. Warm-water plankton (e.g. warm-temperate species) are moving north and cold-water plankton (e.g subarctic species) are moving out of the North Sea. Particular rapid movement is seen along the European Continental Shelf up to 1000 km over 50 years. Based on Beaugrand *et al.* (2003).

5. Cue for reproduction (but also light, food)

6. Cold water -> orgs. live longer, mature later than similar species in warmer water

7. Water T regulates the pace of ecosystem activity, often shifting the balance between abundance of organisms

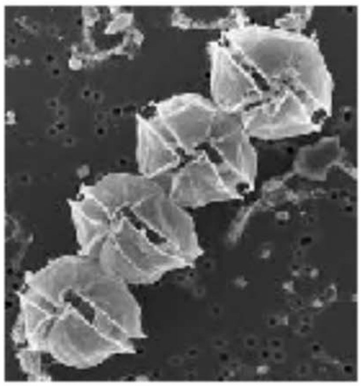
- Survival of larval stages by prolonging the planktonic stage -> ↑ predation -> ↓ adult population
- Affects feeding efficiency of certain invertebrates -> indivs. don’t survive -> replaced by others
- Affects composition of phytopk. Communities at large scales by controlling stratification of water column and, thus, nutrient and light availability in surface waters
  - Shift to N2 fixers in oligotrophic oceans

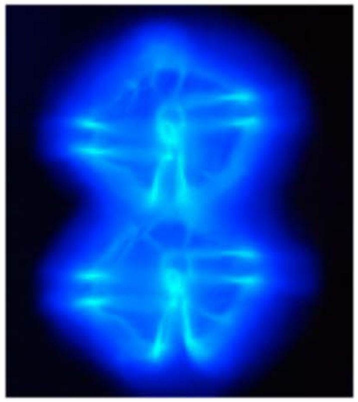
8. Some orgs. maintain a high constant body T regardless of water T and are thus independent of environmental T changes

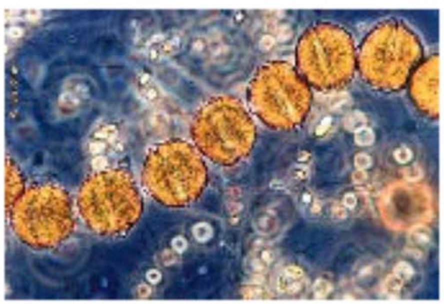
Temperature (#5)

↑Temp, ↑bloom formation window

Bloom duration vs T







Alexandrium catenella

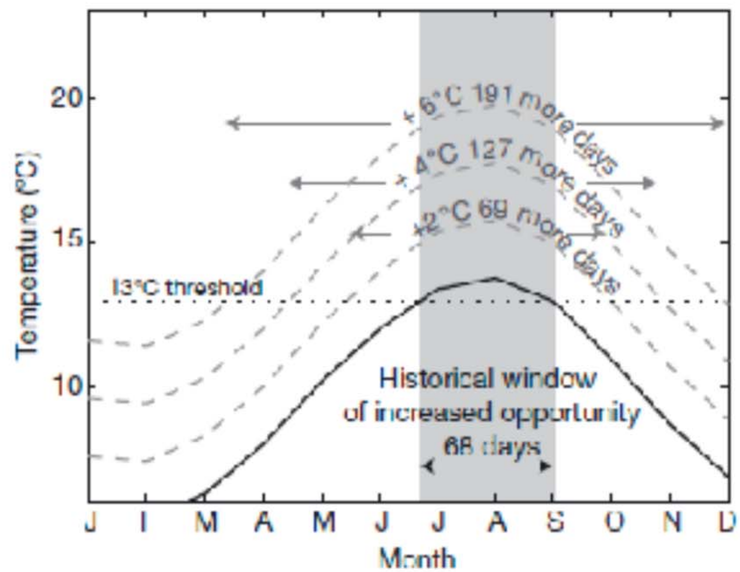


Fig. 1. *Alexandrium catenella.* Expansion of the annual temporal window for blooms of the saxitoxin producing dinoflagellate in Puget Sound, Washington, USA, at projected sea surface warming levels of +2, +4, and +6°C. The species is limited to blooming at temperatures over 13°C; with a 6°C average increase, the annual bloom window could expand from the historical value of 68 d to as long as 259 d (from Moore et al. 2008)

Fu et al 2012

http://www.hitredtide.org/images/images_photo_large/Photo_18b_Alexandrium_catenella.jpg

Also Arctic spring bloom

Salinity and marine organisms

- Osmosis vs. diffusion!
  - Sea cucumber + FW -> swells, dies
  - \+ hi $S^o/_{oo}$ SW -> shrivels, dies
- Most marine algae, invertebrates, sharks: $S^o/_{oo}$ internal fluids ~ surrounding SW (but not by same compounds) = isotonic
  - Open ocean; deep ocean: little $S^o/_{oo}$change
  - Euryhaline (coastal) vs. stenohaline (open ocean)
- Fishes, mammals, birds & reptiles: blood fresher than SW -> loss of water so they drink SW to retain water = hypotonic
  - Osmoregulators vs. osmoconformers

Salinity (cont.)

- Nutrients -> growth-controlling physiological processes
- Gas content:
  - respiration, photosynthesis;
  - buoyancy (bubbles, swim bladders)
  - Circulatory system (O_2, Fe, Cu)
  - Adaption to H_2S (sediments, vents)
  - but also toxic (H_2S, CH_4) to others!
- Organic compounds -> vitamins, bacterial/ archeal respiration & growth

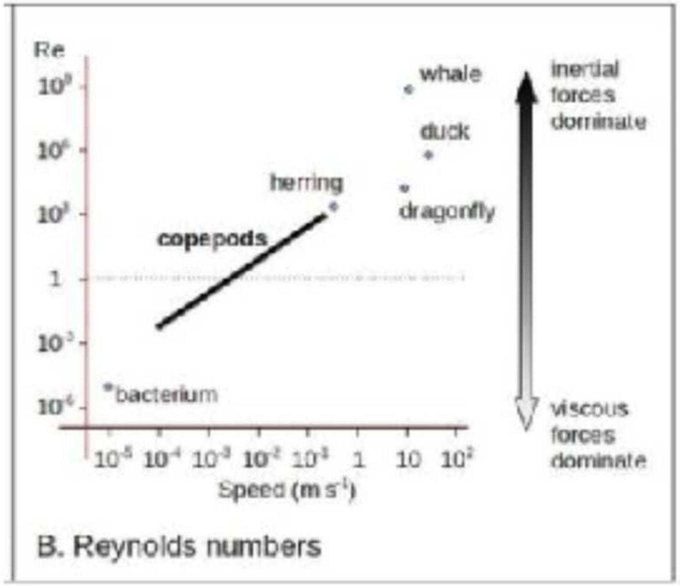
Density, viscosity & specific gravity

Water is denser than air so organisms don't need the same supporting structures **BUT** water is more viscous than air

- Flattened or bristly shapes to retard sinking = plankton
- By maintaining light-weight fluids (Cl^- & NH_4^+ instead of SO_4^{2-}; same $S^o/_{oo}$ but lower density) = sharks
- Oil- and gas-filled swim bladders; other gas-filled spaces
- Water viscosity sets "speed limit" for small organisms (large animals limited by turbulent drag); but viscosity also prevents their sinking

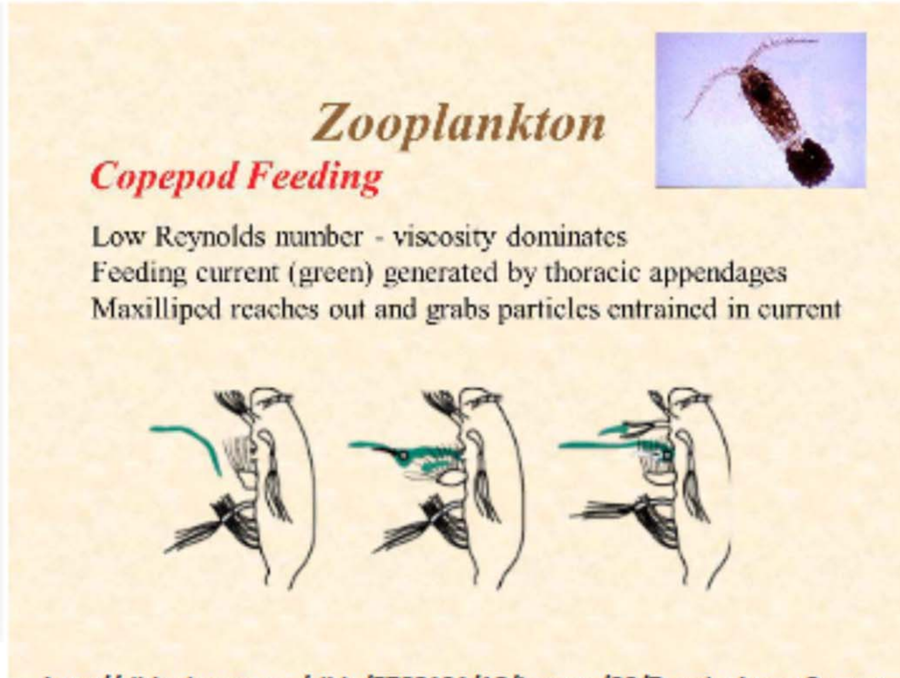
$$Re = \frac{\text{inertial forces (density, veloc., size)}}{\text{viscous forces (viscosity)}}$$

Reynolds Numbers



B. Reynolds numbers

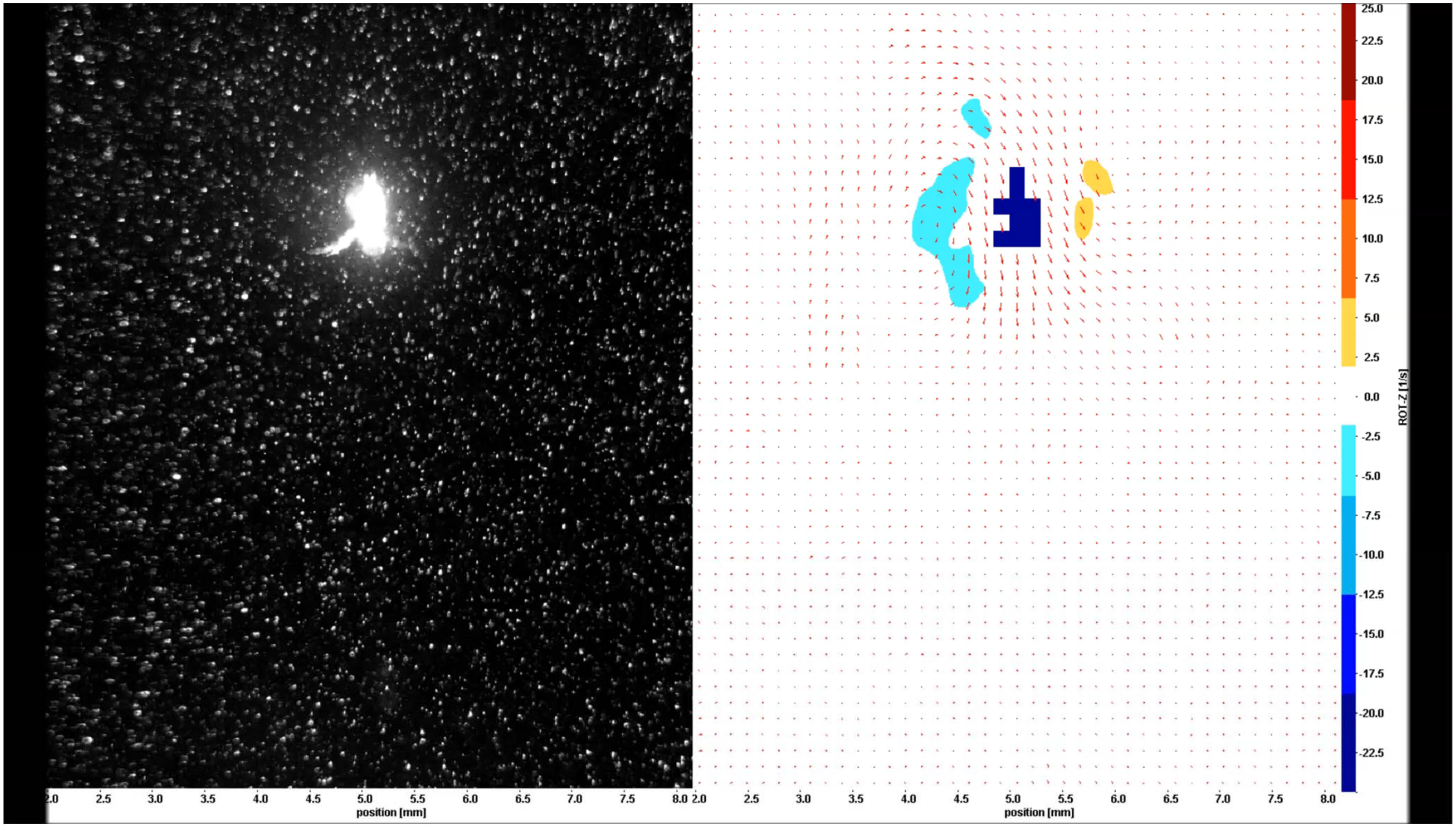
Concept from [Tidelman (2002)] adapted by Willis (2013)



http://slideplayer.com/slide/5700121/18/images/22/Zooplankton+Copepod+Feeding+Low+Reynolds+number+-+viscosity+dominates.jpg

Animal & Velocity	RE
Whale @ 1 m/s	300,000,000
Tuna @ 10 m s-1	30,000,000
Copepod @ 20 cm s-1	30,000
Sea Urchin sperm @ 0.2 mm s-1	0.03
Bacterium @ 0.01 mm s-1	0.00001

From Vogel 1981, adapted by Levinton 2001



Kiørboe et al. 2014 PNAS,
https://www.pnas.org/content/suppl/2014/07/25/1405260111.DCSupplemental
http://www.tkboe.aqua.dtu.dk/Research-areas/Observing-zooplankton-with-high-speed-video
https://www.youtube.com/watch?v=cSaKK9S5kBw

Pressure

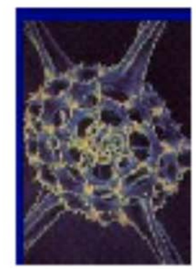
- Doesn't exclude life from deep ocean, but may limit vertical ranges of motile forms
- Affects gas-filled organs and pressure-sensitive enzymes (their rate and structure)
  - Deep-living orgs. are resistant to pressure changes while shallower-living ones are not
    - Shallow: use gas for buoyancy control; streamline shape
    - Deep: use oil & fats for buoyancy conytol
  - Or stay at one depth
  - Some can migrate daily >400m (= 40 atms)

Buoyancy

Important for energy expenditure: swimming vs floating

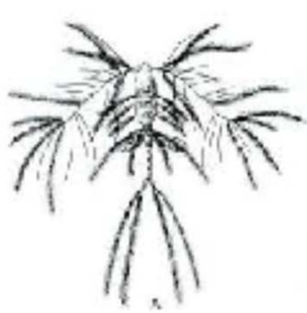
Some organisms are neutrally buoyant, others have adaptations:

- Gas chambers: Chamber nautilis, Portuguese Man of War
- Swim Bladders: Fish
- Oil droplets: Copepods, Diatoms
- Ion exchange: Deep-sea shrimp, ctenophores, salps
- Spines, ruffles, feathery appenditures: Radiolarians, Copepods
- Denser tissues: some large mammals, sharks, must swim
- Lighter tissues: mammal blubber



Temp↓, viscosity ↑: so smaller organisms float better in colder waters, have less adaptations

Tropical copepod



Polar copepod

Light

- Photosynthesis (phytopk)
- Escape predation (vertical migration zoopk, fish countershading)
- Predation (vertical migration; escape or prey)
- Reproduction (from phytopk to corals to all)
- Camouflaging/ countershading (fish)
- Bioluminescence (phytopk, zoopk, fish)

Water motion (mainly plankton)

- Behavioral: flagella (dinoflagellates,microzoopk)
- Physiological: ion exchange, oil droplets
- Structural:
  - silicification
    - Diatoms: pelagic vs. benthic, summer vs. winter, tropics vs. poles
  - Spines
  - Size: surface area/volume ratio (+ floatation, + nutrients)

↓

New challenge: ocean acidification (and multiple stressors)

Since Industrial Revolution (1880s) to now, the pH of surface ocean waters has fallen by **0.1 pH units**. Since the pH scale, like the Richter scale, is logarithmic, **this change represents approximately a 30 percent increase in acidity**.

- **2100**: estimate to drop **by 0.3-0.4 pH units**
- **2300**: estimate to **drop by 0.77 units**

New challenge: ocean acidification

1. ↓pH & Behavior: Fish sound detection ↓, settlement ↓, predation ↑? (Castro et al. 2017)

2. ↓ pH & Morphology: negative impacts on calcification
   - Shell formation, thickness and shape: conch, urchin, pteropods, coccolithophores
   - Survival: pteropods

3. ↓ pH & Metabolism: Growth
   - Fish larval stages (Moran & Stettrup 2010): weight, growth rate and condition factors were reduced as [CO_2] ↑
     BUT size variance and mortality did not change = adaptation potential?

4. ↓ pH & [O_2] & nutrients and ↑T & UV & nutrients (Gao et al. 2019): phytopk regional and species physiological variations; sometimes +, sometimes -
And many more…