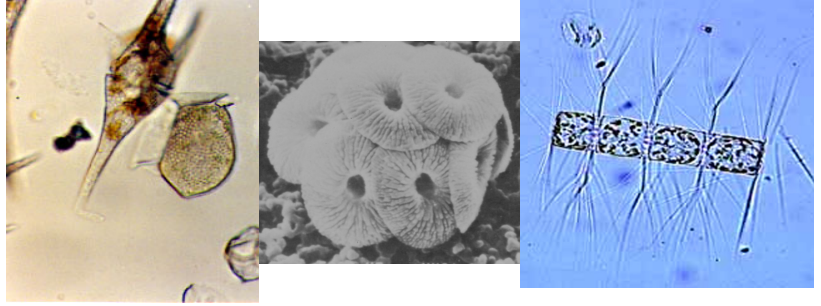
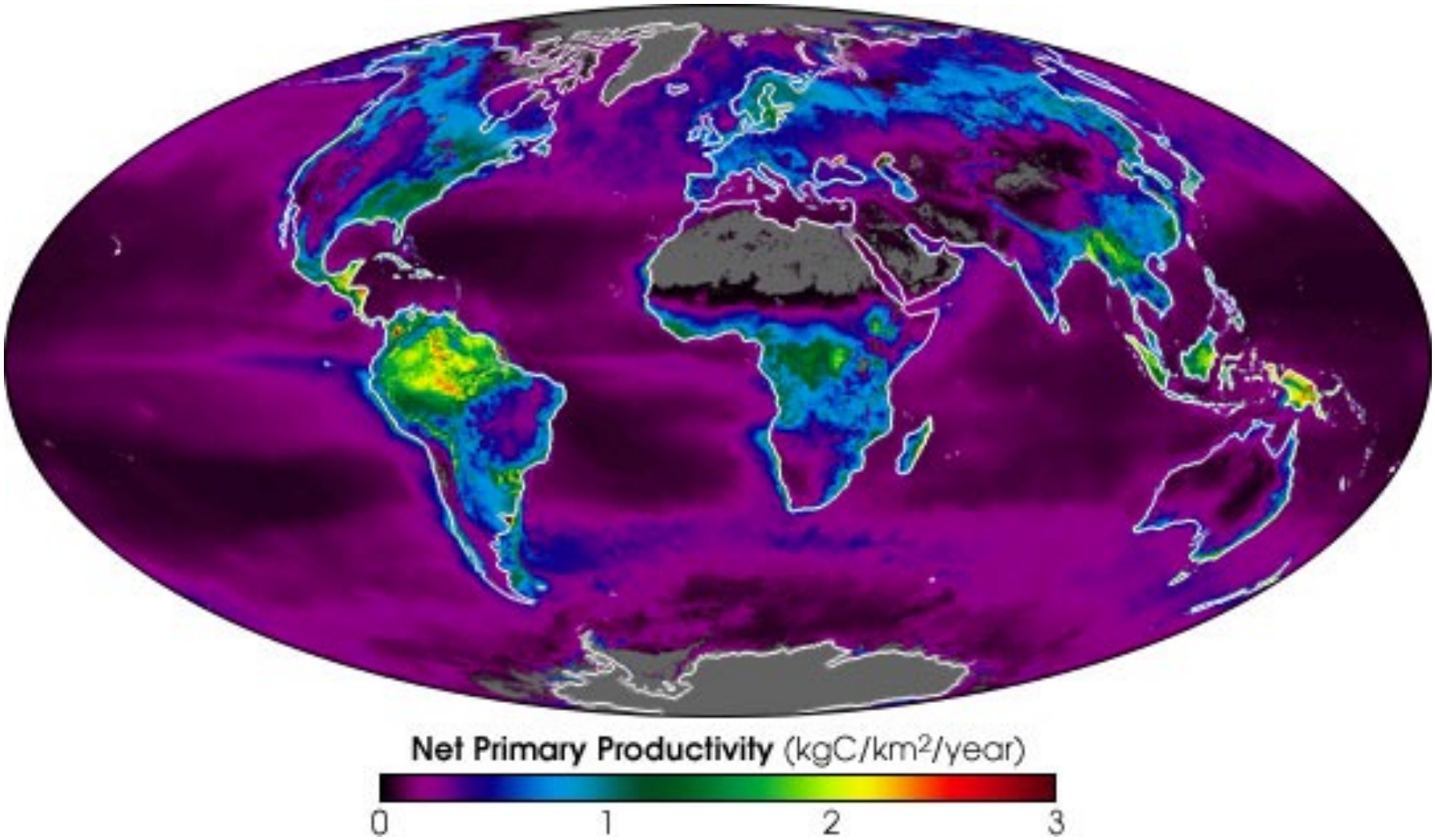
Opening Thought Question – 2/20

- Why do phytoplankton blooms in Antarctica occur in the Austral Summer?
- Think of one hypothesis that addresses this question.

Pelagic (open ocean) ecology:

It all starts with primary producers





Water-column processes and primary production in the sea

1. The importance of irradiance & photosynthesis

2. How does water column mixing and nutrient availability drive phytoplankton biomass?

3. What are the causes of plankton “blooms” ?

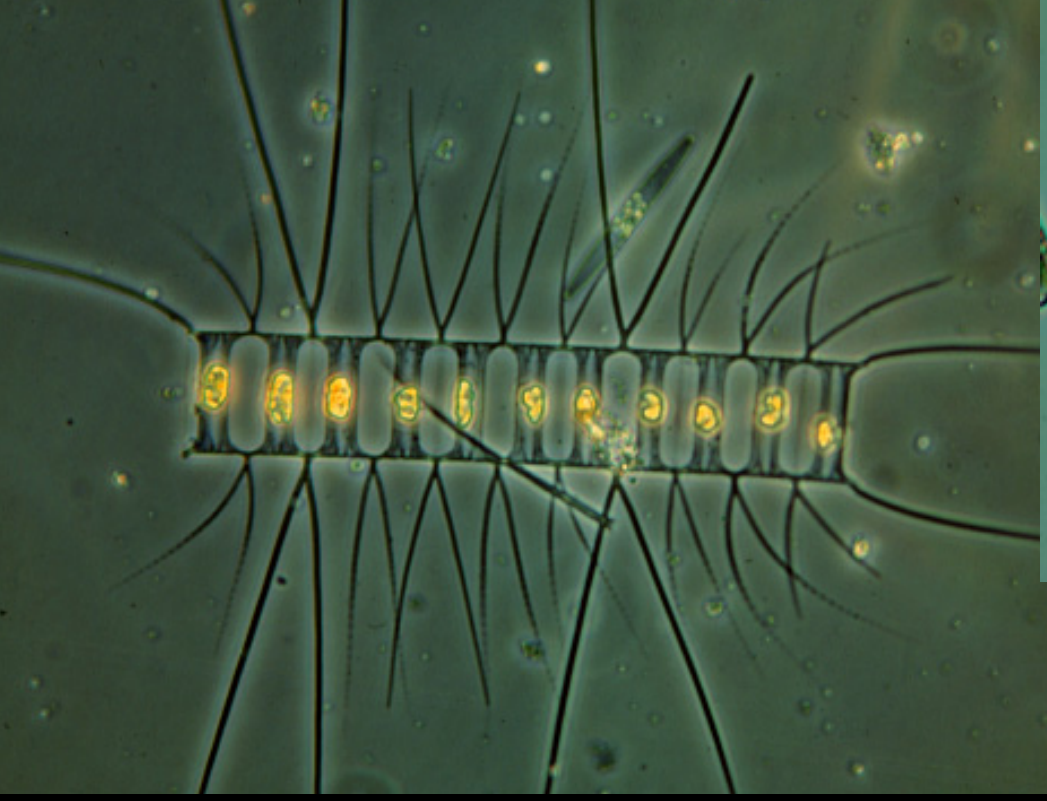
Classification of systems based on “productivity”

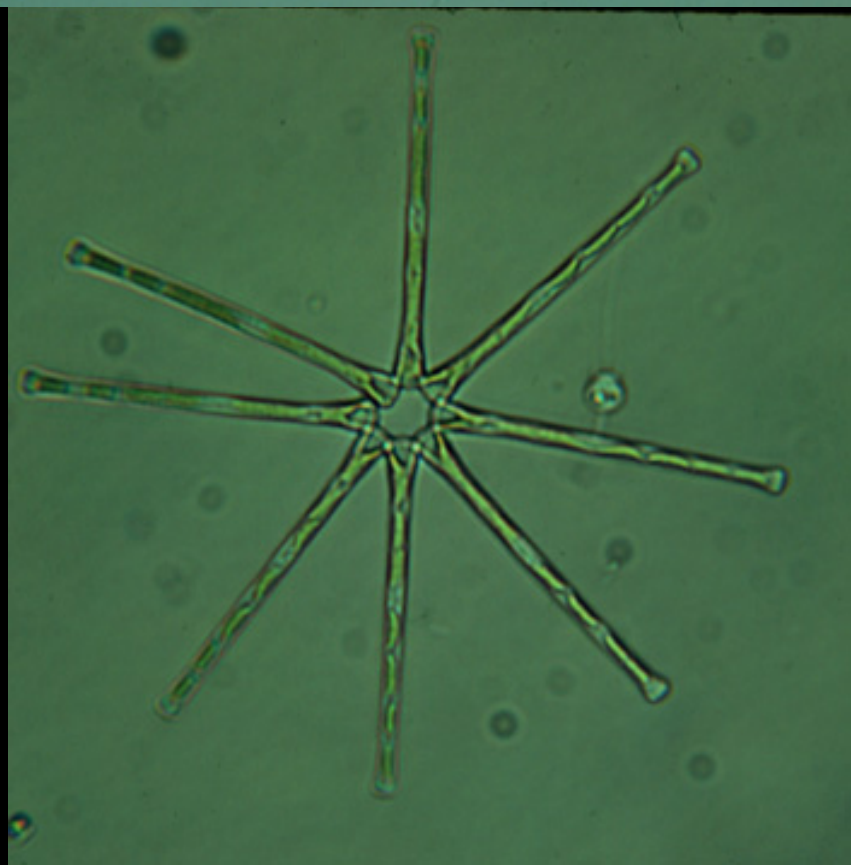
Eutrophic systems:

nutrients only limiting following seasonal periods of high productivity. Productivity driven by replenishment of nutrients when mixed layer breaks down(coastal, temperate, subpolar)

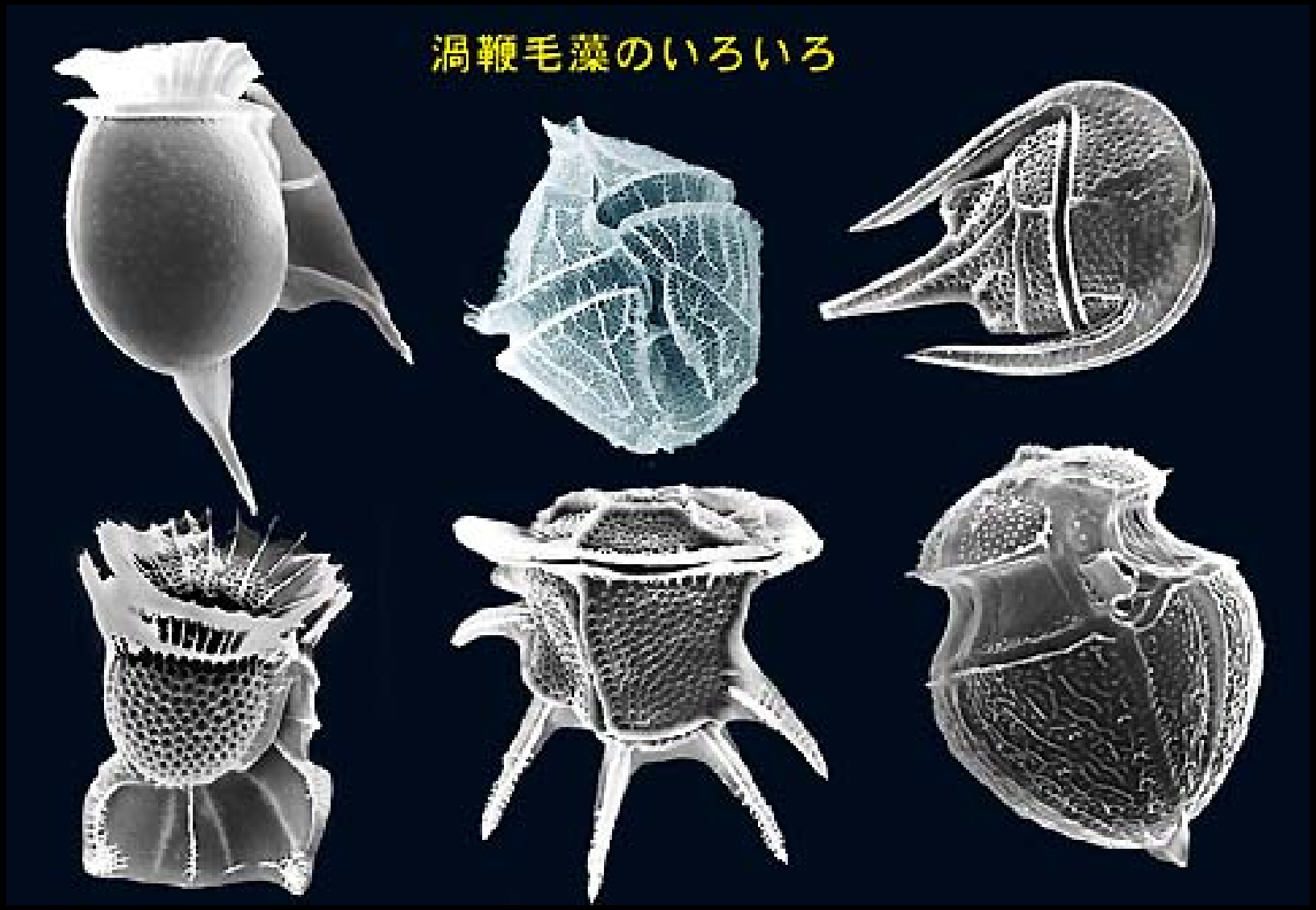
Oligotrophic systems:

nutrient limitation in euphotic zone leads to low productivity. Productivity driven by regeneration of nutrients from grazer and predator waste products
(tropical)

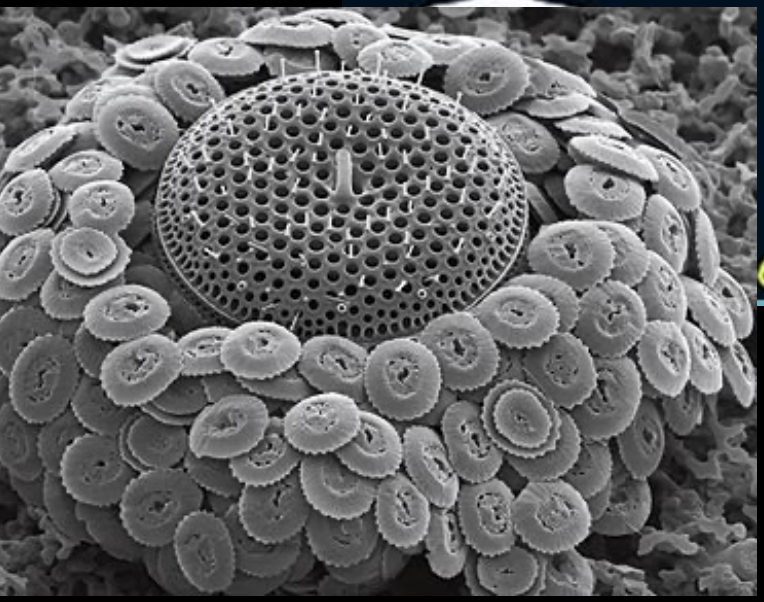


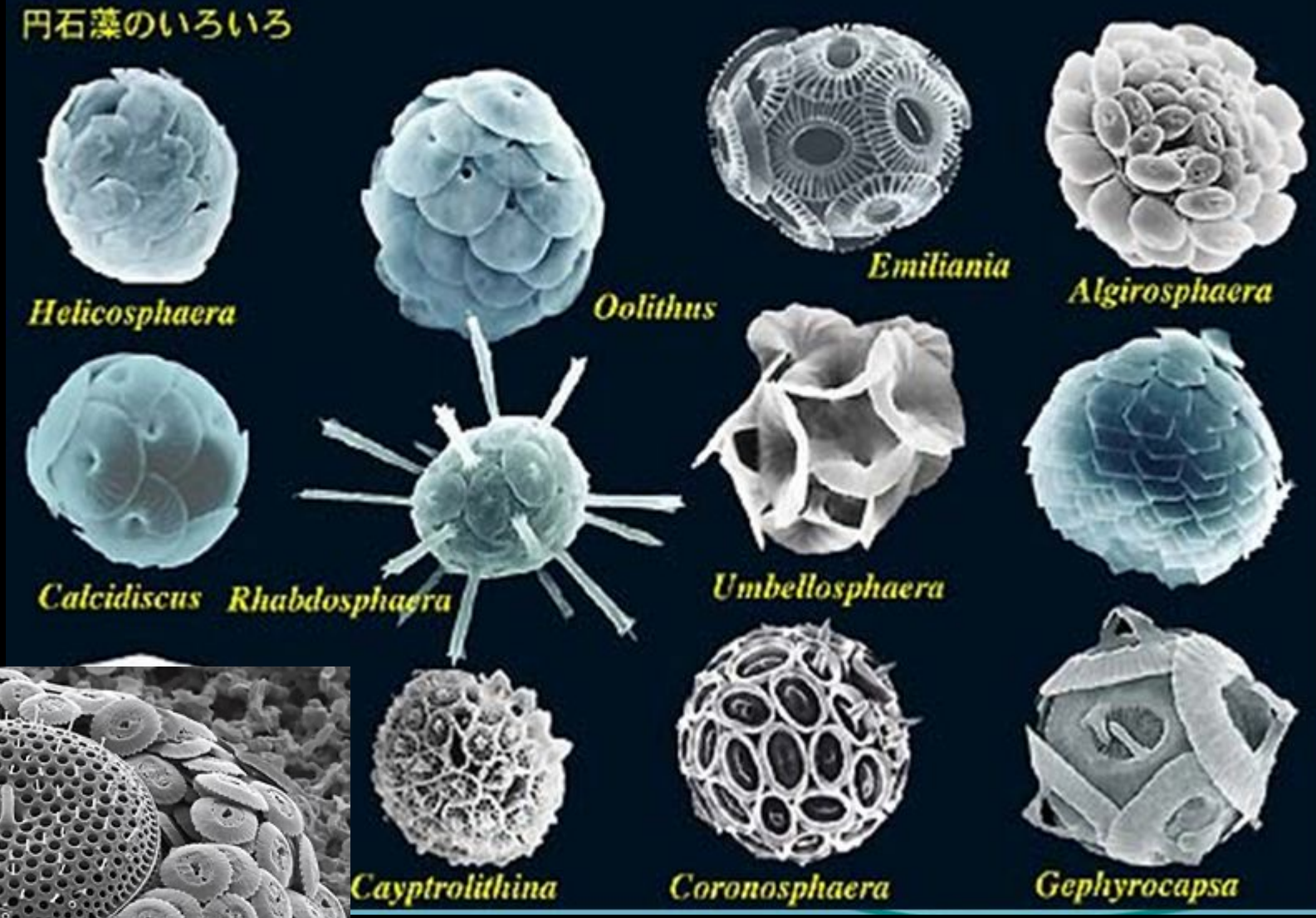


Diatoms



Dinoflagellates



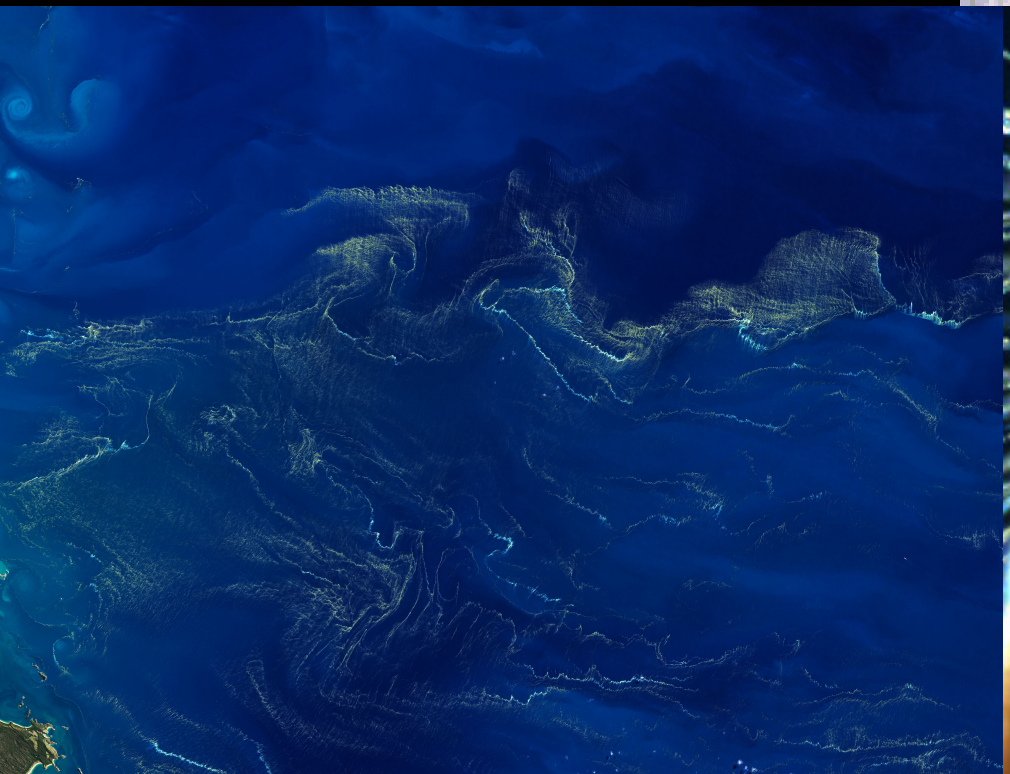


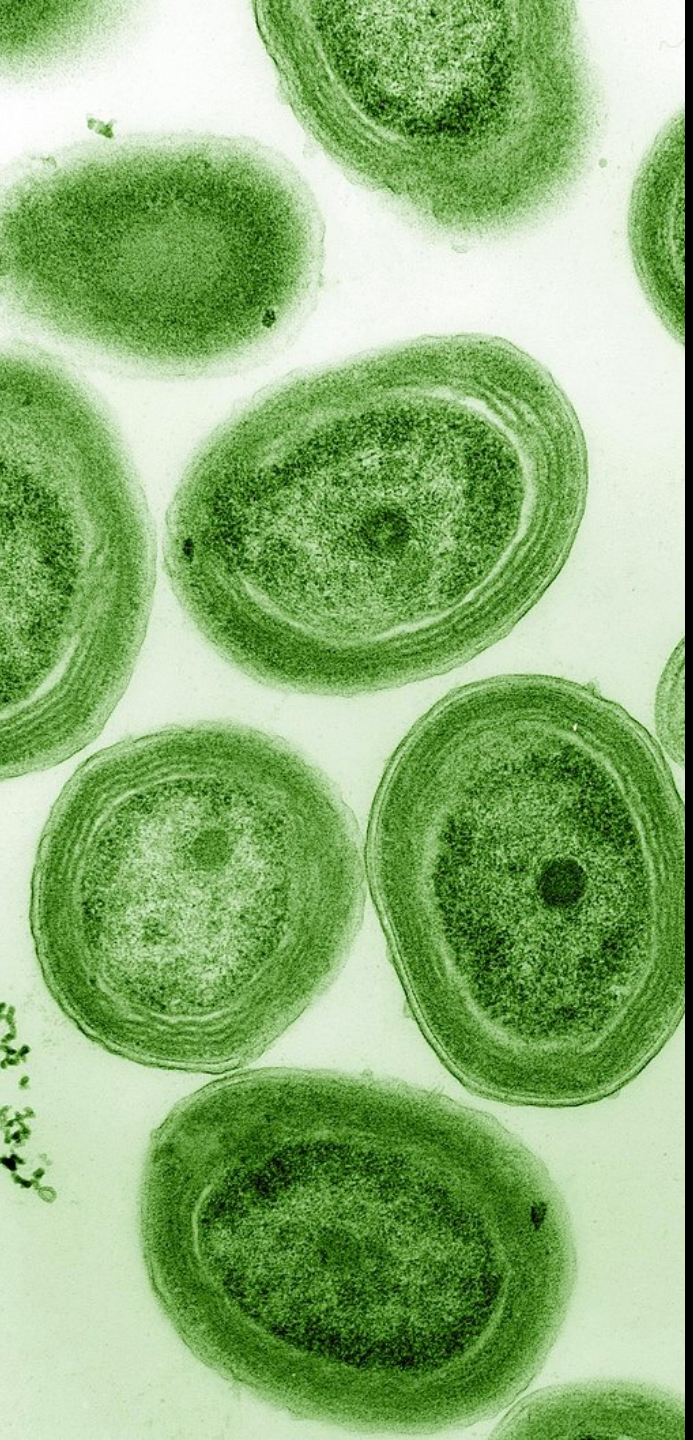
Coccolithophorids

-late summer, nutrient poor waters

-used in paleotemperature reconstruction

Cyanobacteria (blue green algae)





Other photosynthetic bacteria

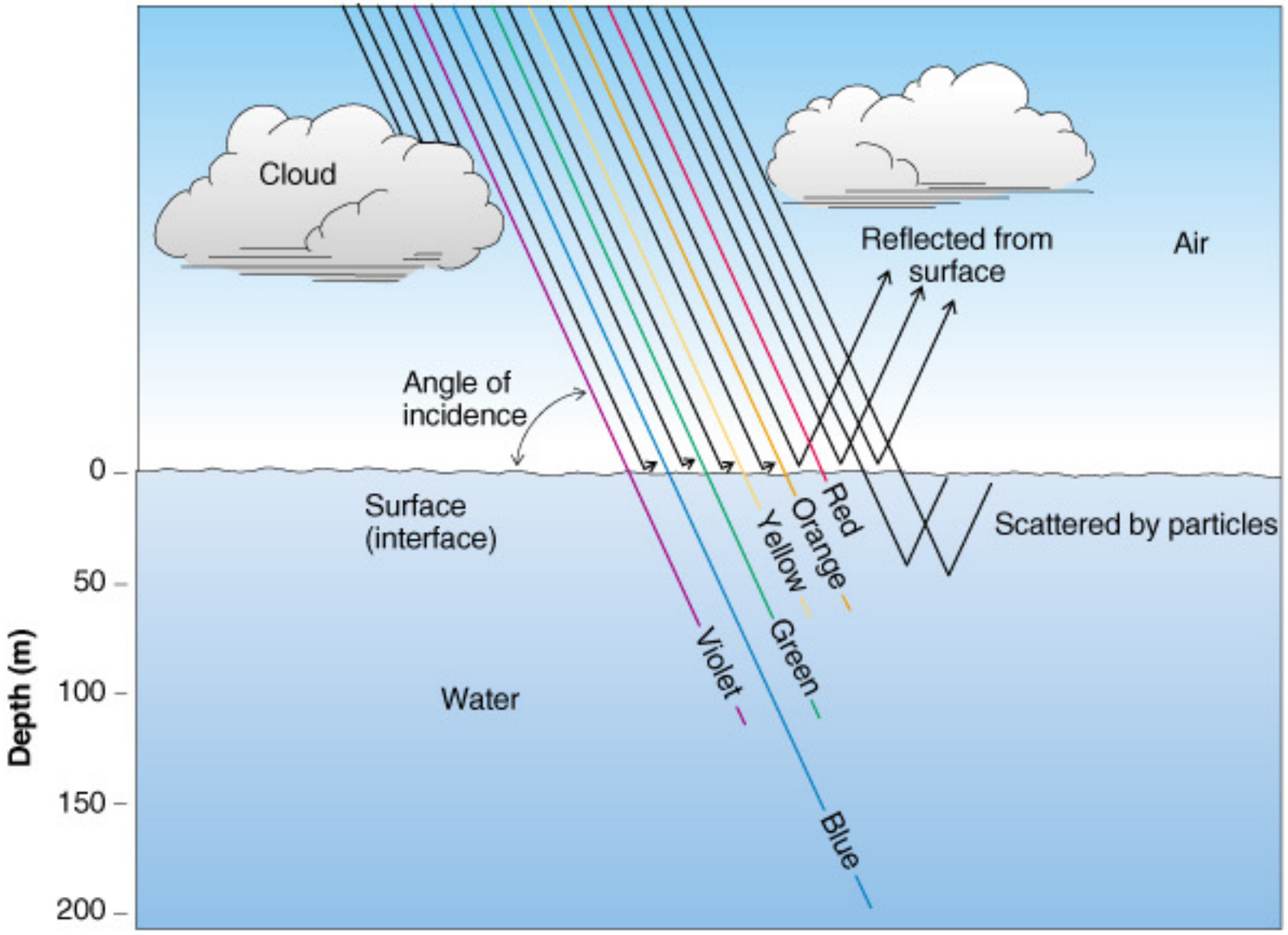
Prochlorococcus: smallest known phototroph

- contributes 30-80% of primary production in the world's oligotrophic (nutrient poor) oceans

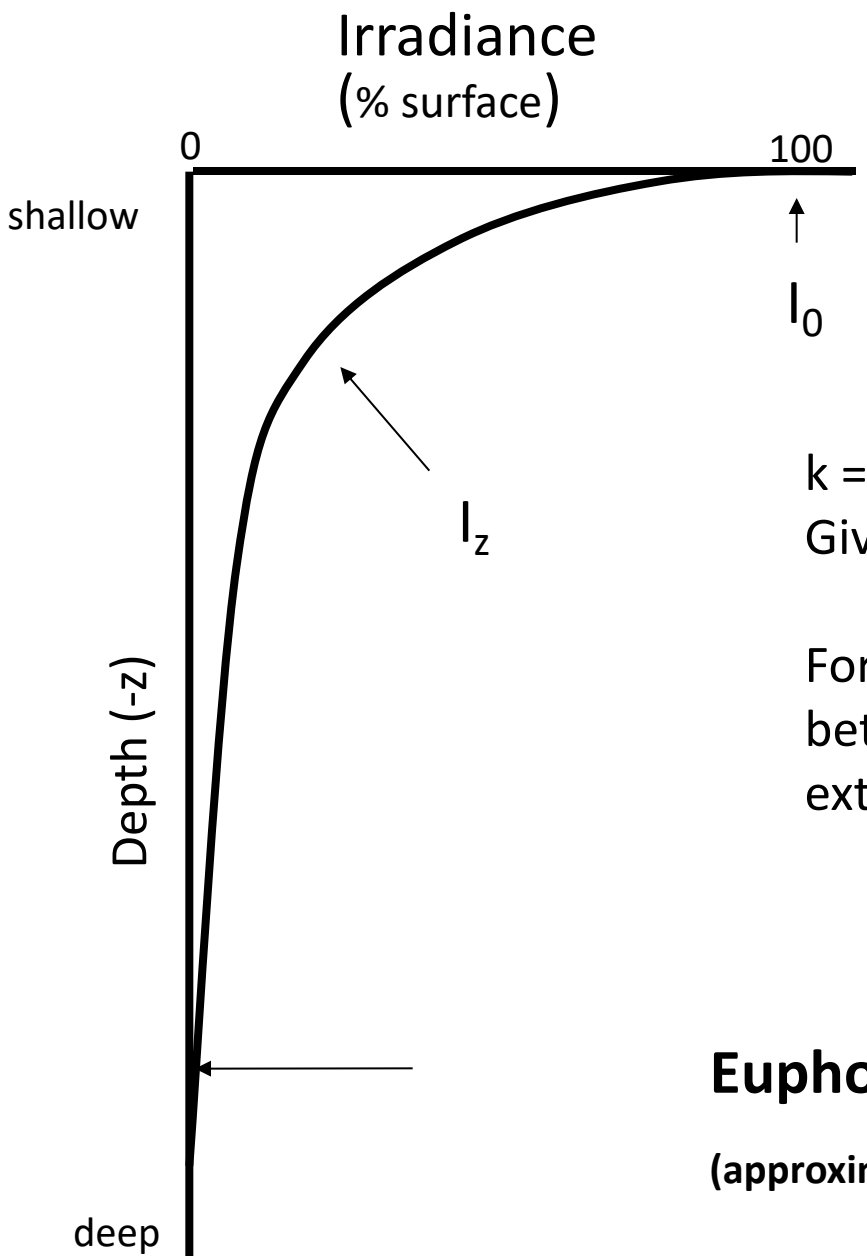
Genomic analysis reveals two different strains:

- Low light strain: 80-200m deep
- High light strain: nearer to surface

Light quality and quantity change with depth



Light extinction as a function of depth



Beer/Lambert law: $I_z = I_0 e^{-kz}$

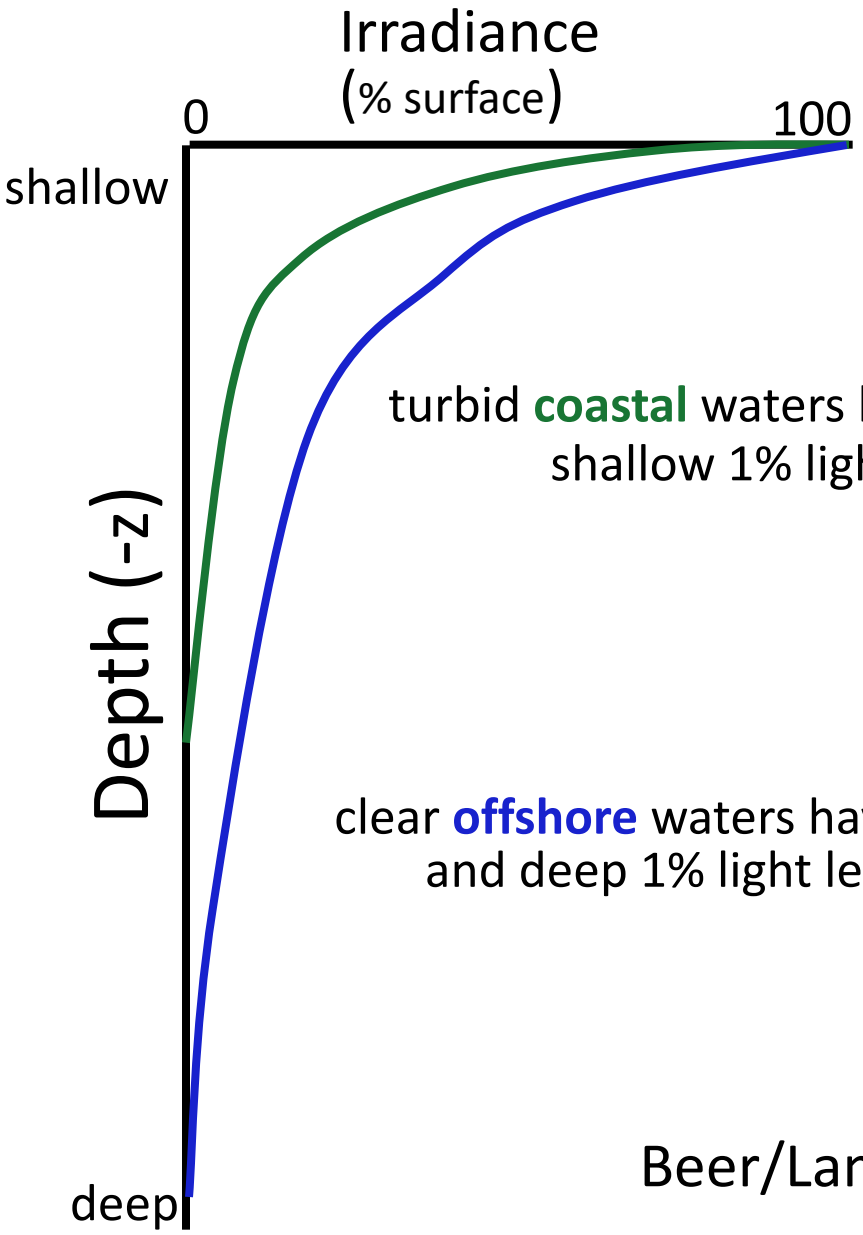
k = extinction coefficient
Given I_z and I_0 you can calculate 'k'

For a given z (depth), the greater the difference between I_z and I_0, the greater the k (high light extinction = high 'k')

Euphotic zone: where $I_z = 0.01 \times I_0$

(approximately…. Can be 0.001 in some tropical waters)

Variation in extinction coefficients with "particulate" load



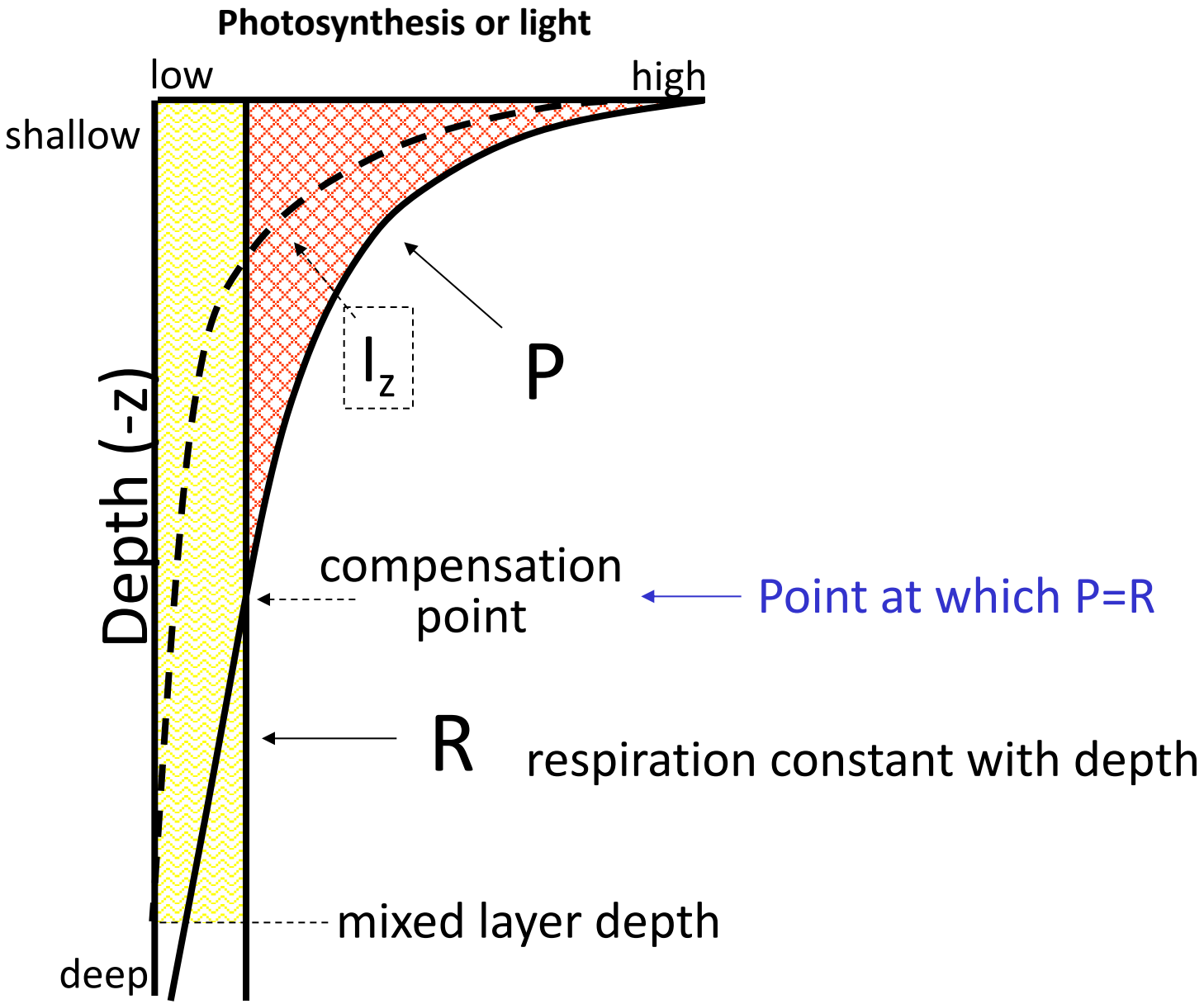
turbid **coastal** waters have high k and shallow 1% light levels

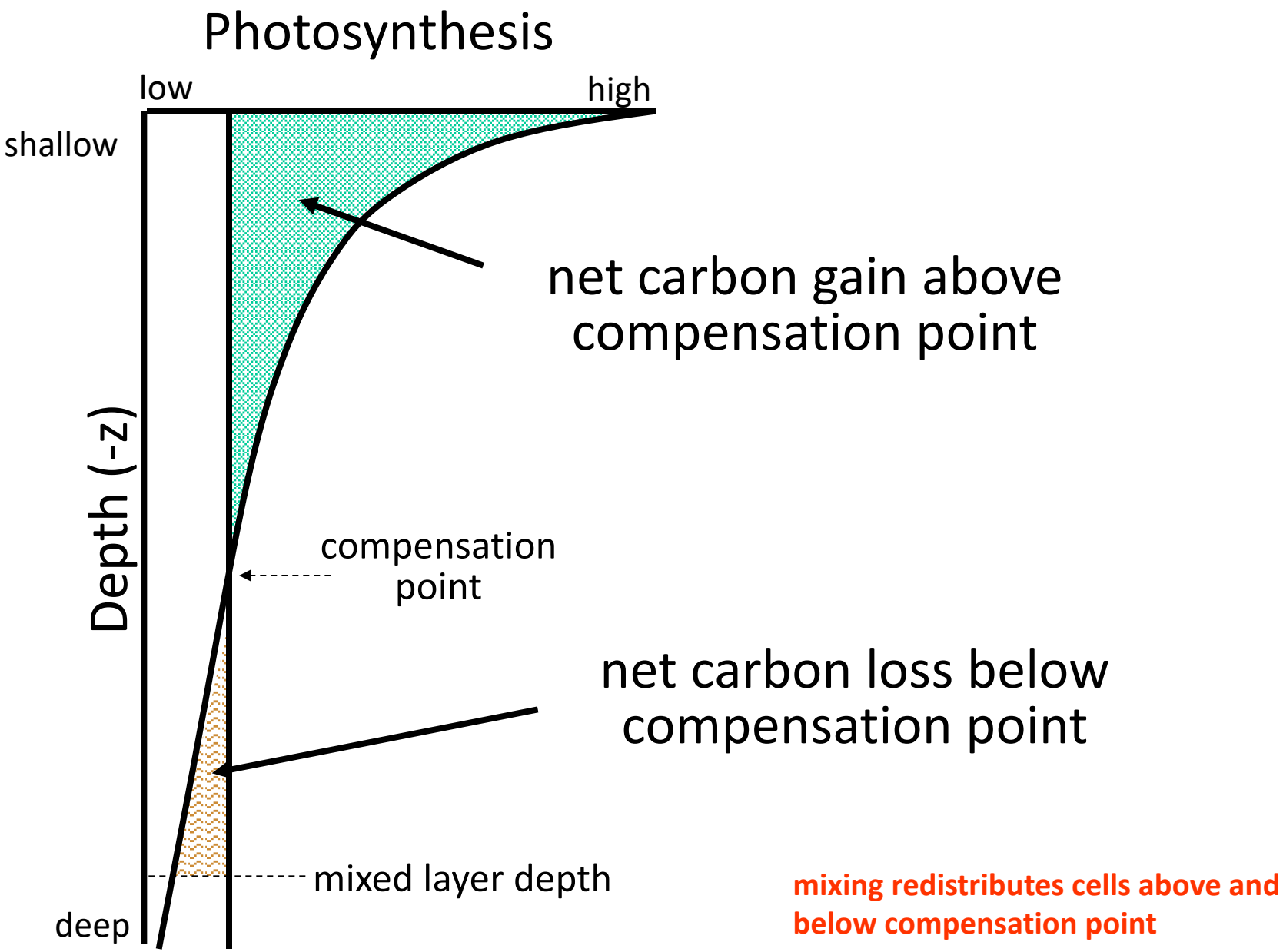
clear **offshore** waters have low k and deep 1% light levels

water body		k
Oceanic		
	Sargasso Sea	0.03
	Gulf Stream (Bahamas)	0.08
	Hawaii	0.03
	Eastern North Pacific	0.11
Coastal		
	Gulf of California	0.17
	Chesapeake Bay	2.1
	San Francisco Bay (outer)	1.0
	San Francisco Bay (inner)	10.0

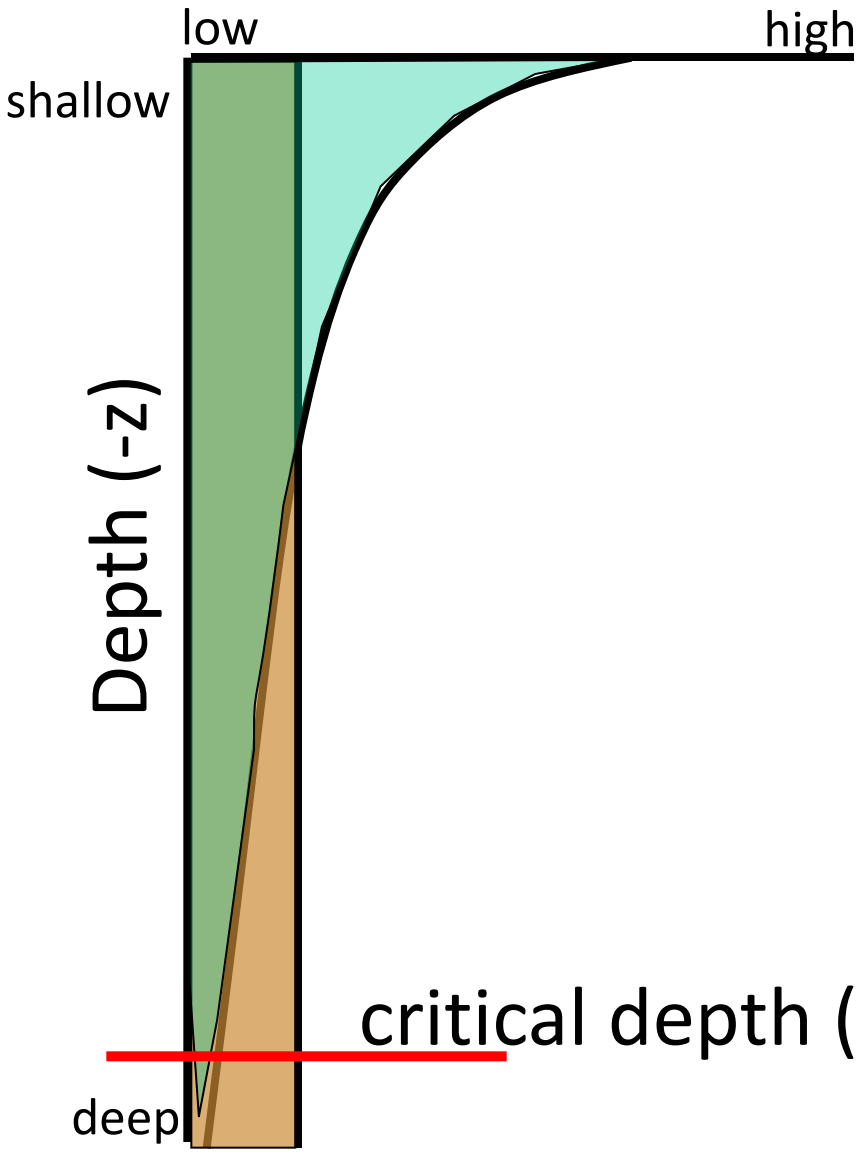
Beer/Lambert law: $I_z = I_0 e^{-kz}$

photosynthesis tracks light levels




Photosynthesis
low
high
shallow
Depth (-z)
net carbon gain above compensation point
compensation point
net carbon loss below compensation point
mixed layer depth
deep
mixing redistributes cells above and below compensation point

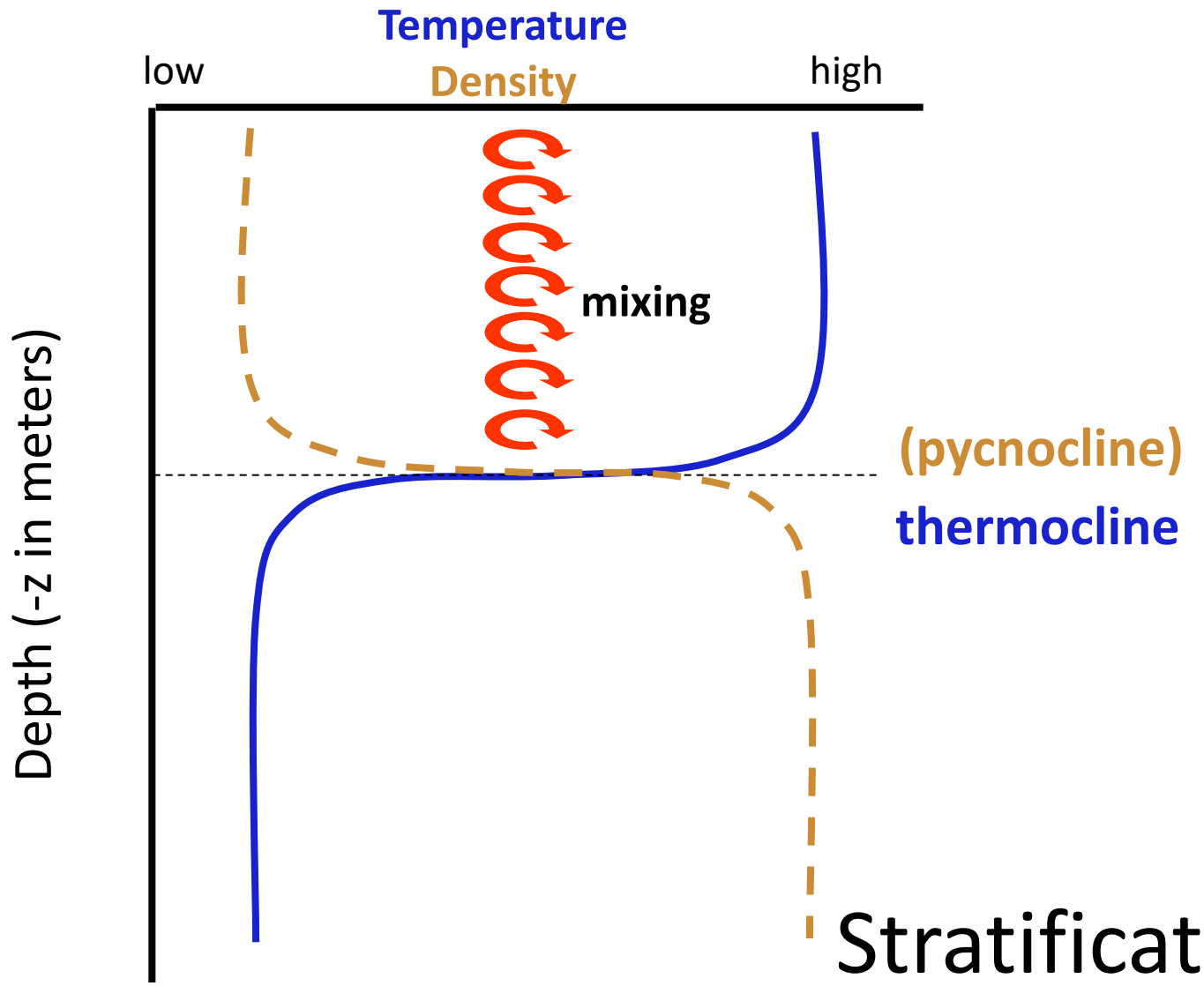
Photosynthesis



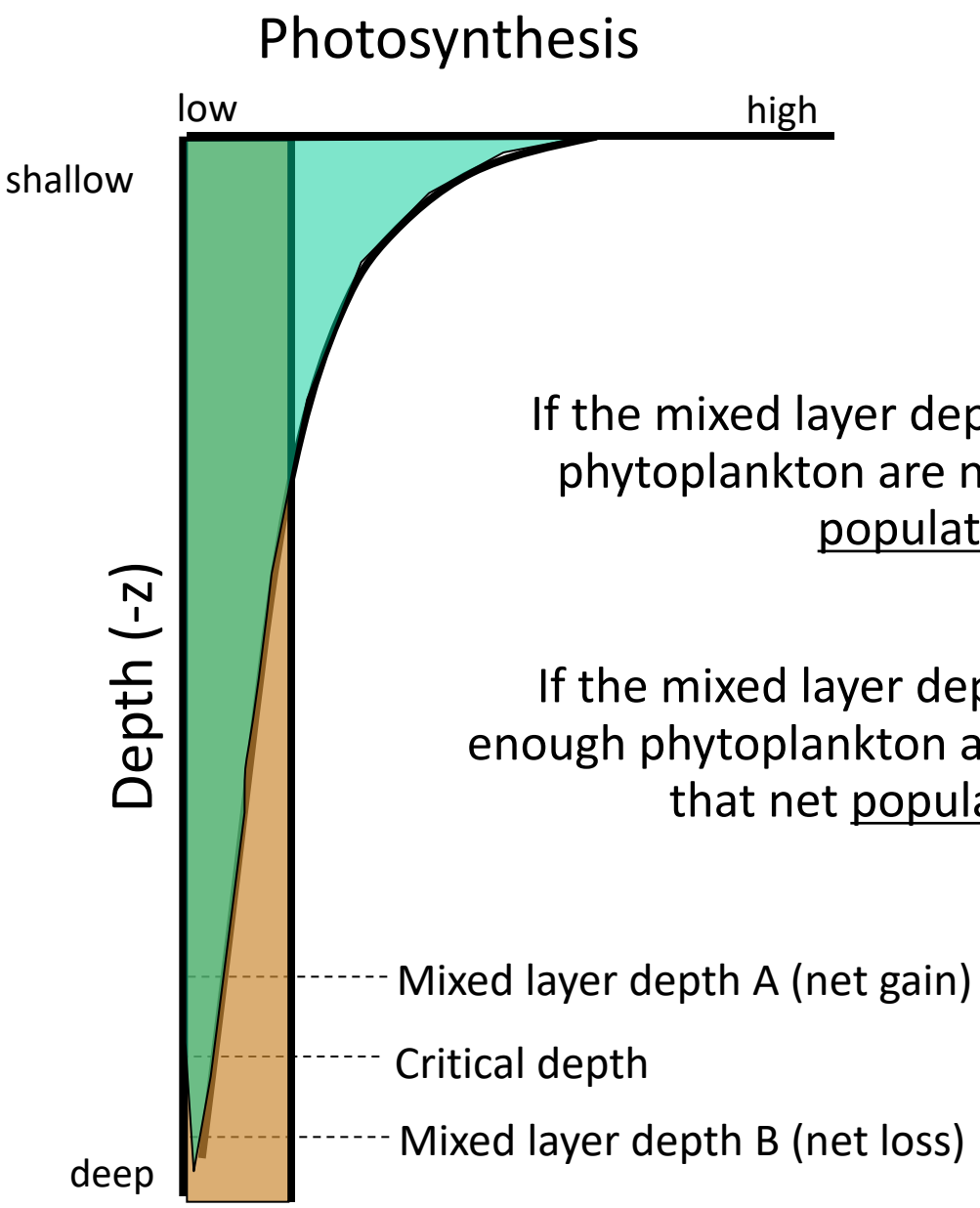
(area of green = area of brown)

critical depth (z) = $\int_{z}^{0} P - \int_{z}^{0} R = 0$

Mixed layer depth
(density barrier to mixing)



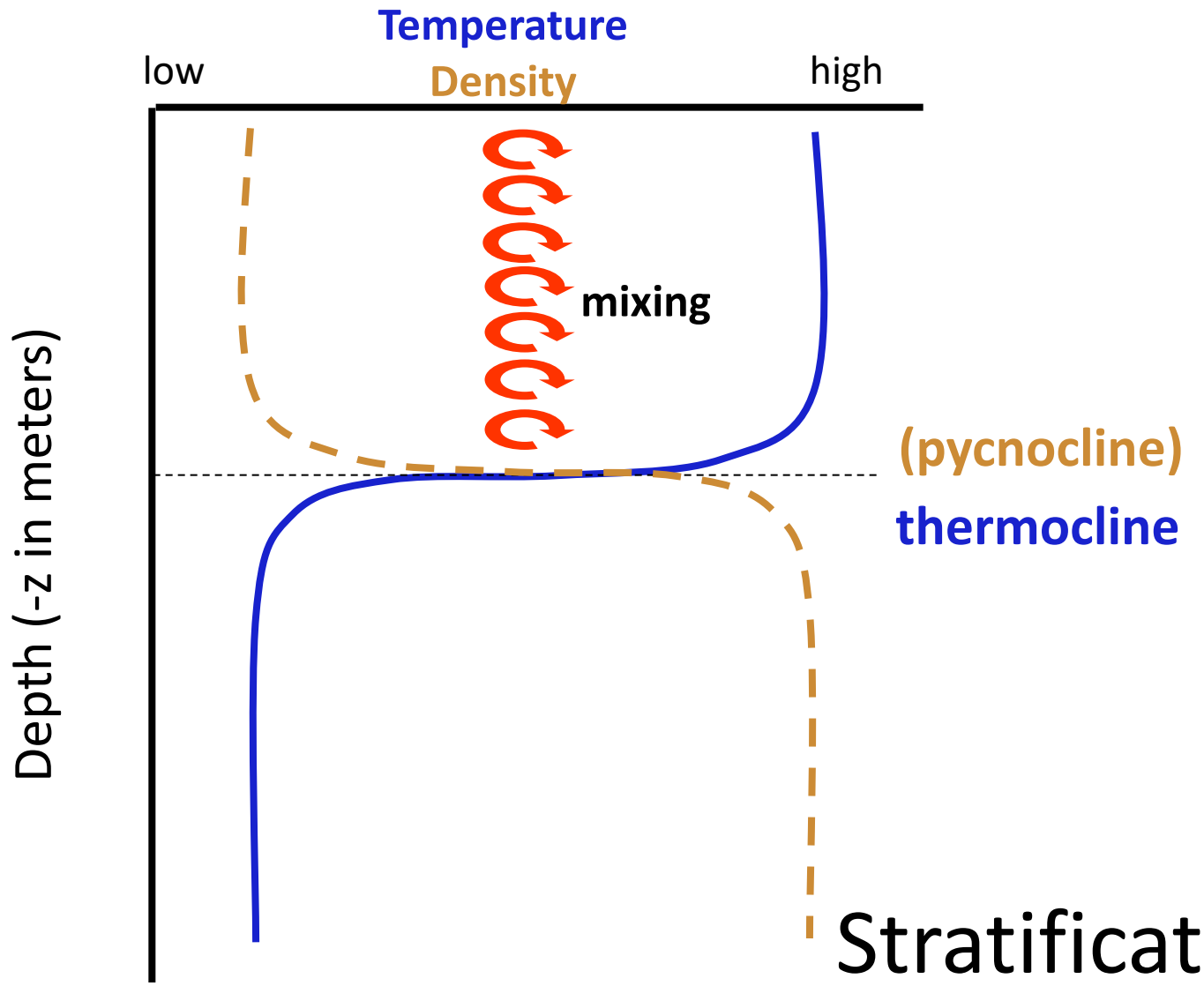
Stratification



If the mixed layer depth is above the critical layer depth, phytoplankton are not mixed below critical depth and <u>population growth</u> is positive

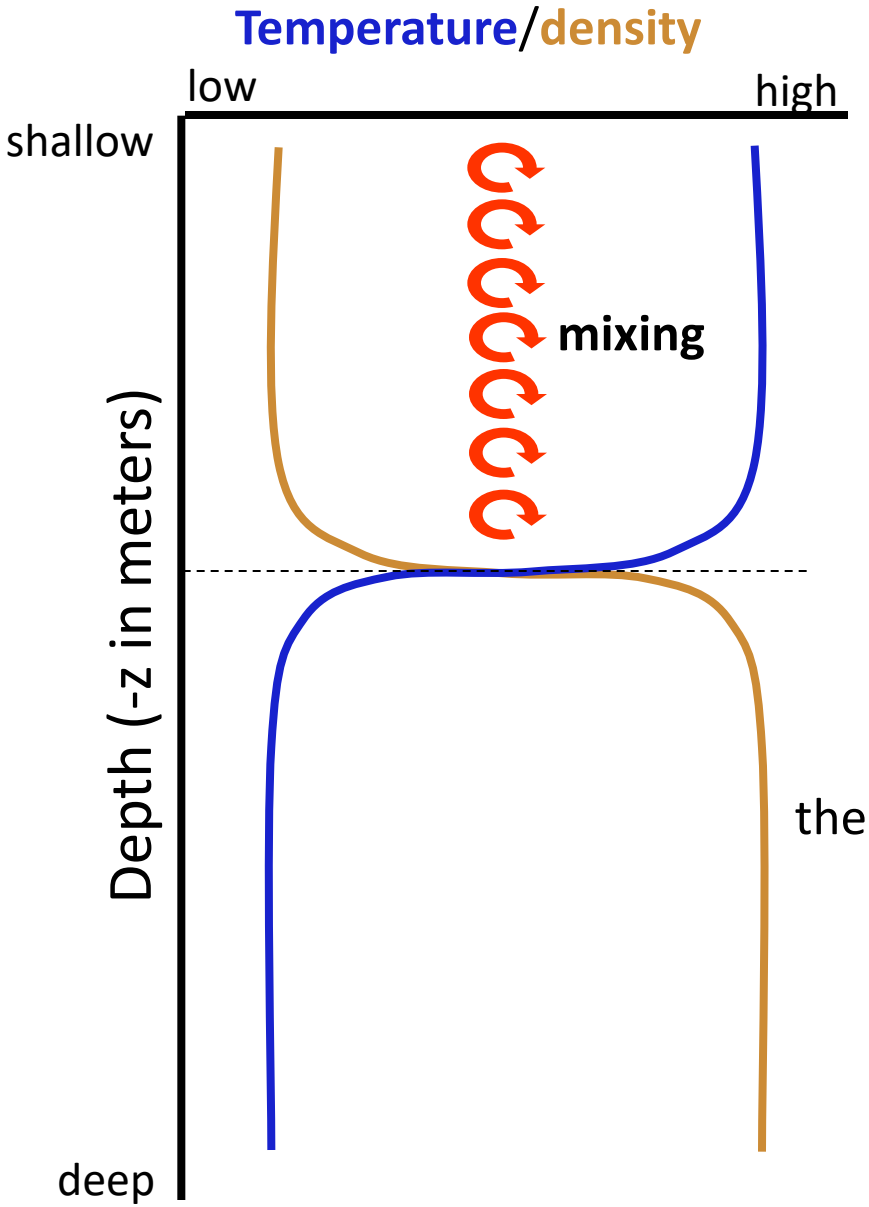
If the mixed layer depth is below the critical depth, enough phytoplankton are mixed below the critical depth that net <u>population growth</u> is negative

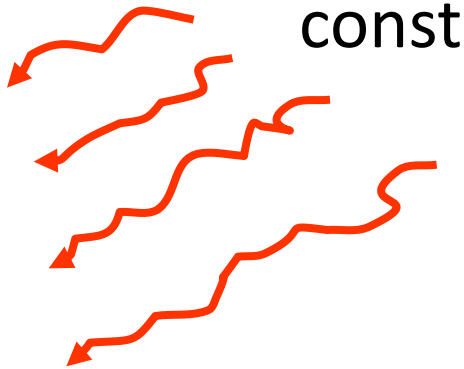
Mixed layer depth
(density barrier to mixing)



Stratification

Tropical systems





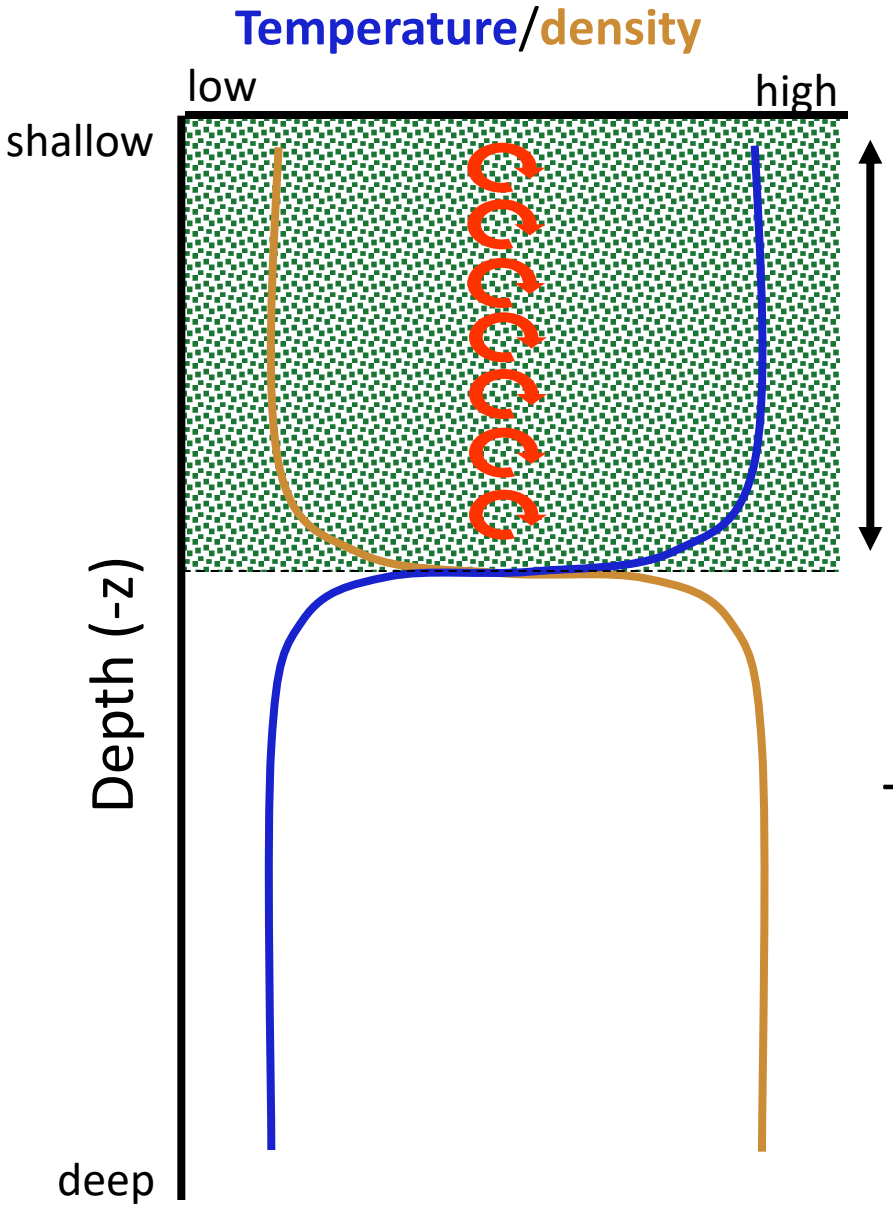
constant heat

thermocline **(pycnocline)**

density differences above/below thermocline serve as barrier to mixing and particle movement

Stratification

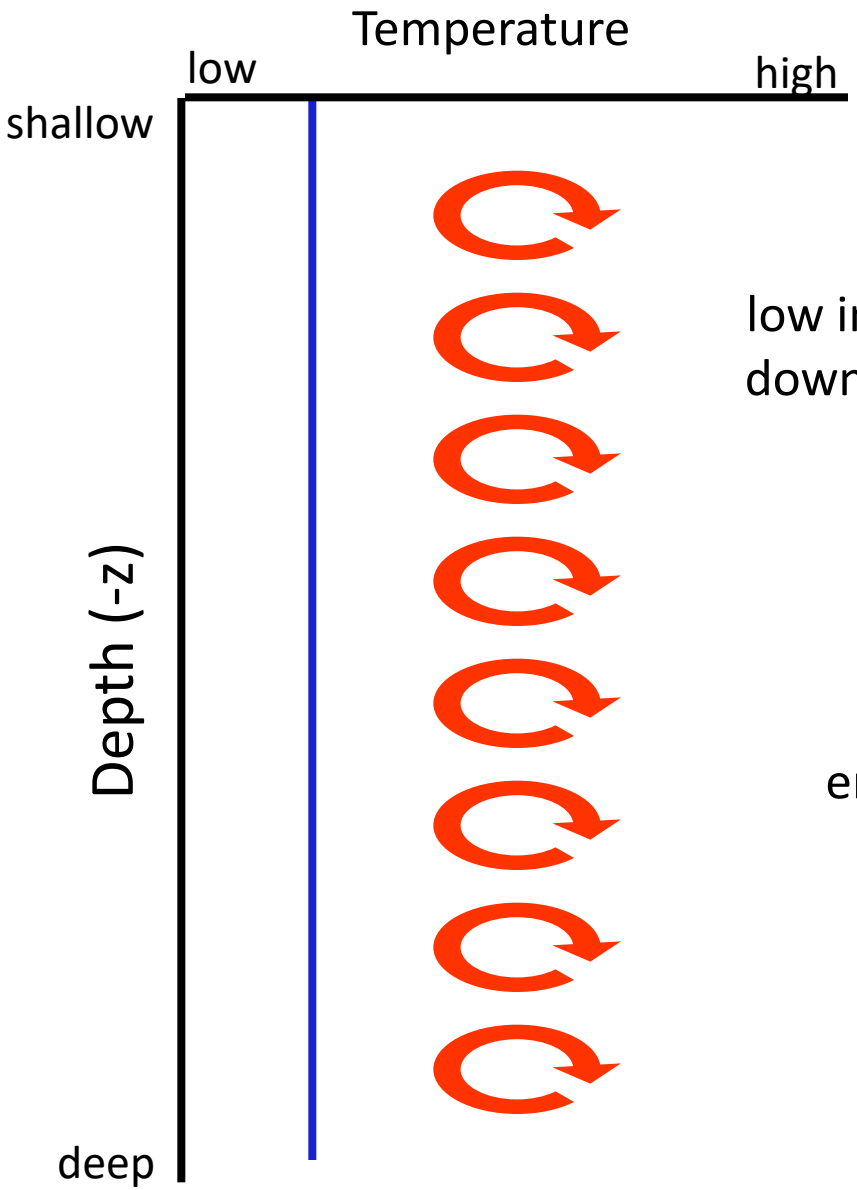
Tropical systems



mixed layer, within which cells are uniformly distributed - depth determined by wind, etc.

The thermocline, pycnocline, & mixed layer are permanent features of tropical systems

Seasonality in temperate systems

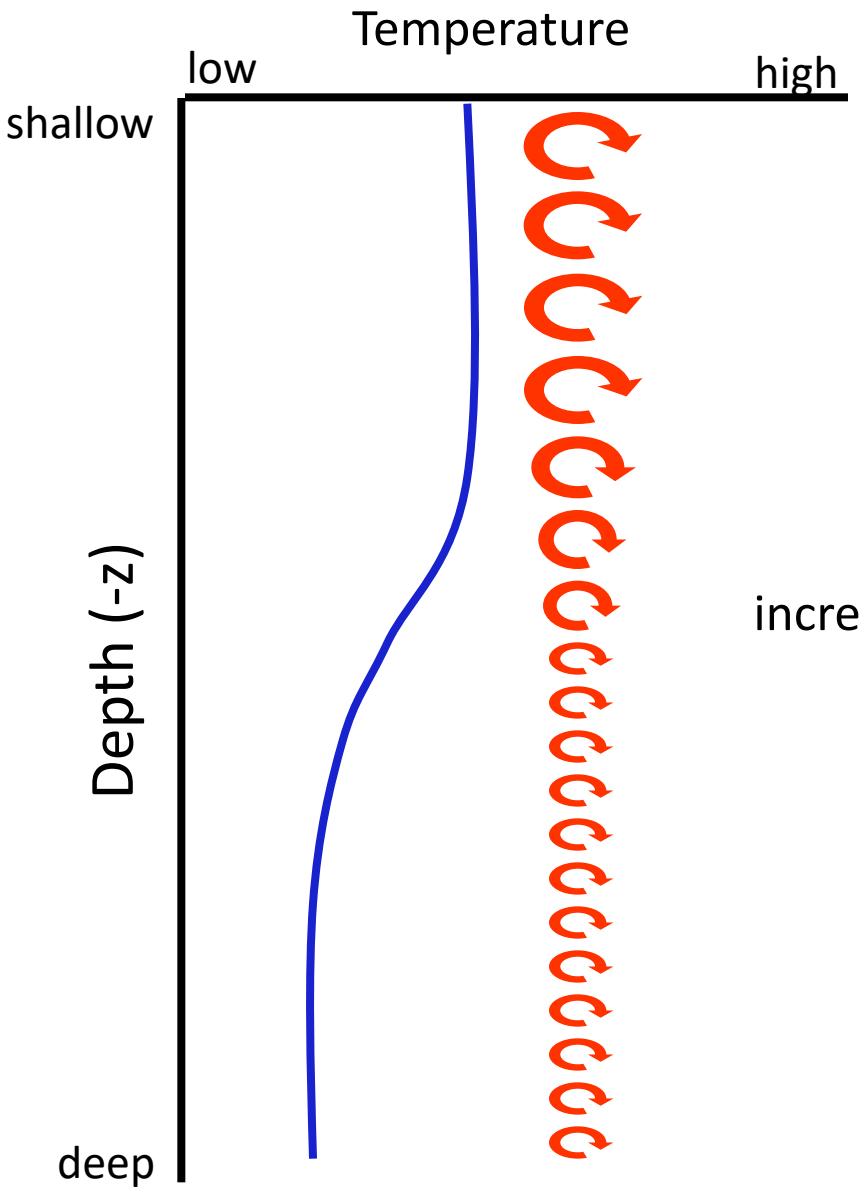


winter

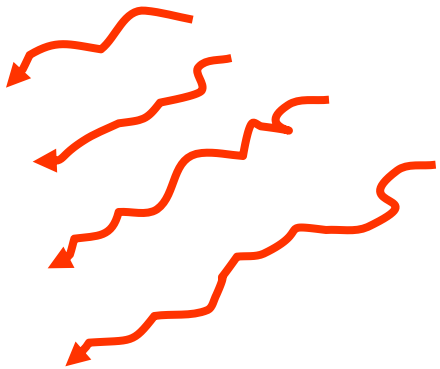
low incident heat and large storms break down temperature and density gradients inhibiting stratification

entire water column is well mixed

Temperate systems

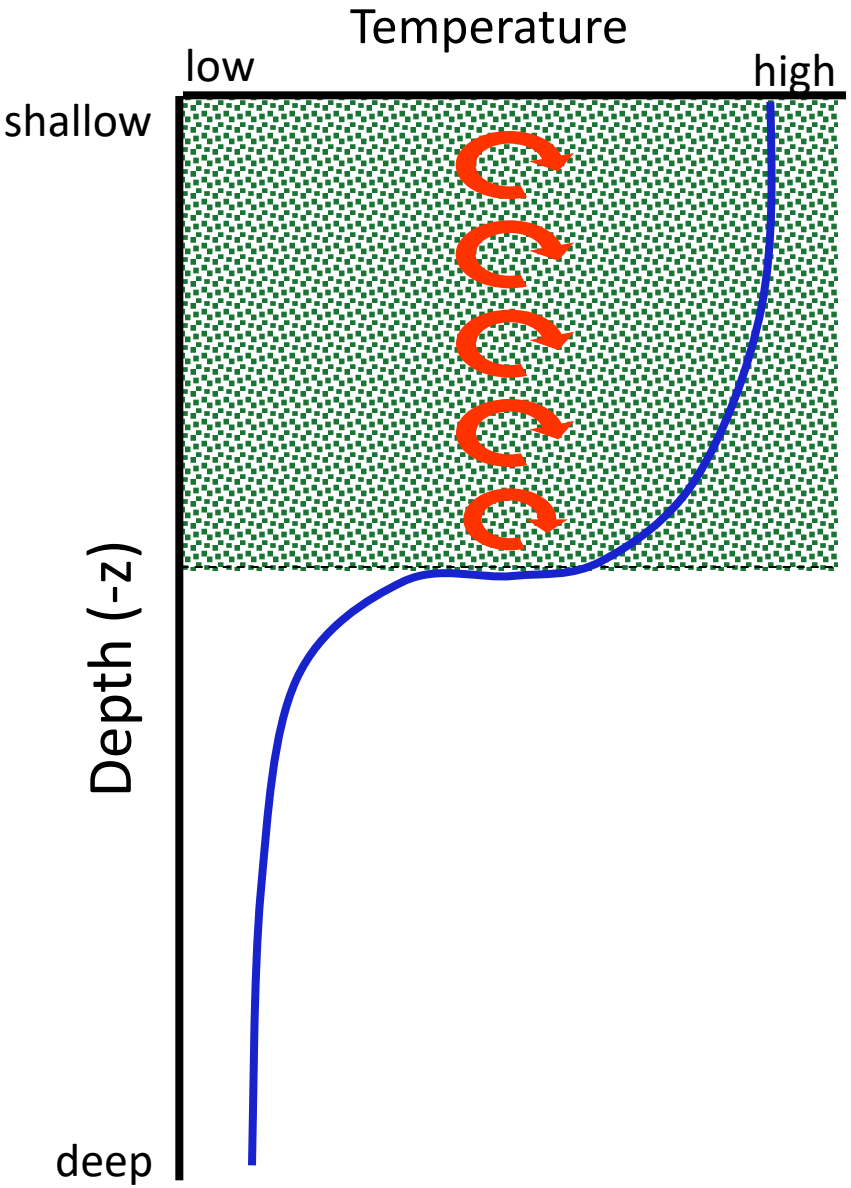


early spring



increased heating of surface waters begins to build thermocline

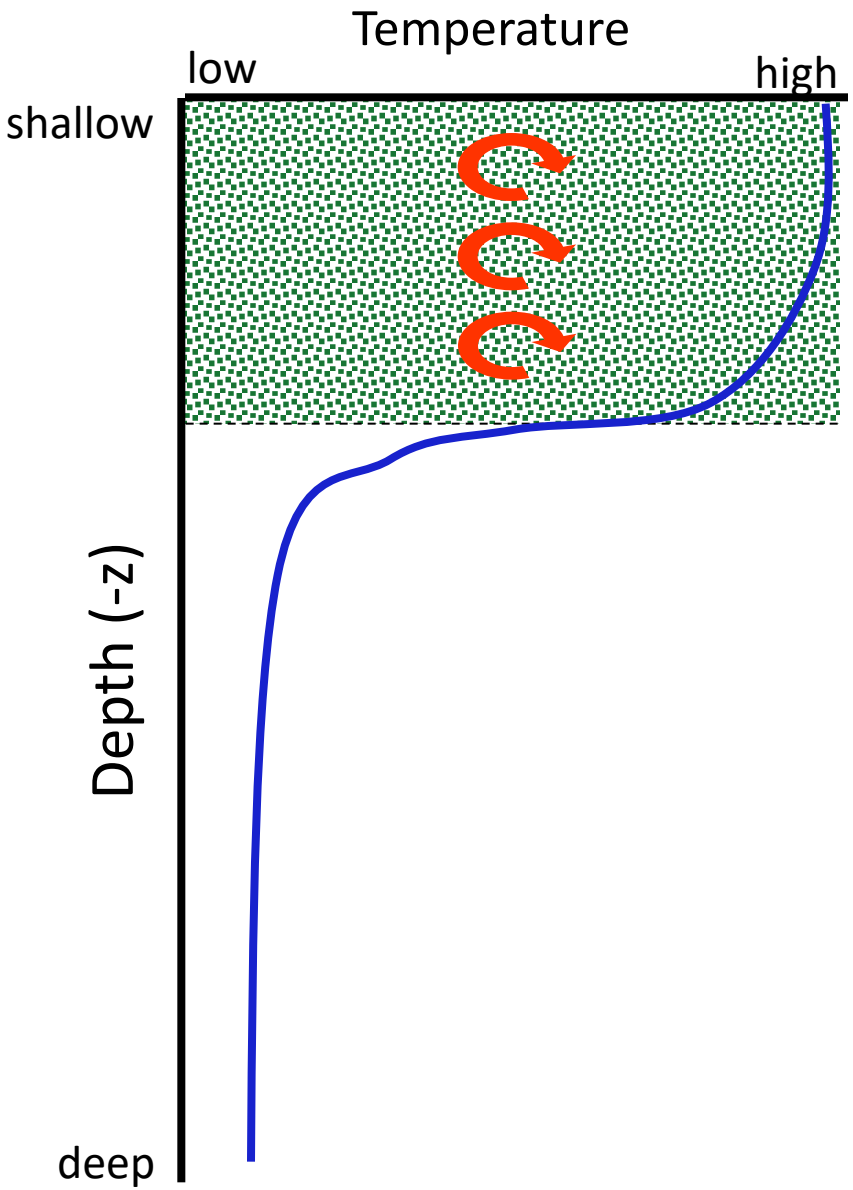
Temperate systems



mid spring

water column well stratified with relatively deep mixed layer

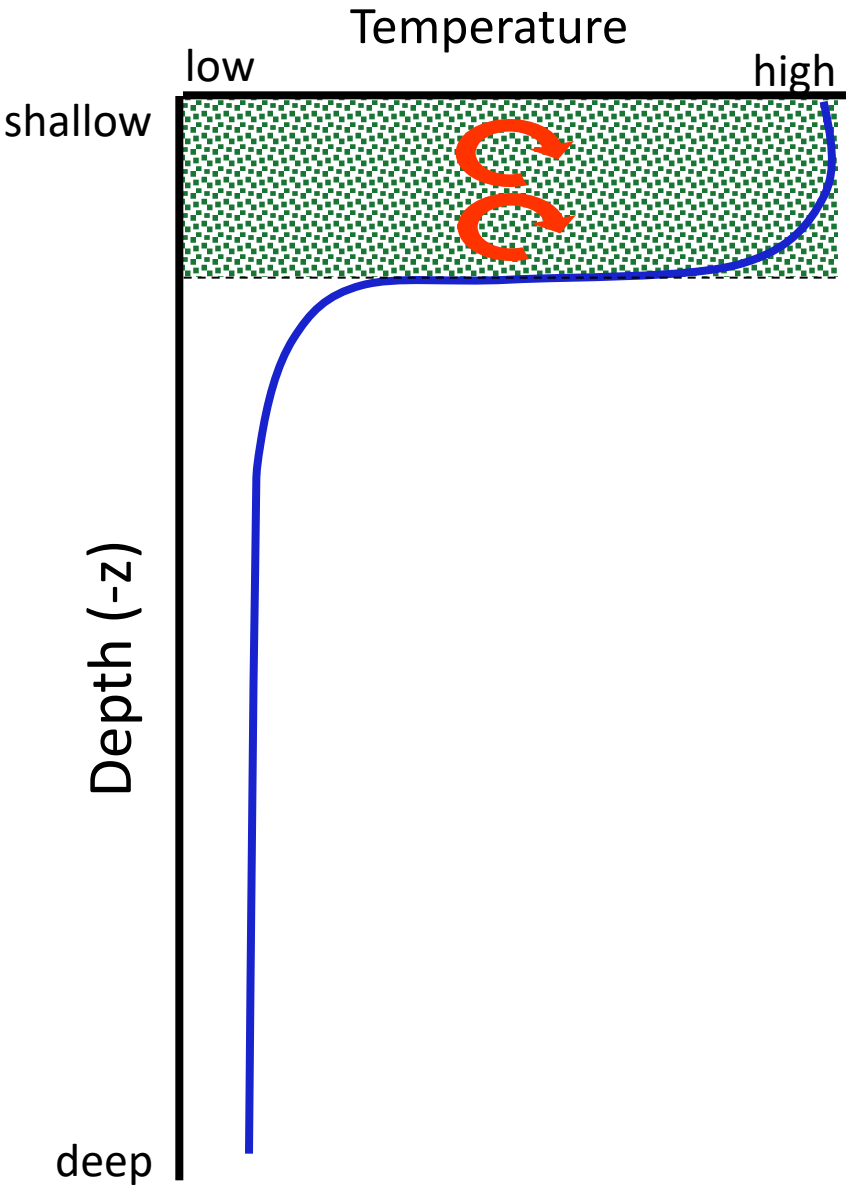
Temperate systems



late spring

increased heating brings thermocline shallower and causes thinner mixed layer

Temperate systems

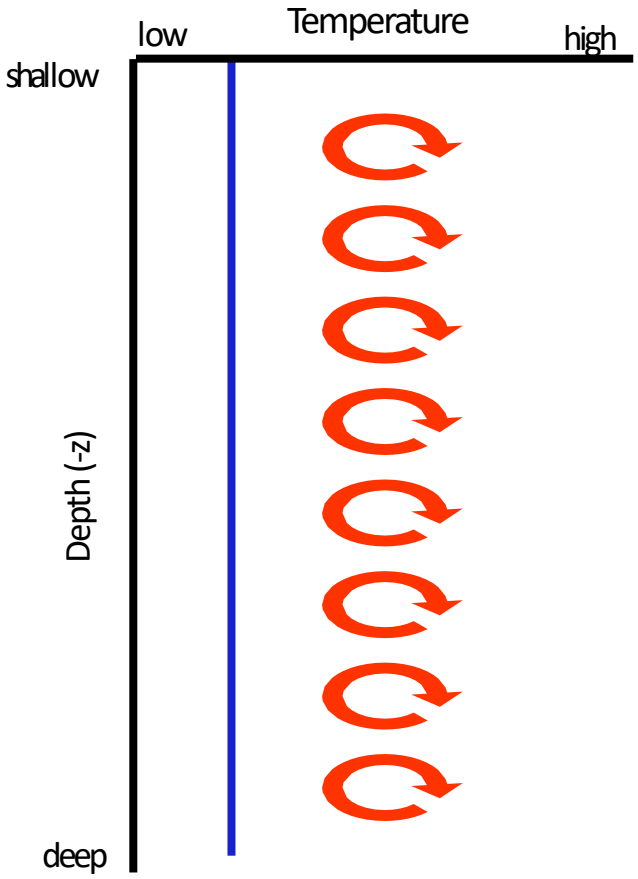


summer

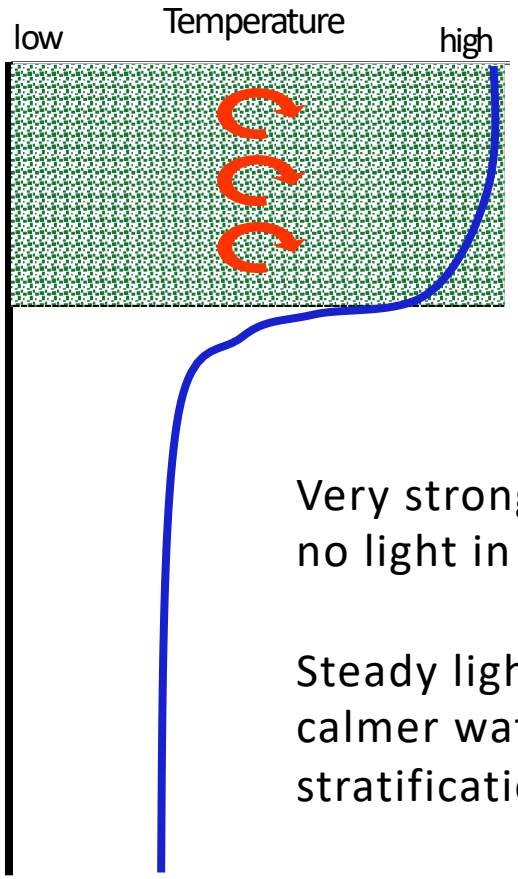
shallow thermocline and mixed layer are well developed

Polar systems

winter



summer



Very strong mixing and almost no light in Winter

Steady light intensity and calmer waters lead to some stratification in Summer

Tropical systems: critical depth and mixed layer are relatively constant

Temperate systems: critical depth increases and mixed layer decreases from winter to summer, then reverses

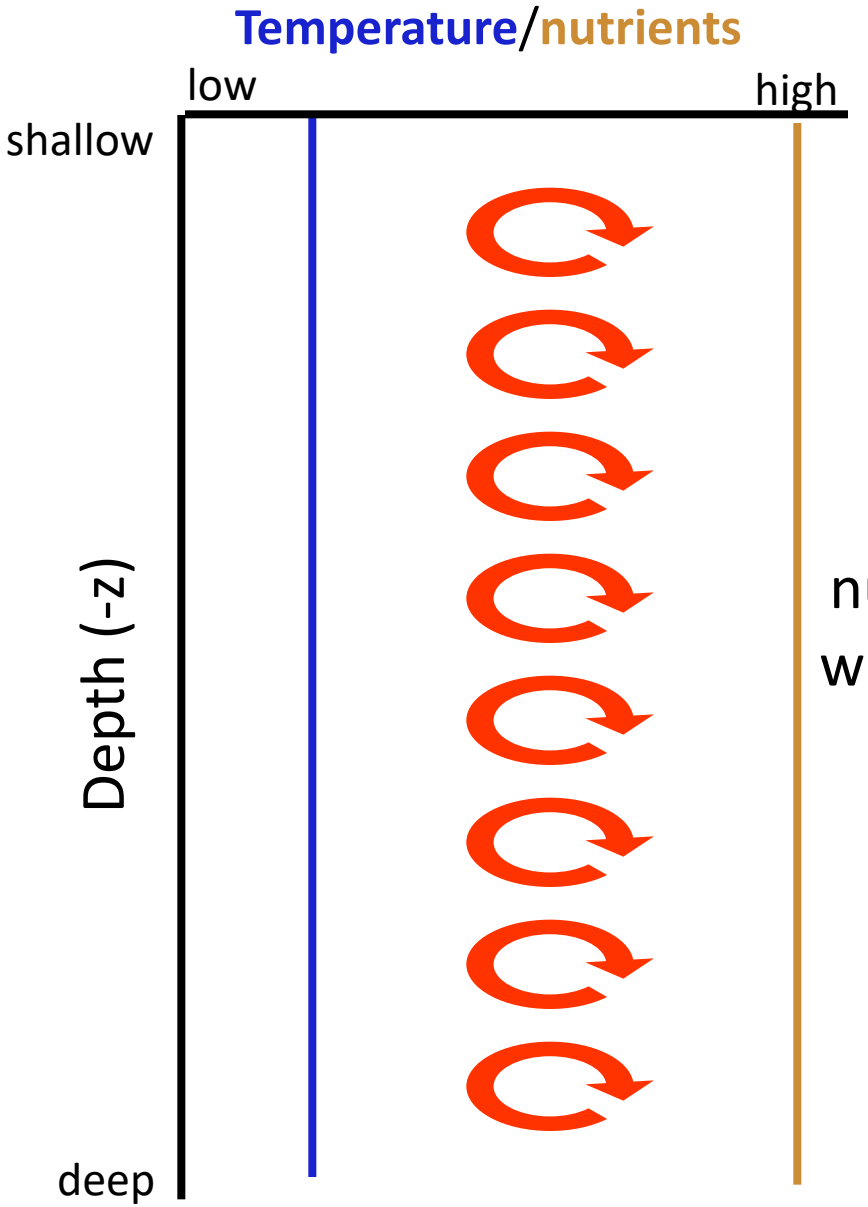
Polar systems: consistent mixing with less developed mixed layer in summer due to increased light availability (generally high nutrients, low light, especially in the summer)

Consequences for phytoplankton?

1. When do we see high/low concentrations of phytoplankton?

2. When do we see phytoplankton blooms?

Weak stratification

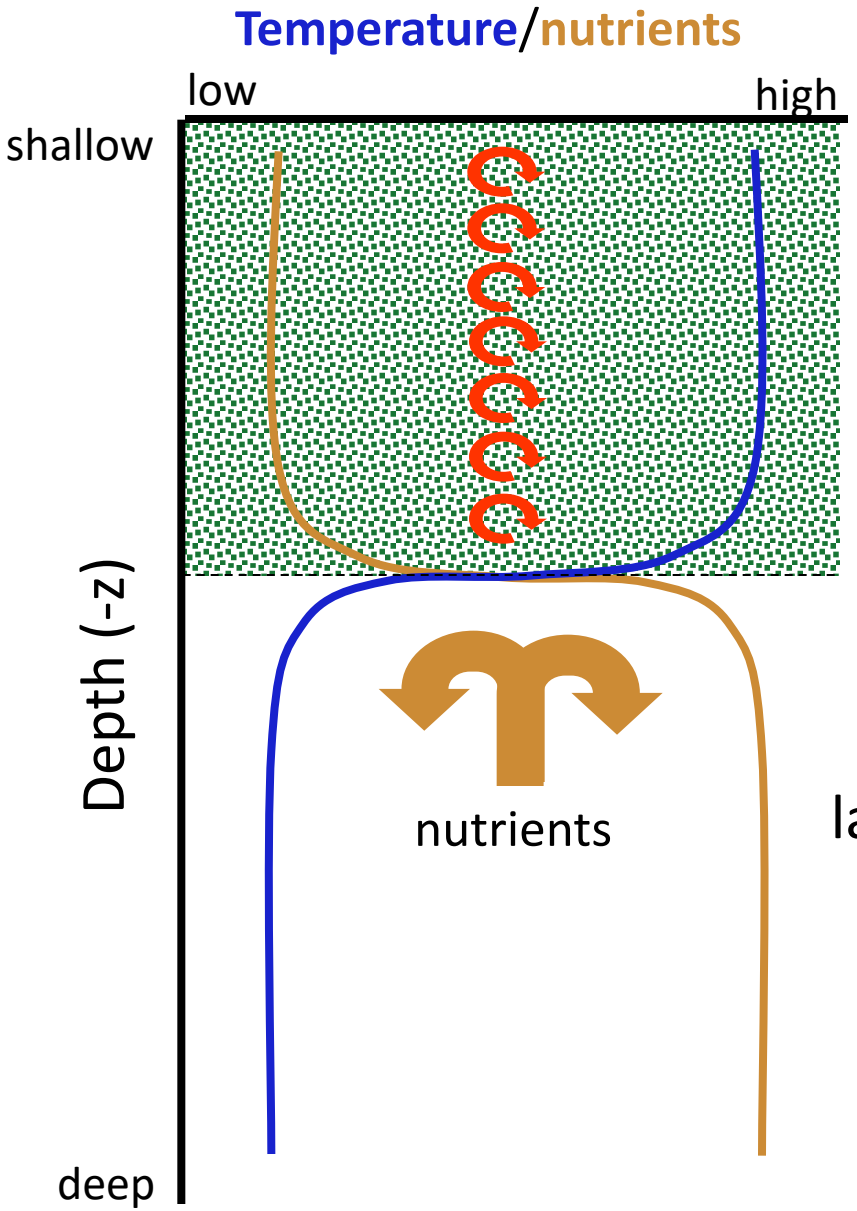


temperate winter

nutrients are in high concentration when water column is not stratified

nutrients depleted by phytoplankton are replenished from deep water

Strong stratification

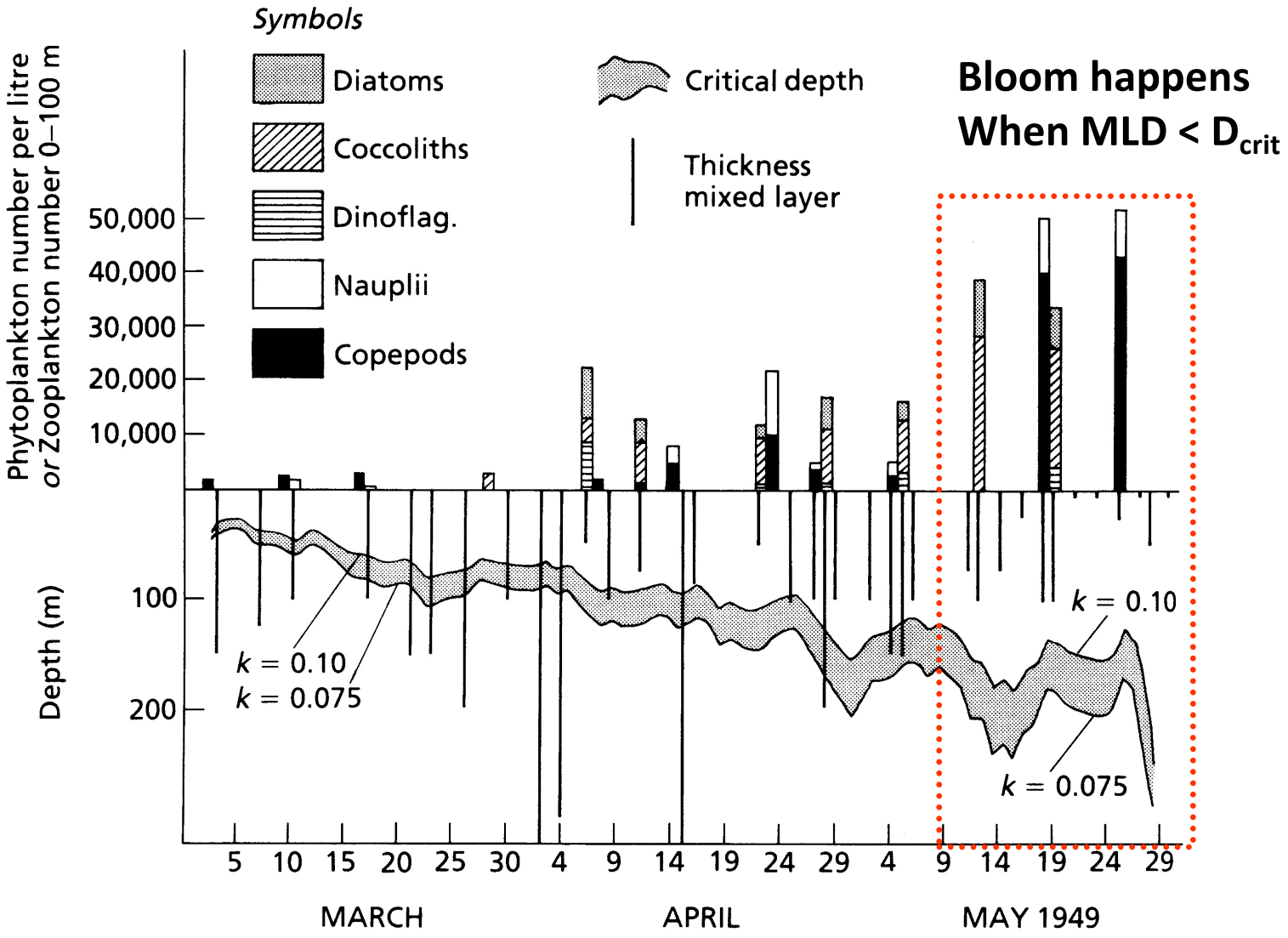


temperate summer/fall

tropical year-round

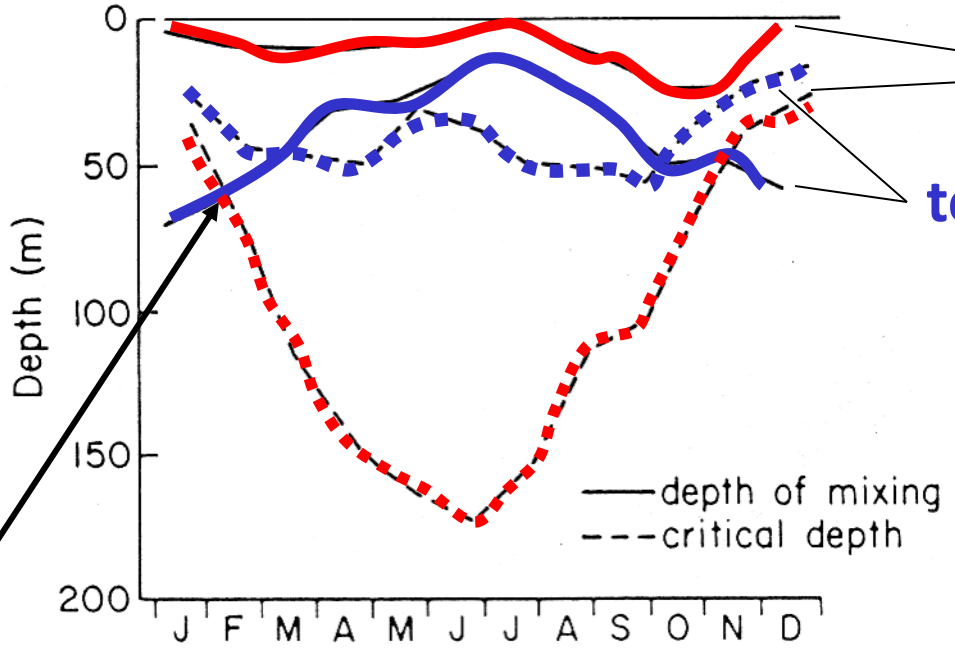
nutrients are depleted in mixed layer because replenishment from deep water is blocked by thermocline

Are plankton blooms predictable?



from Sverdrup 1953

Seasonal variation in critical and mixing depths

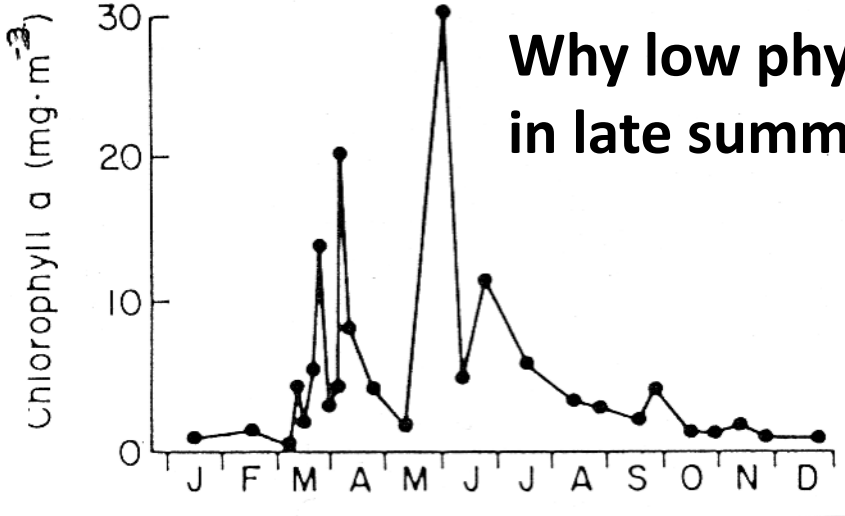


tropical

temperate

Timing of $C_d = M_d$ varies with latitude

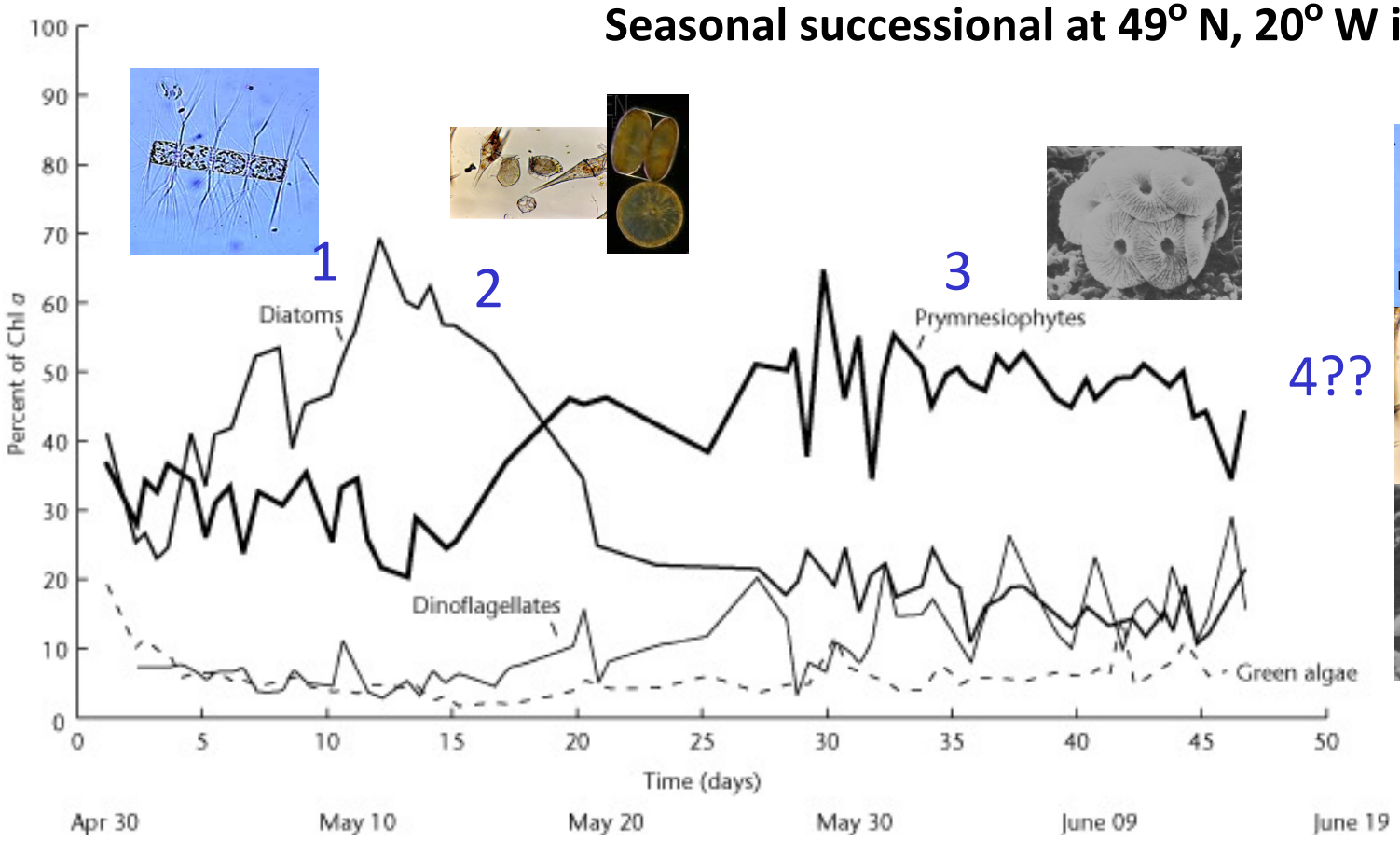
Phytoplankton

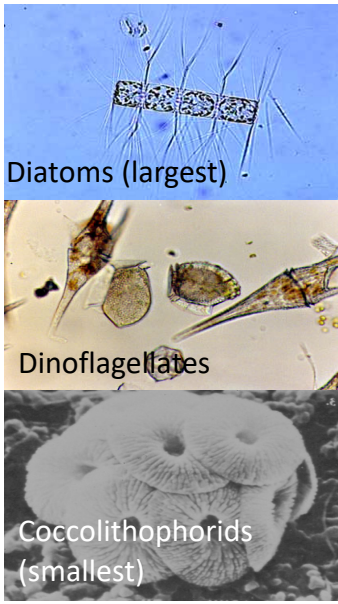


Why low phytoplankton biomass in late summer?

temperate

Seasonal successional at 49° N, 20° W in Spring 1990





1. Mixing declines, critical depth deepens; high nutrients favor large diatoms; rapid growth (1-2x per day) and high population density (100-1000 cells ml^{-1})

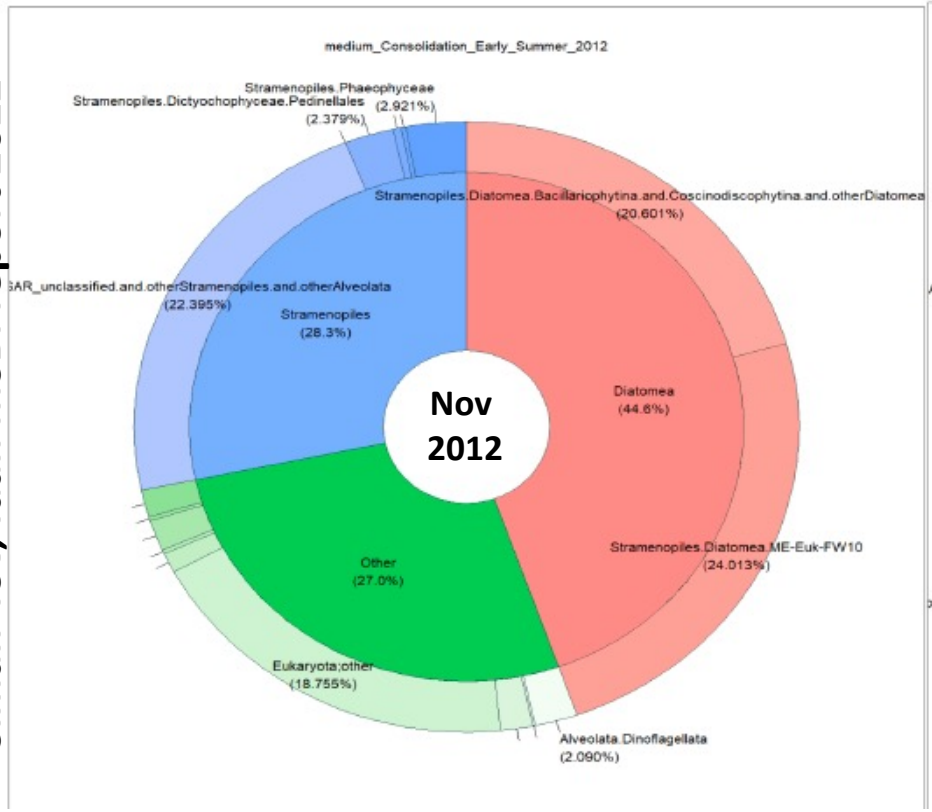
2. Stratification intensifies, nutrients depleted; small diatoms and dinoflagellates dominate; growth and population density drop (20-100 cells/ml)

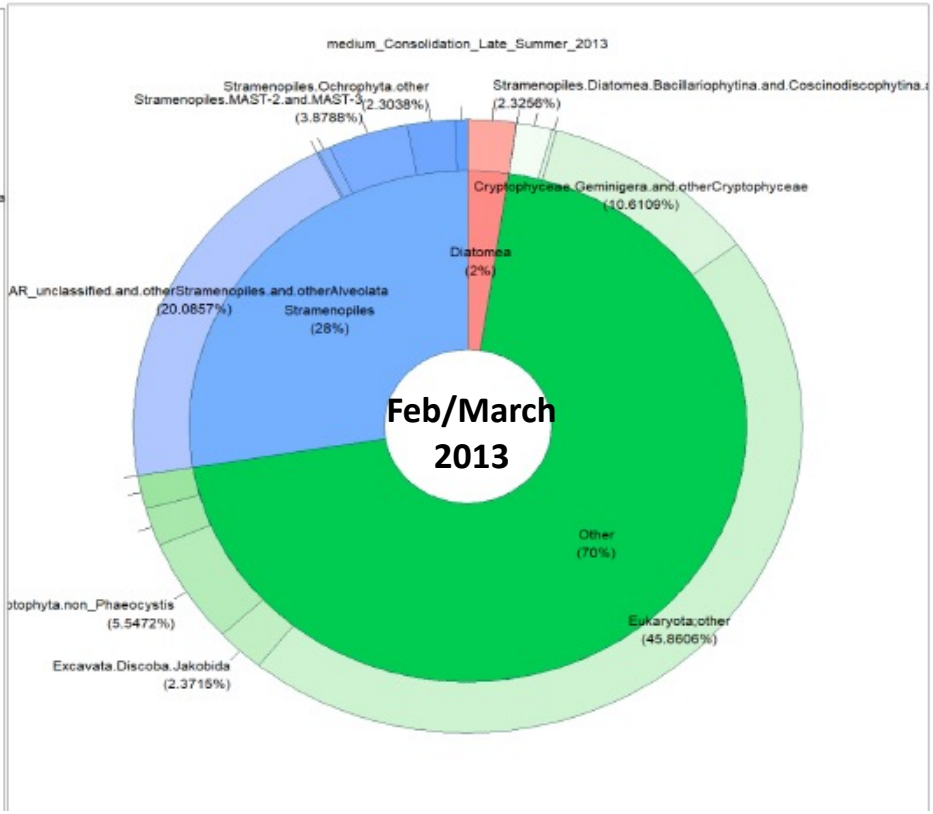
3. Highly stratified, low nutrients; dinoflagellates and coccolithophores dominate

4. Extremely stratified, very low N; dominated by small, motile algae (won't sink) and cyanobacteria (*Prochlorococcus,* Synechococcus) and UCYN-A

Remember phytoplankton distributions in Antarctica?

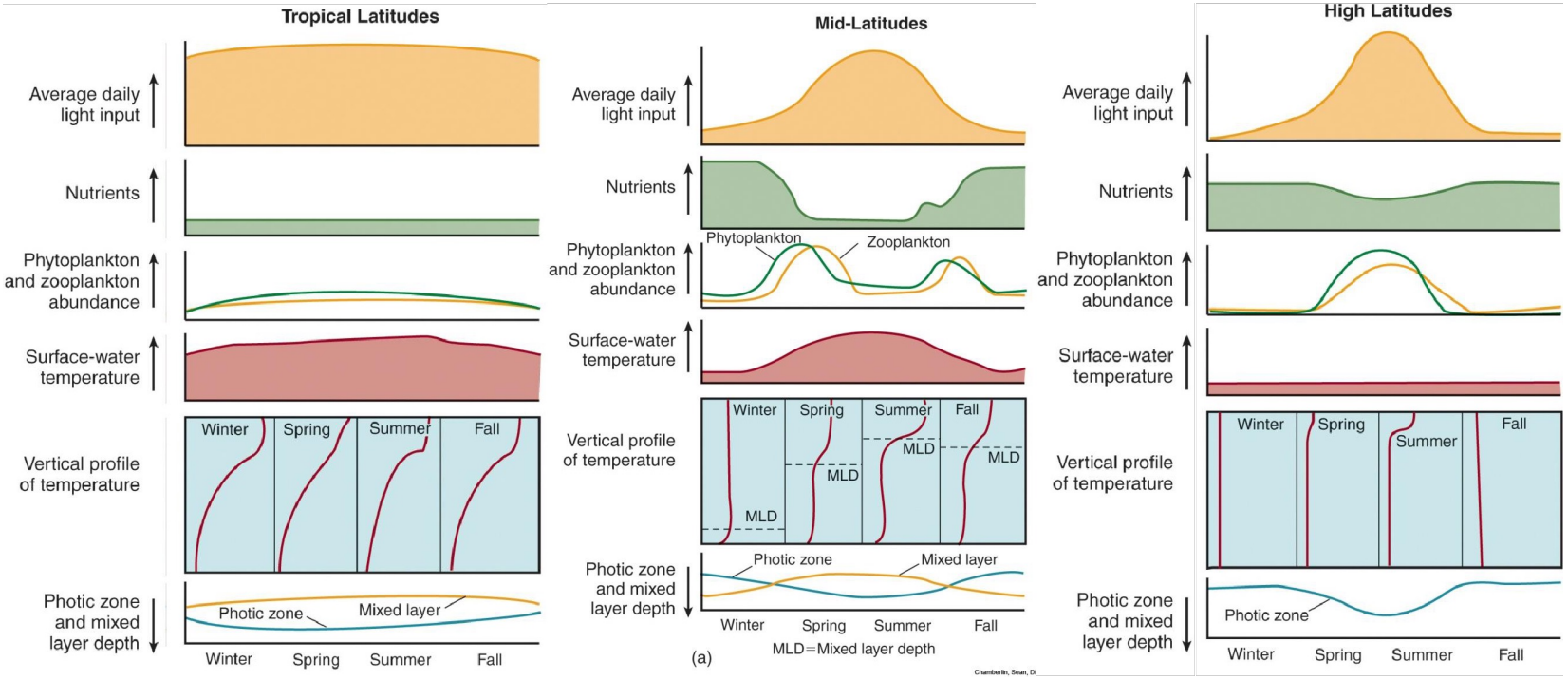
= diatoms





Siman-Tov, Idan MSBI report 2022

Seasonal Changes at different latitudes



Tropical mixed layer is nutrient limited year-round

- blooms are rare
- vertical stratification of species composition

Temperate mixed layer is nutrient limited in late-summer and fall

- spring bloom, very predictable
- occasional fall bloom when strength of mixed layer decreased and critical depth is still deep
- Seasonal patterns of species “succession”

Polar mixed layer develops in summer and is nutrient rich

- more light limited
- one large summer bloom

Polar mixed layer develops in summer and is nutrient rich

- one large summer bloom…unless climate is disrupted

Temperature

Fluorescence: proxy for biomass