# MARINE ECOLOGY

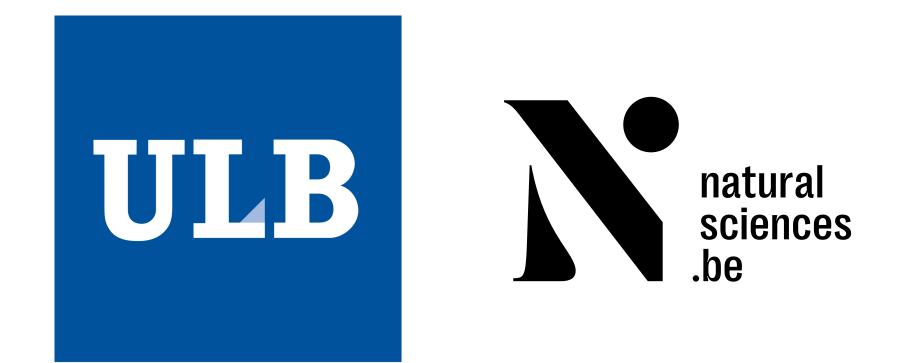
Course Information Anton Van de Putte 2022 – 2023

#### RESEARCHER

#### Data manager

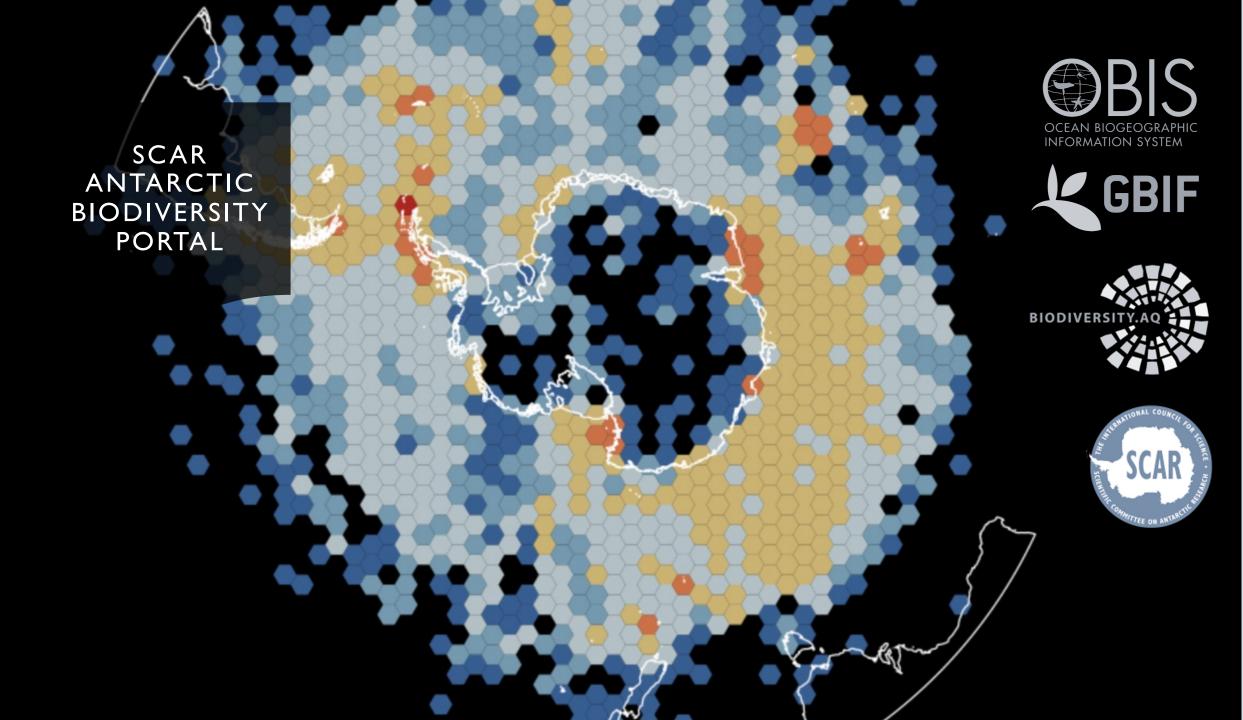
#### Policy advisor





### CONTACT

# • E-mail: anton.van.de.putte@ulb.be



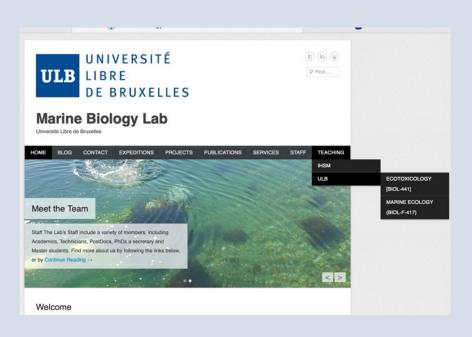
#### COURSE SCHEDULE

Date	Time	Lecture	Lecturer	Location
11/10/2023	09:00-12:00	Oceanography, geology, history, and technology	МК	VUB, D.0.02
17/10/2023	08:00-18:00	Excursion with Simon Stevin (ULB students)	МК	Oostend
18/10/2023	08:00-18:00	Excursion with Simon Stevin (VUB students)	МК	Oostend
25/10/2023	09:00-12:00	Analysis of data collected during the excursion	МК	VUB, 2 computer rooms
<del>08/11/2023</del>	<del>09:00-12:00</del>	Pelagic biological processes	AVdP	ULB, S.UC2.236
15/11/2023	09:00-12:00	Coral reef ecology	МК	VUB, D.0.02
22/11/2023	09:00-12:00	Benthic biological processes	AVdP	ULB, S.UC2.236
29/11/2023	09:00-12:00	Practical	AVdP	ULB, S.UC2.236
06/12/2023	09:00-12:00	Connectivity of populations	МК	VUB, D.0.02
13/12/2023	09:00-12:00	Case study: Southern Ocean + global change in the ocean	AVdP	ULB, S.UC2.236
20/12/2023	09:00-12:00	Q&A	AVdP+MK	ULB, S.UC2.236
			AVdP: Anton Van der Putte MK: Marc Kochzius	



#### BIOL-F417 - Marine ecology - 202223





#### COURSE INFORMATION

#### https://uv.ulb.ac.be/

https://biomar.ulb.ac.be

https://canvas.vub.be/

(might be delayed)



Slides of the course

Books

 $\sim$ 

At the « Bibliothèque des Sciences et Techniques »

Both ULB and VUB students have access (for the latter, contact the desk in the library)

Advanced course: not covered by a single book, even not by multiple ones; several parts based on original scientific literature

« Framework »: Valiela I. 2015. Marine Ecological Processes. Springer (on line version available).

- « Framework »: Valiela I. 2015. Marine Ecological Processes. Springer.
- Thurman HV. 1990. Essentials of oceanography 3rd ed. Columbus, Ohio : Merrill Pub. Co
- Segar DA 2007. An introduction to ocean sciences 2<sup>nd</sup> edition. Minneapolis/St. Paul, MN: West Pub.
- Levinton JS 1995. Marine biology : function, biodiversity, ecology. New York : Oxford University Press 420 p.
- Sheppard Ch 2000. **Seas at the millennium : an environmental evaluation** New York : Pergamon
- Steele, John H.2001 Encyclopedia of ocean sciences vol 1-6
- Castre & Huber 219 Marine Biology McGraw Hill, New York

# BOOKS

#### ENGLISH

## Taught in English but

- Most of us are not native speakers
- Not an English language course
- Do not hesitate to ask questions (rather small audience)

#### Exam

- In English (prefered)
- But you have the right to have it in French (ULB students) or in Dutch (VUB students) (NB:Tropimundo in English, mandatory)

#### THE COURSE WITHIN YOUR MASTER



Marine Biology does not stop at the end of the course!



Depending on your cursus further excursions during your Master on temperate or tropical shores: you'll need what you learned in this course!



(ULB MA-BIOR A-D: BIOL-F-416 Stage de Biologie marine)

#### EVALUATION

#### • Method(s) of evaluation

- Oral examination starting with the critical presentation of a scientific article in relation with the course (submitted for approval to the titular)
- Written reports for the practicals
- Mark calculation method (including weighting of intermediary marks)
- If the marks for the oral exam and practicals are both higher or equal to 8/20, then the final mark will be calculated as 70% for the oral exam and 30% for the practicals. If the mark of either the oral exam or the practicals is lower than 8/20, then the final mark will be the lower of these.

#### EXAM

# Oral, 30 minutes long

# Time and data will be planned together with you

Be present 30 minutes in advance



#### EXAM STRUCTURE

# EXAM STRATEGY

- For the discussion, the knowledge of the course is necessary!
- This discussion may possibly bring you to other subjects (transverse comparisons).
- So, if you choose an article on the impact of global change on coral reefs, expect questions dealing with coral reefs but also on chemical oceanography or on top-down control in benthic ecosystems (for instance).
- Articles from Nature and Science are hard!

#### EXAM ARTICLE

- a recent (not earlier than 2016) scientific research article
- not a review, not a descriptive faunistic list, not a data paper, not a popular science paper
- avoid inventories or natural history of a species or taxon
- in relationship with the course
- ecological processes; effects of global change; connectivity in the marine environment
- in case of a modelling article, be sure to master the modelling aspects (be able to explain how an independent variable is acting on the dependent variables)

#### EXAM ARTICLE EXAMPLES

- Are fisheries impacting breeding seabirds of the North Sea?
- Are coral reef sea urchins controlled by bottom-up or top-down factors?
- Do the introduced starfish *Asterias amurensis* have an impact in Southern Australia?
- Do food or wave impact control biodiversity on sandy beaches?





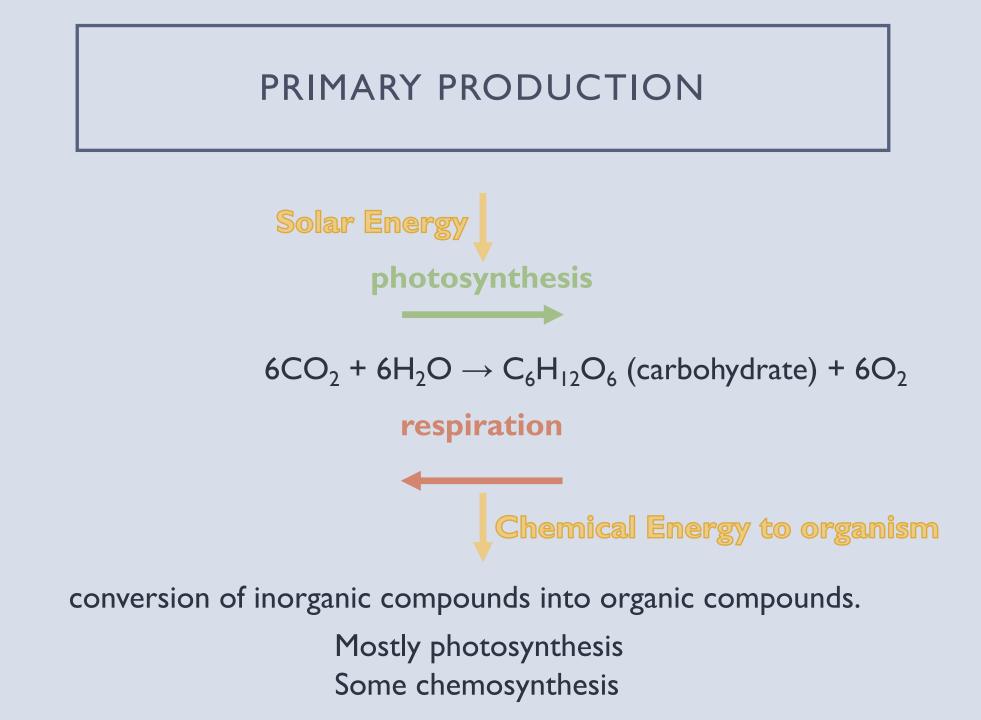
#### MARINE ECOLOGY



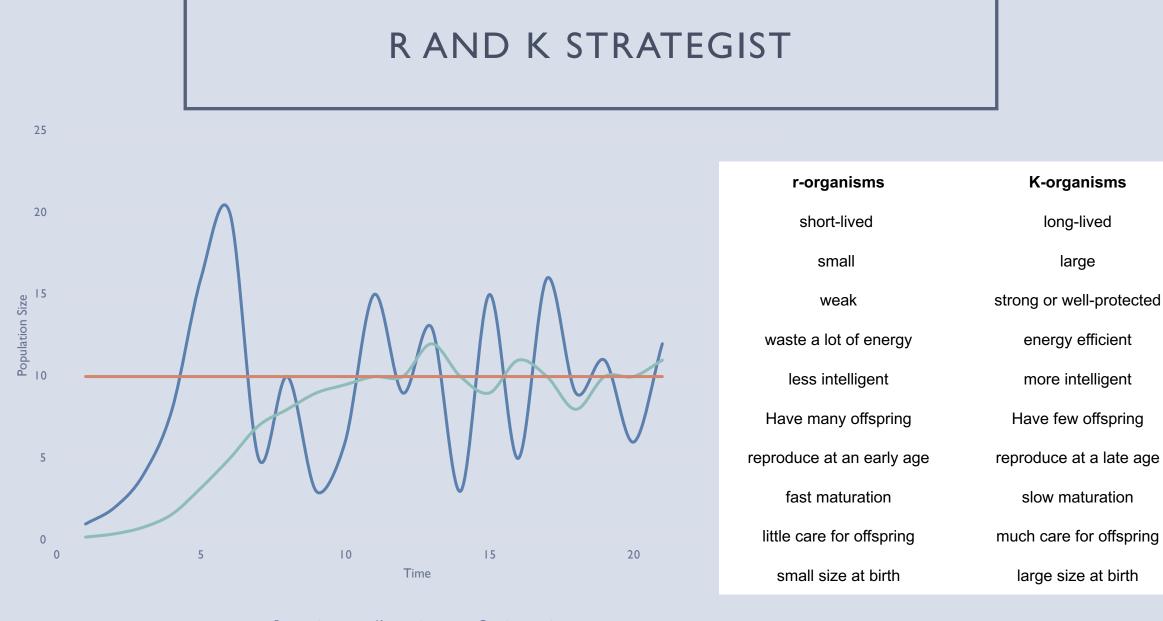


Marine relating to or found in the sea (Ocean, Sea, Estuary) **Ecology** the study of organisms and how they interact with the environment around them

#### FUNDAMENTALS OF BIOLOGY AND ECOLOGY



#### HOW POPULATIONS GROW

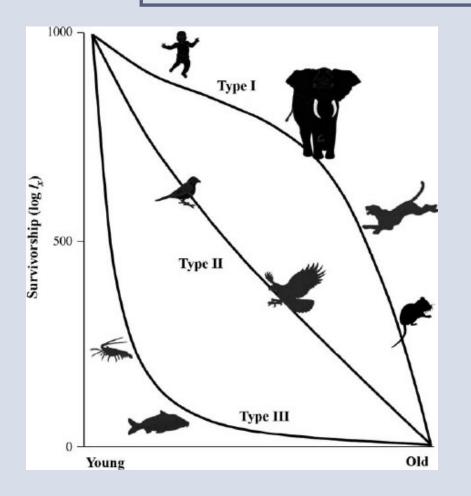


#### R AND K STRATEGIST



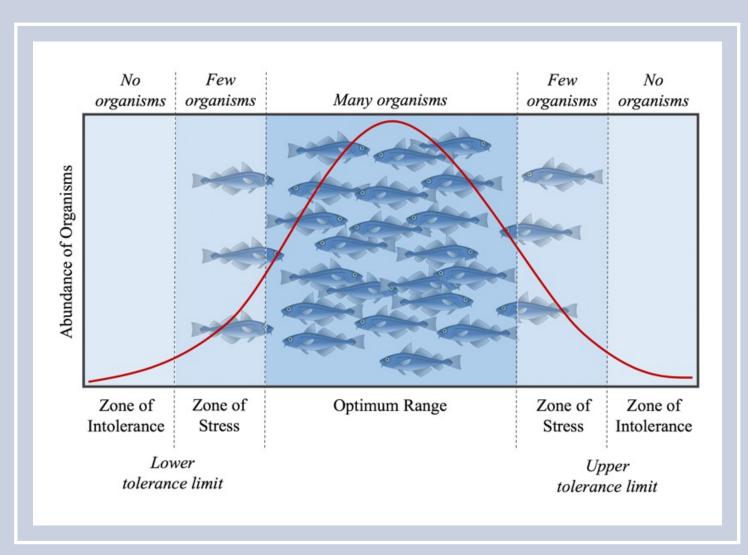


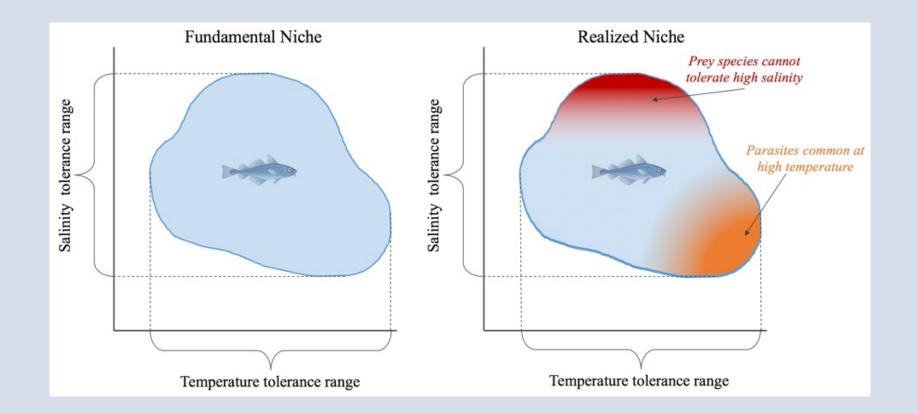
#### SURVIVOR SHIP CURVE



#### ECOLOGICAL NICHE

- abiotic and biotic
- To grow, reproduce, and survive





# FUNDAMENTAL VS REALIZED NICHE

#### PRINCIPLE OF ALLOCATION

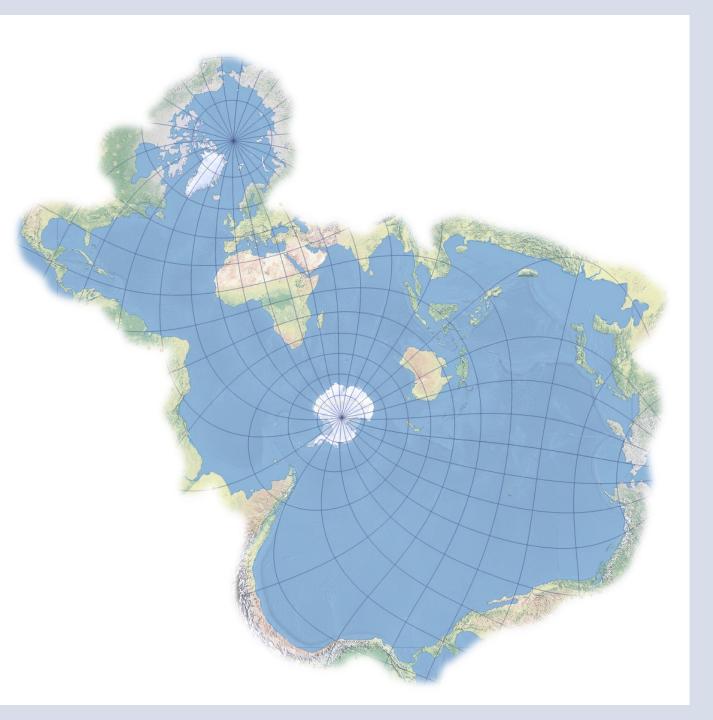
# Finite quantity of resources

Zero sum game

# leads to trade-offs



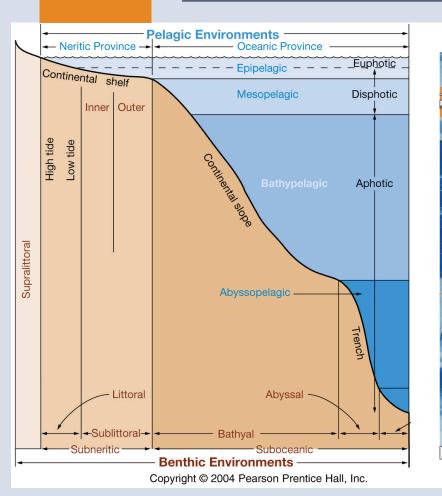
# QUESTIONS

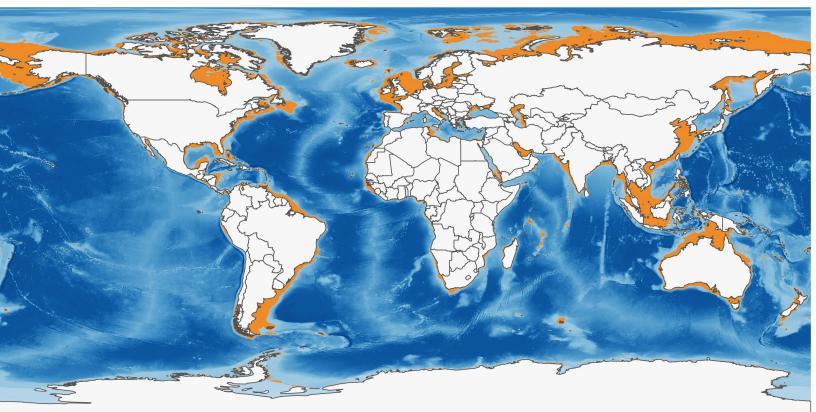


# THE PELAGIC ENVIRONMENT

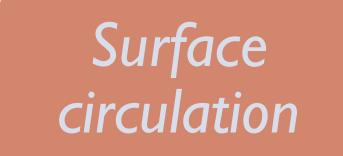
<u>πέλαγος</u> (pélagos) 'open sea'

# NERITIC PROVINCE





#### OCEAN CIRCULATION (RECAP)



Thermohaline circulation

# Surface currents

# Coriolis effect

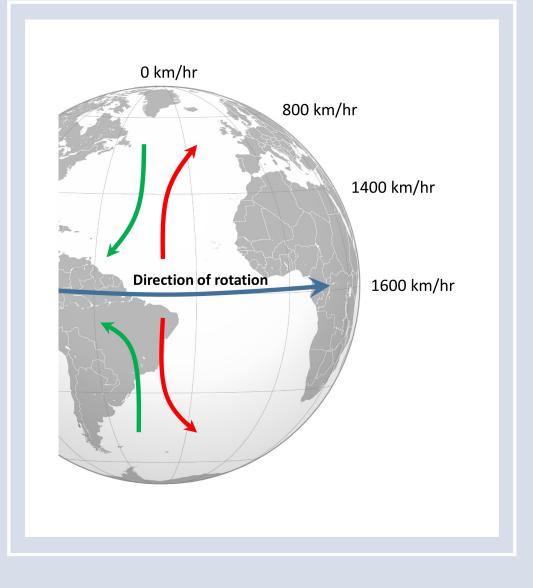
# SURFACE CIRCULATION

# Up- and downwelling

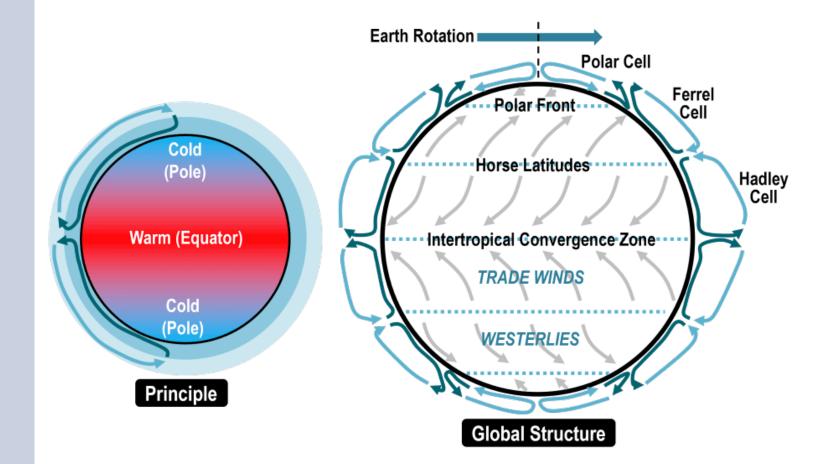
#### CORIOLIS EFFECT

Northern hemisphere: deflection to the right

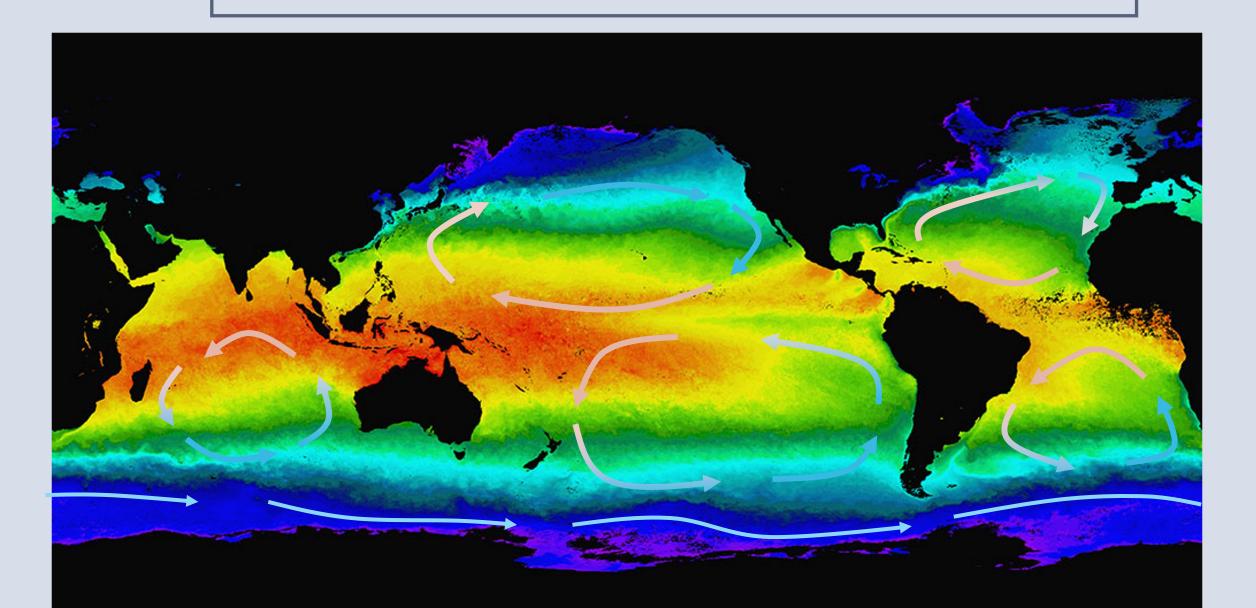
Southern hemisphere: deflection to the left



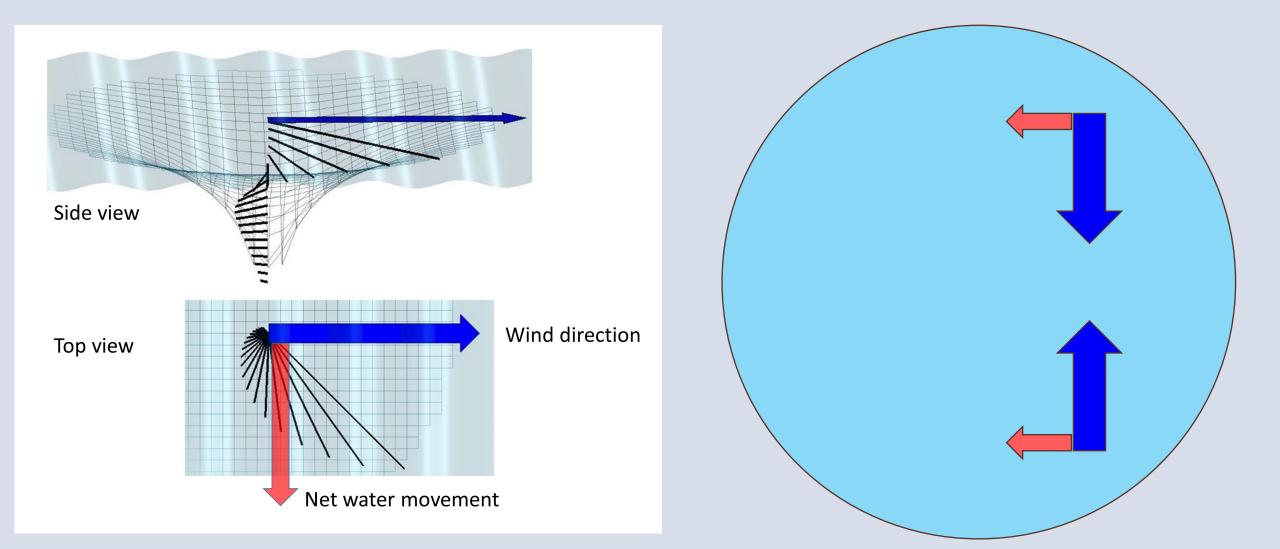


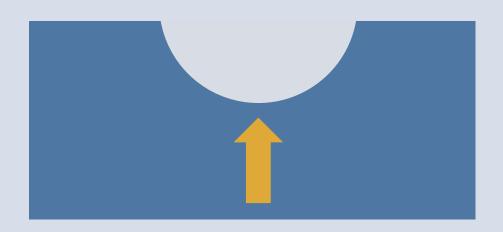


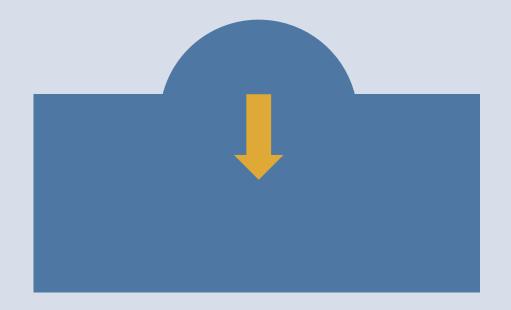
#### SEA SURFACE TEMPERATURES AND GYRES



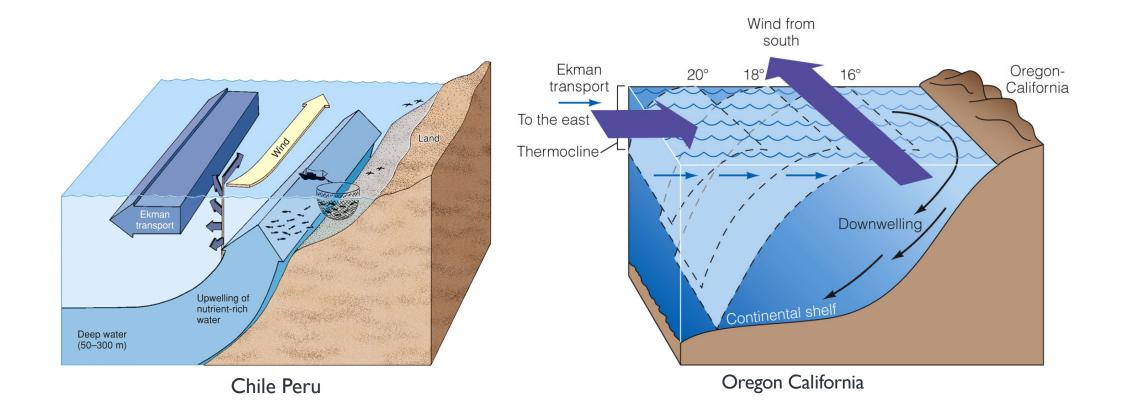
## **EKMAN TRANSPORT**





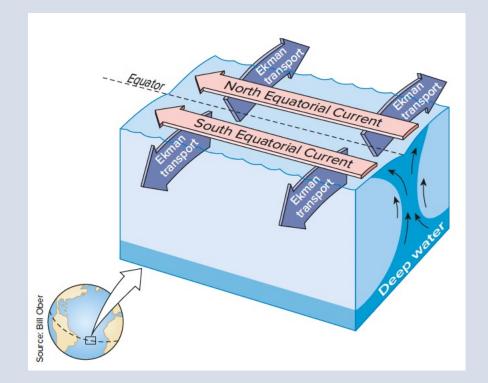


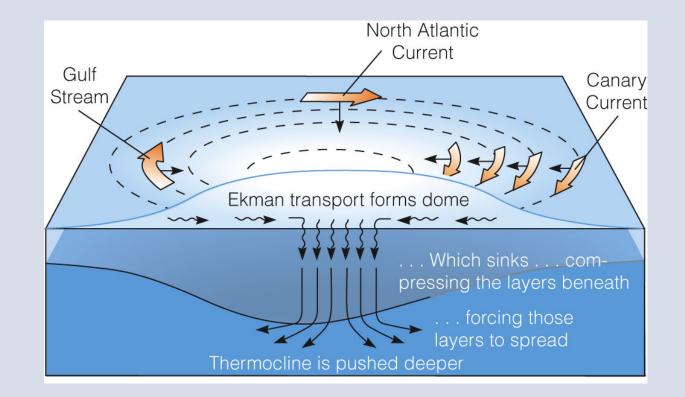
#### UP-AND DOWNWELLING

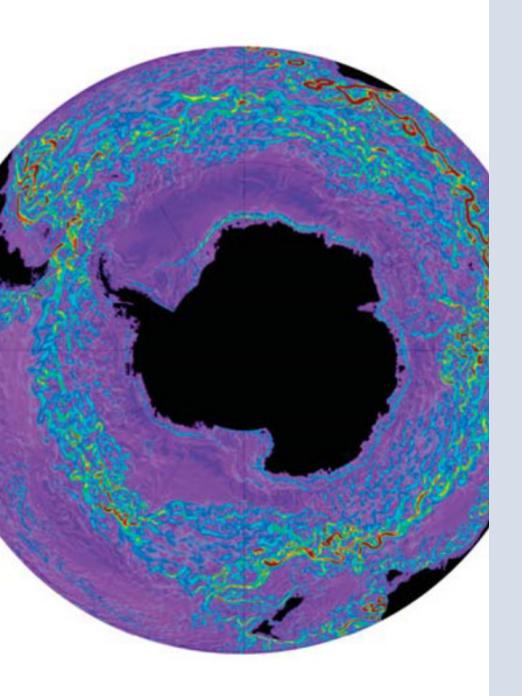


# COASTAL UP- AND DOWNWELLING

# **UP-AND DOWNWELLING**







#### SOUTHERN OCEAN UPWELLING

• Driven by westerlies

# UPWELLING AND DOWNWELLING

#### Upwelling

- Coastal
- Equatorial
- Antarctic

#### Downwelling

- Centre of oceanic gyres
- Coastal downwellings

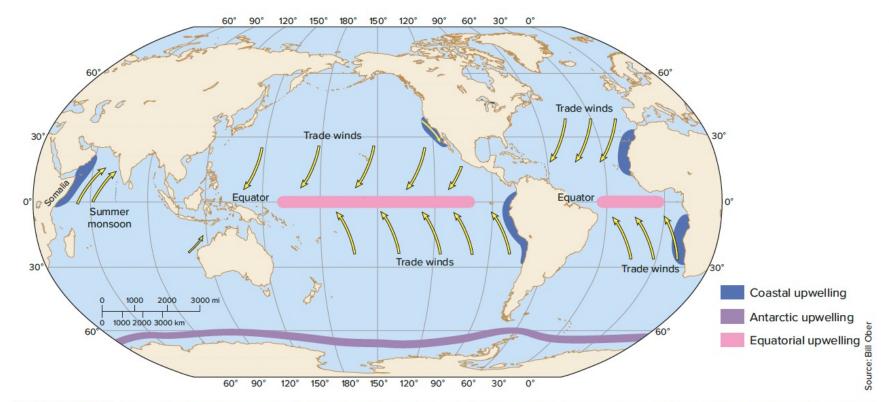


FIGURE 15.31 The major upwelling areas of the world in relation to the prevailing winds. These areas are among the most productive parts of the ocean (see Fig. 15.26). Less intense or more sporadic upwelling occurs in many other areas.

#### THERMOHALINE CIRCULATION

Ocean is stratified

Light water

warm

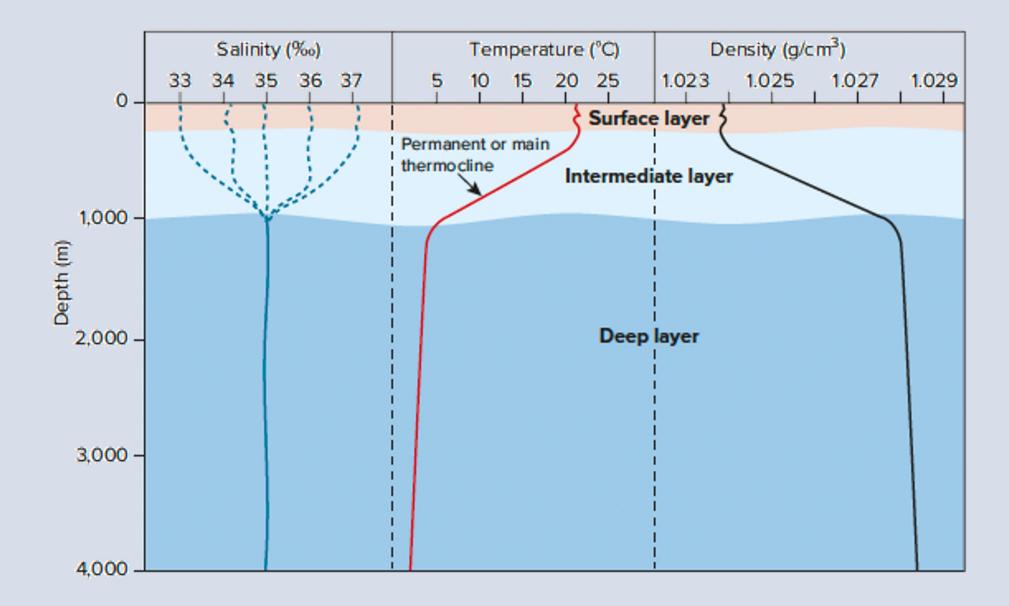
"light"

Dense water

Cold

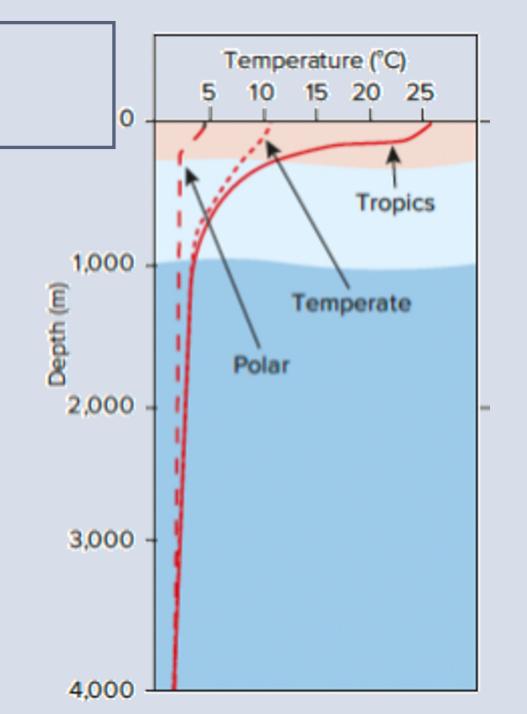
Dense

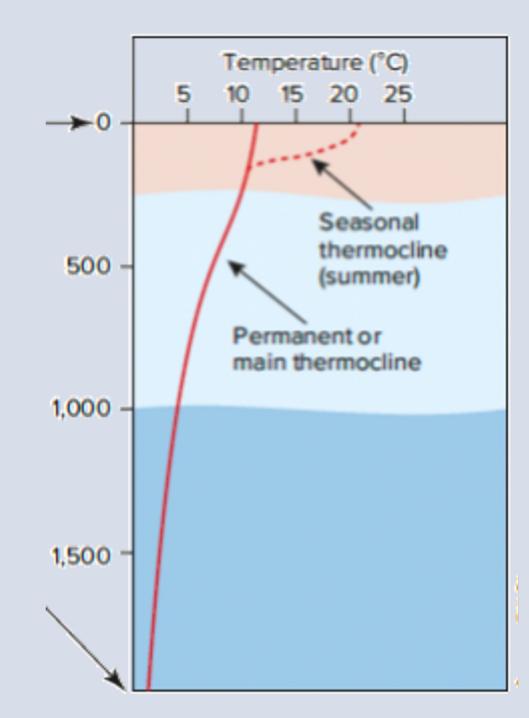
• The ocean has three main layers: the surface or mixed layer, the intermediate layer, and the deep layer.

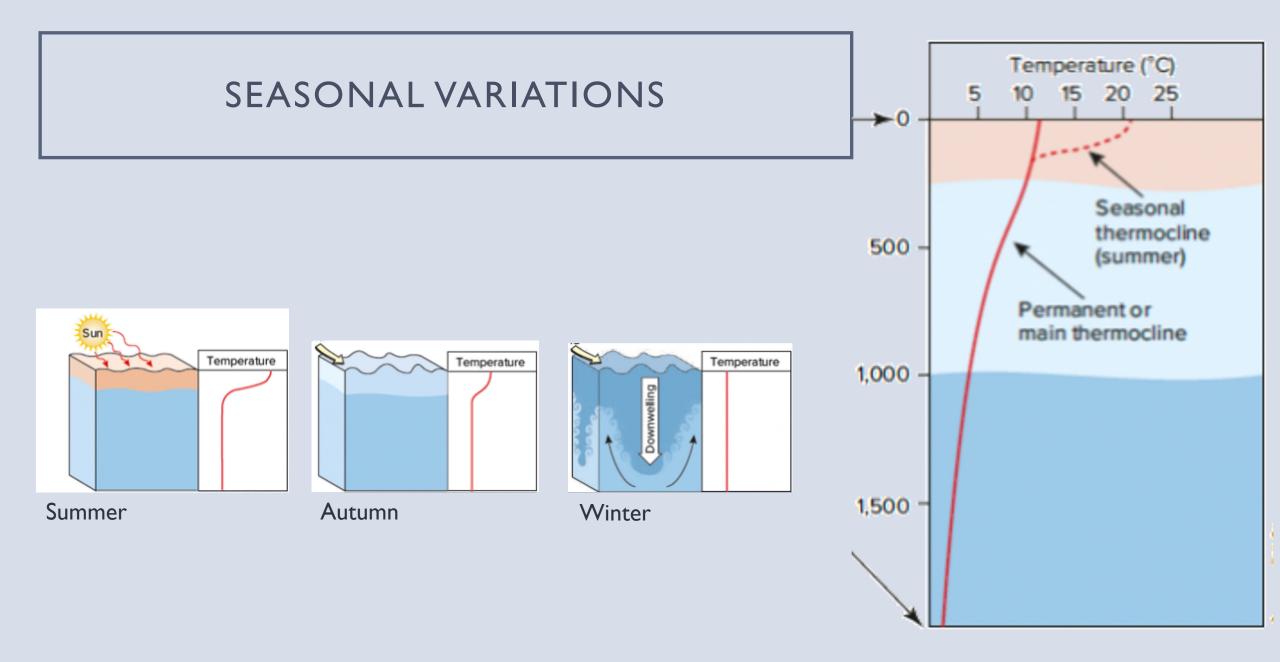


#### LATITUDAL VARIATION

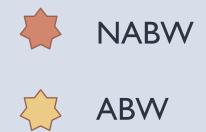
- Surface temperature varies with latitude,
- highest surface temperature in the tropics.
- Deep-water temperature and salinity much more uniform

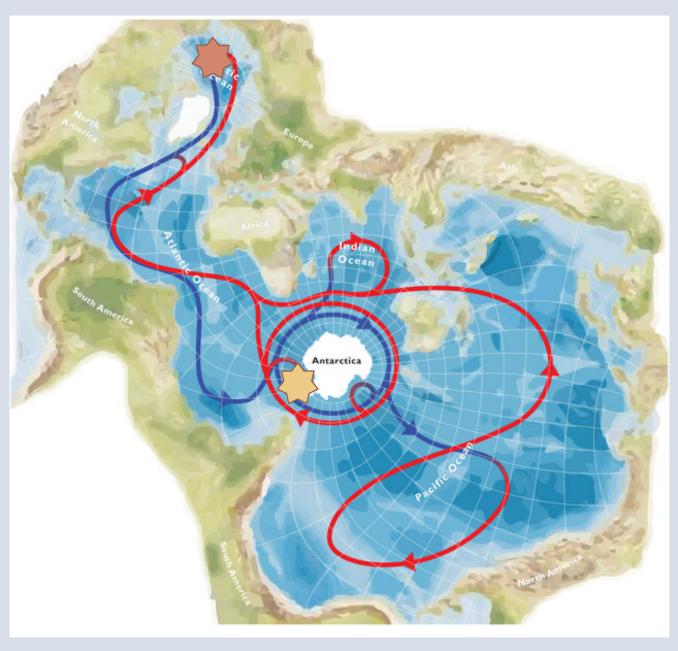


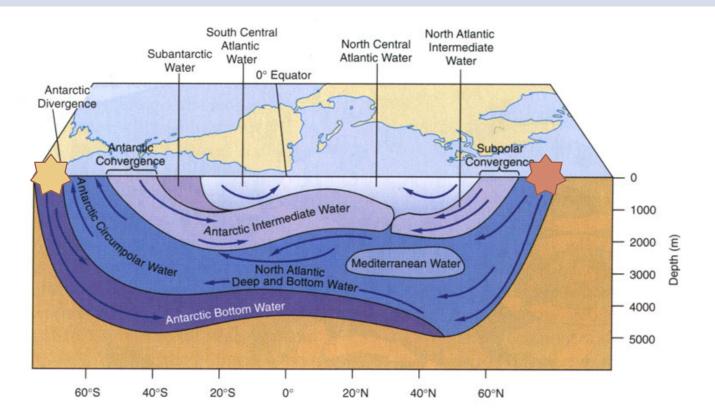


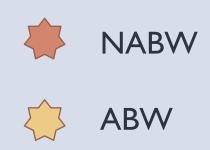


• The globe viewed on a Spilhaus projection; in contrast to conventional projections, this portrays the ocean fringed by land. The global thermohaline circulation is shown in cartoon form, with upper-layer flow in red and lower-layer flow in blue.





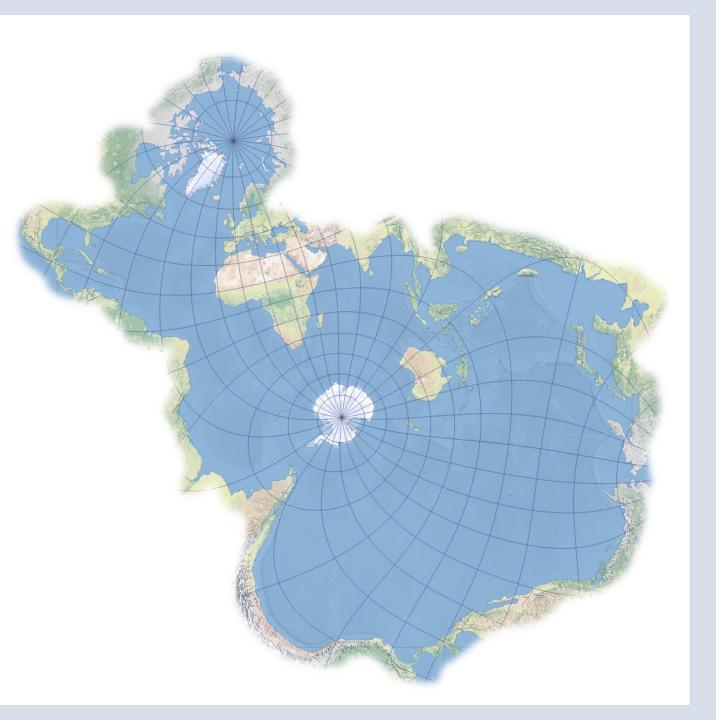




**FIGURE 8–27** A vertical cross section of the Atlantic Ocean shows the various water masses that form layers at different depths. Antarctic Bottom Water is the densest water mass and it flows northward from around Antarctica. North Atlantic Bottom Water sinks near Greenland and flows southward over the top of the Antarctic Bottom Water. Intermediate depth water masses are formed and sink at the Antarctic and subpolar convergences. The near surface layers are more complex. Note the tongue of Mediterranean Water that spreads across the North Atlantic Ocean from the Straits of Gibraltar at about 2-3,000 m depth between 20°N and 55°N.



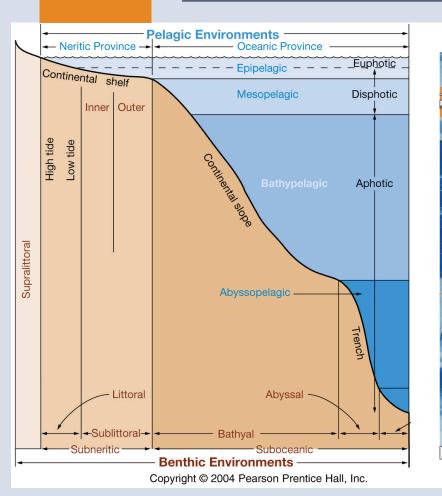
# QUESTIONS

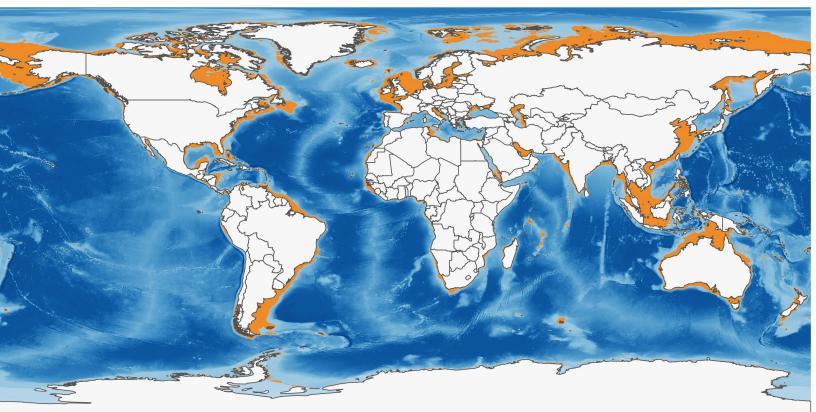


# I. DIVISIONS OF THE MARINE ENVIRONMENT

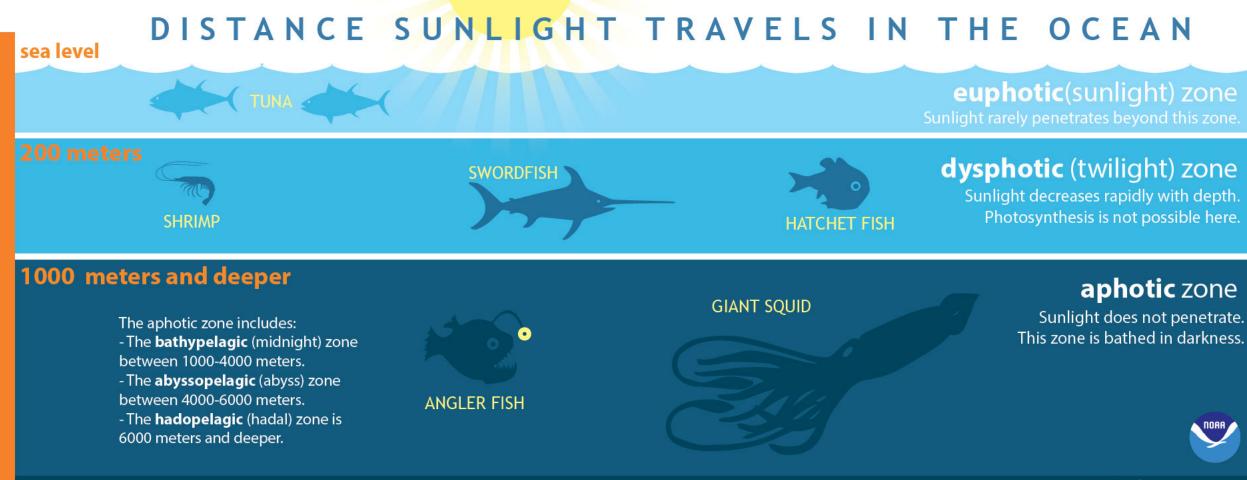
<u>πέλαγος</u> (pélagos) 'open sea'

# NERITIC PROVINCE

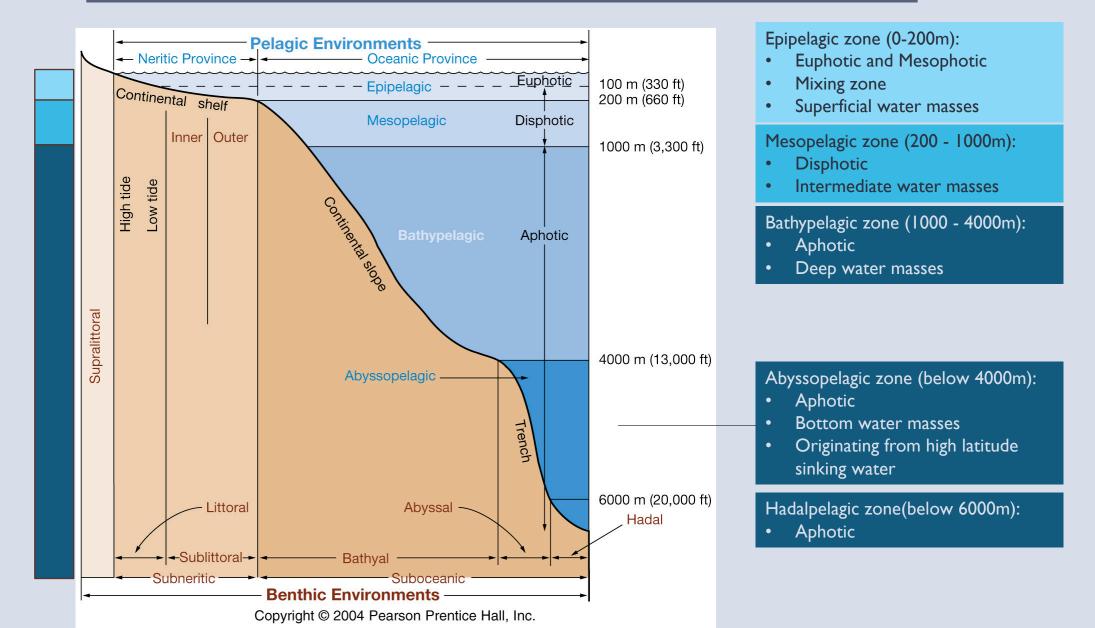




# I. DIVISIONS OF THE MARINE ENVIRONMENT



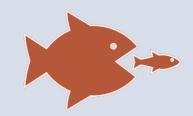
# I.I. ZONES OF THE PELAGIC DOMAIN



## SIMPLE ECOSYSTEM

• Primary Producers

Consumers & Food Chain



• Detritus & DOM



# GASSES IN THE OCEANS

#### • Gasses

- oxygen (O<sub>2</sub>)
- carbon dioxide (CO<sub>2</sub>)
- nitrogen (N<sub>2</sub>)
- Solubility
  - Pressure
  - Temperature
  - Salinity



# N2 78% 11% O2 21% 6% CO2 0.04% 83% Total 99.04% 100%

Air

**Total Ocean** 

**Surface Ocean** 

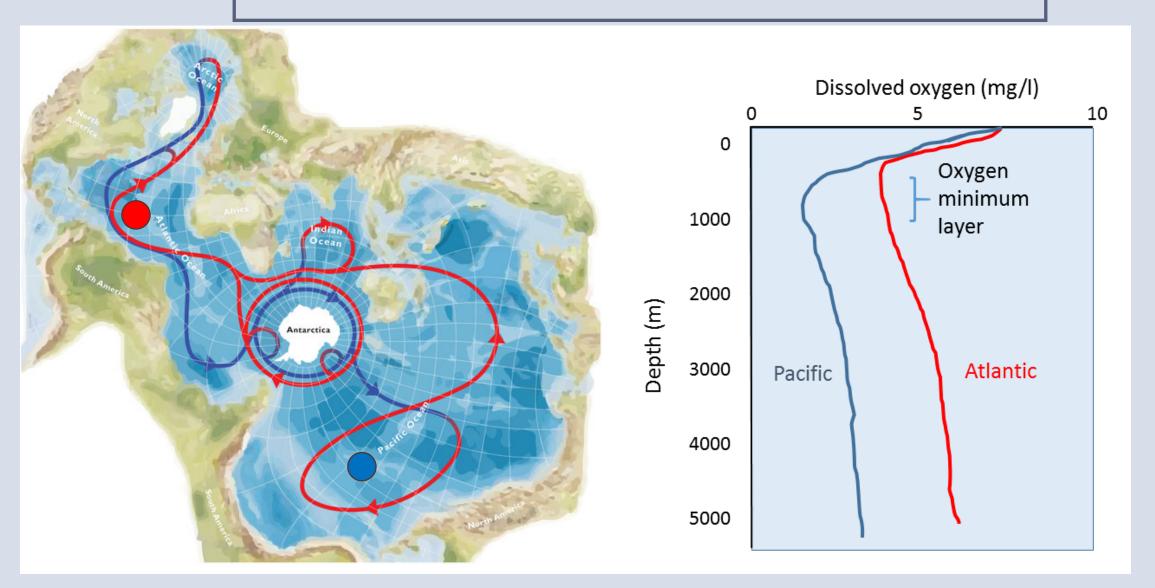
48%

36%

15%

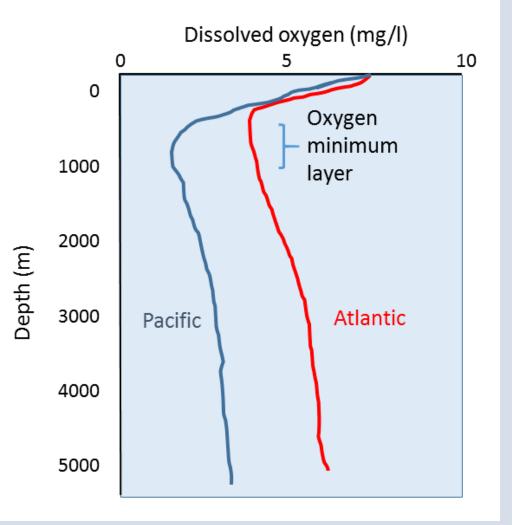
**99%** 

#### OXYGEN



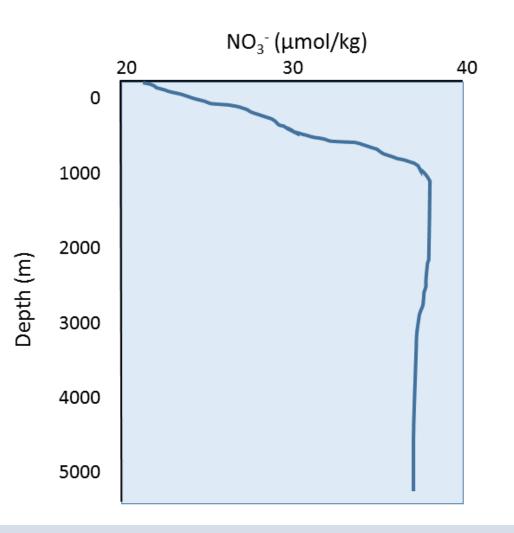
## OXYGEN

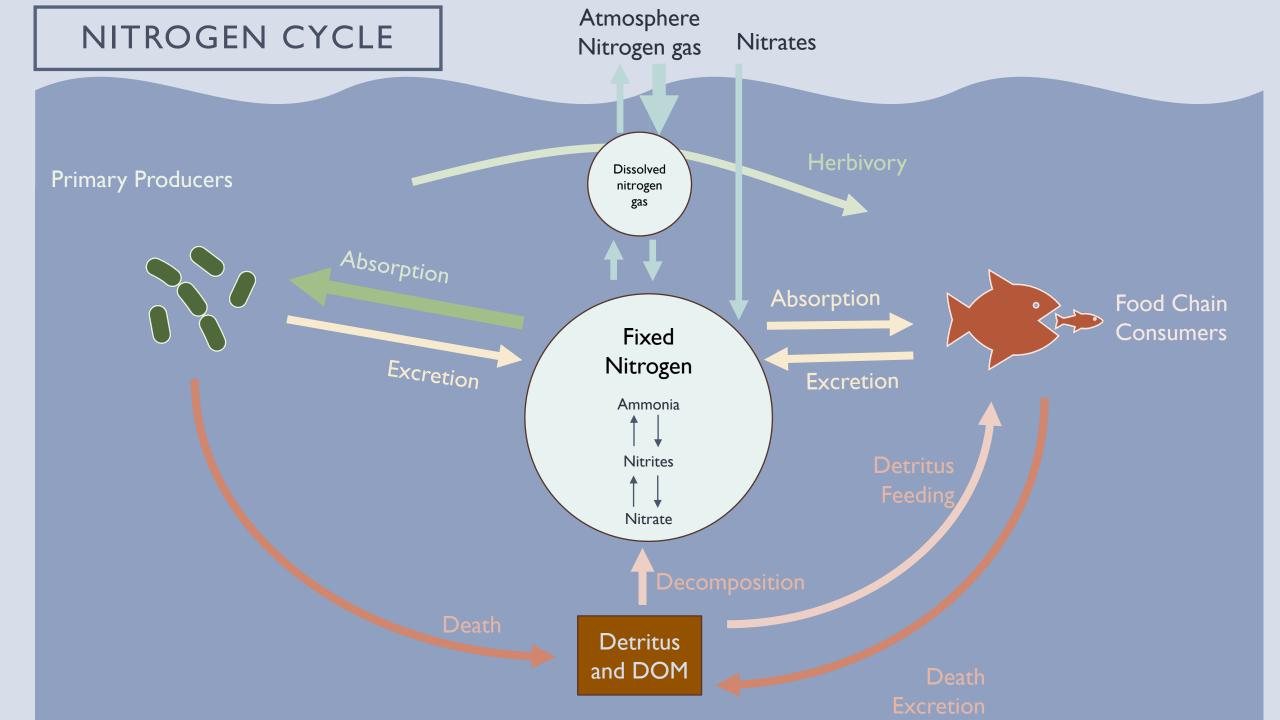
- Surface
  - exchange from atmosphere
  - Produced by primary productivity
- Oxygen minimum layer
  - No exchange
  - No primary productivity
- Deep water
  - Cold
  - high pressure
  - Ocean circulation



# NITROGEN AND NUTRIENTS

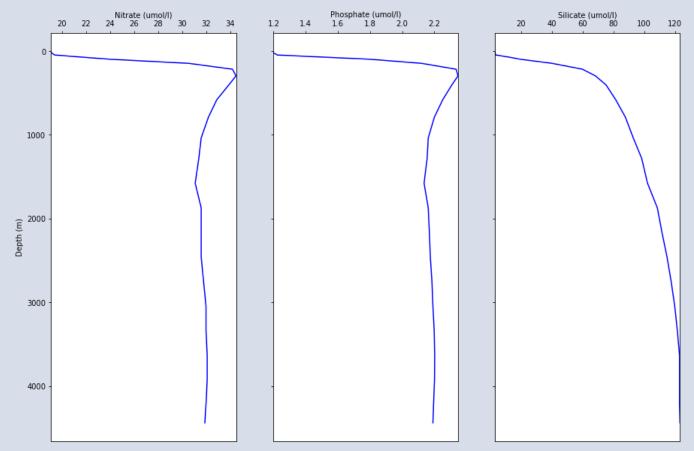
- Surface
  - used by primary producers
- Increase with depth
  - No longer consumed
  - No primary productivity
- Deep water
  - Regenerated through decomposition



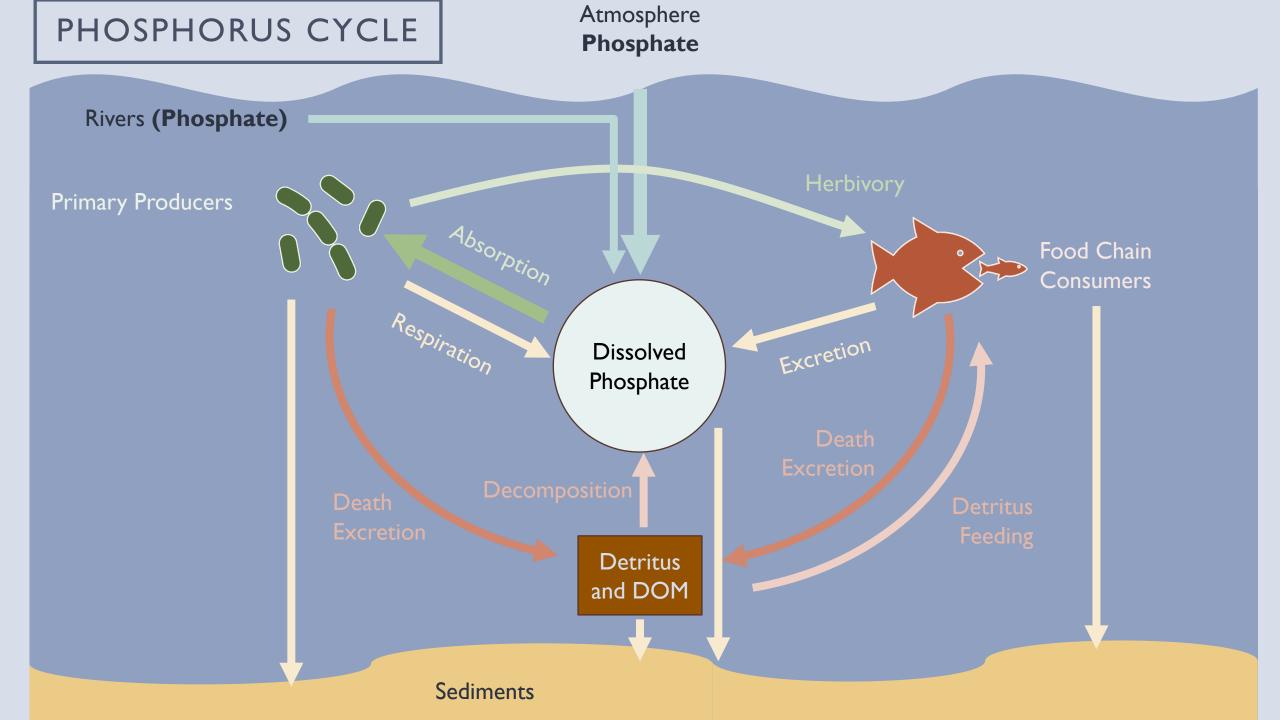


# NITROGEN AND NUTRIENTS

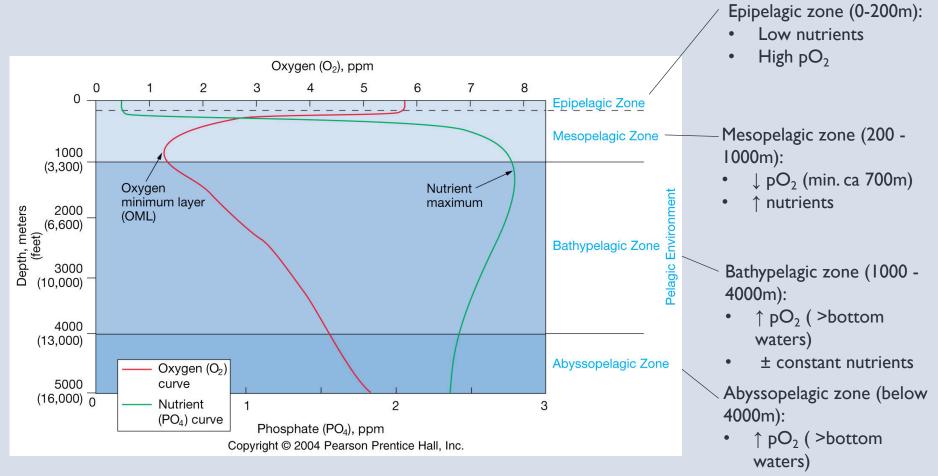
- Nitrate
- Phosphate
- Silicate



Nitrate, phosphate, and silicate profiles from an open-ocean location in the South Atlantic (52° S, 35°13'58.8" W), north of South Georgia Island (image by PW, data from 2014, World Ocean Database).



# I.2. VERTICAL DISTRIBUTION OF O<sub>2</sub> AND NUTRIENTS



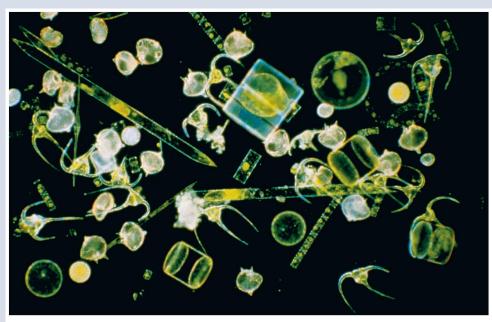
± constant nutrients



# QUESTIONS



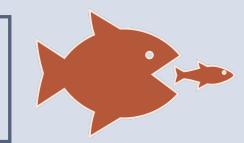
- Seston
  - Plankton: Unable to move against currents (dependent on the water mass)
  - Tripton: Particulate organic matter (POM) / marine snow





"Marine snow" Photo: Henk-Jan Hoving/GEOMAR

#### NEKTON

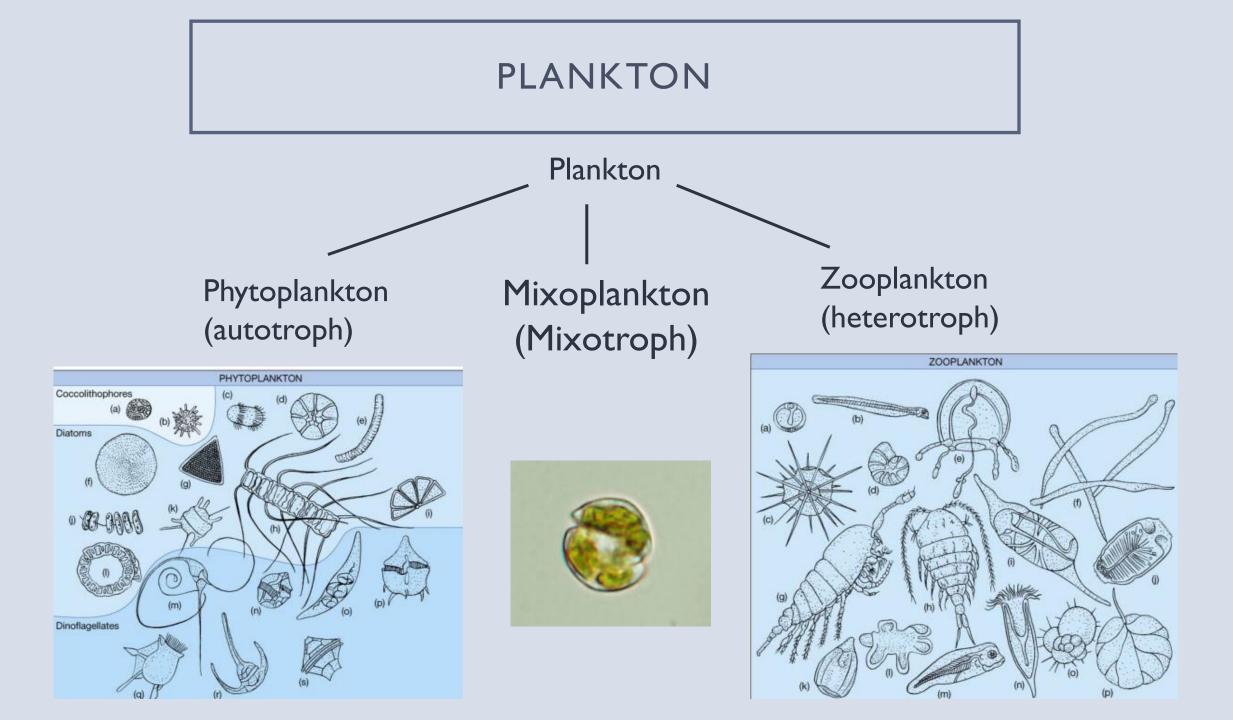




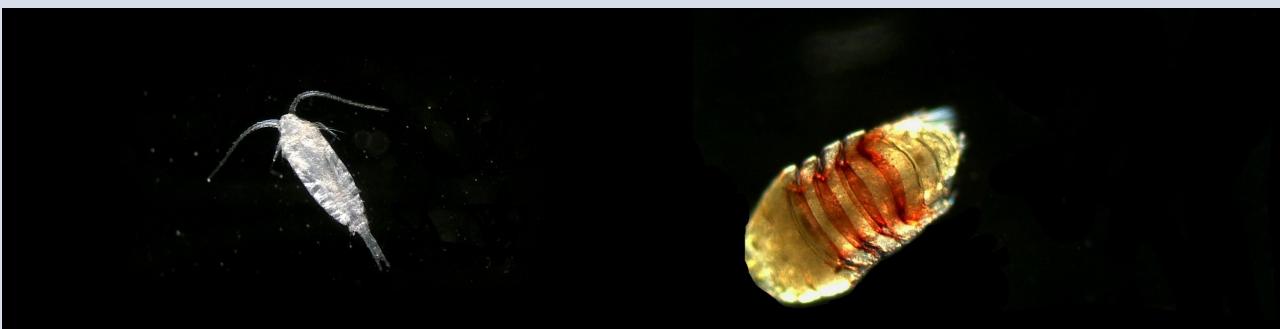
#### <u>Nekton</u>:

Able to swim against currents (independent on water masses)

© Bruno de Giusti. An underwater picture taken in Moofushi Kandu, Maldives, showing predator bluefin trevally sizing up schooling anchovies



- **Holoplanktonic**: spend their entire life in the plankton, drifting wherever the currents take them.
- copepods, certain jellyfish species, some diatoms and amphipods.



- **Meroplanktonic** spend only a portion of their life cycle in the plankton.
- larval crabs and lobsters live in the plankton for the first portion of their life until they are large enough to settle on the seafloor.
- copepods, certain jellyfish species, some diatoms and amphipods.
- Larval fish



- Meroplankton
  - seastar
  - barnacles









# 2.1. DEFINITIONS

Aquaticlivefood.com.au

Ultraplankton	< 2µm
<u>Nano</u> plankton	2 – 20 <u>µm</u>
Microplankton	20 – 200 µm
Mesoplankton	0.2 – 20 mm
macroplankton	2-20 cm
Megaplankton	20-200 cm

Net Plankton





Daylymail.co.uk

#### **PYTHOPLANKTON**

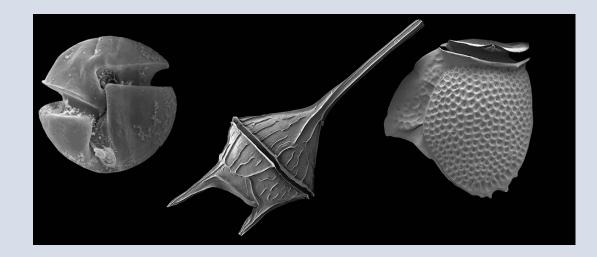
Diatoms

- Silicate dioxide box (frustulae)
- Generally larger

#### dinoflagellates

- Two flagella
- Generally smaller





## HARMFUL ALGAE BLOOMS

- Blooms can harm people, animals, and the environment when they
- Produce toxins (poisons)
- Become too dense
- Use up the oxygen in the water
- Release harmful gases



A harmful algal bloom offshore of San Diego County, California. (NOAA, With permisson from Kai Schumann)

#### HARMFUL ALGAE BLOOMS

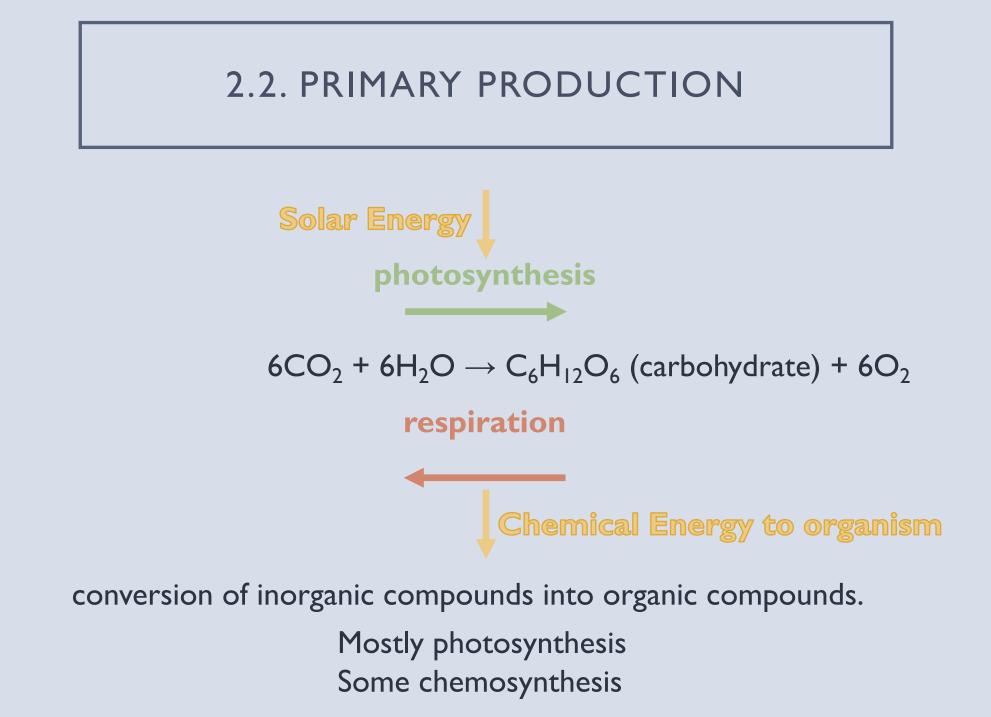
- Cyanobacteria (sometimes called blue-green algae) (freshwater)
- Dinoflagellates (sometimes called microalgae or red tide)
- Diatoms (sometimes called microalgae or red tide)



# QUESTIONS

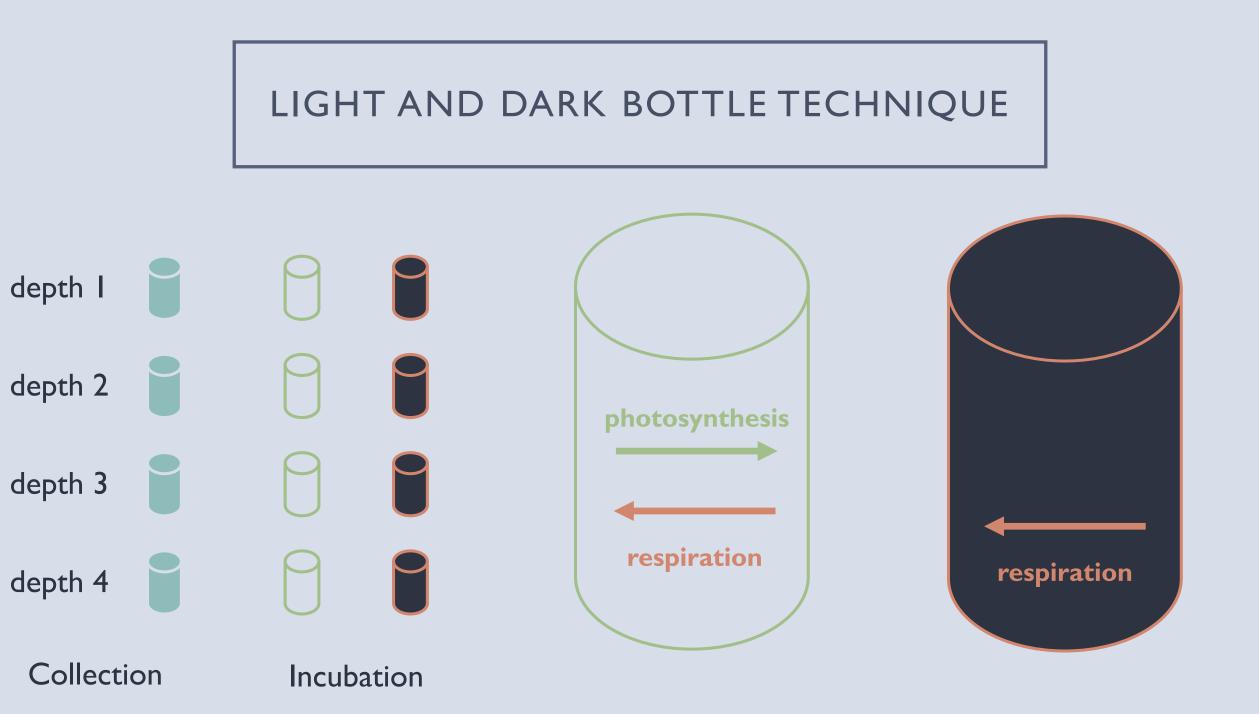
## EPIPELAGIC

• Primary Production



#### 2.2. PRIMARY PRODUCTION

- Gross primary productivity: total amount of organic material synthesized during photosynthesis or chemosynthesis.
- Net primary productivity: difference between the gross productivity and the amount of organic material used during respiration.
- Respiration: energy required for metabolic activity
- Net productivity = Gross productivity Respiration



# **I4C METHOD**

- A known amount of radioactive carbon in the form of bicarbonate is added to a water sample.
- The uptake of carbon by the primary producers is determined by measuring their radioactivity.

#### STANDING CROP OF PHYTOPLANKTON

- Phytoplankton are free-floating microscopic plants which are the primary producers of the oceanic system.
- In this method, either the number of plankton or the total weight of plankton per unit volume or unit area is measured.
- Standing crop is **not equal** to productivity

# PRIMARY PRODUCTION

• What are limiting factors?

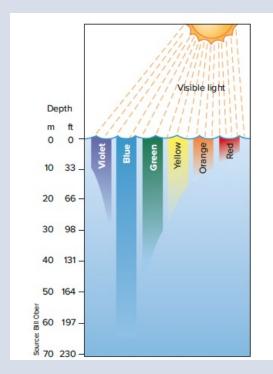
#### PRIMARY PRODUCTION

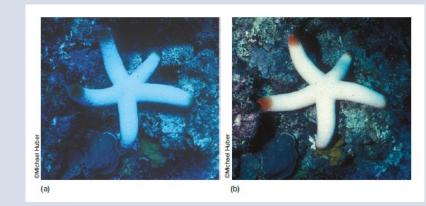




#### Nutrients

#### LIGHT IN THE OCEAN



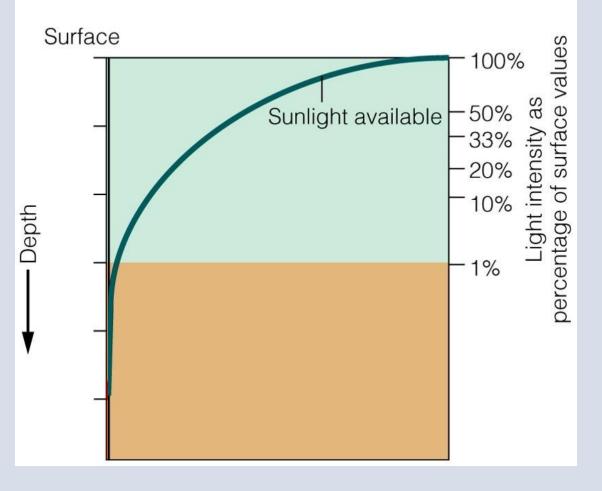


- Sea water absorb the photosynthetic active radiation (PAR)
- I<sub>z</sub>: PAR at depth

 $I_z = I_0 e^{-kz}$ 

Where k: extinction coefficient

z: depth I<sub>0</sub>: surface PAR



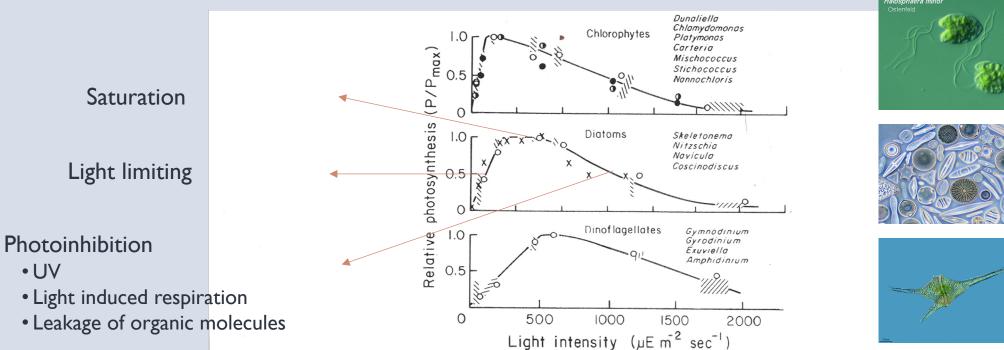
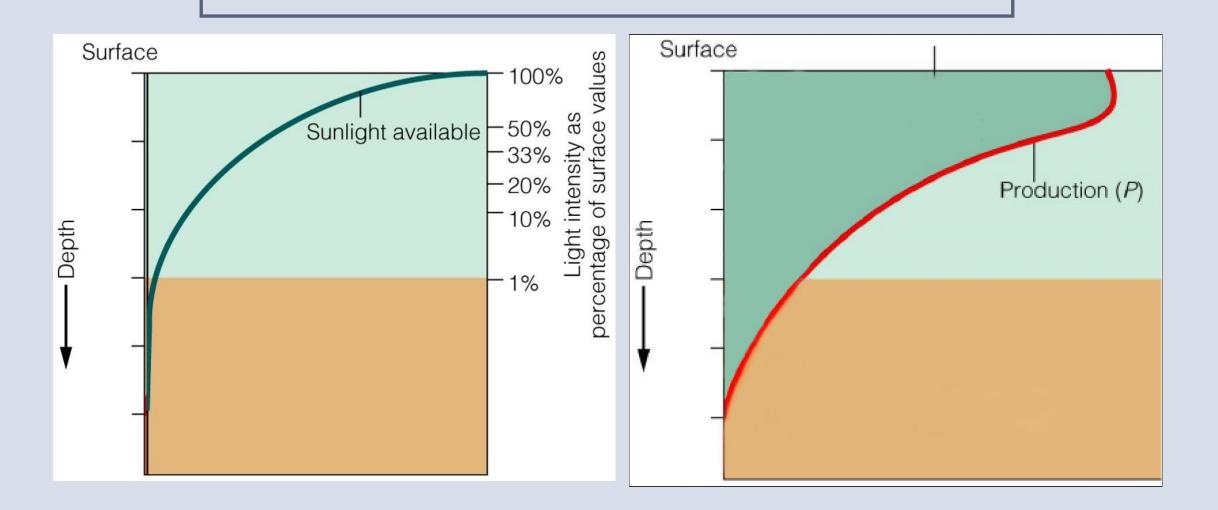


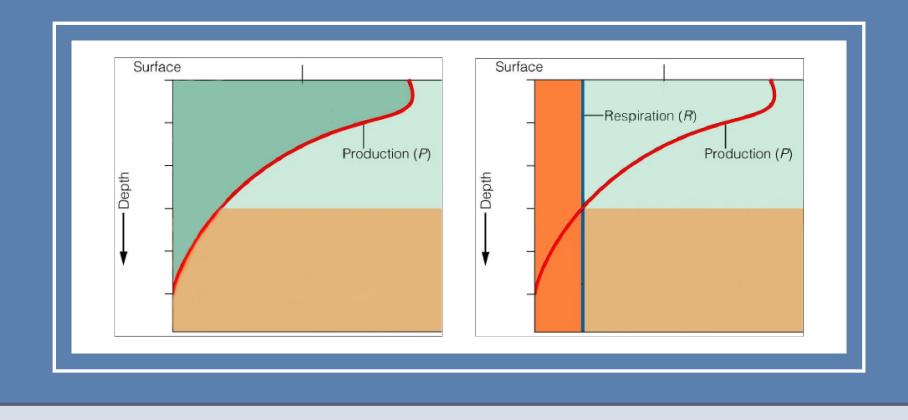


Figure 2-5. Curves of relative photosynthesis  $(P/P_{max})$  versus light intensities for three algal groups. The chlorophytes include green and flagellated greens. Shaded rectangles represent the dispersion of points obtained experimentally using neutral filters in cultures grown with an irradiance of 1.3  $\mu$ E m<sup>-2</sup> sec<sup>-1</sup>: open circles correspond to cultures in natural light: solid and half-solid circles are cultures at 0.48 and 1.98  $\mu$ E m<sup>-2</sup> sec<sup>-1</sup> and measured in the harbor at Woods Hole. Crosses correspond to the data of Jenkin (1937). Adapted from Ryther (1956).

#### Differs according to taxa

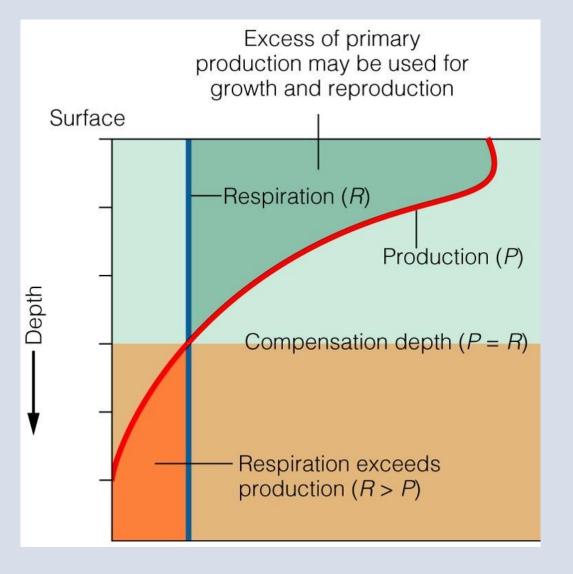
#### PRODUCTION

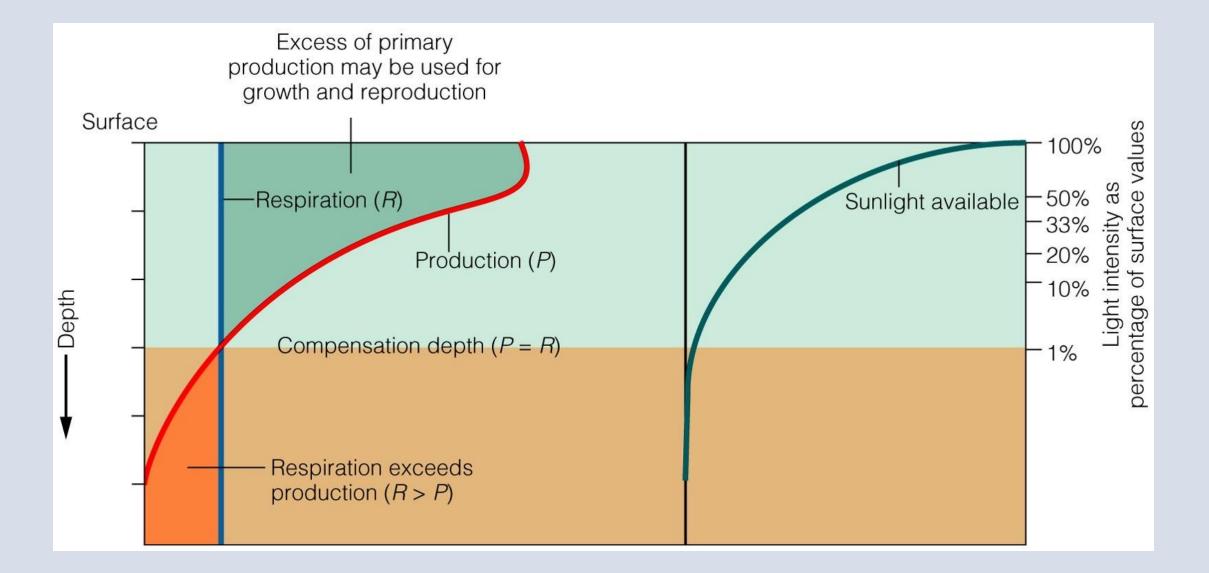


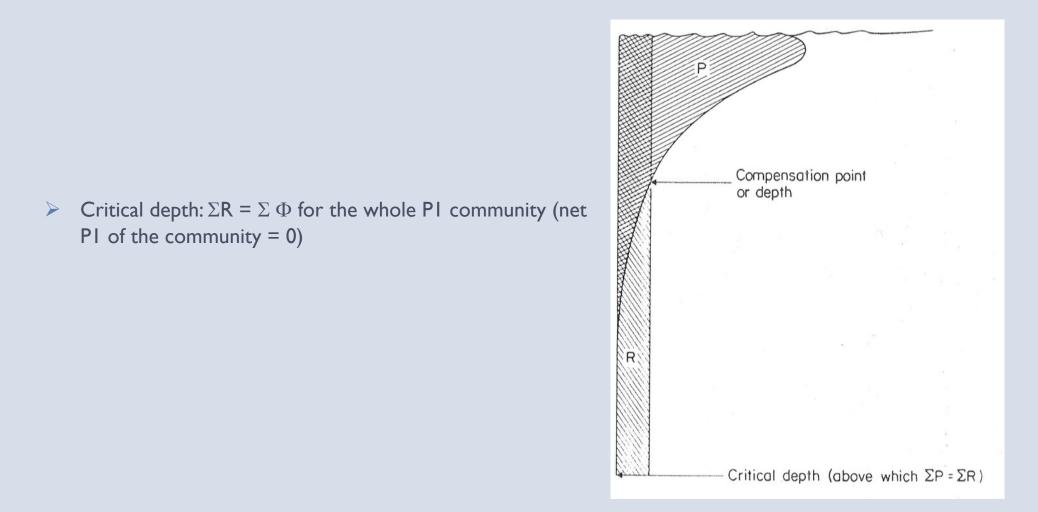


# RESPIRATION

- Sea water absorb the photosynthetic active radiation (PAR)
- But respiration  $\neq$  function of depth
- > Compensation depth:  $R = \Phi$  for a particular species







- What is a nutrient ?
  - Only for PI, not for consumers !
  - Major nutrients: C, N, P, O, Si, Mg, K, Ca
    - N: proteins

Inorganic forms in sea water:

- $NH_4^+$ : no reduction necessary  $\rightarrow$  most favorable
- $NO_3^-$ ,  $NO_2^-$ : have to be reduced (nitrate reductase)
- Most marine inorganic N as  $NO_3^-$  (1µM to > 25µM) (Nitrite)
- P: energy storage (ATP), enzyme phosphorylation

Inorganic forms in sea water:

- <u>D</u>issolved <u>Inorganic Phosphate</u> (PO<sub>4</sub><sup>2-</sup>) (most favorable)
- <u>D</u>issolved <u>O</u>rganic <u>P</u>hosphate
- Si: diatom frustule
- Trace nutrients: Fe, (Cu, V, Cd)

#### Abundant in sea water

• Uptake

Described by

Michaelis-Menten equation:

V= Vmax . C Ks + C

Vmax= Uptake velocity at saturation C= nutrient concentration in SW Ks= nutrient concentration in SW at which V=Vmax/2 (constant)

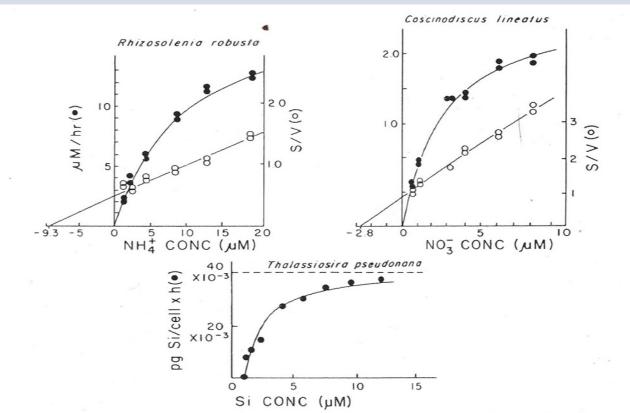
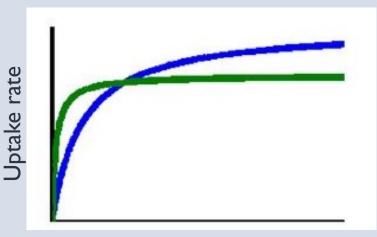


Figure 2-13. Michaelis-Menten curves (filled circles) and Woolf plots (open circles) fitted to data on uptake ( $\mu$ mole/hr) of ammonium, nitrate, and silica by three diatoms at different nutrient concentrations ( $\mu$ mole/liter). S is the concentration of nutrient being taken up, V is the uptake velocity. The x-intercepts of the top two graphs provide the estimate of  $K_s$ . Adapted from Eppley et al. (1969) and Paasche (1973).

• Uptake: low and high Ks

Species 1Species 2

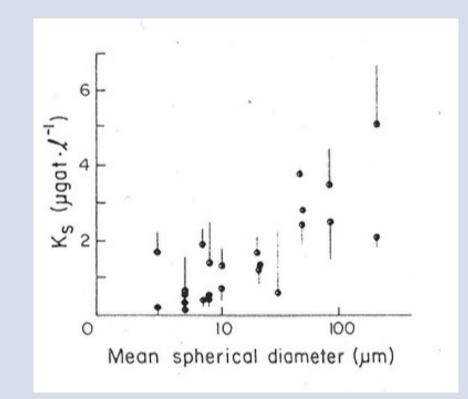
KsI < Ks2 VmaxI < Vmax2



Nutrient concentration

- Species with a low Ks favoured in low nutrients concentrations but lower capacity  $\rightarrow$  no or limited blooms
- Species with a high Ks favoured in high nutrients concentrations and able to incorporate high amounts of nutrients → blooms

#### Ks depends on size



**Figure 2-14.** Half-saturation  $(K_s)$  values for nitrate uptake by phytoplankton of different size. The bars show the 95% confidence limits for the highest and lowest mean  $K_s$  reported. Adapted from Malone (1980).

#### • Ks differ according to habitat

**Table 2-2.** Half-Saturation Constants for Nitrate of Three Species of Algae

 Obtained from Coastal and Oceanic Environments in the Atlantic"

Species	Source	$K_s$ (Mean $\pm 95\%$ confidence interval)
Cyclotella nana	Moriches Bay	$1.87 \pm 0.48$
	Edge of shelf	$1.19 \pm 0.44$
	Sargasso Sea	$0.38 \pm 0.17$
Fragilaria pinnata	Oyster Bay	$1.64 \pm 0.59$
	Sargasso Sea	$0.62 \pm 0.17$
<i>Bellerochia</i> spp.	Great South Bay	$6.87 \pm 1.38$
	Off Surinam	$0.12 \pm 0.08$
	Sargasso Sea	$0.25 \pm 0.18$

" From Carpenter and Guillard (1971). © Ecological Society of America, reprinted by permission.

Valiela 2009

• Ks

• Usually lower in nano- (flagellates) than in microphytoplankton (diatoms)

 Usually higher in coastal communities rich in nutrients (selection for high Ks species)



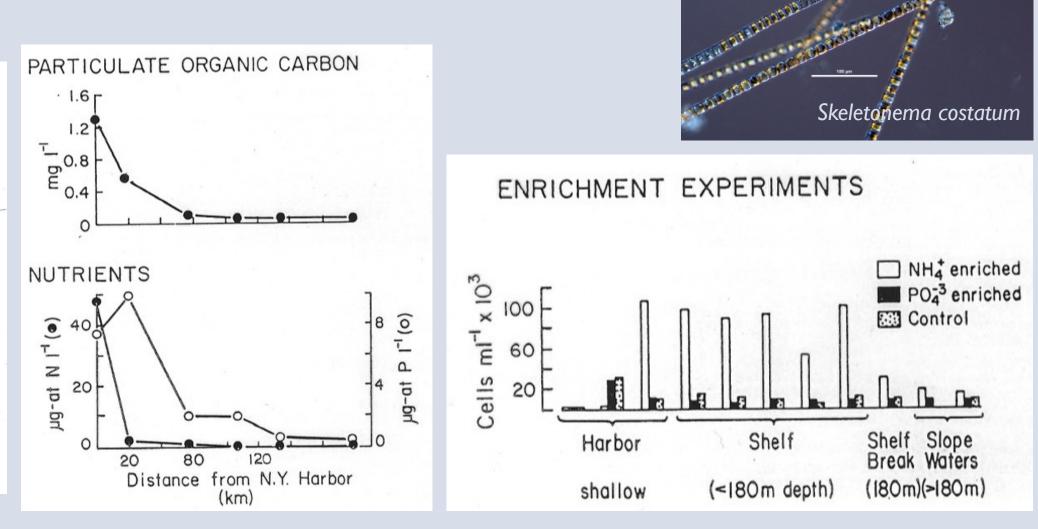
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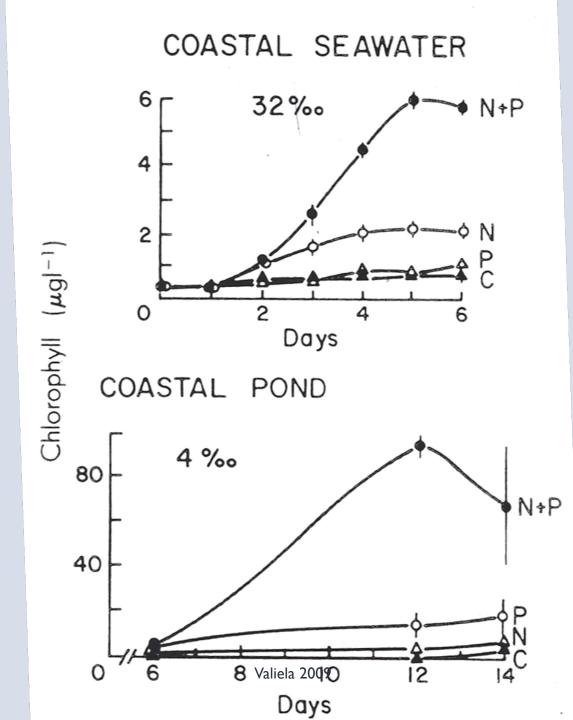
# NUTRIENTS NAND P

Figure 2-24. Top and middle: Concentrations of particulate organic carbon and nutrients in surface water in a transect from New York Harbor to offshore. Bottom: Growth of Skeletonema costatum in water samples that were enriched with ammonium or phosphate and in unenriched samples. The sequence of stations is in relation to their distance from the source of nutrients in New Harbor. The inoculum York which the experiments with were started was of the same size as the left-most station in graph. Adapted from the Ryther and Dunstan (1971). © AAAS, reprinted by permission.

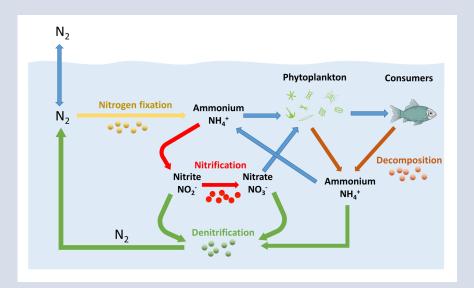


## NUTRIENTS NAND P

Figure 2-21. Enrichment experiments with coastal seawater of Vineyard Sound (salinity 32‰), Massachusetts, and a freshwaterdominated coastal pond (salinity 4‰) in Falmouth, Massachusetts. N+P, addition of nitrogen and phosphorus; P, addition of phosphorus; N, addition of nitrogen; C, control, no nutrient addition. Adapted from Vince and Valiela (1973) and unpublished data of Nina Caraco. Values are mean  $\pm$ standard error of several replicates.



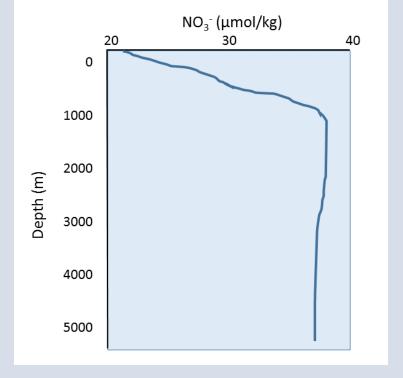
- Sources of N (and P)
  - I. Fixation of Atmosperic  $N_2$
  - 2. Land run-off (rivers): principally NO<sub>3</sub>-
  - 3. Coastal bottom waters (upwelling!): principally NO3<sup>-</sup>
  - 4. Excretion/elimination by water column consumers: principally NH<sub>4</sub><sup>+</sup>
- NO<sub>3</sub><sup>-</sup> based PI: « new production »
- NH<sub>4</sub><sup>+</sup> based PI: « regenerated production »



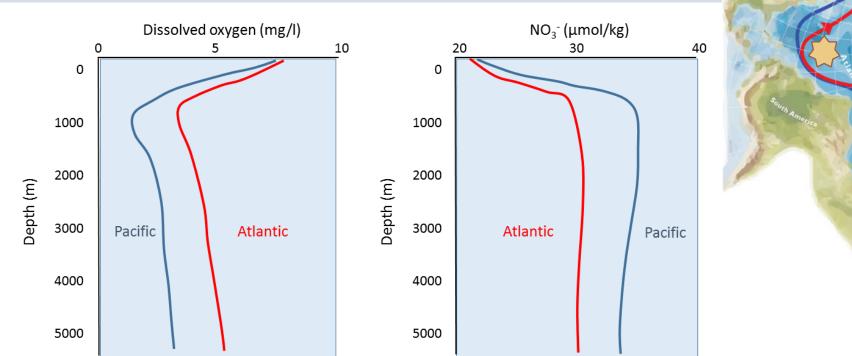
Simplified nitrogen cycle in the ocean. Coloured dots represent the marine bacteria responsible for nitrogen cycling

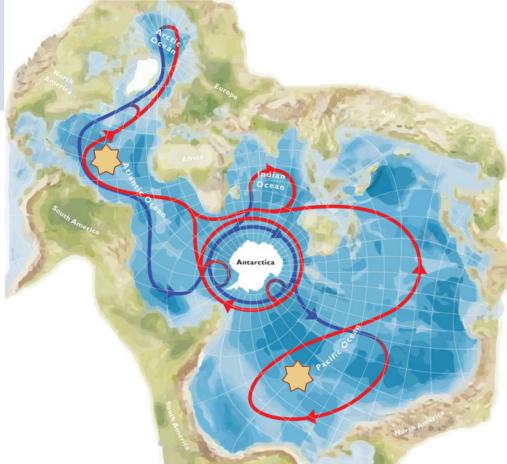
low at the surface

- rapidly consumed
- do not have the chance to accumulate
- levels increase at depth
  - no longer consumed
  - regenerated through decomposition



# Representative nutrient (nitrate) profile for the open ocean



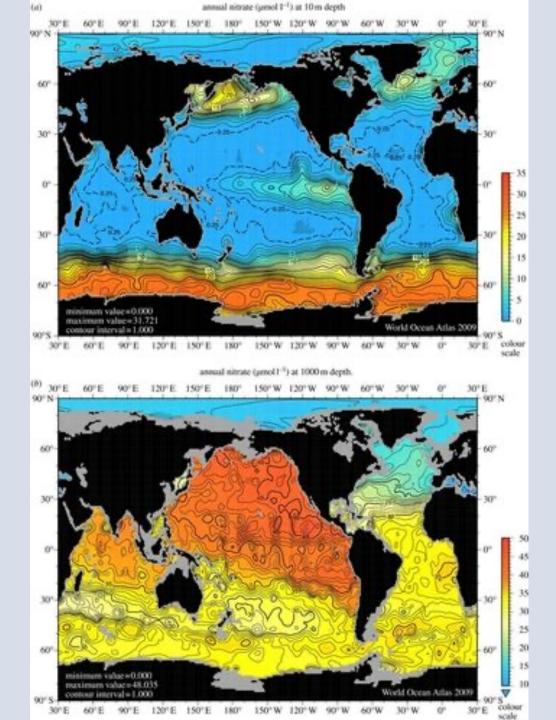


Representative nutrient (nitrate) profile for the open ocean

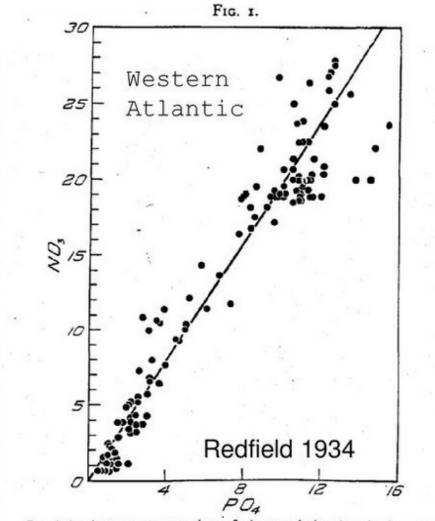
© Introduction to Oceanography by Paul Webb © Spilhausen map Mike Meredith

# Figure 1. Nitrate concentrations in (*a*) surface waters of the ocean and (*b*) at 1000 m depth

The marine nitrogen cycle: recent discoveries, uncertainties and the potential relevance of climate change, Volume: 368, Issue: 1621, DOI: (10.1098/rstb.2013.0121)

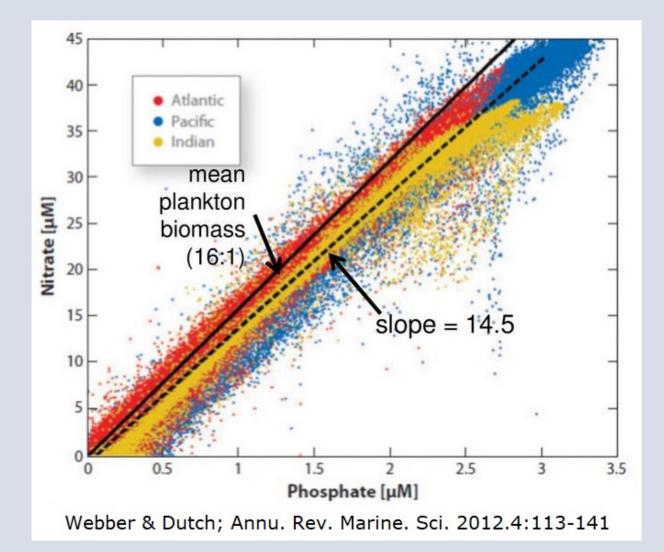


- N and P
  - In most marine environments, N is the main limiting nutrient
  - P is limiting in some eutrophicated environments (see later)



Correlation between concentrations of nitrate and phosphate in the waters of western Atlantic Ocean. Ordinate, concentration of nitrate, units  $10^{-3}$  millimols per liter; abscissa, concentration of phosphate, units  $10^{-4}$  millimols per liter. The line represents a ratio of  $\triangle N : \triangle P = 20 : 1$  milligram atoms.

- C:N:P
  - In many phytoplanktonic primary producers, the C:N:P ratio is typically 106 : 16 : 1 = Redfield ratio
  - If Sea Water nutrient concentrations depart from this ratio, a limitation is very probable



	Nitrates (mg/l) Green alga																	
		0.1	1.0	2.0	3.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	25.0	30.0	35.0	40.0	45.0	50.0
<b>es</b> (mg/l)	0.01	10.00	100.00	200.00	350.00	500.00	750.00	1000.00	1250.00	1500.00	1750.00	2000.00	2500.00	3000.00	3500.00	4000.00	4500.00	5000.00
	0.05	2.00	20.00	40.00	70.00	100.00	150.00	200.00	250.00	300.00	350.00	400.00	500.00	600.00	700.00	800.00	900.00	1000.00
	0.1	1.00	10.00	20.00	35.00	50.00	75.00	100.00	125.00	150.00	175.00	200.00	250.00	300.00	350.00	400.00	450.00	500.00
	0.2	0.50	5.00	10.00	17.50	25.00	37.50	50.00	62.50	75.00	87.50	100.00	125.00	150.00	175.00	200.00	225.00	250.00
	0.3	0.33	3.33	6.67	11.67	16.67	25.00	33.33	41.67	50.00	58.33	66.67	83.33	100.00	116.67	133.33	150.00	166.67
	0.4	0.25	2.50	5.00	8.75	12.50	18.75	25.00	31.25	37.50	43.75	50.00	62.50	75.00	87.50	100.00	112.50	125.00
	0.5	0.20	2.00	4.00	7.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00
	0.6	0.17	1.67	3.33	5.83	8.33	12.50	16.67	20.83	25.00	29.17	33.33	41.67	50.00	58.33	66.67	75.00	83.33
	0.7	0.14	1.43	2.86	5.00	7.14	10.71	14.29	17.86	21.43	25.00	28.57	35.71	42.86	50.00	57.14	64.29	71.43
	0.8	0.13	1.25	2.50	4.38	6.25	9.38	12.50	15.63	18.75	21.88	25.00	31.25	37.50	43.75	50.00	56.25	62.50
	0.9	0.11	1.11	2.22	3.89	5.56	8.33	11.11	13.89	16.67	19.44	22.22	27.78	33.33	38.89	44.44	50.00	55.56
	1	0.10	1.00	2.00	3.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	25.00	30.00	35.00	40.00	45.00	50.00
	1.1	0.09	0.91	1.82	3.18	4.55	6.82	9.09	11.36	13.64	15.91	18.18	22.73	27.27	31.82	36.36	40.91	45.45
	1.2	0.08	0.83	1.67	2.92	4.17	6.25	8.33	10.42	12.50	14.58	16.67	20.83	25.00	29.17	33.33	37.50	41.67
-	1.3	0.08	0.77	1.54	2.69	3.85	5.77	7.69	9.62	11.54	13.46	15.38	19.23	23.08	26.92	30.77	34.62	38.46
Ĕ	1.4	0.07	0.71	1.43	2.50	3.57	5.36	7.14	8.93	10.71	12.50	14.29	17.86	21.43	25.00	28.57	32.14	35.71
Phospha	1.5	0.07	0.67	1.33	2.33	3.33	5.00	6.67	8.33	10.00	11.67	13.33	16.67	20.00	23.33	26.67	30.00	33.33
	1.6	0.06	0.63	1.25	2.19	3.13	4.69	6.25	7.81	9.38	10.94	12.50	15.63	18.75	21.88	25.00	28.13	31.25
	1.7	0.06	0.59	1.18	2.06	2.94	4.41	5.88	7.35	8.82	10.29	11.76	14.71	17.65	20.59	23.53	26.47	29.41
	1.8	0.06	0.56	1.11	1.94	2.78	4.17	5.56	6.94	8.33	9.72	11.11	13.89	16.67	19.44	22.22	25.00	27.78
	1.9	0.05	0.53	1.05	1.84	2.63	3.95	5.26	6.58	7.89	9.21	10.53	13.16	15.79	18.42	21.05	23.68	26.32
	2	0.05	0.50	1.00	1.75	2.50	3.75	5.00	6.25	7.50	8.75	10.00	12.50	15.00	17.50	20.00	22.50	25.00
	2.1	0.05	0.48	0.95	1.67	2.38	3.57	4.76	5.95	7.14	8.33	9.52	11.90	14.29	16.67	19.05	21.43	23.81
	2.2	0.05	0.45	0.91	1.59	2.27	3.41	4.55	5.68	6.82	7.95	9.09	11.36	13.64	15.91	18.18	20.45	22.73
	2.3 2.4	0.04 0.04	0.43 0.42	0.87 0.83	1.52 1.46	2.17 2.08	3.26 3.13	4.35 4.17	5.43 5.21	6.52	7.61 7.29	8.70 8.33	10.87	13.04	15.22	17.39	19.57	21.74
	2.4	0.04	0.42	0.83	1.40	2.08	3.13	4.17	5.21	6.25 6.00	7.29	8.33	10.42 10.00	12.50 12.00	14.58 14.00	16.67 16.00	18.75 18.00	20.83 20.00
	2.5	0.04	0.40	0.80	1.40	2.00	5.00	4.00	5.00	0.00	7.00	8.00	10.00	12.00	14.00	10.00	10.00	20.00

#### NUTRIENTS: SI

- Si limitation may terminate diatom blooms
- Few clearly documented cases

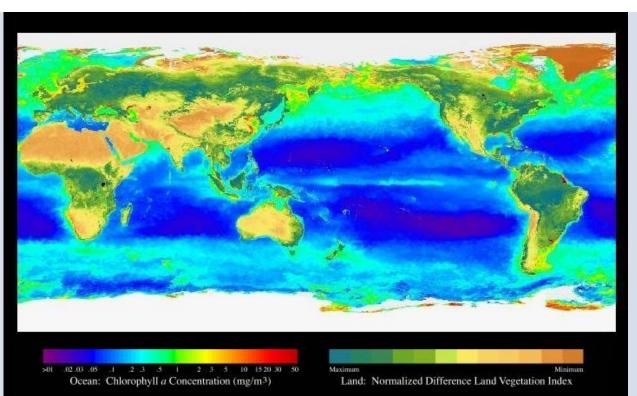


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- Component of ferredoxin involved in electron transfer from photosystem I to NADP<sup>+</sup>
- From terrestrial origin (rivers, airborne)  $\leftarrow \rightarrow$ 
  - high concentrations (I 3 nM) in coastal zones,
  - low to very low concentrations (<1 0.06 nM) in oceanic zones</li>

N:P Ratio [molar] @ Depth [m]=first

# Global nitrogen to phosphorus ratio is plotted for the global surface ocean



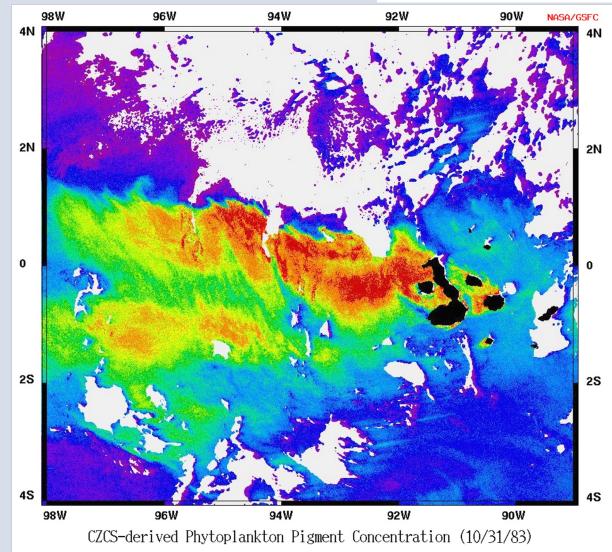
Global distribution of surface chlorophyll levels. Chlorophyll (a proxy for phytoplankton mass/standing stock)

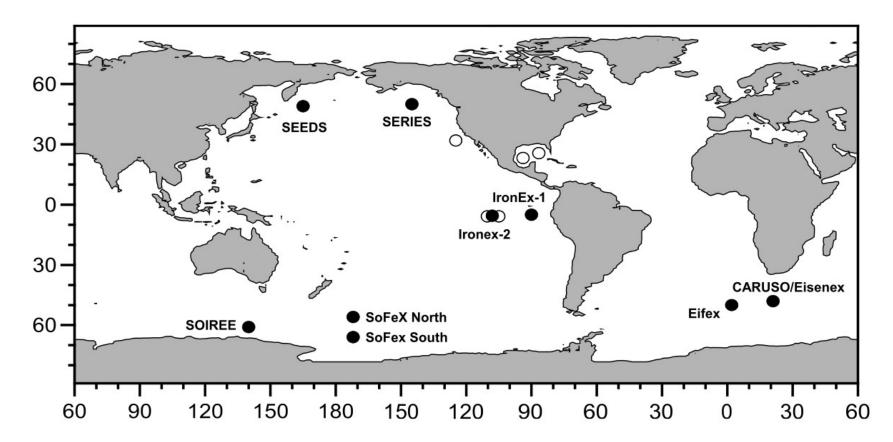
- Component of ferredoxin involved in electron transfer from photosystem I to NADP<sup>+</sup>
- From terrestrial origin (rivers, airborne)  $\leftarrow \rightarrow$ 
  - high concentrations (I 3 nM) in coastal zones,
  - low to very low concentrations (<I 0.06 nM) in oceanic zones</li>
- Limiting in oceanic zones  $\rightarrow$  <u>High Nutrients Low Chlorophyll</u> (HNLC) regions

Galapagos Islands

• First demonstrated as limiting in the equatorial Pacific

Ocean pigment concentration image obtained from the Nimbus-7 Coastal Zone Color Scanner on 31 October 1983 in the vicinity of the Galapagos Islands in the eastern equatorial Pacific Ocean. The concentrations in October 1983 were very high on the western side of the islands and extended for over 1000 kilometers to the west as a result of the westward flowing surface currents.

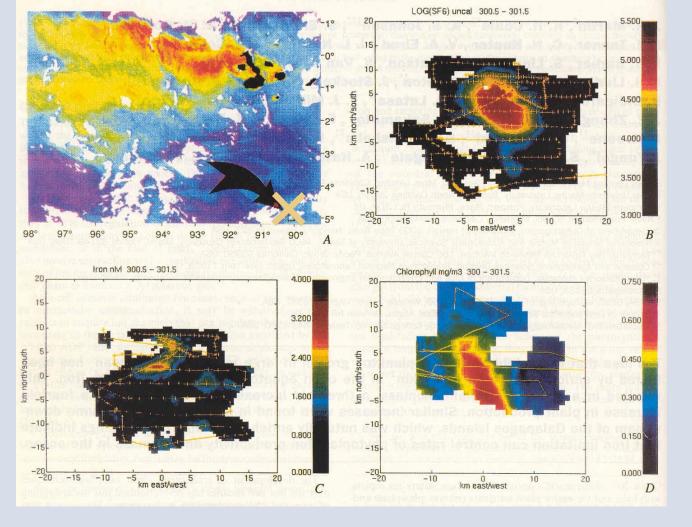




**Figure 2.** Chart showing the locations (filled circles) of the nine in situ Fe enrichment experiments conducted thus far. Moreover, also indicated are the open circle off California for the IronEx test site [*Coale et al.*, 1998], two open circles for two extra patches during IronEx-2 not further discussed here, and two experiments GreenSea 1 and 2 at unknown positions in the Gulf of Mexico [*Markels and Barber*, 2001].

Field Fe enrichment experiment (64 km<sup>2</sup>) IronEx1: single enrichment

YD 301 = 28 oct



Nature 371:124 (1994)

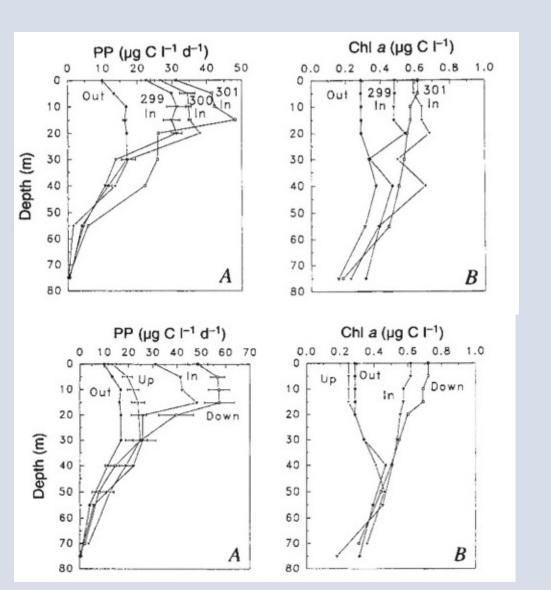
IronExI

PI:x4

Chla: X3

FIG. 3 Vertical profiles, for the 3 days following fertilization, of primary production, PP, (A) chlorophyll a concentrations, Chl a, (B) as a function of time inside and outside the patch. Outside values are depicted for YD 299. Primary production was measured using  $H^{14}CO_3^-$  uptake determined at various light levels, in incubations on board the ship. Chlorophyll was determined from filtered and extracted samples as in Fig. 1D. The errors associated with the chlorophyll analyses are generally <0.02 µg C l<sup>-1</sup>. The depth to which the water column was enriched was ~35 m up to YD 301 (just before subduction). It is in the upper 35 m that the differences are most pronounced. Productivity and chlorophyll both converge by 75 m.

FIG. 4 Comparison of vertical profiles of primary production (A) and chlorophyll a concentrations (B) for stations inside and outside the fertilized patch, and stations upstream (westward) of the Galapagos Islands and downstream (eastward) of the Galapagos Islands.



Nature 371: 124 (1994)

Second field Fe enrichment experiment in the Eq Pacific IronEx2: multiple enrichments

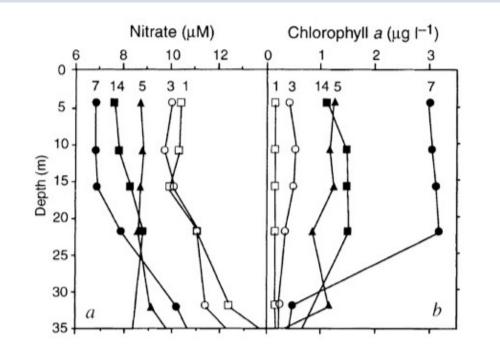


FIG. 3 a, Vertical profiles of mixed-layer nitrate from the daily 'inside-patch' stations of patch 1. Numbers at the top of each profile indicate the day of the patch 1 experiment. These plots illustrate the depletion of nitrate as the bloom reached its peak near days 7–9. The subsequent increase (day 14) is thought to be the result of mixing. Nitrate concentrations both inside and outside the patch converged to about 10  $\mu$ M by ~50 m. *b*, As *a* but for mixed-layer chlorophyll *a*.

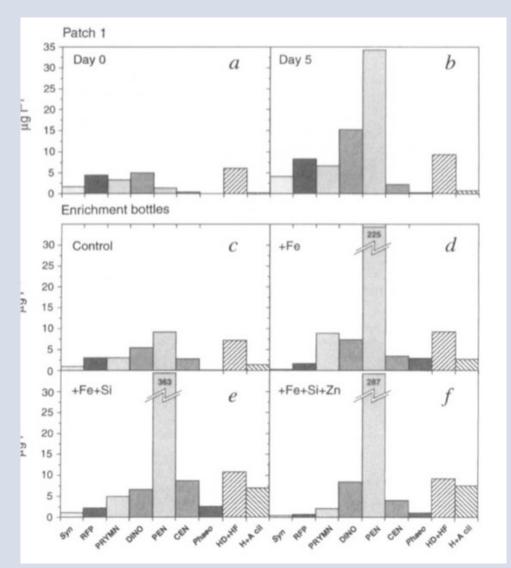


Chla: X27

#### And the winners are

#### diatoms

FIG. 4 a, Plankton community composition within patch 1 at day 0 of the experiment as expressed in  $\mu g C I^{-1}$ . This composition is similar to that observed at the 'outside-patch' stations over time. The groups represented include: Syn, Synechococcus spp.; RFP, red fluorescing picoplankton; PRYMN, Prymnesiophytes; DINO, autotrophic dinoflagellates; PEN, pennate diatoms; Phaeo, Phaeocystis; HD + HF, heterotrophic dinoflagellates + heterotrophic flagellates; H + A cil, heterotrophic+ autotrophic ciliates. Shaded bars indicate autotrophic biomass and diagonally hatched bars indicate heterotrophic biomass (the most likely grazers on the smaller size fraction of autotrophs). b, Taxonomic composition of patch 1 on day 5 of the experiment indicating increases in all classes of phytoplankton, especially the diatoms. c-f. Results of the bottle enrichment experiments performed on deck in 20-litre carboys<sup>8</sup> to test the effects of other potentially limiting nutrients. Water was collected using 30-litre Go Flo bottles deployed on Kevlar hydrowire and tripped with a Teflon messenger. Water was transferred to acid-cleaned, 20-litre polycarbonate bottles within a class 100 clean lab. chained to the deck of the ship. Treatments include: c, control, nothing added; d, +2 nM iron added; e, +2 nM iron, +10 µM silicic acid; f, +2 nM iron, +10 µM silicic acid, +2 nM zinc. Results indicate that diatoms in bottle enrichments with added iron outperformed the mesoscale experiment and that bottles with added silicic acid enhanced diatom growth relative to those without silicic acid. Zinc did not appear to have a positive effect on growth. Note the scale break in the diatom bar. Numbers at the top of the bar indicate the micrograms of carbon per unit volume attained in this group.

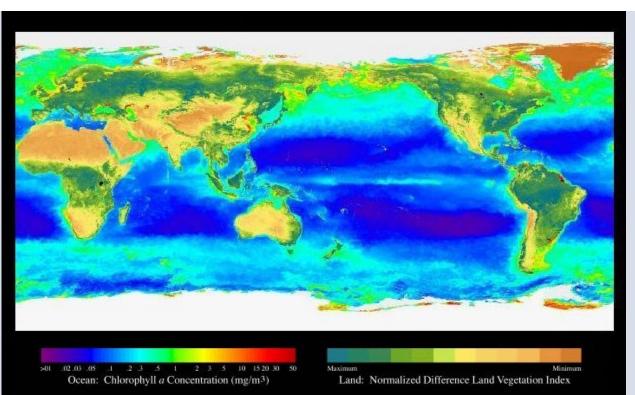


Nature 383: 495 (1996)

IronEx2

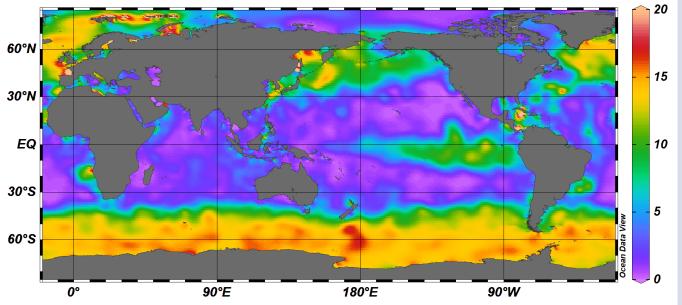
P:P Ratio [molar] @ Depth [m]=first

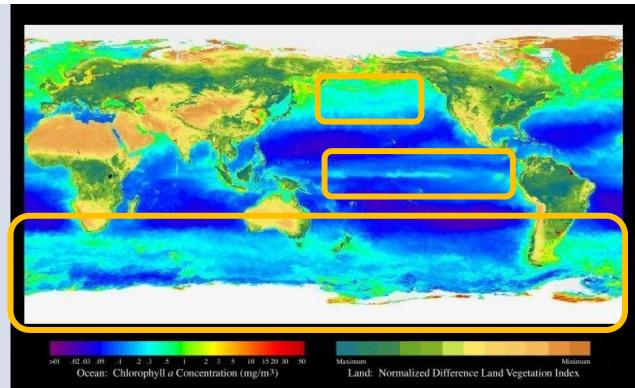
# Global nitrogen to phosphorus ratio is plotted for the global surface ocean



Global distribution of surface chlorophyll levels. Chlorophyll (a proxy for phytoplankton mass

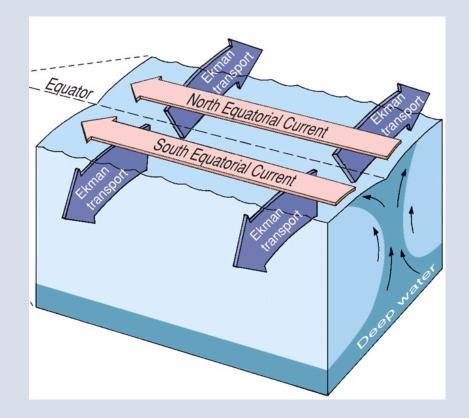
N:P Ratio [molar] @ Depth [m]=first



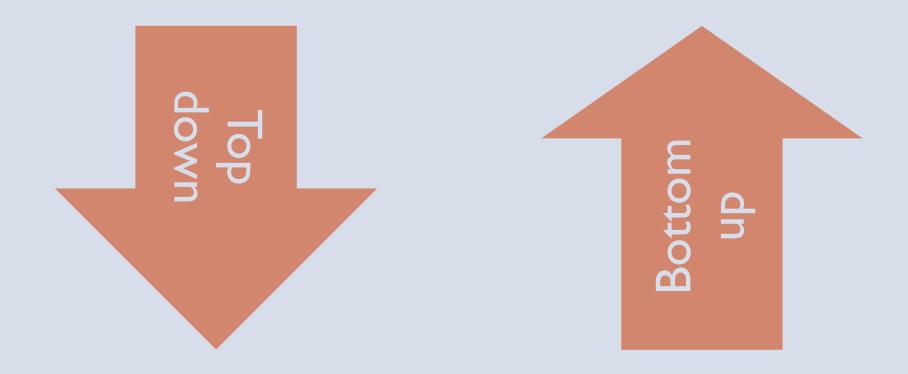


#### High-nutrient, low-chlorophyll regions

- Principal HNLC Fe limited regions:
  - North Pacific
  - Equatorial Pacific
  - Antarctica
- Linked to the presence of an offshore upwelling with no land runoff

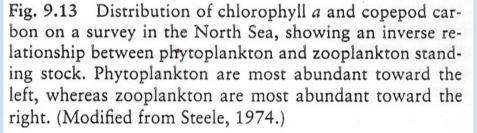


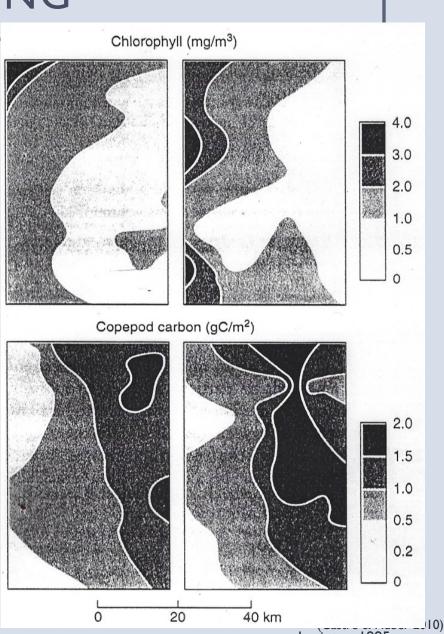
#### WHAT CONTROLS PRIMARY PRODICTION?



# GRAZING

- Some indications
  - Inverse horizontal spatial distributions





Levinton 1995

### 2.2. PRIMARY PRODUCTION

• Highly variable according to regions and seasons: 0 -100%

	, ,	Percentage of prod. eaten by herbivores		umber of trophic	Source
		nerorvores		steps	
Dharan la chan					
Phytoplankton		<b>7</b> 7 <i>′</i>			<b>D</b> 11 (1071)
Long Island Sound, USA		73,5		4	Riley (1956)
Narragansett Bay, USA		0-30*		4	Martin (1970)
Cochin Backwater, India		10-40			Qasim (1970)
Beaufort Sound, USA		1.9-8.9			Williams et al. (1968)
Offshore California		7-52 (ave. 23)			Beers and Stewart (1971)
Peruvian upwelling		92, 54-61		3	Walsh (1975), Whitledge (1978)
Open Seas (all phytoplankton)					
Georges Bank		50-54		4	Riley (1963), Cohen et al. (1981
North Sea		75-80	5	4-6	Crisp (1975)
Sargasso Sea		100	1	5	Menzel and Ryther (1971)
Eastern Tropical Pacific		39-140 (ave. 70) <sup>h</sup>		5	Beers and Stewart (1971)

" Annual consumption except where indicated otherwise. These values are rough but best possible estimates based on many assumptions and extrapolations.

<sup>b</sup> Leaves only; 0.5-1.4% of total production is consumed by herbivores (Bray, 1961).

" This considers grass-cattle-man as the food chain.

<sup>d</sup> Includes above- and below-ground production and consumption.

" Leaves and buds only.

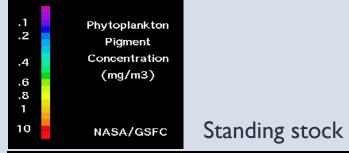
<sup>1</sup> This is an estimate of consumption of organic matter in the water column. Larger zooplankton consume about 20%, microplankton and bacteria an additional 43%. In the bottom, benthic animals use an estimated 31% of net primary production.

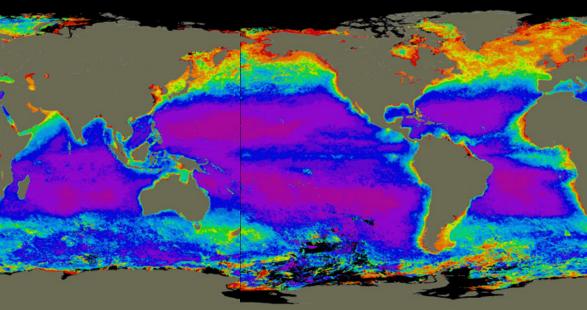
\* Of standing stock of algae.

<sup>h</sup> Includes only microzooplankton that passed through a 202  $\mu$  mesh. The biomass of these small species was about 24% of that of the larger zooplankton. Total consumption could easily be larger than reported if any of the larger species are herbivorous.

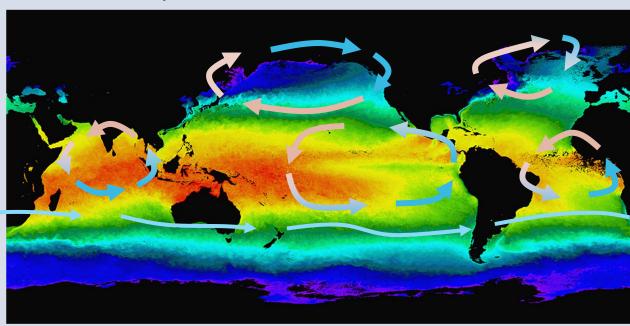
## SPACE

• Hydrographic factors



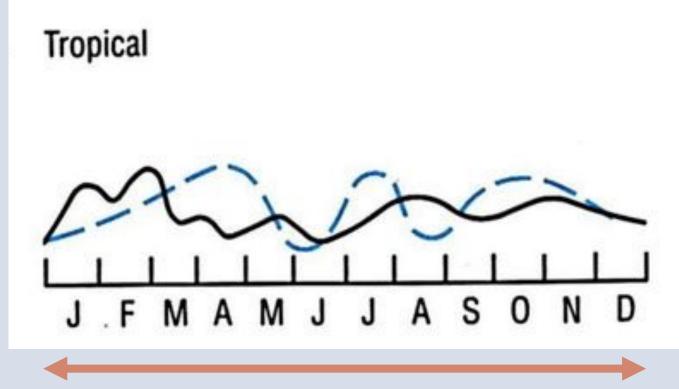


#### Sea surface temperature



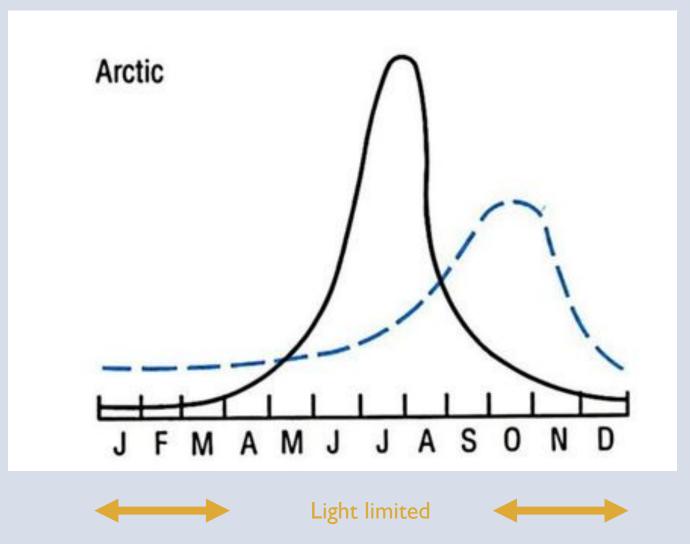
Phytoplankton biomass

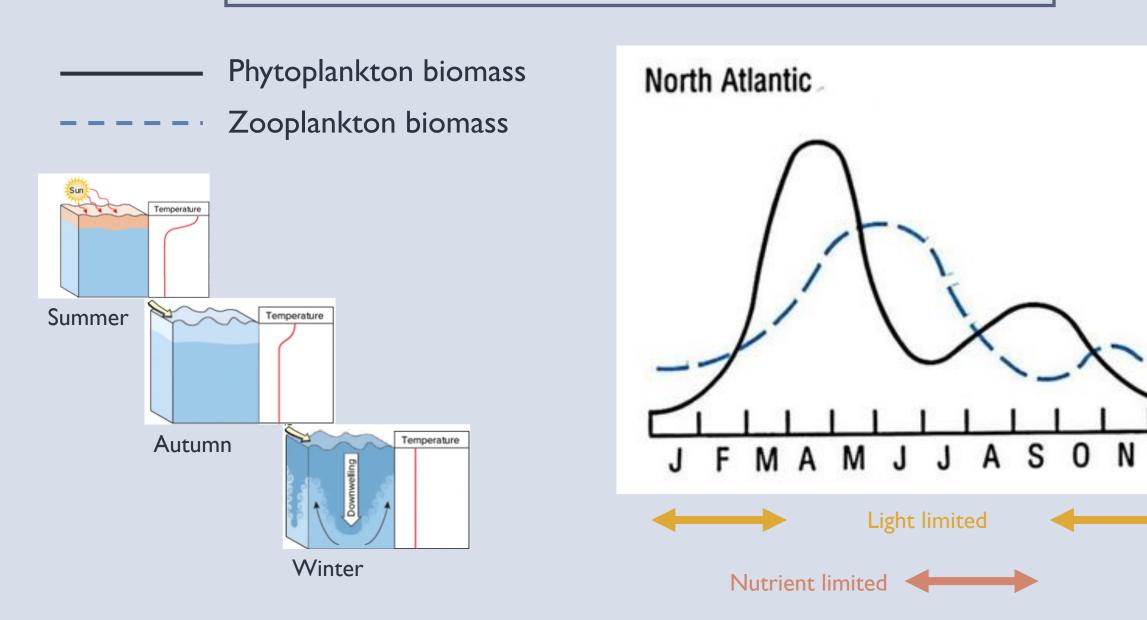
--- Zooplankton biomass



Nutrient limited

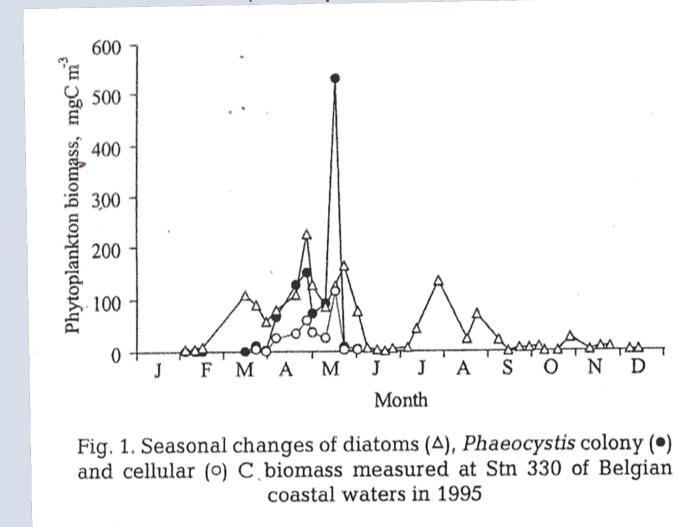
- Phytoplankton biomass
- --· Zooplankton biomass





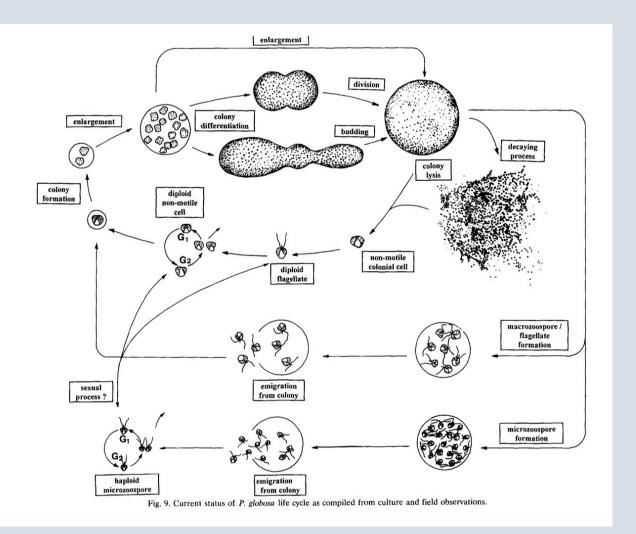
D

• Temperate North Atlantic (eutrophicated conditions)



Rousseau et al 2002

- Temperate North Atlantic (eutrophicated conditions)
- Phaeocystis globosa cycle



Rousseau et al 1994

Time - Seasons

- Temperate North Atlantic (eutrophicated conditions)
- Phaeocystis globosa

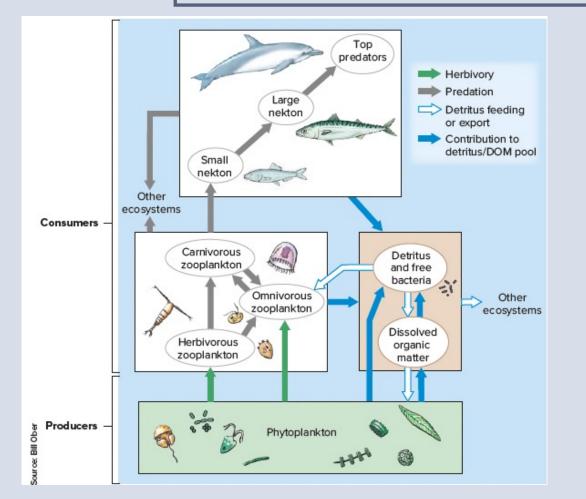


envlit.ifremer.fr

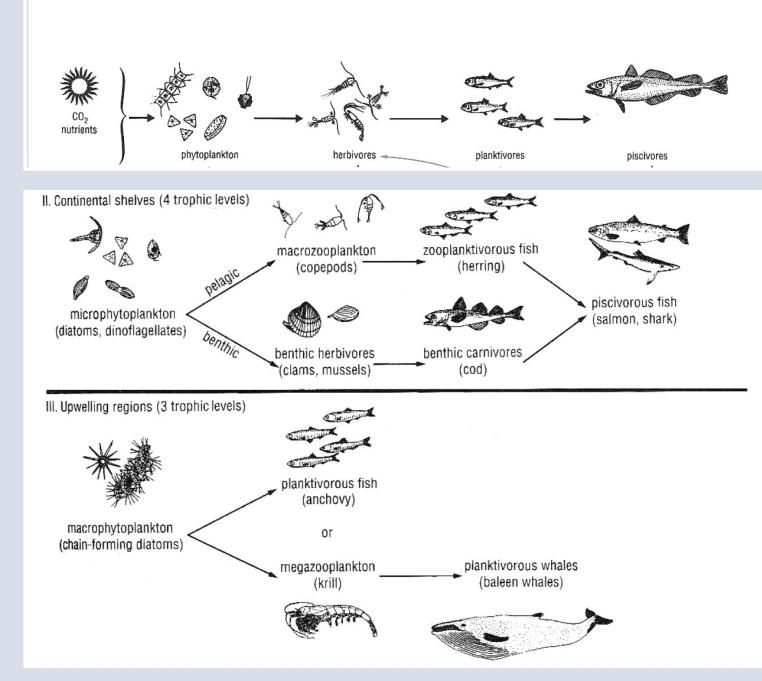


# QUESTIONS

#### EPIPELAGIC FOODWEBS



#### EPIPELAGIC FOODWEBS



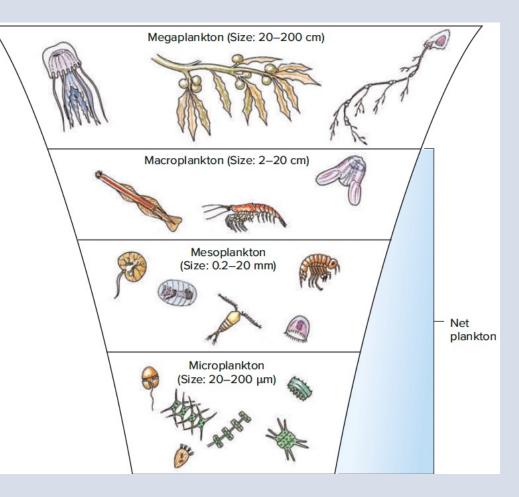
• 70's

 Dinoflagellates + diatoms -> copepods ->herring -> mackerel >tuna

• Based on net plankton

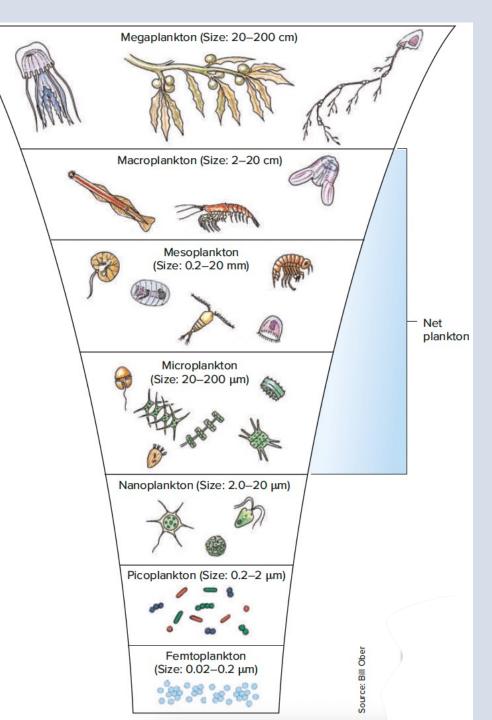
#### PLANKTON= NEW UNDERSTANDING

- Finer Filters
- fluorescent dyes
- Genomics
- Metagenomics



#### PLANKTON= NEW UNDERSTANDING

- Femtoplankton
  - virusses
- Picoplankton
  - Archaea
  - (cyano)Bacteria (>=50% Primary production)
- Nanoplankton



#### PROTOZOANS

- Small enough to consume pico- and nanoplankton
- Flagellates
- Cilliates
- Foraminiferans
- radiolarians

#### MICROBIAL LOOP

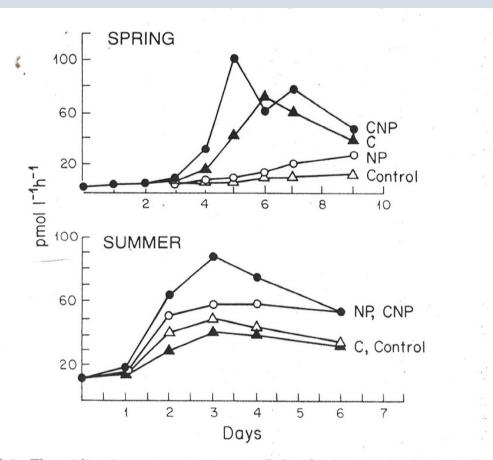


FIGURE 9-1. Thymidine incorporation rate in Baltic Sea bacteriplankton, in batch enrichment experiments done in early spring (top), and summer (bottom). Enrichments consisted of addition of sucrose (C),  $NH_4Cl$  (N), or  $KH_2PO_4$  (P). control batches received no additions. Adapted from Kuparinen and Kuosa (1993).

*Bacteria:* bottom-up control by nutrients (inorganic and organic)

 Table 2.4
 Carbon: nitrogen ratios in various organisms.

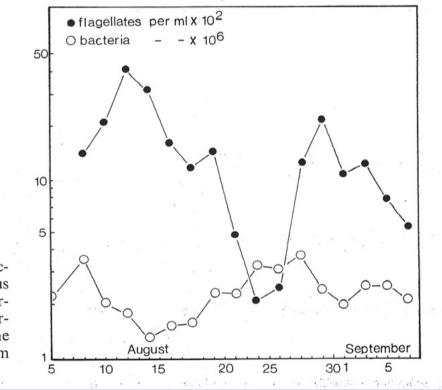
Terrestrial tracheophytes	> 100:1
Marine tracheophytes	17-70:1
Macroalgae	10-60:1
Fungi	10:1
Phytoplanktonic algae	6-10:1
Bacteria	< 6 : 1

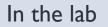
#### MICROBIAL LOOP

#### Bacteria: top-down control by nanoflagellates

What Is bad about these figures?

#### In the field





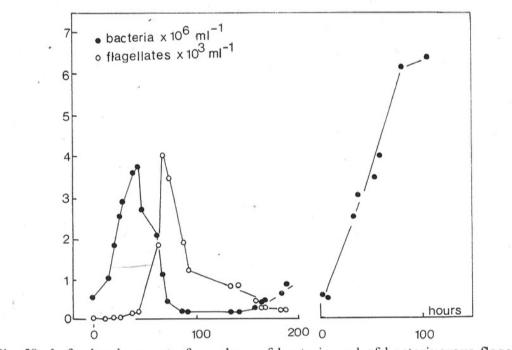
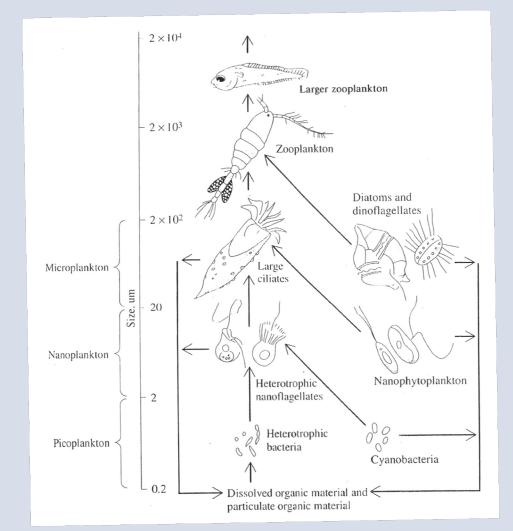


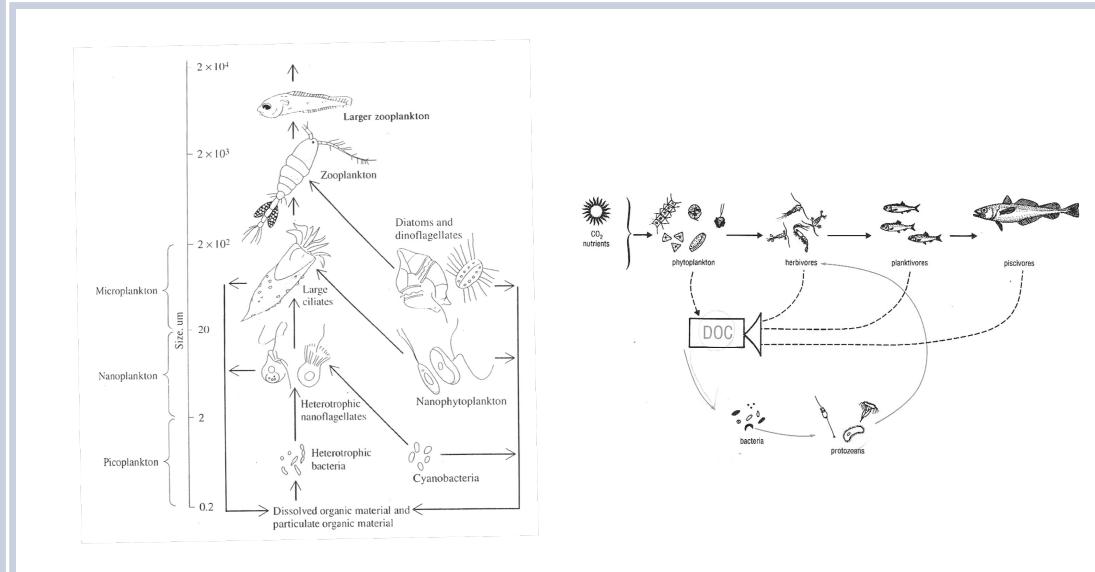
Fig. 58. Left: development of numbers of bacteria and of bacterivorous flagellates in a seawater sample filtered to remove larger plankters. Right: same water sample, but with the flagellates being removed as well. Redrawn from Fenchel [136]

Fig. 59. Numbers of bacteria and bacterivorous flagellates in the surface waters of Limfjorden, Denmark, over one month. Redrawn from Fenchel [136]

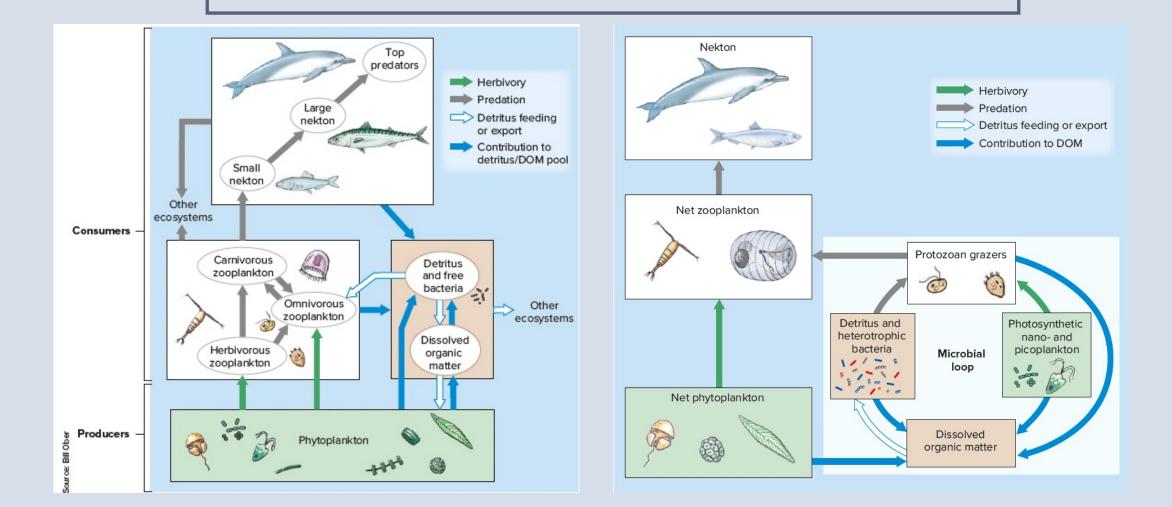
#### . MICROBIAL LOOP

#### Nanoflagellates (auto- and heterotrophs): topdown control by ciliates





### EPIPELAGIC FOODWEBS



#### . MICROBIAL LOOP

• Energy flow:

 $P_n = P_1 \cdot E^n$ 

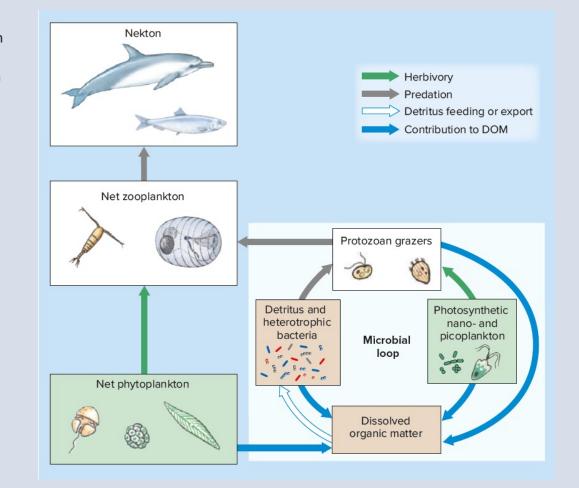
Where P<sub>n</sub>: production of trophic level n P<sub>1</sub>: primary production of the community Energy absorbed by level n E: ecological efficiency= Energy ingested by level n

E <1 (0.1 – 0.5) n: trophic level

Much more trophic levels are involved than previously assumed

 $\rightarrow$  Energy/C from P<sub>1</sub> entering the microbial loop almost totally dissipated in the loop

→ Energy/C transfer between the microbial loop and the linear food chain is low

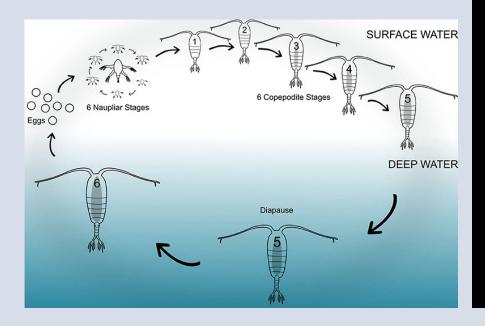


## 2.3. CONSUMERS

• 2.3.2. Linear food-chain: nekton

Marine copepods from a single drop of water collected off Melbourne, Florida.

life cycle of Calanus finmarchicus © Holly Jenkins (NOC)





protists – diatoms, dinoflagellates, radiolarians, and foraminifera

© Christian Sardet, Plankton – Wonders of the Drifting World, Univ. Chicago Press 2015



 Representative members of gelatinous zooplankton. Organisms from at least eight phyla are included among the gelata. (a) Nemertean. (b) Phaeodarian radiolarian. (c) Salp with parasitic copepod. (d) Lobate ctenophore. (e). Narcomedusan hydrozoan. (f) Nudibranch mollusc. (g). Chaetognath. (h) Physonect siphonophore. (i) Coronate scyphozoan. (j) Polychaete.



- Cnidaria
- Jellyfish
- Ctenophora
- Beroe cucumis with Parasitic amphipod Hyperia galba, © Alexander Semenov



- Pteropods
- Shelled, sea butterfly
   © Steve Ringman
- Unshelled, sea snail
- Clione Limacina



- Chordata
- Salps







#### Photo: Mike Stukel / Florida State University

# **NEKTON: FISH**

Teleostean fishes

• Better studied (fisheries)



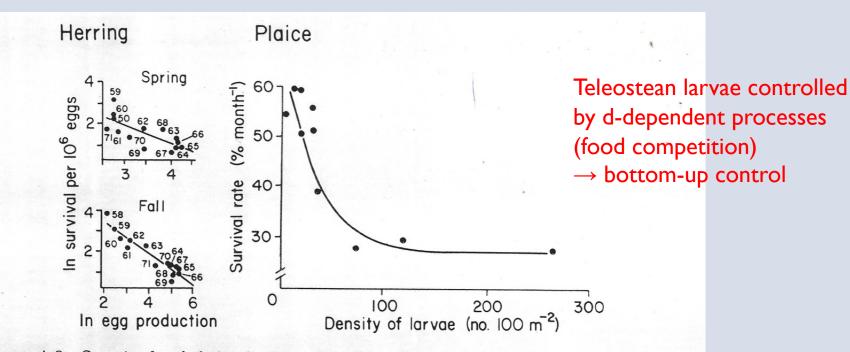


FIGURE 4-9. Survival of fish during the first year of life (age 0) at different densities. Data for spring and fall herring cohorts from Winters (1976). Plaice data from Lockwood (1978).



## **NEKTON: FISH**

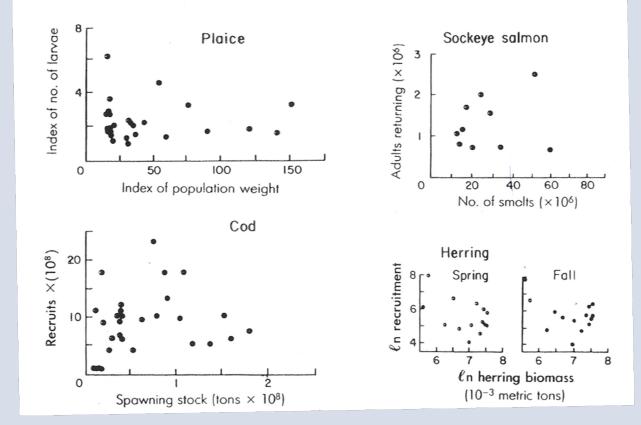
• 2.3.2. Linear food-chain: nekton

Teleostean fishes

• Better studied (fisheries)



• Most = r strategists (many eggs/larvae with low energetic investment)



Recruitment in adult teleostean populations independent of population size  $\rightarrow$  top-down control

Figure 4-10. Recruitment in fish populations in relation to density. Top left: Recruitment of plaice in to the North Sea fishery in relation to stock density. The values are dimensionless indices obtained from catch statistics [adapted from Cushing (1975)]. Bottom left: Recruitment of cod in Arcto-Norwegian waters (1940–1969) in relation to the abundance of spawners [adapted from Garrod and Clayden (1972)]. Top right: Recruitment of sockeye salmon in Skeena estuary, British Columbia [adapted from Ellis (1977)]. Smolts refer to young fish leaving rivers for the sea. Bottom right: recruitment of herring in southern Gulf of St. Lawrence, Canada. Adapted from Winters (1976). © Canadian Journal of Aquatic and Fisheries Sciences, reprinted by permission.

Valiela 2009

# NEKTON: BIRDS AND MAMMALS

- k strategists (few youngs with high energetic investment)
- « full scale experiment »: whale hunting

**Table 9-3.** Rough Estimates of Whale and Seal Stocks, Migratory Losses, and Food Consumption in Prepelagic Whaling and in Recent Times"

	Whales			Seals
	Initial	Recent	Percent removed	Recent
Stock	46	8	83	3.5
Loss from				
Antarctic Ocean	19	3	84	Not migratory
Food	Percentage left			
consumption	unconsumed			
Krill	190	43	77	64
Fish	4	1	75	6
Squid	12	5	58	7

<sup>a</sup> Values are in millions of tons. Data on food consumption by penguins, other birds, and fish are not available. Adapted from Laws (1977a,b).



## NEKTON: BIRDS AND MAMMALS

• « full scale experiment »: whale hunting

	Principal foods	Changes in population
Penguins	· · · ·	
Emperor (Aptenodytes forsteri)	Fish	No significant increase
King (A. patagonica)	Mainly squid	Marked increase $(5\% y^{-1})$
Adelie (Pygoscelis adeliae)	60% krill, 40% fish and other	Local increases (2.3% y <sup>-1</sup> ) in whaling areas
Chinstrap (P. antarctica)	Krill	Marked increase, extended range
Gentoo ( <i>P. papua</i> )	Benthic fish, some krill	Some increases
Macaroni (Endyptes chrysolophus)	75–98% krill, 2–25% fish	(Increases of 9% $y^{-1}$ )
Seals		
Crabeater (Lobodon arcinophagus)	94% krill, 3% fish, 2% squid	Earlier maturity, increase in numbers (7.5% y <sup>-1</sup> )
Fur (Arctocephalus gazella)	34% krill, 33% fish, 33% squid	Population explosion (14–17% y <sup>-1</sup> ) especially in overlap
		with range of baleen whales; appearance of new colonies



Populations of krill-eating penguins and seals increased in parallel with whale hunting →
Bottom-up control of krill-eating vertebrates by food

<sup>a</sup>Data from Conroy (1975), Stonehouse (1975), Laws (1977a,b), Payne (1977), Øritsland (1977), Croxall and Prince (1979), Hinga (1979), Laws (1985), and Cooper et al. (1990).

#### THE DEEP SEA

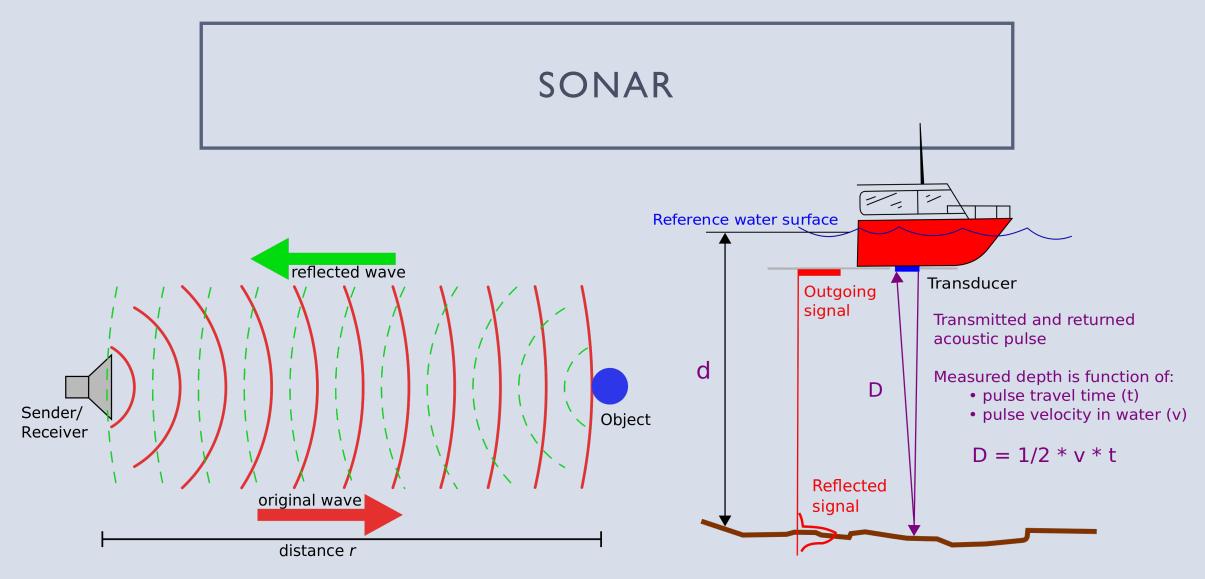
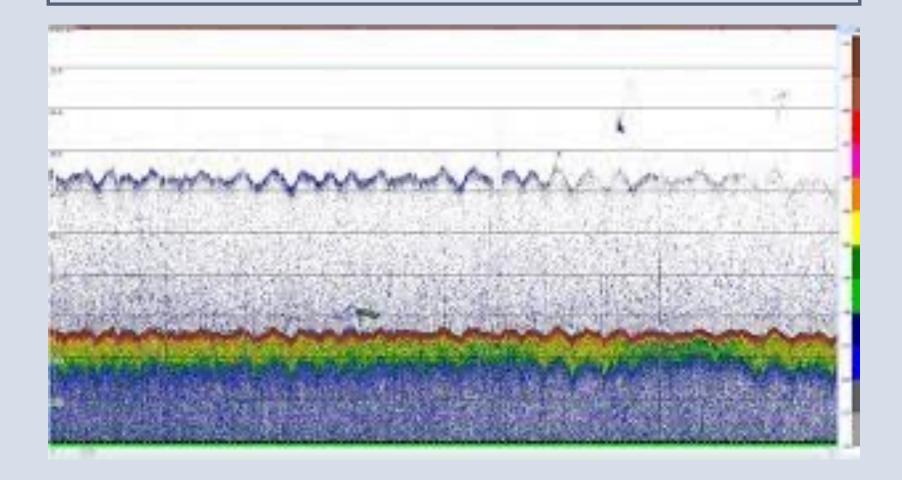


Figure 9-1. Acoustic depth measurement

#### FALSE SEAFLOOR



#### SCATTERING LAYERS

Echo

strength

(dB)

0-

-5-

-11-

-18--22-

-27 --32 --38 -

-43--49--54-

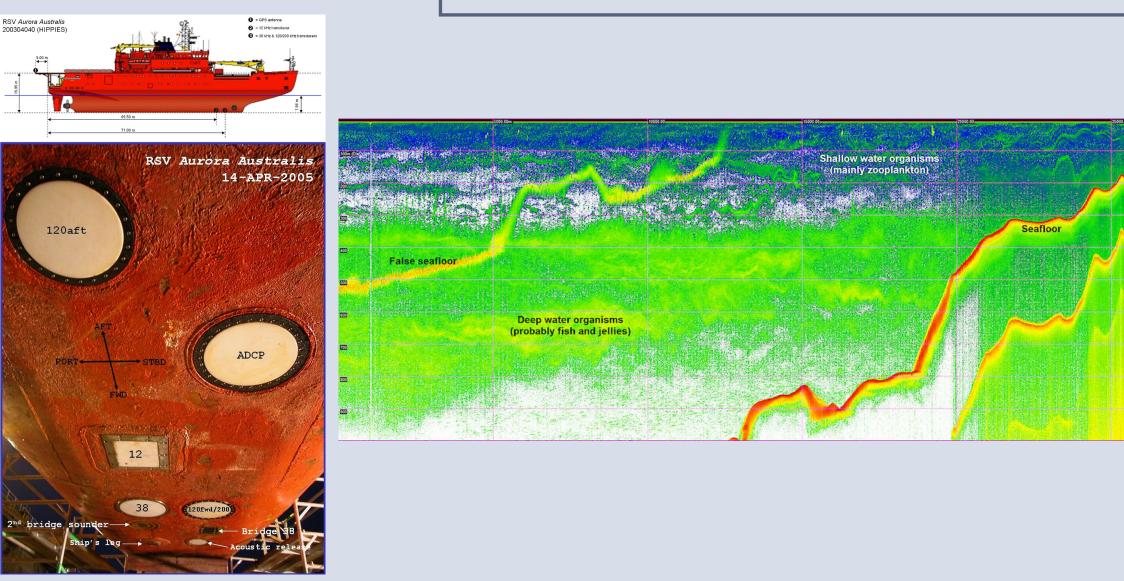
-60 --65 --70 --76 --81 -

-87 --92 --98 -

-103-

-114--119--125-

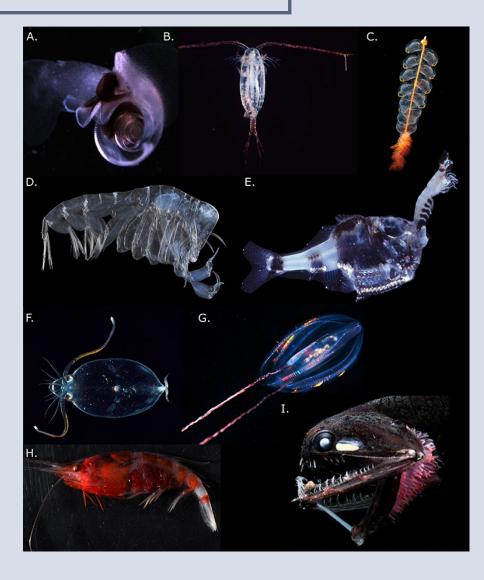
-130-

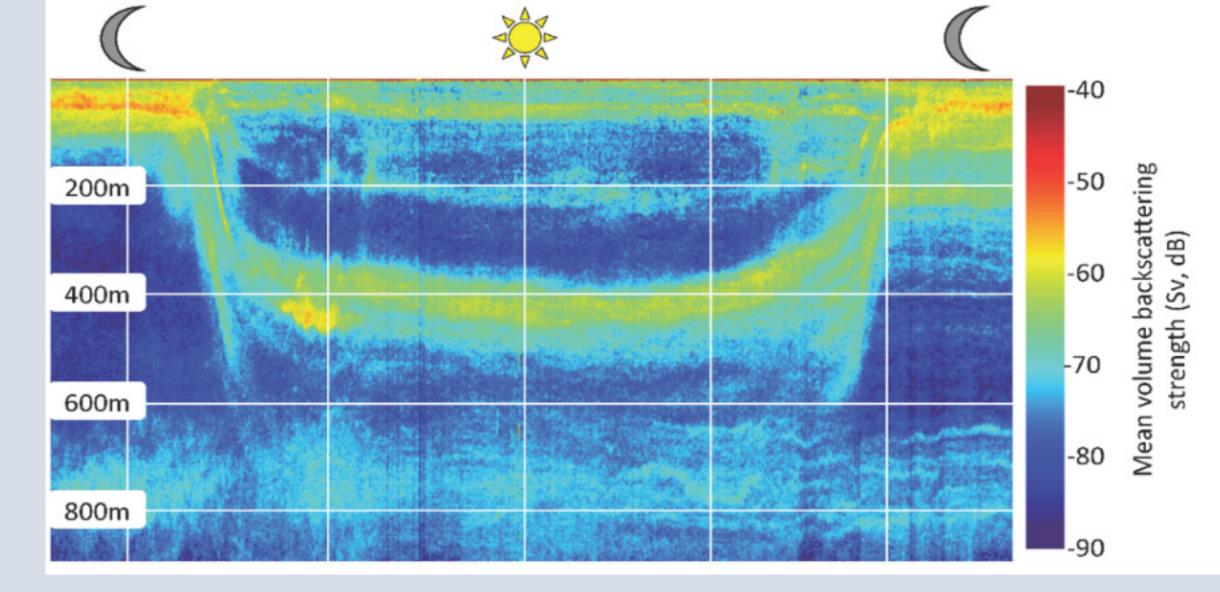


### DIEL VERTICAL MIGRATION

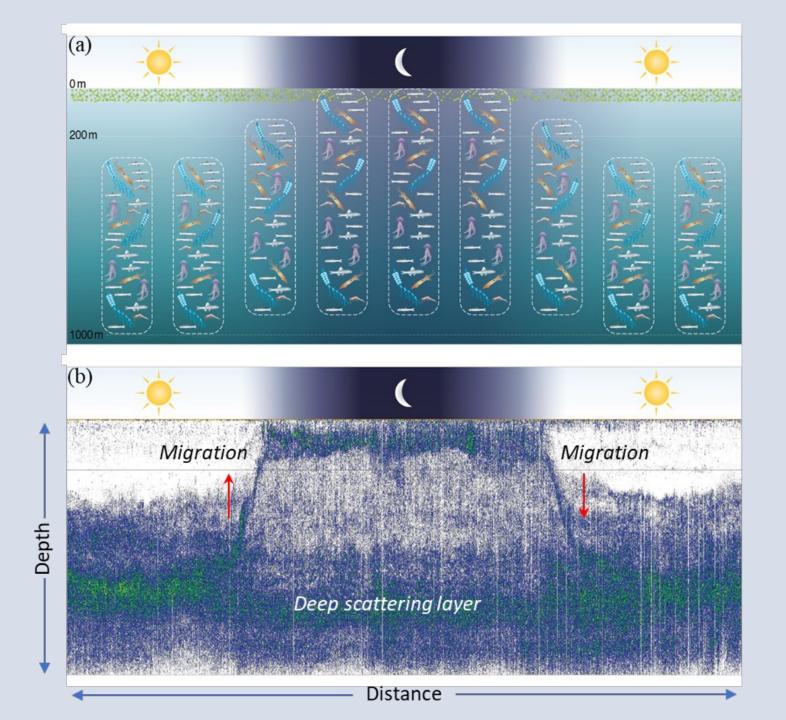
(A) sea butterfly (credit: R. Hopcroft, NOAA); (B) copepod (credit: U. Kils);
(C) siphonophore (credit: K. Raskoff, NOAA); (D) amphipod (credit: E.A. Lazo-Wasem); (E) Hatchetfish feeding on a crustacean (credit: F. Costa); (F) glass squid (credit: E. Widder, NOAA);
(G) comb jelly (credit: A. Semenov);
(H) decapod (credit: S. Fielding); and (I) dragonfish (credit: E. Widder/HBOI, NOAA).

Freer J and Hobbs L (2020) DVM:The World's Biggest Game of Hide-and-Seek. Front. Young Minds. 8:44. doi: 10.3389/frym.2020.00044

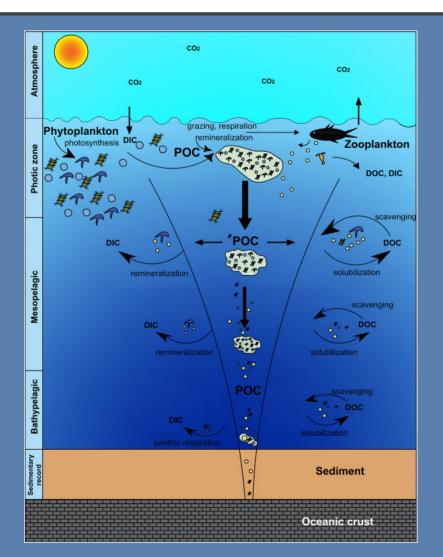




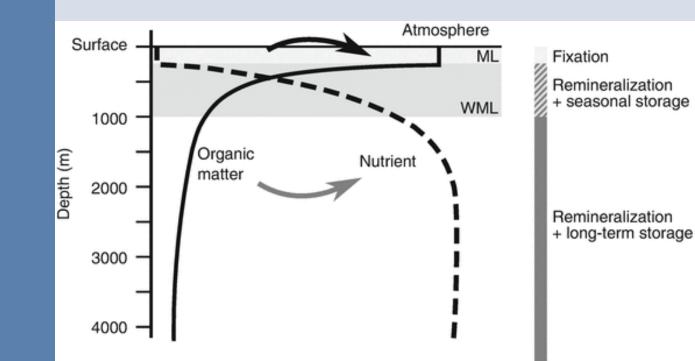
This echogram illustrates the ascending and descending phases of the diel vertical migration through the water column. The yellows and reds are indicative of the greatest density of animals. *Image courtesy of DEEP SEARCH - BOEM, USGS, NOAA*.



#### BIOLOGICAL CARBON PUMP



- Export
  - Sinking
  - Active Transport
  - Physical Transport
- Remineralization and Transfer
- Vertical Profiles



#### MESOPELAGIC FISH



Lanternfish with blue bioluminescense (From Adobe Stock, Sam)

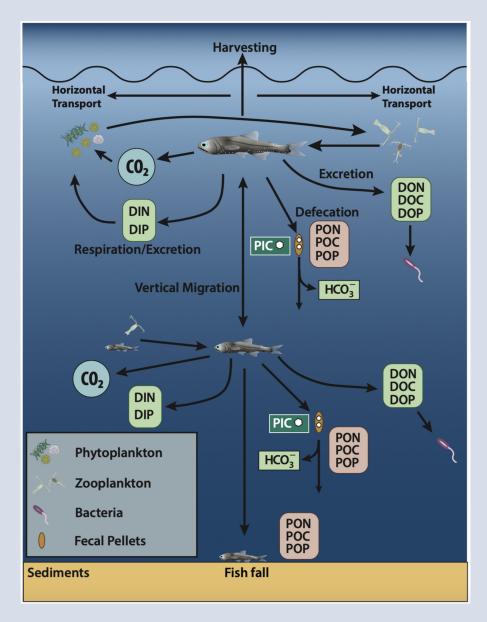
- small, abundant fish living in the mesopelagic zone between the depth of 200-1000m
- bioluminescence

#### GONOSTOMATIDAE





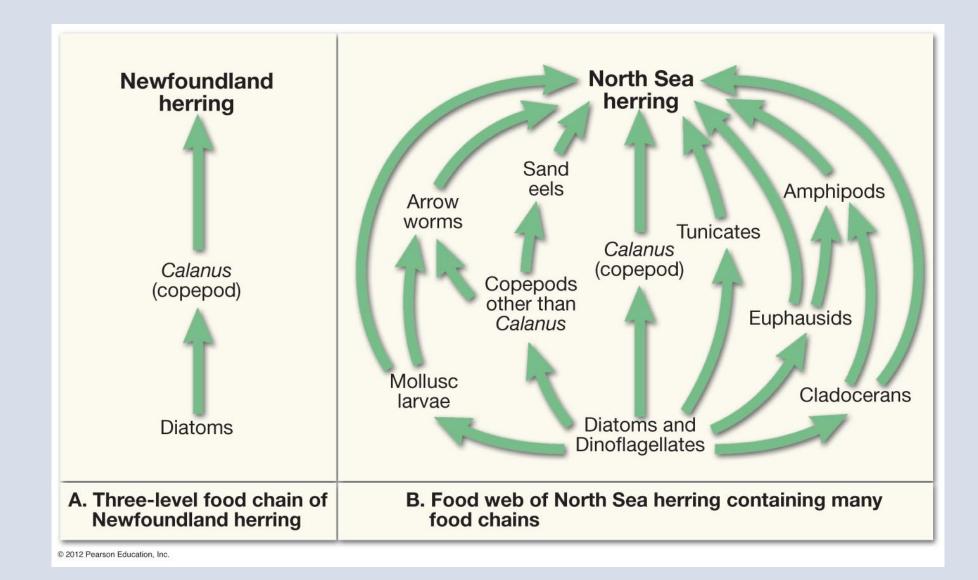
- Gnostomatidae AKA "Bristlemouths"
- most abundant of all mesopelagic fish
- most abundant vertebrate
   humans, birds, and amphibians
- Up to one quadrillion individuals or 10<sup>15</sup> fish!

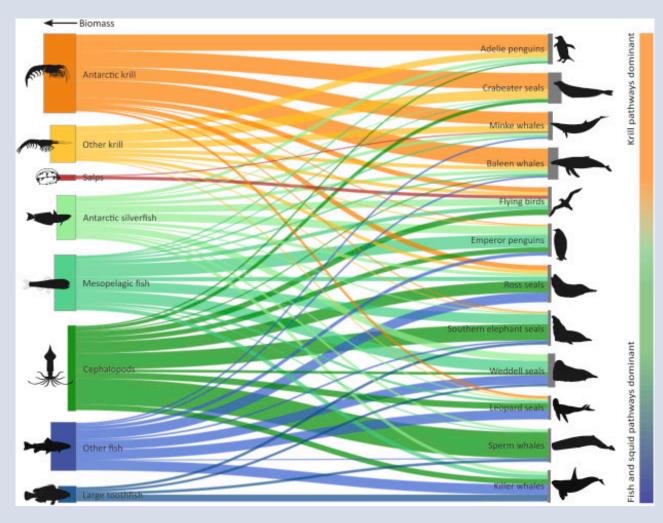


#### CARBON PUMP

Limnology & Oceanography, Volume: 66, Issue: 5, Pages: 1639-1664, First published: 17 February 2021, DOI: (10.1002/Ino.11709)

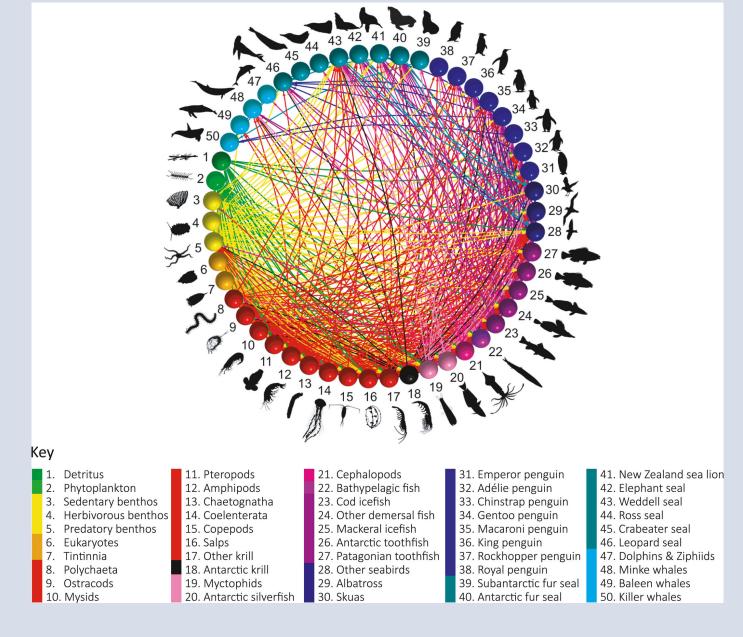
#### FOOD CHAINS AND FOODWEBS





 Sankey diagram depicting predator-prey interactions between mid-trophic level groups of interest and <u>marine mammal</u> and bird functional groups within the Prydz Bay

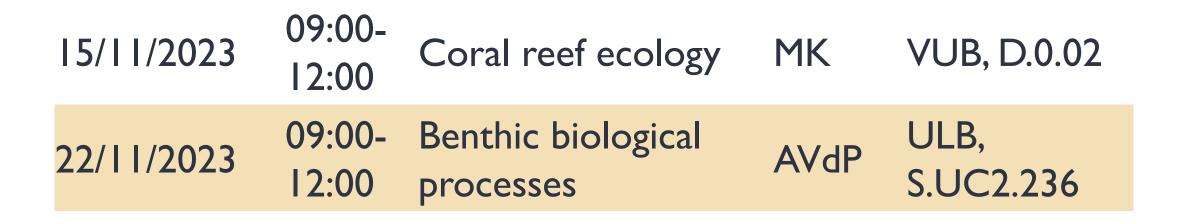
© McCormack et al.2020 c



- network diagram for the 50 trophic groups and their associated interactions
- Nodes are colored according to broad taxonomic groups (e.g., yellow for benthic organisms, red for zooplankton) with numbers corresponding to the name of the group listed in the key. Silhouettes are representative of the types of organisms associated with each node. Edges (i.e., connections) are colored according to prey species/group and are directed toward the relevant predator node. This overall representation shows the complexity of trophic connections present in the database, which are more clearly resolved in regional food web configurations

- Food chains don't exist in real ecosystems
- Almost all organisms are eaten by more than one predator (and vice versa)
- Food webs reflect the multiple and shifting trophic interactions.

- Many species don't fit in convenient categories
- Omnivores
- Detrivores
- Parasites
- Cannibalism



#### NEXT CLASSES