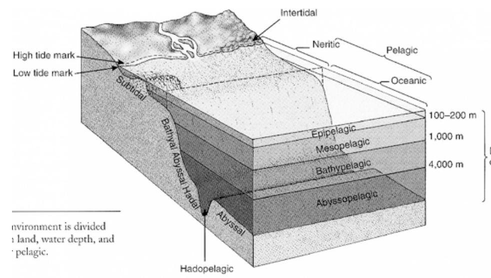
Ecology of the Water Column (Biological Oceanography)

I. Ocean Circulation

II. Water Column Production
   A. Coastal Oceans
   B. Open Oceans
   E. Micronutrients
   F. Harmful Algal Blooms

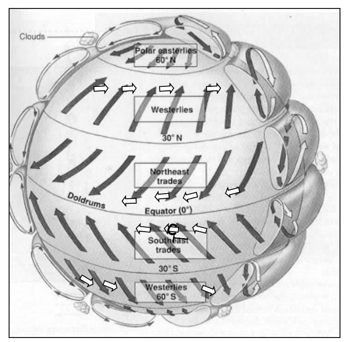
III. Zooplankton and Nekton

Includes the coastal zone and the pelagic zone, the realm of the oceanographer



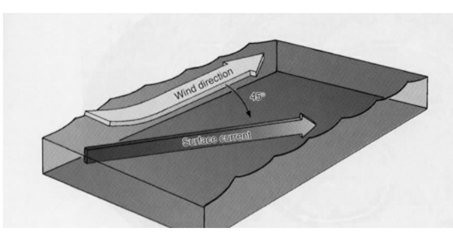
The water column is also important to benthic production over a great part of the ocean

I. Ocean Circulation

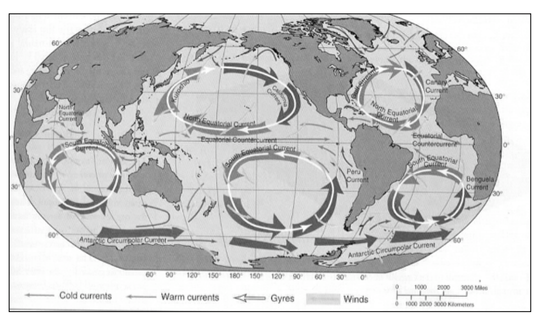


Winds and coriolis forces push waters to the right in the northern hemisphere, left in the South

Because of the Coriolis Effect, surface currents do not move parallel to the wind but at an angle of 45 deg. from wind direction

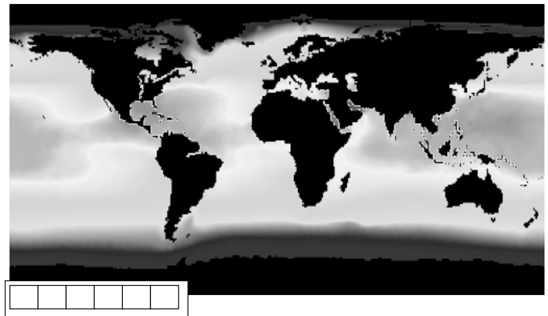


In the main ocean basins, the currents form circular systems (gyres) that dominate global circulation and climate.



Global Ocean Temperatures in August

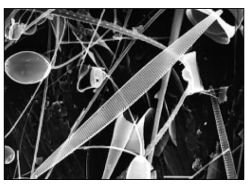
Identify the effects of circulation on ocean temperatures



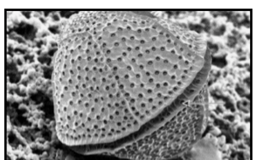
II. Water Column Primary Productivity

Who are the producers?
Geographic Patterns?
Seasonal Patterns?

What are the important primary producers in the water column?



Diatoms



dinoflagellates

Cyanobacteria
Coccolithophorids
Cryptomonads

All microscopic and mostly as single cells or short chains

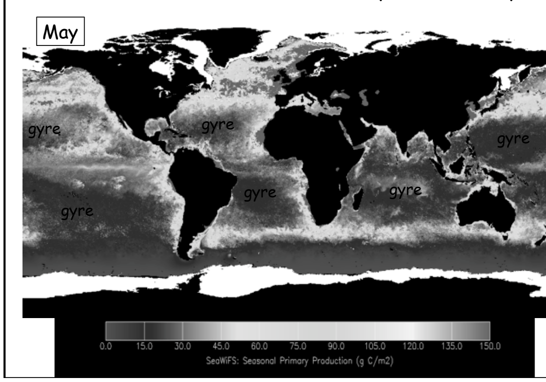
Production by phytoplankton is generally lower than that of bottom plants

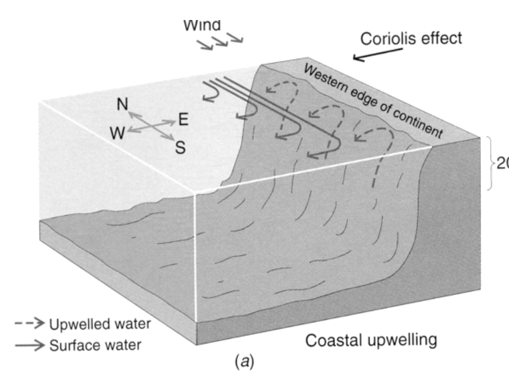
Table 9.1

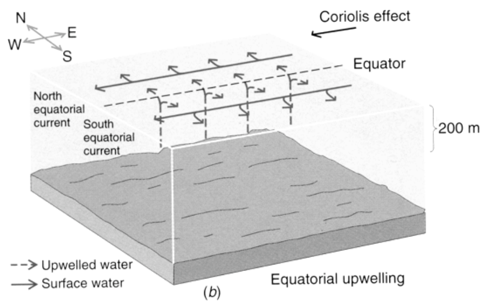
Typical rates of primary production in various marine environments*

ENVIRONMENT	RATE OF PRODUCTION (grams of carbon fixed/m²/yr)
Pelagic Environments	
Arctic Ocean	0.7–1
Southern Ocean (Antarctica)	40–260
Subpolar seas	50–110
Temperate seas (oceanic)	70–180
Temperate seas (coastal)	110–220
Central ocean gyres**	4–40
Equatorial upwelling areas**	70–180
Coastal upwelling areas**	110–370
Benthic Environments	
Salt marshes	260–700
Mangrove forests	370–450
Seagrass beds	550–1,100
Kelp beds	640–1,800
Coral reefs	1,500–3,700
Terrestrial Environments	
Extreme deserts	0–4
Temperate farmlands	550–700
Tropical rain forests	460–1,600

Global Pattern of Marine Primary Productivity





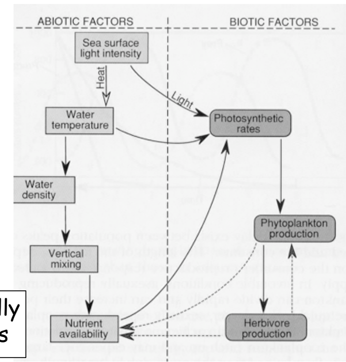


High Nutrient Low Chlorophyll regions (HNLC)

Intense Herbivory or Trace Metal Limitation?

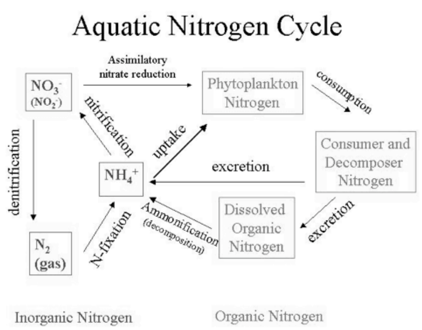
(iron, manganese, zinc, cobalt)

Forcing agents for Phytoplankton Production



Especially Nitrates

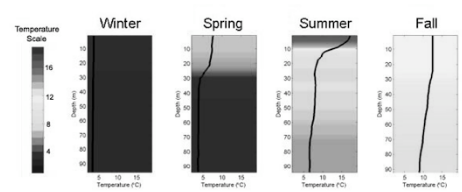
Ocean Nitrogen Cycle



Productivity of phytoplankton also influenced by mixing in the water column:

- **Delivery of nutrients**
- **Vertical movement of algae**

Seasonal Temperature profile, coastal Maine



Cycles of productivity are influenced by changes in the light compensation depth that are a function of incident light and absorption

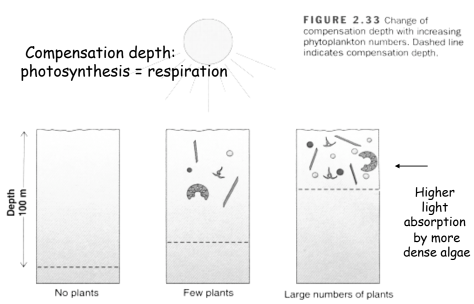


FIGURE 2.33 Change of compensation depth with increasing phytoplankton numbers. Dashed line indicates compensation depth.

The Compensation depth is a physiological concept: The depth at which the rate of photosynthesis for an individual plant equals the rate of respiration by that plant.

The Critical depth is an ecological concept applied to the whole community of plants and related to vertical mixing of the water:

The Compensation depth is a physiological concept:
The depth at which the rate of photosynthesis for an individual plant equals the rate of respiration by that plant.

The Critical depth is an ecological concept applied to the whole community of plants and related to vertical mixing of the water:

It is the depth to which the total phytoplankton biomass may be circulated and still spend sufficient time above the compensation depth to have the total production equal the total respiration for a given time period

Thus the depth of vertical mixing is another important determinant of productivity

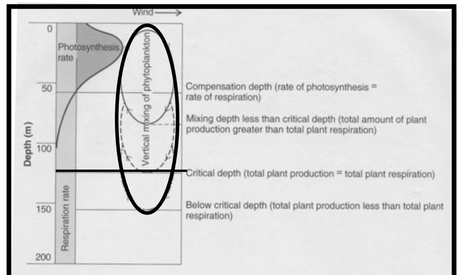
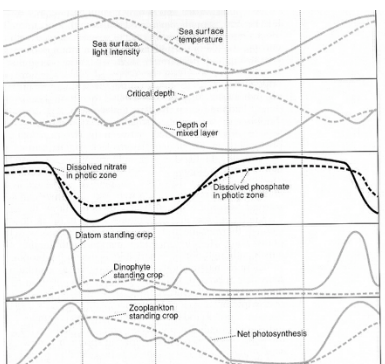


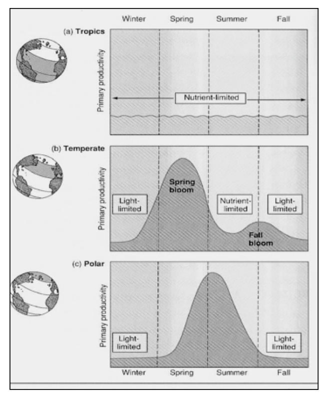
FIGURE 2.35 The relationship between the compensation depth and the critical depth. Critical depth is the depth to which the total phytoplankton biomass may be circulated and still spend enough time above the compensation depth to have a total production equal to its total respiration during the same time period. (Modified from *Productivity Of The Seas* D. H. Cushing, Oxford biology Reader, #78, 1975. Copyright 1975 Butterworth Heinemann. Reprinted by permission.)

Seasonality in the temperate zone results in two distinct peaks



Spring Summer Autumn Winter Spring

Cycles are different in other regions



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Lenes et al.

Limnol. Oceanogr., 46(6), 2001, 1261–1277
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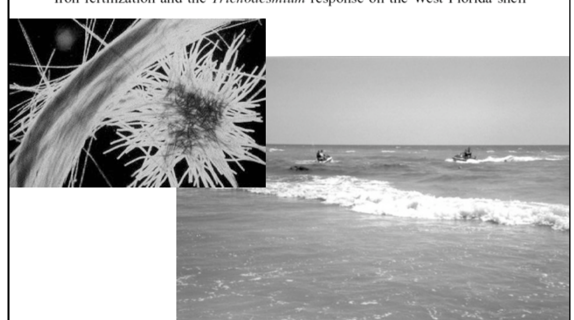
Iron fertilization and the *Trichodesmium* response on the West Florida shelf



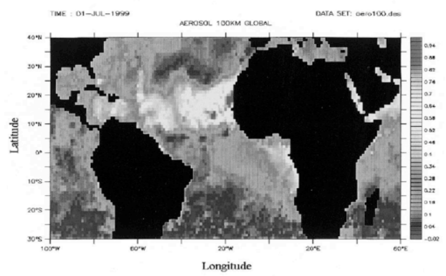
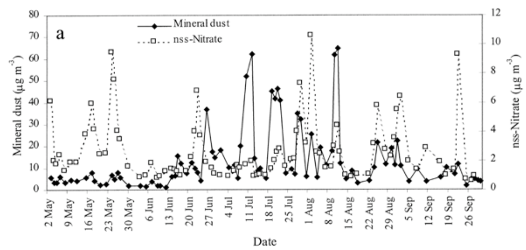


Fig. 3. AVHRR imagery of the 1999 aerosol optical thickness of the atmosphere, adjacent the Sahara Desert and above the Gulf of Mexico, during (a) 17 June, (b) 24 June, and (c) 1 July—from the Satellite Active Archive at PMEL (Pacific Marine Environmental Laboratory).



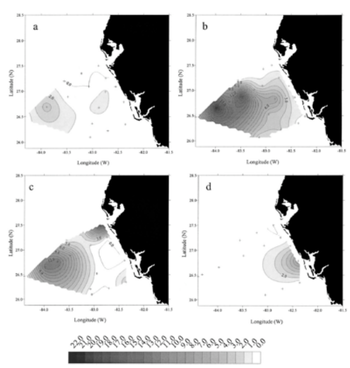
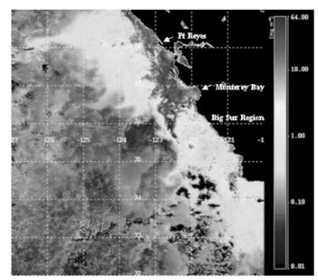
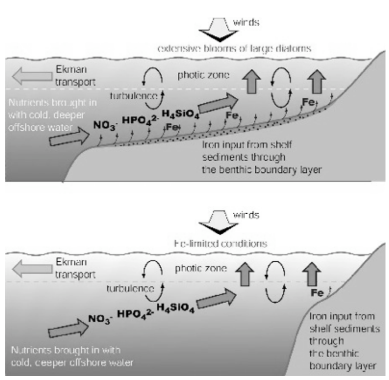


Fig. 7. The 1999 surface distributions of *Trichodesmium* populations (colonies L⁻¹) across the West Florida shelf during (a) 5–8 June, (b) 5–7 July, (c) 6–8 August, and (d) 7–9 September.



Upwelling along the California coast has different effects on productivity depending on river inputs and width of the continental shelf margin (Ken Bruland and Colleagues)



- >10 nM
- Fe
- < 1 nM
- Fe

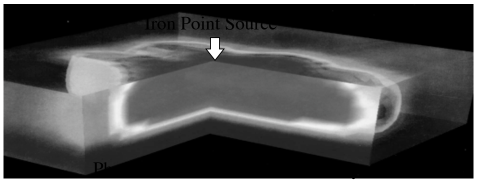
Iron Limitation of Ocean Phytoplankton

<u>Observations</u>

- Tropical Pacific Ocean,near the equator, rich in N and P but low in plant life.
- Light levels are plentiful
- What limits plant biomass?

<u>Iron Experiments</u>

- Multiple additions of dissolved iron to attain 2 nM (225 kg in 80 km^2). Sulphur Hexafluoride used as tracer.
- Control is area with no iron added, only SF6 and acid solution
- Navigate ship following buoys that mark the water masses
- Measure light, chlorophyl a, nutrients, biomass, CO2 pp



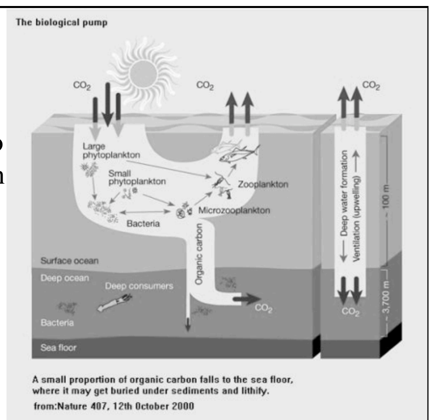
- Photosynthetic capacity: immediate and sustained increases.
- Phytoplankton Growth rate: doubled, abundance increased 20x.
- Nitrate concentrations: declined by half.
- Shift dominance to larger diatoms; release control by herbivory

Iron Ex Experiments

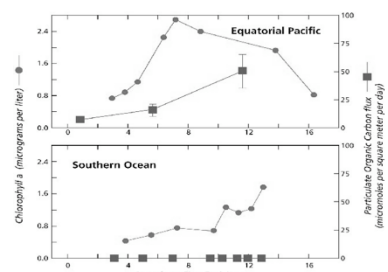
- Results of iron enrichment experiments taken from the US JGOFS (Joint Global Ocean Flux Study) newsletter

Experiment	Date	Results
IronExI	1993	3-fold increase in chlorophyll
IronExII	1996	10-fold increase in chlorophyll, 90μatm drawdown in CO2
SOIREE	1999	6-fold increase in chlorophyll, 25μatm drawdown in CO2
EisenEx	2000	4-fold increase in chlorophyll
SEEDS	2001	40-fold increase in chlorophyll
SOFeX (N)	2002	Greater than 10-fold increase in chlorophyll, Greater than 40μatm drawdown in CO2
SOFeX (S)	2002	Greater than 10-fold increase in chlorophyll, Greater than 40μatm drawdown in CO2
SERIES	2002	Greater than 10-fold increase in chlorophyll

What happens to the Carbon Produced during these Blooms?



Iron Ex Experiments



This graph shows the difference in the rate of carbon assimilation and drawdown in the Equatorial Pacific and the Southern Ocean.

Mesoscale Iron Enrichment Experiments 1993–2005: Synthesis and Future Directions

P. W. Boyd, T. Jickells, C. S. Law, S. Blain, E. A. Boyle, K. O. Buesseler, K. H. Coale, J. J. Cullen, H. J. W. de Baar, M. Follows, M. Harvey, C. Lancelot, M. Levasseur, N. P. J. Owens, R. Pollard, R. B. Rivkin, J. Sarmiento, V. Schoemann, V. Smetacek, S. Takeda, A. Tsuda, S. Turner, A. J. Watson

Since the mid-1980s, our understanding of nutrient limitation of oceanic primary production has radically changed. Mesoscale iron addition experiments (FeAXs) have unequivocally shown that iron supply limits production in one-third of the world ocean, where surface macronutrient concentrations are perennially high. The findings of these 12 FeAXs also reveal that iron supply exerts controls on the dynamics of plankton blooms, which in turn affect the biogeochemical cycles of carbon, nitrogen, silicon, and sulfur and ultimately influence the Earth climate system. However, extrapolation of the key results of FeAXs to regional and seasonal scales in some cases is limited because of differing modes of iron supply in FeAXs and in the modern and paleo-oceans. New research directions include quantification of the coupling of oceanic iron and carbon biogeochemistry.

Boyd et al. 2007 *Science 315 Pg. 312*

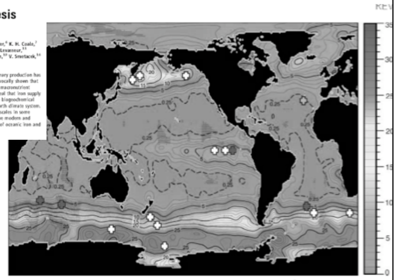


Fig. 1. Annual surface mixed-layer nitrate concentrations in units of µmol liter^{-1} (48), with approximate site locations of FeAXs (white crosses), FeNXs (red crosses), and a joint Fe and P enrichment study of the subtropical LNLC Atlantic Ocean (FeeP; green cross). FeAXs shown are SEEDS I and II (northwest Pacific; same site but symbols are offset), SERIES (northeast Pacific), IronEX I and II (equatorial Pacific; IronEX II is to the left), EisenEx and EIFEX (Atlantic polar waters; EIFEX is directly south of Africa), SOIREE (polar waters south of Australia), SOFEX-S (polar waters south of New Zealand), SOFEX-N (subpolar waters south of New Zealand), and SAGE (subpolar waters nearest to New Zealand). FeNX sites shown are the Galapagos Plume (equatorial Pacific), Antarctic Polar Front (polar Atlantic waters), and the Crozet and Kerguelen plateaus (Indian sector of Southern Ocean; Crozet is to the left of Kerguelen). For the geographical positions of the FeAXs, see (8). FeeP investigated whether N-fixing phytoplankton are simultaneously limited by Fe and P; see Table 1.

Table 1. The main findings from the 12 FeAXs (in chronological order from left to right) conducted between 1993 and 2005 [for additional details, see (8)]. See tables S1 to S3 for further details of initial conditions, ecosystem structure, and biogeochemical responses. Light climate, defined as the mean irradiance available to phytoplankton in the mixed layer, was calculated according to $I = I_0[1 - \exp(-K_w z)]/K_w z$, where I is mean mixed-layer irradiance (PAR), I_0 is the subsurface PAR, K_w is the vertical light attenuation coefficient (m^{-1}), and z is the depth of the upper mixed layer. Dilution rate is the mean growth rate of the SF_6-labeled patch over the duration of each FeAX. Each property is expressed volumetrically but can readily be converted to a column integral by using the data on mixed-layer depth (MLD). Terms prefixed with a delta such as ΔDIC denote maximum minus initial concentrations; nc, no significant change (relative to the surrounding HNLC waters); blank cells indicate that no data are currently available. The ratio of maximum to minimum primary production is based on column integrals.

Property	IronEX I (6)	IronEX II (30)	SOIREE (49)	EisenEx (56)	SEEDS I (57)	SOFEX-S (54, 58)	SOFEX-N (58)	EIFEX (46)	SERIES (17)	SEEDS II (59)	SAGE (59)	FeeP (59)
Fe added (kg)	450	450	1750	2350	350	1300	1700	2820	490	480	1100	1840
Temperature (°C)	23	25	2	3 to 4	11	−1	5	4 to 5	13	9 to 12	11.8	21
Season	Fall	Summer	Summer	Spring	Summer	Summer	Summer	Summer	Summer	Summer	Fall	Spring
Light climate (µmol quanta m^{-2} s^{-1})	254 (max) to 230 (min)	216 to 108	59 to 33	82 to 40	178 to 39	103 to 62	125 to 74		173 to 73		59 to 52	
Dilution rate (day^{-1})	0.27	0.18	0.07	0.04 to 0.43	0.05	0.08	0.1		0.07 to 0.16			0.4
Chlorophyll, t = 0 (mg m^{-3})	0.2	0.2	0.2	0.5	0.9	0.2	0.3	0.6	0.4	0.8	0.6	0.04
Chlorophyll, maximum (mg m^{-3})	0.6	3.3	2.3	2.8	23.0	2.5	2.4	3.0	5.5	2.4	1.3	0.07
MLD (m)	35	40*	65*	80*	13	35	45	100	30*	30	70*	30*
Bloom phase (duration, days)	Evolving (5) subducted	Decline (17)	Evolving (13)	Evolving (21)	Evolving (10)	Evolving (28)	Evolving (27) subducted	Partial decline, evolving (37)	Decline (25)	Evolving (25)	No bloom (17)	No bloom (7)
ΔDIC (mmol m^{-3})	6	26	17	14	58	21	13		36		nc	<1
ΔDMS (µmol m^{-3})	0.8	1.8	2.9	1.3, then to 0†	nc	nc	Increased		8.5, then to −5.7†	nc	nc	nc
Dominant phytoplankton	Mixed	Diatom	Diatom	Diatom	Diatom	Diatom	Mixed	Diatom	Diatom	Mixed	Mixed	*Cyanobacteria Prochlorococcus*
Export	nc	Increase	nc	nc	nc	Increase	Increase§	Increase	Increase	nc	nc	
Mesozooplankton stocks	Increase‡	Increase	nc	nc	nc	nc	nc	Increase	Increase	Increase	nc	nc
Primary production (max/min ratio)	4	6	9	4	4	6	10	2	10		2	1.7

*Changes in MLD were observed during the study; the maximum MLD is shown (for initial MLD, see table S1). †An initial increase in DMS concentration followed by a decline by the end of the study. ‡Based on anecdotal evidence. §Increased export was mainly associated with a subduction event.

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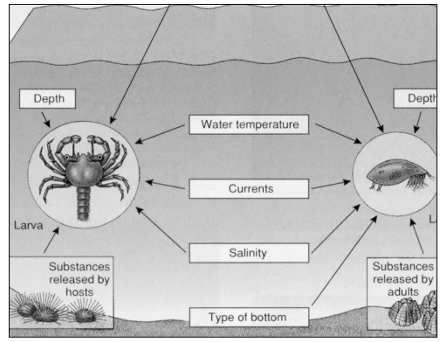
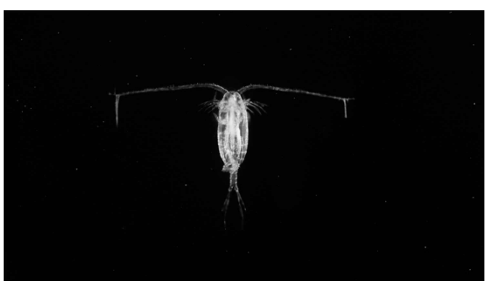
The Meroplankton are the drifting larvae of bottom-dwelling animals



The principal herbivores of phytoplankton in the ocean are the copepods which feed by creating currents, and capturing algae using a "feeding basket" made by appendages

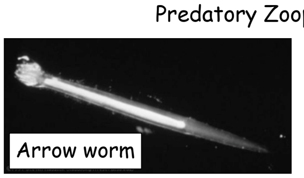


Others use filters to remove food from the water

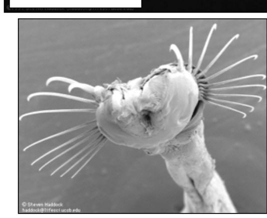
Salp

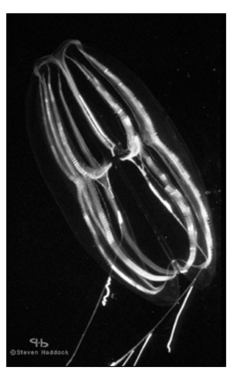
Sea butterfly

Predatory Zooplankton

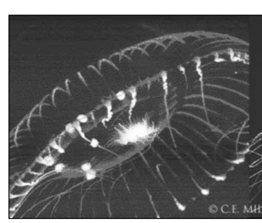


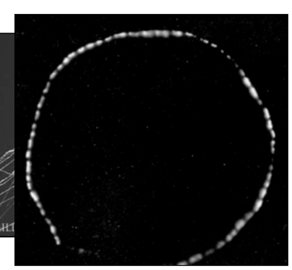
Arrow worm





Many Phytoplankton and Zooplankton are bioluminescent; they account for most of the bioluminescense in the sea





Many Phytoplankton and Zooplankton (and fish) undergo daily vertical migrations of a meter to tens of meters

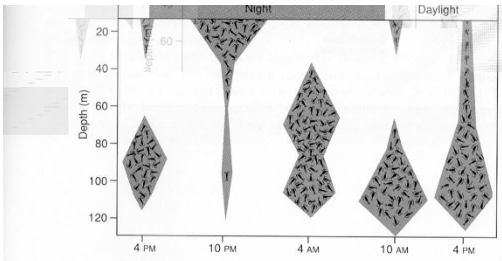


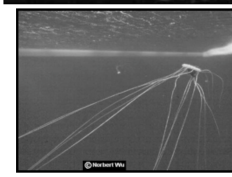
FIGURE 14.22 The depth distribution at different times of day of a vertically migrating copepod.

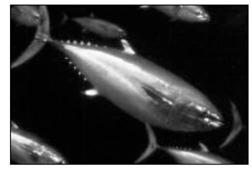
IV. The Nekton

The nekton consists mostly of Larger, predatory type animals

School of squid

Anchovy

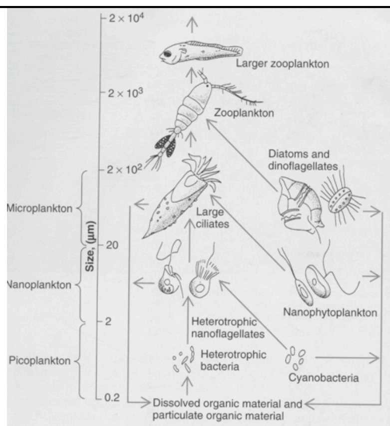




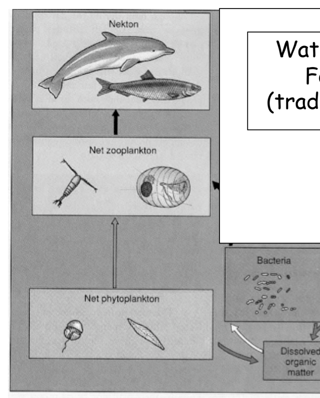
Tuna

V. Water Column Food Web

(Simplified)

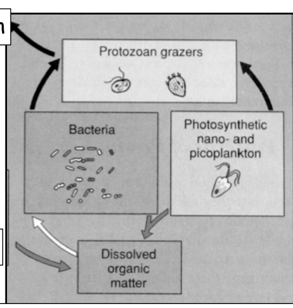


Water Column Food Web (traditional view)



The microbial food web, an important component of water column trophic dynamics

To Zooplankton



From Algae

Water Column Food Web (modern view)