CHAPTER

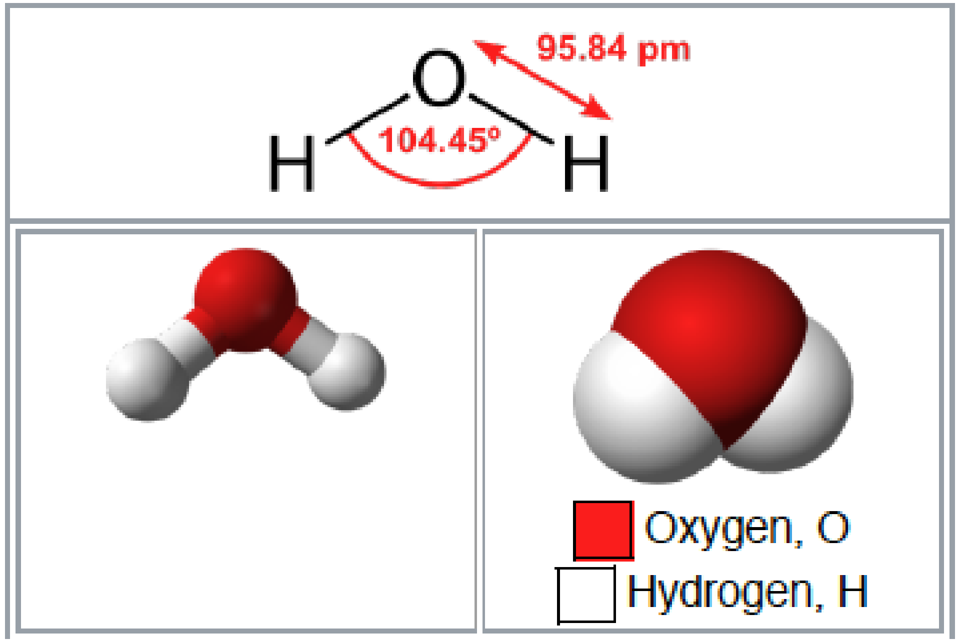
# 8

# Inland Waters

OUTLINE

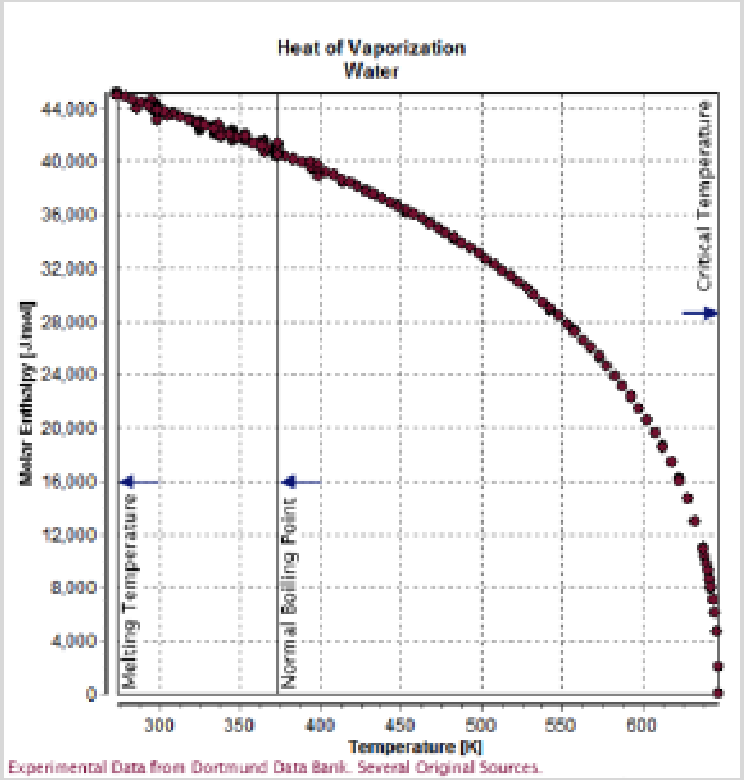
# Special Properties of Water

Polar Molecule



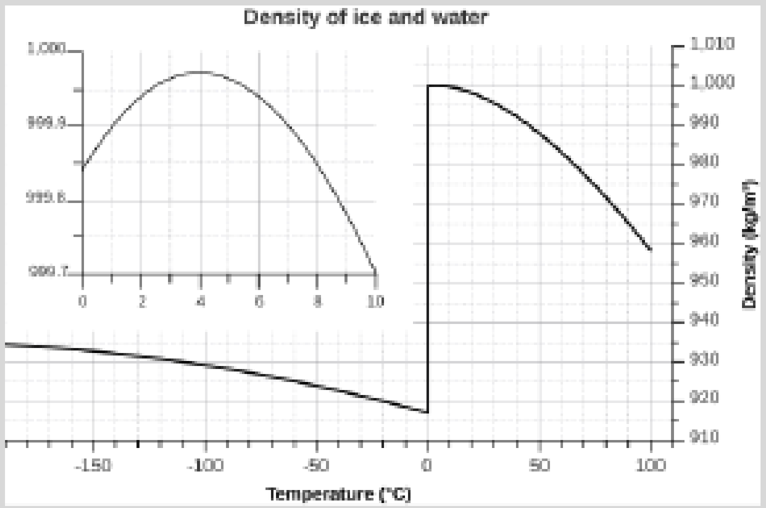

- Excellent Solvent
- Surface Tension
- Capillary Action

Heat Capacity and Heats of Vaporization

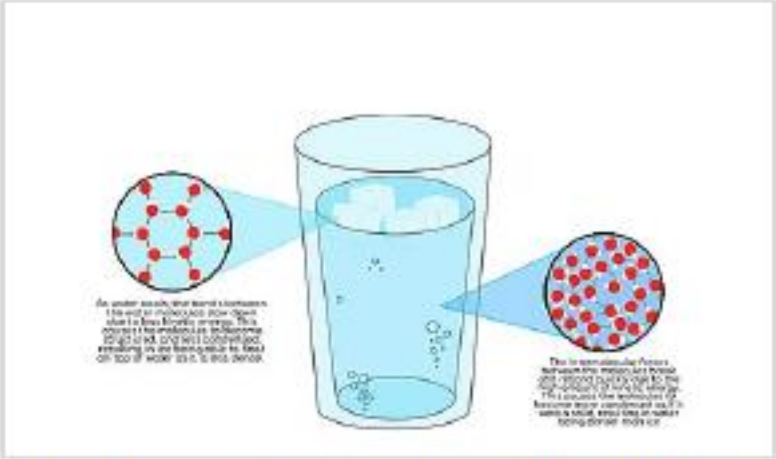



Heat of vaporization of water from melting to critical temperature

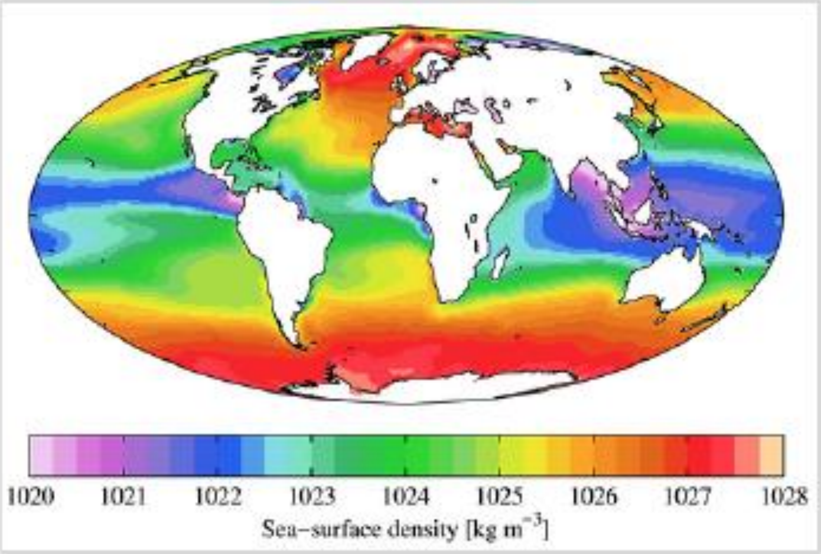
# Special  Properties of Water




Density of ice and water as a function of temperature



The difference in the molecular structures of water and ice.




WOA surface density

# Ion Chemistry

## Cations

($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, and $K^{+}$)

## Anions

($HCO_3^-$, $CO_3^-$, $SO_4^{2-}$, and $Cl^-$)

## Atmospheric Deposition

### Marine Salts

($Na^{+}$, $Ca^{2+}$, $Mg^{2+}$)

### Acid ions

($SO_4^{2-}$, $NO_3^-$)

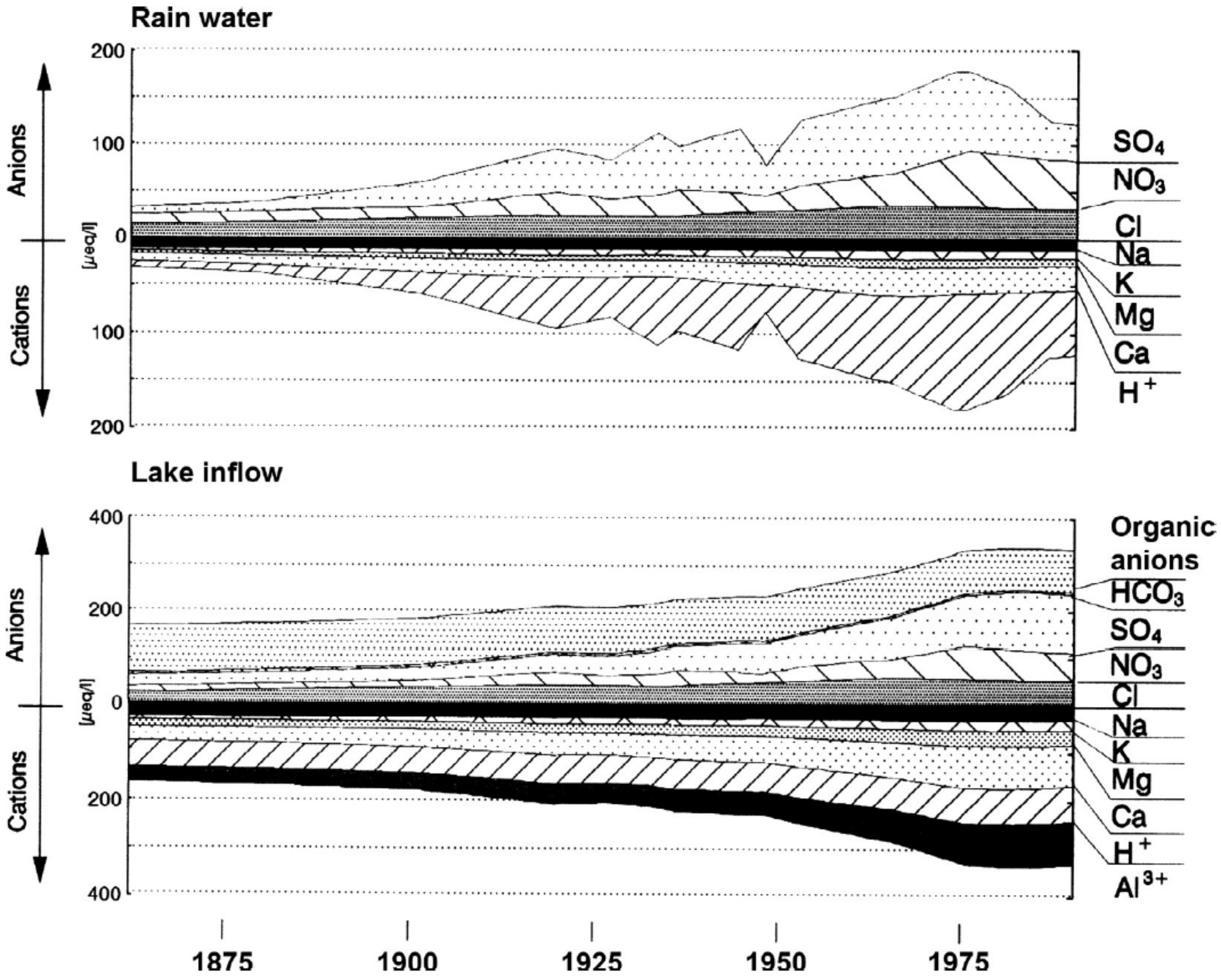



FIGURE 8. 6 A paleolimnological reconstruction of changes in the charge balance of rain and lake inflow over the period of the Industrial Revolution. Note that while rainwater became more acidic over the record (increasing contribution of $H^+$ and the acid anions $SO_4^{2-}$ and $NO_3^-$ through time) the interflow waters have seen little change in pH ($H^+$). Instead, large increases in the concentrations of sulfate and nitrate over time have been accompanied by increases in the base cations ($K^+$, $Mg^{2+}$, $Ca^{2+}$) and in soluble $Al^{3+}$. *Source: Hinderer et al. 1998.*

# Gas Diffusion and Solubility

Dissolved Inorganic Carbon (DIC)

$\boldsymbol{\Sigma}CO_2$

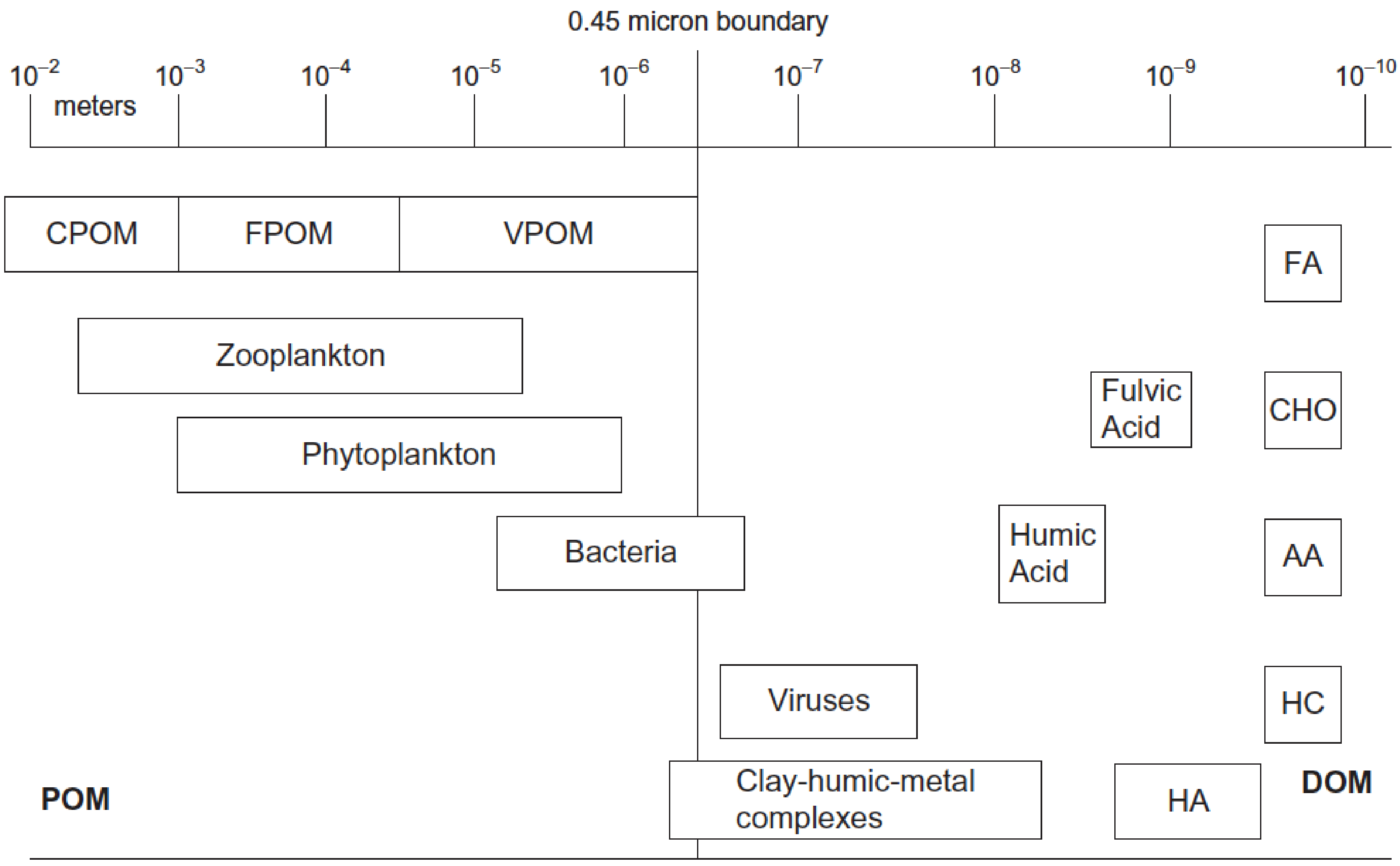
$$CO_2 + H_2O <=> H^+ + HCO_3^- <=> 2H^+ + CO_3^{2-}$$

| | | |
|---|---|---|
| pH < 4.3 | CO2 | |
| pH 4.3– 8.3 | $HCO_3^-$ | Acid Neutralizing Capacity (ANC) pH 4.3 |
| pH > 8.3 | $CO_3^-$ | |

TABLE 8.1 Estimates of $CO_2$ Outgassing from Inland Waters

| Zone-class | Area of inland waters ($1000s\ km^2$) min-max | $pCO_2$ (ppm) median | Gas exchange velocity ($k_{600}$, $cm\ hr^{-1}$) median | Areal outgassing ($g\ C\ m^{-2} yr^{-1}$) median | Zonal outgassing ($Pg\ C\ yr^{-1}$) median |
|---|---|---|---|---|---|
| **Tropical (0°–25°)** | | | | | |
| Lakes and reservoirs | 1840–1840 | 1900 | 4.0 | 240 | 0.45 |
| Rivers (>60–100 m wide) | 146–146 | 3600 | 12.3 | 1600 | 0.23 |
| Streams (>60–100 m wide) | 60–60 | 4300 | 17.2 | 2720 | 0.16 |
| Wetlands | 3080–6170 | 2900 | 2.4 | 240 | 1.12 |
| **Temperate (25°–50°)** | | | | | |
| Lakes and reservoirs | 880–1050 | 900 | 4.0 | 80 | 0.08 |
| Rivers (>60–100 m wide) | 70–84 | 3200 | 6.0 | 720 | 0.05 |
| Streams (<60–100 m wide) | 29–34 | 3500 | 20.2 | 2630 | 0.08 |
| Wetlands | 880–3530 | 2500 | 2.4 | 210 | 0.47 |
| **Boreal and Arctic (50°–90°)** | | | | | |
| Lakes and reservoirs | 80–1650 | 1100 | 4.0 | 130 | 0.11 |
| Rivers (>60–100 m wide) | 7–131 | 1300 | 6.0 | 260 | 0.02 |
| Streams (<60–100 m wide) | 3–54 | 1300 | 13.1 | 560 | 0.02 |
| Wetlands | 280–5520 | 2000 | 2.4 | 170 | 0.49 |
| **Global** | | *Global land area* | | | |
| Lakes and reservoirs | 2800–4540 | 2.1–3.4% | | | 0.64 |
| Rivers (>60–100 m wide) | 220–360 | 0.2–0.3% | | | 0.30 |
| Streams (<60–100 m wide) | 90–150 | 0.1–0.1% | | | 0.26 |
| Wetlands | 4240–15 220 | 3.2–11.4% | | | 2.08 |
| **All inland waters** | **7350–20 260** | **5.5–15.2%** | | | **3.28** |

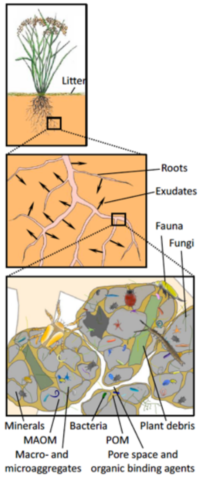
*Source: Aufdenkampe et al. 2011. Used with permission of the Ecological Society of America.*



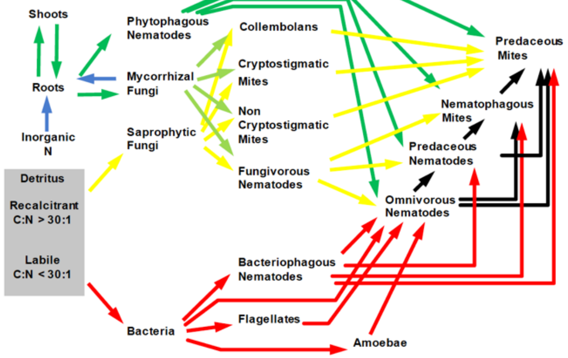

AA = amino acids; CHO = carbohydrates; CPOM = coarse particulate organic matter;
FA = fatty acids; FPOM = fine particulate organic matter; HA = hydrophilic acids;
HC = hydrocarbons; VPOM = very fine particulate organic matter

FIGURE 8.7 Size range of particulate and dissolved organic matter and carbon compounds in natural waters. The distinction between dissolved and particulate organic carbon is operationally defined, with investigators typically considering organic molecules that pass through a 0.45-mm filter dissolved. *Source: Reproduced from Hope et al. 1994.*

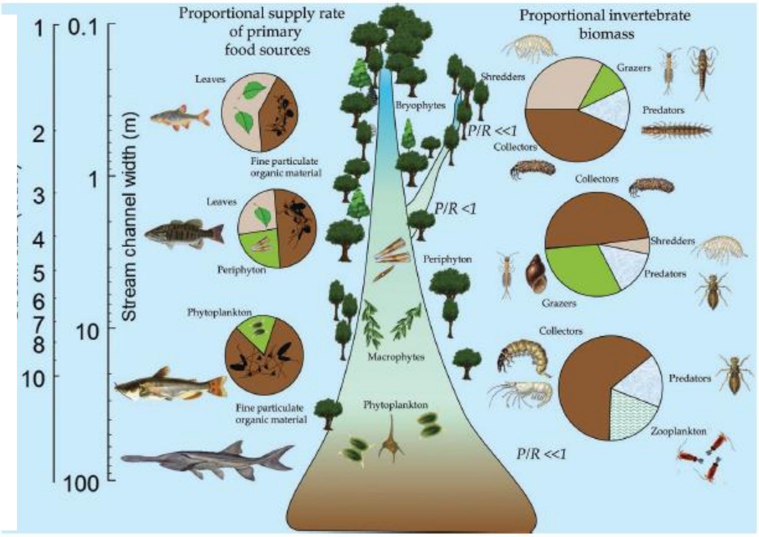
# Food Webs



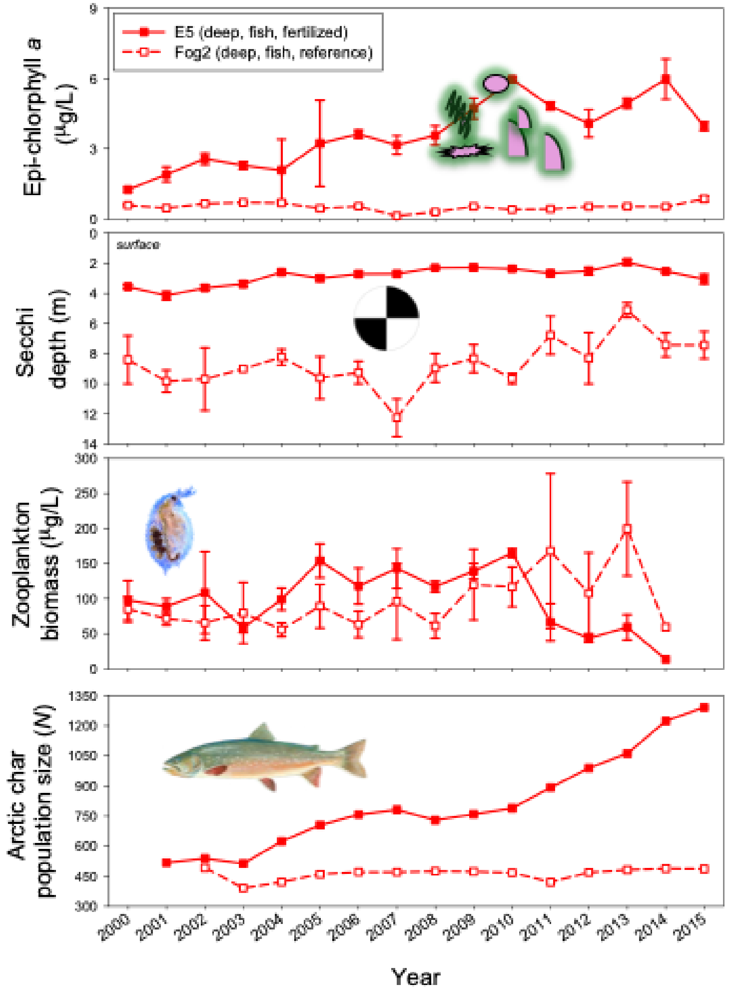
Litter
Roots
Exudates
Fauna
Fungi
Minerals
Bacteria
Plant debris
MAOM
POM
Macro- and microaggregates
Pore space and organic binding agents

Shoots
Roots
Inorganic N
Detritus
Recalcitrant C:N > 30:1
Labile C:N < 30:1
Phytophagous Nematodes
Mycorrhizal Fungi
Saprophytic Fungi
Bacteria
Collembolans
Cryptostigmatic Mites
Non Cryptostigmatic Mites
Fungivorous Nematodes
Bacteriophagous Nematodes
Flagellates
Amoebae
Predaceous Mites
Nematophagous Mites
Predaceous Nematodes
Omnivorous Nematodes

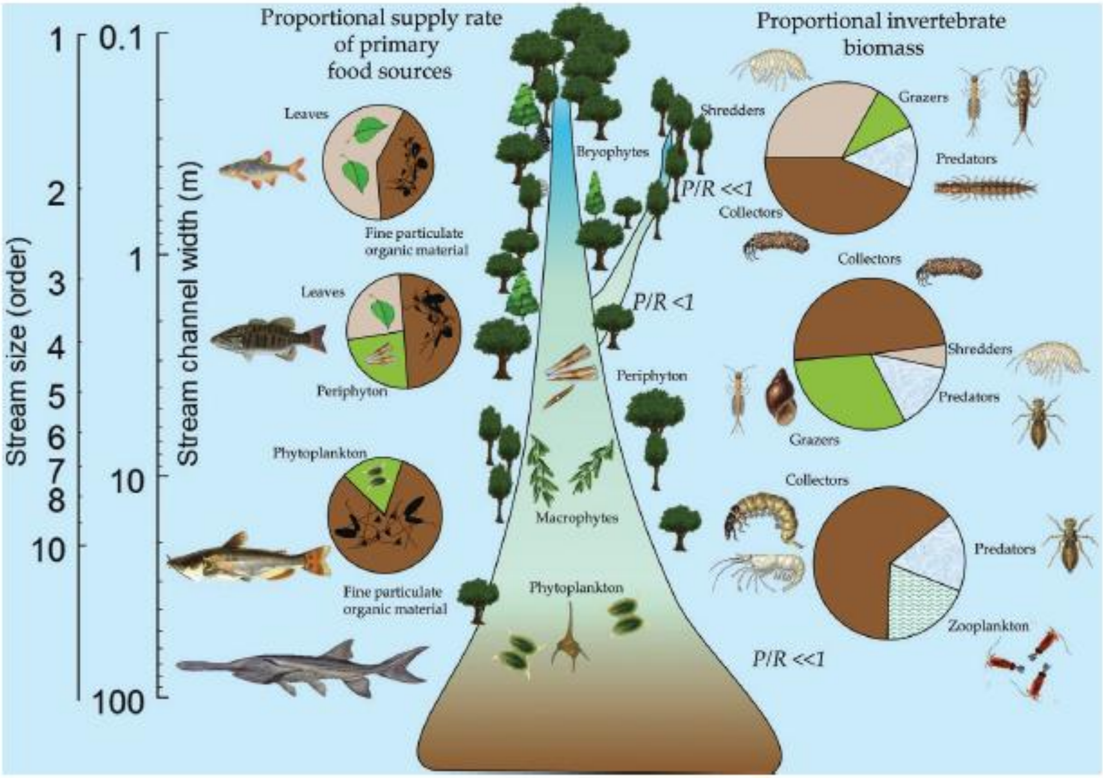



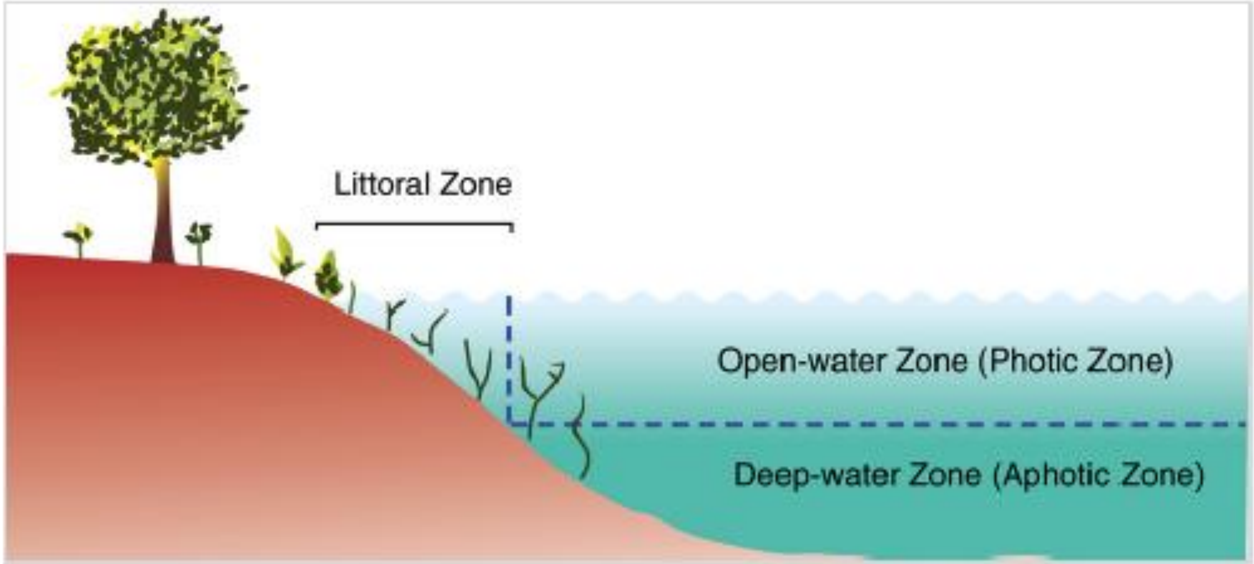
Stream channel width (m)
0.1
1
10
100
1
2
3
4
5
6
7
8
10
Proportional supply rate of primary food sources
Proportional invertebrate biomass
Leaves
Fine particulate organic material
Bryophytes
P/R <<1
P/R <1
Periphyton
Phytoplankton
Macrophytes
Shredders
Collectors
Grazers
Predators
Zooplankton

E5 (deep, fish, fertilized)
Fog2 (deep, fish, reference)
Epi-chlorphyll a (µg/L)
Secchi depth (m)
surface
Zooplankton biomass (µg/L)
Arctic char population size (N)
Year
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

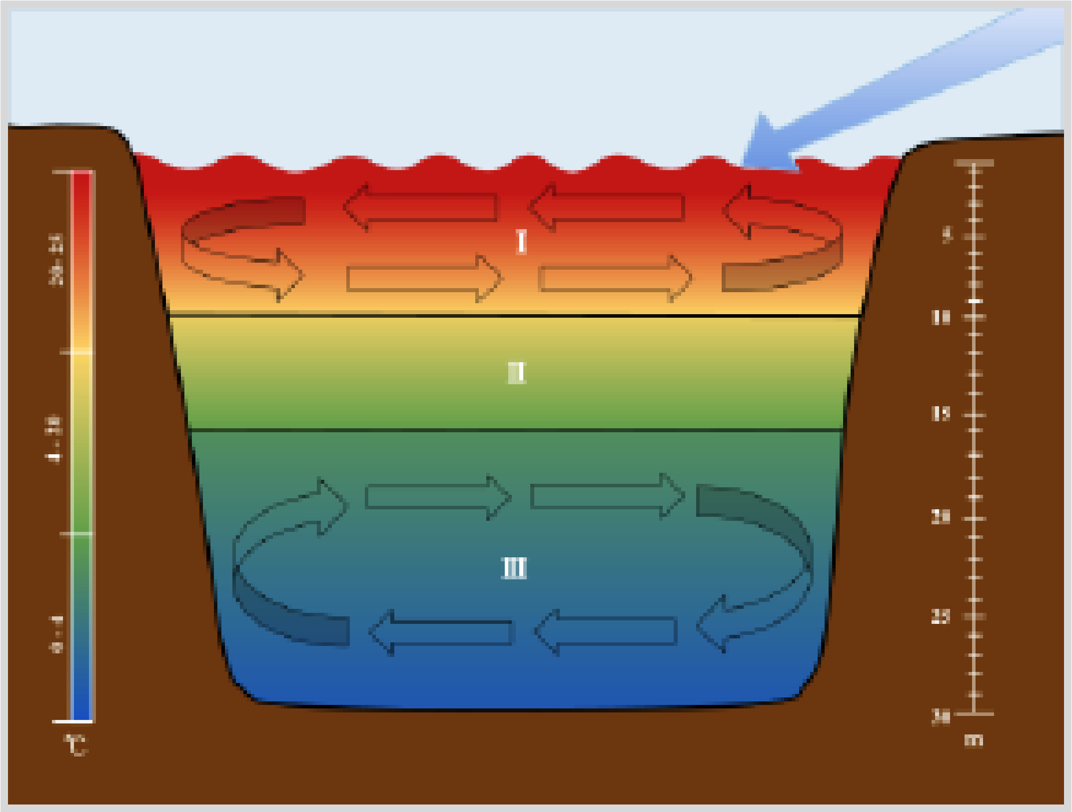
# Lakes




The three primary zones of a lake are the littoral zone, the open-water (also called the photic or limnetic) zone, and the deep-water (also called the aphotic or profundal) zone.

# Stratification

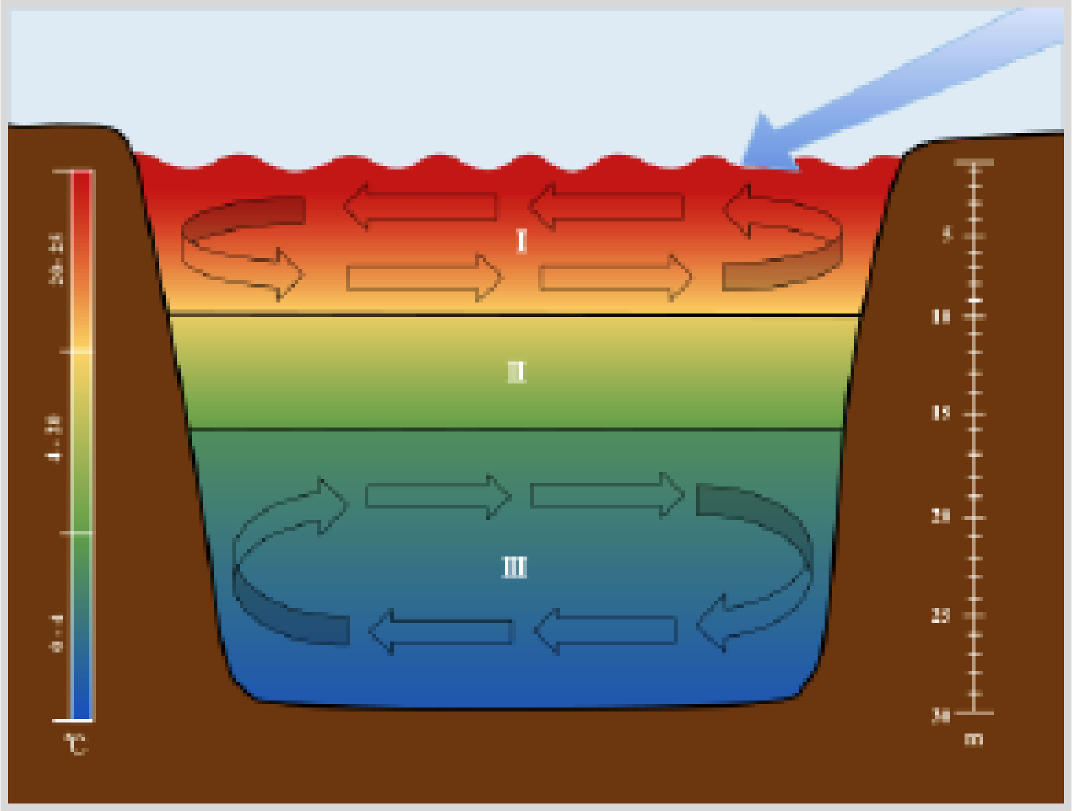


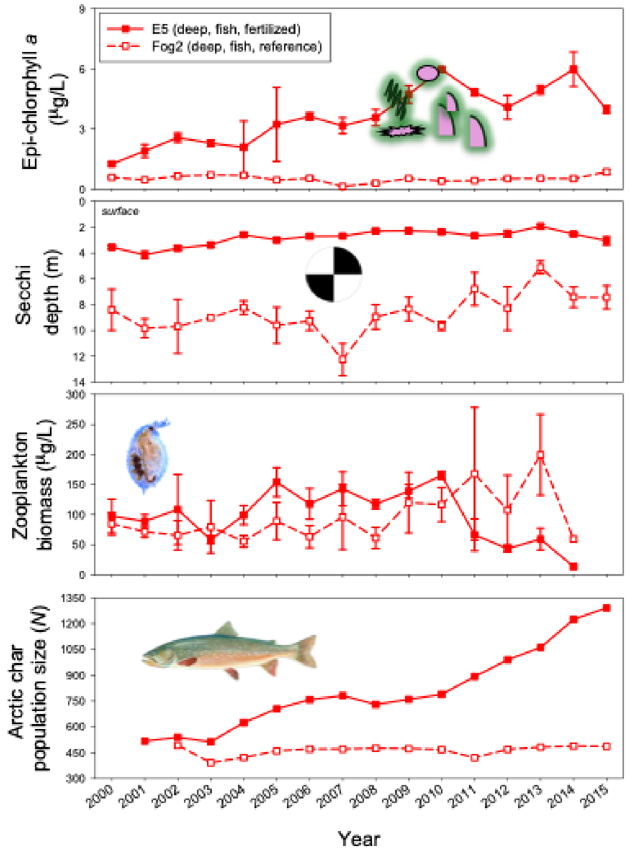

I. Epilimnion

II. Metalimnion (*aka* Thermocline)

III. Hypolimnion

# Stratification



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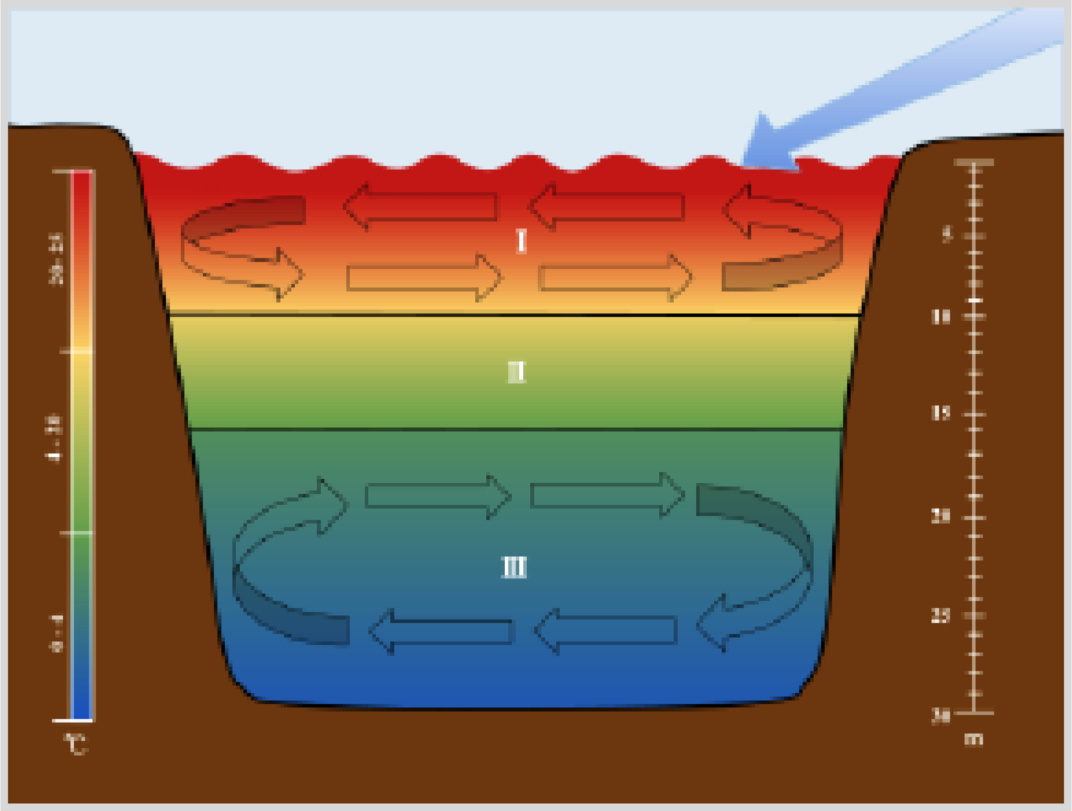
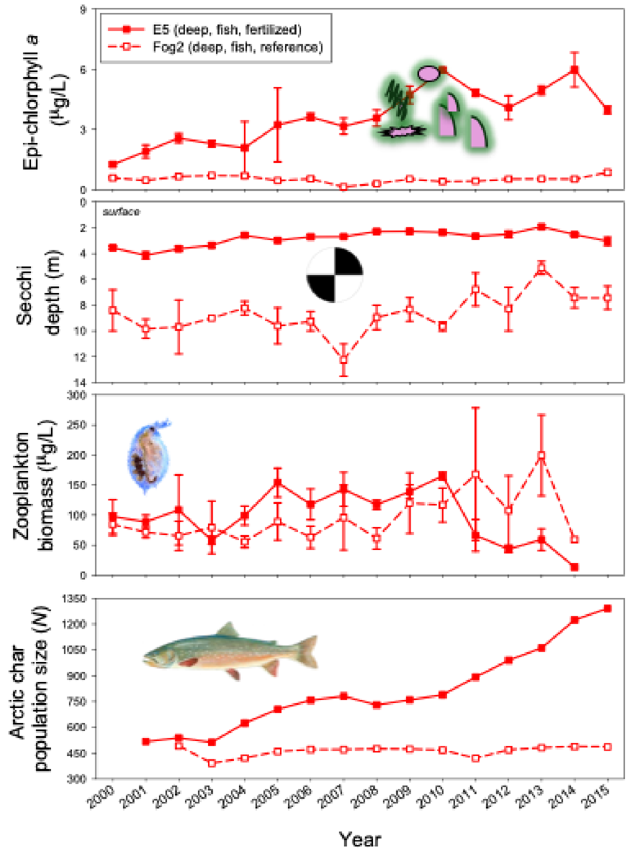
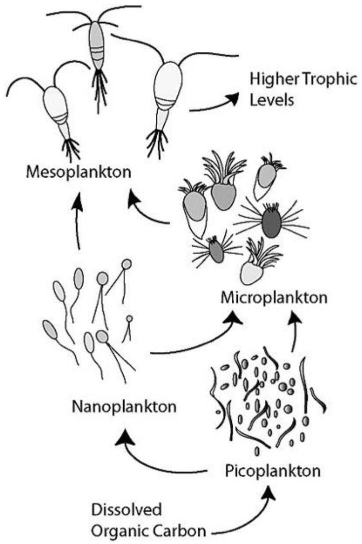
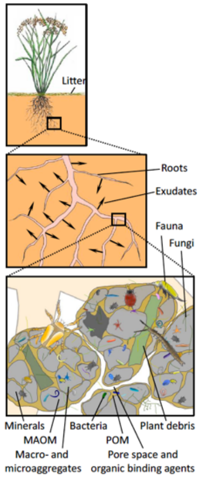


# Food Webs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Exudates
Fauna
Fungi
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Plant debris
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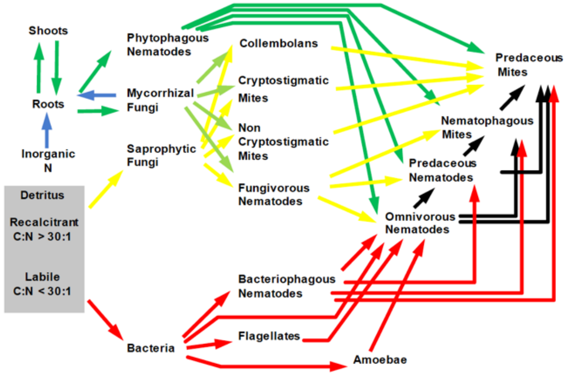
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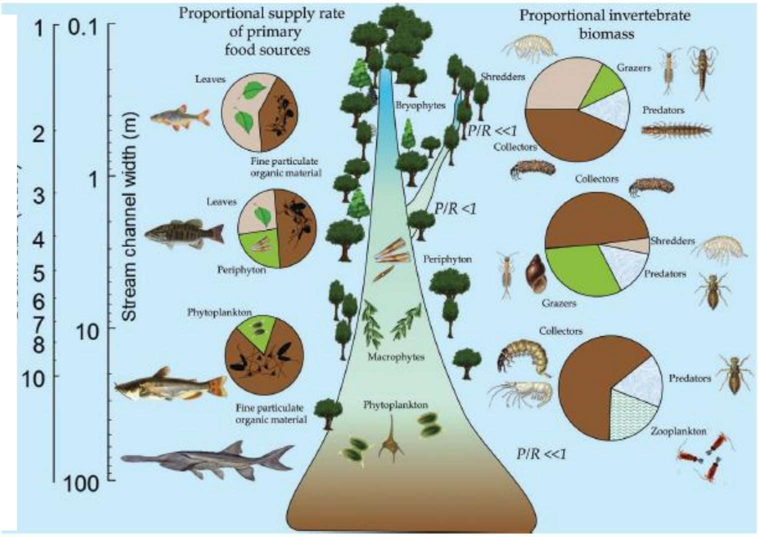
Omnivorous Nematodes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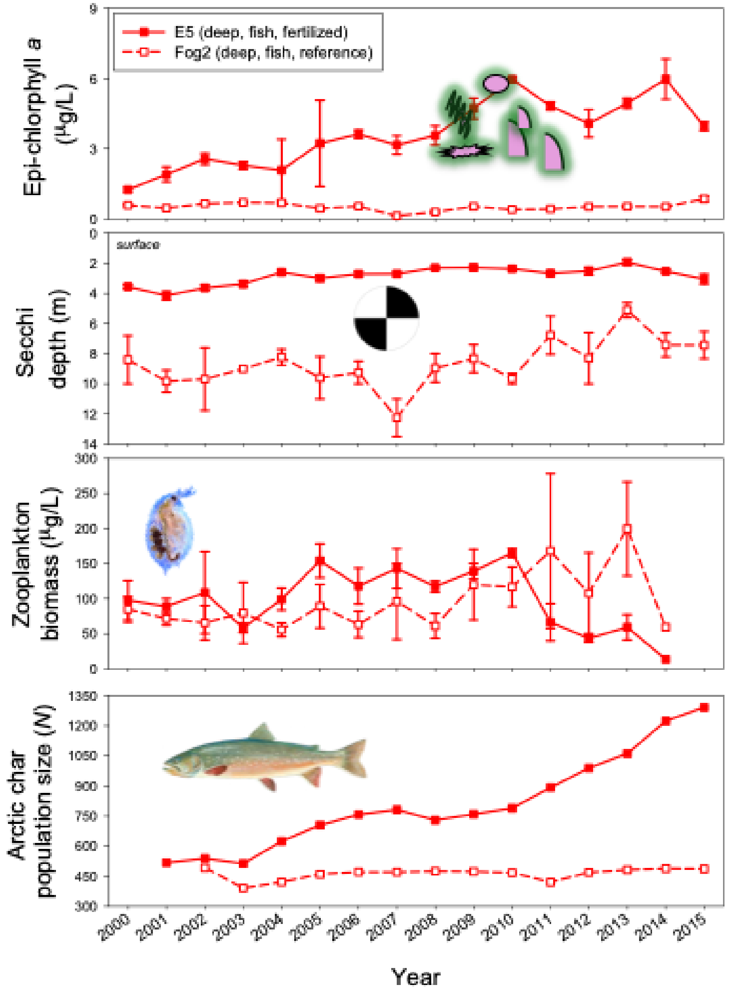
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surface
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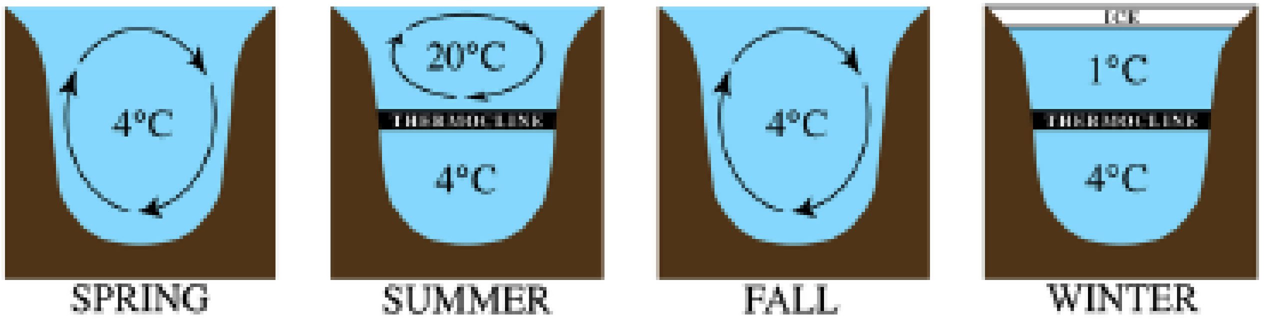
Arctic char population size (N)
Year
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

# Lake Turnover




- Dimictic Lakes
- Polymictic Lakes
- Meromictic Lakes

$O_2$

Dissolved Nutrients

Anthropogenic Influences

- Nutrient loads
- Pollution (particulates, Salts, Etc…)
- Temperature (Climate Change)

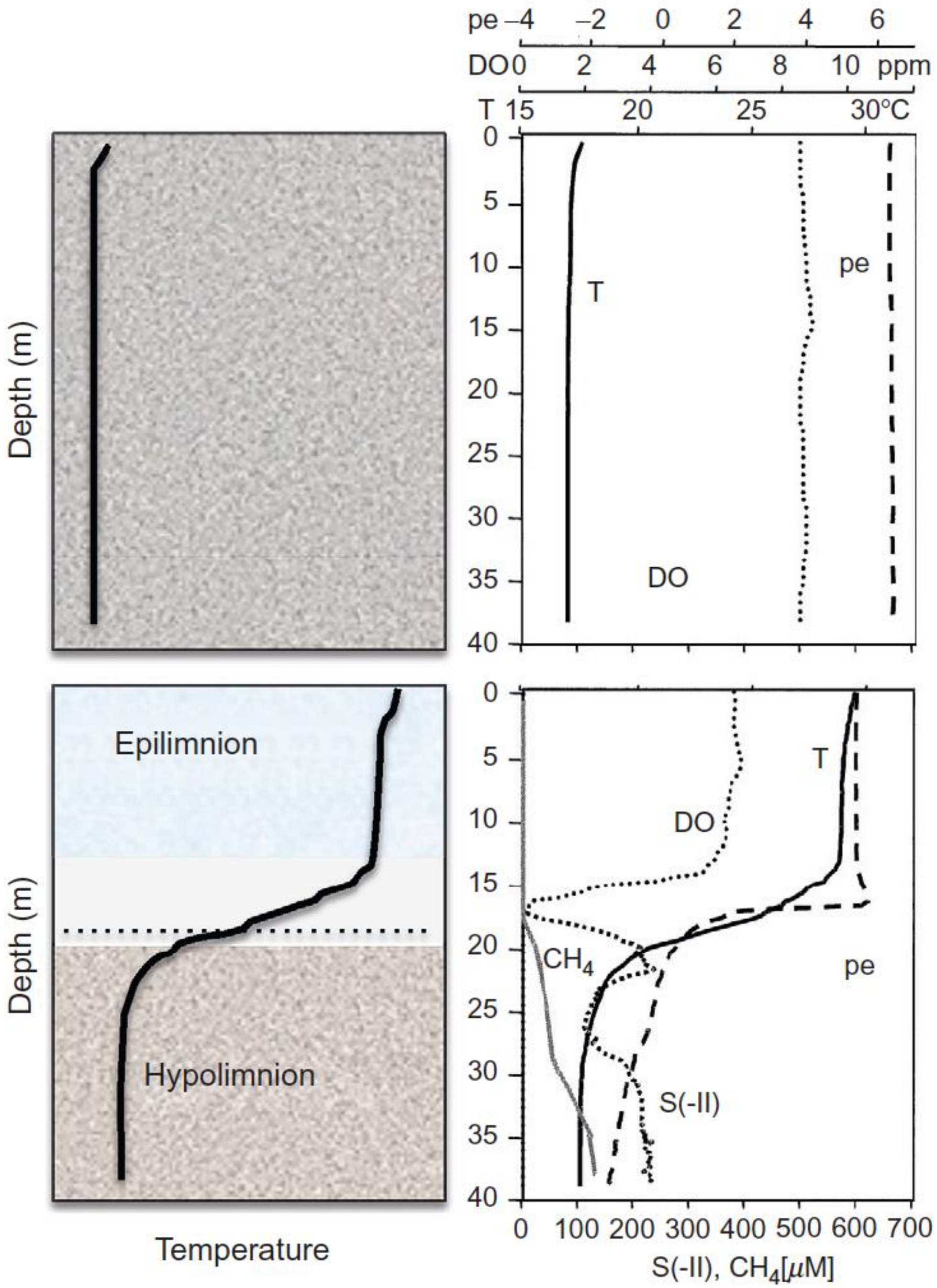



FIGURE 8.10 In the upper panels are shown a hypothetical and an actual lake temperature profile during winter (data from January). The lower panels show profiles during the period of summer stratification (data from July). The *dashed line* in the lower left panel indicates the lake thermocline. Depth profiles for temperature (T), dissolved oxygen (DO), redox potential (pe), total sulfide (S(-II)) and methane ($CH_4$) measured in the water column of Lake Kinneret in the Afro-Syrian rift valley during 1999. *Source: From Eckert and Conrad 2007. Used with permission of Springer.*

# Anthropogenic Influences

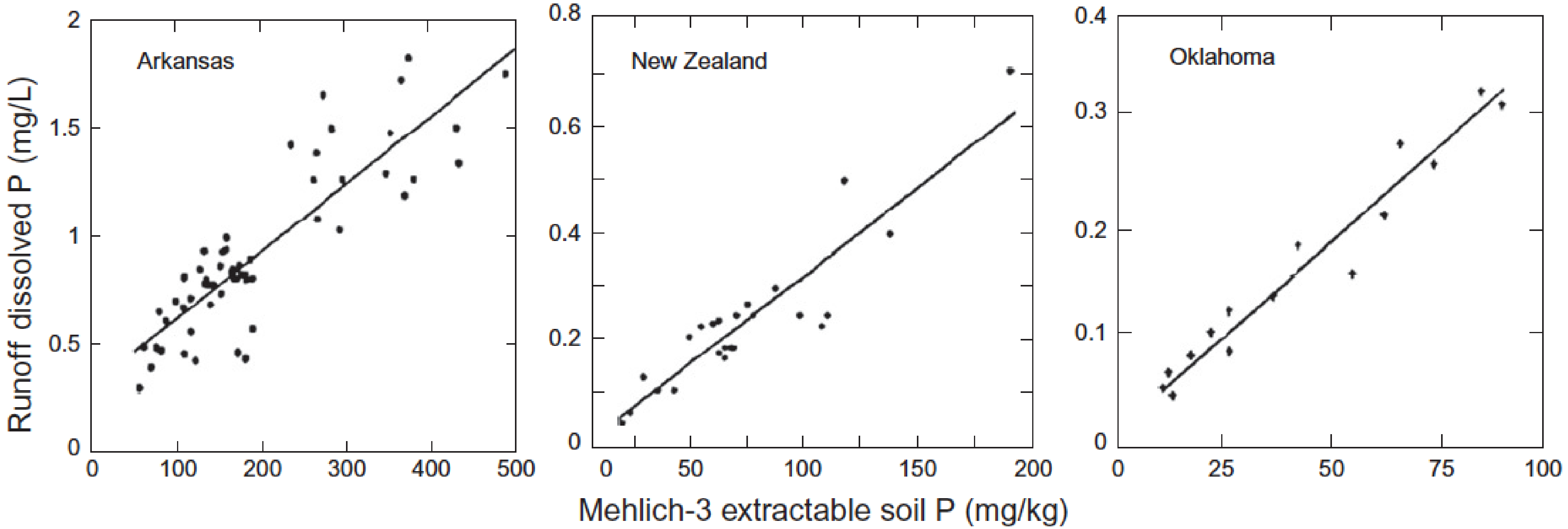



FIGURE 8.4 The nutrient content of surface waters reflect nutrient loading to their catchments. In A–C, the extractable soil phosphorus in agricultural watersheds is a good predictor of the concentrations of dissolved P in receiving streams. *Source: Sharpley et al. 1996. Used with permission of the Soil and Water Conservation Society.*

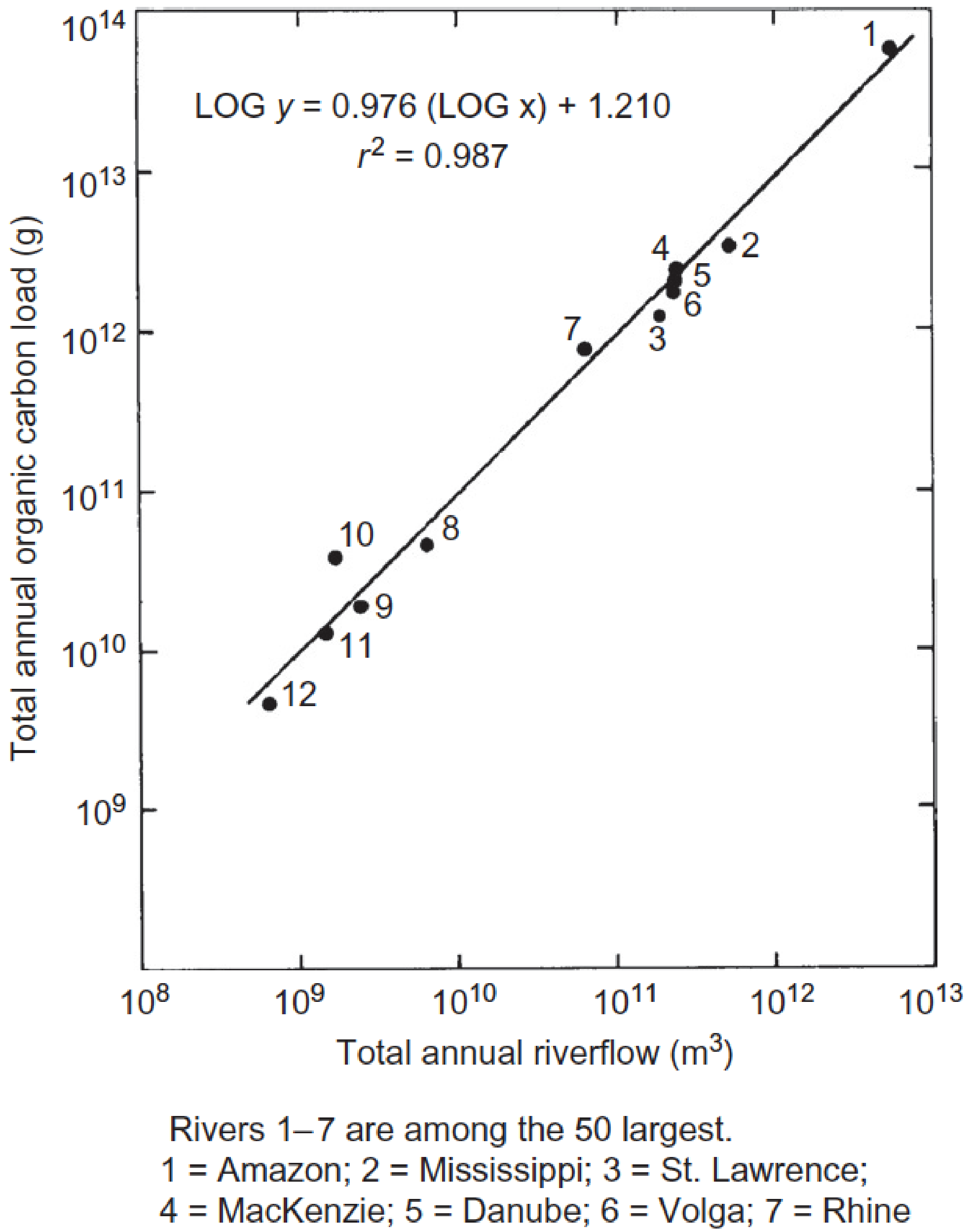



**FIGURE 8.8** Total annual load of organic carbon shown as a logarithmic function of total annual riverflow for major rivers of the world. *Source: From Schlesinger and Melack 1981 with a revision of the data for the St. Lawrence derived from Pocklington and Tan (1987). Used with permission of the Ecological Society of America.*

# Reflection 9

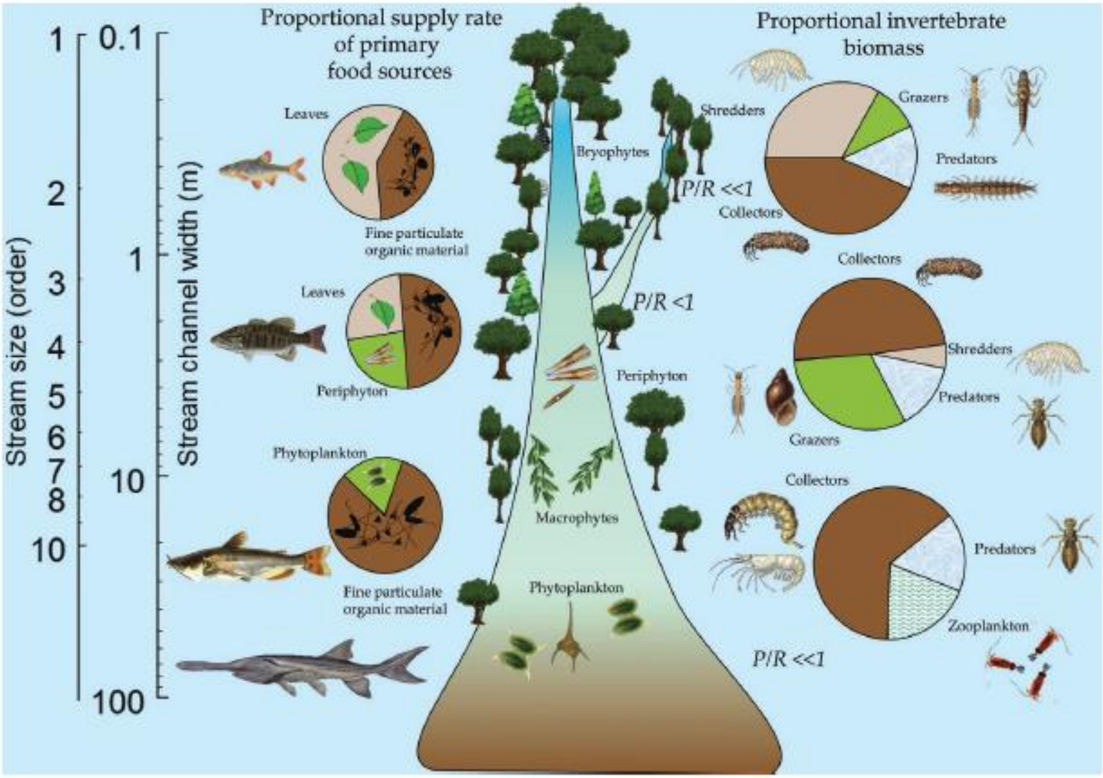
The main takeaway for me this week was understanding the similarities and differences in nutrient recycling between aquatic and terrestrial ecosystems. Dr. Moore emphasized that the key distinction lies in where and when these processes occur spatially and temporally. In aquatic systems, such as lakes, stratification separates zones of production and decomposition. Without seasonal turnover, the deeper layers would become anaerobic, which would negatively affect productivity within the lake. In contrast, terrestrial ecosystems function as more closed systems, where most nutrients fueling biological processes originate within the system itself.

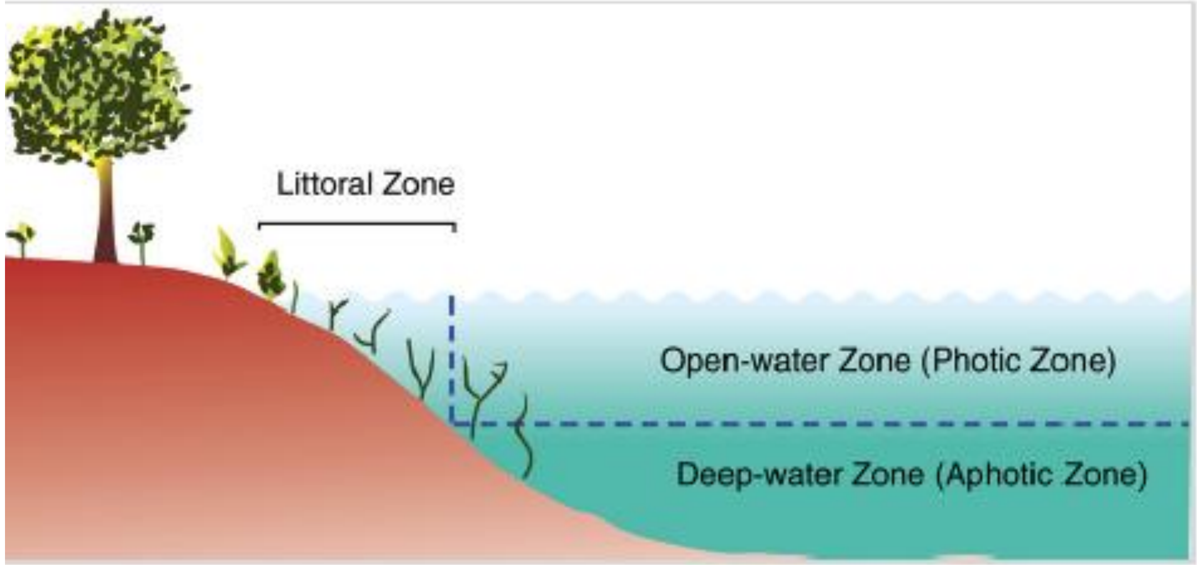
An interesting thing I learned this week was how looking at terrestrial versus aquatic ecosystems from different scales can sort of make them appear more similar or more different in terms of structure and function. When we started talking about lake and stream ecosystems, I felt like I was able to make a lot of connections from some of the limnology case studies I read in my previous ecosystem ecology class with Ed Hall. The dynamics of aquatic ecosystems- especially in Colorado- have become a lot more interesting to me in the past couple of years in ESS, and I've decided to pursue a career in water resources (for now) because of that!

I think the most interesting thing we learned this week was about the different layers of lakes. I still don't quite understand everything surrounding the Littoral Zone, Photic Zone, and the Aphotic Zone, but I think it's really interesting to know there are so many different aspects of ecosystems that I didn't know before. Over this next week, I'm going to go more in-depth to understand it better, as it seems important to understand how it applies to the overall mechanics of lake systems.

# Streams

# Lakes

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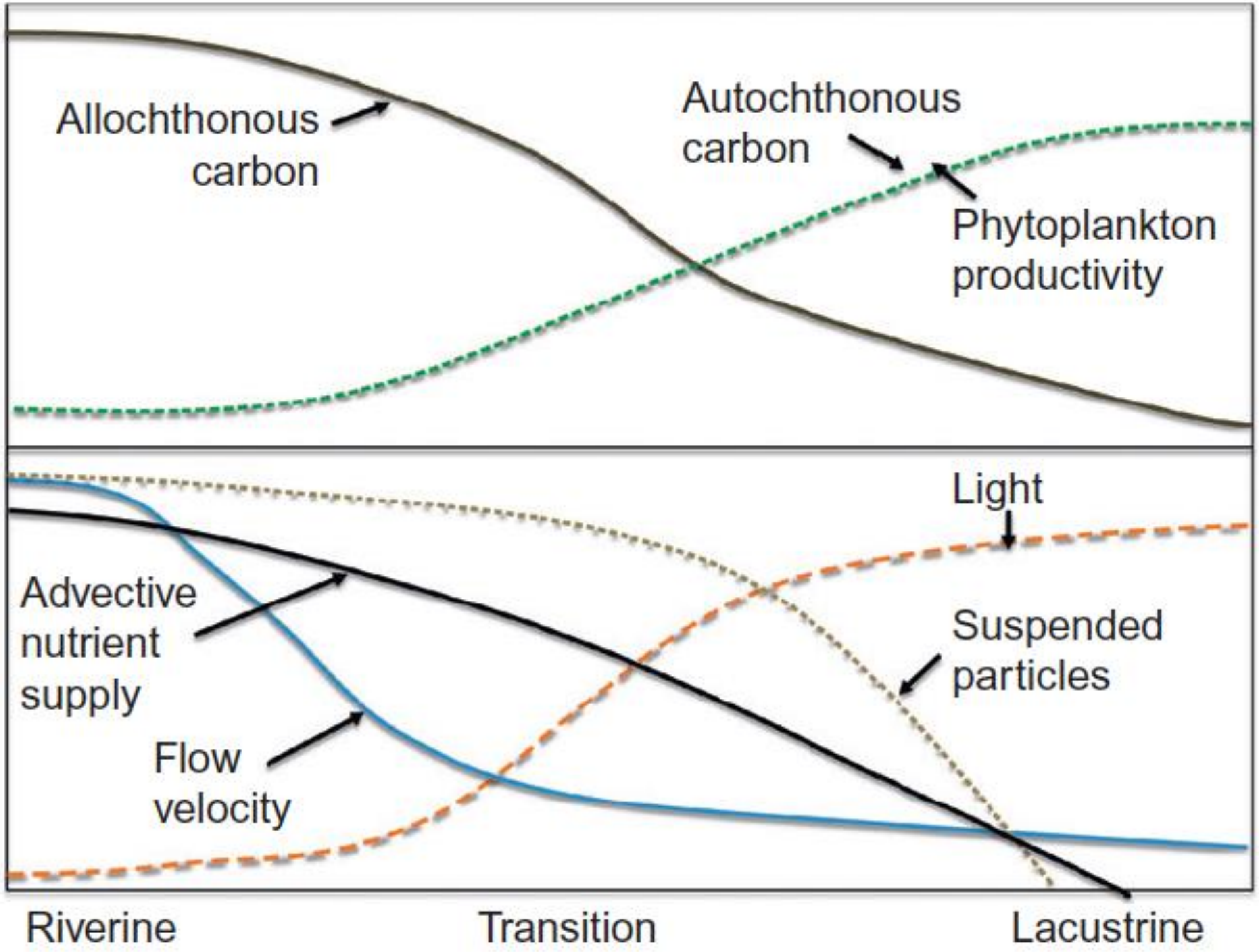



FIGURE 8.19 Commonly observed shifts in flow, light, nutrients, and sources of organic matter in the transition between rivers and lakes.

# Trophic Status of Lakes

TABLE 8.2 Lake Classification by Trophic Status

| Trophic type | Mean primary productivity (mg C $m^{-2}$ $d^{-1}$) | Phytoplankton biomass (mg C $m^{-3}$) | Chlorophyll a (mg $m^{-3}$) | Light extinction coefficient ($\eta m^{-1}$) | Total Organic Carbon (mg $L^{-1}$) | Total P ($\mu g$ $L^{-1}$) | Total N ($\mu g$ $L^{-1}$) |
|---|---|---|---|---|---|---|---|
| Ultra-oligotrophic | <50 | <50 | 0.01–0.05 | 0.03–0.08 | | <1–5 | <1–250 |
| Oligotrophic | 50–300 | 20–100 | 0.3–3 | 0.05–1 | <1–3 | | |
| Oligomesotrophic | | | | | | 5–10 | 250–600 |
| Mesotrophic | 250–1000 | 100–300 | 2–15 | 0.1–2.0 | <1–5 | | |
| Mesoeutrophic | | | | | | 10–30 | 500–1100 |
| Eutrophic | >1000 | >300 | 10–500 | 0.5–4.0 | 5–30 | | |
| Hypereutrophic | | | | | | 30–>5000 | 500–>15,000 |
| Dystrophic | <50–500 | <50–200 | 0.1–10 | 1.0–4.0 | 3–30 | <1–10 | <1–500 |

*Source: Modified from Wetzel 2001 (Table 15.13, p. 389).*

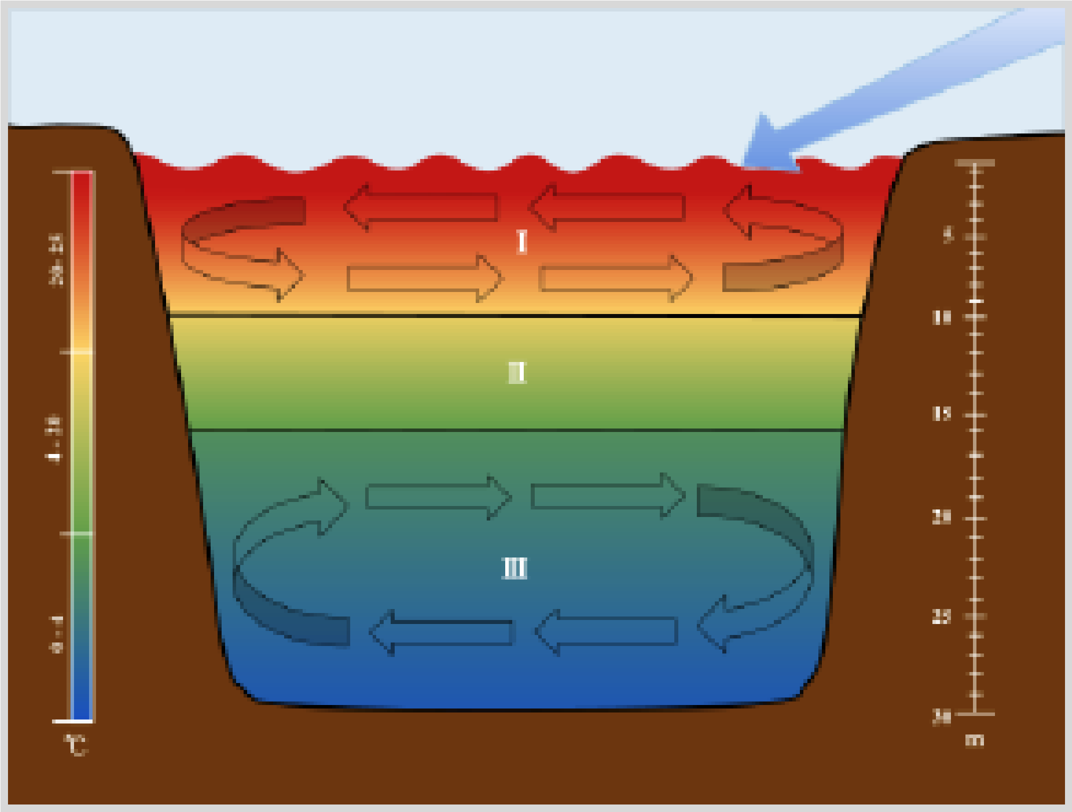
$$\mathrm{NPP} = ([O_2]_{t2} - [O_2]_{t1})_{\mathrm{LIGHT}} \tag{8.6}$$

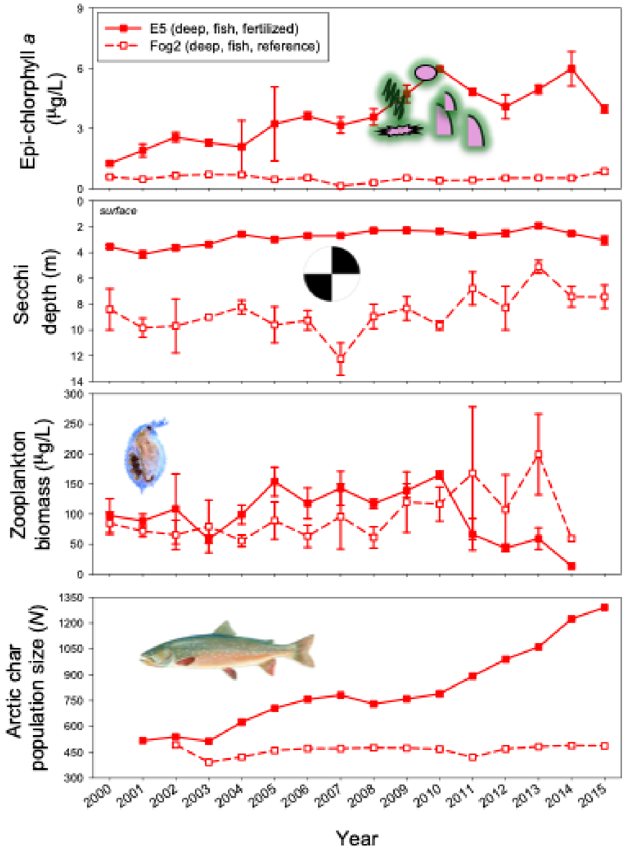
$$\mathrm{GPP} = ([O_2]_{t2} - [O_2]_{t1})_{\mathrm{LIGHT}} - ([O_2]_{t2} - [O_2]_{t1})_{\mathrm{DARK}}. \tag{8.7}$$

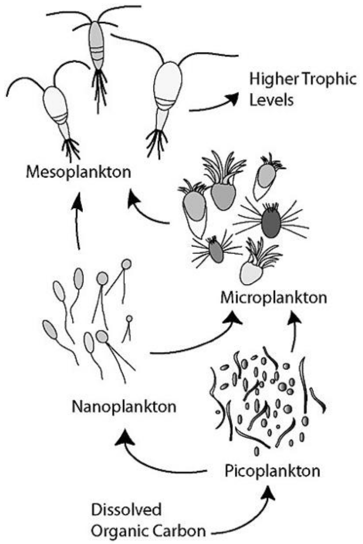
$$\Delta\mathrm{Storage} = [\mathrm{Inputs}] - [\mathrm{Outputs}] \tag{8.4}$$

$$\Delta S = [P_W + P_B + A_I] - [R_W + R_B + B + H_O], \tag{8.5}$$

where $\Delta S$ = change in C storage within the lake, $P_W$ = water column photosynthesis, $P_B$ = benthic photosynthesis, $A_I$ = allochthonous input of organic carbon, $R_W$ = water column respiration, $R_B$ = benthic respiration, $B$ = permanent burial in sediments, and $H_O$ = hydrologic loss of organic carbon from outflows.



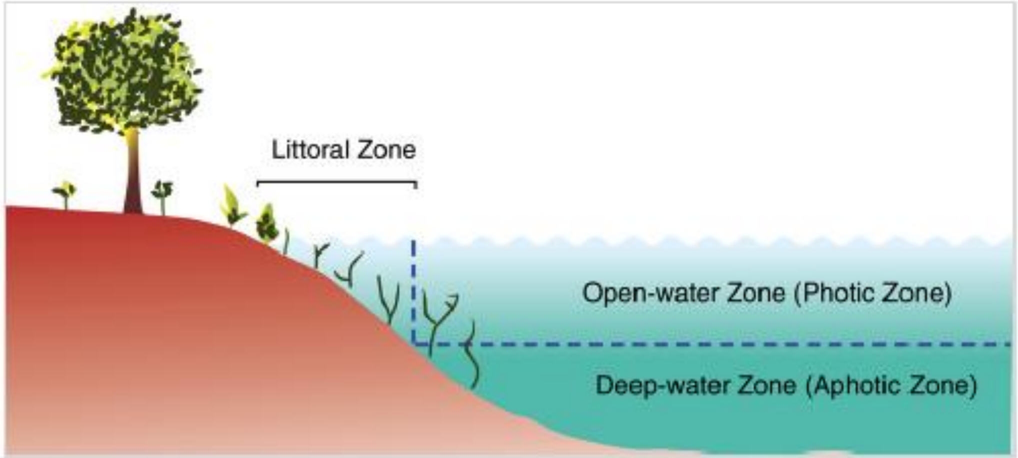



# Carbon Cycling in Lakes

$$\Delta\text{Storage} = [\text{Inputs}] - [\text{Outputs}] \tag{8.4}$$

$$\Delta S = [P_W + P_B + A_I] - [R_W + R_B + B + H_O], \tag{8.5}$$

where $\Delta S$ = change in C storage within the lake, $P_W$ = water column photosynthesis, $P_B$ = benthic photosynthesis, $A_I$ = allochthonous input of organic carbon, $R_W$ = water column respiration, $R_B$ = benthic respiration, $B$ = permanent burial in sediments, and $H_O$ = hydrologic loss of organic carbon from outflows.




The three primary zones of a lake are the littoral zone, the open-water (also called the photic or limnetic) zone, and the deep-water (also called the aphotic or profundal) zone.

**TABLE 8.3** Organic Matter Budgets for Lawrence Lake in Michigan and Mirror Lake in New Hampshire

| | **Lawrence Lake, MI** | | **Mirror Lake, NH** | |
|---|---|---|---|---|
| **Inputs** | **$g\,C\,m^{-2}\,yr^{-1}$** | **Inputs** | **$g\,C\,m^{-2}\,yr^{-1}$** | **Inputs** |
| Net primary production (NPP) | 191.4 | 88% | 87.5 | 83% |
| POC | | | | |
| Phytoplankton | 43.3 | 20% | 78.5 | 74% |
| Epiphytic algae | 37.9 | 18% | 2.2 | 2% |
| Epipelic algae | 2 | 1% | – | – |
| Macrophytes | 87.9 | 41% | 2.8 | 3% |
| Bacterial $CO_2$ fixation | – | – | 4 | 4% |
| DOC released by macrophytes | | | | |
| Littoral | 5.5 | 3% | – | – |
| Pelagic | 14.7 | 7% | – | – |
| Imports | 25.1 | 12% | 17.93 | 17% |
| POC | 4.1 | 2% | 6.63 | 6% |
| DOC | 21 | 10% | 11.3 | 11% |
| **Total available organic inputs** | **216.5** | | **105.43** | |
| **Outputs** | **$g\,C\,m^{-2}\,yr^{-1}$** | **Outputs** | **$g\,C\,m^{-2}\,yr^{-1}$** | **Inputs** |
| Respiration | 159.7 | 74% | 87.53 | 83% |
| Benthic | 117.5 | 55% | 43.13 | 41% |
| Water column | 42.2 | 20% | 44.4 | 42% |
| C Storage in Sediments | 16.8 | 8% | 7.6 | 7% |
| Exports | 38.6 | 18% | 10.2 | 10% |
| POC | 2.8 | 1% | 1.05 | 1% |
| DOC | 35.8 | 17% | 9.15 | 9% |
| **Total removal of carbon** | **215.1** | | **105.33** | |

*Sources: Rich and Wetzel 1978; Jordan and Likens 1975.*

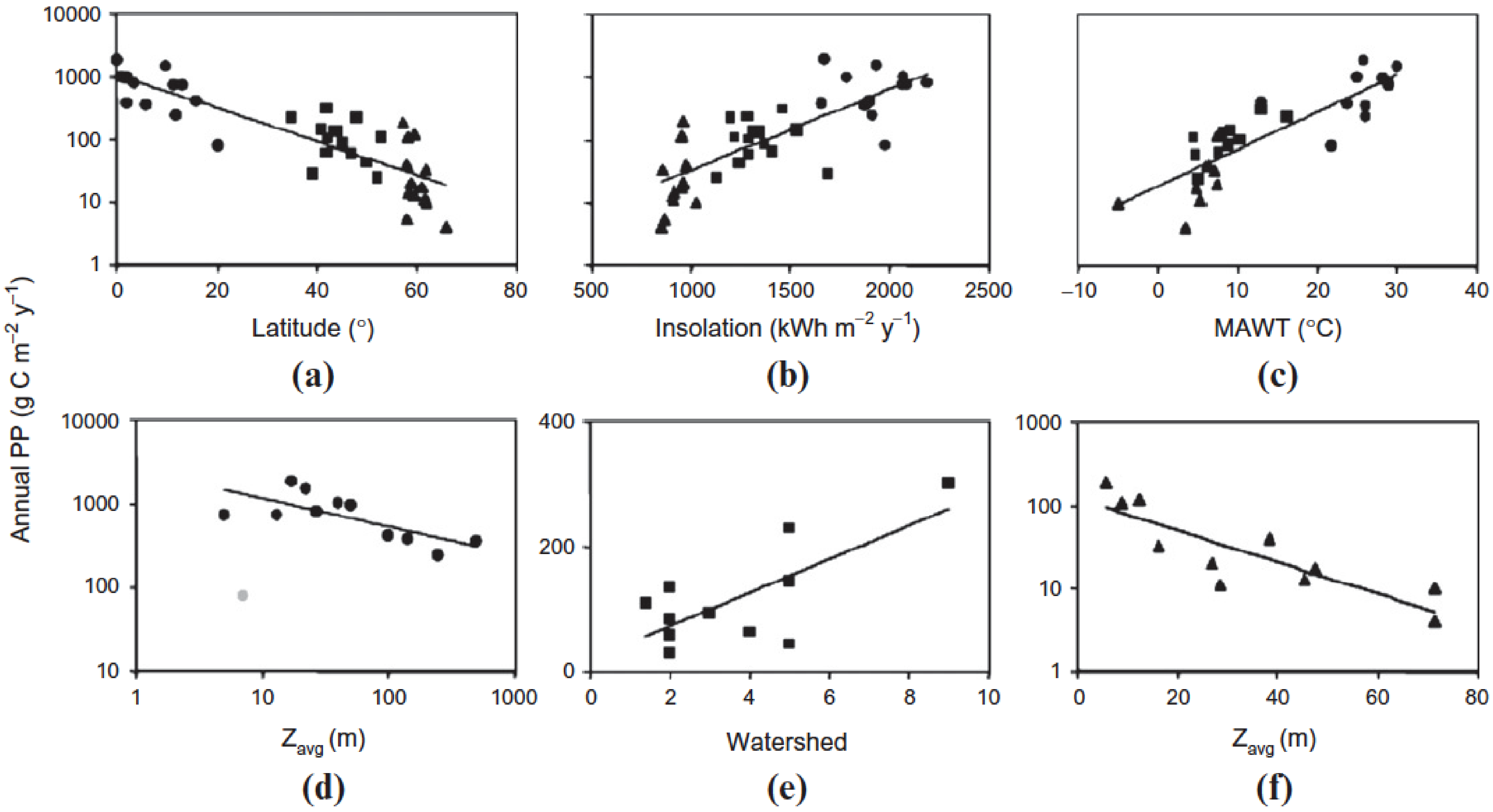
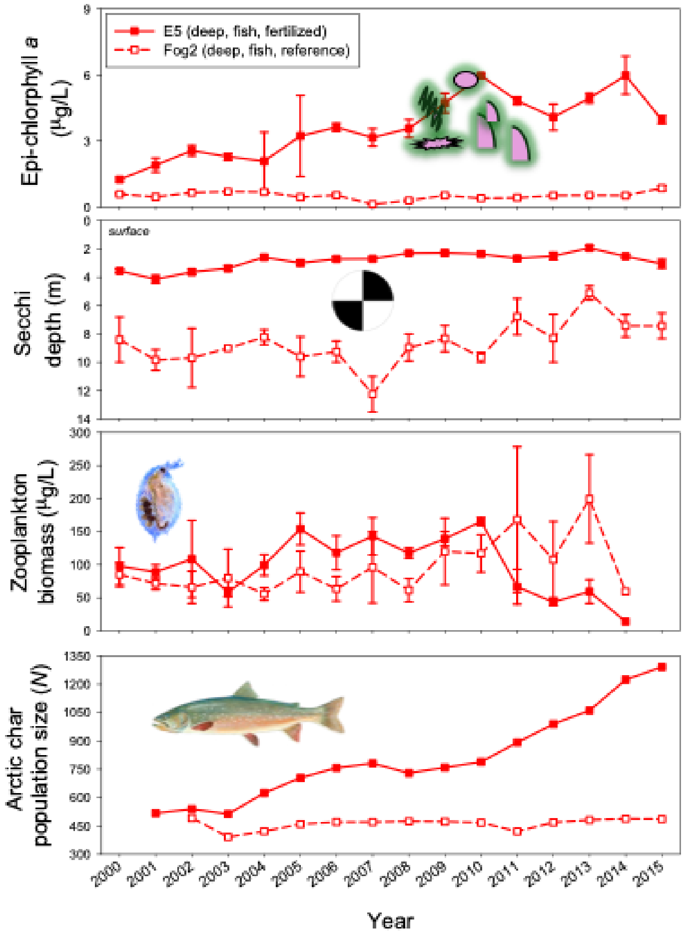



FIGURE 8.12 Global-scale relationships between annual primary production and the environmental variables: (a) latitude, (b) incident solar radiation, (c) mean annual water temperature, (d) depth, (e) watershed to lake area ratio, and (f) average lake depth (z). *Source: From Alin and Johnson 2007. Used with permission of the American Geophysical Union.*



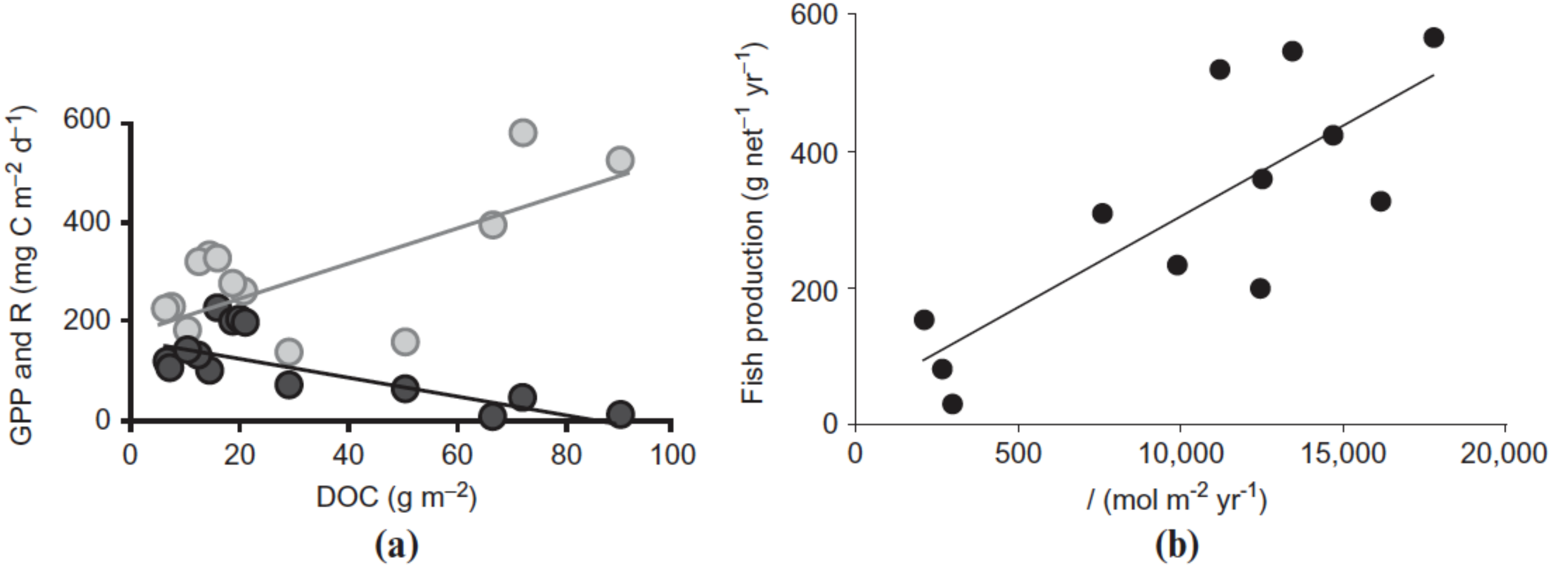
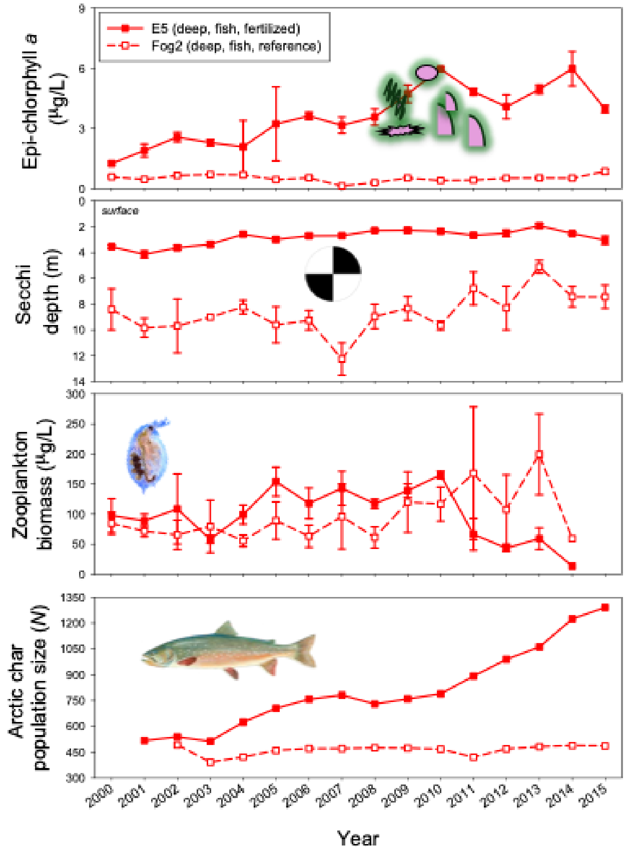
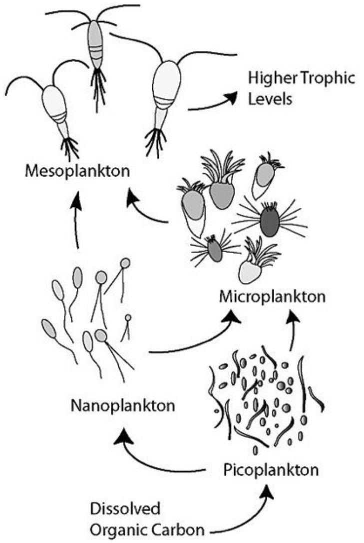




FIGURE 8.15 Light limitation of primary and secondary production in Swedish lakes. (a) Whole-lake gross primary production (GPP, *dark gray circles*) and respiration (R, *light gray circles*) for 15 lakes in northern Sweden. (b) Fish production as a function of the annual light climate (I, representing the mean PAR in the whole-lake volume during the ice-free period) for 12 lakes in northern Sweden ($r_2=0.63$, $p=0.002$). *Sources: (a) From Ask et al. 2012, used with permission of American Geophysical Union; (b) from Karlsson et al. 2009, used with permission of Nature Publishing Group.*

# Phosphorus Cycle in Lakes



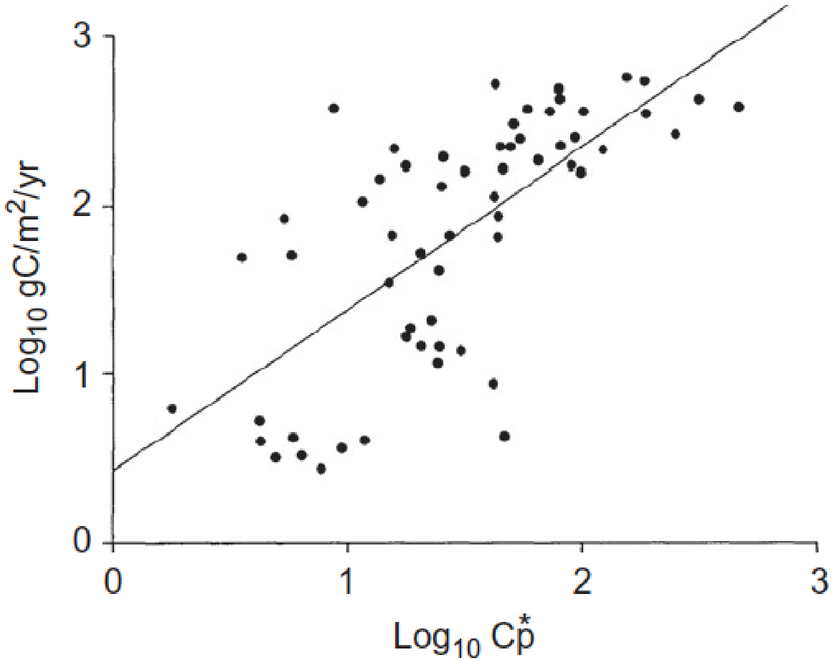




FIGURE 8.13 The relationship between net primary production and the phosphorus concentration of lakes of the world is fit by the line log [P] = 0.83 log NPP + 0.56 ($r = 0.69$). Schindler excluded lakes with N:P ratios in inputs of <5:1 from this analysis. *Source: Adapted with permission from Schindler (1978).*

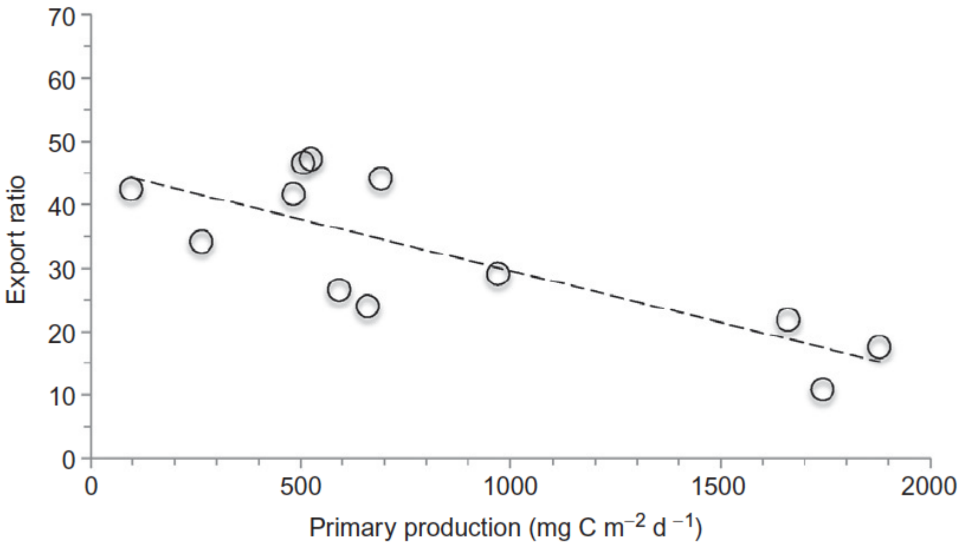



FIGURE 8.17 The percentage of planktonic productivity that sinks to the hypolimnion in lakes as a function of their net primary production. *Source: Modified from Baines and Pace 1994. Used with permission of NRC Research Press.*

# N and P in Lakes

Sucrose + N + P

→ Blue-green Algae

Sucrose + N

→ Phytoplankton

FIGURE 1.5 An ecosystem-level experiment in which a lake was divided and one half (distant) fertilized with phosphorus, while the basin in the foreground acted as a control. The phosphorus-fertilized basin shows a bloom of nitrogen-fixing cyanobacteria. *Source: From Schindler (1974); www.sciencemag.org/content/184/4139/897.short. Used with permission.*

# Sulfur Cycling in Lakes

Oxidized → Reduced

Reduced → Oxidized

| | $H_2O/O_2$ | C | N | S |
|---|---|---|---|---|
| $H_2O/O_2$ | X | Photosynthesis $CO_2 \rightarrow C$ $H_2O \rightarrow O_2$ | | |
| C | Respiration $C \rightarrow CO_2$ $O_2 \rightarrow H_2O$ | X | Denitrification $C \rightarrow CO_2$ $NO_3 \rightarrow N_2$ | Sulfate-Reduction $C \rightarrow CO_2$ $SO_4 \rightarrow H_2S$ |
| N | Heterotrophic Nitrification $NH_4 \rightarrow NO_3$ $O_2 \rightarrow H_2O$ | Chemoautotrophy (Nitrification) $NH_4 \rightarrow NO_3$ $CO_2 \rightarrow C$ | Anammox $NH_4 + NO_2 \rightarrow N_2 + 2H_2O$ | ? |
| S | Sulfur Oxidation $S \rightarrow SO_4$ $O_2 \rightarrow H_2O$ | Chemoautotrophy (Sulfur-based Photosynthesis) $S \rightarrow SO_4$ $CO_2 \rightarrow C$ | Autotrophic Denitrification $S \rightarrow SO_4$ $NO_3 \rightarrow N_2/NH_4$ | X |

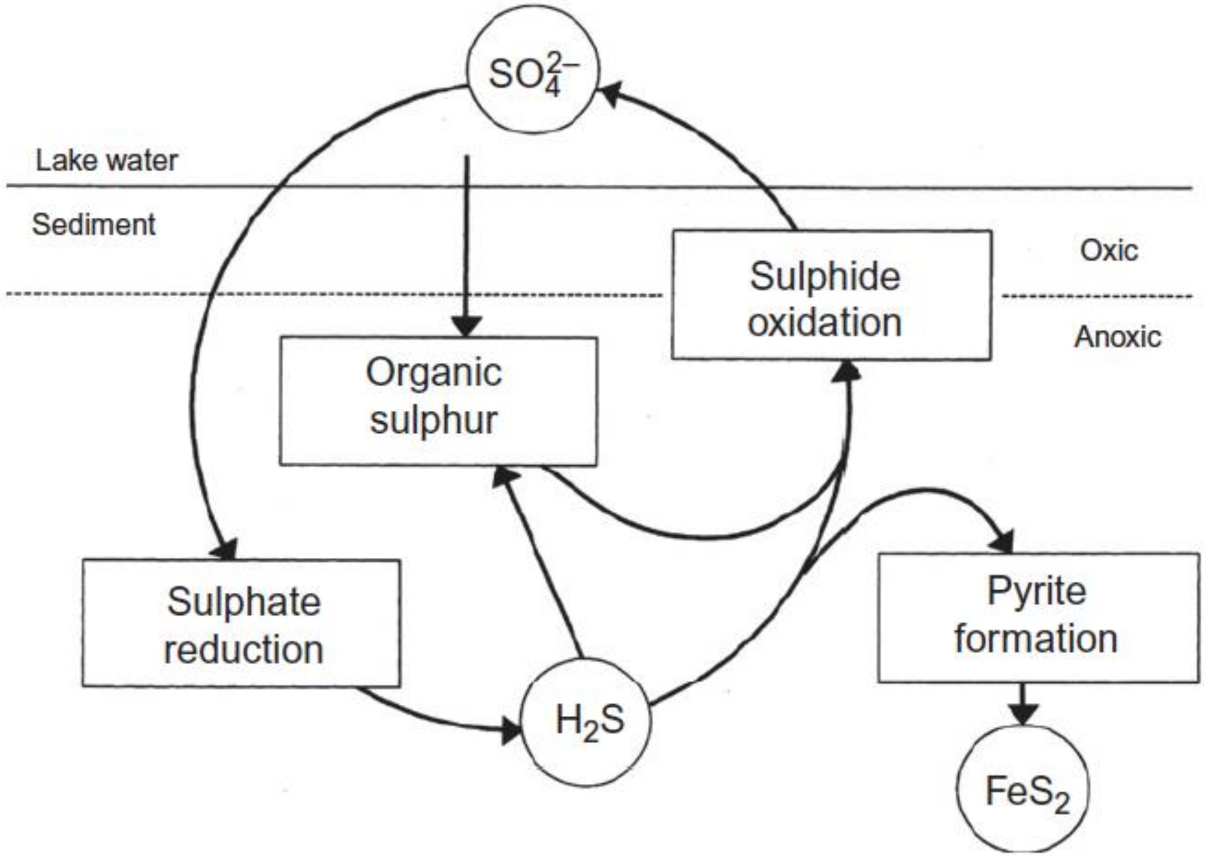



FIGURE 8.18 A simplified lake sediment sulfur cycle. *Source: From Holmer and Storkholm 2001.*

# Estuaries

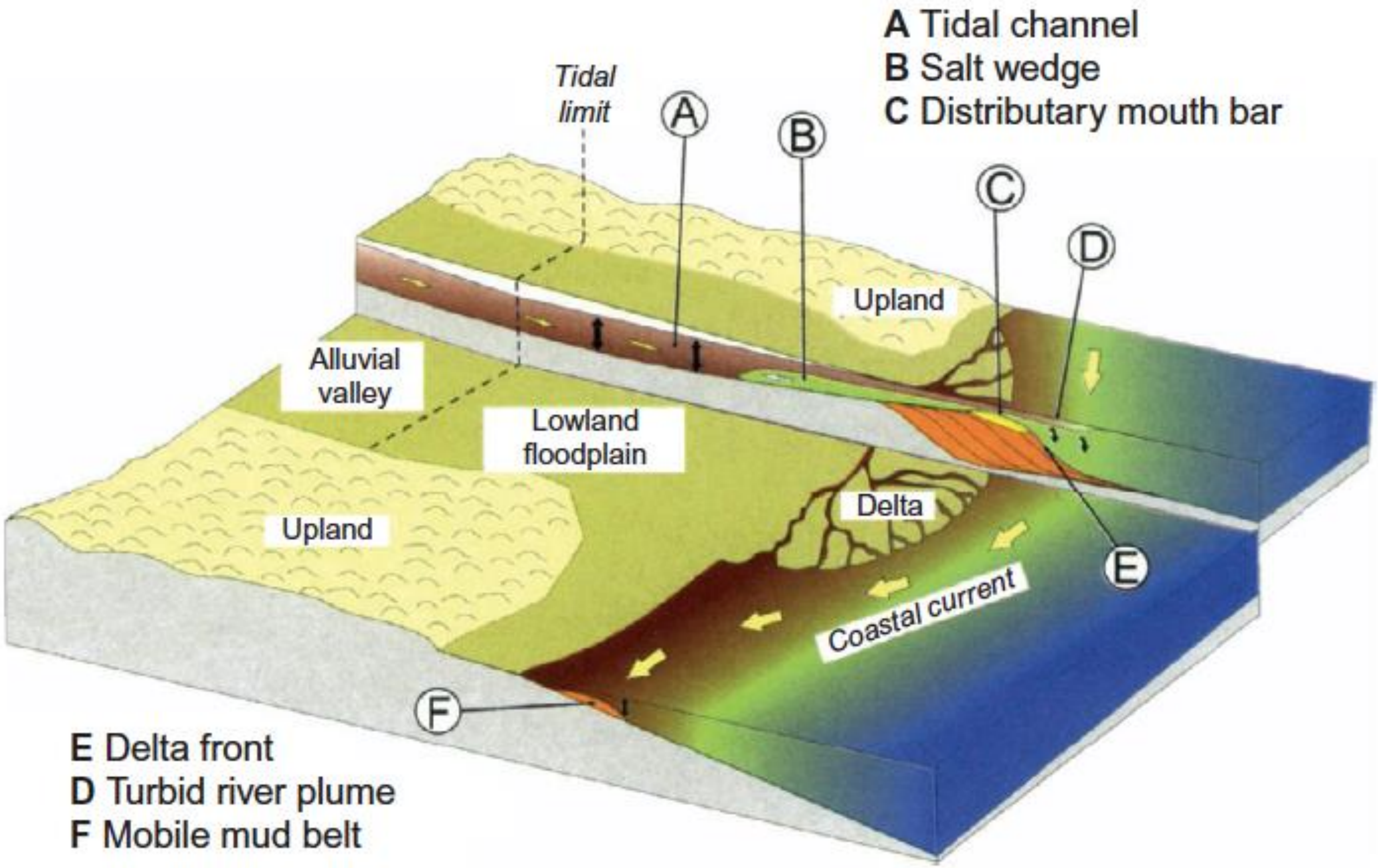



FIGURE 8.31 Generic diagram of a river estuary. The estuary boundaries are defined as the upper limit of the tidal influence within the river inflow to the coastal boundary of freshwater influence. *Source: From Bianchi and Allison 2009. Used with permission of the National Academy of Sciences.*

**TABLE 8.7** A Compilation of Literature Estimates of GPP, R, and NEP for Streams, Rivers, and Estuaries from Whole-Ecosystem Metabolism Estimates

| Ecosystem | GPP ($g\ Cm^{-2}\ d^{-1}$) | R ($g\ Cm^{-2}\ d^{-1}$) | NEP ($g\ Cm^{-2}\ d^{-1}$) | Global R ($Pg\ Cy^{-1}$) | Global net heterotrophy ($Pg\ Cy^{-1}$) |
|---|---|---|---|---|---|
| Streams ($n = 62$) | 0.73±0.14 (0.02–5.62) | 1.93±0.19 (0.29–8.16) | −1.20±0.15 (−5.86–2.51) | 0.19 | 0.12 |
| River ($n = 37$) | 0.91±0.10 (0.06–2.28) | 1.53±0.15 (0.20–3.54) | −0.66±0.11 (−2.06–1.60) | 0.16 | 0.07 |
| Estuaries ($n = 31$) | 3.14±0.41 (0.72–10.4) | 3.51±0.32 (0.83–7.58) | −0.39±0.21 (−2.98–2.86) | 1.20 | 0.13 |

Note: Given is the mean standard error and the minimum and maximum in brackets. Ecosystems with the same superscript are not statistically different.

*Source: Adapted from Battin et al. 2009.*

# Estuarine Water Budgets and Mixing

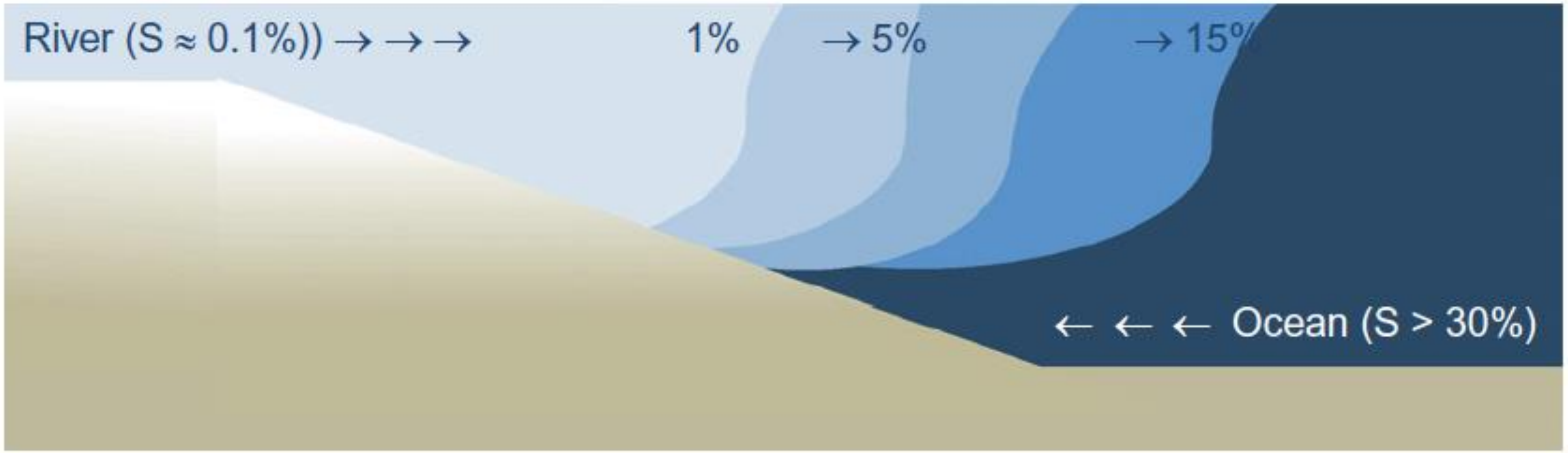
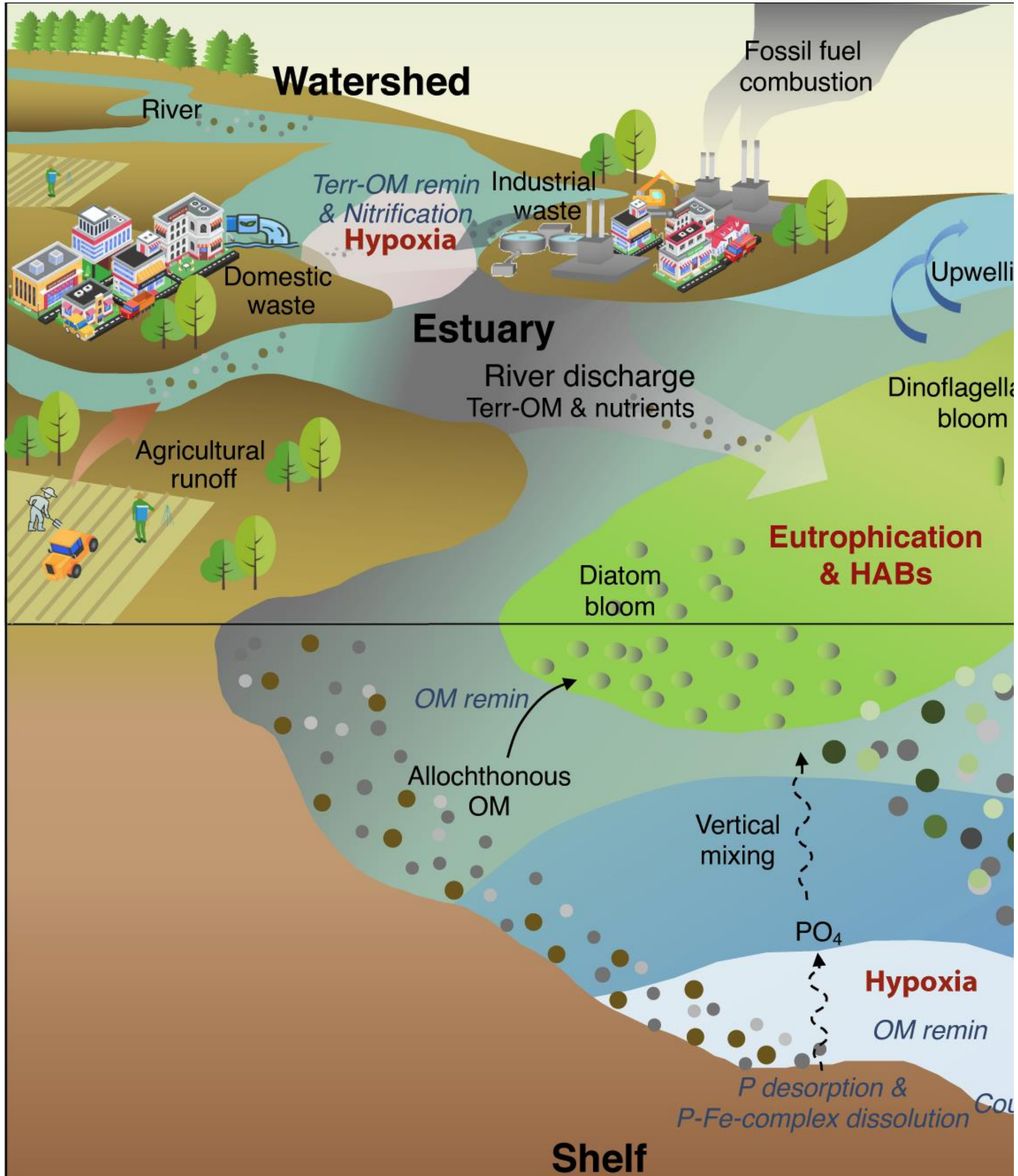



FIGURE 8.32 A diagram of a generic salinity gradient within a coastal estuary. River waters interacting with ocean waters lead to a gradient from fresh to full-strength ocean waters. The greater density of saltwater often leads to a salt wedge underlying a plume of less saline surface waters.

- Precipitation of dissolved humic compounds
- Cations in seawater replace $H^+$ on exchange sites of humic materials
- Materials flocculate and sink into estuarine sediments
- Flocculation of dissolved sediments and Plant debris



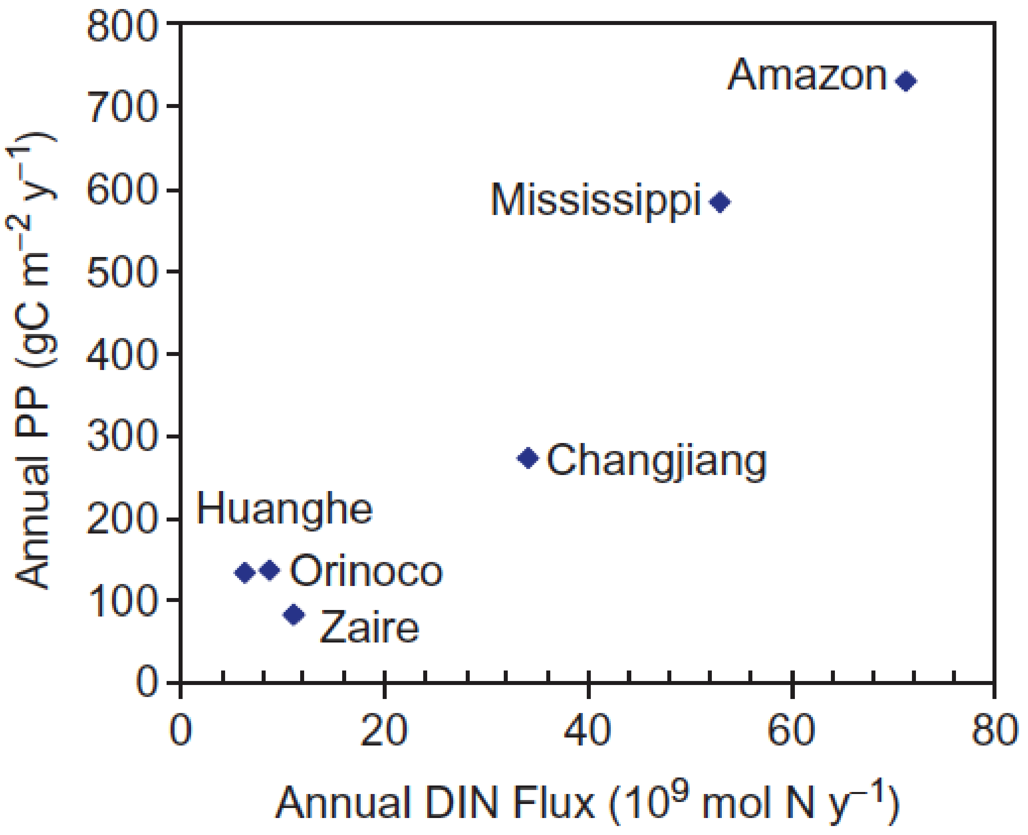
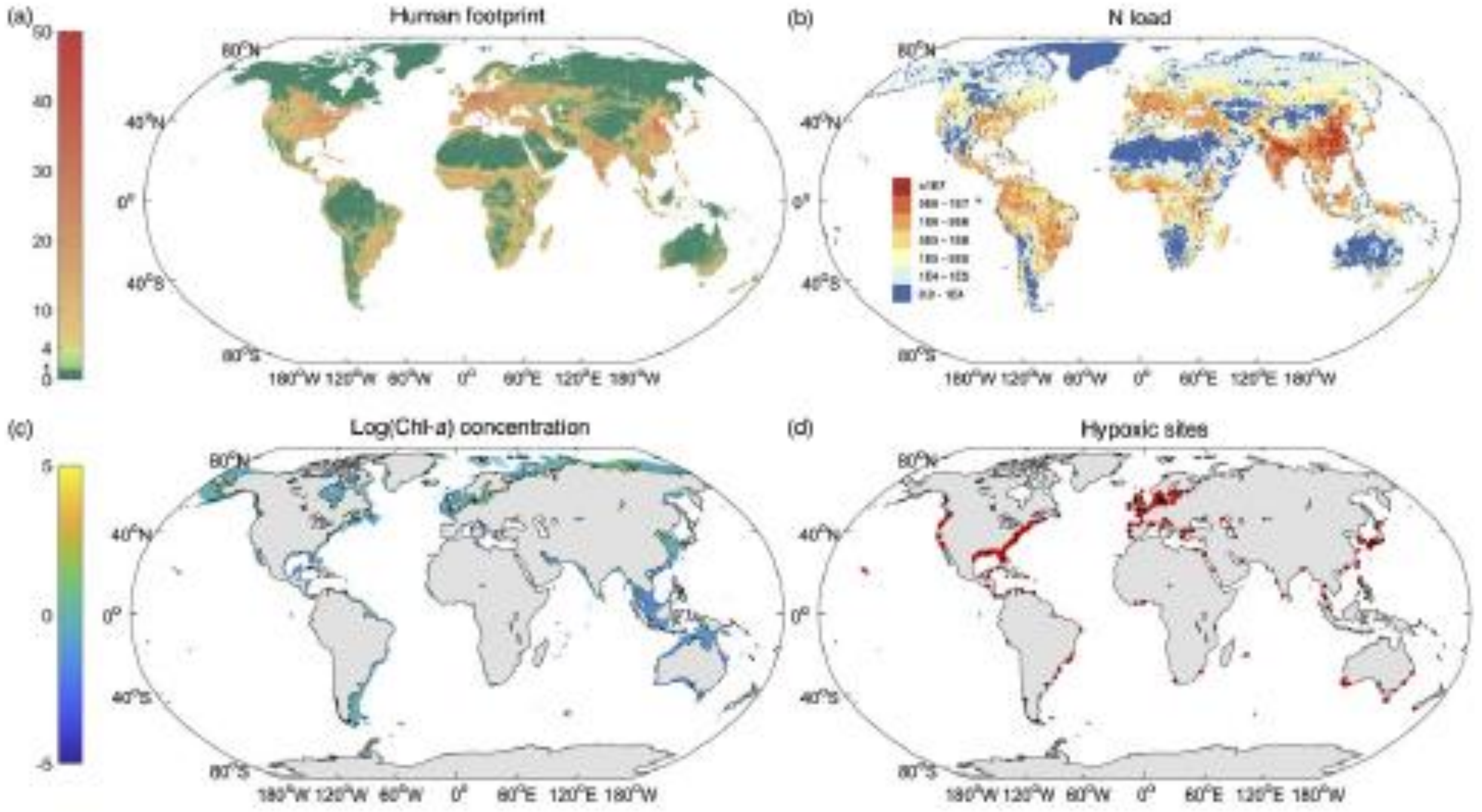




FIGURE 8.34 Relationship between primary production in coastal shelf waters impacted by major rivers and riverine DIN flux. *Source: Adapted from Dagg et al. 2004.*


(a)
Human footprint
50
40
30
20
10
4
1
0
80°N
40°N
0°
40°S
80°S
180°W 120°W 60°W 0° 60°E 120°E 180°W
(b)
N load
80°N
40°N
0°
40°S
80°S
180°W 120°W 60°W 0° 60°E 120°E 180°W
(c)
Log(Chl-a) concentration
5
0
-5
80°N
40°N
0°
40°S
80°S
180°W 120°W 60°W 0° 60°E 120°E 180°W
(d)
Hypoxic sites
80°N
40°N
0°
40°S
80°S
180°W 120°W 60°W 0° 60°E 120°E 180°W

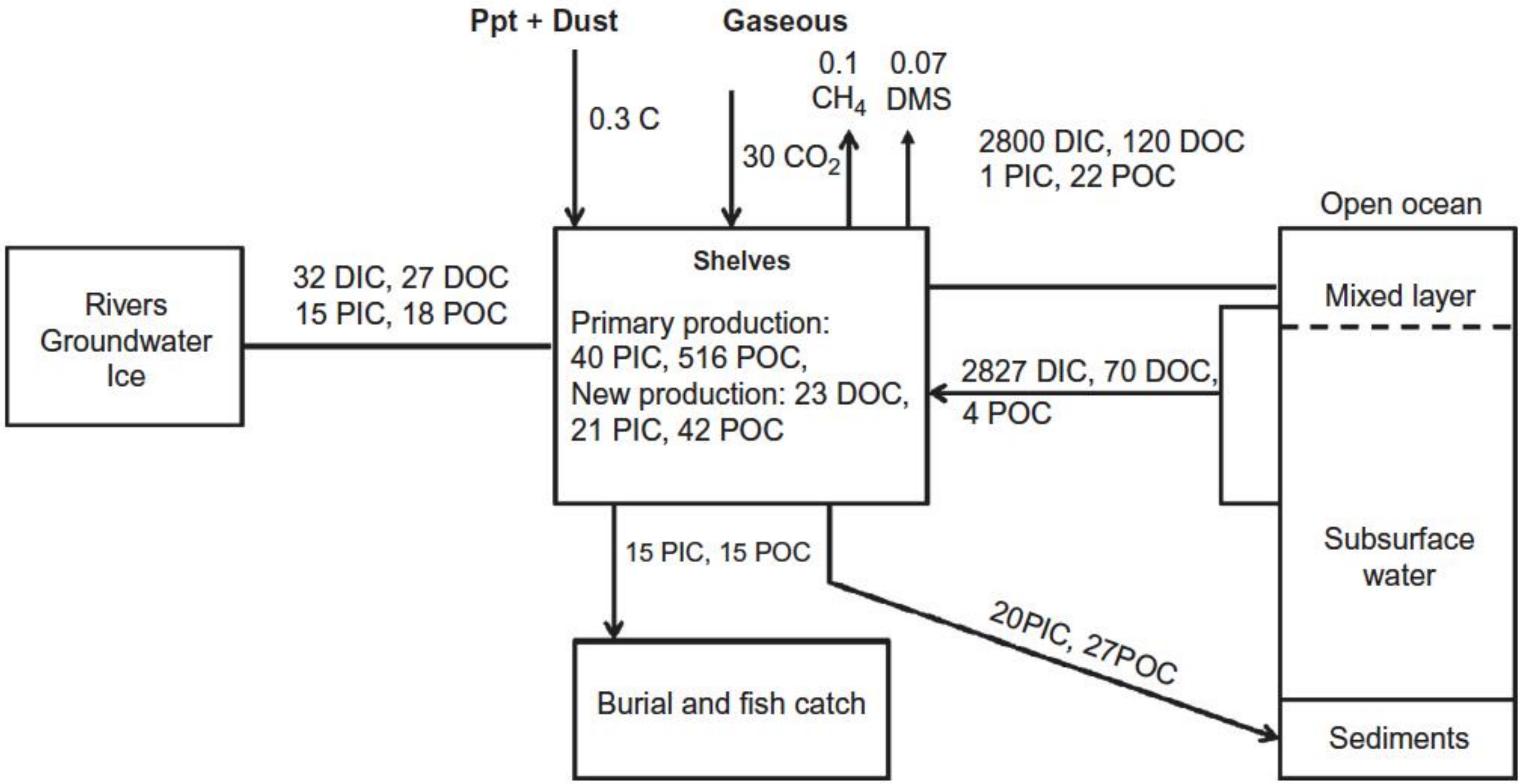
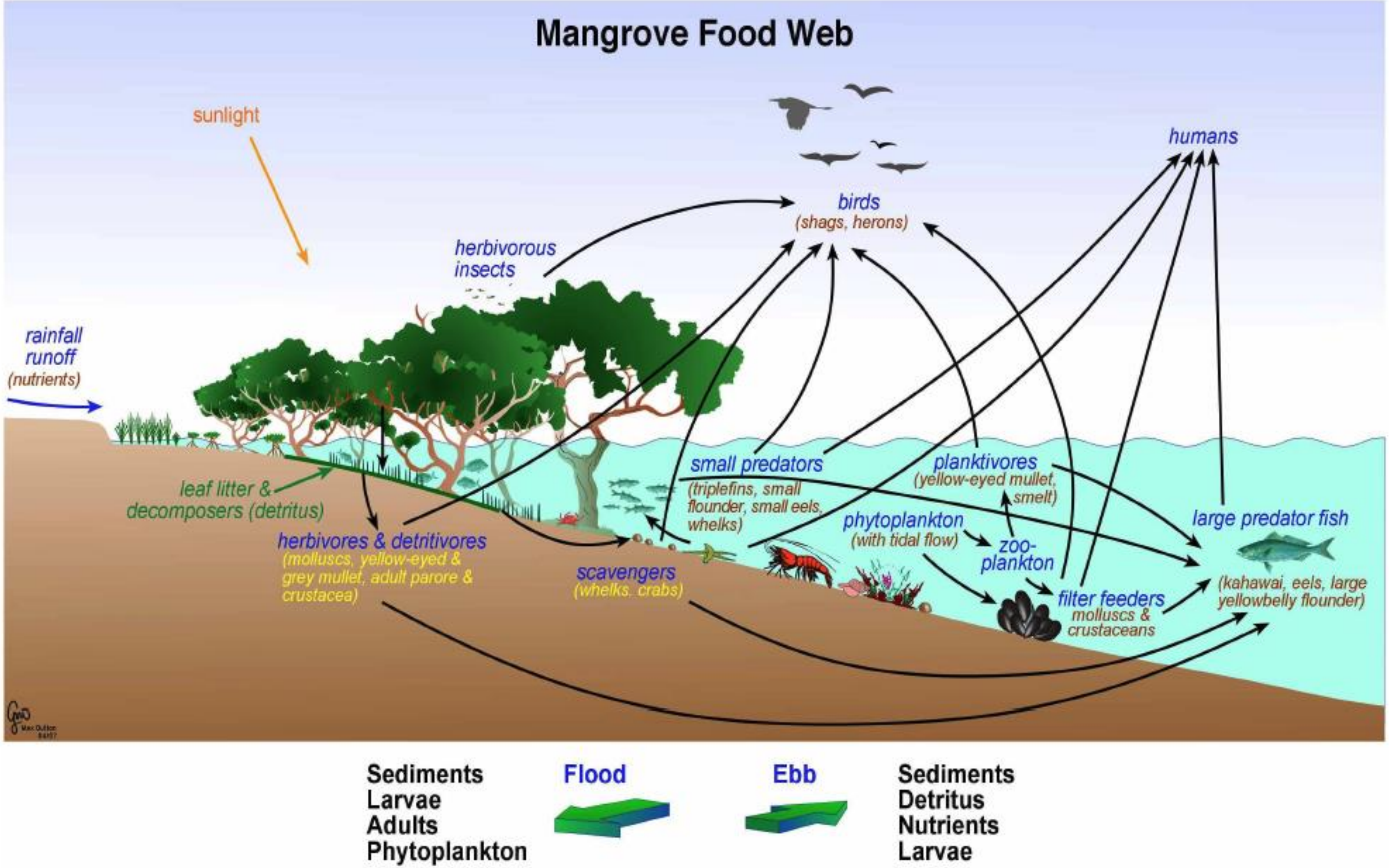



FIGURE 8.33 Mass balance of carbon in continental shelves (flows are in $10^{12}$ mol C $yr^{-1}$). *Source: From Chen-Tung and Borges 2009.*



Mangrove Food Web
sunlight
humans
birds
(shags, herons)
herbivorous insects
rainfall runoff
(nutrients)
leaf litter &
decomposers (detritus)
herbivores & detritivores
(molluscs, yellow-eyed & grey mullet, adult parore & crustacea)
scavengers
(whelks, crabs)
small predators
(triplefins, small flounder, small eels, whelks)
planktivores
(yellow-eyed mullet, smelt)
phytoplankton
(with tidal flow)
zoo-plankton
filter feeders
molluscs & crustaceans
large predator fish
(kahawai, eels, large yellowbelly flounder)
Sediments
Larvae
Adults
Phytoplankton
Flood
Ebb
Sediments
Detritus
Nutrients
Larvae

# Salt Marsh Food Webs

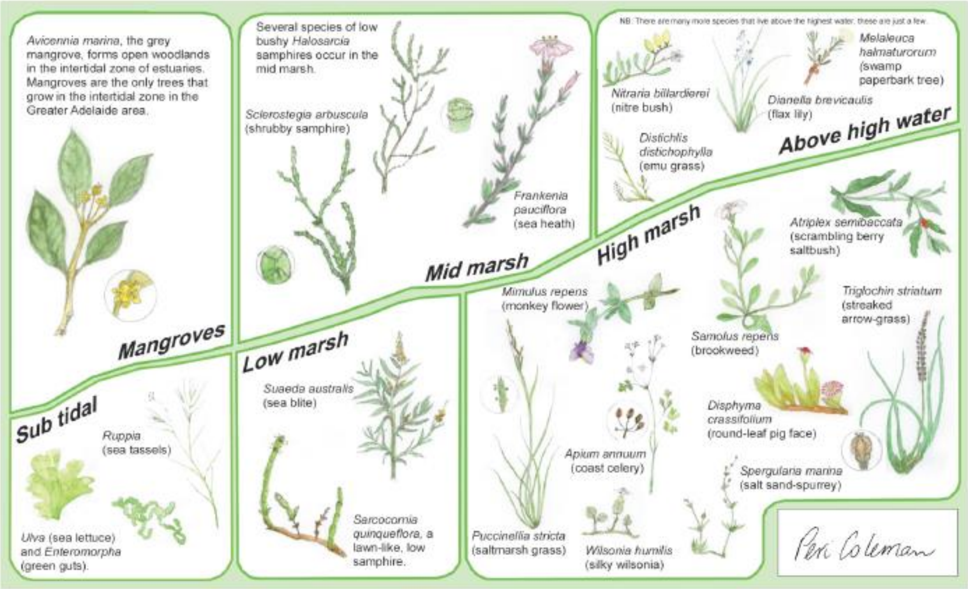



**Figure 6**. Salt marsh vegetation zonation.

**Table 2.** Average soil physical and chemical observations

| | Low marsh | Mid marsh | High marsh |
|---|---|---|---|
| Moisture % | 60 | 37 | 20 |
| Chloride (mg/kg dried soil) | 85 293 | 23 572 | 10 364 |
| pH | 7.59 | 7.86 | 8.26 |

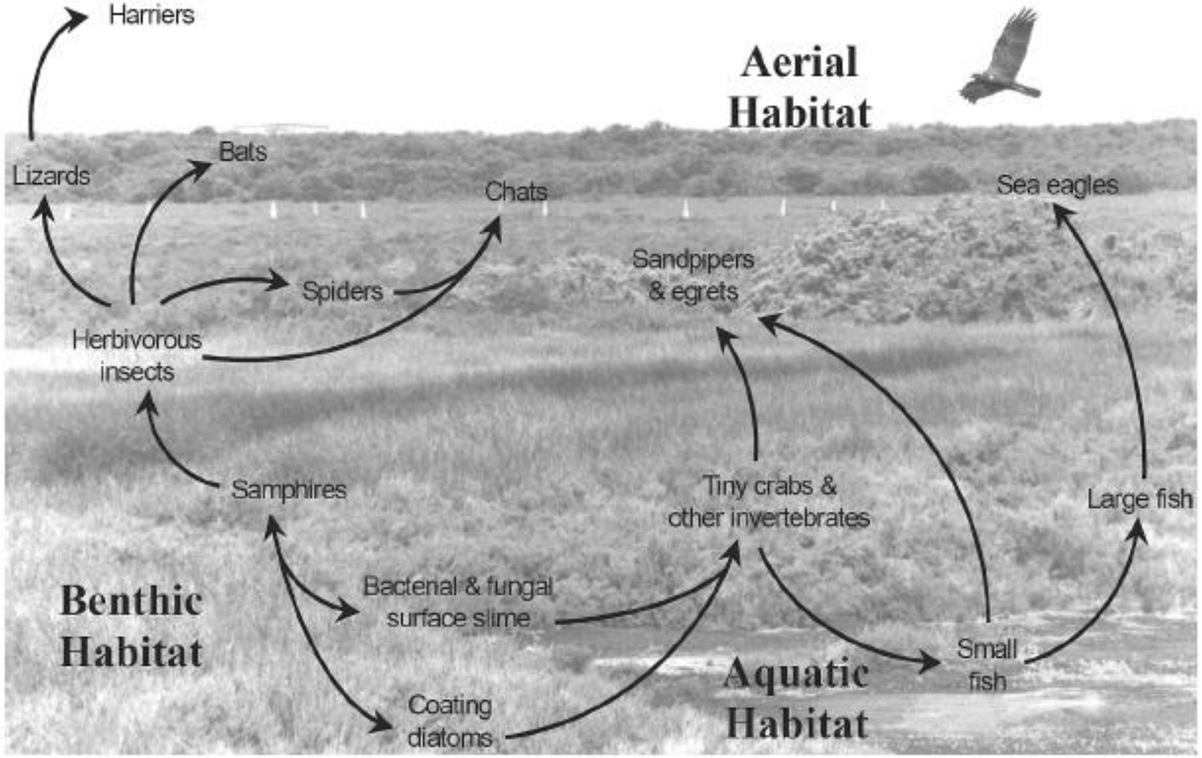
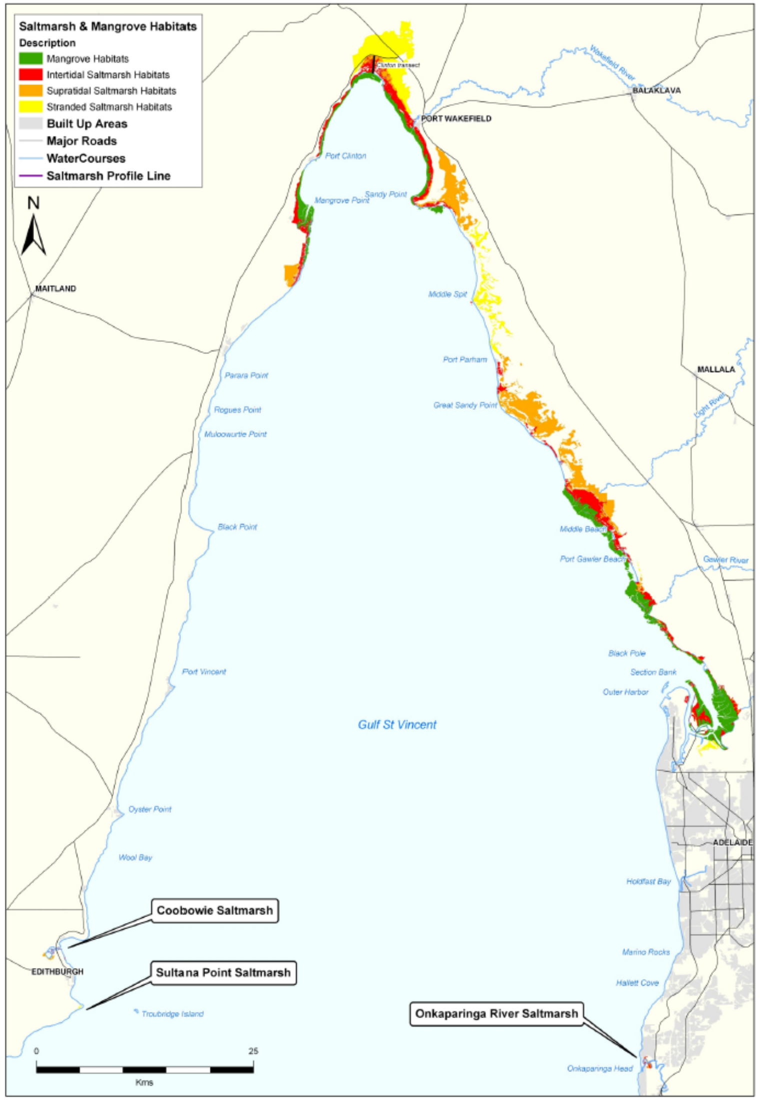



**Figure 7.** Salt marsh foodwebs.



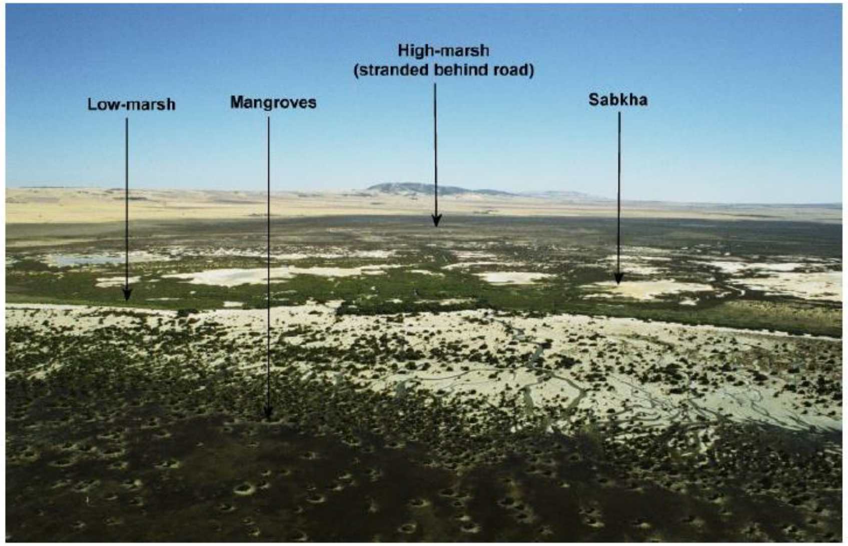




**Figure 1.** Salt marsh habitats at the head of Gulf St Vincent.

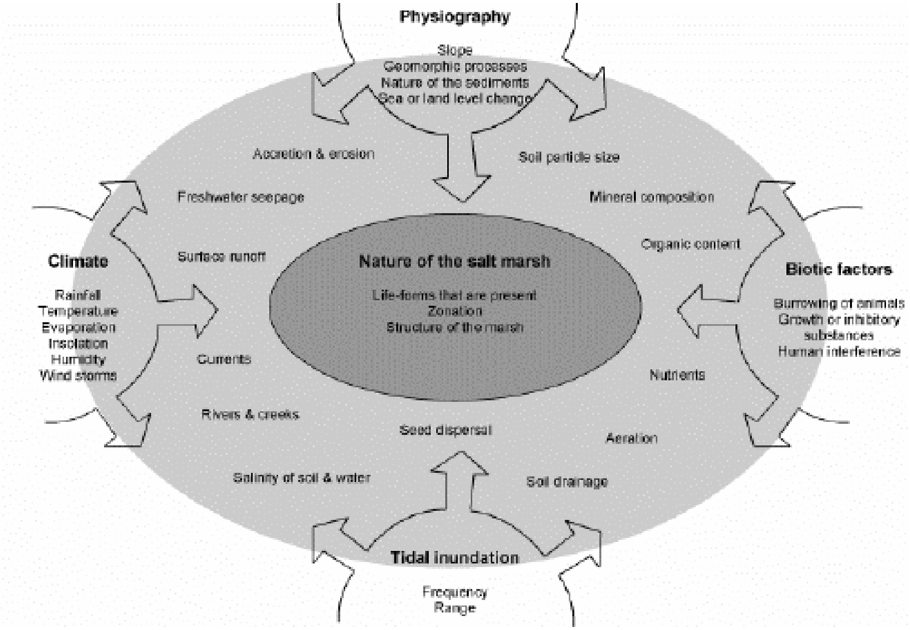
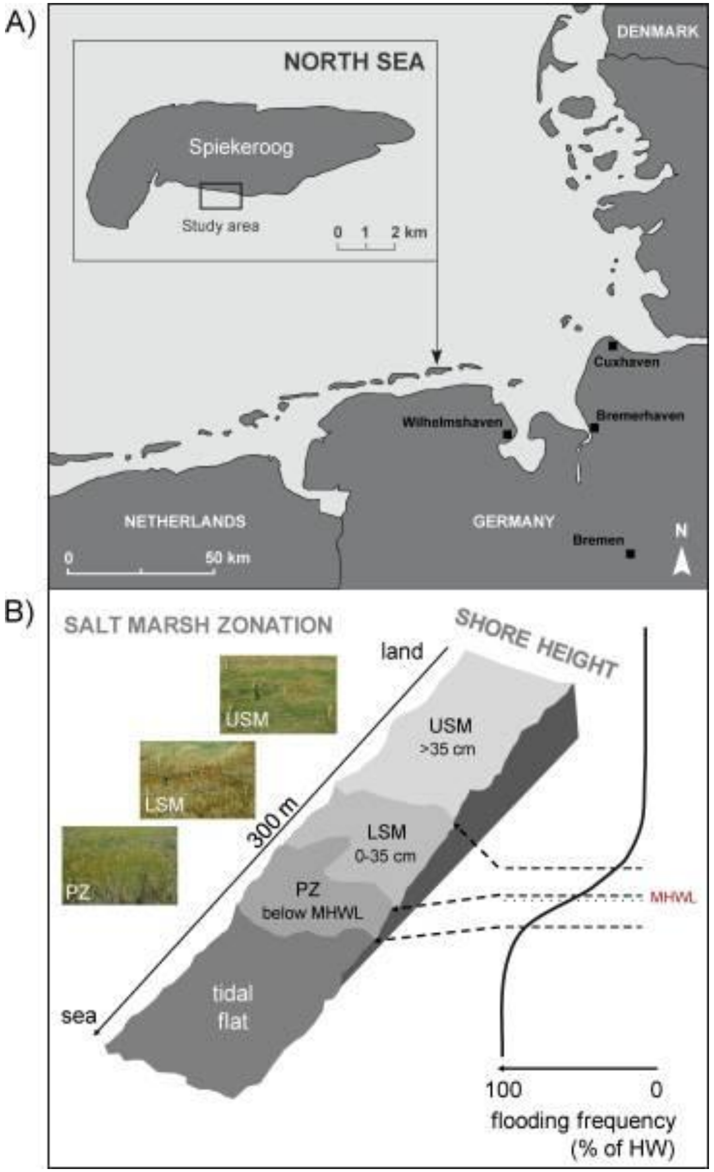
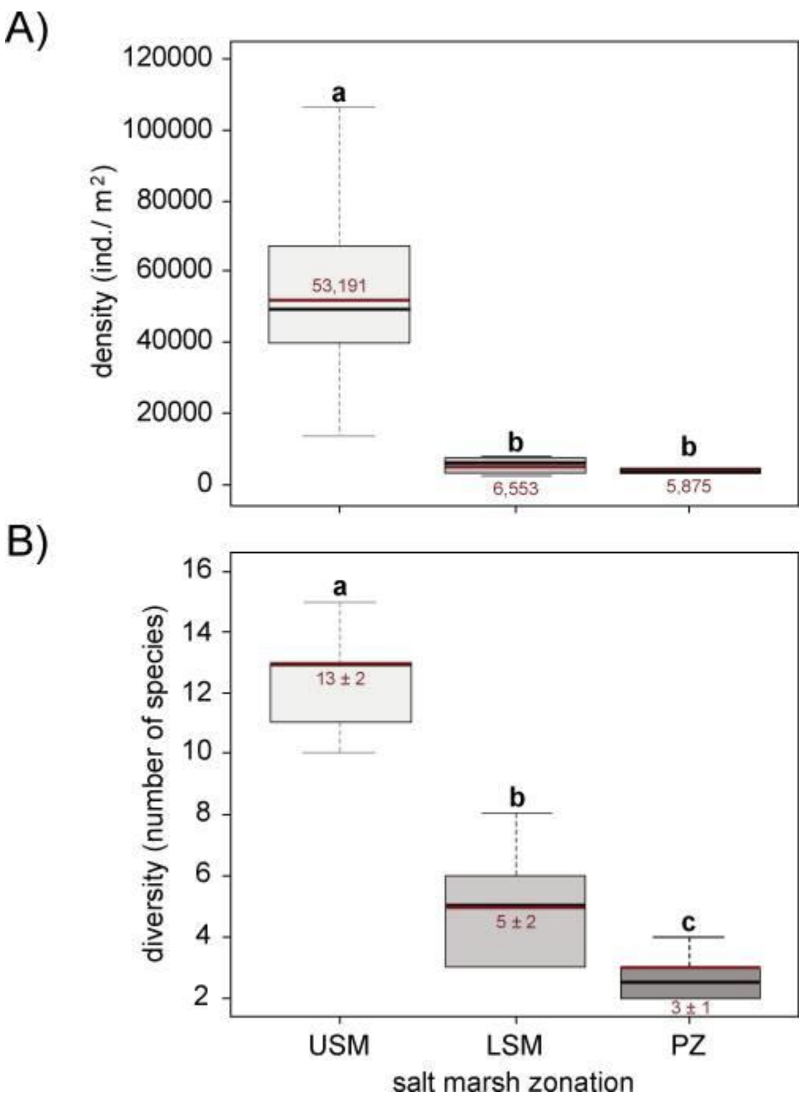


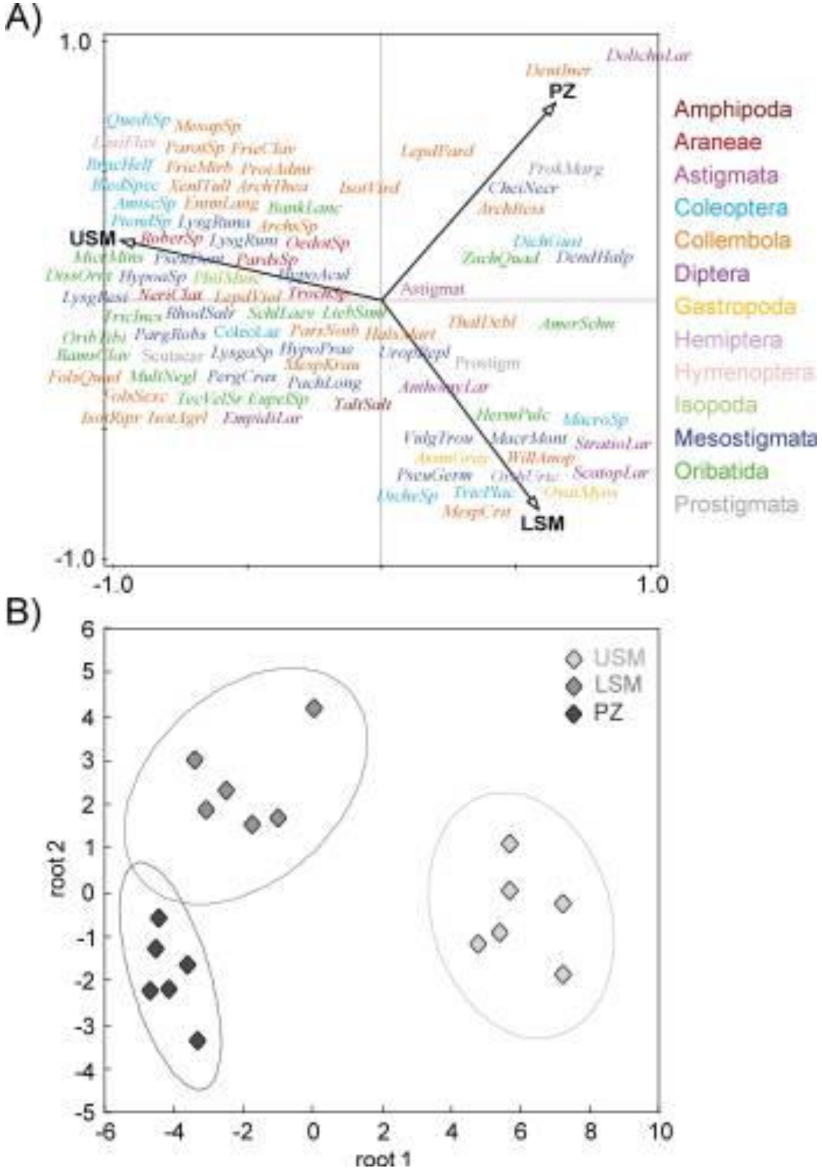

**Figure 4.** Environmental factors that influence salt marshes (after Lear & Turner 1977).

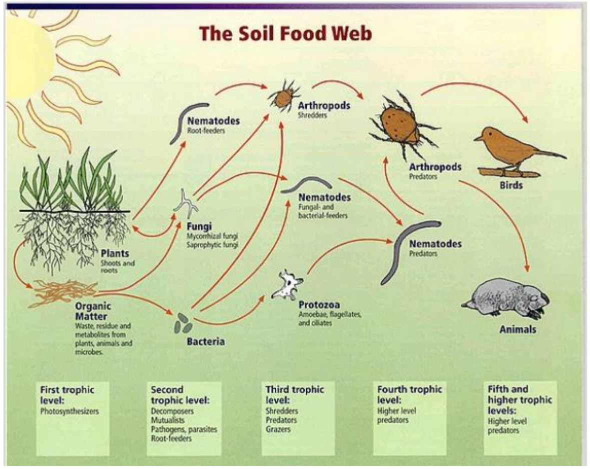
**Table 2.** Average soil physical and chemical observations

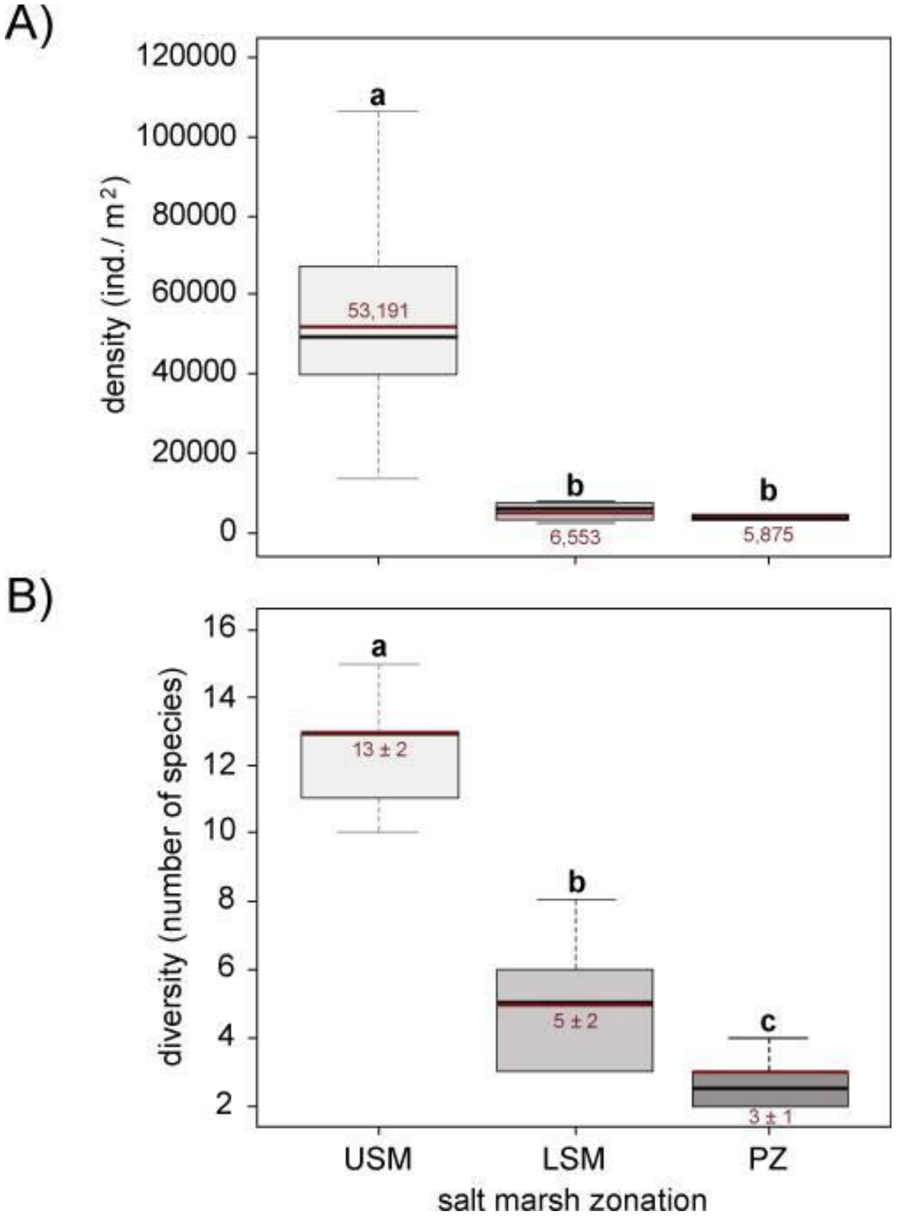
| | Low marsh | Mid marsh | High marsh |
|---|---|---|---|
| Moisture % | 60 | 37 | 20 |
| Chloride (mg/kg dried soil) | 85 293 | 23 572 | 10 364 |
| pH | 7.59 | 7.86 | 8.26 |

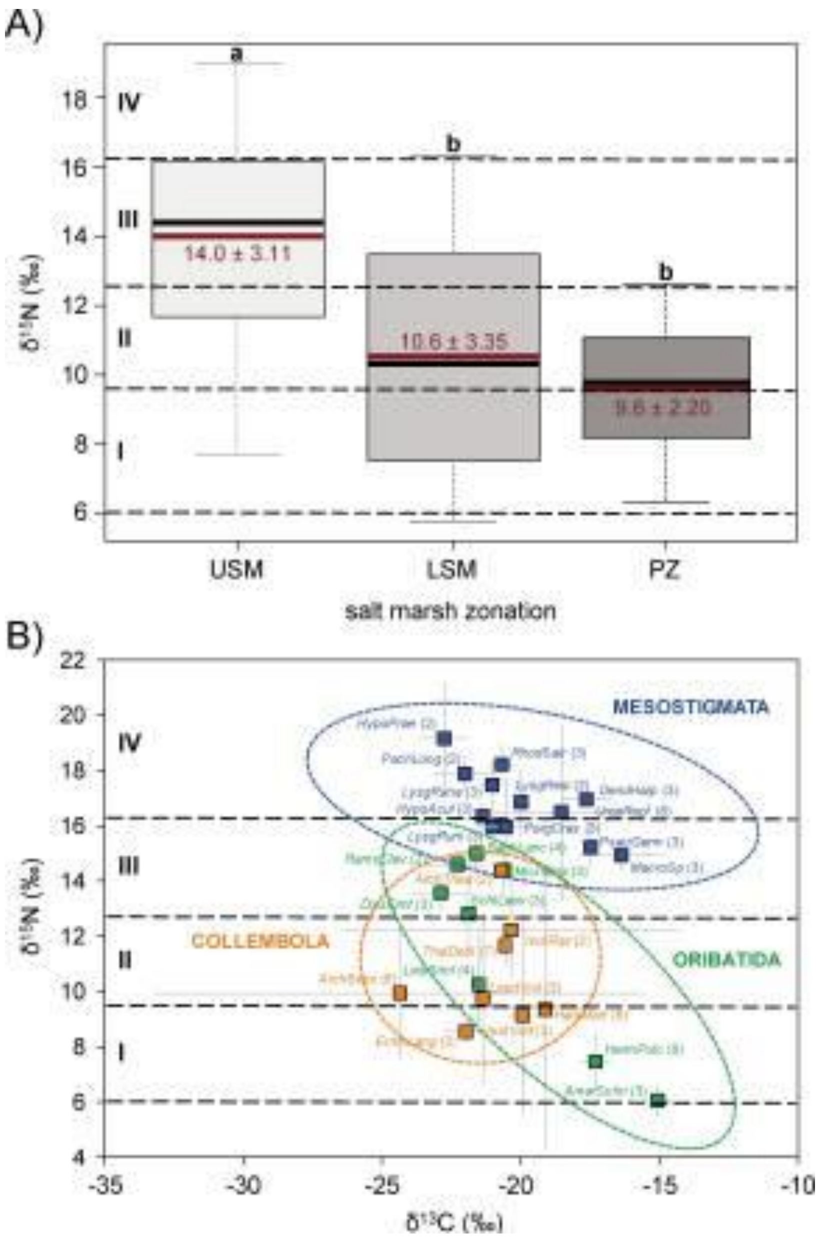

A)
NORTH SEA
Spiekeroog
Study area
0 1 2 km
DENMARK
Cuxhaven
Wilhelmshaven
Bremerhaven
NETHERLANDS
GERMANY
Bremen
0
50 km
N
B)
SALT MARSH ZONATION
SHORE HEIGHT
land
USM
>35 cm
LSM
0-35 cm
PZ
below MHWL
300 m
tidal
flat
sea
MHWL
100
0
flooding frequency
(% of HW)


A)
density (ind./ m²)
120000
100000
80000
60000
40000
20000
0
a
53,191
b
6,553
b
5,875
B)
diversity (number of species)
16
14
12
10
8
6
4
2
a
13 ± 2
b
5 ± 2
c
3 ± 1
USM
LSM
PZ
salt marsh zonation


A)
1.0
-1.0
-1.0
1.0
PZ
USM
LSM
Amphipoda
Araneae
Astigmata
Coleoptera
Collembola
Diptera
Gastropoda
Hemiptera
Hymenoptera
Isopoda
Mesostigmata
Oribatida
Prostigmata
B)
USM
LSM
PZ
root 2
root 1
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-4
-2
0
2
4
6
8
10


The Soil Food Web
Nematodes
Arthropods
Arthropods
Birds
Fungi
Nematodes
Nematodes
Plants
Organic Matter
Protozoa
Bacteria
Animals
First trophic level:
Second trophic level:
Third trophic level:
Fourth trophic level:
Fifth and higher trophic levels:


A)
density (ind./ m²)
120000
100000
80000
60000
40000
20000
0
a
b
b
53,191
6,553
5,875
B)
diversity (number of species)
16
14
12
10
8
6
4
2
a
b
c
13 ± 2
5 ± 2
3 ± 1
USM
LSM
PZ
salt marsh zonation


A)
δ¹⁵N (‰)
IV
III
II
I
a
b
b
14.0 ± 3.11
10.6 ± 3.35
9.6 ± 2.20
USM
LSM
PZ
salt marsh zonation
B)
MESOSTIGMATA
COLLEMBOLA
ORIBATIDA
IV
III
II
I
δ¹⁵N (‰)
δ¹³C (‰)

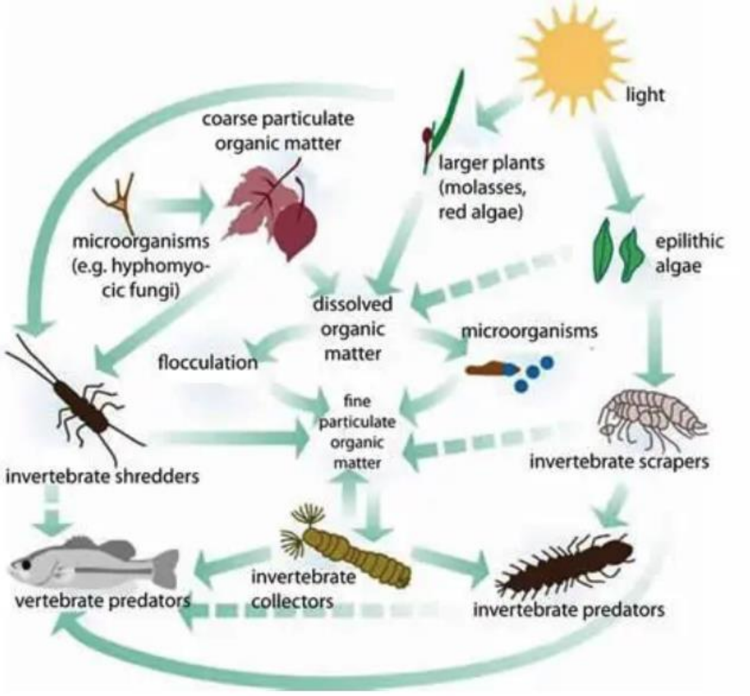
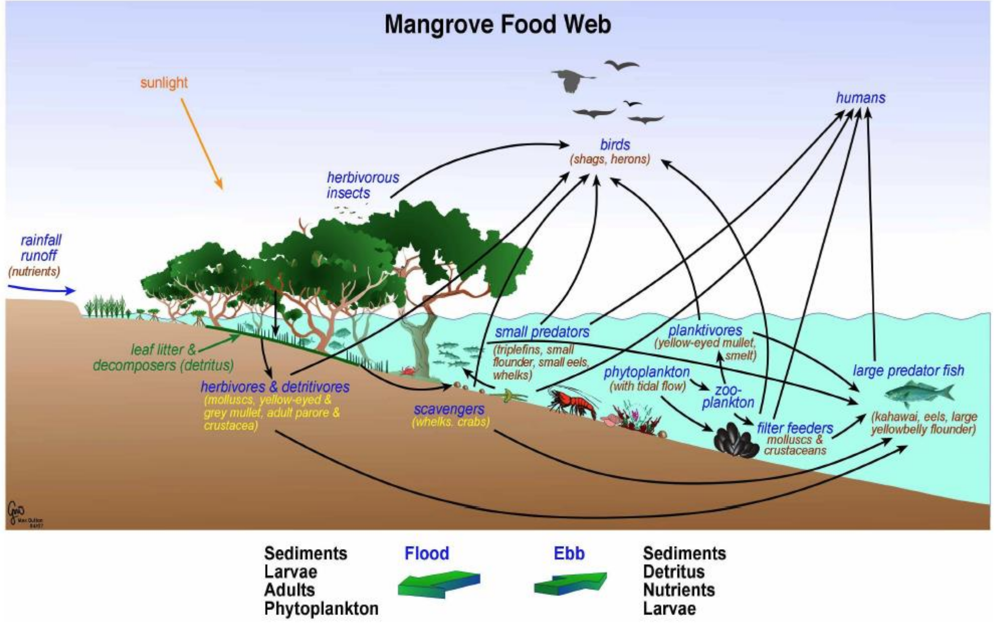
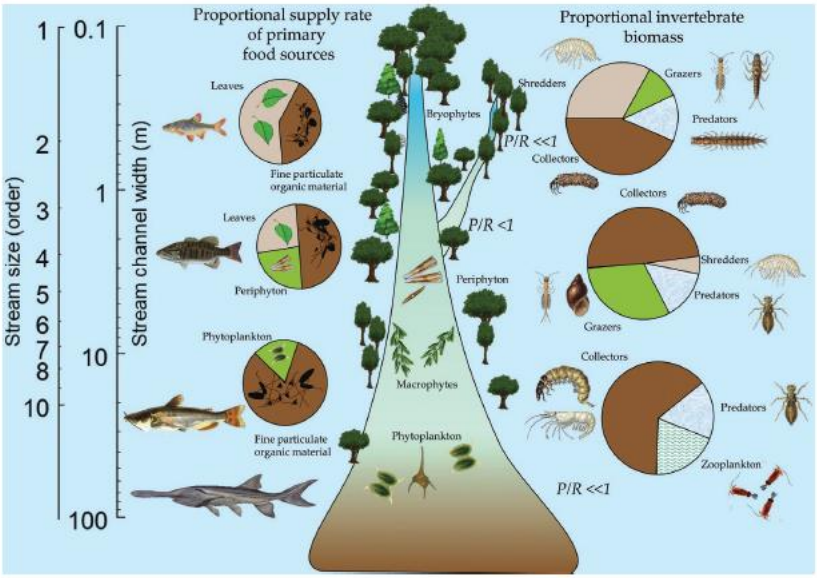
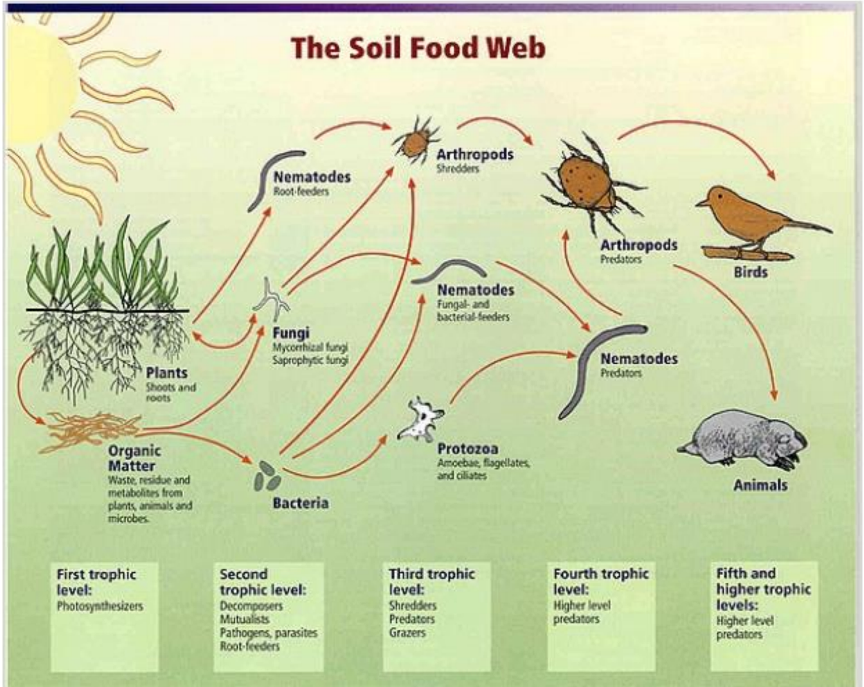



Image credit: USDA




Plot

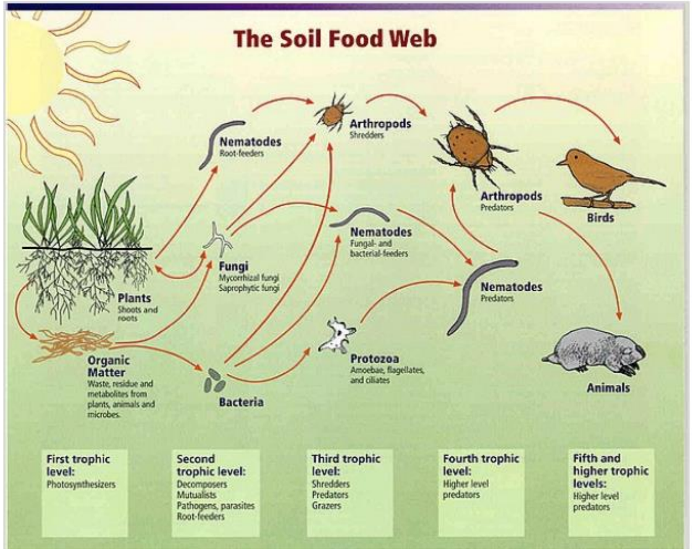
C vs S

C vs Resources

FCL mean and Max

Oxidized ⟶ Reduced

| Reduced ⟶ Oxidized | $H_2O/O_2$ | C | N | S |
|---|---|---|---|---|
| $H_2O/O_2$ | X | Photosynthesis<br>$CO_2 \longrightarrow C$<br>$H_2O \longrightarrow O_2$ | | |
| C | Respiration<br>$C \longrightarrow CO_2$<br>$O_2 \longrightarrow H_2O$ | X | Denitrification<br>$C \longrightarrow CO_2$<br>$NO_3 \longrightarrow N_2$ | Sulfate-Reduction<br>$C \longrightarrow CO_2$<br>$SO_4 \longrightarrow H_2S$ |
| N | Heterotrophic Nitrification<br>$NH_4 \longrightarrow NO_3$<br>$O_2 \longrightarrow H_2O$ | Chemoautotrophy (Nitrification)<br>$NH_4 \longrightarrow NO_3$<br>$CO_2 \longrightarrow C$ | Anammox<br>$NH_4 + NO_2 \rightarrow N_2 + 2H_2O$ | ? |
| S | Sulfur Oxidation<br>$S \longrightarrow SO_4$<br>$O_2 \longrightarrow H_2O$ | Chemoautotrophy (Sulfur-based Photosynthesis)<br>$S \longrightarrow SO_4$<br>$CO_2 \longrightarrow C$ | Autotrophic Denitrification<br>$S \longrightarrow SO_4$<br>$NO_3 \longrightarrow N_2/NH_4$ | X |



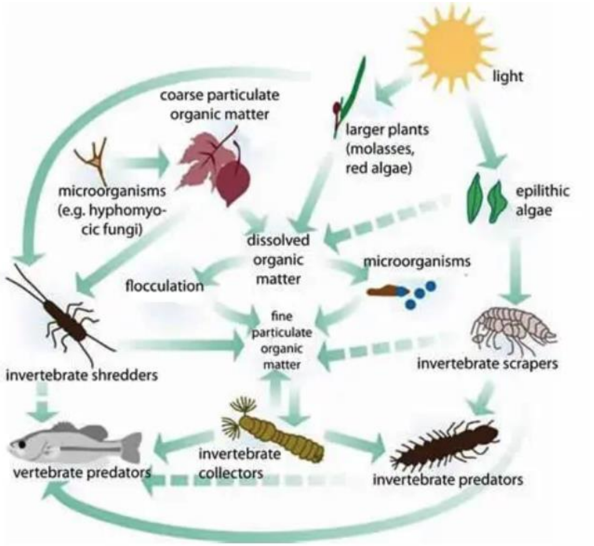
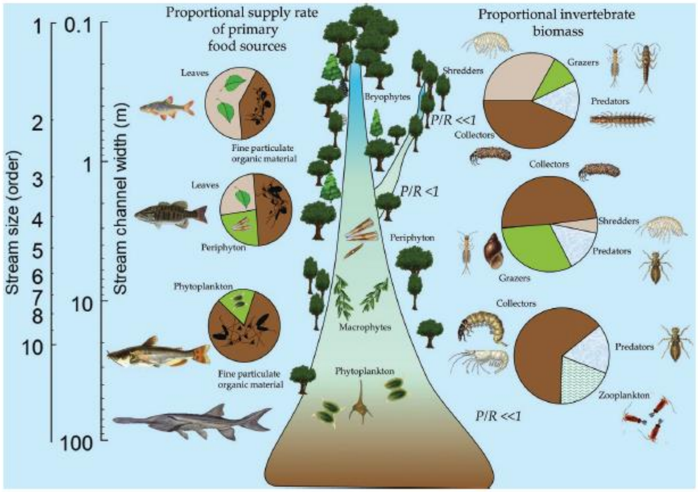
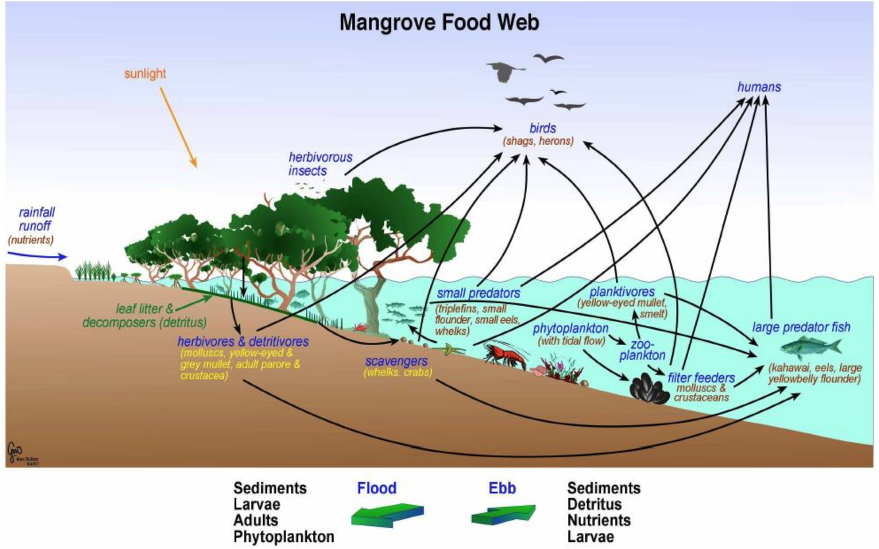




Image credit: USDA




Where do these reaction occur?

Conditions?

**Program: ______(name)____________________ Logic Model**

**Situation:**

| **Inputs** | **Outputs** | | **Outcomes -- Impact** | | |
|---|---|---|---|---|---|
| | *Activities* | *Participation* | *Short* | *Medium* | *Long* |
| | | | | | |

**Assumptions**

**External Factors**

Rev. 7/09