The Oceans

OUTLINE

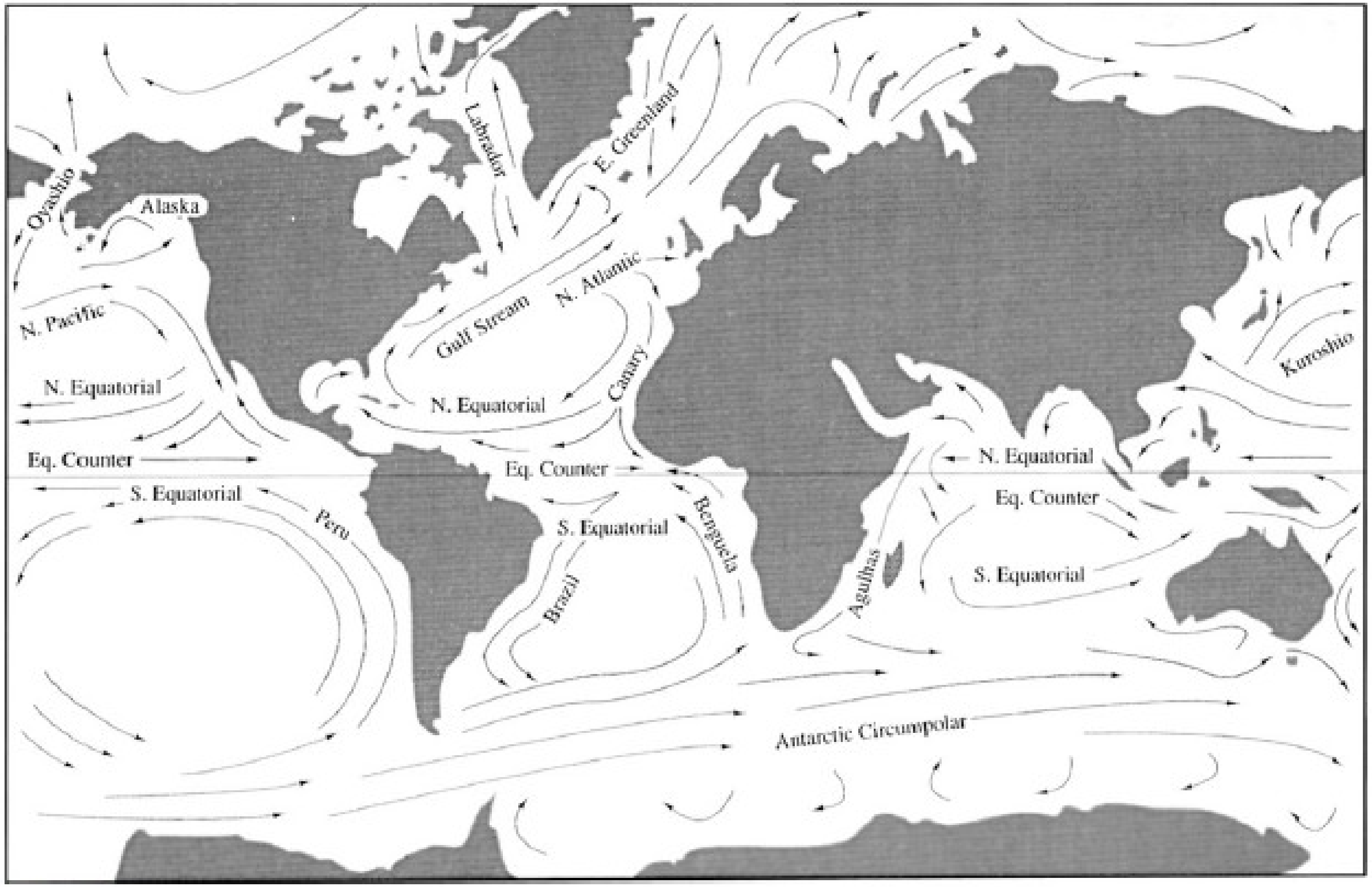


FIGURE 9.1 Major currents in the surface waters of the world's oceans. *Source: From Knauss (1978). Used with permission of Dr. John Knauss.*

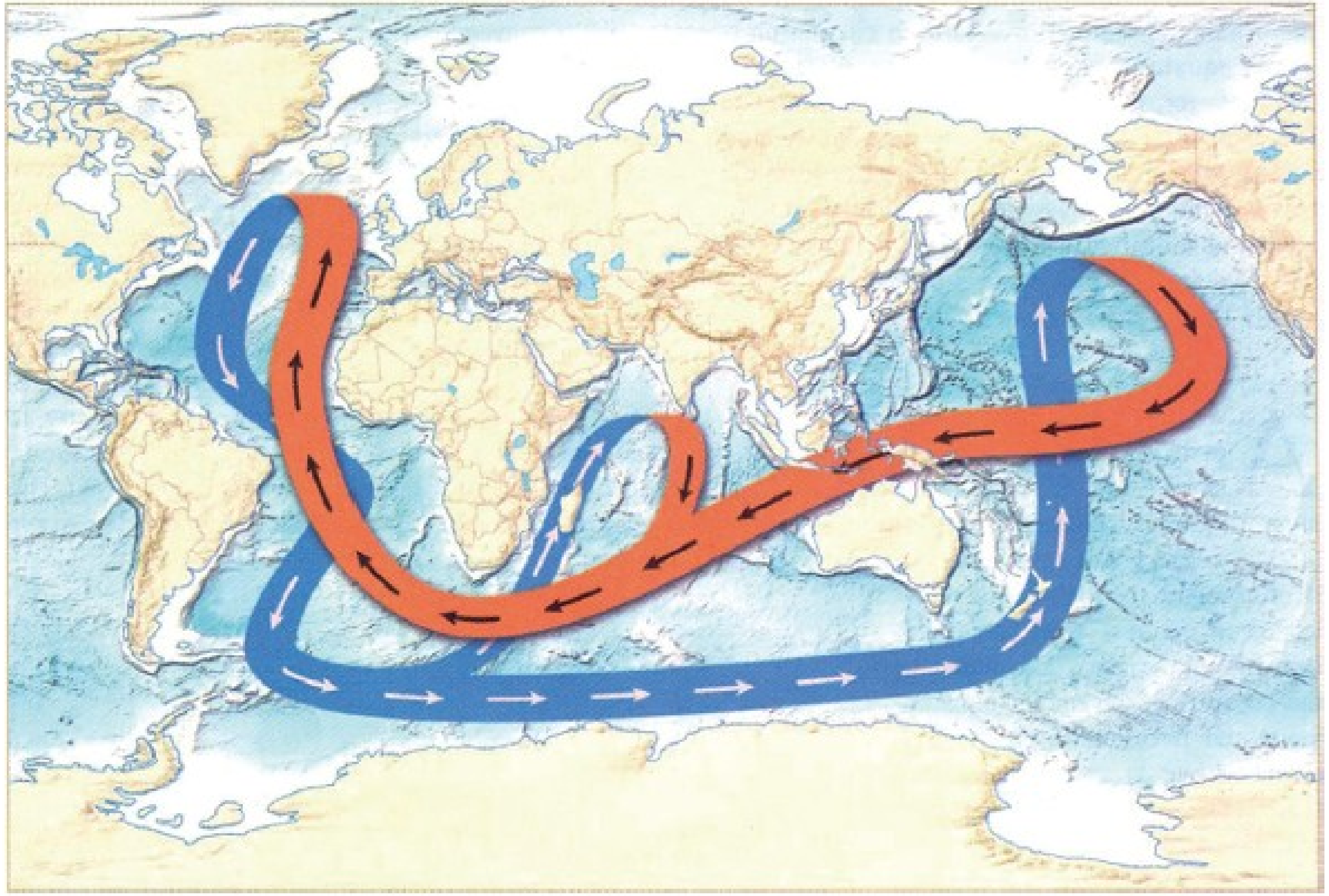


FIGURE 9.3 The global ocean thermohaline circulation forms a conveyor that moves water among the various ocean basins in surface (*red*) and deep-water (*blue*) currents. *Source: From Lozier (2010). Used with permission of the American Association for the Advancement of Science.*

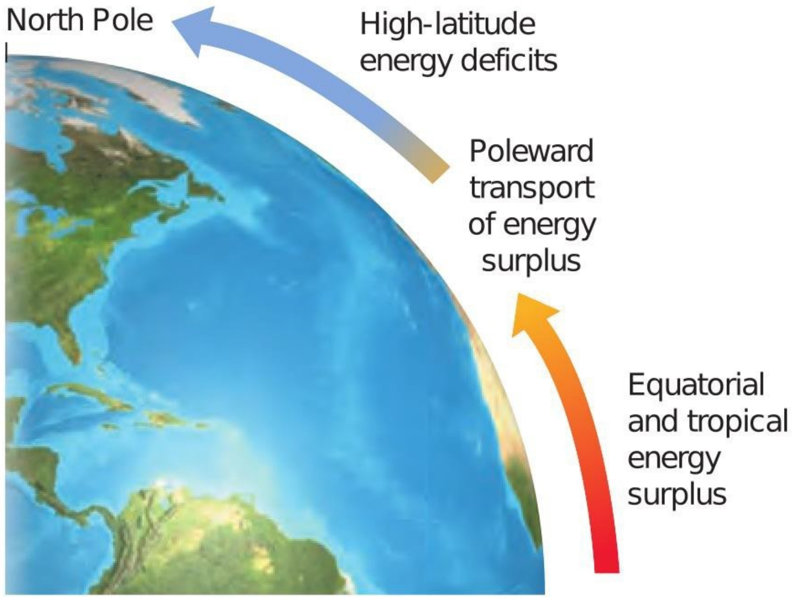
Earth’s Clima
Syste

7.1 INSOLATION

Incoming solar radiation is the energy input for the climate system. Insolation varies by latitude, as well as on a daily and seasonal basis with changing day length and Sun angle. (*Chapter 2; review Figures 2.9, 2.10, and GIA 2*)

7.2 EARTH’S ENERGY BALANCE

The imbalance created by energy surpluses at the equator and energy deficits at the poles causes the global circulation patterns of winds and ocean currents that drive weather systems. (*Chapter 3; review Figure 3.13*)



Figures GIA 7.1-7.2

2012-2016 Temperature Anomalies

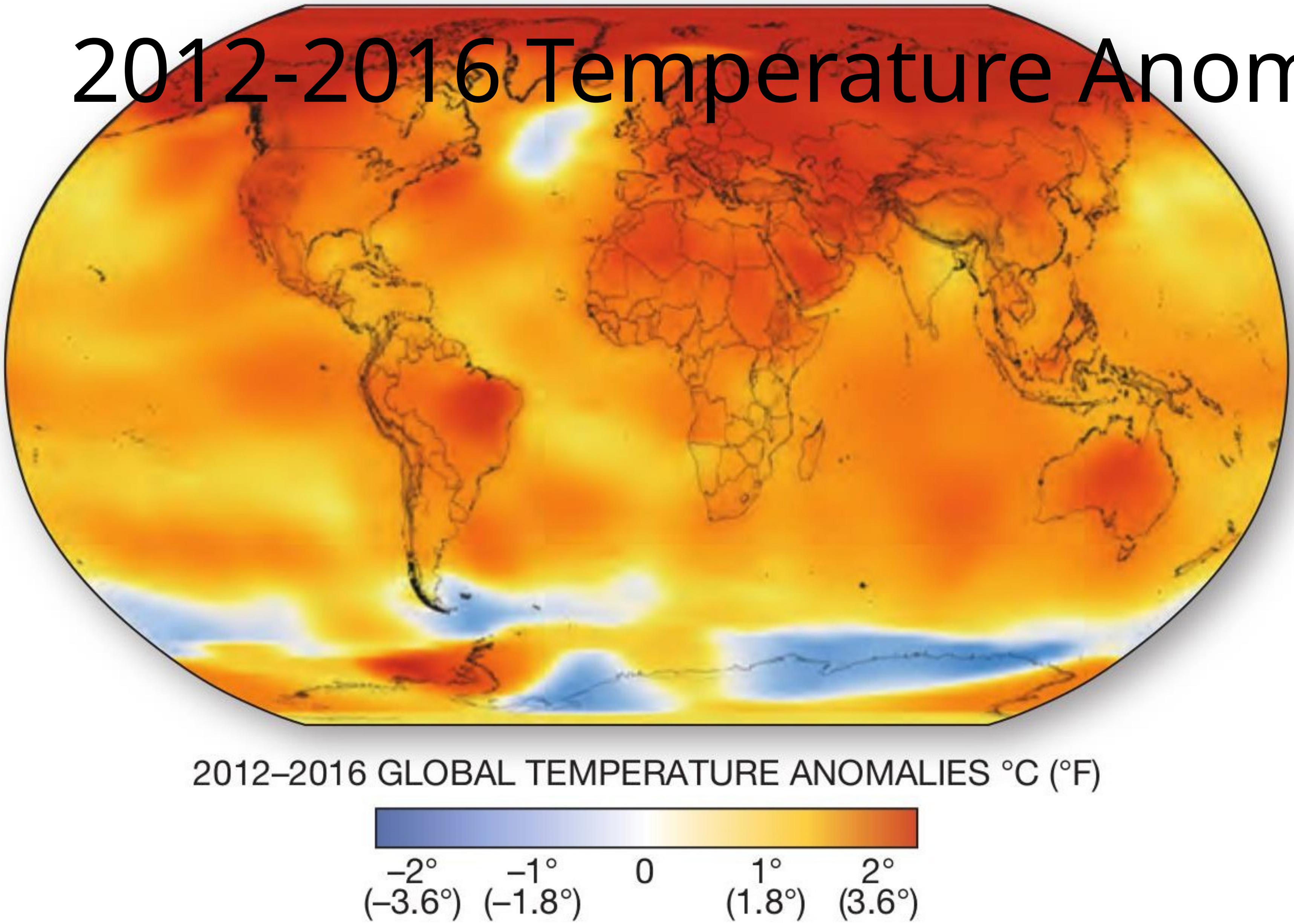


Figure 8.22

Loss

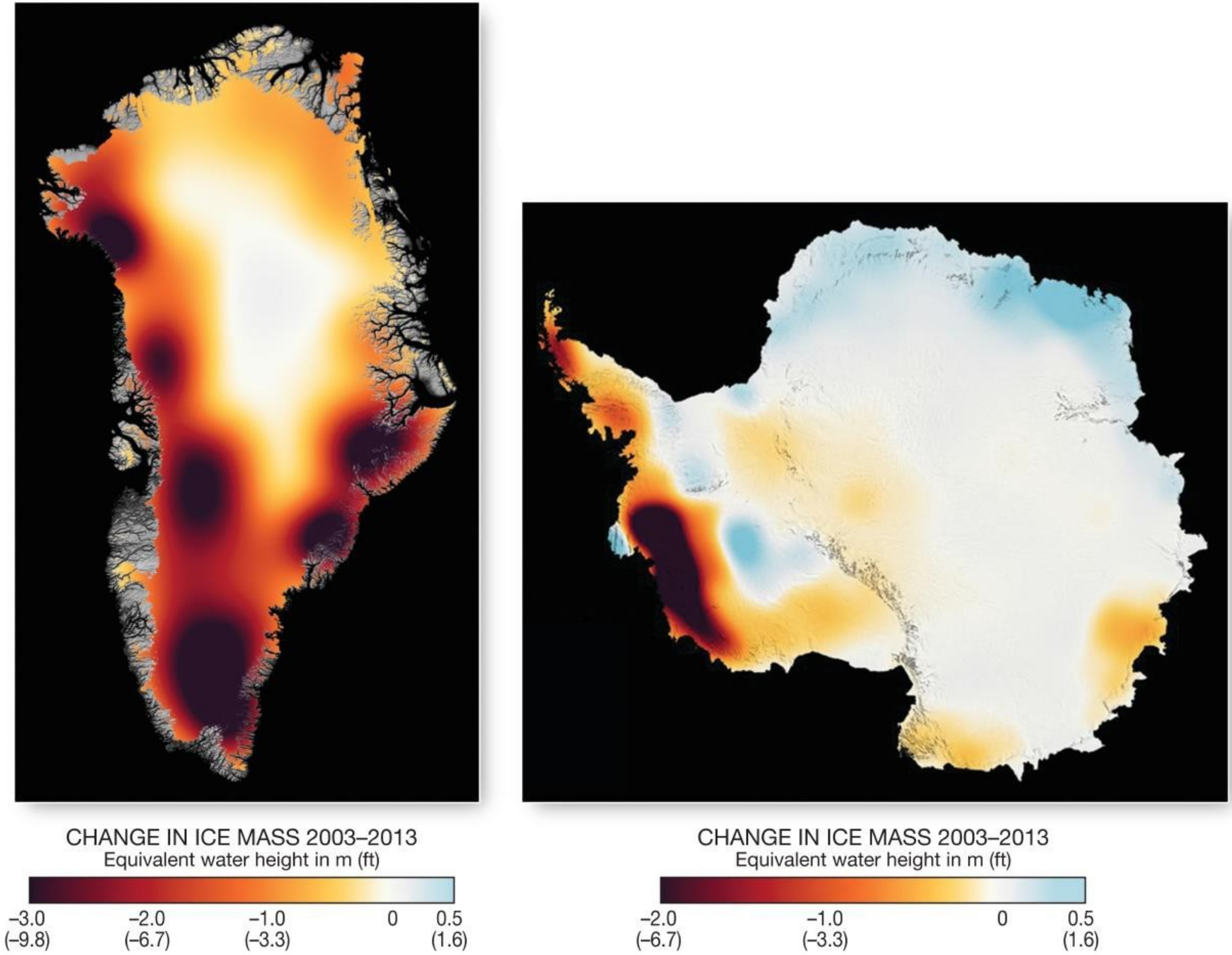


Figure 8.24

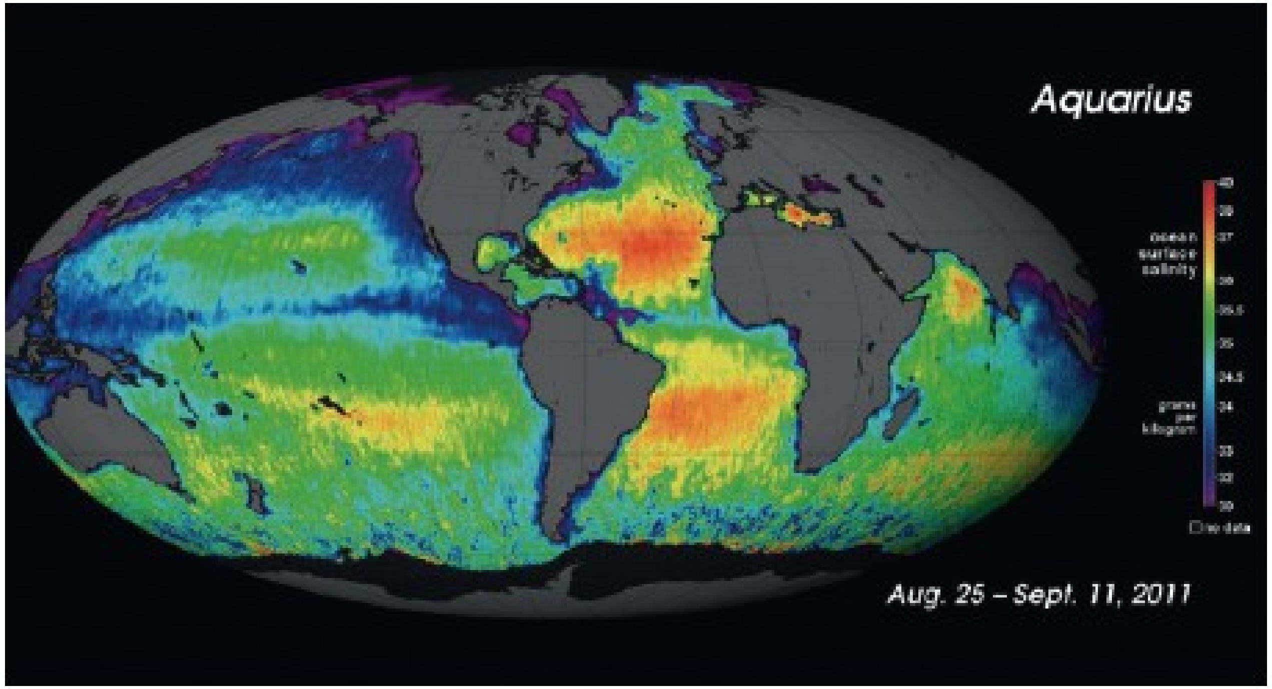


FIGURE 9.5 Salinity of the surface waters of the world's oceans. *Source: From NASA Aquarius (http://www.nasa.gov/mission_pages/aquarius/multimedia/gallery/pia14786.html).*

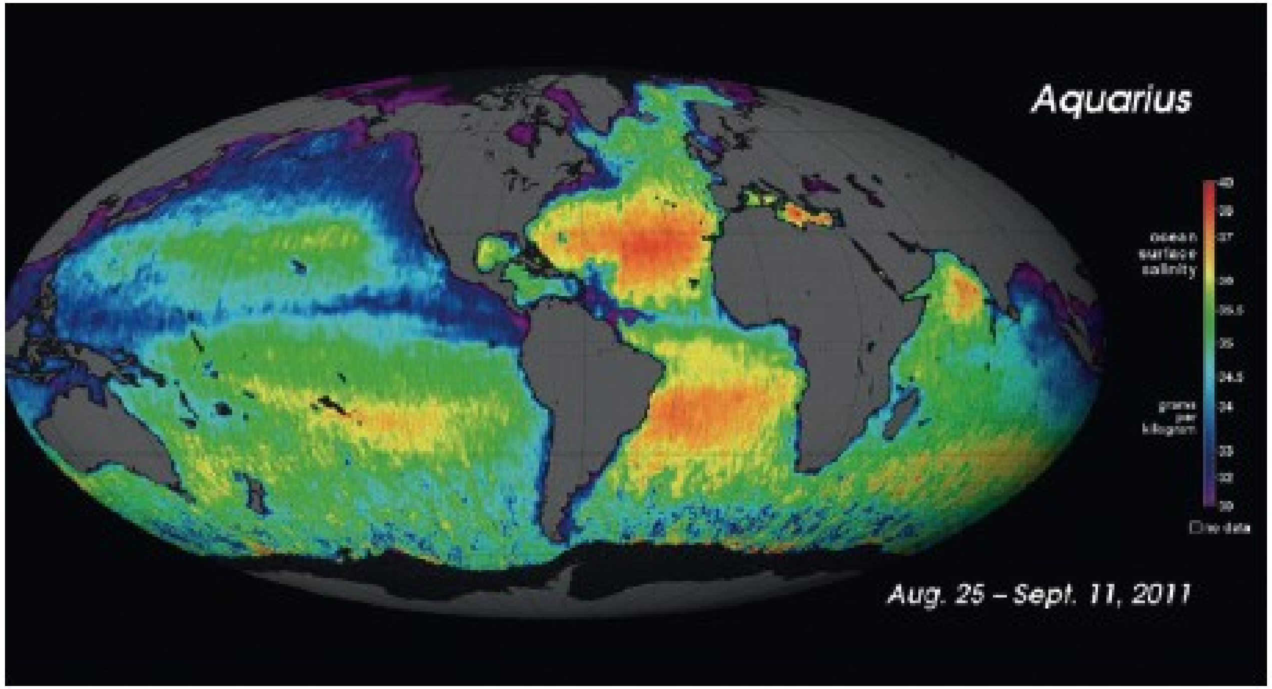
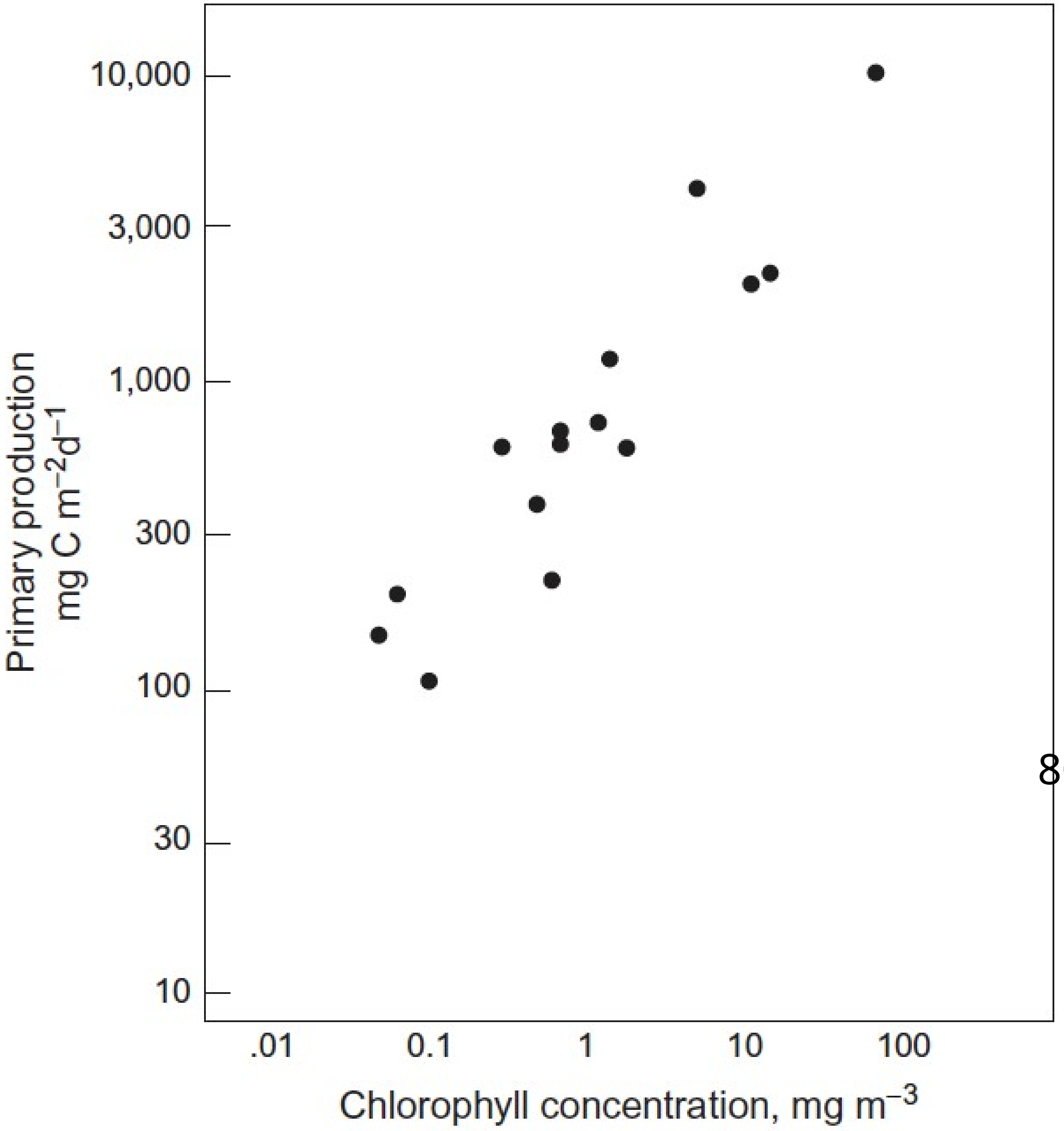


FIGURE 9.5 Salinity of the surface waters of the world's oceans. *Source: From NASA Aquarius (http://www.nasa.gov/mission_pages/aquarius/multimedia/gallery/pia14786.html).*



Net Primary Production

23-27 x 10^{15} g C / yr

- Oxygen-Bottle
- C^{14}
- **δ**^{17}O
- Remote Sensing

DOC

17 % of NPP
6000 yr MRT

70 % consumed by Bacteria
80 – 90 % decomposed to inorganic forms (CO_2, NO_3, PO_4

FIGURE 9.7 Net primary productivity as a function of surface chlorophyll in waters of coastal California. *Source: From Eppley et al. (1985),* Journal of Plankton Research. *Reprinted by permission of Oxford University Press.*

TABLE 9.2 Estimates of Total Marine Primary Productivity and the Proportion That Is New Production

Province	% of ocean	Area ($10^{12}m^2$)	Mean production (g C $m^{-2}yr^{-1}$)	Total global production (10^{15}g C yr^{-1})	New production[a] (g C $m^{-2}yr^{-1}$)	Global new production (10^{15}g C yr^{-1})
Open ocean	90	326	130	42	18	5.9
Coastal zone	9.9	36	250	9.0	42	1.5
Upwelling area	0.1	0.36	420	0.15	85	0.03
Total		**362**		**51**		**7.4**

[a] *New productivity defined as C flux at 100 m.*
Source: From Knauer (1993). Used with permission of Springer-Verlag.

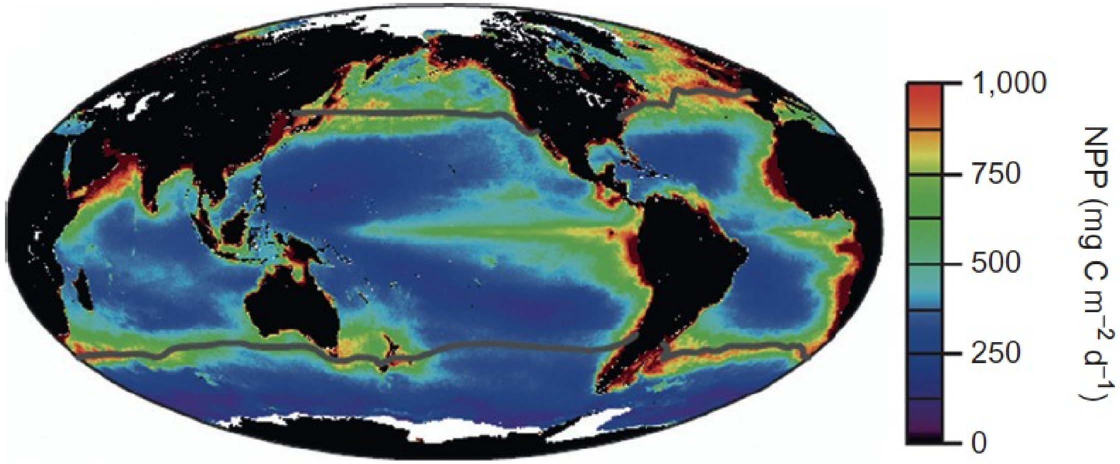


FIGURE 9.8 Global map of marine NPP. *Source: From Behrenfeld et al. (2006).*

Fate of Marine NPP

POC

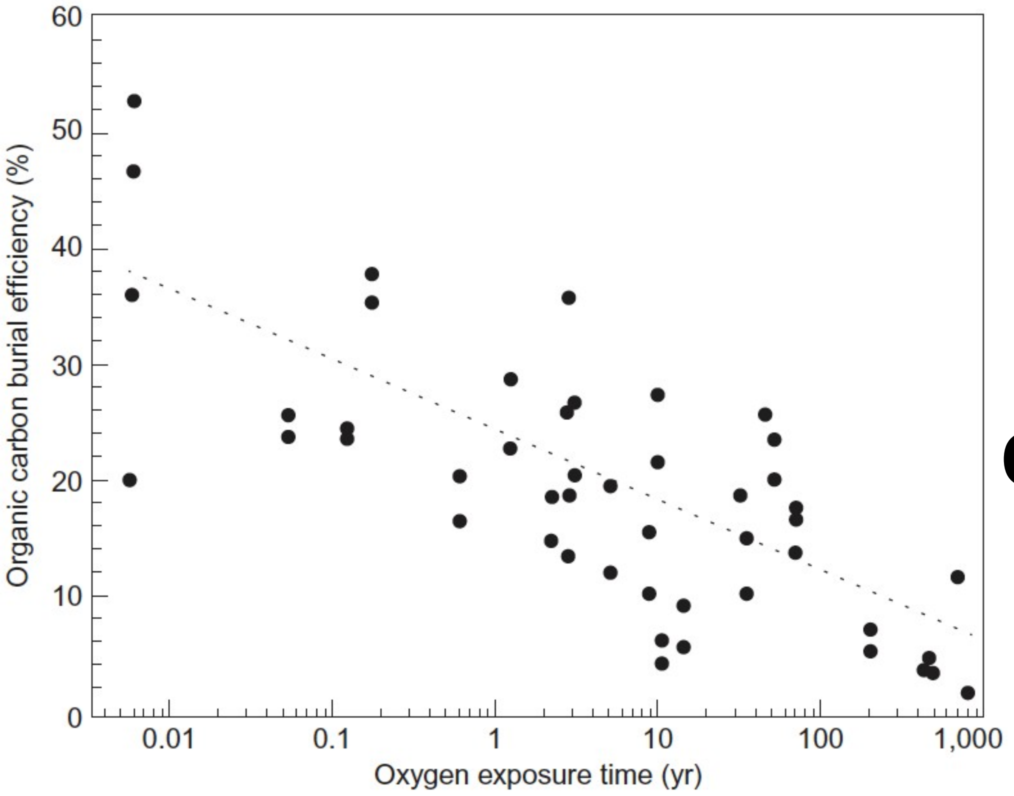


FIGURE 9.9 Organic carbon burial efficiency versus the time of its exposure to O_2 in sediments of the eastern North Pacific Ocean. *Source: From Hartnett et al. (1998).*

7.4×10^{15} g C / yr sinks to deep ocean waters

0.157×10^{15} g C / yr incorporated into sediments

0.12×10^{15} g C /yr buried in ocean sediments (1% of NPP

Ocean as a net heterotrophic system

P/R < 1.0

Biogenic Carbonates

A large number of marine organisms precipitate carbonate in their skeletal and protective tissues by the reaction:

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3\downarrow + H_2O + CO_2. \quad (9.3)$$

$$H_2O + CO_2 \rightarrow H^+ + HCO_3^- \rightarrow H_2CO_3. \quad (9.4)$$

When the skeletal remains of carbonate-producing organisms sink to the deep ocean, they dissolve:

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-. \quad (9.5)$$

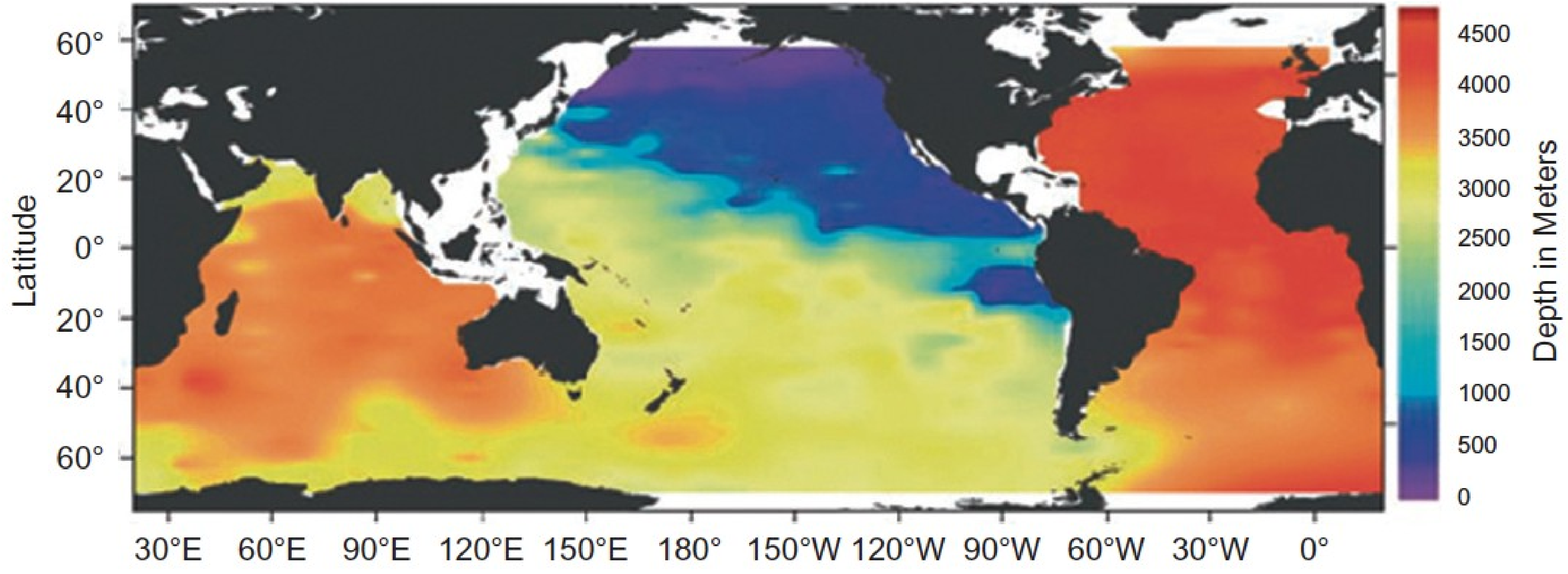


FIGURE 9.14 Calcite saturation depth in the world's oceans. *Source: Feely et al. (2004). Used with permission of the American Association for the Advancement of Science.*

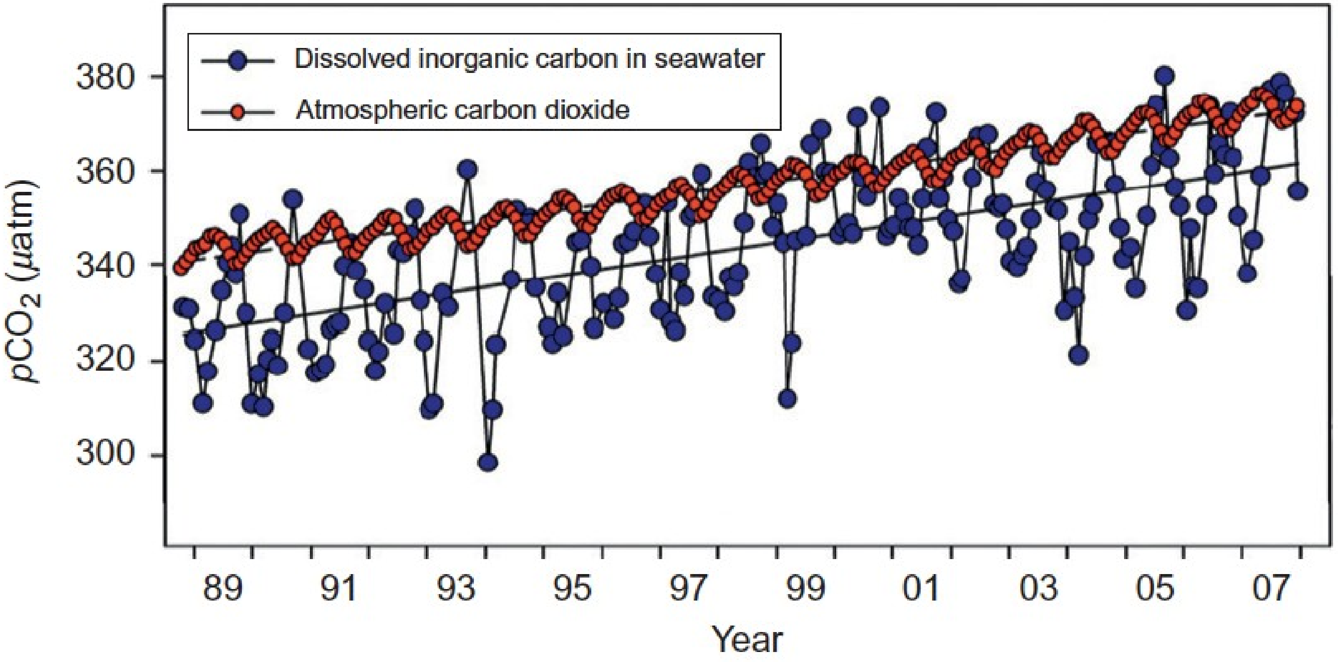


FIGURE 9.15 Dissolved carbon dioxide in seawater (dissolved inorganic carbon + total alkalinity) and pCO_2 in Earth's atmosphere at Mauna Loa, Hawaii, since 1989. *Source: From Dore et al. (2009). Used with permission of the National Academy of Sciences.*

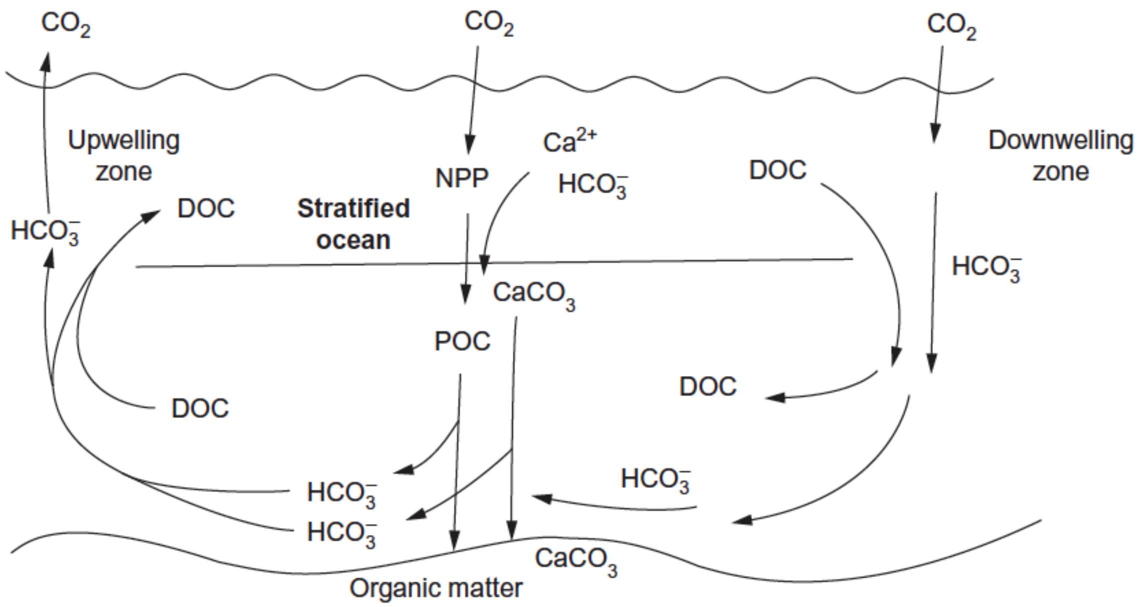
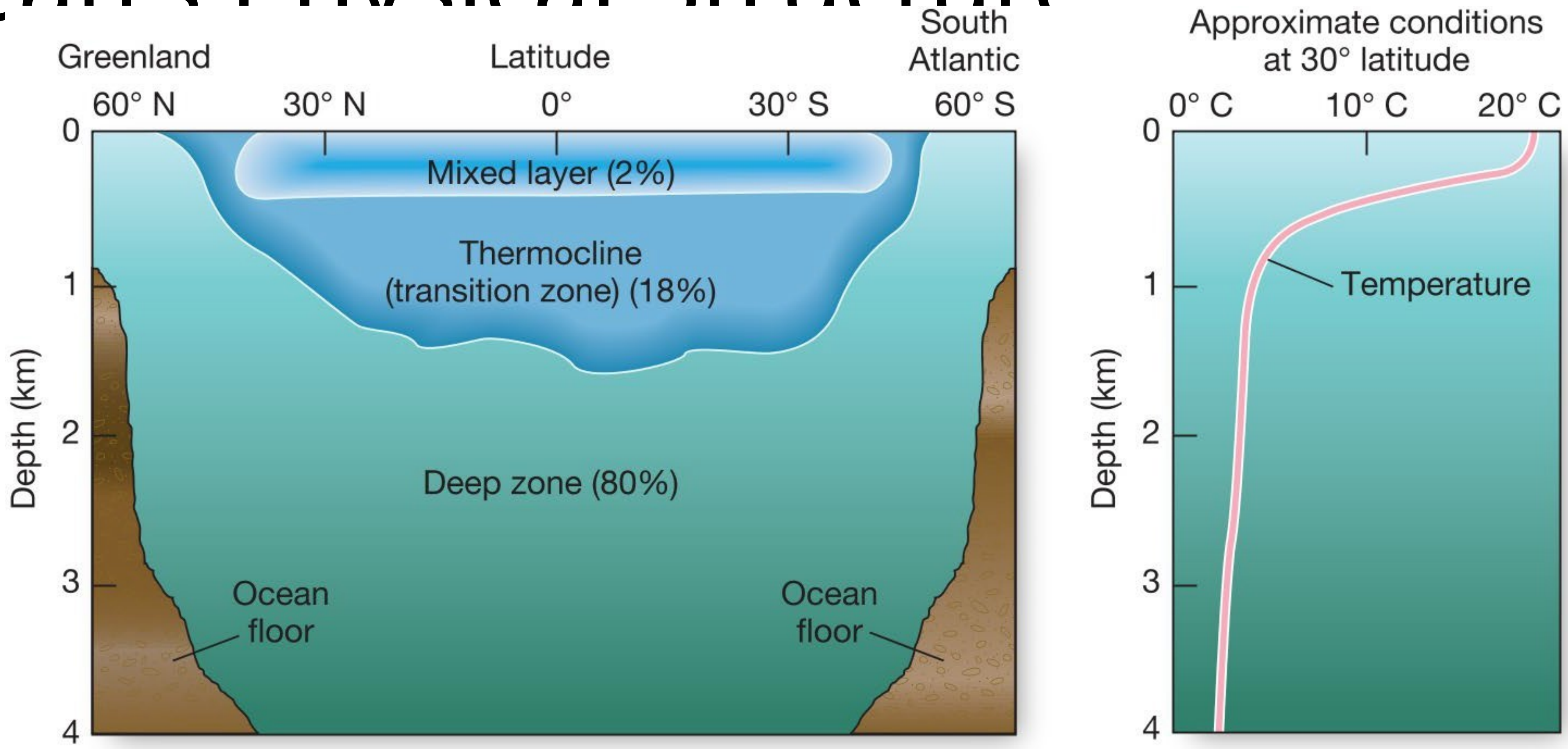


FIGURE 9.16 The marine biotic pump, showing the formation of organic matter (POC) and carbonate skeletons in the surface ocean and their downward transport and the downwelling of DOC and bicarbonate to the deep ocean.

Ocean’s Physical Structure



(a) Vertical zonation by latitude.

(b) Temperature change with depth at 30° latitude.

TABLE 9.3 Calculation of the Sources of Nutrients That Would Sustain a Global Net Primary Productivity of 50×10^{15} g C/yr in the Surface Waters of the Oceans

Flux	Carbon (10^{12} g)	Nitrogen (10^{12} g)	Phosphorus (10^{12} g)
New primary production[a]	50,000	8800	1200
Amounts supplied			
By rivers[b]		50	2
By atmospheric deposition[c]		67	1
By N fixation[d]		150	—
By upwelling		700	100
Recycling (by difference)		7800	1100

Note: Values taken from Figures 9.21 and 9.22, with rounding. Based on an approach developed by Peterson (1981).

[a] *Assuming a Redfield atom ratio of 106:16:1.*

[b] *N from Galloway et al. (2004); P from Meybeck (1982).*

[c] *Duce et al. (2008).*

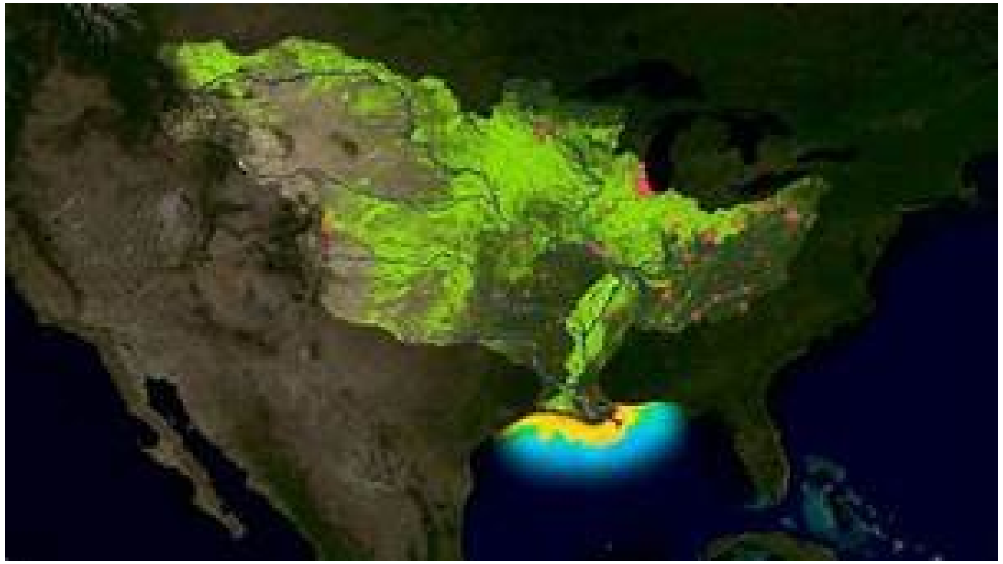
[d] *Deutsch et al. (2007).*

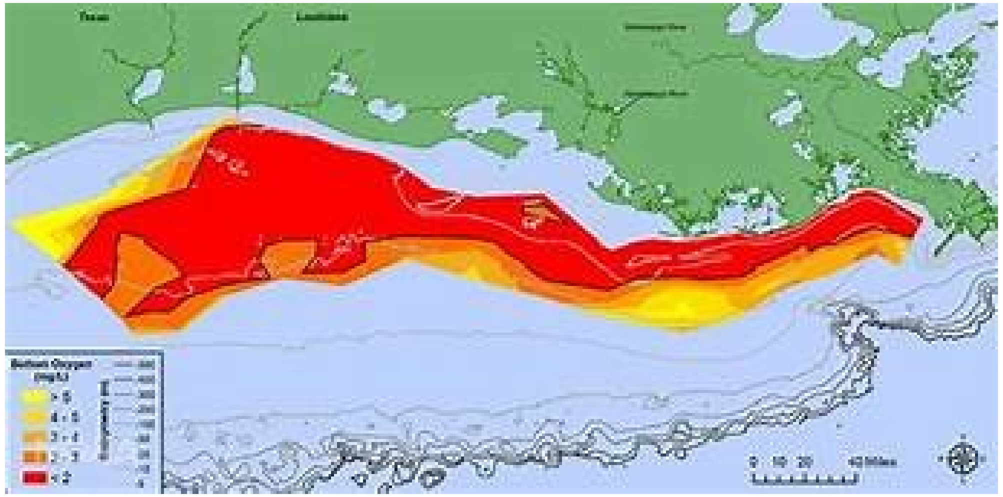
Thresholds and Tipping Points

Dead-Zones - How are they formed?

Gulf of Mexico

1. Mississippi River carries nitrogen-rich material (e.g., Fertilizer, Urban Run-off, sewage) into Gulf
2. Microbes feed on nitrogen-rich materials
3. Microbes die and decompose – depleting O_2.
4. Organism avoid low-oxygen zone.
5. Organisms that cannot avoid zone, die.





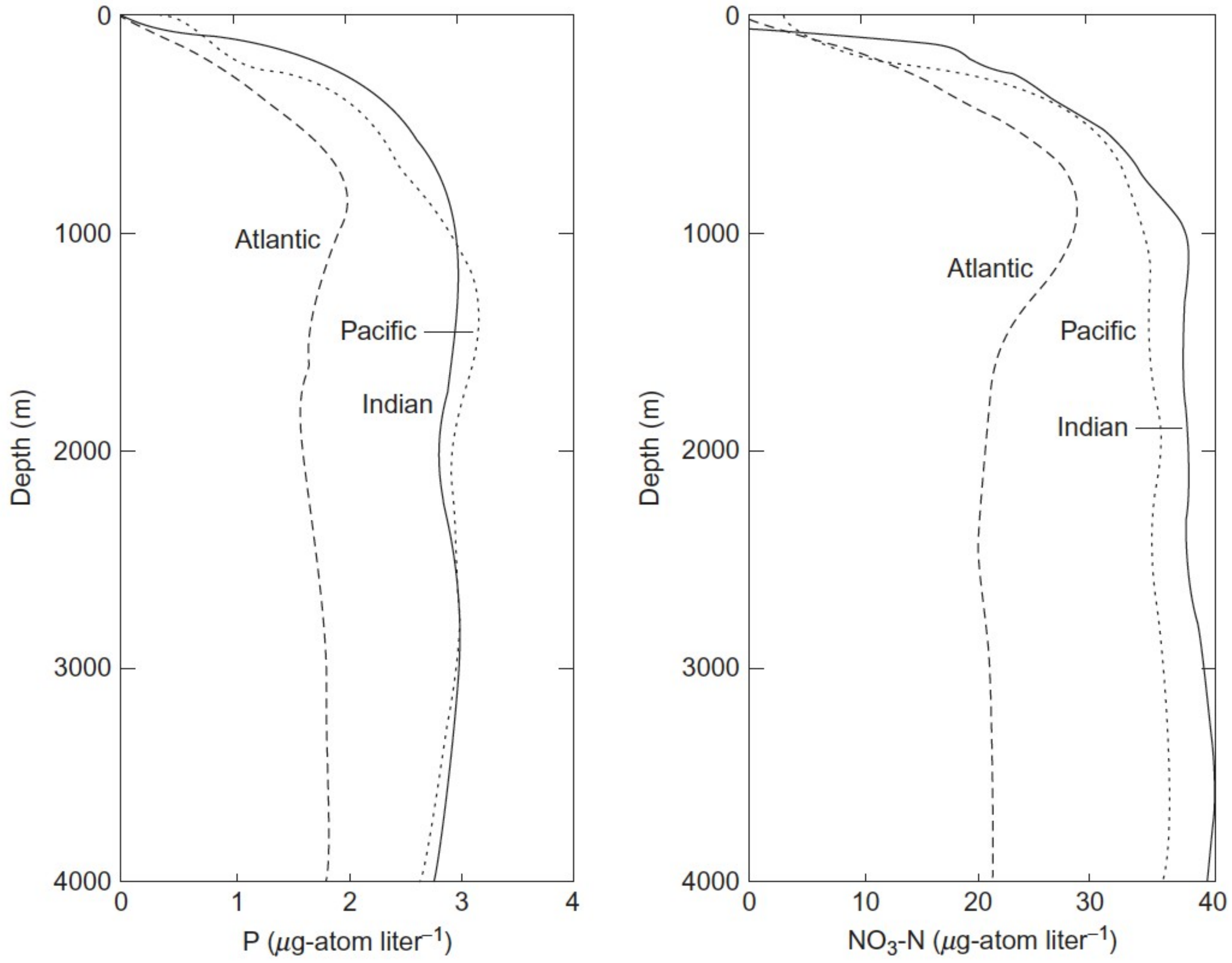


FIGURE 9.18 Vertical distribution of phosphate and nitrate in the world's oceans. *Source: From Svedrup et al. (1942).*

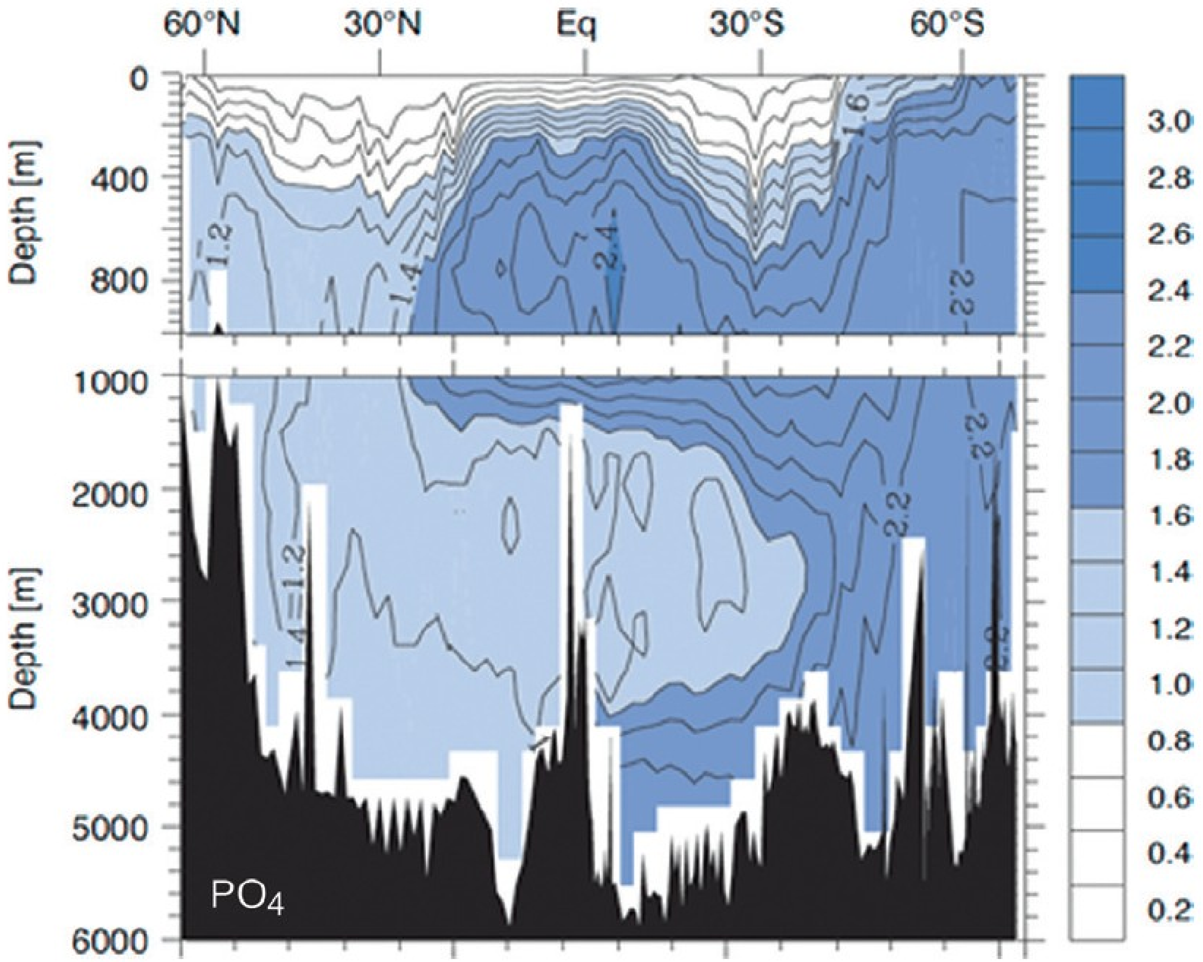


FIGURE 9.19 Phosphorus in the Atlantic Ocean, showing the increase in its concentration in deep waters as they travel from north to south. *Source: From Sarmiento and Gruber (2006). Used with permission of Princeton University Press.*

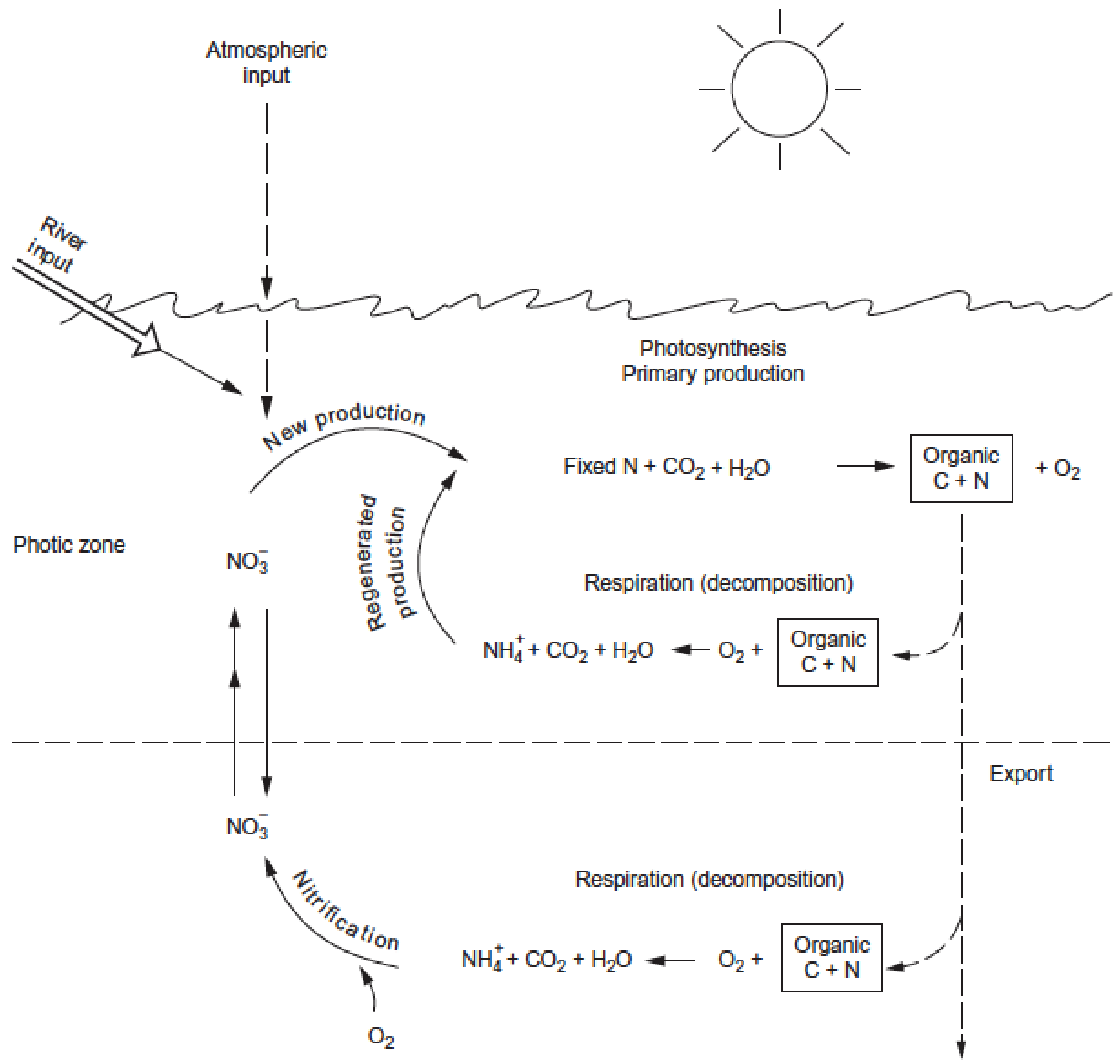


FIGURE 9.20 Links between the nitrogen and the carbon cycles in the surface ocean. Nitrogen regenerated in the surface waters is largely assimilated by phytoplankton as NH_4, while that diffusing and mixing up from the deep ocean is NO_3. When organic matter sinking to the deep ocean is mineralized, its nitrogen content is initially released as NH_4 and converted to nitrate by nitrifying bacteria. "New production" can be estimated as the fraction of net primary production that is derived from nitrate from rivers, atmospheric deposition, nitrogen fixation, and upwelling from the deep sea. *Source: From Jahnke (1990).*

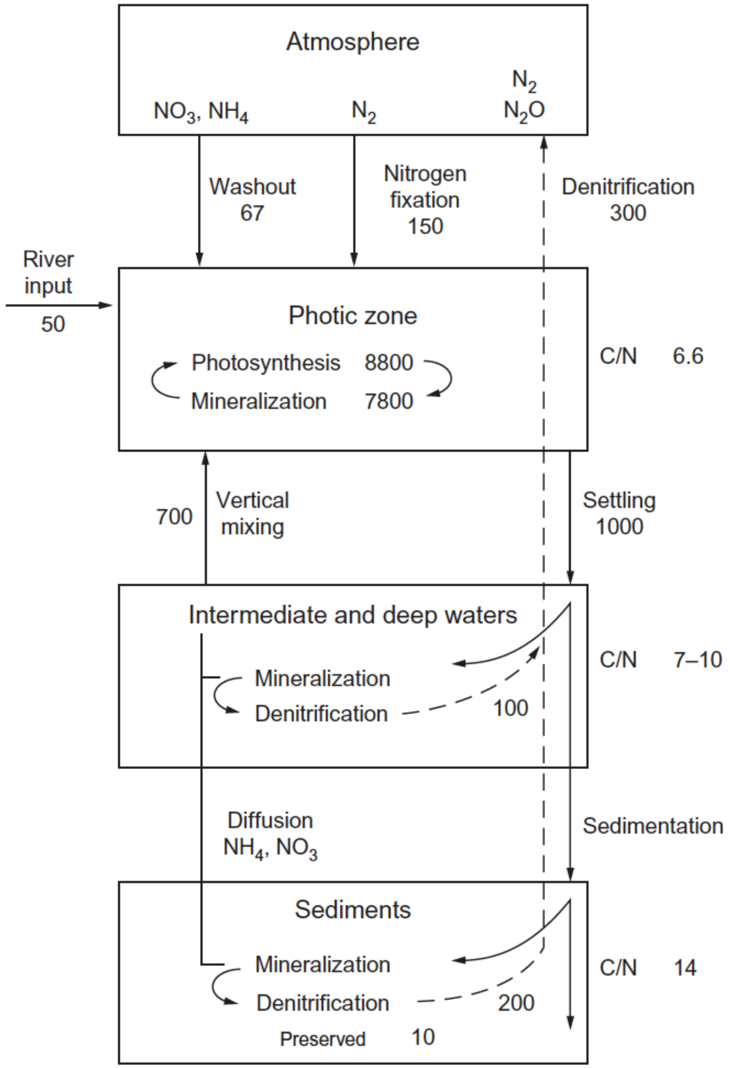
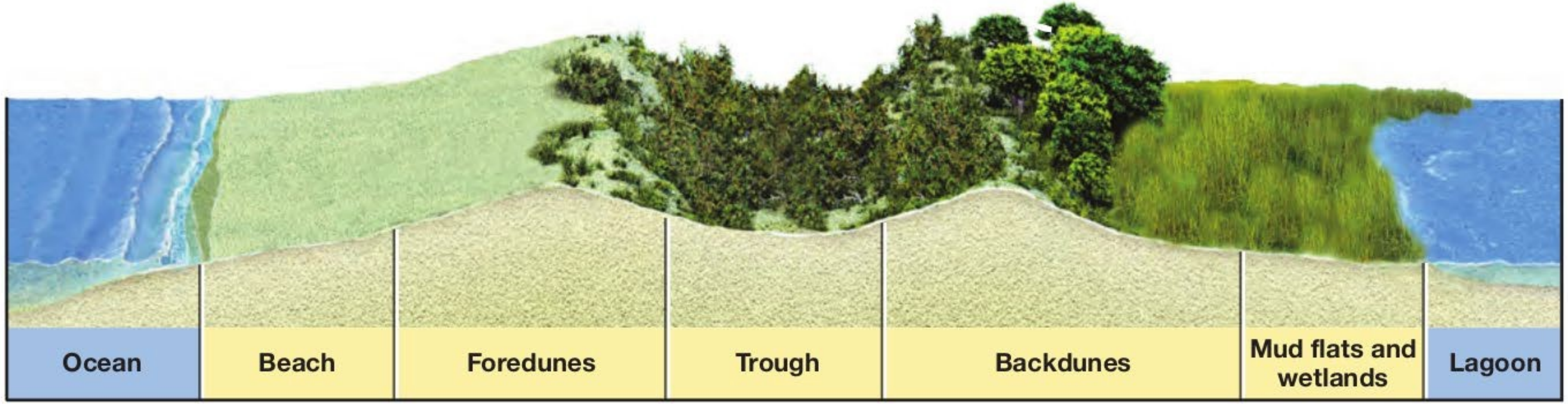
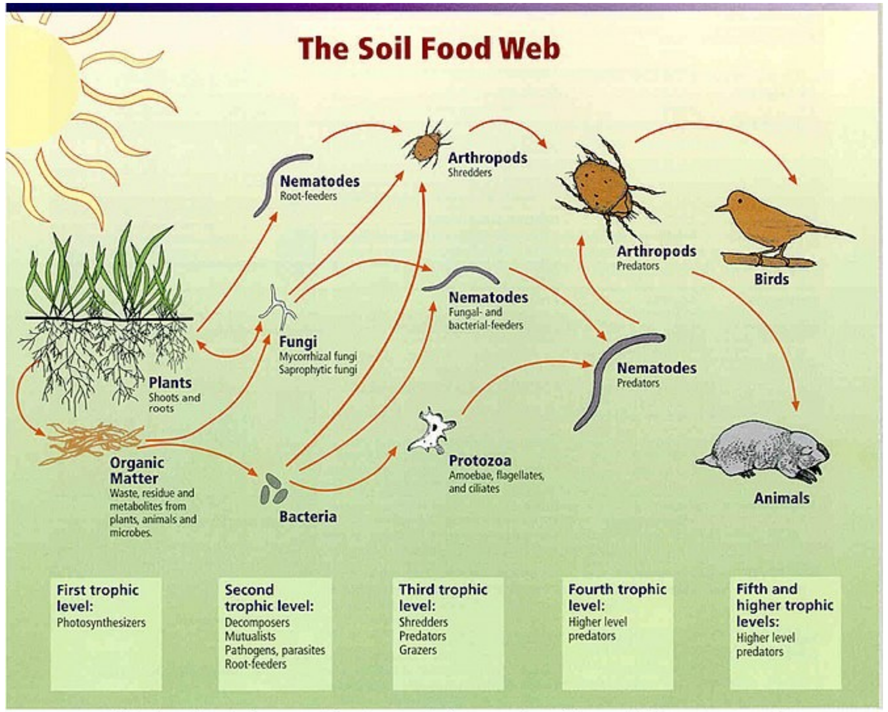


FIGURE 9.21 Nitrogen budget for the world's oceans, showing major fluxes in units of 10^{12} gN/yr. From an original conception by Wollast (1981), but with newer data added for atmospheric deposition (Duce et al. 2008), nitrogen fixation (Deutsch et al. 2007), riverflow (Galloway et al. 2004), denitrification (Brandes and Devol 2002), and nutrient regeneration in surface waters (compare Table 9.3). The global values have been rounded.





Relationships between soil food web, plants, organic matter, and birds and mammals
Image courtesy of USDA Natural Resources Conservation Service
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_food_web.html.

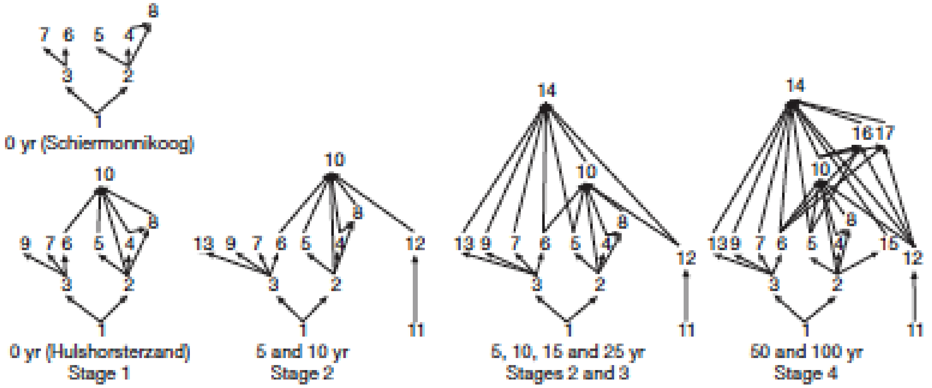
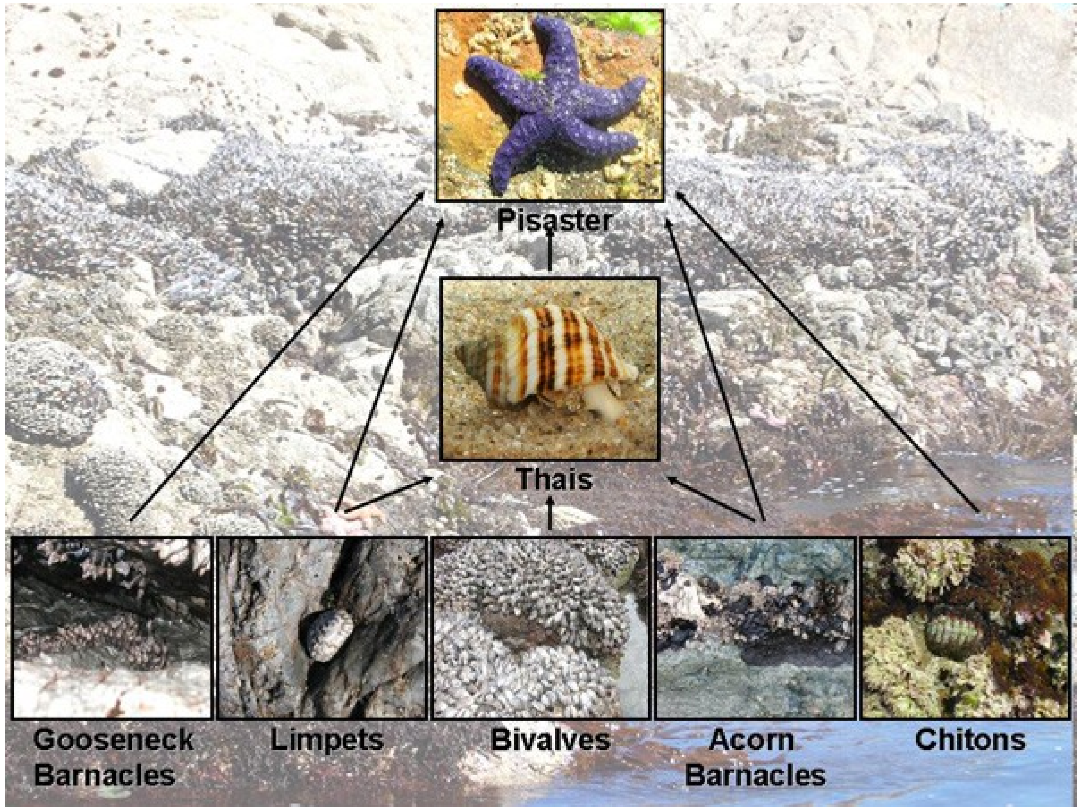
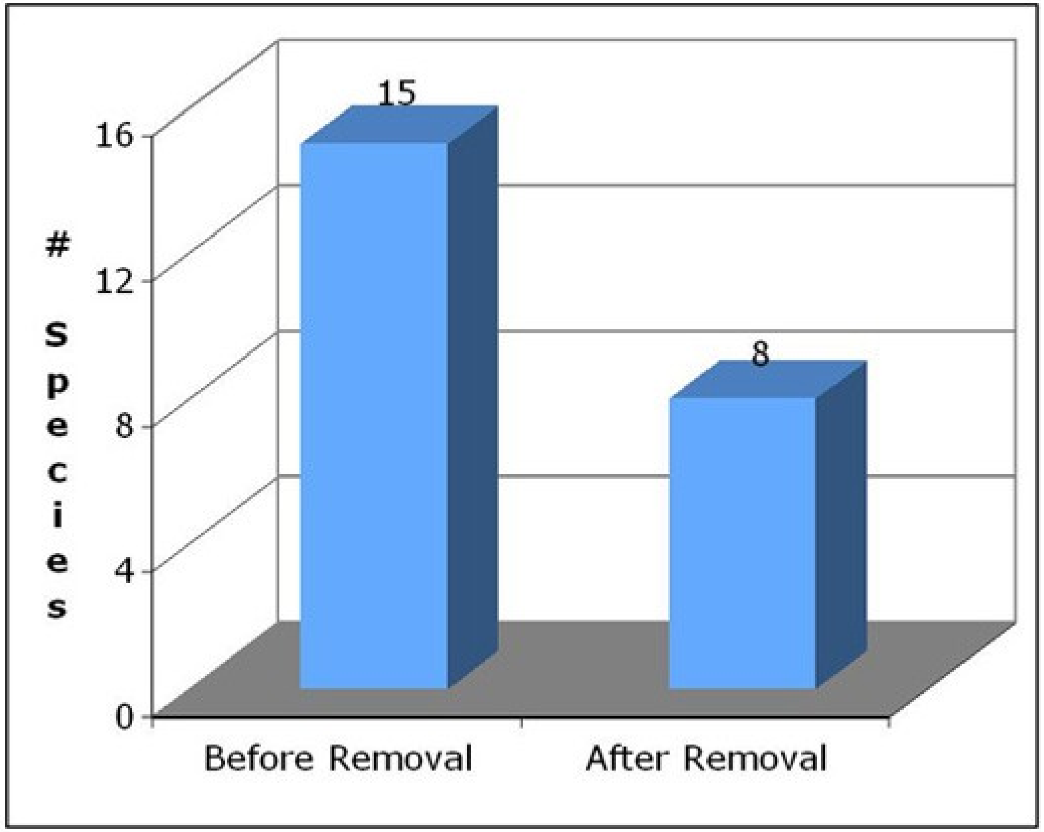


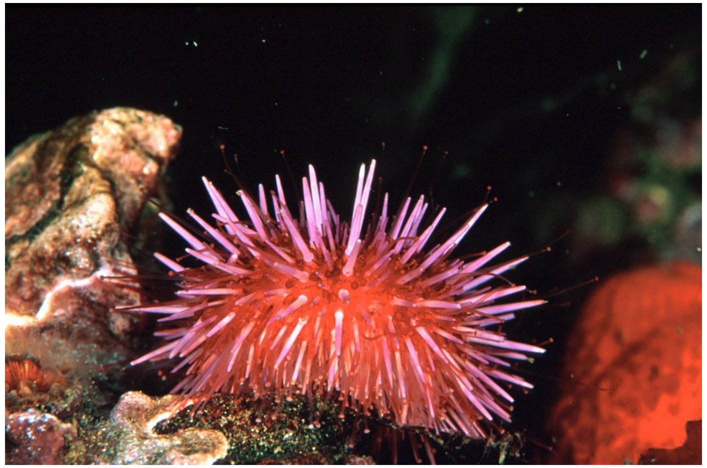
Figure 1 | Observed connectedness structures of the below-ground food webs of Schiermonnikoog and Hulshorsterzand, representative of the four successional stages. The numbers refer to the trophic groups: 1, detritus; 2, bacteria; 3, fungi; 4, flagellates; 5, bacterivorous nematodes; 6, fungivorous nematodes; 7, noncryptostigmatic mites; 8, amoebae; 9, cryptostigmatic mites; 10, predatory nematodes; 11, roots; 12, phytophagous nematodes; 13, collembolans; 14, predatory mites; 15, bacterivorous mites; 16, nematophagous mites; and 17, predatory collembolans. Years refer to soil age see Methods). For details and exceptions, see Supplementary Table 1.

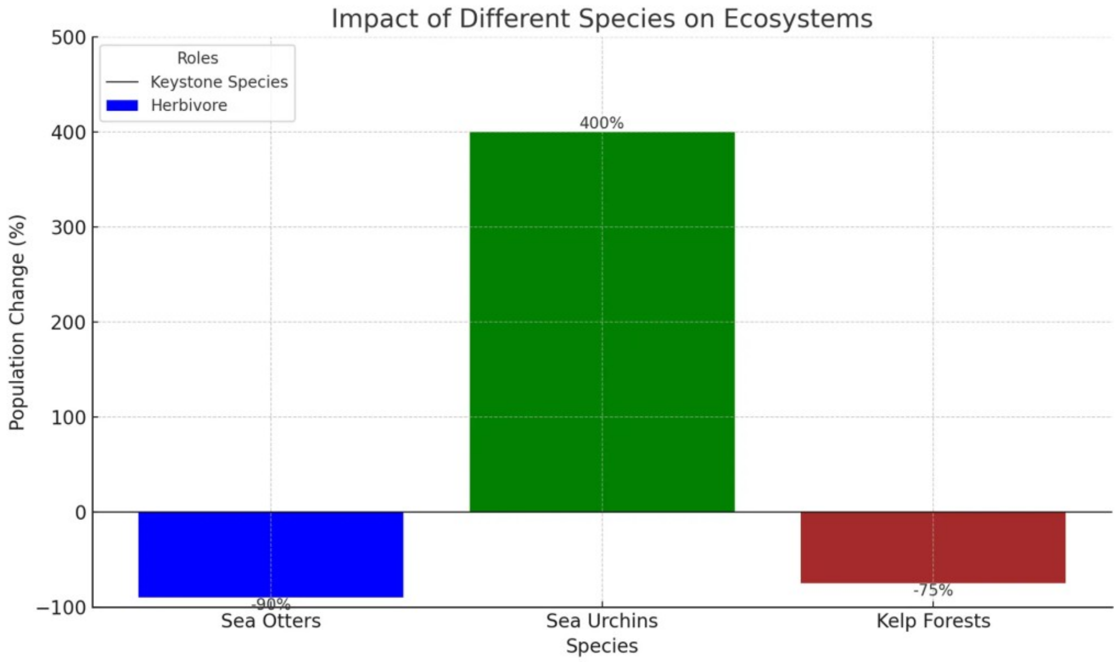
Rocky Intertidal

Keystone Species Concept



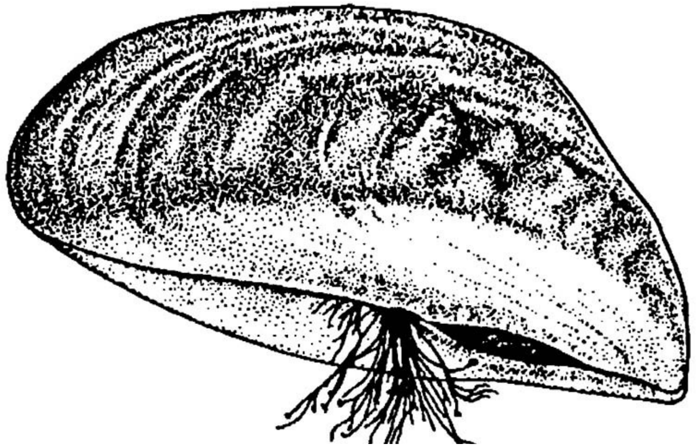





Impact of Different Species on Ecosystems
Roles
Keystone Species
Herbivore
Population Change (%)
500
400
300
200
100
0
−100
400%
-90%
-75%
Sea Otters
Sea Urchins
Kelp Forests
Species

Rocky Intertidal

- Competition for Space
- Byssal Threads



Changes in Sea Level

- Sea-level fluctuations expose a range of coastal landforms to tidal and wave processes.
- The quantity of ice locked up in the ice sheets of Antarctica and Greenland and in many mountain glaciers can increase or decrease and result in sea- level changes accordingly.
- At the peak of the Pleistocene glaciation
- (18,000 B.P.), sea level was about 120 m lower
- than it is today.
- If Antarctica and Greenland became ice-free, sea level would rise at least 65 m worldwide.

Oceanic Acidification

- Ocean absorbs CO_2 from the atmosphere, forms carbonic acid in the seawater, and reduces the ocean pH value.
- Current ocean mean pH is 8.1.
- pH could decrease by 0.4 to 0.5 units by the end of this century.

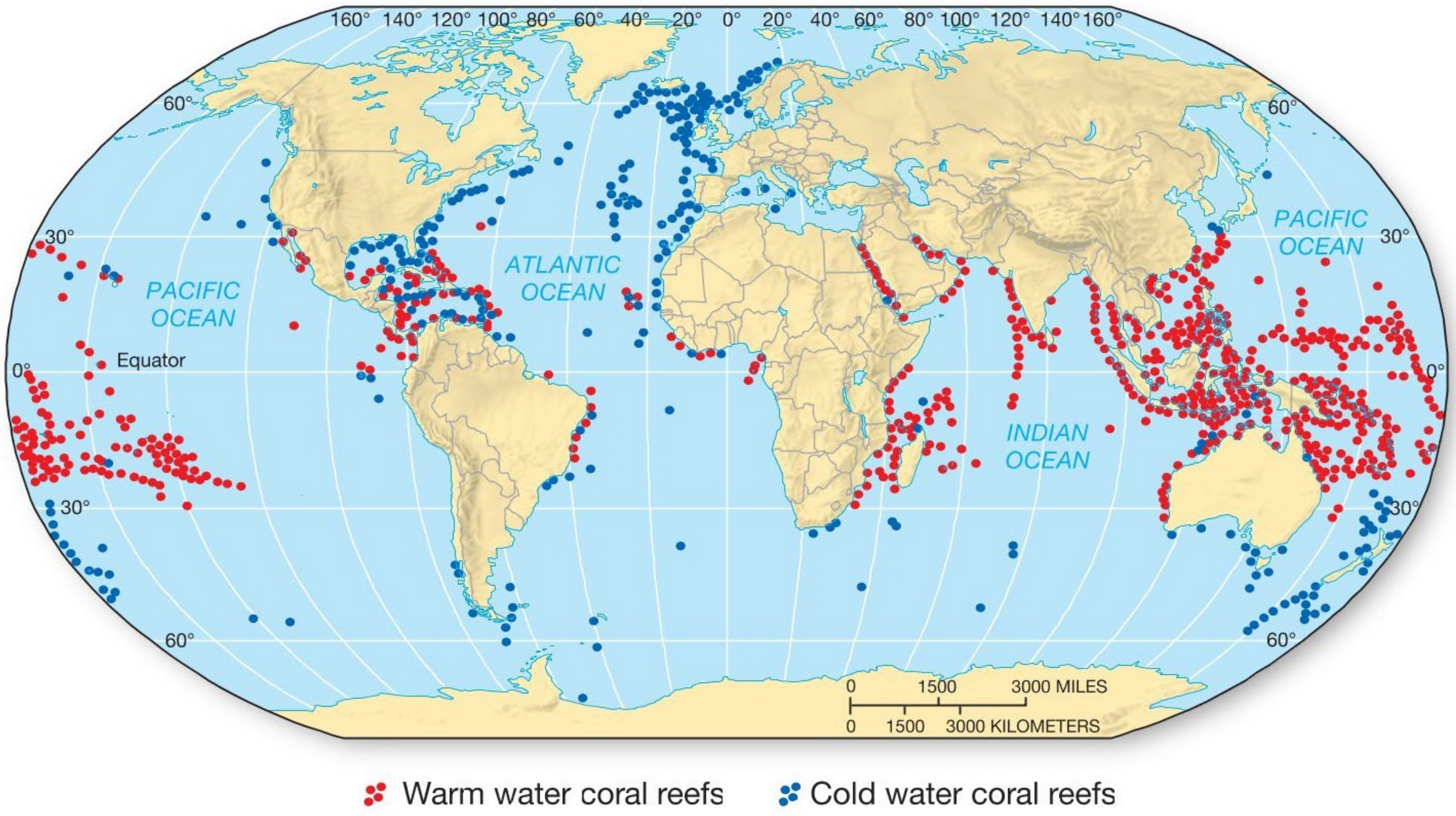
Coral Formations and Coral Reefs

- A coral is a simple marine animal with a small, cylindrical, saclike body called a *polyp*.
- Corals live in a symbiotic relationship with algae.
- Corals cannot photosynthesize.
- Algae perform photosynthesis and provide corals with 60% of their nutrition.
- Corals secrete calcium carbonate forming a hard and calcified external skeleton.

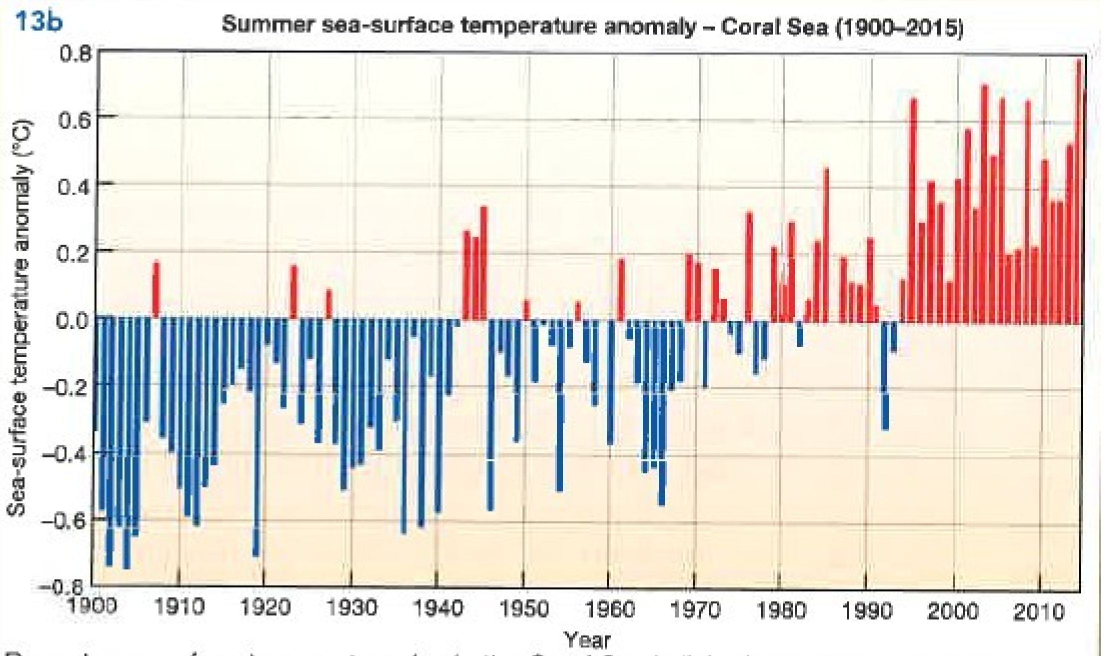
Coral Reefs

- Skeletons of corals accumulate and
  form coral rocks.
- Coral reefs are biologically derived sediment rocks built upon volcanic
  seamounts or other submarine features.

Distribution of Coral Reefs



Coral Bleaching Problem



Recent sea-surface temperature rise in the Coral Sea is linked to coral bleaching in Australia's Great Barrier Reef.

Thermal Stress and Coral Bleaching

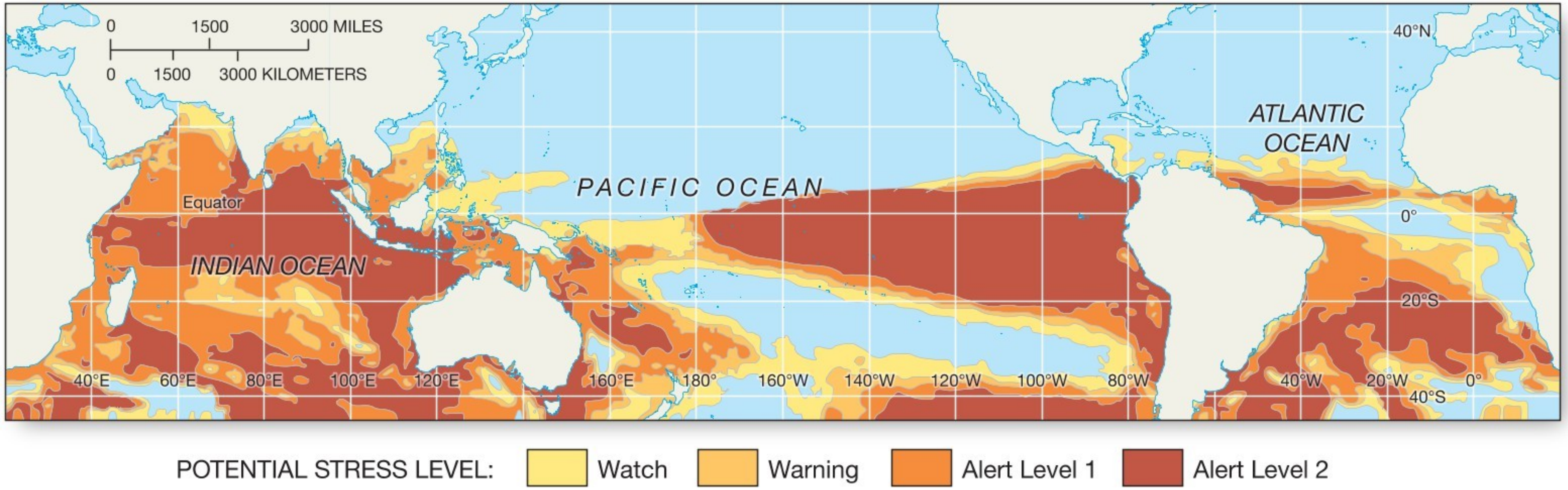


Figure 13.25

Thresholds and Tipping Points