LESSON 8

MEADOWS AND DESERTS OF THE SEA

On the Elusive Concept of Ocean Productivity

1 The problem of sustainable yield
2 Food for fish: primary production
3 Mapping primary production
4 The production machine
5 The great nutrient cycles
6 Food chains and food webs
7 Archetypes of zooplankton

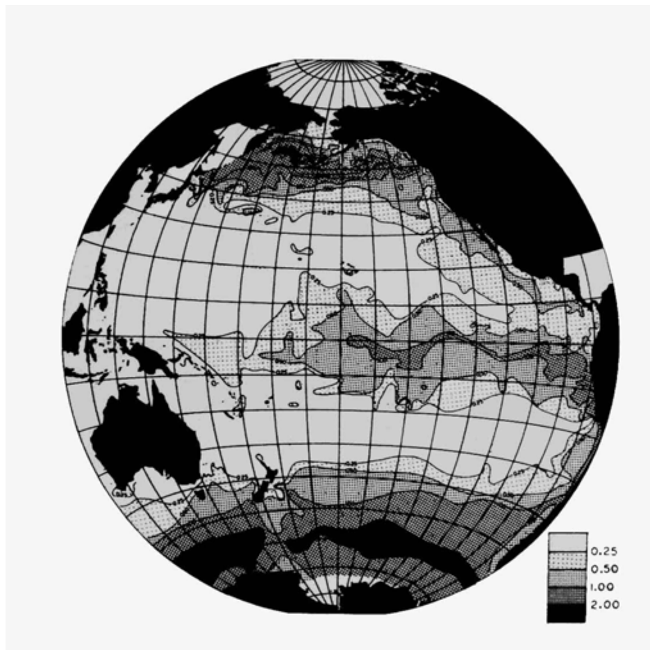

Fig. 8.01. Phosphate concentrations below surface waters in the Pacific, according to J. L. Reid (1962). Nitrate shows similar patterns. Abundant nutrients make for meadows in the sea.

Production varies widely in the sea; it is largely controlled by nutrient supply and the availability of sunlight.

The crucially important nutrients are phosphate (Fig. 8.01) and nitrate (which has a distribution similar to that of phosphate), as well as silicate (which tends to follow the same distribution patterns but with important exceptions). Silicate is the nutrient that allows diatoms to make shells of glass. Diatoms are an important group of primary producers sometimes referred to as "grass of the sea." Primary production in the sea is carried out both by photosynthetic bacteria and microscopic algae, including diatoms and dinoflagellates. It is measured in terms of grams of carbon fixed per square meter per year (or per day). Typical values are around 100 production units (grams of carbon per year, gC/yr); somewhat lower than the equivalent photosynthetic fixation on land.

The central questions of interest are the controls on production – largely the supply of nutrients wherever sunlight is adequate – and the manner of transfer of the matter generated in primary production into fish and consumers at the end of the food chain (*apex consumers*), including seabirds, whales and other marine mammals, and prominently people. This dual focus informs the discussions about the amount of food available for apex consumers in the context of fishery resources. One major topic concerns the amount of carbon fixed each year per unit area, by chlorophyll-bearing organisms. An early global estimate of this production is by R. H. Fleming (the third author of the *Oceans* text) (1). His map nicely shows the major features of the productivity of the sea (Fig. 8.02). The other topic centers on the food chain. The “length of the food chain,” as emphasized in the 1960s by Woods Hole oceanographer John Ryther, turned out to be the most significant element of this concept (2).

The ocean’s productivity is nothing like the one on land, where trees, brush and grass dominate. The fact is, the green primary producers in the sea, on the whole, are microscopically small and are unavailable for consumption by large animals. Only small creatures can eat the tiny algae. In turn these small organisms feed small zooplankton and fishes, which serve as food for the larger animals that are of interest to fisheries. In other words, it takes several steps in the “food chain” till we come to the apex consumers. At each step, typically, only 10 to 20% of the matter at the lower step is transferred to the next higher level. After two such transfers, a few percent of the original primary production is left to feed the apex consumer. After four transfers, less than one thousandth is left.

In the deserts of the sea – the central gyres and other warm-water regions – the chain is long. This is why the desert, in spite of having millions of green microbes in each liter of water, does not support large animals. In contrast, regions of deep mixing and upwelling, where the microbial algae are relatively large and food chains are much shorter therefore, support abundant marine mammals and seabirds, and fisheries. The question that moves to the foreground, then, is what controls the length of food chains. The answer holds the key to understanding the productivity patterns that matter to apex consumers. In the same manner, when asking how global warming will affect the productivity of the sea, we must ask how the warming of the planet affects the length of the food chain.

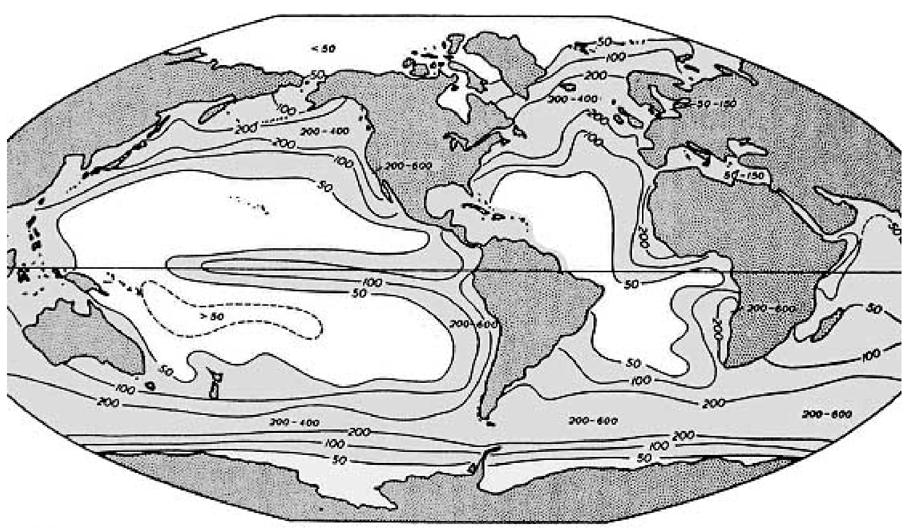

Fig. 8.02. Primary production of the ocean in grams of carbon per square meter per year, according to R.H. Fleming (1957). The central deserts are shown in white.

To anticipate the answer: both the amount of nutrients and the particular mixture that is locally available to support primary production help determine the length of the food chain. Specifically, a high supply of silicate shortens the food chain.

Notes and references

1. R.H. Fleming, 1957. *General features of the ocean*. In:J.W.Hedgpeth (ed.) *Treatise on Marine Ecology and Paleoecology.* Geological Society of America Memoir v.67, p.87-107.

2. J. H. Ryther, 1969. *Photosynthesis and fish production in the sea.* Science 166, 72-76. Ryther was at Woods Hole from 1951 to 1981.

Images

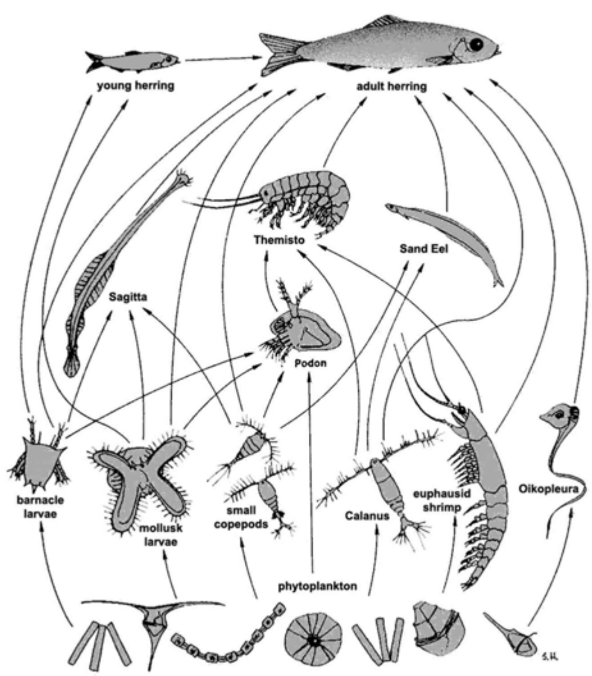

Fig. 8.03. The food web supporting herring, according to Hardy (1924).

Fig. 8.04. Atlantic cod, victim of the tradedy of the commons.

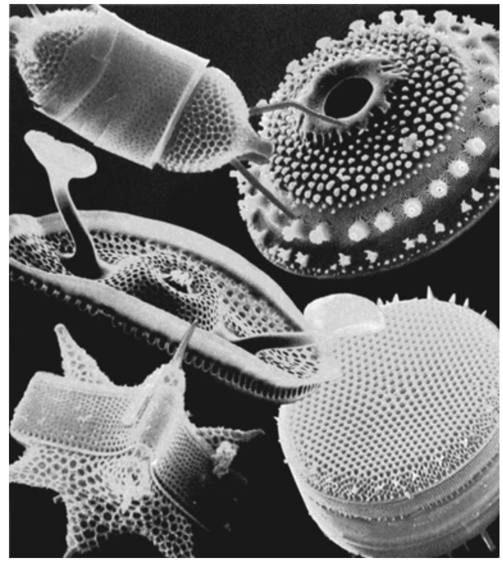

Fig. 8.05. Diatoms, grass of the sea.

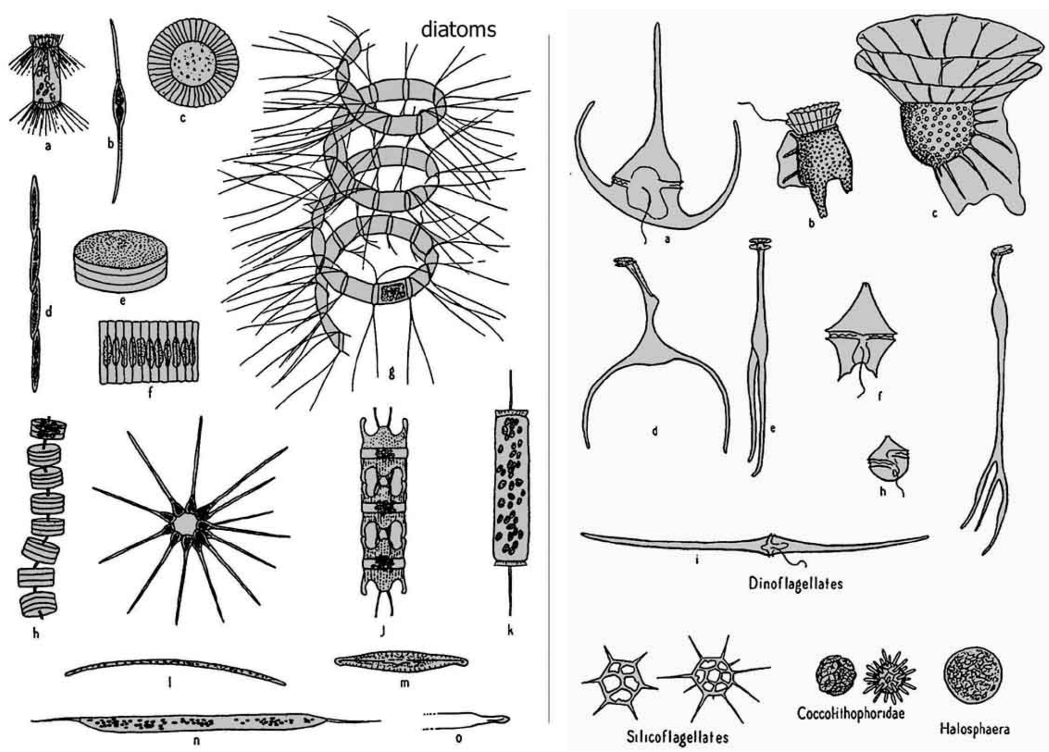

Fig. 8.06. At the base of the food chain in high-production regions: diatoms (left) and dinoflagellates (right), as presented in Sverdrup et al. (1942). *Chaetoceros*, a common form making bristly chains in upwelling regions, is marked "g."

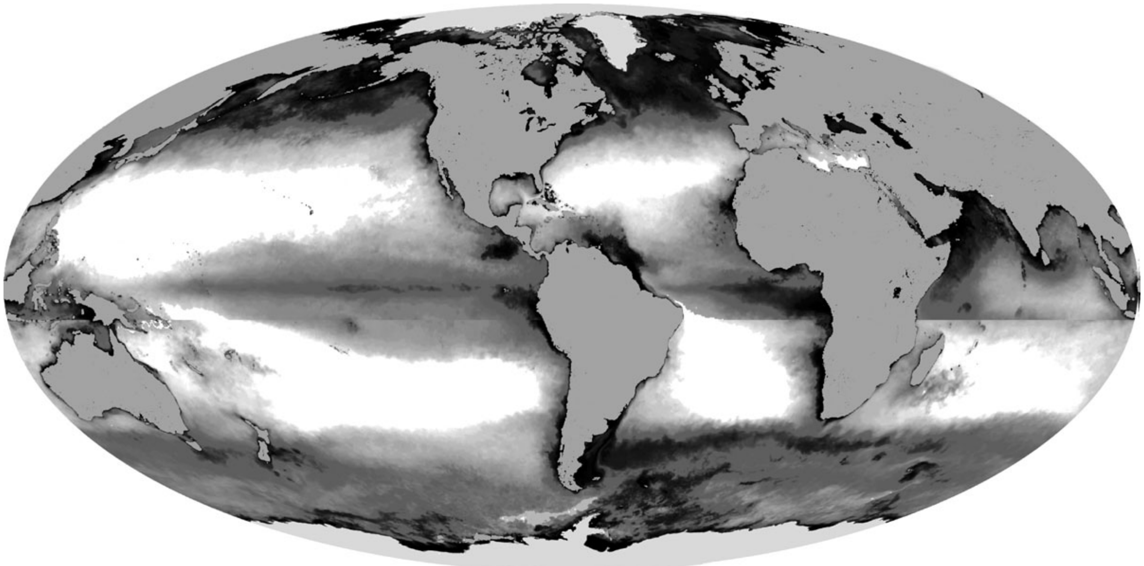

Fig. 8.07. A productivity map based on chlorophyll distribution as seen from satellites. Shown is the annual maximum. Darker regions have the higher productivity; the ocean deserts are shown white.

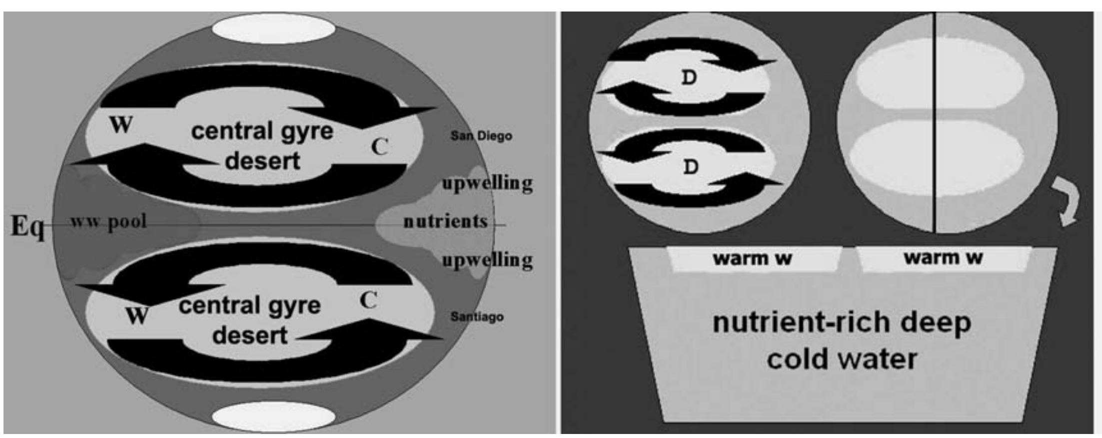

Fig. 8.08. Schematic representation of high- and low-production regions in the Pacific basin (left) and a vertical profile (right) showing the contrast between nutrient-poor warm-water lenses and nutrient-rich deep waters.

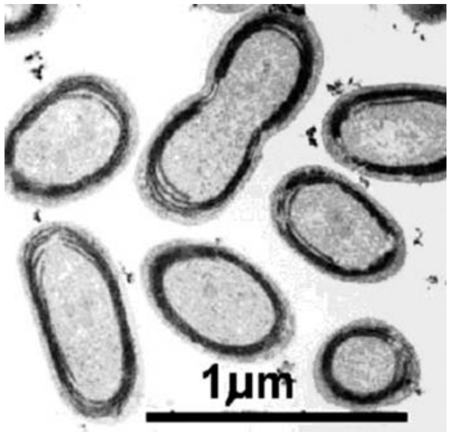

Fig. 8.09. The photosynthesizing bacterium *Prochlorococcus.*

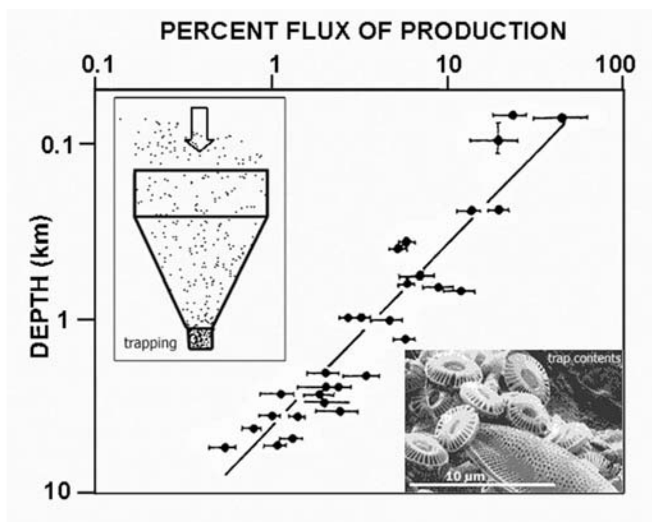

Fig. 8.10. Export production: food for benthic animals. The supply decreases markedly with depth. Data points represent amount of organic matter found in traps, as percent of overlying production, according to E. Suess, Kiel. Insets: principle of a trap, and contents (coccoliths, diatom) of a trap set out off Santa Barbara, California. Notice the logarithmic x- and y-scales.

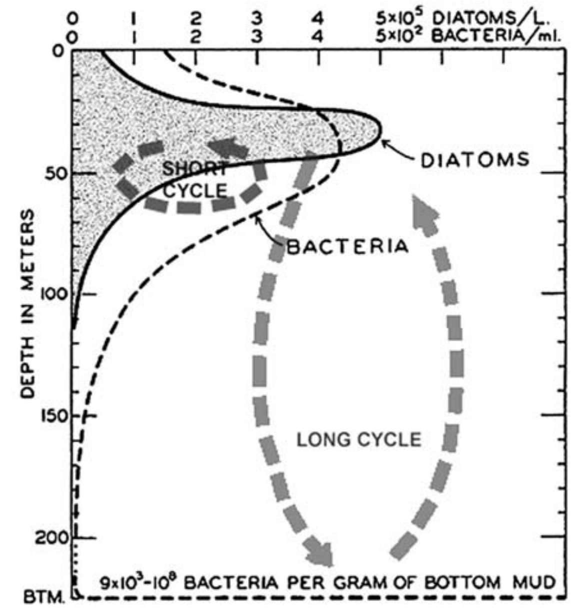

Fig. 8.11. Nutrient cycles in the sea run between photosynthesis in the sunlit layer to the bacteria in the water and in the bottom mud. The bacteria cause decay, liberating nutrients for renewed production. The illustration is in Sverdrup et al. (1942); cycles here added.

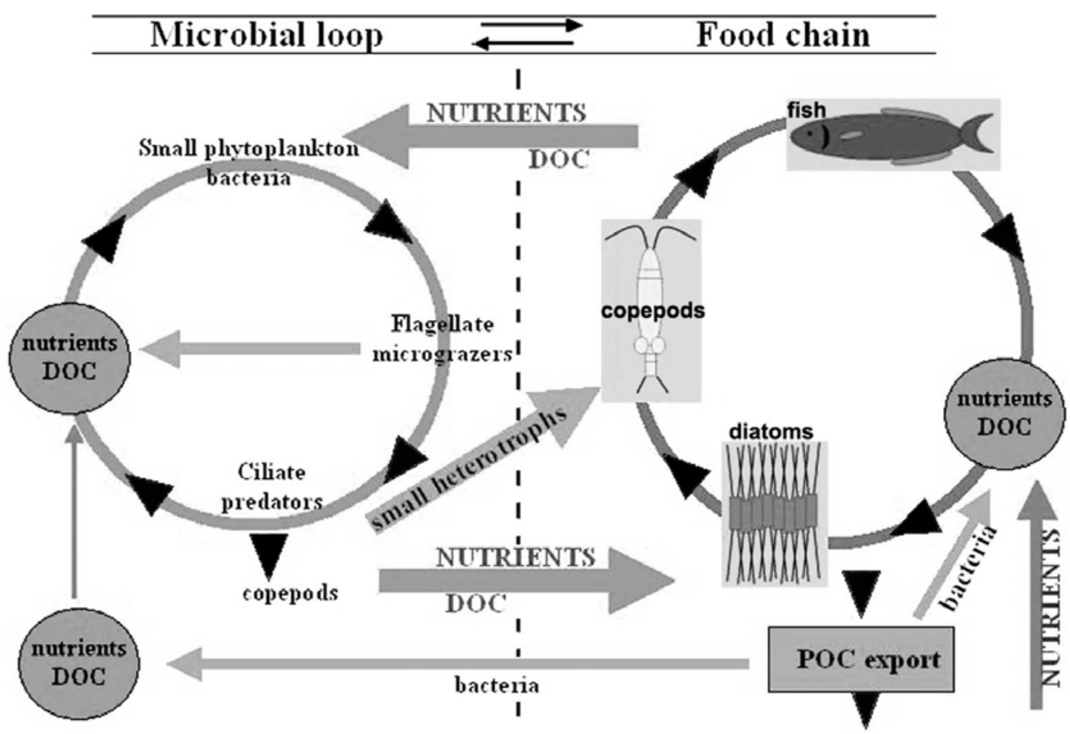

Fig. 8.12. Relationship between the traditional food chain (diatoms – copepods – fish, on the right) to the microbial loop that dominates production in the sea over vast regions (left). DOC, dissolved organic carbon; POC, particulate organic carbon.

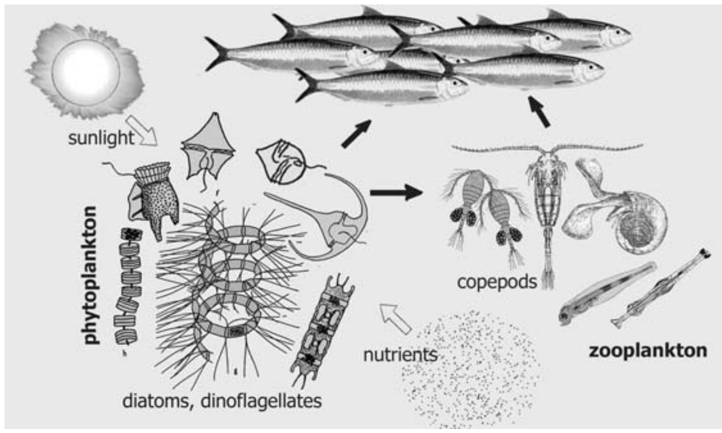

Fig. 8.13. The short food chain supports fish.

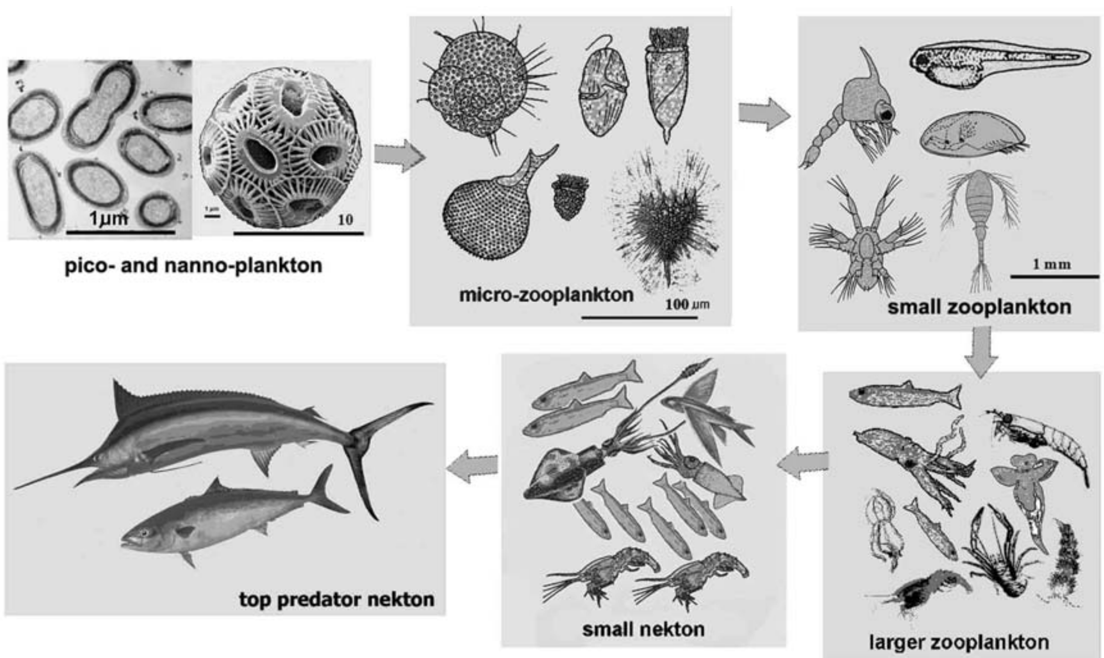

Fig. 8.14. The long food chain, beginning with pico- and nanno-plankton, has many steps and yields little in terms of fish. “Small zooplankton” measured in mm, “large zooplankton” in cm.

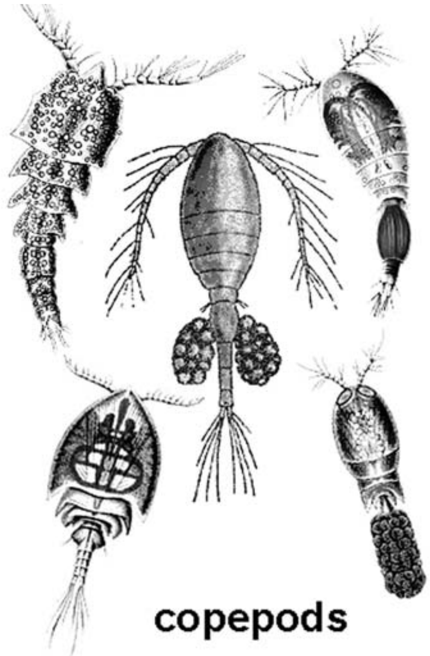

Fig. 8.15. Copepods, as drawn in Sverdrup et al. (center) and by E. Haeckel (all others).

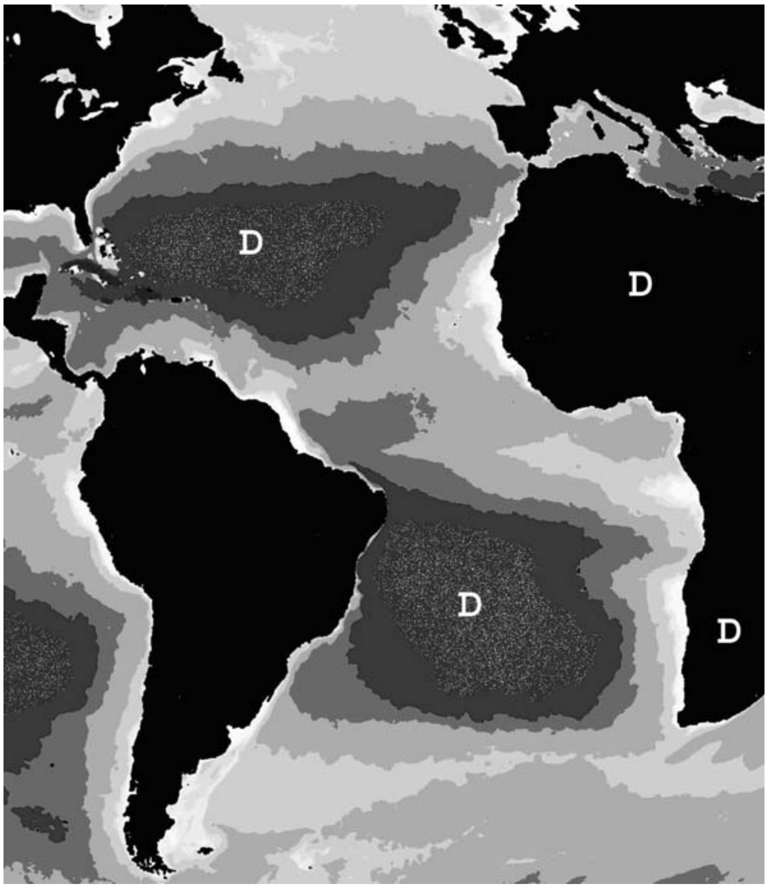

Fig. 8.16. Desert regions in the sea and on land (marked “D”). In the sea, a warm water layer hinders upward mixing of nutrients into the sunlit zone. On land, lack of water makes deserts. Image based on NASA satellite data.

Figure sources (where based on sources in the literature, on the web or in museum exhibits: figures are considerably modified and adapted for present purposes, using Adobe Photoshop; drawings and photographs by the author are marked “orig.”):
1, Reid 1962; 2, Fleming 1957; 3, Hardy 1924; 4, Aquarium Copenhagen (orig.); 5, SIO Explorations; 6, Sverdrup et al. 1942 (see Ch. 2 for reference); 7, SeaWIFS NASA; 8, orig.; 9, microphoto courtesy S.W. Chisholm, MIT; 10, E. Suess, 1980, and additions; 11, Sverdrup et al. 1942, and additions; 12, orig.; 13, orig., with drawings in Sverdrup et al. 1942, SIO Explorations, CalCOFI Atlas, and H. Murayama (see Ch. 1 for reference); 14, orig., with images from MIT, Geo Bremen, Sverdrup et al. 1942, E. Haeckel (see Ch. 1 for reference), L.A. Museum of Nat. Hist. (orig.), J. Sumich 1976, and others; 15, E. Haeckel and Sverdrup et al. 1942; 16, SeaWIFS NASA. **References**: J.L. Reid, 1962. *On the circulation, phosphate-phosphorus content and zooplankton volumes in the upper part of the Pacific Ocean.* Limnology and Oceanography, 7, 287-306; R.H. Fleming, 1957. *General features of the ocean*. In: J.W.Hedgpeth (ed.) *Treatise on Marine Ecology and Paleoecology.* Geological Society of America Memoir v.67, p.87-107; A.C. Hardy cited in J.L. Sumich, 1976, *An Introduction to the Biology of Marine Life.* Wm. C. Brown, Dubuque (Iowa), 348pp.; E. Suess, 1980, *Particulate organic carbon flux in the oceans - surface productivity and oxygen utilization,* Nature, 288, 260-263; U.S. National Aeronautics and Space Administration.