ENVIRONMENTAL STUDIES 30
P.J. Richerson

LECTURES 16 AND 17. Ocean Systems - Continental Shelves and Pelagic Systems

I. Marine Hydro-climate and Production Processes

A. Ocean Circulation

1. Heat budgets and stratification in the sea

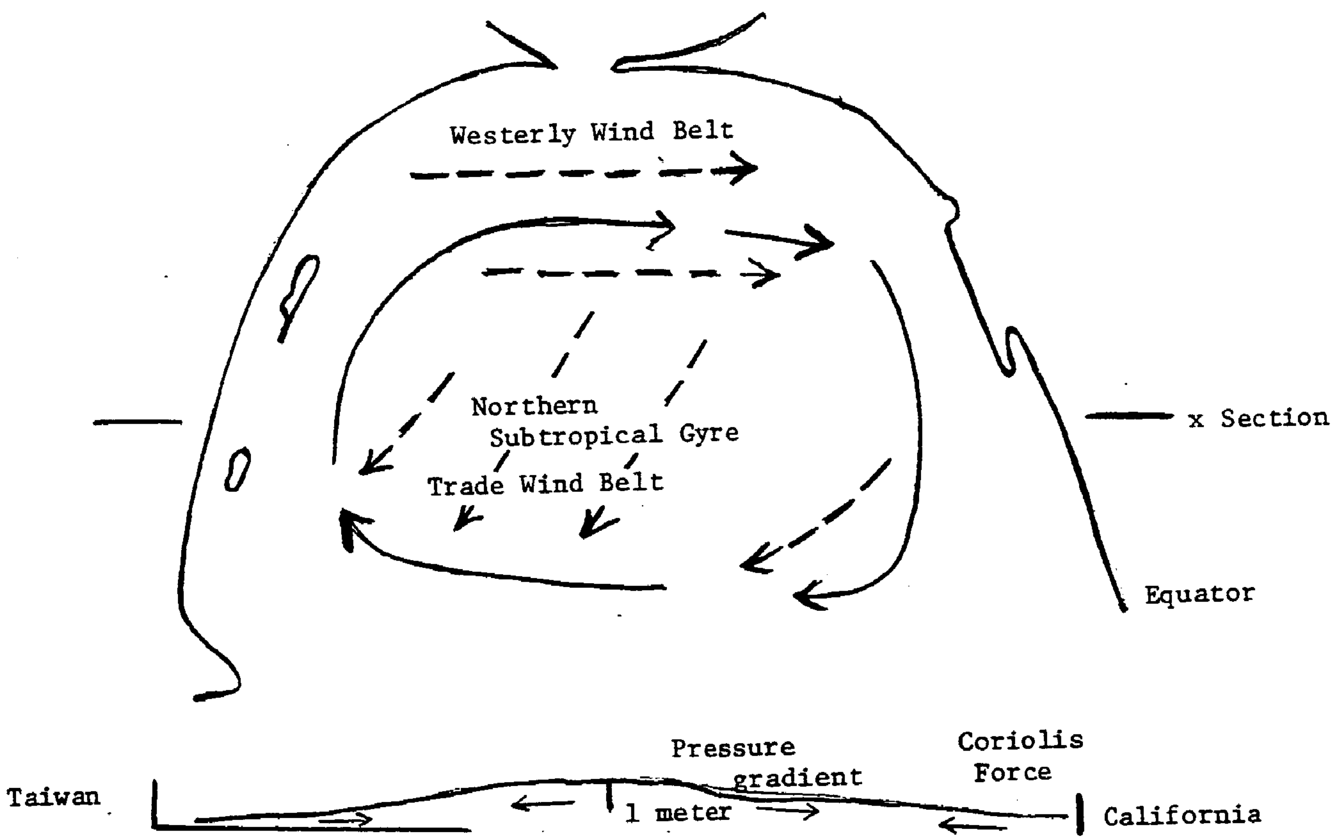
   a. Earth gains heat in the tropics, loses it near the poles.
   b. Tropical regions tend to have strongly stratified water columns (permanent thermoclines) while polar regions tend to be unstratified all the time.
   c. This pattern is augmented by the circulation pattern of the ocean.

2. Surface Currents

   a. The most active circulation of the oceans is in surface currents, currents above the permanent thermocline, driven by the wind (e.g. in the top 500-1000 m of the ocean).
   b. Acts as a horizontal heat engine to circulate heat poleward.
   c. Surface currents are <u>geostrophic</u>.

      (1) Coriolis force very important
      (2) wind driven current tends to the right of the wind in the northern hemisphere. Ocean currents actually flow parallel to sea surface contours.

Idealized North Pacific Ocean -- Figure 16.1



3. Abyssal Currents.

a. Deep water is formed by co:d water in polar regions and flows slowly equator-ward at depth.

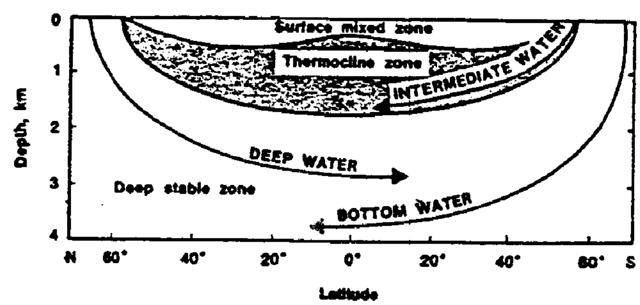


Figure 16.2

b. Deep currents form the source of cold water that keeps the tropics strongly, permanently stratified.

4. Upwelling circulations.

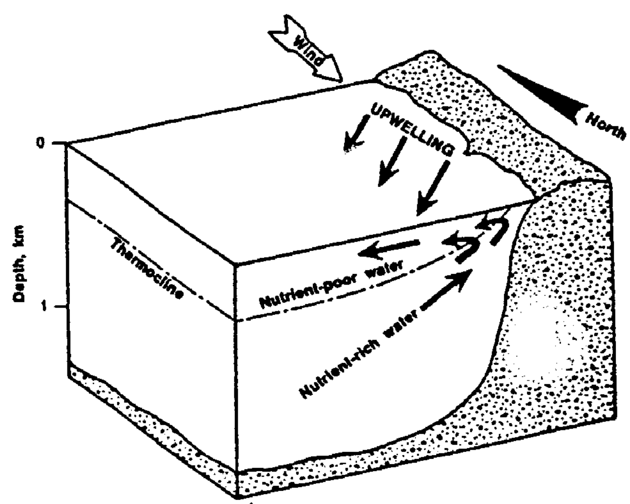


Figure 16.3

a. Boundary currents accelerate when the wind speed increases, and try to climb up to the right to restore geostrophic flow. They are then replaced close to shore by upwelled water.

b. Upwelled water warms, and doesn't sink again when the wind relaxes but mixes with the surrounding coastal water.

5. Currents and Stratification: Very strong currents can erode stratification by creating enough turbulence to destroy thermoclines, or greatly weaken them. Examples include the strong equatorial currents in the Eastern Pacific and the tidal currents of shallow seas like the North Sea or the upper Gulf of California.

B. Ocean Ecosystem processes

1. Deep water has a vast reservoir of nutrients

Figure 16.4 (from slide in lecture)

2. This reservoir is only available where mixing is high.

Figure 16.5 (from slide in lecture)

a. Upwelling zones
b. Coastal areas (recycling from the bottom, and more mixing).
c. High latitudes

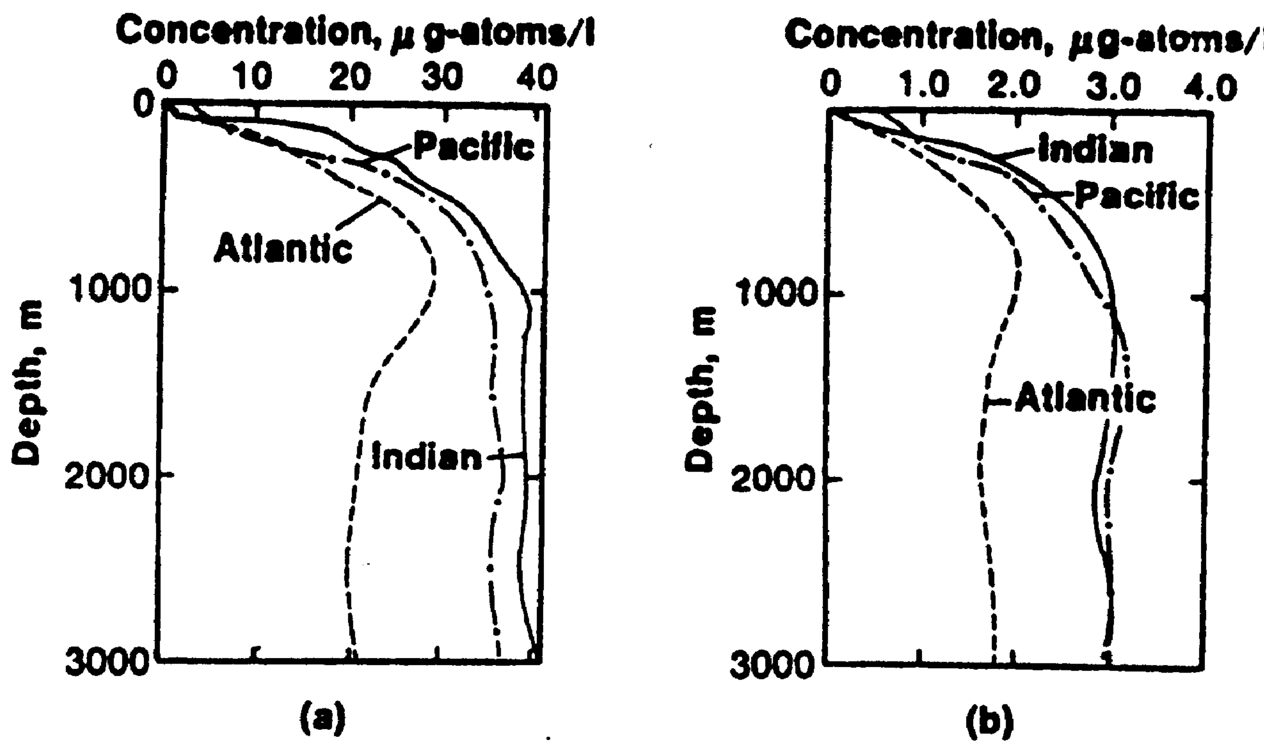
3. Fisheries potential of the sea:

a. Table:

	Metric Tons of Primary Production (Fresh Weight)	Trophic Levels % eff.	Ton Fish
Oceanic Province	16.3×10^{10}	610	16×10^{5}
Coastal	3.6×10^{10}	415	12×10^{7}
Upwelling	0.1×10^{10}	2.520	12×10^{7}
			240 (Millionmetric tons)

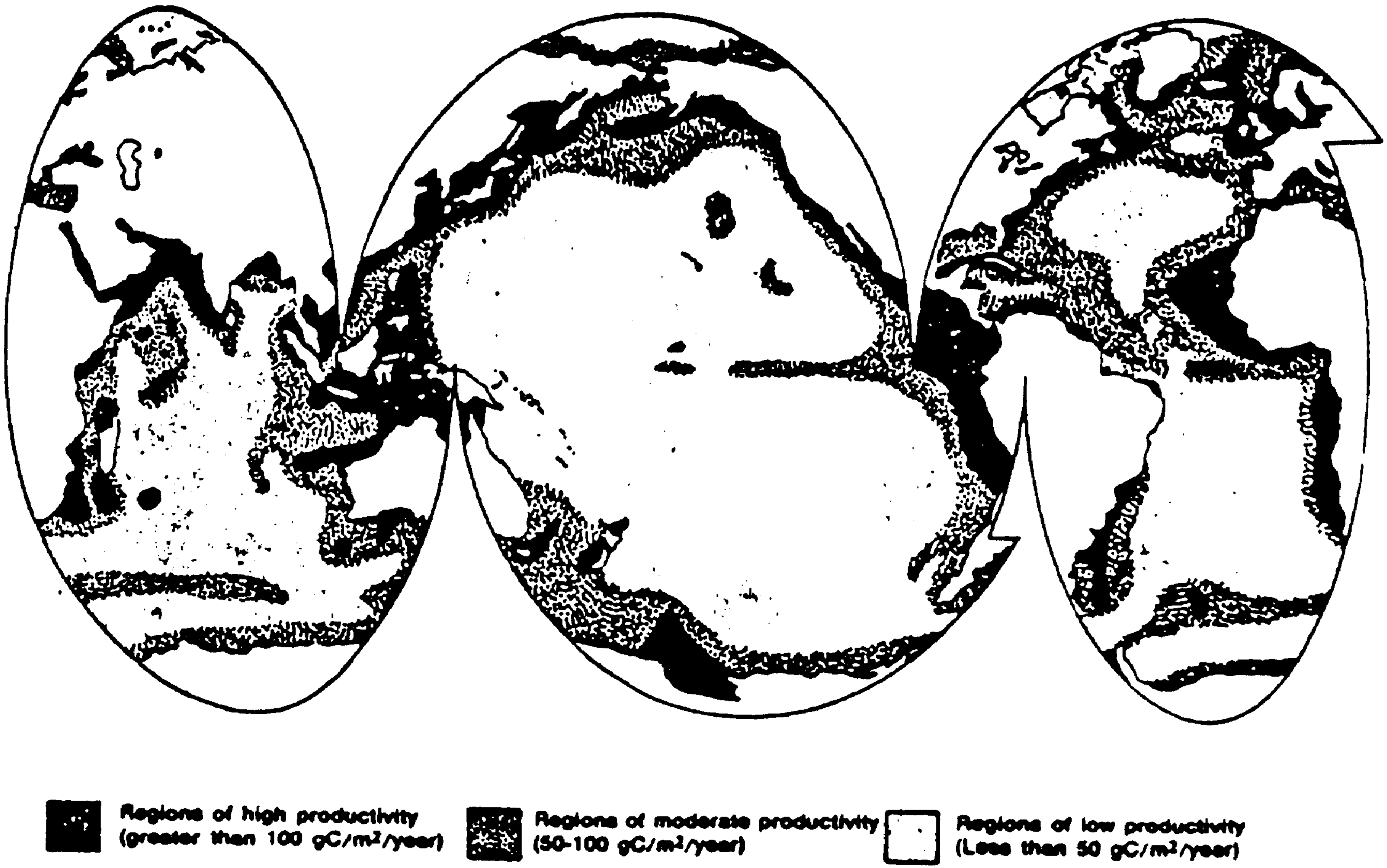
b. Less than 50% of the production can be captured, say 100 MMT
c. The world's present catch is about 70 MMT, many over exploited stocks, the most valuable species.

Figure 16.4



Distribution of nitrate (a) and phosphate (b) with depth in the three major ocean basins. From H. U. Sverdrup, Martin W. Johnson, and Richard H. Fleming, THE OCEANS: *Their Physics, Chemistry, and General Biology*. © 1942, renewed 1970. By permission of Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

FIGURE 16.5



Regions of high productivity (greater than 100 $gC/m^2/year$)
Regions of moderate productivity (50-100 $gC/m^2/year$)
Regions of low productivity (Less than 50 $gC/m^2/year$)

. Growth of the world human population and of global fish catches, 1950–73. From FAO catch and landing statistics.

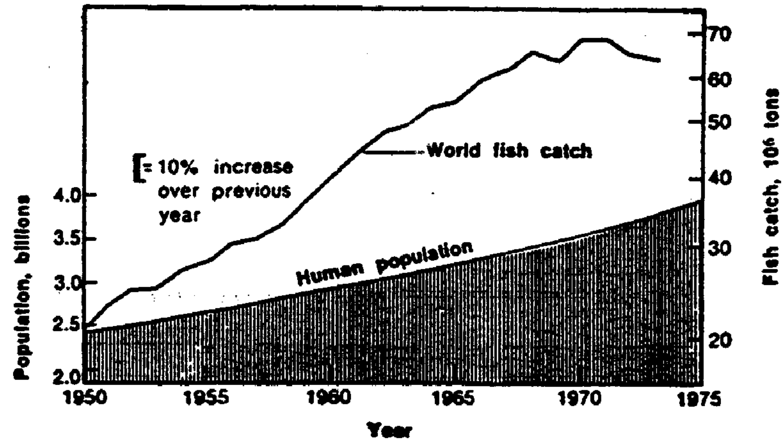


Figure 16.6

d. Any big increase in fish production will require harvest lower on the food chain, e.g. Antarctic krill instead of whales.

II. Littoral Habitats

A. Intertidal Zone

1. Very strong zonation as a result of strong physical gradients (see **Figure 16.7** [from slide ...

2. Richest intertidal zones in warm temperate areas with cool summers and mild winters (e.g. California Intertidal organisms are very prone to overheating in the tropics or freezing at higher latitudes during low tide.

3. Some resources especially shellfish on muddy bottoms. Important area for scientific research becaus is compact and exposed for experimentation.

4. High energy, wel ixed environment. Nutrients well renewed. Many <u>suspension feeders</u>, such as barnacles, mussels, and anemones, filter plankton from the water. Extreme mixing is a general feature of littoral environments due to wave surge, tidal currents, and bottom friction. The dangers are great cal damage, burying in sedimen ut the constant renewal of plankton and minera ts usually makes them very pr ctive.

B. Coral Reefs (see **Figure 16.8** for gen structure).

1. Reef forming corals are restricted to the tropics, especially the west sides of oceans where currents are warm. The reason is that warm temperatures drive CO_2 gas from solution and make the deposition of the $CaCO_3$ of coral skeletons easier.

2. Coral reefs grow mostly on subsiding platforms and have had to reform to keep up with sea-level rises since the Pleistocene. They also require quite clear water to grow, since the main energy requirement is met by symbiotic algae, not of the corals themselves. A deep littoral zone is a requirement. (This was Darwin's theory based on his observations of the <u>Beagle</u> voyage. Long controversial, it has recent been confirmed by borings into the center of atolls.)

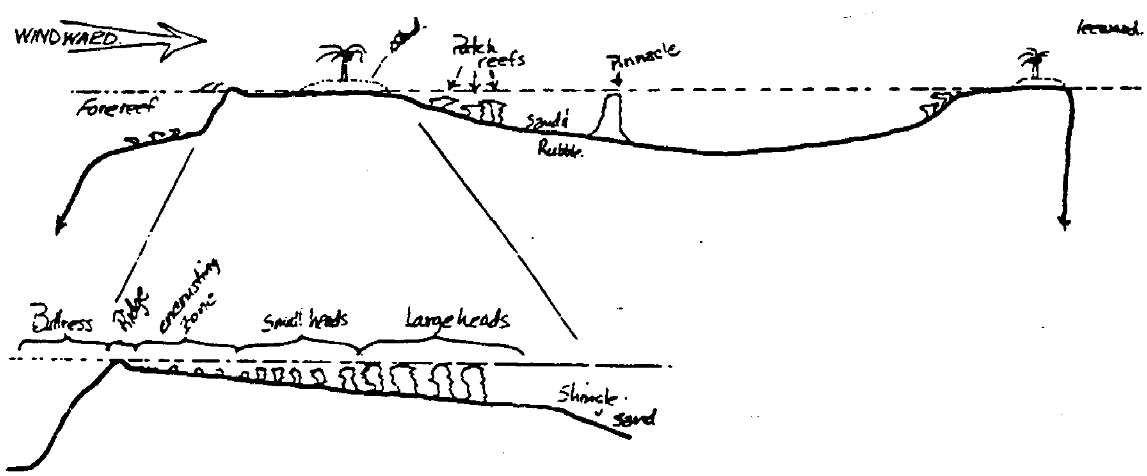
3. Although coral reefs must grow in low-product , oceans, they are themselves quite productive. The reason seems to be that reefs recycle nutrients very effectively, much like the tropical forest. The close association of the primary producers with their hosts conserves excreted nutrients. The reef organisms collect the sparse plankton from the surrounding sea, but relatively few nutrient-laden particles leak off the reef.

4. Coral reefs are noted, like the tropical forests, for their extremely high biotic diversity.

C. **Macrophytic Communities.** Some littoral zones have areas dominated by macrophytic algae (e.g. kelps) or higher plants (e.g. turtlegrass or eelgrass) just beyond the intertidal zone. Again, because turbulence is high and the water surrounding these communities is constantly renewed, they tend to be fairly productive. Suspension feeding animals trap and recycle nutrients in close proximity to the plants as well.

Figure 16.7 (from slide in lecture)

Figure on Coral Reef



III. Coastal Habitats

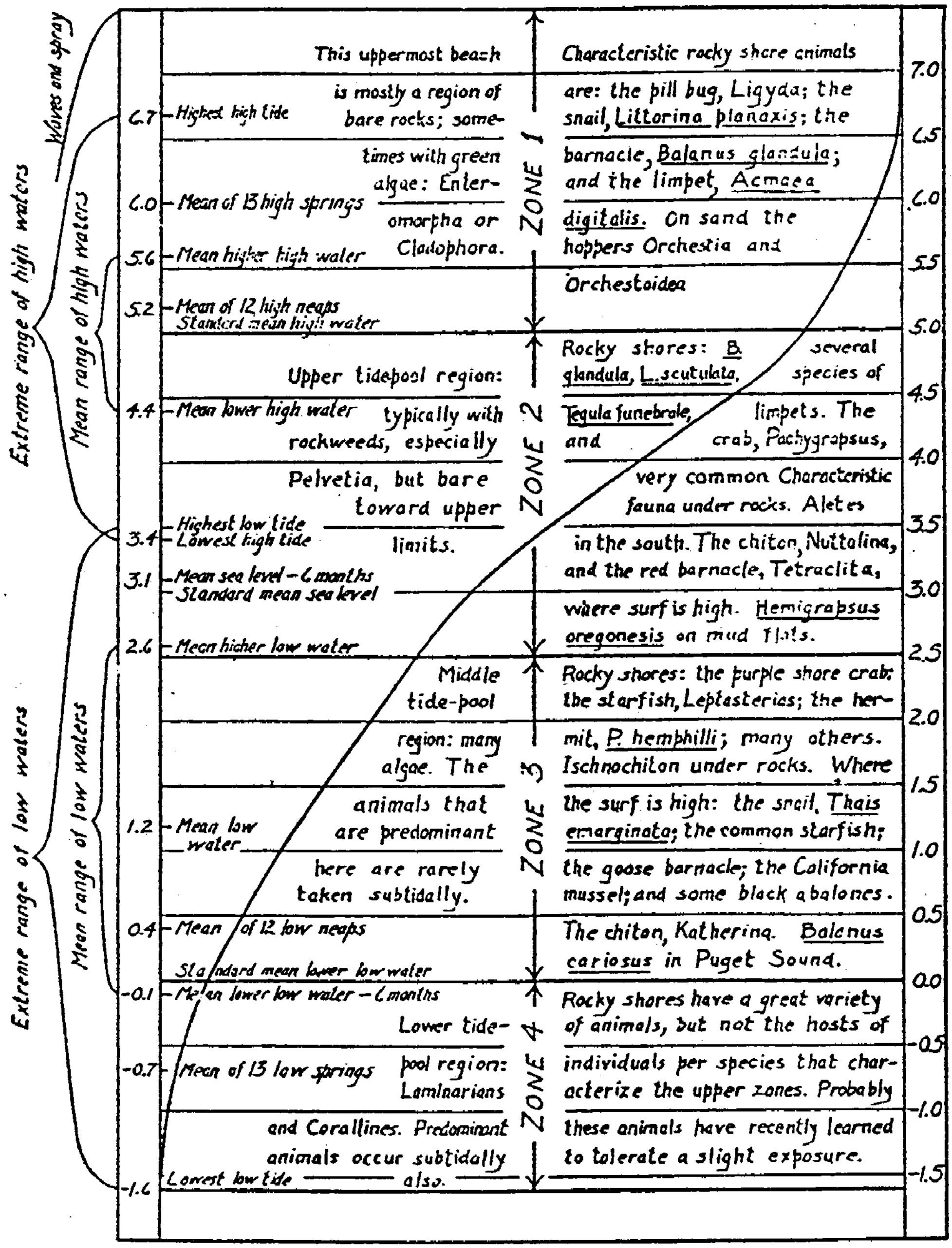
A. Plankton and Nekton

1. **Phytoplankton.** The primary producers of the ocean, except for the littoral fringe and odd exceptions like sargassum weed, are microscopic algae. Two groups dominate:

   a. **Diatoms** - single-celled or colonial algae with silicious (glass) shells, fitting like a pillbox.
   b. **Dinoflagellates** - usually solitary algae with a cellulose wall and two flagella, one of which is transverse and spins the cell.

Many other groups contribute to the plankton, bluegreen algae, silica-flagellates, coccolithophones, etc. The size and shapes of the algae vary enormously, from 2-3 microns to 100 or more. Generally, small species dominate in low productivity areas and large ones in high productivity ones. The usual explanation is that small phytoplankton have a greater surface/volume ratio, which is an advantage when nutrients are scarce. Large species also sink more quickly if they lack flagella, something that can be tolerated only if growth rates are high.

FIGURE 16.7: This is the zonation scheme of Ed Ricketts, the marine biologist friend of John Steinbeck who inspired the Doc character in the Cannery Row books.



-A diagram to illustrate the vertical zoning of animals according to relative lengths of exposure to air and water. The height figures apply to Crissy Wharf in San Francisco Bay, but the relative heights and the character of the exposure curve are the same for any point on the open Pacific coast. The data shown at the left-hand margin and the data from which the curve is drawn are from tide predictions and recordings for a six-months period.

2.**Zooplankton** - The smaller animals of the plankton are a very diverse and heterogeneous group, ranging from protozoa to fish larvae. They form a complex food web in the open ocean, but a rather shorter one in the more productive coastal oceans. Four basic "life styles" can be distinguished:

a. **Migratory zooplankton**. These animals, predominately crustaceans, graze in the euphotic zone at night, and retreat to the darker depths during the day. This is most likely an anti-predator adaptation, although several other explanations have been proposed.

b. **Non-migratory plankton**. Mostly jellyfish, and their relatives, tunicates, and some very highly modified snails. These animals are usually virtually transparent, probably in order to escape predation, which also presumably frees them of the need to migrate. They are often good sized animals. Many are mucous net feeders. They either spin mucous nets or have mucous covered bodies that entangle small plant and animals that are subsequently consumed.

c. **Surface dwellers**. This groups has few species but is quite interesting. It includes the Portuguese Man-of-War and the purple sail (colonial relatives of jellyfish) and a snail that preys on the purple sail. The snail floats from one purple sail to another on a raft of bubbles it blows. It also includes a water-skater, Halobates, one of the very few marine insects.

d. **Deep living plankton** - usually large, red- colored crustaceans. These live entirely in the dark and do not undergo migrations.

Many animals in the plankton do not spend their whole life there, but are the dispersal stages of benthic or littoral invertebrates. A large fraction of these more sedentary animals have such larvae. A few animals, like the jellyfish, have benthic larvae, but planktonic adults.

An account of even the higher-level taxonomy of the plankton is a bit long for our purposes. Some common and representative groups include:

Foraminifera - shelled amoeba, which are major contributors of calcareous material to the ocean. They are very important for geological dating and paleoclimatological studies. Their shell look like miniature chambered nautilus.

Siphonophores - colonial relatives of the jellyfish. These rather large animals are important components of the gelatinous, transparent non-migratory plankton.

Heteropods and Pteropods - very highly modified snails. Heteropods are fish-shaped whereas pteropods swim with wing-like modifications of their feet. These two are representative of many invertebrate classes that contribute a few bizarrely modified species to the plankton.

Copepods and euphausids - These two groups of crustaceans are the ungulates of the plankton. In most situations they make up the dominant part of the herbivore biomass. The copepod group is particularly diverse, and includes many carnivores as well.

Planktonic tunicates - These are primitive relatives of the vertebrates, and many species are members of the non- migrating plankton. One kind secretes a house cum filter-feeding machine, while another is barrel-shaped and pumps water through itself, jet-engine fashion.

3. **Nekton** - The fish of open water habitats are dominated by slim, silvery, fast moving fish.

The smallest fish, such as sardines and anchovies, eat zooplankton and phytoplankton. Such fish often support very large fisheries, but in both the California and Peru upwelling regions they have been mysteriously inconsistent performers. To this day, no one has figured out why the Monterey sardines, made famous by John Steinbeck, disappeared. They were actually replaced by anchovies. There is some suspicion that there is an unpredictable flip- flop between anchovies and sardine in coastal California waters. Some biologists are (privately) predicting a comeback for sardines in the next couple of years.

The larger fish (and squids) are usually active predators of zooplankton or other fish. A great many of these fish are commercially valuable -- salmon, cod, mackerel, tuna, billfish, yellowtail, bonita. I've seen gill nets set in the Gulf of California for nektonic species, in which every fish caught was a nice food fish. Sharks are also common in the nekton, including the large predators like great white and hammerheads and the very large filter feeding basking sharks.

The marine mammals also play a large role in the nekton. The toothed whales (dolphins, killer whales, sperm whales) are predators on fish. The baleen whales (e.g. California grey, blue whales) are filter feeders on the large zooplankton like euphausids.

Marine birds (pelicans, frigate birds, cormorants, etc.) are major elements of the food chain, especially near land. Their guano is an important source of fertilizer in dry areas like Peru, where there is no rain to wash away the droppings.

The management of fisheries is a perennial problem. Valuable stocks, particularly coastal ones, are liable to over-fishing. The resource is a common property one and if entry is unrestricted, the early successful fishermen attract a host of imitators who buy boats, flood the market and over exploit the stock. Once the big investment in boats is made, the fishermen are very reluctant to limit fishing because they may go broke. Fisheries management is also complicated because biologists generally do not understand the population biology of the stocks very well.

B. Benthos

Benthic communities are very strongly controlled by substrate. Hard rocky substrates favor attached (sessile) suspension feeders. Quiet, muddy bottoms are usually dominated by <u>deposit</u> feeders, burrowing animals that process sediment the way an earthworm processes dirt. Deposit feeders include many marine worms, some clams and snails, and some kinds of sea urchins. In between these extremes, a great range of habitats occur. The most important series of benthic habitats are the soft-bottom communities, since most of the ocean bottom is soft. In areas with strong currents, the bottom is mostly sandy, and very mobile, not unlike sandy dunes on land. Such habitats are difficult places to live because animals are liable to be buried, and because the current winnows out all the organic material. Strong, rapidly digging suspension feeders like pismo clams dominate the fauna. Low energy environments favor fine-grained sediments with a mixture of deposit and suspension feeders. A collection of predators and scavengers live in both kinds of soft bottom habitats.

Benthic fishes are much more diverse in body form than are nektonic fish. The fish associated with hard bottoms are often chunky (see bass, rock cod) or laterally flattened. A very characteristic form of lateral fattening is common in the fish of soft bottoms, as in the soles, flounders, halibuts and other flatfish.

The bottom fish and shellfish of coastal oceans support large fisheries.

IV. Open Ocean Habitats

A. Plankton and Nekton

The plankton and nekton of the open ocean are generally similar to those of the coastal ocean. The difference is the lower productivity of blue water habitats. Within the general groups, the open ocean species usually differ from coastal ones, and the open ocean food chains are longer and more complex. The diversity of the open ocean is generally greater, even though biomass is much lower.

Because the open ocean is so deep, a large series of sub- thermocline plankton-nekton communities are present. The most important of these are the migrating lantern-fishes (mictophids) that form the deep scattering layer (echo sounder reflective) in the open sea. These fishes migrate from perhaps 300-400 m near the surface at night. At greater depths, odder and odder species are found. Often these fish have luminescent organs of uncertain function.

B. **Benthos**

The benthos of the abyssal was quite poorly known until powerful dredges and serviceable underwater cameras became available after WW II. Now the deep-sea benthos is known to have quite high diversity, although population densities are low. Also, like the plankton, the communities of the deep sea are rather large in areal extent, so there are few communities. Most of the invertebrates of the deep sea benthos are not highly specialized in form. Brittle stars, snails, urchins, amphipods, and shrimp are among the forms represented. A few are very odd indeed like monoplacophorans, a sort of segmented snail that has figured in controversies over mollusc evolution. Many of the fish appear to be migrants from shallow water. Others are unique to the depths.

The deep-sea benthos exists on a mixture of fine detrital rain and large chunks of falling food matter. The relative importance of the two is unknown. The large chunks (fish bodies and the like) are only a small part of the material that starts down from the top of the thermocline, but it sinks quite rapidly and will likely arrive more or less intact. The smaller material sinks so slowly that it is likely to be largely metabolized before it reaches the bottom. Because of the logistical difficulty of working in this habitat, it is rather poorly understood.

Environmental Studies 30 Peter J. Richerson

Discussion Questions -- Ocean Systems

1. Ocean fisheries are very difficult to manage for optimum yield. What do you think are the main reasons for the problems?

2. The zooplankton of the sea conforms to the classical latitudinal diversity gradient. Tropical oceans are much richer in species than temperate or arctic ones. However, lakes are much less diverse and do not exhibit the latitudinal gradient. Phytoplankton diversities are much more comparable. Why might the rather similar communities of the two aquatic "biomes" have this confusing pattern?

3. Do you suppose that competitive exclusion plays any role in the complex zonation of the intertidal zone?