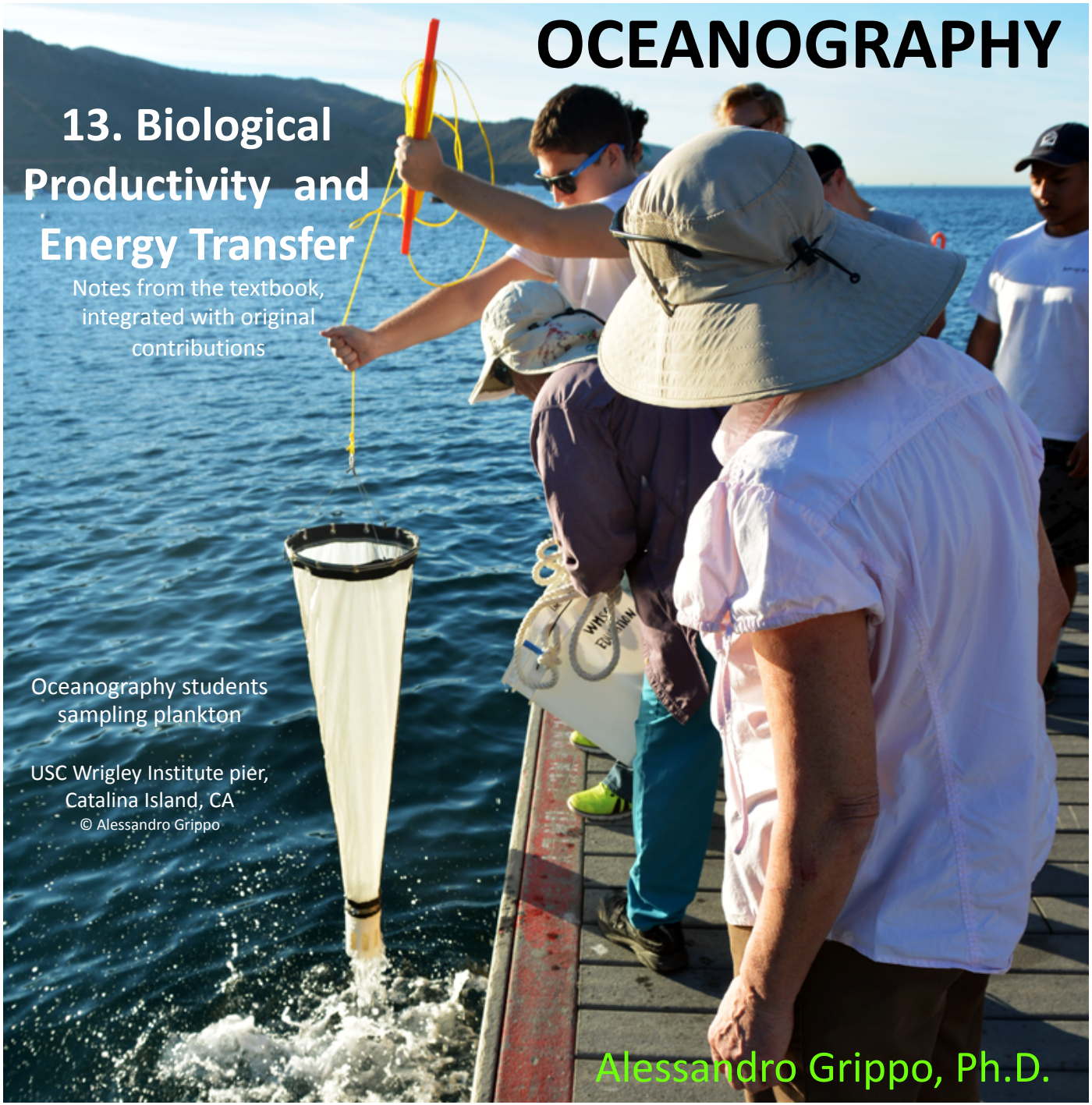
OCEANOGRAPHY

13. Biological Productivity and Energy Transfer

Notes from the textbook, integrated with original contributions



Oceanography students sampling plankton

USC Wrigley Institute pier, Catalina Island, CA

Alessandro Grippo, Ph.D.

introduction

- Biological productivity refers to storage of energy as organic matter by organisms
  - photosynthesis vs. chemosynthesis
- Oceanic photosynthetic producers include plants, algae, bacteria
  - Mostly *phytoplankton*
- Productivity changes with latitude and ocean depth
- Feeding relationships represented by food chains and food webs
- Oceans are being overfished

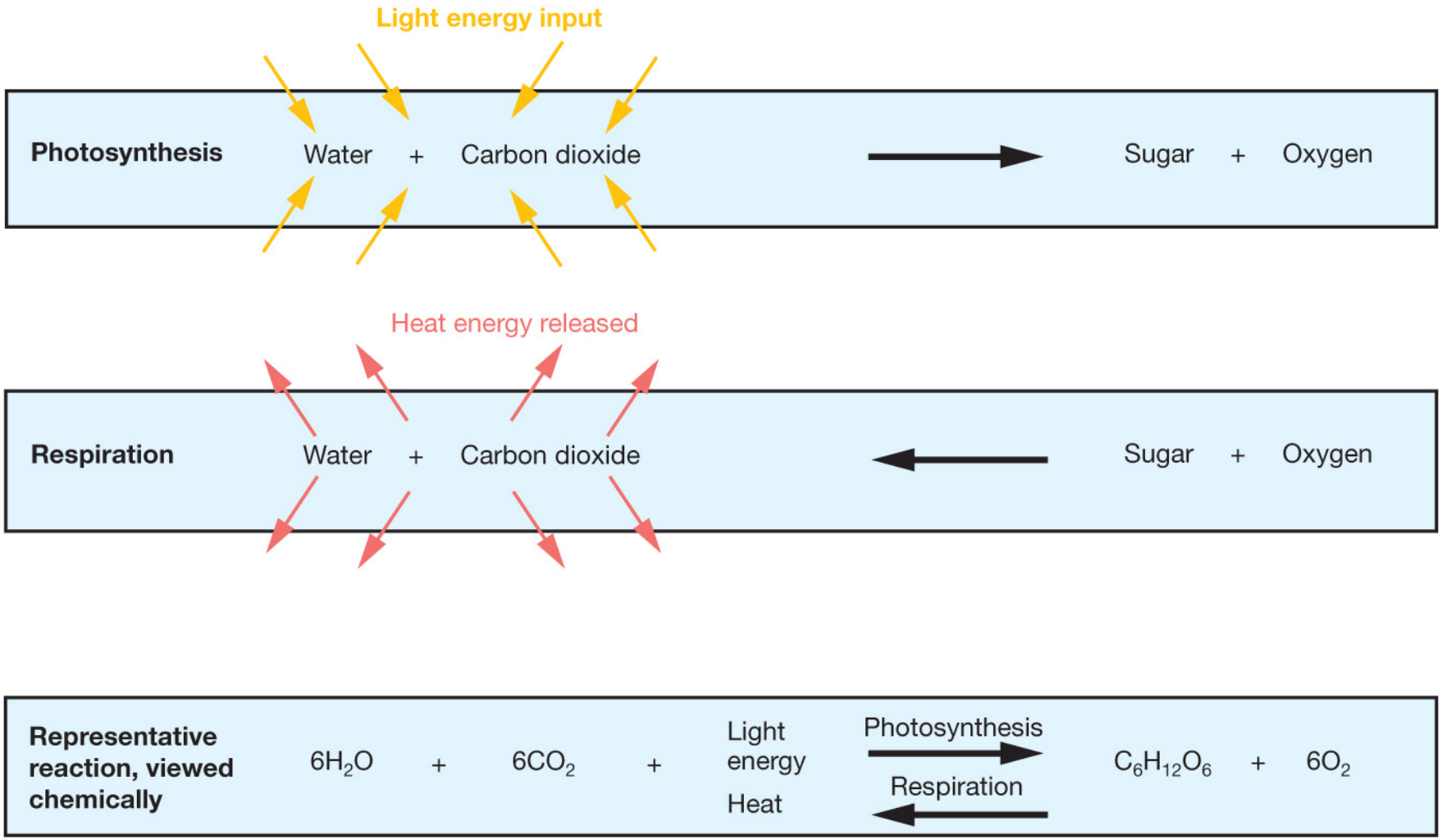
What is Primary Productivity?

- Primary productivity is the rate at which some living organisms store energy through the formation of organic matter, using energy derived from
  - The Sun (Photosynthesis)
  - Chemical reactions (Chemosynthesis)

- Other organisms consume this organic matter as food

- 99.9% of the ocean's biomass relies directly or indirectly only on photosynthesis for food

Photosynthesis



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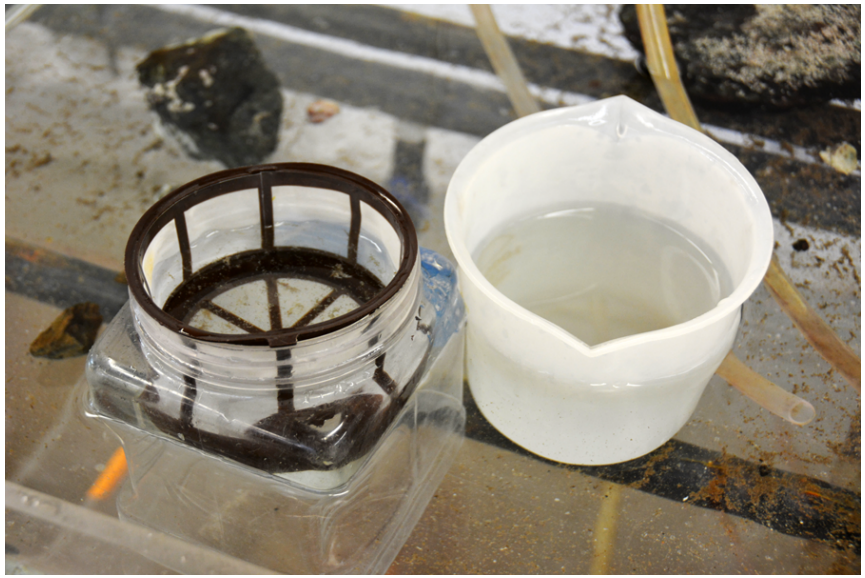
Measurement of Primary Productivity

- Directly, using cone-shaped plankton nets
- Lowering collecting bottles in the ocean
- Measuring the amount of ^{14}C in seawater
- Monitoring ocean color with satellites to determine the presence of chlorophyll
  - Chlorophyll is a green pigment used to capture energy from the Sun and perform photosynthesis
  - The color of ocean water is strongly affected by the amount of chlorophyll

The collected phytoplankton is poured from the phytoplankton net into a jar

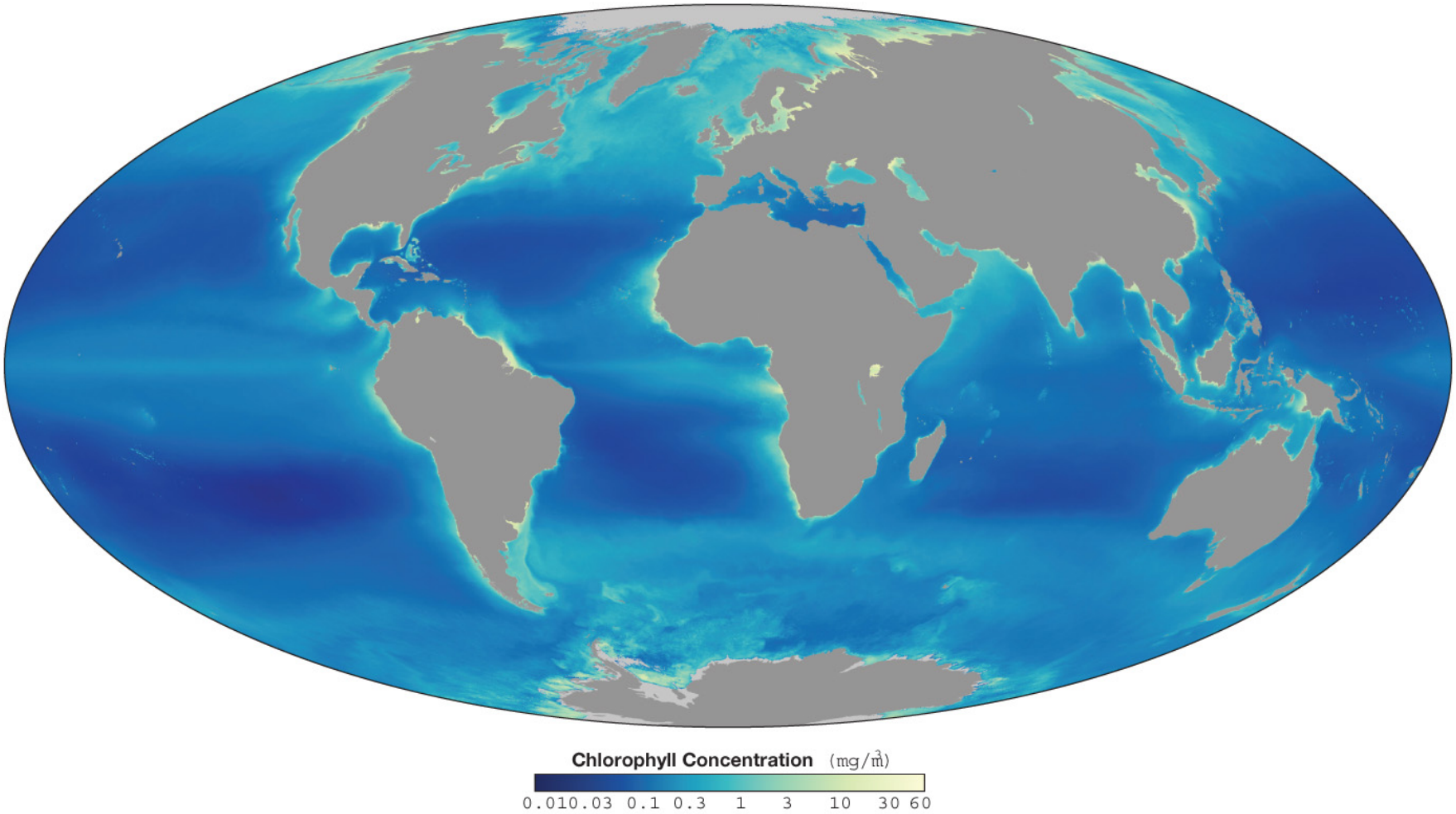


The water is then sampled in the lab and analyzed for both abundance and type of plankton

Notice the greenish color of the water and some visible macroorganisms

University of Southern California Wrigley Marine Institute, Catalina Island, Los Angeles county, California

Ocean Chlorophyll – SeaWiFS



An example of a world oceans color map from satellite, showing the relative chlorophyll concentration

Factors Affecting Primary Productivity

Two main factors:

- Availability of nutrients
  - Nitrogen, phosphorus, iron, silica, carbon, etc.
- Availability of solar radiation
  - Photosynthesis cannot proceed unless light energy (solar radiation) is available
    - The atmosphere is highly transparent, so land plants in general have plenty of light
    - Water is much less transparent than air, so the ocean remains mostly in the dark

nutrients

- Water runoff takes solid materials and dissolved ions to the ocean
- These ions act as nutrients for marine life
- Because continents are the major source of nutrients, the greatest concentrations of marine life are found along the continental margins
- Marine life, as a consequence, decreases with increasing distance from the coastline and with increasing depth in the water column (no light)

nutrients (continued)

- Lack of nitrogen (as nitrates) and phosphorus (as phosphate) can limit productivity
  - Nitrogen is recycled 10 times per year
  - Phosphorus is recycled every 4 years
- Carbon is always abundant in the ocean and does not limit productivity
- When these three are available, their relative ratios C:N:P in algal tissues are 106:16:1 (Redfield ratio)
- Iron can also severely limit productivity

solar radiation availability

- Solar energy can be *detected* to a maximum depth of 1000 m
- Even so, enough light to allow for photosynthesis only penetrates to a depth of 100 m (compensation depth for photosynthesis)
- The zone that extends from the surface to a 100 m is defined as the **euphotic zone**
- Photosynthesis in the ocean is therefore restricted to the uppermost water surface and those seafloor areas that are shallow enough for sunlight to penetrate
  - In coastal areas, due to turbidity or microscopic organisms abundance, the euphotic zone can be restricted to a depth of only 20 m

Nutrients and Solar Radiation

how they differ between open ocean and coastal areas?

- In the open ocean, far from continental margins, there is more transparency but there are fewer nutrients

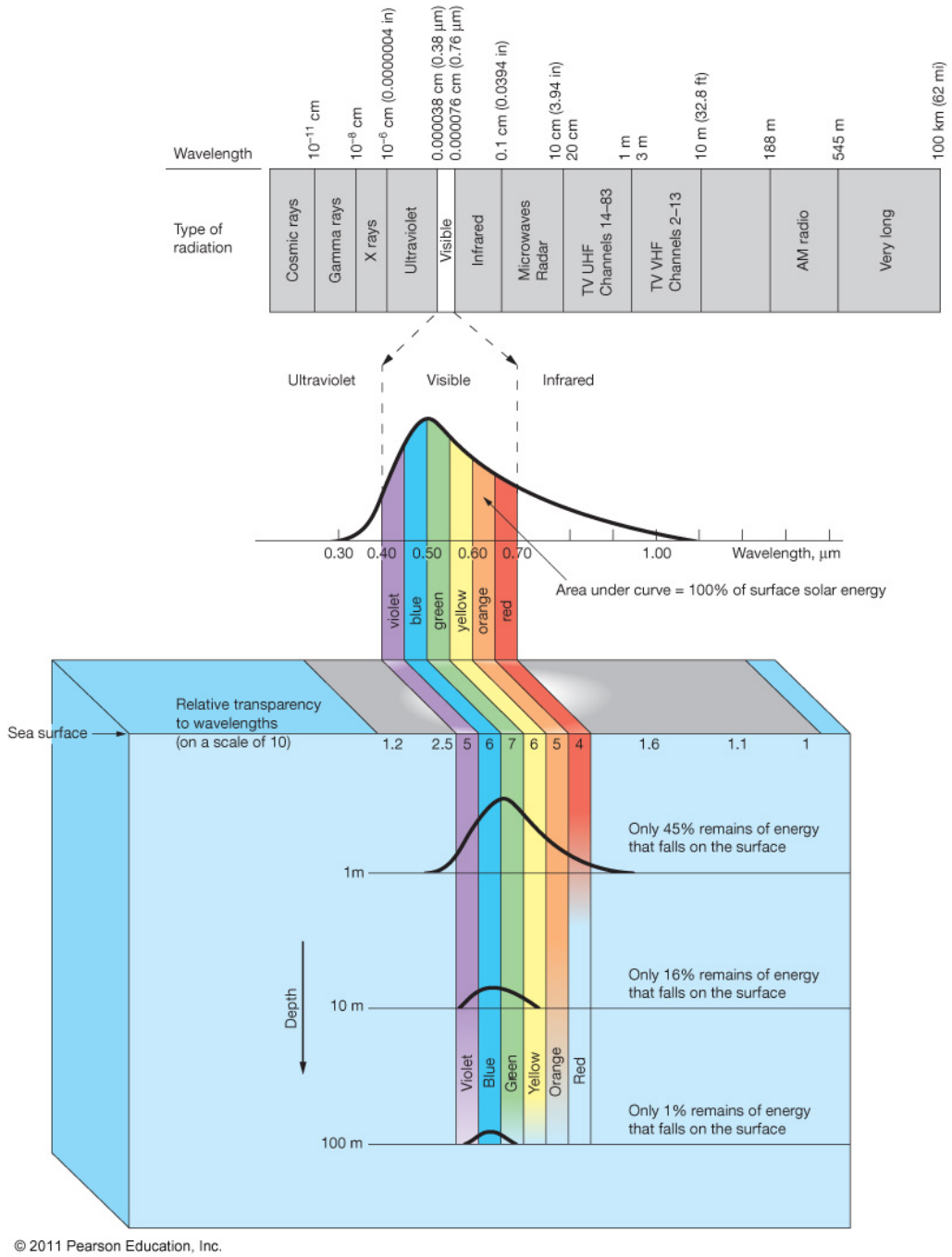
- In coastal regions light penetration is much less but there are many more nutrients

- Since productivity is much higher in coastal areas, the most important factor affecting the distribution of life in the ocean is nutrient availability

Light Transmission in Ocean Water

- Solar radiation affects three major components of the ocean:
  - Ocean winds
  - Ocean stratification
  - Primary productivity

- Most solar radiation reaches Earth in the visible light range of the electromagnetic spectrum



Transmission of Light in Seawater

Visible field: colors and white light

Lower energy waves used for heat and communication (radio waves)

Higher energy waves are damaging to living organisms (UV radiation, X-rays, gamma rays)

Our eyes “see” the radiation that an object reflects back (the rest being absorbed)

The figure to the left shows how solar radiation is selectively absorbed with increasing water depth

Blue wavelengths penetrate deepest
Longer wavelengths (red, orange) absorbed first

Water color and life in the ocean

- The color of the ocean waters ranges from deep blue to yellow-green
- Ocean water color is influenced by:
  - Amount of turbidity from runoff
  - Amount of photosynthetic pigment (chlorophyll), which is function of primary productivity
- A Secchi Disk is used to measure water transparency

- Coastal waters (and upwelling areas) are biologically very productive and almost always yellow-green in color because of their high content in yellow-green marine algae and suspended particles, all of them scatter light in the yellow-green field

- Water in the open ocean is less productive and has less turbidity, so it is usually a clear blue. Water molecules scatter the light in the blue wavelengths

- Photosynthetic algae and bacteria are microscopic but they occur in such high numbers that the change in ocean waters color can be detected from satellites
  - High chlorophyll concentration waters are said to be eutrophic
    - Eutrophic waters are usually found in shallow-water coastal regions, areas of upwelling, high-latitude regions
  - Low chlorophyll concentration waters are said to be oligotrophic
    - Oligotrophic waters are usually found in tropical open ocean region

Why Are the Margins of the Oceans So Rich In Life?

- Ocean stability is ideal for sustaining life, and it is maximized in the open ocean
- So why is there more life in coastal waters, where stability is minimal?
- Marine organisms can be stressed!
  - Shallow waters allow greater seasonal variation in temperature and salinity, open ocean waters do not
  - Tides can uncover/cover coastal areas and make the water column alternatively thicker or thinner
  - Waves break along coastlines, releasing bursts of energy that was originated somewhere else

- In spite of hardship encountered in coastal waters, organisms have evolved over geologic time to withstand these variability and colonize virtually every imaginable biological niche, as long as nutrients are available

- Along continental margins there are still differences in productivity

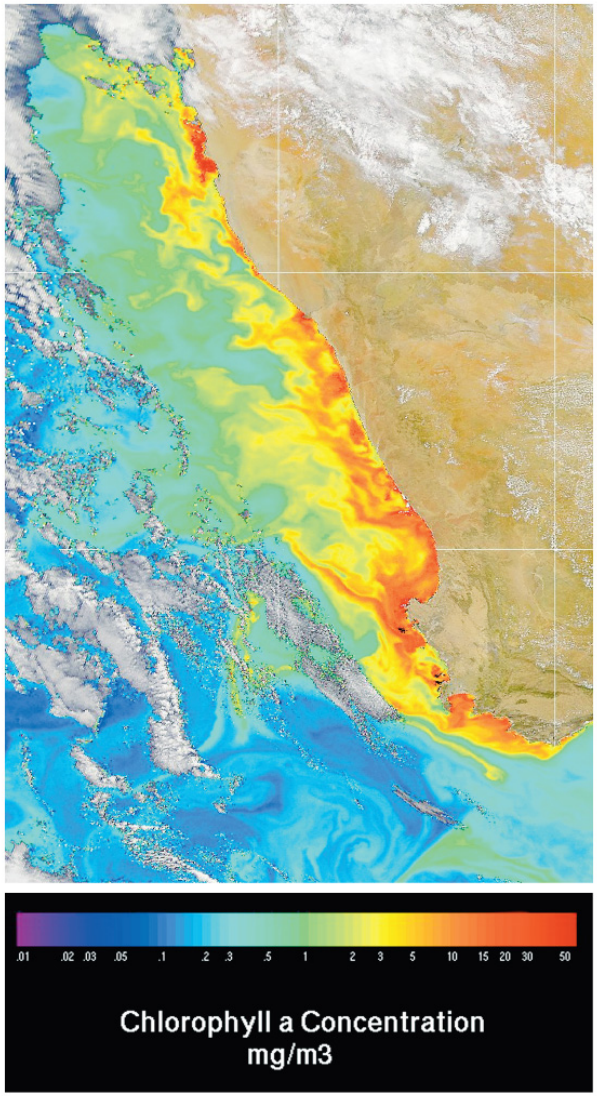
- Given an equal amount of nutrients, lower temperature waters are better for primary productivity because they can hold on to higher amounts of nutrients, O_2 and CO_2 than warm waters

Upwelling and nutrient supply

- Upwelling is a flow of deep waters towards the surface
- It brings cold, nutrients- and dissolved gases-rich waters from the deep bottom to the euphotic zone
- In areas of upwelling phytoplankton booms and becomes food for larger organisms
- Warming of the surface though creates ocean layering and inhibits primary productivity

Where does upwelling occur in the oceans?

- Areas of coastal upwelling are sites of high productivity
- Along western margin of continents, where surface currents are moving towards the equator
  - Ekman transport causes surface waters to move away from these coasts, so nutrient-rich waters from depths of 200 m to 1000 m constantly rises to replace it
- Along the equator, where the process of equatorial upwelling occurs



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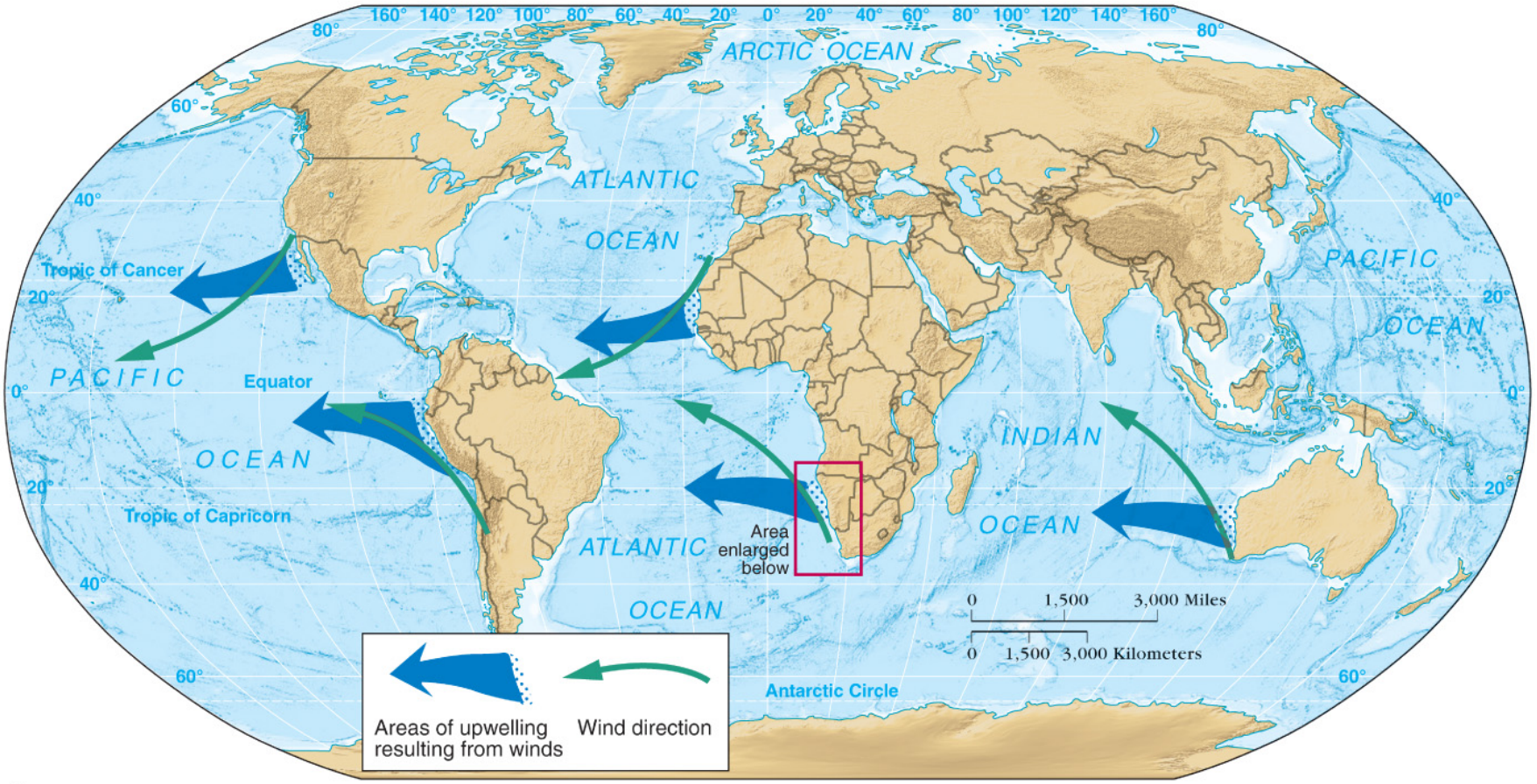
Upwelling and Nutrient Supply



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Biological Productivity and Energy Transfers

End of part 1