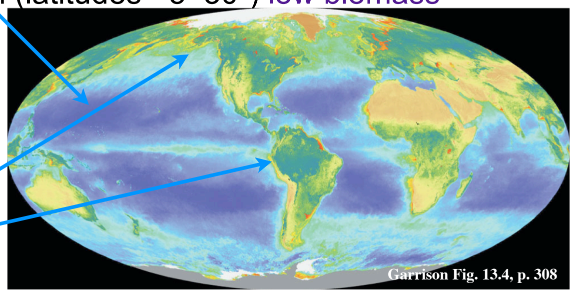
Global Pelagic Biomass

- What causes differences in primary productivity?
  - Satellite chlorophyll biomass as a surrogate for productivity
  - Open ocean (latitudes ~5–30˚) low biomass
  - Neritic (& open ocean latitudes ~30–70˚) moderate
  - Upwelling high



Garrison Fig. 13.4, p. 308

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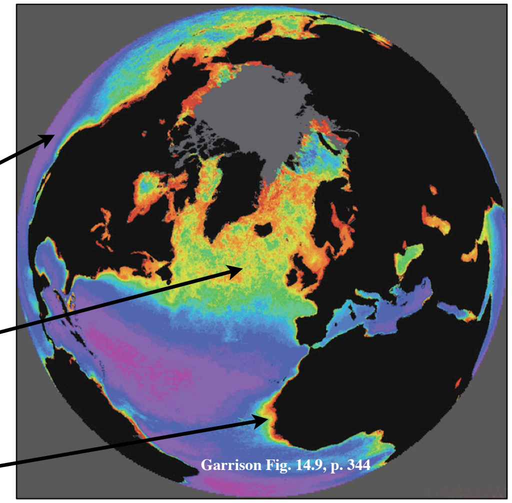
Global Pelagic Biomass

- Peak biomass in spring
  - Open ocean (latitudes ~5–30˚) low biomass
  - Neritic & open ocean (latitudes ~30–70˚) moderate to high
  - Upwelling high



Garrison Fig. 14.9, p. 344

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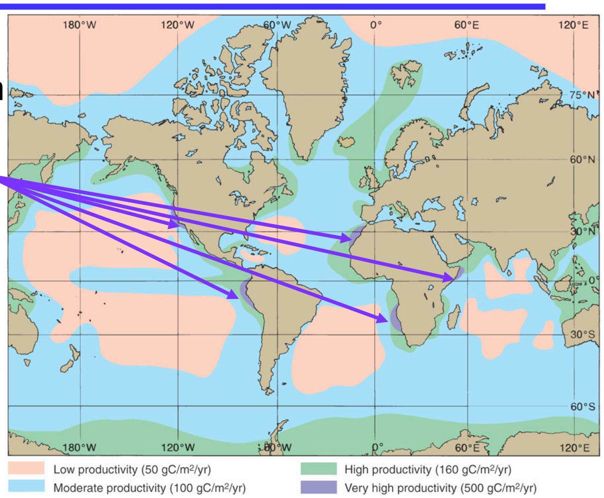
Global Pelagic Productivity

- Primary production highest in upwelling areas
  - 500+ gC/m^2/yr
  - Eastern boundary currents
  - Nutrient supply



Sverdrup, Duxbury & Duxbury 2004

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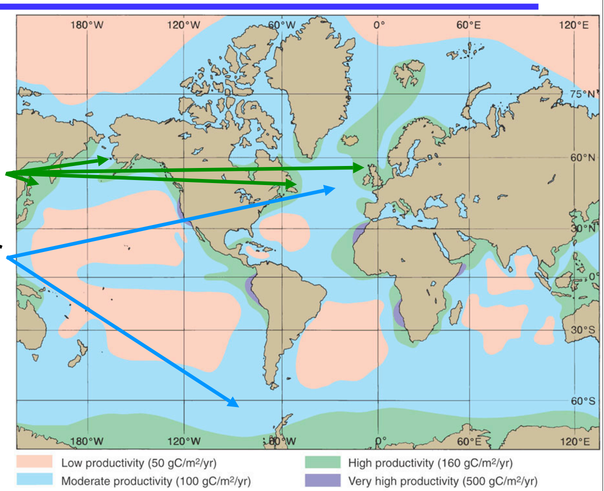
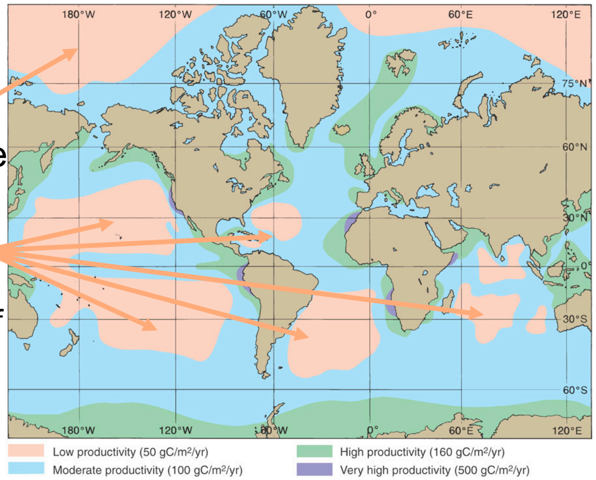
Global Pelagic Productivity

- High to moderate production on shelf & temperate & subpolar oceanic
  - 100-500 gC/m^2/yr
  - Neritic & cooler oceanic



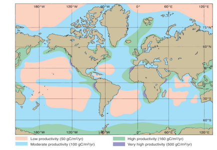
Global Pelagic Productivity

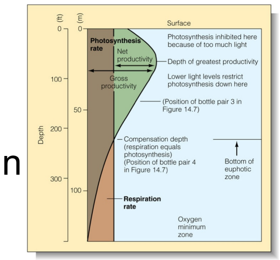
- Low production in polar & low-latitude oceanic
  - <100 gC/m²/yr
  - Centers of oceanic gyres



Light & Primary Production

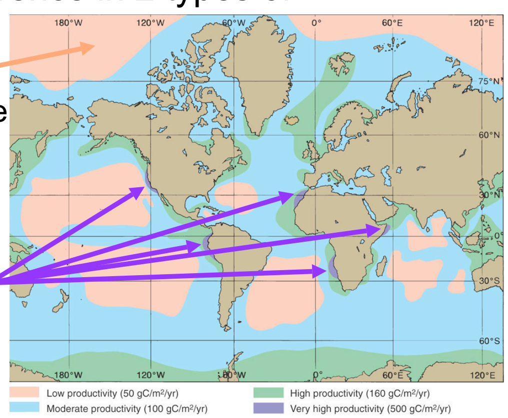
- Light is plentiful at the surface at low latitudes (during the daytime)
  - Also at the surface at high latitudes in summer
- Light is limiting below the surface at all latitudes
  - Also in winter at high latitudes
- Phytoplankton adapt to remain at or near the surface
  - Spines, chains, fats
  - Commonly go dormant in winter





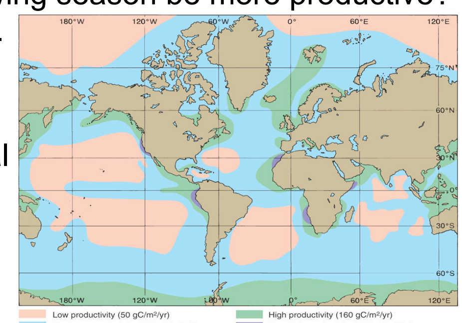
Global Environments 1

- We now know enough to explain primary productivity difference in 2 types of environments
  - Arctic Ocean: poorly productive
    - Light-limited (24-hour dark!) in winter; ice-covered all year
  - Upwelling: very productive
    - Ample nutrient supply & light



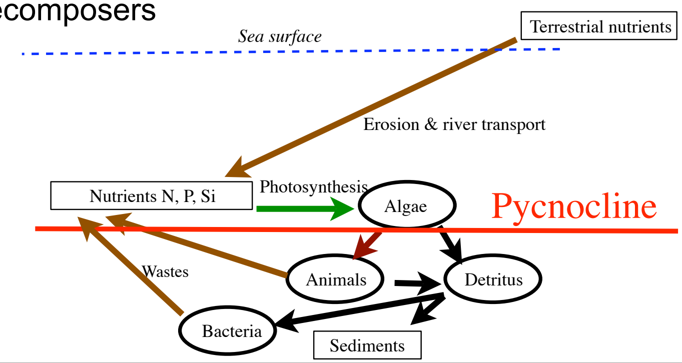
Pelagic Comparisons

- But why?
  - Why should more higher-latitude waters with less light & shorter growing season be more productive?
  - Why should continental shelves be more productive?
  - Why should tropical waters with bright sun year-round be so unproductive?
  - Light is not all the phytoplankton need!



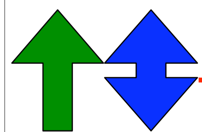
Nutrient Depletion: Review

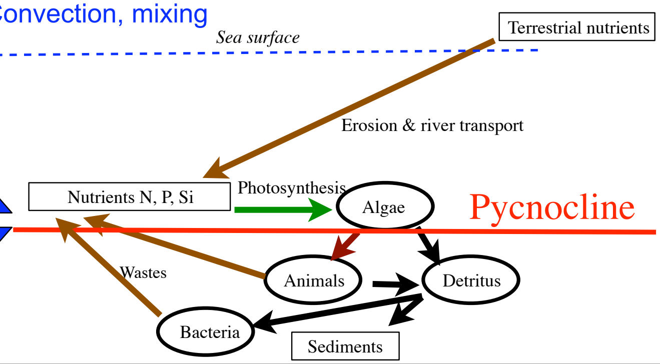
- Organic matter sinks to deep water & bottom
  - Trapped below the pycnocline
  - A portion is regenerated by animal wastes & decomposers



Nutrient Depletion: Review

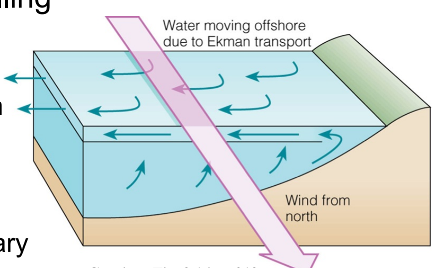
- What processes return nutrients to surface?
  - **Upwelling: one-way flow**
  - Vertical exchange: two-way
    - Convection, mixing





Nutrient Supply: Upwelling

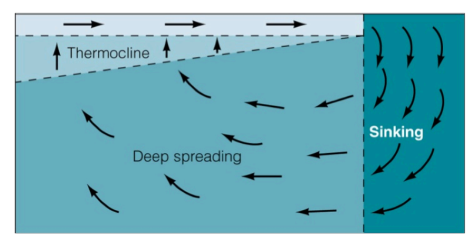
- Nutrients become depleted at the surface due to sinking organic matter
  - Depletion enhanced by strong stable stratification
  - Nutrients replenished by vertical water movement
  - Upward flow = Upwelling
    - Supplies nutrients from deep water
    - Carries phytoplankton up to the light
    - Return flow to deep water is far away
    - All beneficial for primary productivity



Garrison Fig. 9.16, p. 213

Nutrient Supply: Exchange

- Nutrients also supplied by vertical exchange
  - Convection (density-driven)
  - Vertical mixing (wind- or current-driven)
  - Both involve sinking of surface water as it is replaced by upward-moving deep water
  - Carries phyto-plankton away from light as it supplies nutrients
  - May be beneficial (if nutrients are depleted) or detrimental (if light is limiting)



Garrison Fig. 9.24, p. 220

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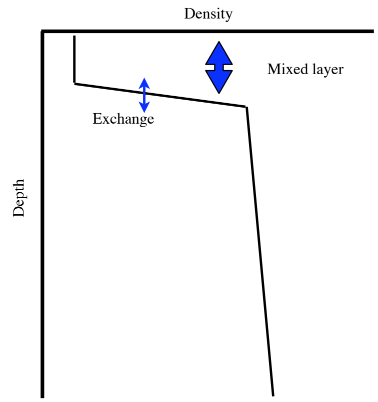
Stratification vs. Exchange

- If there is strong stable vertical stratification:
  - Caused by strong surface heating &/or fresh water
    - Pronounced pycnocline (thermocline, haline)
  - Vertical exchange is weak or absent
    - Mixing restricted to surface layer
    - Pycnocline is a density barrier
  - Surface mixed layer is usually shallow



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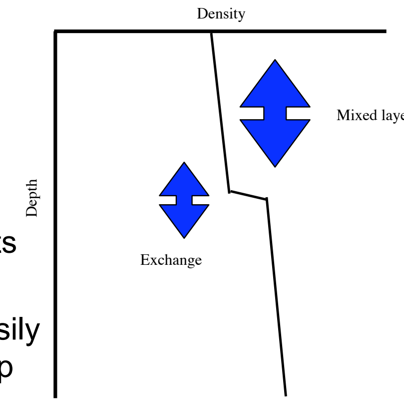
Stratification vs. Exchange

- If there is weak or unstable vertical stratification:
  - Convection caused by
    - Strong surface cooling
    - Sea ice formation
    - Evaporation
      - Weak pycnocline
  - Vertical wind mixing and/or turbulent currents
  - Deep mixed layer
  - Water is exchanged easily between surface & deep



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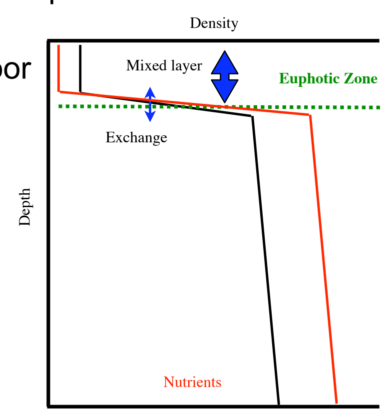
Effects on Photosynthesis

- If there is strong stable vertical stratification:
  - Phytoplankton remain in euphotic zone
    - Light is not limiting
  - But nutrient supply is poor
    - Sustained by:
      - Rivers (if near coast)
      - Regeneration by animals & decomposers
      - Weak vertical exchange
- Productivity declines
  - Nutrient-limited system
  - Example: low-latitude open ocean



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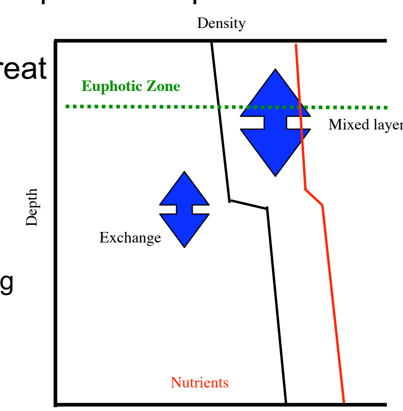
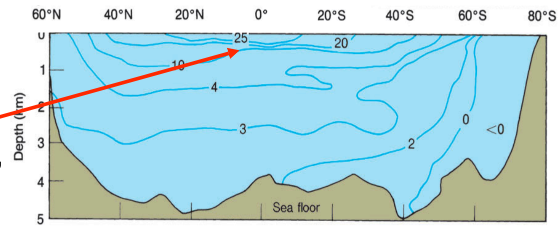
Effects on Photosynthesis

- If there is weak/unstable vertical stratification:
  - Phytoplankton carried deep below euphotic zone
    - For part of the time
  - But nutrient supply is great
- Productivity declines
  - Light-limited system
  - Especially in winter
    - Sunlight is dim
    - Wind & convection strong
  - Examples:
    - High latitudes in winter
    - Well-mixed estuaries

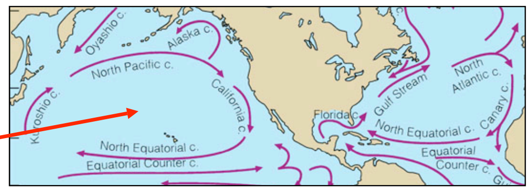


Global Stratification & Mixing

- Low latitude open ocean
  - Strong stratification, weak mixing
    - Little or no seasonal change
  - Convergence of surface water
    - Ekman transport

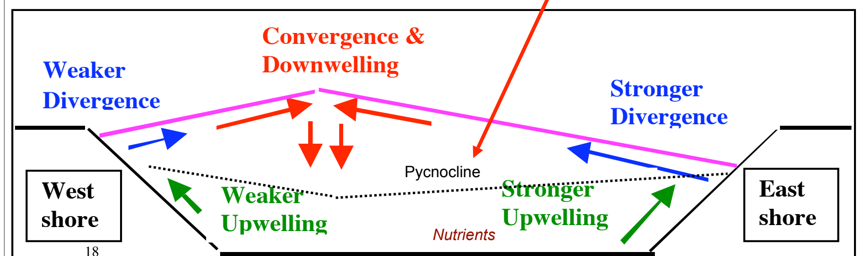


(b) Temperature (°C) in Atlantic Ocean



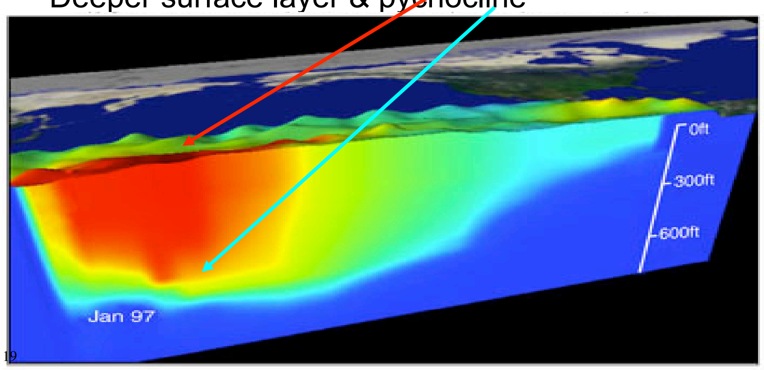
Gyre Surface Water: Review

- Low latitude open ocean
  - Convergence of surface water (Ekman transport)
  - Downwelling in center of gyre
    - Deeper surface layer & pycnocline
    - Deep water nutrient source is less accessible



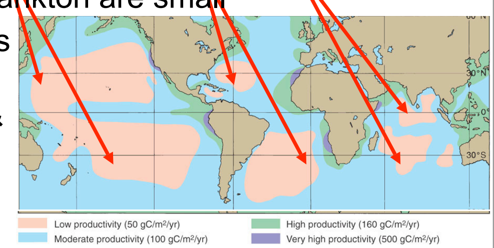
Gyre Surface Water: Review

- Low latitude open ocean
  - Remember western Pacific “warm pool?”
  - Deeper surface layer & pycnocline



Gyre Surface Water: Review

- Low latitude open ocean
  - Strong stable stratification, weak mixing
  - Low nutrient supply & primary production all year
  - Dominant phytoplankton are small
    - Microflagellates swim to depth at which light & nutrients are both available
    - Cyanobacteria fix nitrogen gas to make their own nutrients



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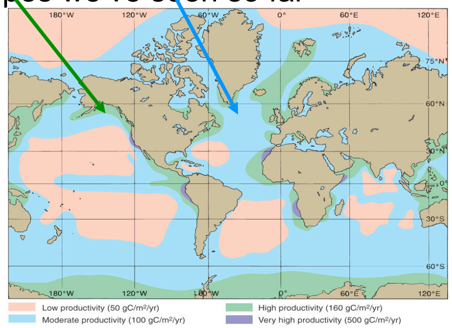
Global Environments II

- What about "coastal" (& temperate/subpolar open ocean)?
  - A mixture of the 3 types we've seen so far
  - They alternate on a seasonal basis
    - Winter: light-limited & unproductive
    - Summer: nutrient-limited & unproductive
    - Spring & autumn: the most productive times of year



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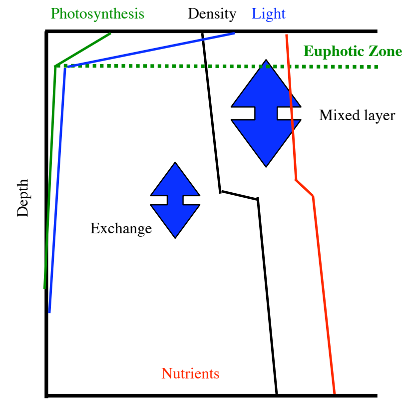
Temperate Seasonal Changes

- Temperate/subpolar latitudes-Winter
  - Low surface light intensity
  - Strong mixing
    - Ample surface nutrient supply
  - Weak or absent stratification & stability
    - Deep mixed layer
    - Phytoplankton mixed to great depths
    - Low productivity
      - Light-limited



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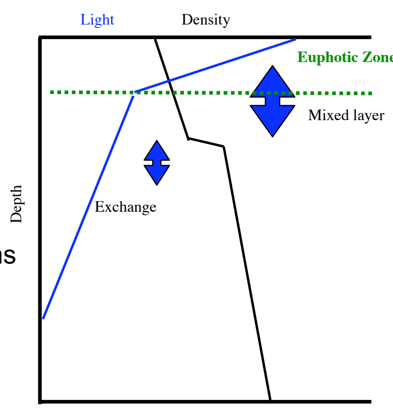
Temperate Seasonal Changes

- Temperate/subpolar latitudes-Spring
  - Light increases
    - Euphotic zone deepens
  - Surface warming
    - Stable vertical thermal stratification begins
  - Storm winds weaken, reduce mixing
    - Moderate pycnocline forms
    - Shallower mixed layer
  - Moderate stratification & stability



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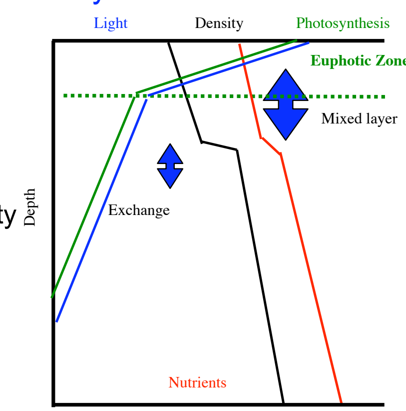
Temperate Seasonal Changes

- Temperate/subpolar latitudes-Spring
  - Moderate surface light intensity
  - Moderate stratification & stability
    - Shallower mixed layer
    - Phytoplankton remain near surface
    - Enhanced light availability
  - Weak mixing
    - Surface nutrients still abundant
    - Start to be consumed by phytoplankton



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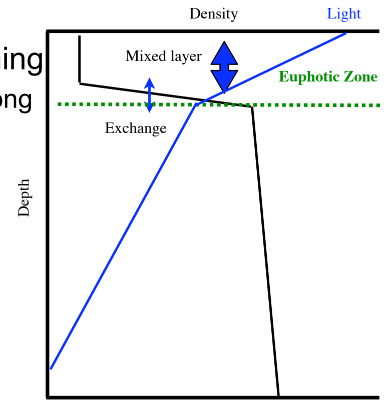
Temperate Seasonal Changes

- Temperate/subpolar latitudes-Summer
  - Light is strongest
    - Euphotic zone deepest
  - Additional surface warming
    - Thermal stratification strong
    - Vertical stability strong
  - Storm winds rare, little mixing
    - Pycnocline strengthens
    - Mixed layer more distinct
  - Strong stratification & stability



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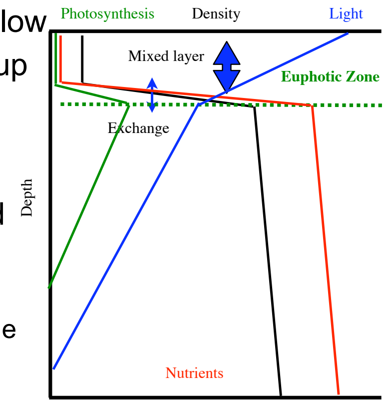
Temperate Seasonal Changes

- Temperate/subpolar latitudes-Summer
  - Strong stratification & stability, weak mixing
  - Surface nutrient supply low
  - Surface nutrients used up
    - Detritus has sunk below pycnocline
    - Nutrient-limited
  - Photosynthesis reduced in surface layer
    - Despite ample light
    - Maximum near pycnocline
      - Light & nutrients both available



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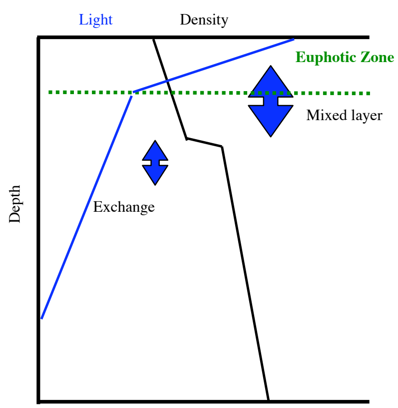
Temperate Seasonal Changes

- Temperate/subpolar latitudes-Autumn
  - Light decreases
    - Euphotic zone shallower
  - Surface cooling
    - Stable vertical thermal stratification weakens
  - Storm winds strengthen, increase mixing
    - Pycnocline weakens
    - Deeper mixed layer
  - Moderate stratification & stability



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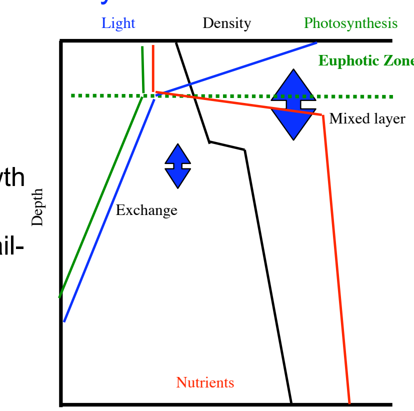
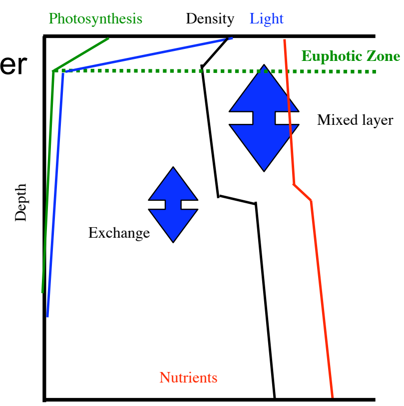
Temperate Seasonal Changes

- Temperate/subpolar latitudes-Autumn
  - Moderate surface light intensity
  - Moderate stratification, stability & mixing
    - Surface nutrients being replenished by mixing
    - Stimulate renewed growth of phytoplankton
    - Despite decrease in avail-able light
      - Less light at surface
      - Deeper mixed layer
    - Late fall: light limitation



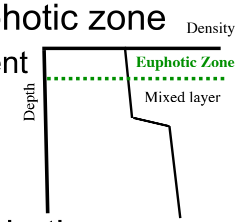
Temperate Seasonal Changes

- Temperate/subpolar latitudes-return to winter
  - Strong mixing
  - Surface cooling creates more dense surface water
    - Vertical instability
    - Convection in addition to wind-driven mixing
  - Restores surface nutrients
  - Deep strong mixing returns phytoplankton to light limitation

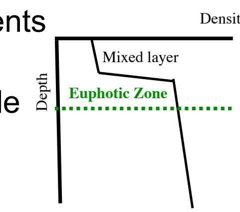


Simple Seasonal Summary

- If mixed layer is deeper than euphotic zone
  - Light limitation despite ample nutrient supply
  - Low to negative productivity
  - Typical in winter

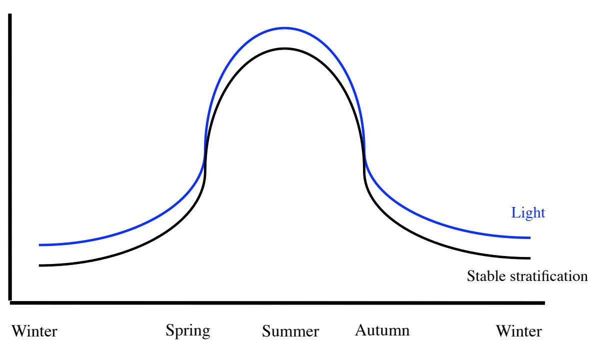


- If mixed layer shallower than euphotic zone
  - Positive net productivity until nutrients run out
  - Then low productivity despite ample light
  - Typical in summer



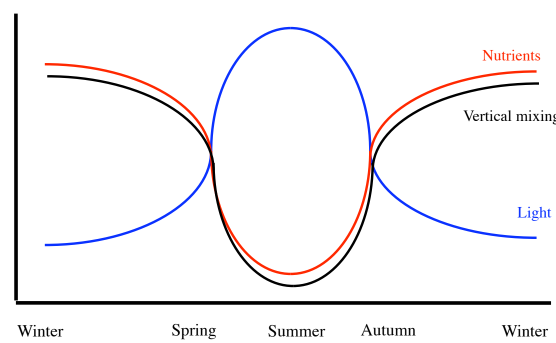
Temperate Seasonal Summary

- Seasonal overview
  - Annual cycle of sunlight is simplest to understand
  - Also represents stable vertical stratification



Temperate Seasonal Summary

- Surface layer nutrients are inverse of light
  - High in winter because of strong mixing
  - Low in summer because of uptake & lack of mixing



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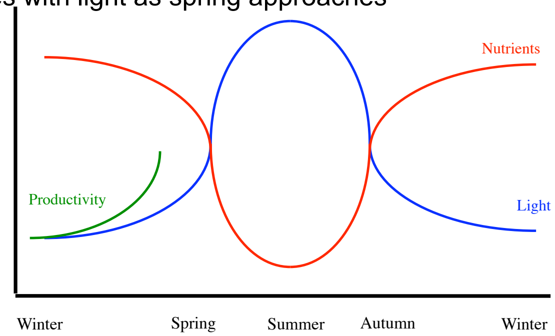
Temperate Seasonal Summary

- Primary productivity (per m^2) low in winter
  - Light limitation because of strong mixing
    - Despite abundant nutrients
    - Increases with light as spring approaches



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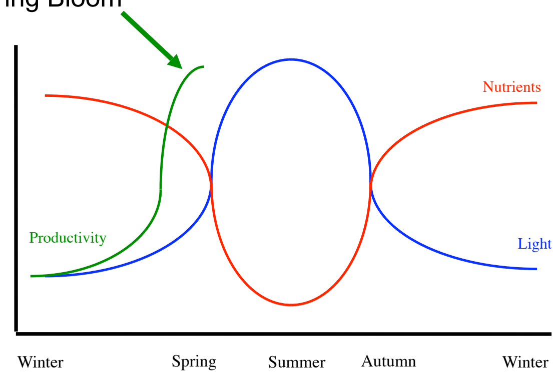
Temperate Seasonal Summary

- Primary productivity increase rapidly in spring
  - No limitation: abundant light & nutrients
    - The “Spring Bloom”



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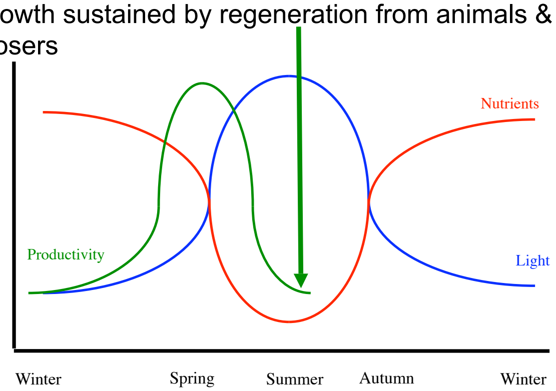
Temperate Seasonal Summary

- Primary productivity declines in summer
  - Nutrient limitation despite abundant light
    - Some growth sustained by regeneration from animals & decomposers



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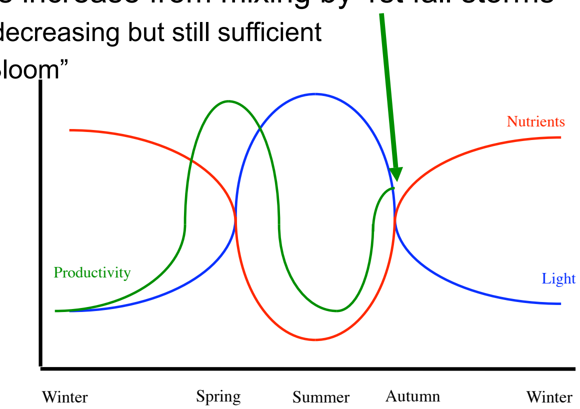
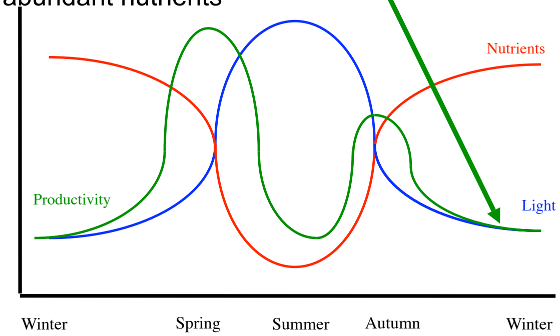
Temperate Seasonal Summary

- Primary productivity rises again in autumn
  - Nutrients increase from mixing by 1st fall storms
    - Light decreasing but still sufficient
    - “Fall Bloom”



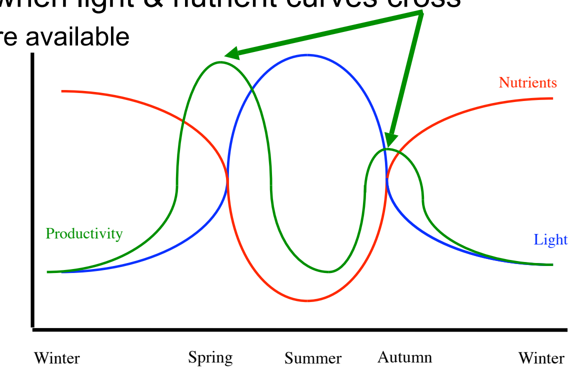
Temperate Seasonal Summary

- Primary productivity drops to low winter level
  - Light limitation because of strong mixing & convection
    - Despite abundant nutrients



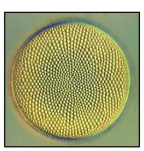
Temperate Seasonal Summary

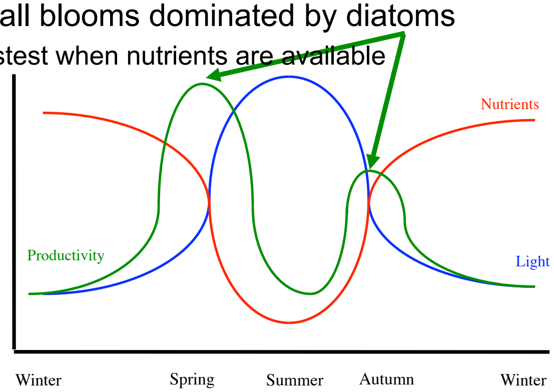
- "Blooms" in spring & fall
  - Light limitation winter, nutrient limitation summer
  - Blooms when light & nutrient curves cross
    - Both are available



Temperate Phytoplankton

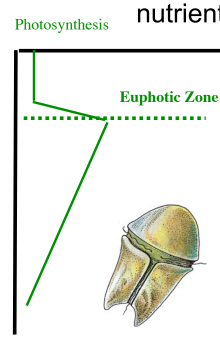
- Different types of phytoplankton dominate in different seasons
  - Spring & fall blooms dominated by diatoms
    - Grow fastest when nutrients are available

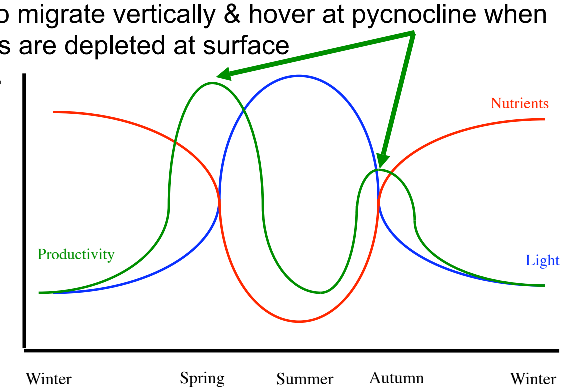




Temperate Phytoplankton

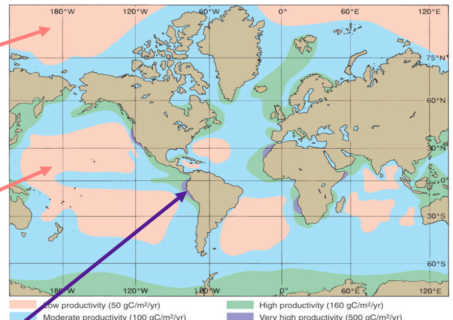
- Summer: diatoms sink (nutrient depletion)
  - Dinoflagellates dominate
    - Ability to migrate vertically & hover at pycnocline when nutrients are depleted at surface





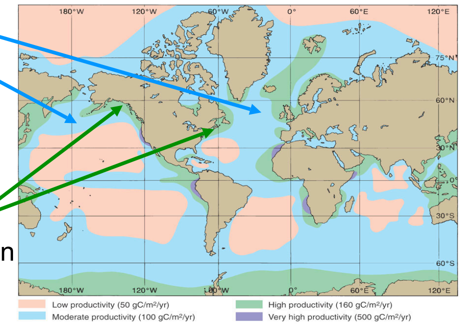
Global Environments III

- Temperate/subpolar open ocean a mixture by season of the 3 types we've seen
  - Winter: light-limited & unproductive
    - Like the Arctic
  - Summer: nutrient-limited & unproductive
    - Like the gyres
  - Spring & autumn: little limit to growth
    - Like upwelling areas



Global Environments III

- Temperate/subpolar open ocean on an annual basis:
  - Between the extremes of low & high productivity
  - But now, what about the coastal zones?
    - More productive than the open ocean
    - What is different on the shelf?



Continental Shelves

- Proximity to land makes for higher productivity
  - Supply of nutrients from continents
  - Runoff provides vertical stability

Garrison Fig. 4.22 p. 101

Continental Shelves

- Shallow water makes for higher productivity
  - Much of area is in "euphotic zone"
  - Shallow bottom is a nutrient reservoir
  - Currents & waves in shallow water provide mixing