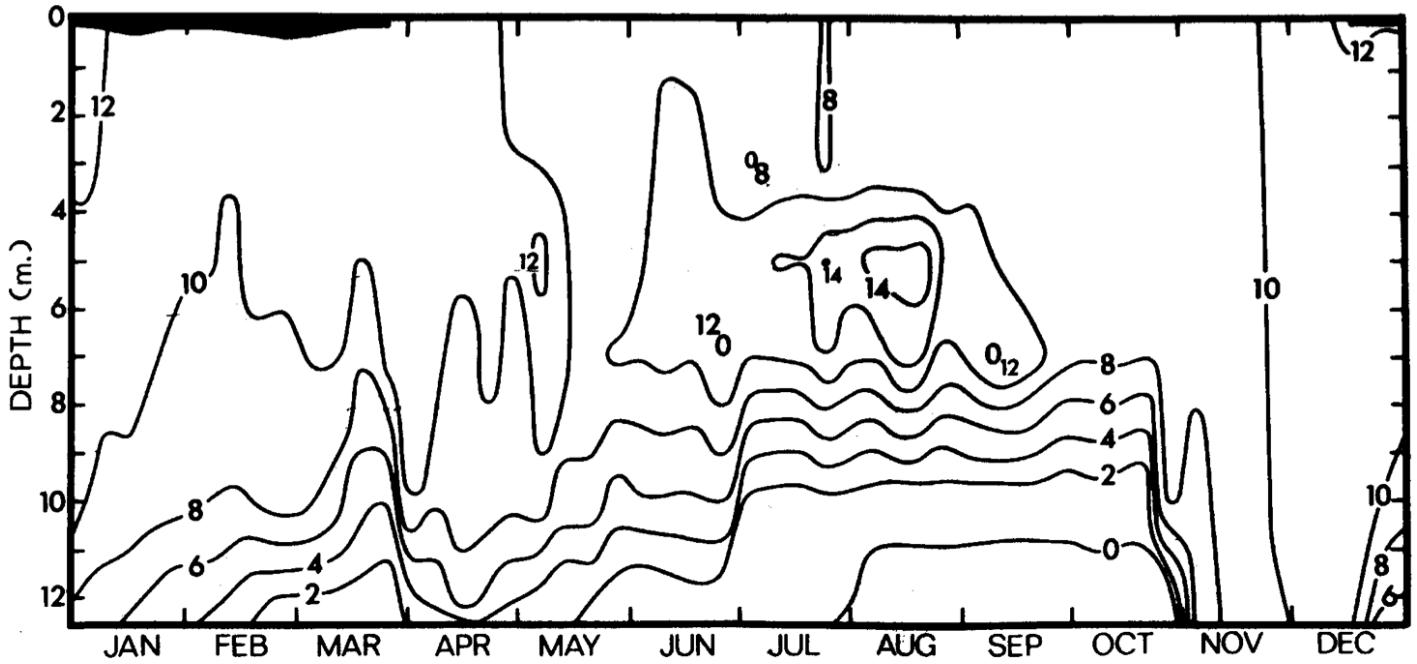
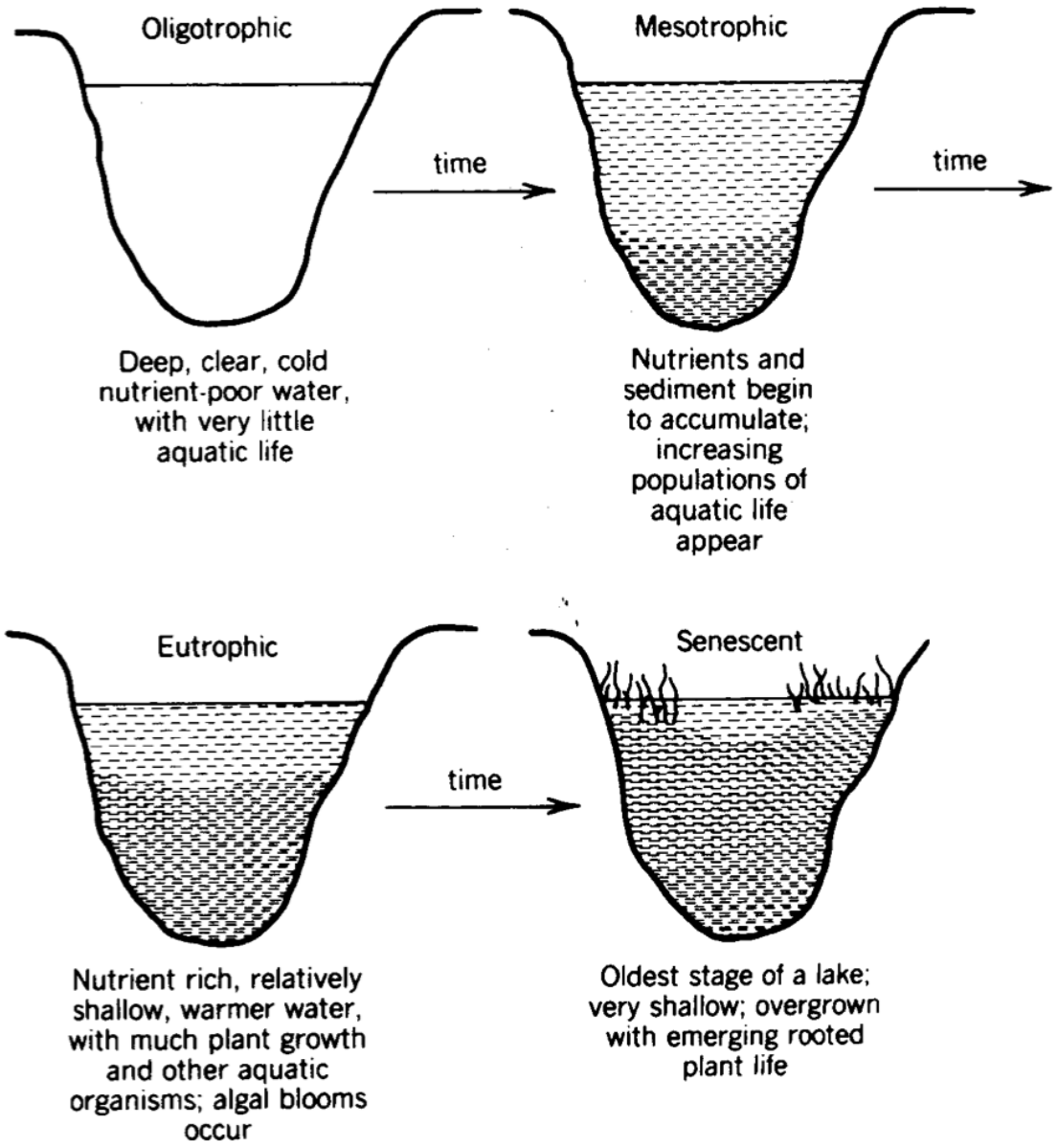
Nutrient Pollution and Eutrophication



Outline of Topics

Lecture question: What is eutrophication?



- Drastic increase in *productivity* with time
- Productivity: net rate of photosynthesis (*net primary productivity*, NPP): net rate of biomass growth
- A natural process, possibly over long time
- Three common productivity levels shown
- *Cultural eutrophication*: human-induced acceleration

Limiting Nutrients (Lecture Question)

What causes cultural eutrophication?

- NPP usually limited by some factor: temperature, sunlight, predation, nutrients
- The *limiting nutrient* is a chemical that limits NPP
- Possible limiting nutrients: N, P, Si (for diatoms), Fe
- Terrestrial NPP often limited by N
- Marine NPP often limited by N, sometimes Fe
- Freshwater NPP often limited by P (photo on left demonstrates)

Cultural Eutrophication (Lecture Question)

So what's so bad about increased productivity?

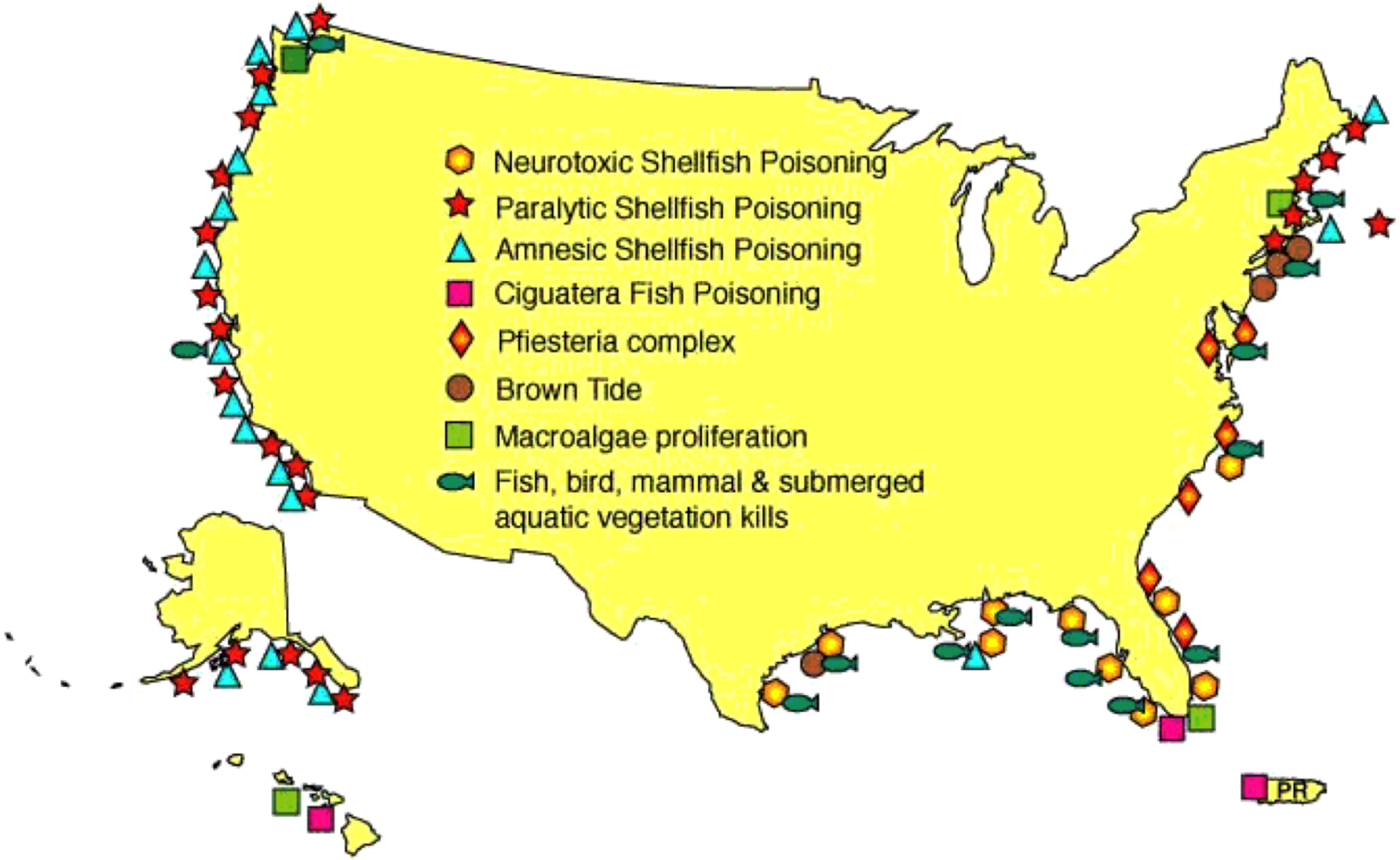
- *Oxygen Depletion*
  - Decomposition of organic material in the sediment causes hypoxia on the bottom of water bodies (esp in summer)
  - Larger day-night fluctuations in dissolved oxygen even in surface water
  - Sediment may release toxic chemicals under anoxic conditions
- *Algae Blooms*
  - A nuisance for recreation and water treatment
  - Some algae blooms are toxic (HABs)
    - HABs are not necessarily pollution-related (for most, the connection is not obvious)
    - Some toxic algae definitely thrive in polluted waters
- *Other Changes*
  - Decreased visibility (bad for submerged aquatic vegetation, SAV)
  - Increased sedimentation rate (bad for bottom-dwellers, reproduction)

How do hazardous algae blooms (HABs) affect human health?

- *Amnesia Shellfish Poisoning*
  - Toxin: domoic acid (can be fatal)
  - GI and neurological disorders
  - Symptoms: nausea, vomiting, abdominal cramps, diarrhea.
- *Ciguatera Fish Poisoning*
  - Toxins: ciguatoxin/maitotoxin (usually not fatal)
  - GI, neurological and CV symptoms
- *Diarrhetic Shellfish Poisoning*
  - Toxin: okadaic acid (not fatal)
  - GI symptoms
- *Neurotoxic Shellfish Poisoning*
  - Toxins: brevetoxins (not fatal)
  - Syndrome almost identical to ciguatera poisoning but slightly less severe
- *Paralytic Shellfish Poisoning*
  - Toxins: saxitoxins (can be fatal)
  - Rapid neurological symptoms: tingling, numbness, burning, drowsiness, etc. Respiratory arrest can occur within 24 hours
- HAB events seems to be rising (may reflect better detection)

Coastal HAB Events in the US

Where in the US do these HAB events occur?



Source: NOAA COP/National HAB office-WHOI

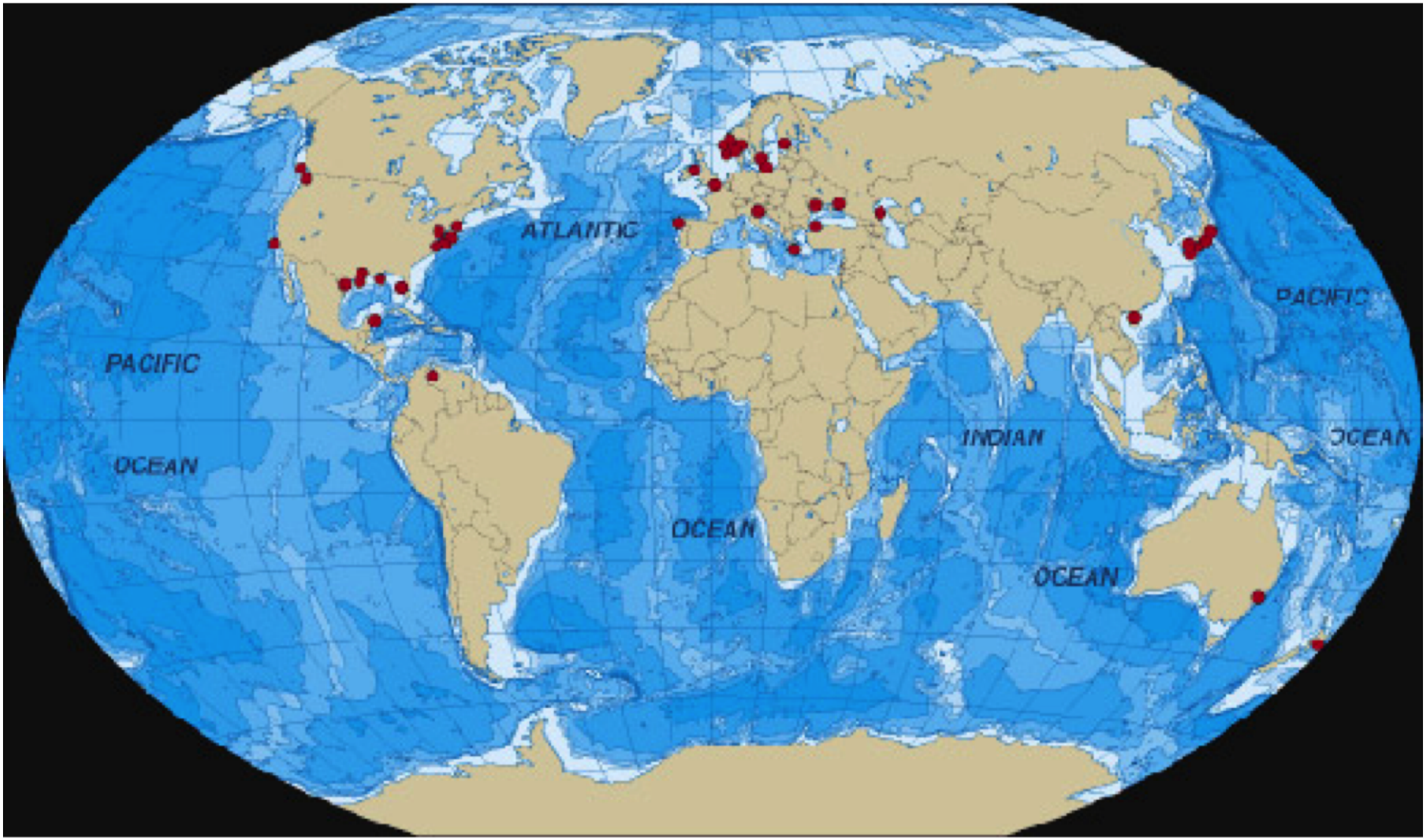
Dead Zones (Lecture Questions)

What are 'dead zones' and how are they formed?

- Dead zones are very large areas with low oxygen levels. They usually occur in oceans but have also been observed in large estuaries and lakes.
  - Can be caused by nutrient pollution (often associated with agricultural fertilizers) and subsequent eutrophication
  - Can also occur naturally: (unpolluted) river flooding empties into the ocean and creates a top layer of freshwater, temporarily cutting off the oxygen supply
- Examples
  - Gulf of Mexico where the Mississippi River empties into the gulf
  - Chesapeake Bay
  - Black Sea: largest dead zone in the world
    - The bottom (below 150 m) is completely anoxic
    - Not caused by pollution but by v slow exchange of water with the Mediterranean through the narrow and shallow Bosporus Strait
  - Kattegat strait (mouth of the Baltic Sea)
  - Northern Adriatic Sea

Global Location of Dead Zones

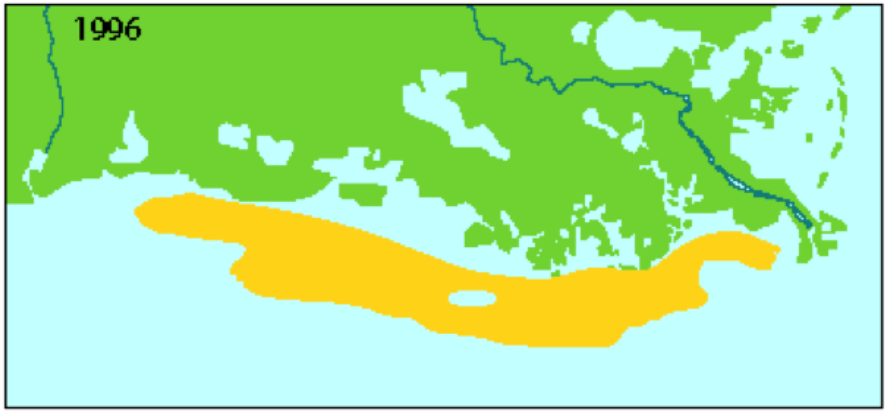
What are some of these dead zones?

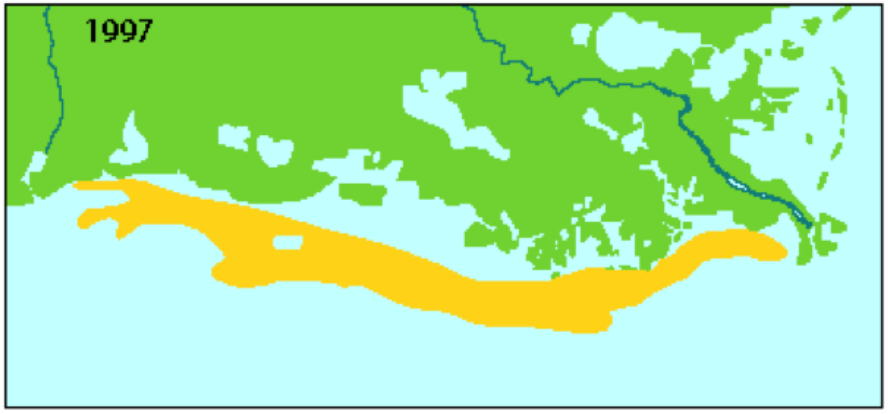


Nutrient Pollution from the Mississippi

How bad is the Gulf of Mexico dead zone?

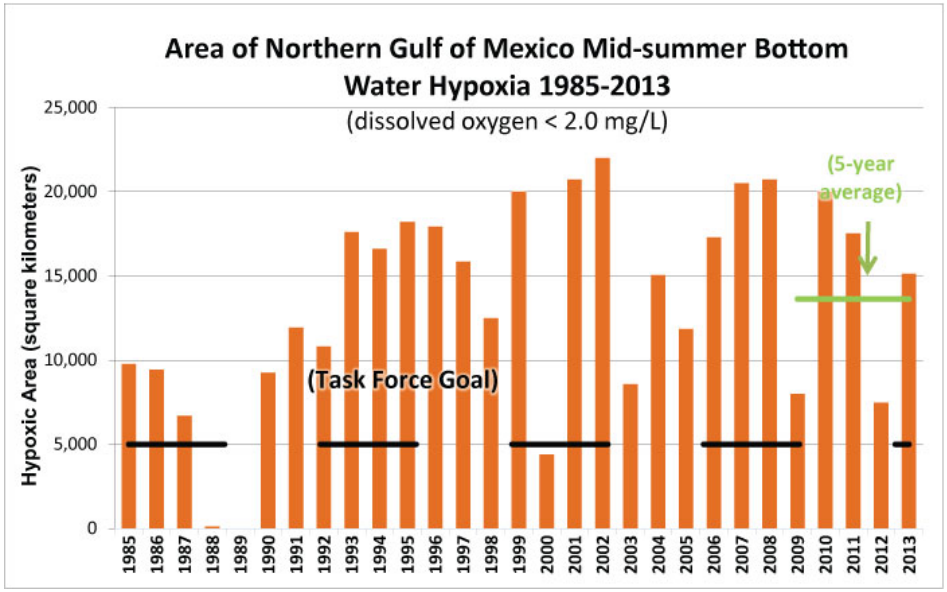
Satellite picture shows the effect of nutrient discharge on algae levels (the green color reflects chlorophyll-a concentration).





COURTESY OF THE GULF OF MEXICO PROGRAM; LAUREL ROGERS

ZONE OF LOW OXYGEN
(yellow) *in the Gulf of Mexico has grown to extend over 5,500 square miles.*



- Gulf of Mexico dead zone forms every summer
- When the algae die they settle to the bottom and begin degrading (and consuming oxygen)
- Oxygen is depleted (mostly below the *pycnocline*) creating the dead zone
- The dead zone has grown in size from 3200 mi^2 (1985–1991) to 5400 mi^2 (2009–2013), about the size of CT

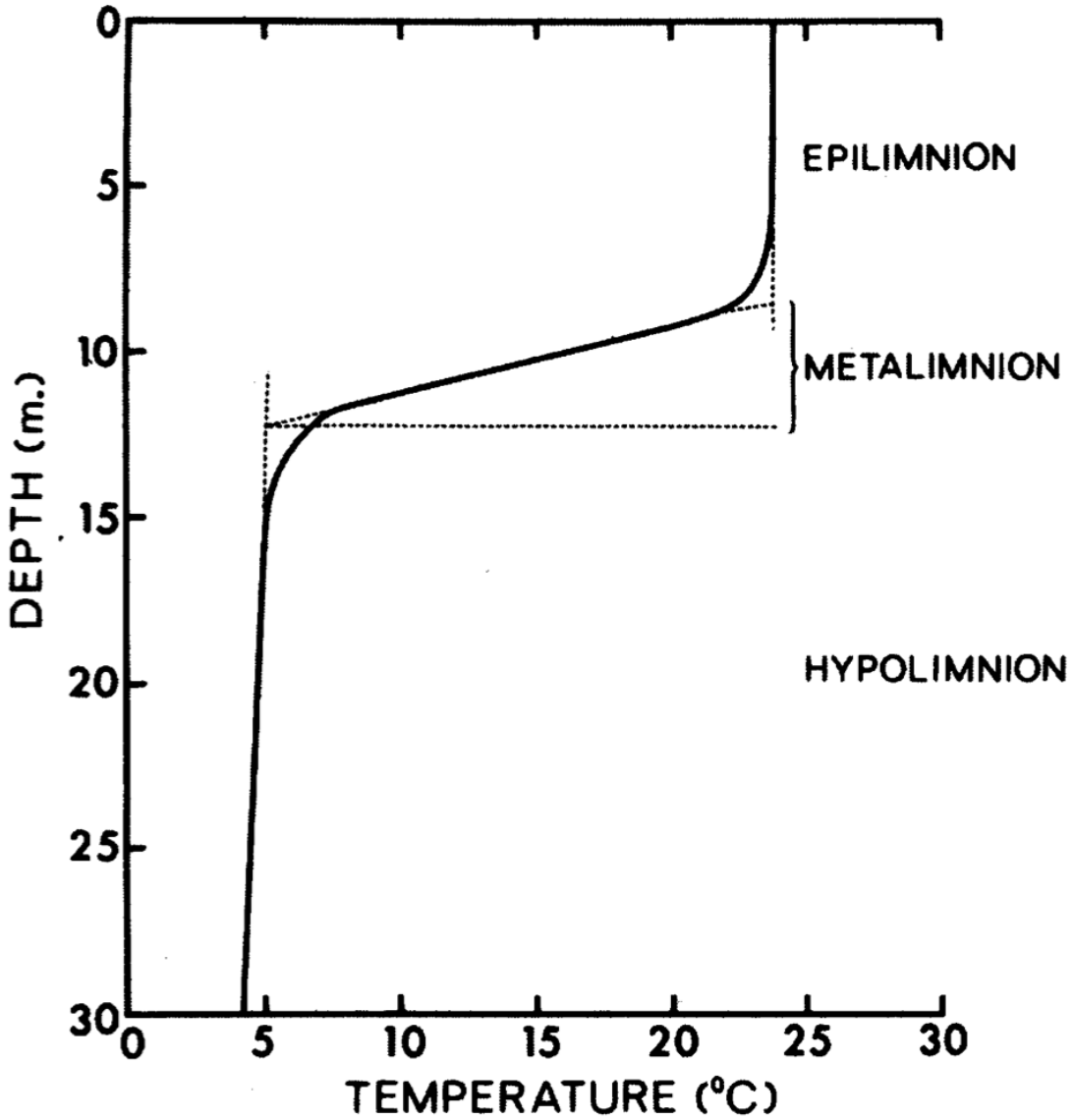
Hypoxia in Lakes

How exactly does hypoxia (low DO) develop in lakes in response to eutrophication?

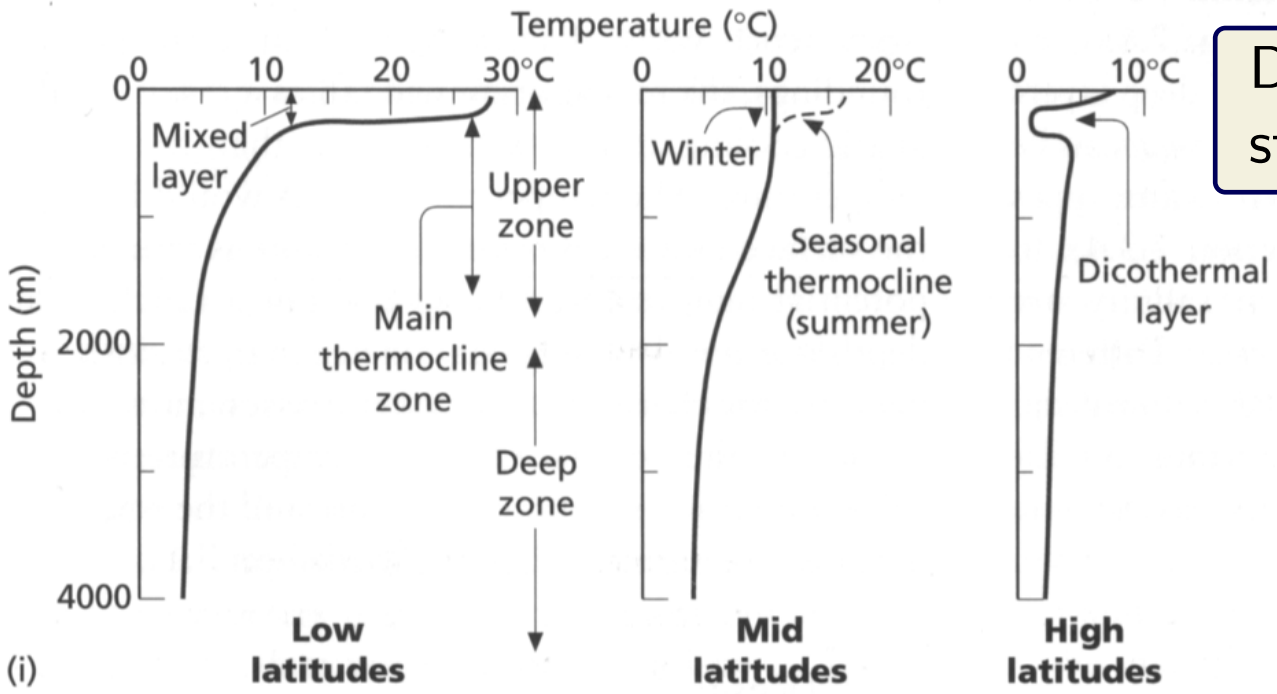
- Hypoxia usually occurs at the bottom of lakes in the summer
  - Prominent example: central basin of Lake Erie
  - But it can also occur at the top of lakes (especially overnight) and in the winter
- Steps to create summer hypoxia in lake bottoms
  1. Eutrophication increases biological productivity over time; spring and summer blooms are common
  2. Algae die and settle to the bottom, where their decomposition presents an oxygen demand
  3. Oxygen demand is greatest in the summer, when biological productivity and rate of decomposition are greatest
  4. At the same time, summer stratification of lakes cuts off the oxygen supply

Thermal Stratification of Water Bodies

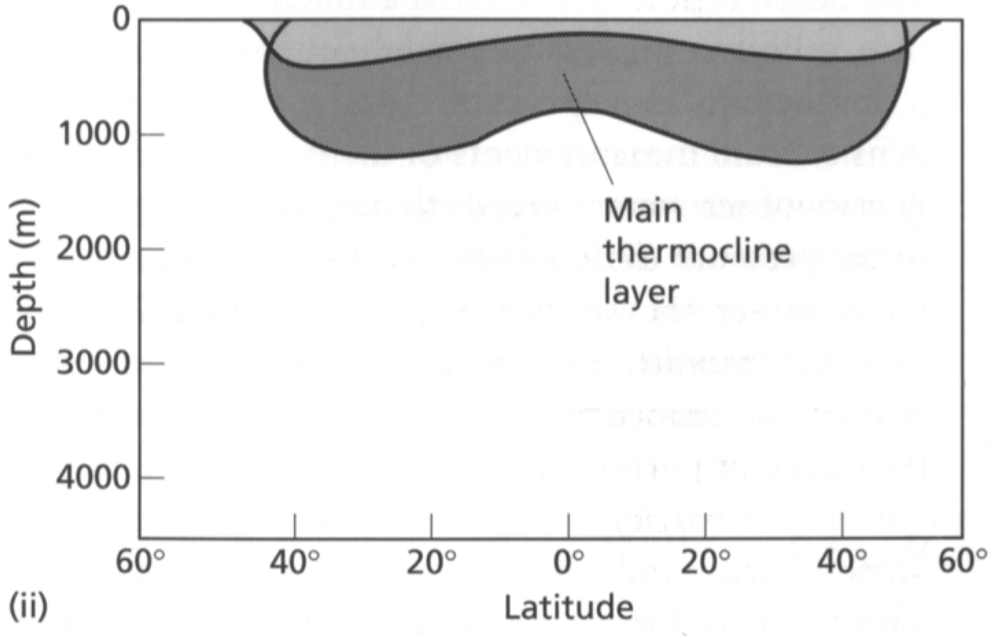
Describe how water bodies stratify into layers.



- Inflection point: *thermocline*
- Mixing between layers is very slow
- Detritus tends to accumulate in the sediment (bottom)
- Hypolimnion has limited access to $O_2(g)$

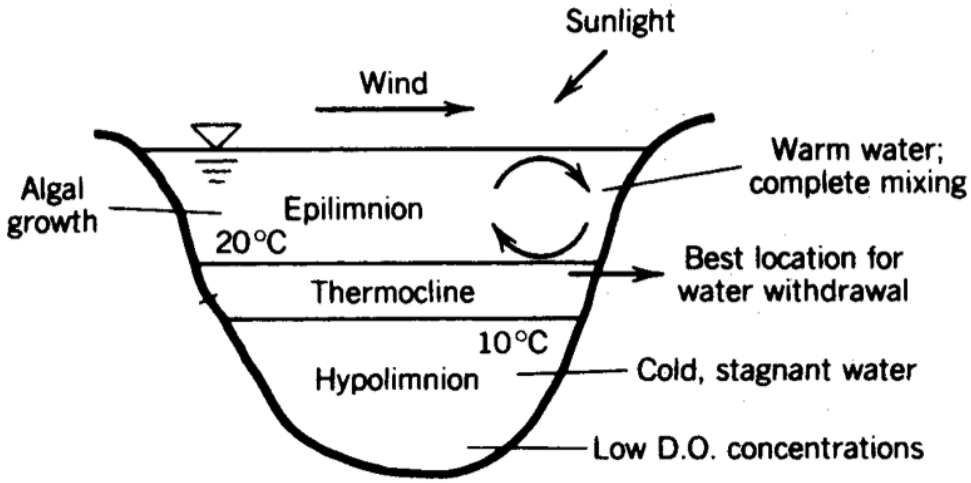


Does the ocean stratify into layers?

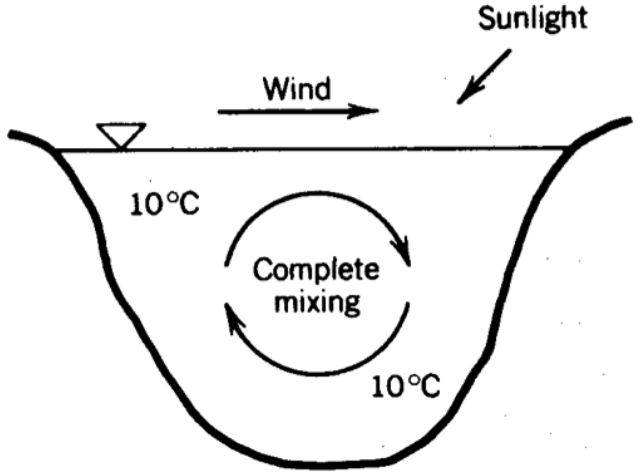


- *surface ocean*: warm, 100–200 m
- *thermocline*: down to 1 km
- *deep ocean*: cold, extends to floor

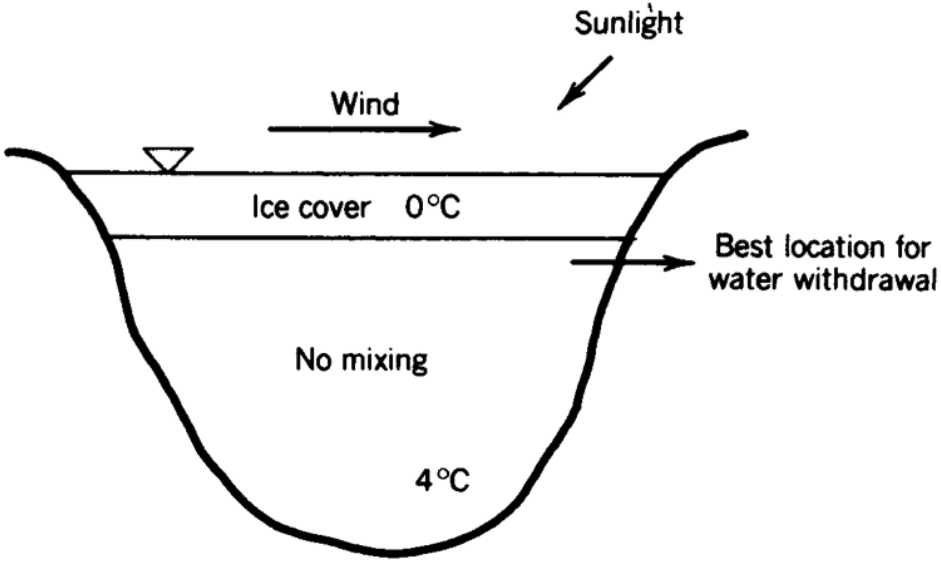
Describe the stratification and mixing processes in dimictic and warm monomictic lakes.



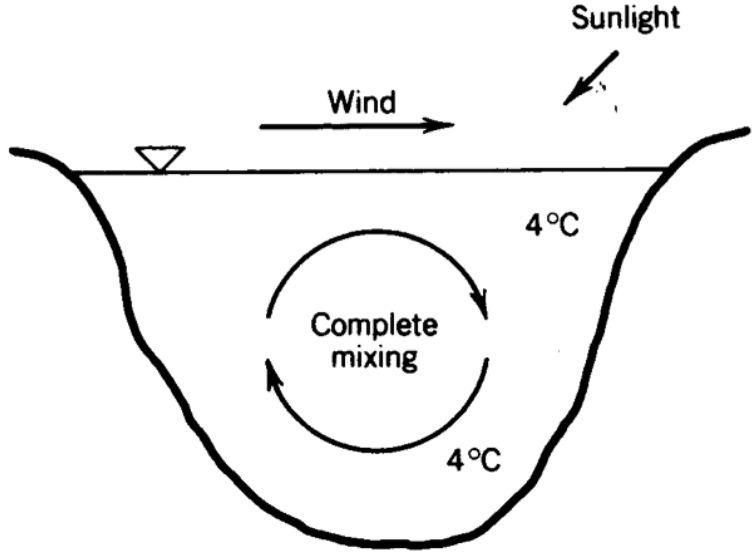
(a) Summer Stratification



(b) Fall Overturn



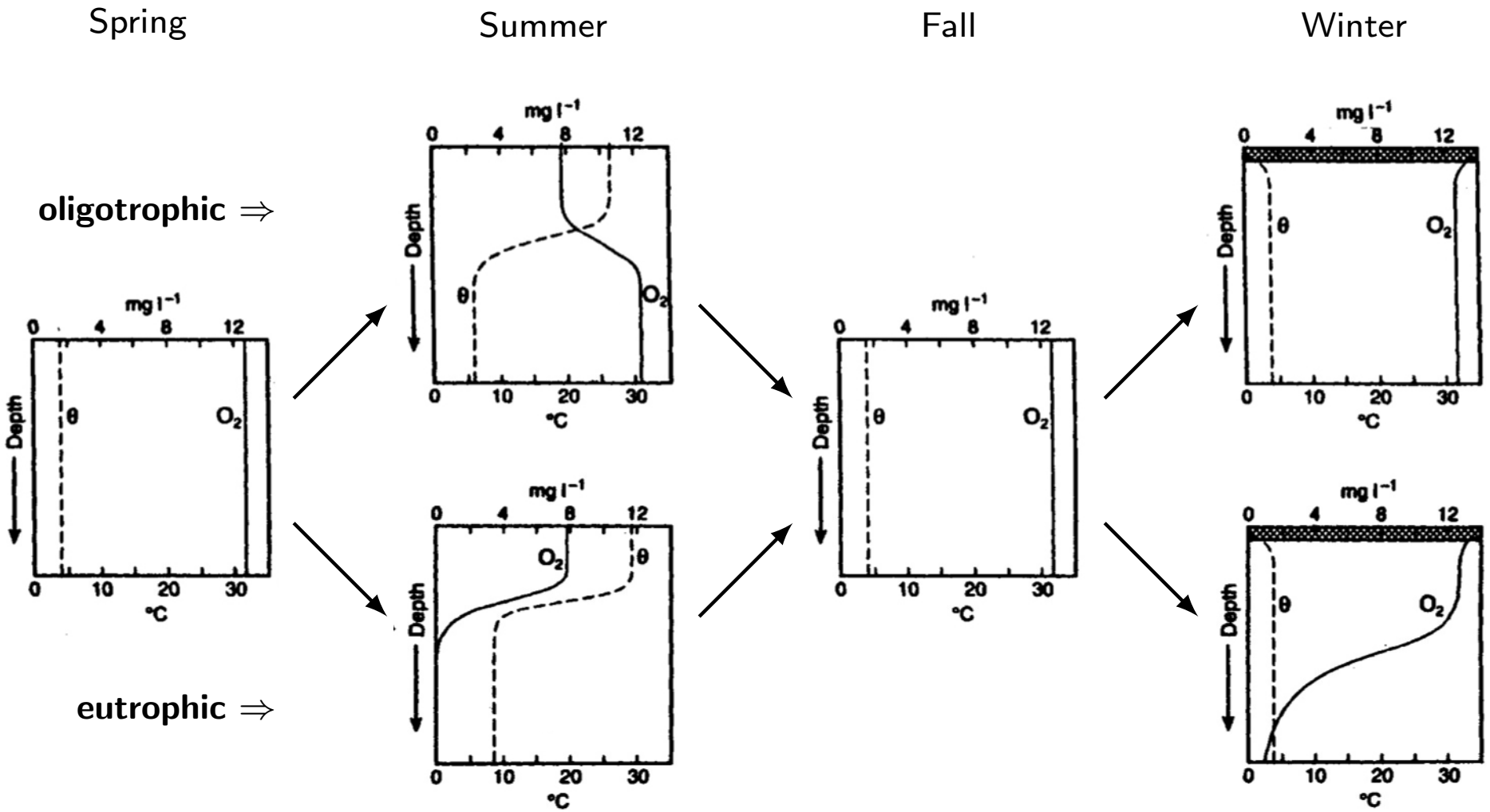
(c) Winter Stagnation



(d) Spring Overturn

Oxygen Depletion in Eutrophic Lakes: Hypolimnion

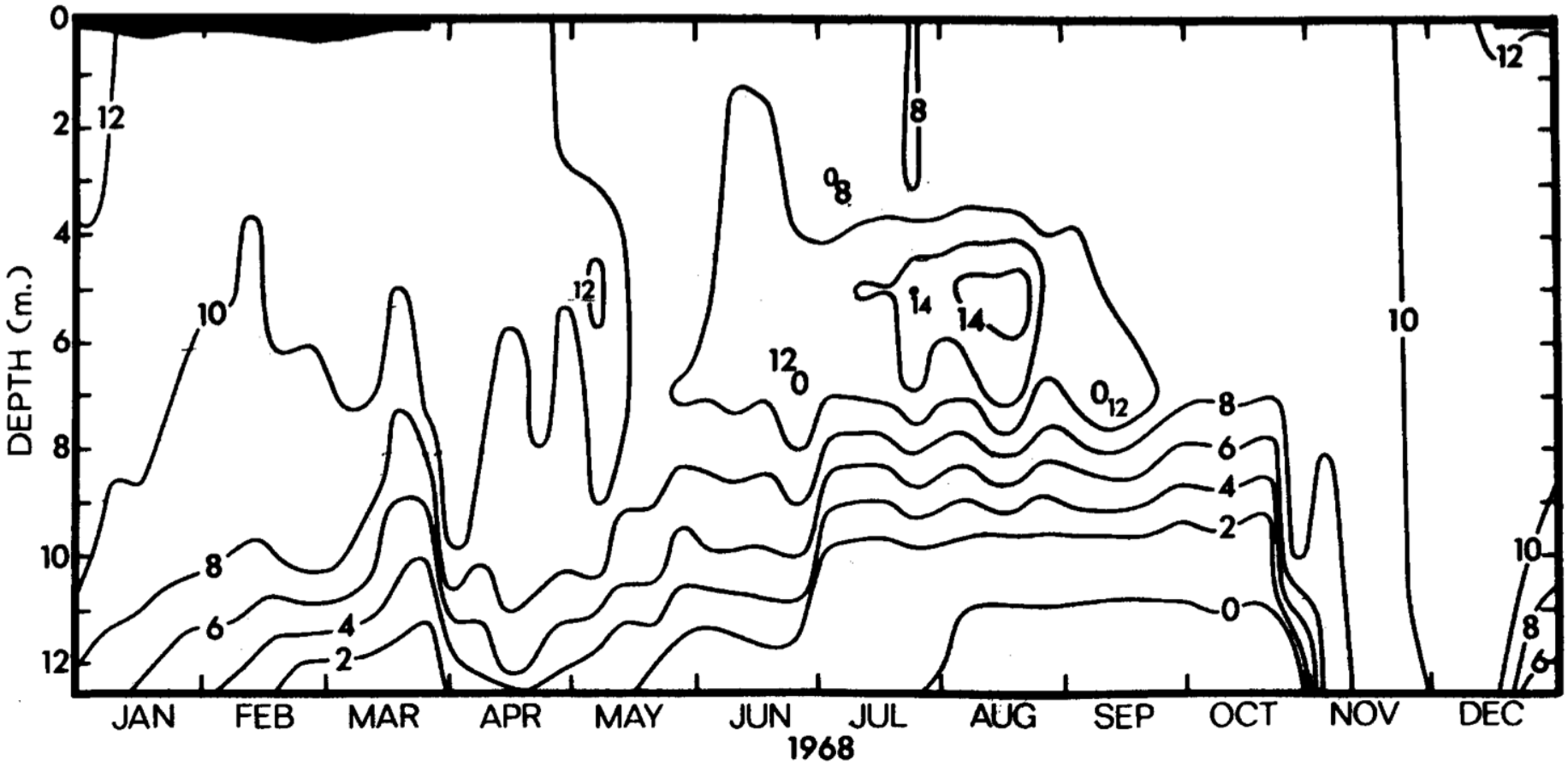
How might seasonal hypoxia might develop in the bottom layer of eutrophic lakes?



So remind me: why install aerators in Westhampton Lake?

Oxygen Depletion in Lake Michigan

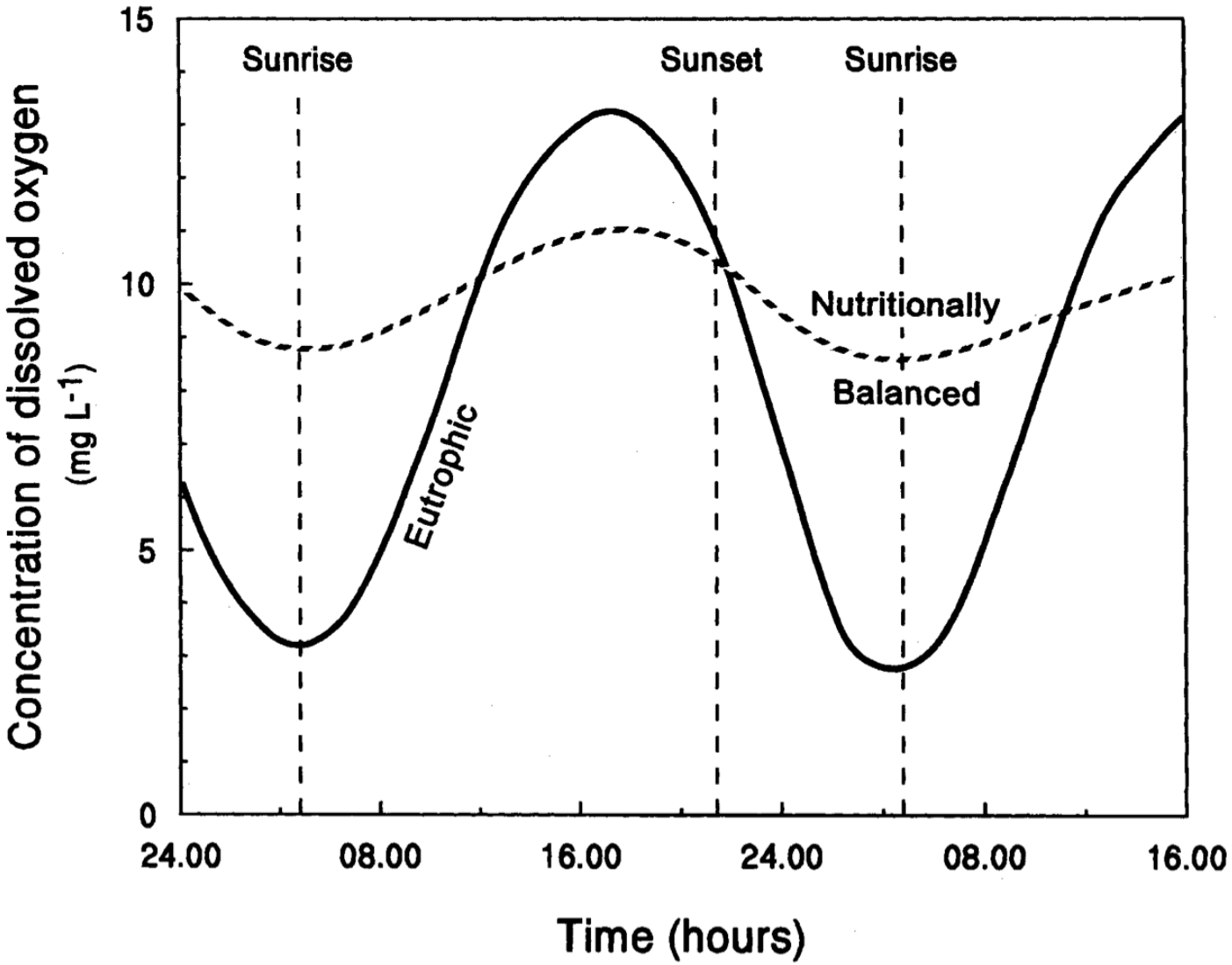
Can I see some real data showing seasonal hypoxia in a lake?



- Contours give DO in mg/L
- Completely anoxic from mid-summer until the fall overturn; hypoxia in winter too

Oxygen Depletion in Eutrophic Lakes: Epilimnion

Is there any way hypoxia can develop in the *top layer* of lakes? How?



- Day-night (diurnal) switch of algae between photosynthesis and respiration
- Conditions may lead to particularly low DO by morning
- Also: algae mats may interfere with O_2 dissolution

Effect of Hypoxia on Chemical Composition

How does oxygen depletion affect the chemical composition of natural waters?

- Reduced forms of chemicals are favored:
  - $HCO_3^- \longrightarrow CH_4(g)$
  - $NO_3^- \longrightarrow NH_3(g)$ or $NH_4^+(aq)$
  - $SO_4^{2-} \longrightarrow H_2S(g)$ or $HS^-(aq)$
  - $Fe(OH)_3(s) \longrightarrow Fe^{2+}(aq)$
- Reduced form of many chemicals are more mobile than their oxidized form
- When hypolimnion is completely depleted of O_2, it will release nutrients into the water, specifically N and P.
  - During mixing (eg fall overturn) can lead to further algae blooms
  - Ecosystems recycle nutrients...nutrient pollution is the gift that keeps giving