Lecture 3: Water as an environment

Outline

- Introductory comments
- Physical properties of water
- Chemical properties of water
- Some closing thoughts

I. Introduction – Water's unique properties are key to their supporting aquatic life.

A. Physical, chemical, and biological properties are interrelated
- each modifies the others and none operates alone
- we split these properties apart for our convenience
- after today, we'll focus on biology

B. Diversity of aquatic habitats
- most of Earth's surface (71%) is water
- fish live from pole to pole, deepest ocean, harsh desert springs, …

C. Remarkable water
- it's because of water's properties that fish can occupy all these systems
- unique density properties
- stable, slow rate of change
- dissolves and transfers ions and nutrients

II. Physical properties of water

A. Density

1. Specific gravity = mass per unit volume
- distilled water at 4C (maximum specific gravity) is 1.0000 g/ml
- dissolving of salt increases specific gravity

a. Relationship to air
- water is 775x as dense as air
- forces of gravity on a fish are minimal

b. Freshwater vs. saltwater
- freshwater (<500mg/l TDS) is 1.0005 g/ml
- seawater (35,000 mg/l TDS) is 1.028 g/ml
- within waterbodies, density doesn't vary greatly with salinity (some exceptions)
- density *is* greatly affected by temperature

2. Movement of fish in water
- density of water has implications for how fish move about

a. Vertical movement – goal: maintain neutral buoyancy
- want to achieve hydrostasis = tend not to sink or float → energetically inexpensive

i. swimbladders
- inflate or deflate to regulate buoyancy
- inflate or deflate through duct into gut (ancestral character) or by use or gas exchange with circulatory system (derived)
- freshwater fish regulate buoyancy over wider range (7-11% of volume)

than marine fishes (4-6%) – why?
- some benthic species have reduced or absent swimbladders

ii. low density tissue
- minimize bone or have cartilage, have oil-filled liver (e.g., sharks)
- ultimate conformers – have to trade off with having to keep swimming

b. Horizontal movement – viscosity creates resistance
- 100x viscosity of air → takes lots of energy for propulsion

i. strategies for locomotion
- strong muscles for vertebral column and fins – e.g., up to 75% of BW in tuna
- specialized fin shapes and quick vs. prolonged motion

ii. strategies for drag reduction – see figure
- fusiform shape – minimizes turbulence
- mucous coating
- scales of sharks break up turbulence into microzones
- schooling behaviors

3. Surface tension = tendency of a liquid to bead up
- water's surface tension highest except for Hg

a. Permits capillary action
- exchange at semi-permeable membranes in kidneys, liver, gills, swimbladder

b. Allows communities to exist at surface
- groups of invertebrates like water striders
- traps food items for planktivores

B. Temperature
- water exhibits high temperature stability and slow rate of change

1. Stability
a. High specific heat
- the amount of (small) calories to raise 1 g of water 1C = 1.000 for water
- highest of any liquids except ammonia and hydrogen

b. Acclimation
- although water conducts heat well, it changes heat slowly (much slower than air)
- allows fish to acclimate, use a full range of temperatures over time

2. State conversion
a. Latent heats of melting and evaporation
- ice doesn't melt easily
- latent heat of melting = 80 cal/g
- higher than all but ammonia

- water doesn't evaporate easily
- latent heat of vaporization = 536 cal/g
- highest of all liquids

b. Natural ranges of temperature
- fishes (collectively) can tolerate from -2 to 40C because it's *stable*
- as long as it doesn't change too quickly, they can *conform*

3. Temperature / density interaction

a. Water is the only substance not heaviest as a solid. Why?
- most molecules are most densely packed as solid spheres
- but, see figure to see relation of density and temperature for water
- ice is tetrahedral and expands relative to water; hence, floats
- at high temperatures, thermal expansion, spherical packing

b. Implications for ice formation
- without these properties , ice would freeze from bottom, eventually freeze solid
- ice freezes from top down – happy outcome for aquatic life!
- water is densest at 4C on bottom, ice insulates water column from colder winter air

c. Temperature stratification – see figure
- temperate lakes and reservoirs – seasonal temperature zonation
- depending on temperature, productivity, and dissolved oxygen, is summer fish tend to stay in thermocline or hypolimnion

C. Light in water

1. Importance
- heating
- photosynthesis
- visibility
- scattering: 100% downwelling, 5% horizontal, 1% upwelling

2. Fate of solar radiation – see figure
- reflection – varies with season, height and angle of sun
-absorption – 53% per meter
- penetration – 40% per meter in distilled water
-scattering – depends upon total dissolved and suspended solids
  - turbidity makes water unproductive and low visibility

3. Attenuation of colors – see figure
- reds quickly absorbed
- greens and blues go deepest
- violets quickly scattered
- daytime green, twilight blue, night yellow

4. Visual acuity of fishes
- pick up light very well
- best exemplified by deep-sea fishes (more later)
- even bluegills can detect 1/10-billionth of normal daylight (=430 meters down in clear sea)
- rods and cones of fishes are adapted to predominant colors of their habitats

III. Chemical properties of water

A. High solvency
- best solvent of any liquid
- acids, bases, salts pass in-out readily without changing water

1. Disassociation into H+ and OH-
- hydrolysis split up molecules and they are thereby dissolved because they bind
- reactions happen because bonds are weak

- opposite of dissociation is condensation

2. Excellent transfer medium
   - because of capillary action, water easily transfer substances into and throughout fish

B. Dissolved solids

1. Saltwater
   - Na^+ and Cl^- make up ~85% of the TDS (35 PPT)

2. Freshwater
   - Na^+ and Cl^- typically leached out to sea
   - major ions are Ca^{++} and HCO_3^-
   - TDS generally 72-400 mg/l
   - in softwater streams, TDS can be 5-20 mg/l

   a. Hardness
      - concentration of divalent cations Ca^{++} and Mg^{++} or equivalent
      - soft water < 20 mg/l as Ca^{++}; hard water > 100mg/l as Ca^{++}
      - hardness indicates ability to chelate (bind) heavy metals
      - heavy metals are 1000x more toxic in soft water

   b. Trace nutrients
      - P and N in PPB range
      - essentially fertilizer – feeds algae, phytoplankton
      - necessary, but there can be *too* much – more later

C. Dissolved gases
   - at 0C, water contains 2% nitrogen by volume (vs. 78% in air), 1% oxygen (vs. 21%), and 0.05% CO_2 (vs. 0.03%)

1. Nitrogen
   - fairly inert
   - some bacteria and cyanobacteria are able to “fix” nitrogen and use it

2. Oxygen

   a. Necessity for respiration
      - most fish require 4-12 mg/l

   b. Problems of too much (supersaturation)
      - not terribly common – below high dams, can occur in aquaculture contexts
      - → embolisms in bloodstream, popeye, death from gas bubble disease
      - e.g., in salmon smolts in Columbia and Snake Rivers

   c. Problems of too little – see figure
      - more typical, esp. in very productive systems where respiration > photosynthesis, lots of decomposition
      - summerkill because of algal blooms in fertile lakes (hypolimnion)
      - winterkill because of ice cover over shallow lakes
      - organic pollution of streams

3. Carbon dioxide

   a. Necessity for photosynthesis

- major source of carbon in organic life forms

b. Role in determining buffering capacity
- CO_2 is a product of respiration
- $CO_2 + H_2O$ H_2CO_3 $H^+ + HCO_3^-$ $H^+ + CO_3^{--}$
  carbonic acid bicarbonate carbonate
- above pH 8.3, little CO_2; below pH 8.3, little CO_3^{--}

c. Alkalinity vs. pH as index of productivity and stability
- alkalinity is the ability to neutralize acidity
- pH not as important as alkalinity or buffering capacity, which maintains stability
- expressed as concentration of acid-neutralizing ions as $CaCO_3$
- acid rain (sulfuric and nitric acids) lowers pH of poorly buffered waters
- counteract by adding carbonates (e.g., limestone, $CaCO_3$)

IV. Concluding thoughts

- water is a benign environment in which good (and bad) substances are readily available
- life began in water
- water’s provided a stable environment for adaptive radiation