Announcements Aug 30

- Field Opportunities – Cienega Creek
- Volunteer Opportunity = The Wildlife Society Meeting Tucson
- Lamprey Photos will be on WEB
- EXAM 1 – Friday Sept 21

Lecture 4 - Chpt 5 – Oxygen, Respiration, Gas Bladder and Energetics

Respiration:
- Oxygen - aquatic vs air
  a) Water 1% O2 vs. Air 21%
- Water 800x dense and 50x more viscous;
  a) energetically more difficult to move and breath (fish 10% energy to breath vs. 1% terrestrial)
- Temperature - 8 O₂/l, 6.5, 5.6 in 10°, 20°, 30° C
- Salt Effects – less O₂ in salt water
- Terrestrial = Bidirectional breathing vs. Fish = Unidirectional
Water vs Air

<table>
<thead>
<tr>
<th>Affected function</th>
<th>Attributes</th>
<th>Respiratory</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>efficiency</td>
<td>solubility</td>
<td>low</td>
<td>high (20 x that in water)</td>
</tr>
<tr>
<td>ventilation</td>
<td>density</td>
<td>high</td>
<td>1000 x lower</td>
</tr>
<tr>
<td>transport</td>
<td>diffusion</td>
<td>slow</td>
<td>$10^6$ x faster</td>
</tr>
<tr>
<td>membrane state</td>
<td>moist</td>
<td>moist</td>
<td>dry</td>
</tr>
</tbody>
</table>

Gills – Site of Gas Exchange

1) Bony or cartilaginous arches that anchor pair of gill filaments
2) Numerous Lamella (primary and secondary) – thin epithelial cells
KEY: Counter Current Exchange System – blood and water flowing in opposite directions
Afferent, Efferent, Primary and secondary lamella and WATER and Blood
KEY: Counter Current Exchange System – blood and water flowing in opposite directions

Need continuous supply of O2 rich water = Ventilation of gills

Moving Water Across Gills:
  Pump with buccal and opercular chambers; a) water enters mouth by buccal expansion; b) water accelerated by simultaneous contraction of buccal and expansion of opercu: Reverse = cough

Sharks, skates and rays – use flaps of skin to create current
What if Low Oxygen?

Fish will increase:
   a) frequency of ventilation (buccal and opercule);
   b) increase ventilatory stroke volume.

Accessory Ventilation
   - Gulp water at surface – higher O2 due to diffusion
   - Breath Air (Gills collapse)
     - Gill modifications – *Clarius batrachus* (walking catfish); thick lamellae; branched structures
     - Skin – well vascularized skin – eels – (*Anguilla anguilla*)
     - Mouth – obligate air breathers, vascularized buccal regions w/ surface convolutions and papillae; gills degenerate – drown if forced immerse
   - Gut – Plecostomus, etc. – Swallow air, O2 in gut – CO2 out at gills.
   - Modified Swim Bladder – Lungfish – need to surface for air; Other with modified = Bichir, Amia (Bowfin); Lepisosteus (Gars)

### Air Breathing Fish

<table>
<thead>
<tr>
<th>Organ used for inspiration for air</th>
<th>Fish</th>
<th>Habitat</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gills</td>
<td>Synbranchus</td>
<td>South America, fresh water</td>
<td>An eel-shaped fish without any common English name</td>
</tr>
<tr>
<td>Skin</td>
<td>Anguilla</td>
<td>North America, Europe, tropical oceans</td>
<td>The common eel, breeds in the soil; larvae migrate to fresh water</td>
</tr>
<tr>
<td>Gill</td>
<td><em>Clarius</em></td>
<td>Southeast Asia, fresh water</td>
<td>A common fish, often called mud eels</td>
</tr>
<tr>
<td>Mouth and opercular cavities</td>
<td>Electrophorus</td>
<td>South America, fresh water</td>
<td>The electric eel</td>
</tr>
<tr>
<td>Mouth and opercular cavities</td>
<td>Astyanax</td>
<td>Southeast Asia, fresh water</td>
<td>Called climbing perch, but not really a perch; related to tetra, the Brazilian fighting fish</td>
</tr>
<tr>
<td>Mouth and opercular cavities</td>
<td><em>Clarias</em></td>
<td>Southeast Asia, tropical oceans</td>
<td>A catfish, known also as the walking catfish</td>
</tr>
<tr>
<td>Mouth and opercular cavities</td>
<td><em>Clarias</em></td>
<td>Pacific Coast of North America</td>
<td>Also called the mudkicker</td>
</tr>
<tr>
<td>Stomach</td>
<td>Pterophysoides</td>
<td>Southeast Asia, fresh water</td>
<td>A small catfish common in home aquarium</td>
</tr>
<tr>
<td>Intestines</td>
<td><em>Ampelognus</em></td>
<td>South America, fresh water</td>
<td>An armored catfish, protected by heavy spines and bony plates</td>
</tr>
<tr>
<td>Swimbladder</td>
<td><em>Arapaima</em></td>
<td>South America, fresh water</td>
<td>An armored catfish</td>
</tr>
<tr>
<td>Swimbladder</td>
<td>Amia</td>
<td>North America, fresh water</td>
<td>The bowfin; range extends north to areas where large rivers have been cleared through water; belongs to primitive group Holostei</td>
</tr>
<tr>
<td>Swimbladder</td>
<td>Lepisosteus</td>
<td>North America, fresh water</td>
<td>The bowfin has a lung, but is not a true lungfish</td>
</tr>
<tr>
<td>Lung</td>
<td>Polypterus</td>
<td>Africa, fresh water</td>
<td>A true lungfish</td>
</tr>
<tr>
<td>Lung</td>
<td><em>Lepisosteus</em></td>
<td>South America, fresh water</td>
<td>A true lungfish</td>
</tr>
<tr>
<td>Lung</td>
<td><em>Propterus</em></td>
<td>Africa, fresh water</td>
<td>A true lungfish</td>
</tr>
<tr>
<td>Lung</td>
<td><em>Neocottus</em></td>
<td>Africa, fresh water, rivers</td>
<td>A true lungfish</td>
</tr>
</tbody>
</table>

*Obligate air breathers*
Gas Transportation:
Hemoglobin; Binds O2 release at tissue;
Some fish one type, others (Salmon & Suckers) have backup

Hemoglobin and Oxygen Disassociation Curves – percent saturation vs. partial pressure Oxygen (pO2)

**Bohr Effect** (lower affinity for O2 in acid due to configuration of O2 binding sites – requires higher pO2 for saturation)

**Root Effect** (never get saturated at lower pH due to `extreme change in configuration)

CO2 lowers pH – forms carbonic acid (H2CO3)
Respiratory surface – CO2 released, decrease H2CO3, Ph up – O2 binds easier
Temperature - Affinity O2 decreases as Temperature increases
  Why cold water fish die at increased temperatures; Tunas and sharks not effected by temperatures

Different fish also show different affinities – toadfish to left of mackeral makes it better for low oxygen environments
Bohr Effect - releases O2 from hemoglobin due to decreased affinity (pH)

Lower affinity for O2 in acid due to configuration of O2 binding sites – requires higher pO2 for saturation

Root - never get saturated at lower pH due to extreme change in configuration

- Lowered pH and increased CO2 decrease O2 carrying capacity
Buoyancy and Gas Bladders

Neutral Buoyancy – minimize cost of everything

1) Incorporate large quantities of low-density compounds
   a) Body 85% water – ½ salinity = lighter – *Mola mola*;

   b) Sharks - Lipids – specific gravity .9 & oils –
      hydrocarbon squalene (s.g. .86 in livers; Also
      cartilaginous skeleton = 1.1 s.g. vs 2.0 bone v. 1.05-1.1
tissues

   c) Teleosts – Sablefish, Medusa fish (pelagic), Rock fish
      – have triglycerides (low density oils) – in deep water
      greatly reduced skeletal elements and muscles;

Problems – energetically problematic and hard to respond

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Buoyancy and Gas Bladders

2) Swimbladders - precise control of buoyancy
   Used for hydrostatic balancing, sound production and
   reception, respiration

Two types:
   - A) Physostomous – connection via pneumatic duct between
     swim bladder and gut
   - Primitive – soft rayed teleosts; Herrings, salmonids, eels,
     osteoglossids, mormyrids, pikes, cyprinids, characins, catfish.
   - Gulp air through duct by force - Mainly shallow water – each 10
     m need 2X air to inflate
   - Release air by “gass-puckerflex” gas spitting reflex – relax
     sphincter and contract swim bladder wall.
Buoyancy and Gas Bladders

2) Swimbladders - Two types:

B) Physoclistous = Closed
Frees fish from surface – over 2/3 of teleosts are physoclistous, some lost Scombrids (tunas) and Darters and Sculpins
Related to ecology of fish – benthic fish = little or no; swift vs slow moving water; vertical migrations

Gas Bladders – usually four layers;
   1) outer = densely woven elastic fibers
   2) next = loosely organized fibers
   3&4) inner two = smooth muscle and epithelium
   quanine crystals just below outer elastic fibers

Gas Secretion

Rete Mirabile = (Wonderful Net) = tight bundle of afferent and efferent capillaries; Source of gas; But need to increase pressure – How??

Three phenomena
1) Effect of acidification on hemoglobin’s ability to hold O2
2) Reduced solubility of gases in solution as lactate and hydrogen ions increase = salting out effect
3) Efficiency of countercurrent exchange
Gas Secretion

What is mechanism?

Gas Gland secretes lactic acid into blood, lowers pH.

Increase partial pressure of CO2 by releasing CO2 from bicarbonate

Bohr Effect – Root Effect = decrease capacity of hemoglobin

More O2 into blood – diffuses into lumen

Greater the length, the more efficient transfer

Deflation = diffusion of gas into blood