* PHYSIOLOGY OF MARINE ORGANISMS

Lecture 7 – Oct 19th, 2015

Intro to Marine Science

Instructor: Lauren Bell

*Learning objectives

After this lesson, you will be able to:

- List the major physiological challenges that are unique to organisms living in a marine environment
- Describe at least three different adaptations to each of these major physiological challenges that marine taxa have utilized to successfully live in the marine environment
- Understand why different taxa groups (e.g., invertebrates versus vertebrates) face a different set of physiological challenges from each other
- Use your knowledge of marine physiological adaptation to propose a basic "design" for an ideal hypothetical organism if given a particular marine environment for it to live in

*Wide diversity of marine life

- ➢ Success of so many different taxa!!
- ➢ Unique ways of dealing with the "issues" of being marine
- ➢ Best 'strategy' in one environment may be less ideal in another

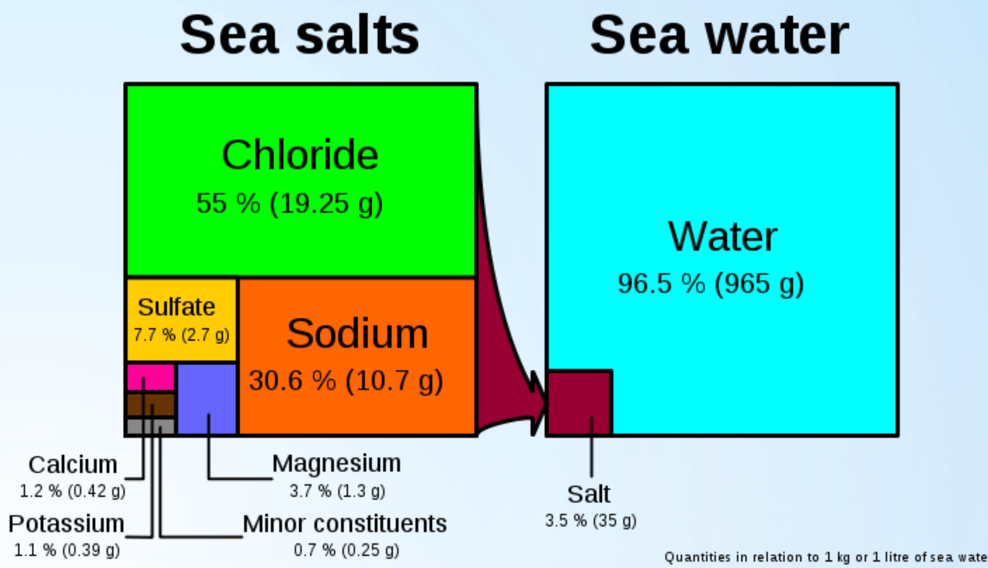
Major physiological considerations:

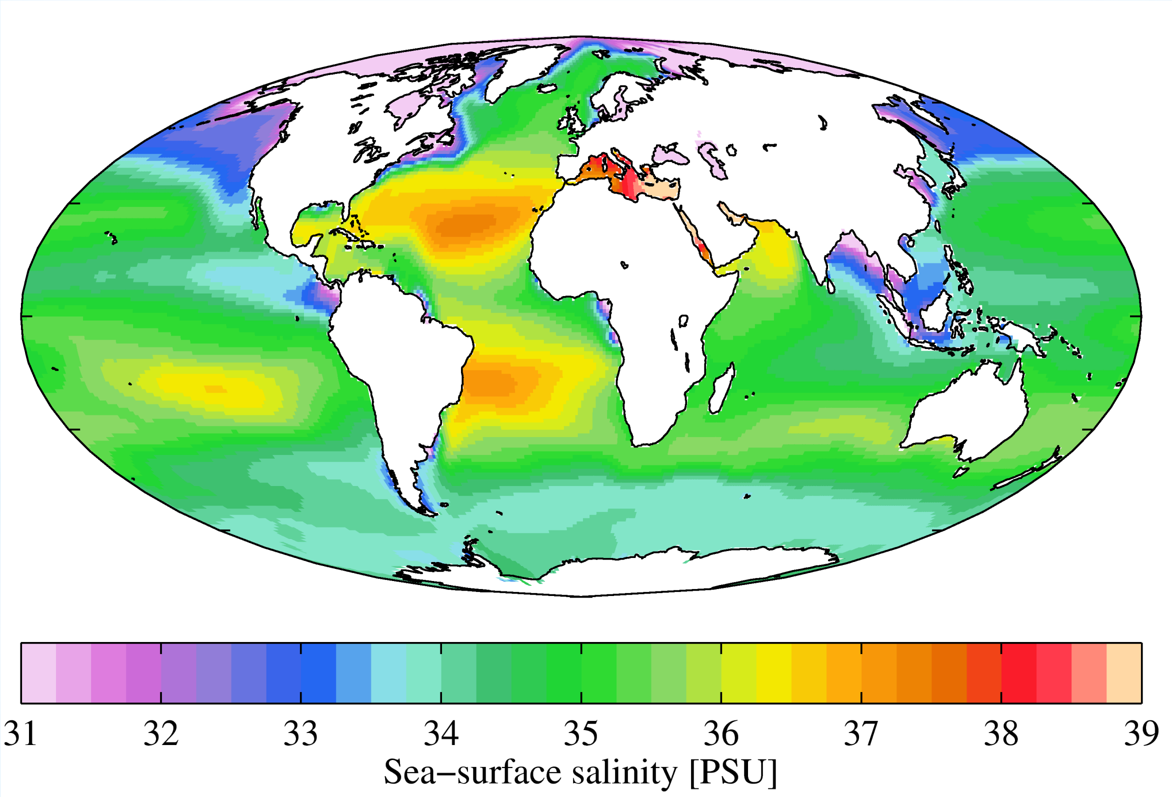
- Buoyancy (goal is to be <u>neutral</u>)
- Osmoregulation (salt balance)
- Energetics
- Thermoregulation
- Respiration (accessing/ maintaining oxygen levels)
- Hydrodynamics
- Pressure

*SALT water

On average, ocean salt concentration around 35‰

Compared to freshwater:
- increases density
- decreases freezing point





*Salt and organisms

Euryhaline

Tolerate and adapt to a wide range of salt concentrations

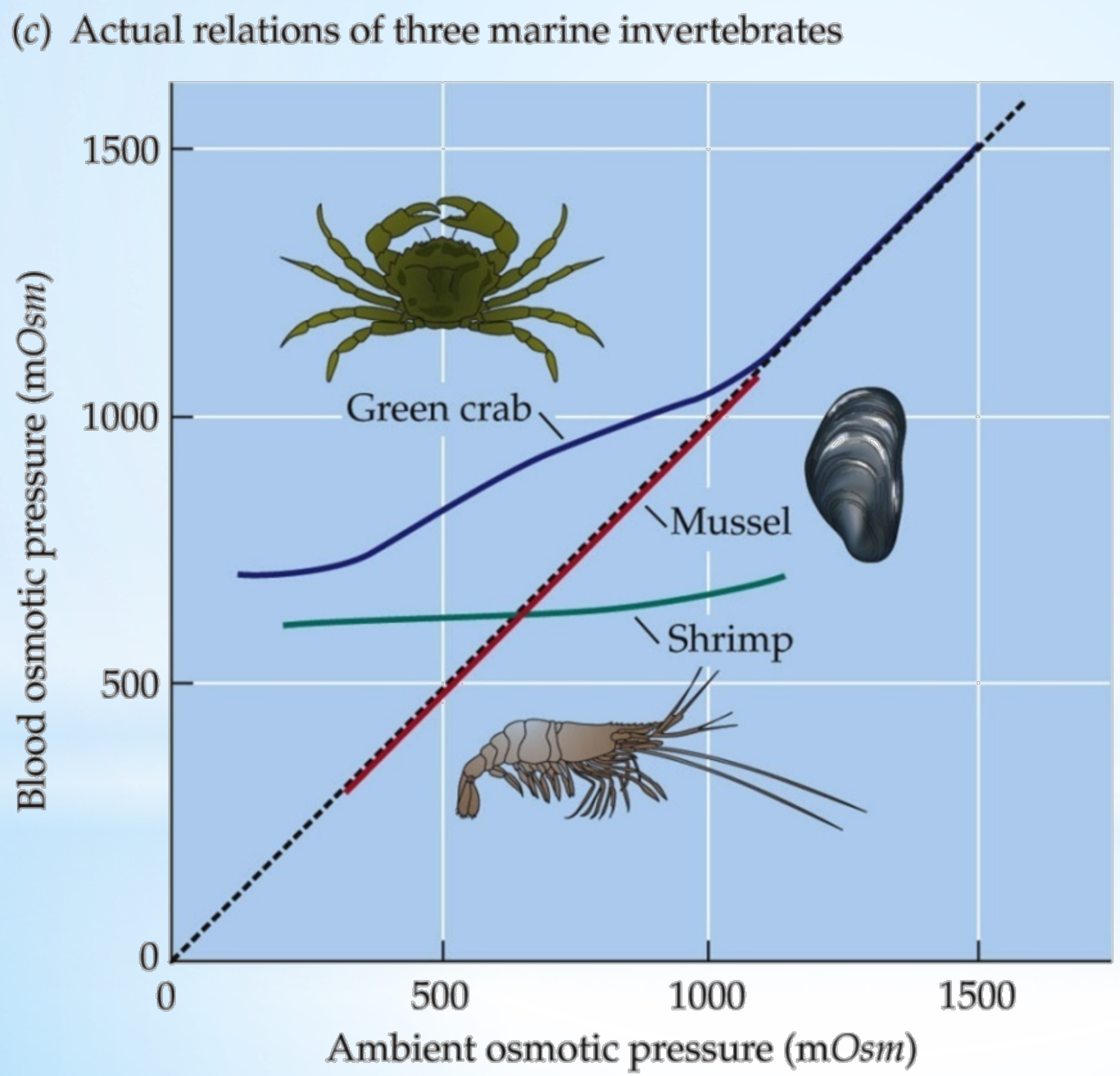
- Anadromous fish
- Intertidal species

Stenohaline

Limited tolerance to varying salt concentration

- Open ocean fish
- Echinoderms

*Conform or "resist"?

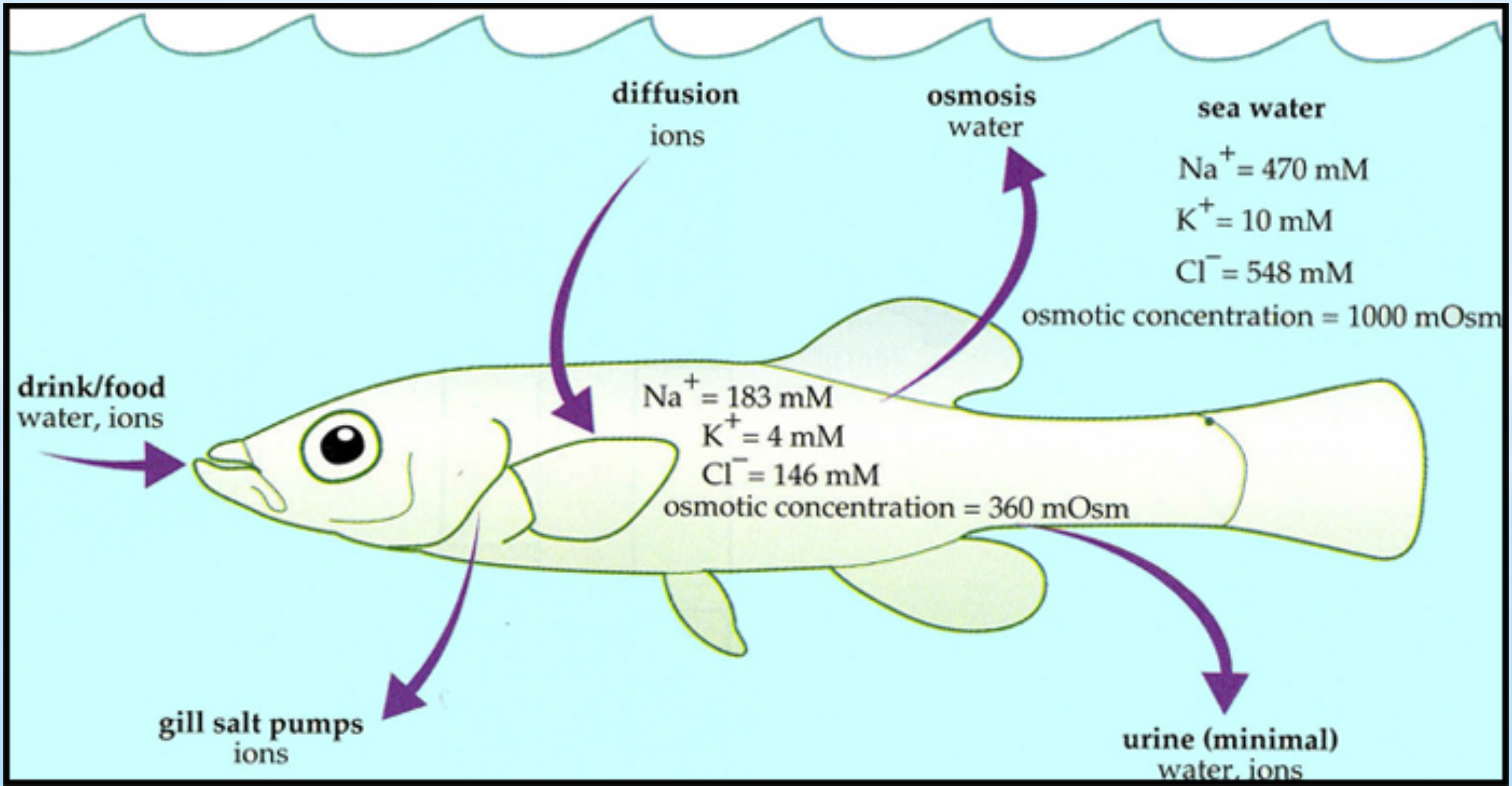


(osmotic pressure ~ amount of salt/dissolved particles)

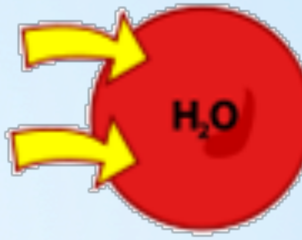
- Conforming means less energy, passive
- Regulation of salt balance requires energy, active process
- Most marine invertebrates are **osmo-conformers**
- Osmotic balance DOES NOT NECESSARILY MEAN ion balance
  (can use other ions to regulate osmotic pressure besides salts)

*Hypo-osmotic (relative to environment)

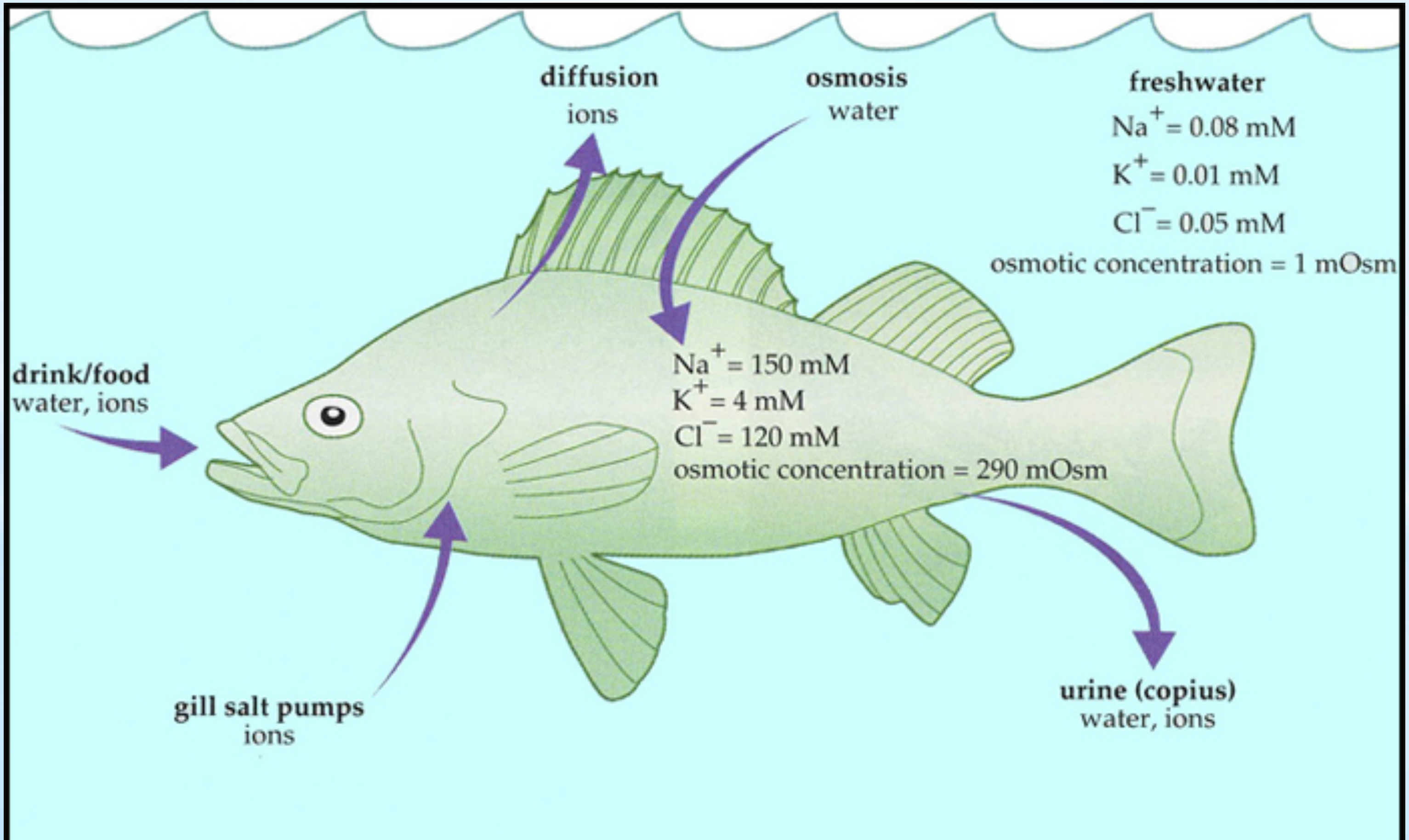
- Ocean way saltier than inside of fish
- Water wants to move OUT OF fish
- Fish drink SW for the **H_2O**, excrete excess salt
- Active transport of salts OUT over gills



*Hyper-osmotic (relative to environment)



- Inside of fish way saltier than freshwater
- Water wants to move INTO fish
- Fish don't drink, produce lots of dilute urine
- Active transport of salt IN over gills

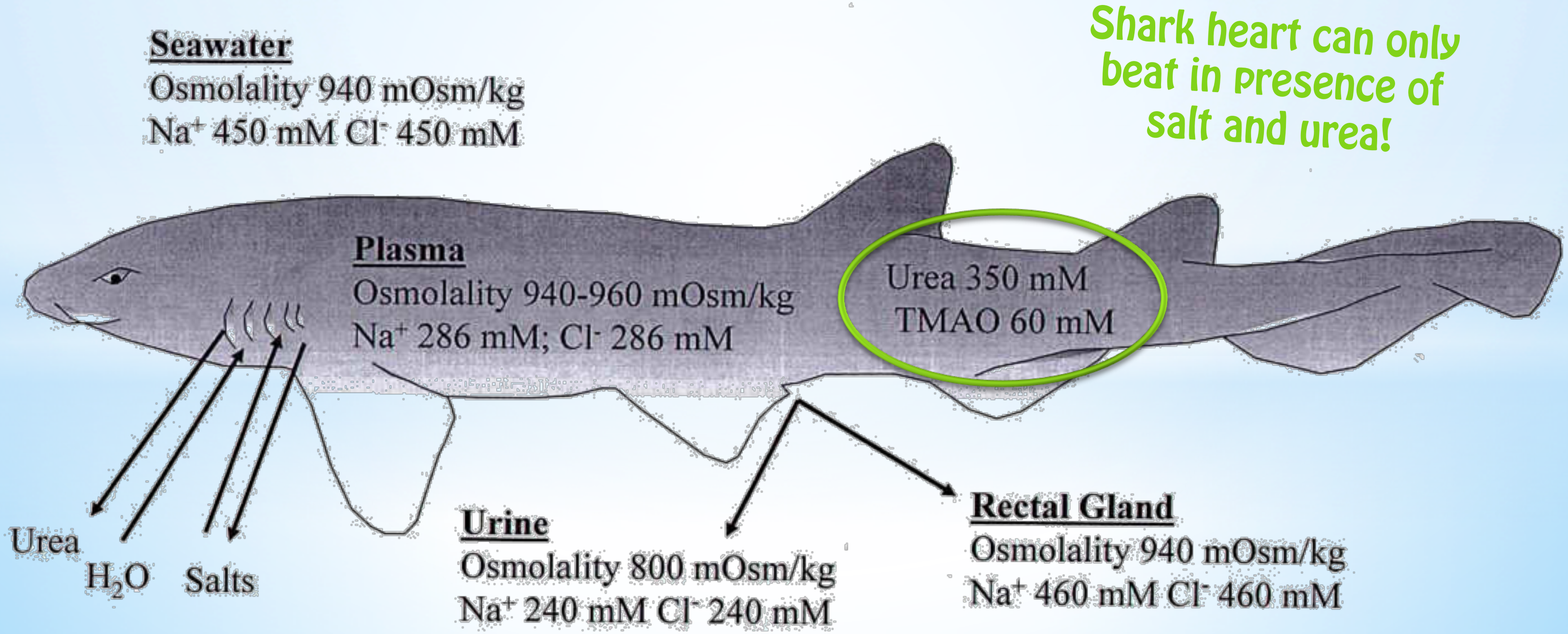


*Iso-osmotic (relative to environment)

- Salt and H_2O concentrations same inside as out
- Sharks: salt ions not enough to balance, also add **urea** and **amino acids**

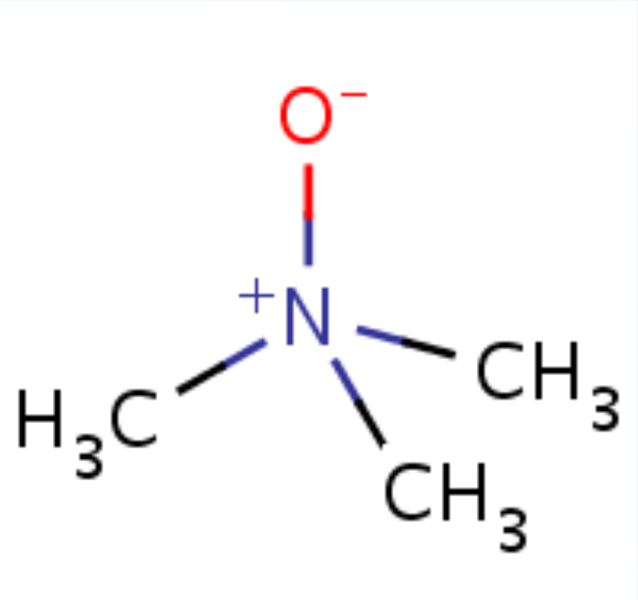
BUT! Urea is toxic (unfolds proteins/enzymes!)

Solution: add TMAO to neutralize



*TMAO (trimethylamine oxide)

- Protects proteins against destabilizing (unfolding)!
- Raises osmotic concentration, depresses freezing point
  - (useful for polar fish!)
- Counteracts:
  - effects of pressure in deep sea animals
  - heat denaturation
  - ammonia toxicity
  - urea toxicity



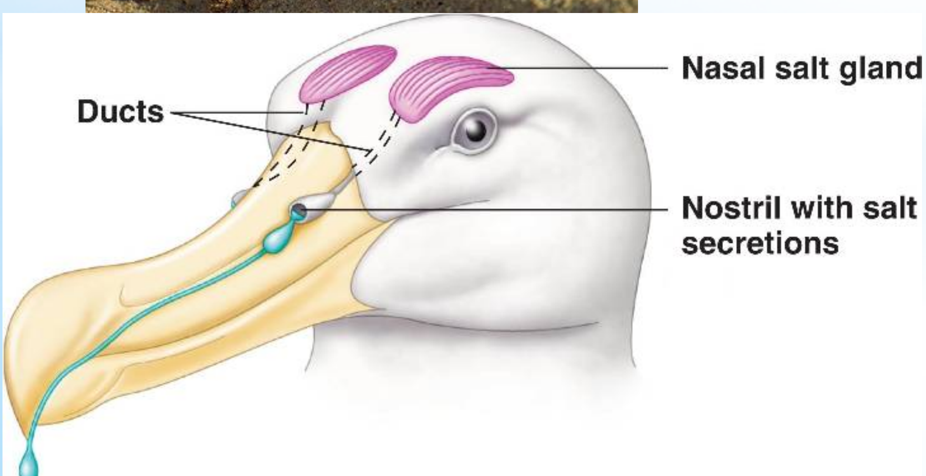
TMA (non-oxide version) is what produces the typical "fishy" sea food odor

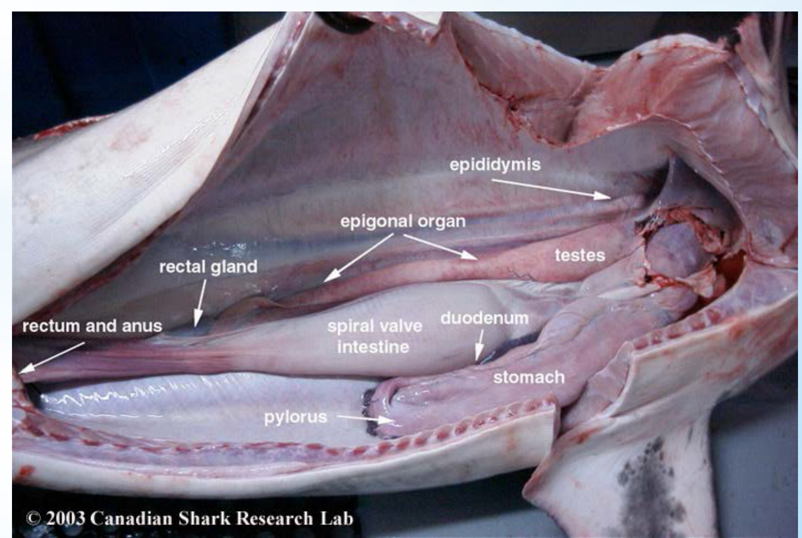
Disorders where build-up TMA, can't produce TMAO (odorless)

*Salt glands

- Kidney not efficient; cannot produce urine more concentrated than sea water
- If drinking sea water and not eliminating excess salt, they would lose more water than they gained

Solution: __Salt-excreting glands__
Lingual salt glands (e.g., crocodiles)
Orbital salt glands (e.g., turtles)
Sublingual salt glands (e.g., snakes)
Nasal glands (e.g., lizards, birds)
Rectal glands (e.g., elasmobranchs)





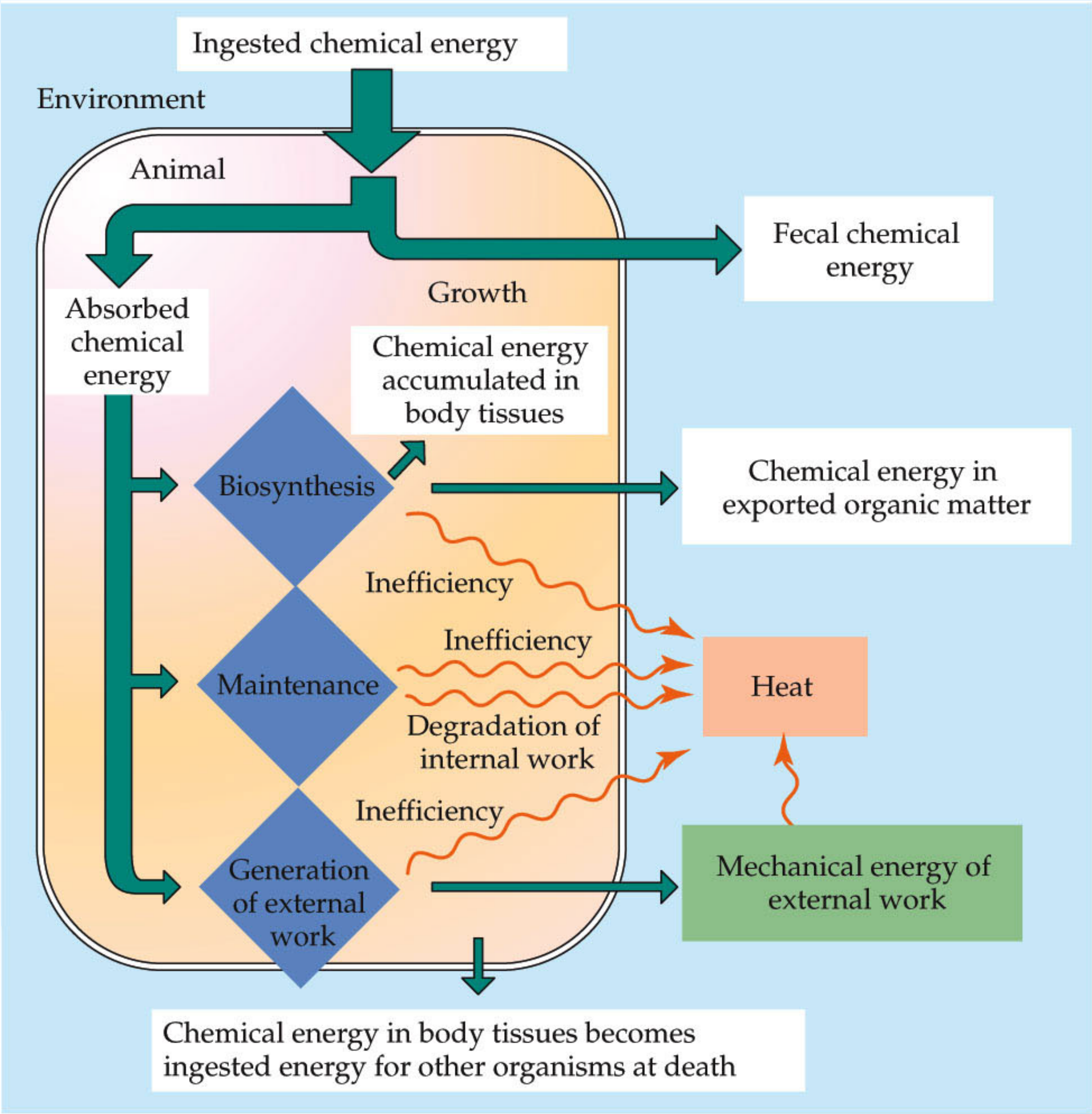
*Energetics

- Marine organisms must ingest energy
- Energy **neither created nor destroyed** – only transformed
- Transformation of energy is always inefficient – there is always some loss

By-product of energy metabolism

=

HEAT



*Energy budget

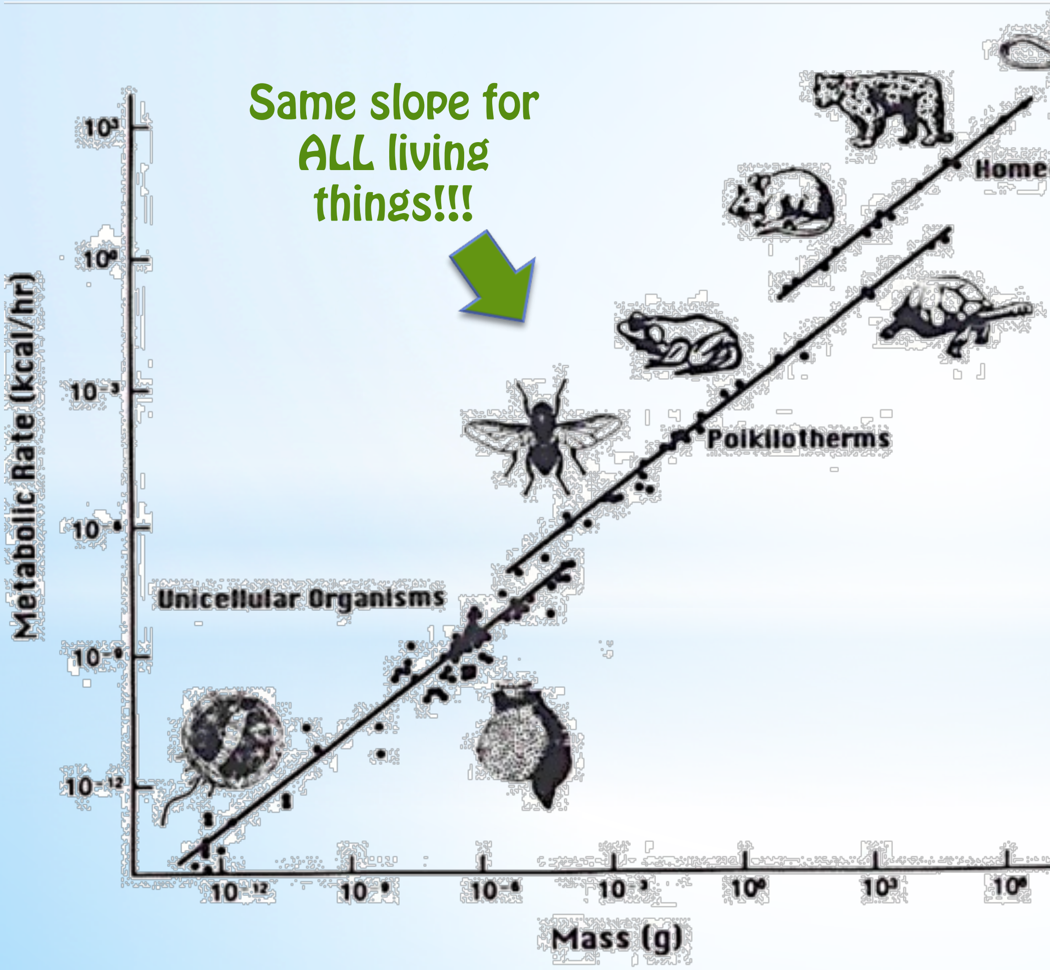
INPUT = OUTPUT

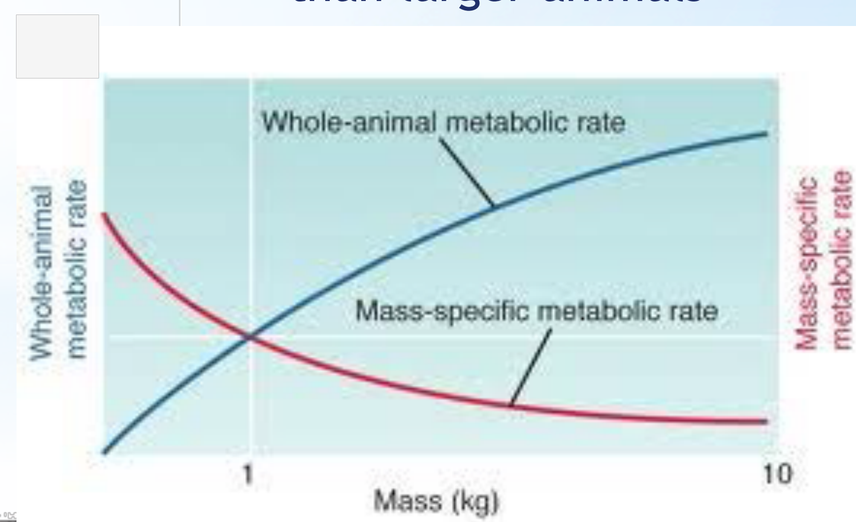
INPUT	OUTPUT	
Food/ Drink	Feces Urine Resting Metabolism Active Metabolism Digestion	**Losses**
	Growth Reproduction	**Production**

Animal metabolism (resting)

- **Metabolic rate** (rate at which energy is transformed) is mass specific
- On the whole, large animals consume more O_2 than smaller animals
- However, small animals use more O_2 per unit of mass

Means smaller animals typically have faster heart rates, greater food consumption, etc. than larger animals





*Calculating resting metabolic rate!

Slope of **0.75** is universal, though 'intercept' changes by taxa

For most fish:

$$MO_2 = 0.45 * (\text{mass})^{0.75}$$

Metabolic rate
liters O_2/hr

Fish specific intercept
liters O_2/(hr * kg)

Fish mass
kg

Calculating resting metabolic rate!

10 kg (22lb) Steelhead

<u>Whole Fish Metabolic Rate</u>

MO_2 = 0.45 lO_2/(hr*kg) * 10 kg $^{0.75}$

MO_2 = 2.53 lO_2/hr

Mass-specific Metabolic Rate

MO_2/kg = 0.45 lO_2/(hr*kg/kg) * (10 $kg^{0.75}$/kg^1)

MO_2/kg = 0.45 lO_2/(hr*kg/kg) * (10 $kg^{-0.25}$)

MO_2/kg = 0.25 lO_2/hr * kg

*Metabolic rate rarely 'resting'

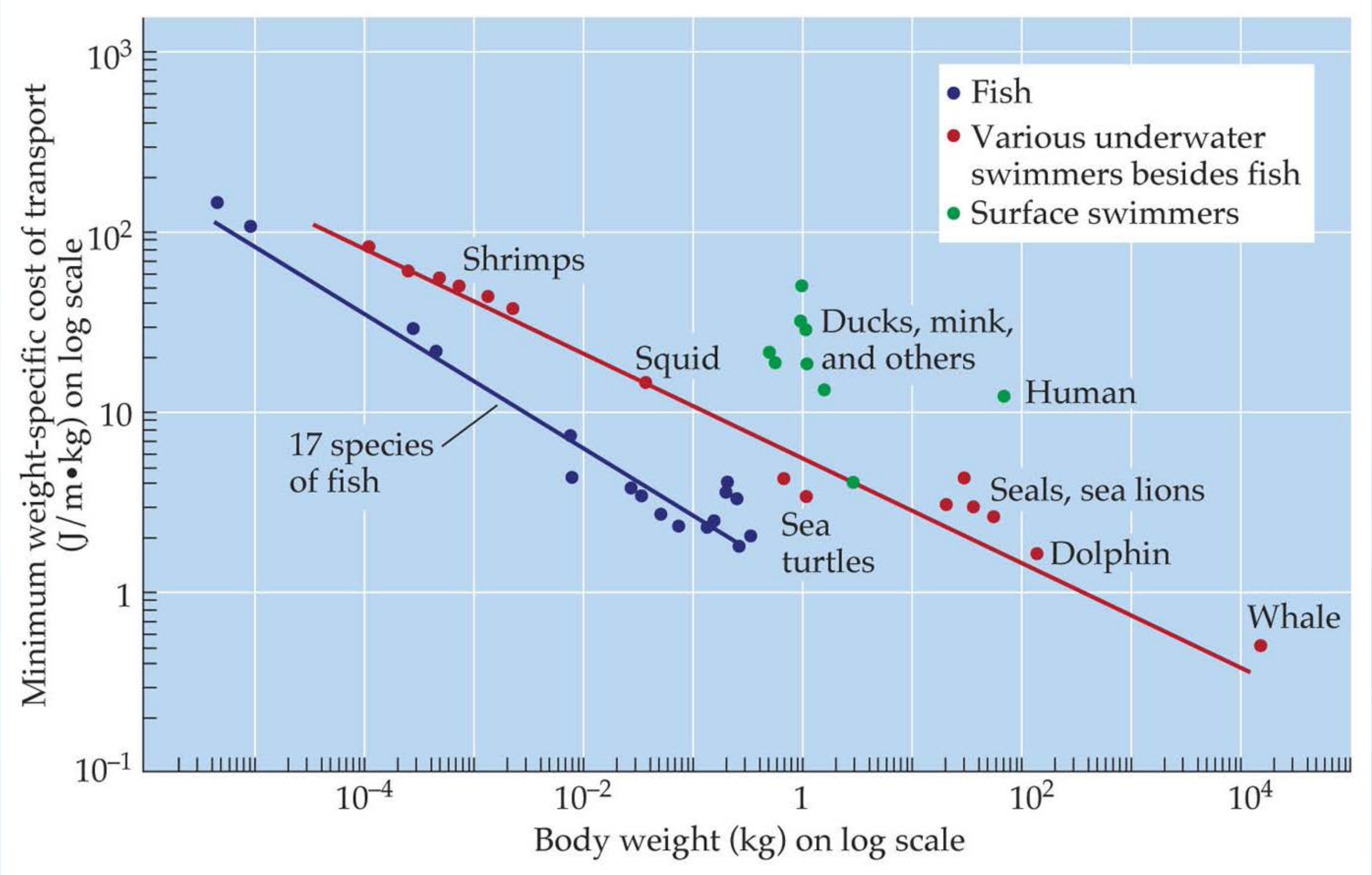
Factor	Response of metabolic rate
Factors that exert particularly large effects	
Physical activity level (e.g., running speed)	↑ with rising activity level
Environmental temperature	*Mammals and other homeotherms:*
	Lowest in thermoneutral zone
	↑ below thermoneutral zone
	↑ above thermoneutral zone
	Fish and other poikilotherms:
	↑ with increasing temperature
	↓ with decreasing temperature

*Metabolic rate rarely 'resting'

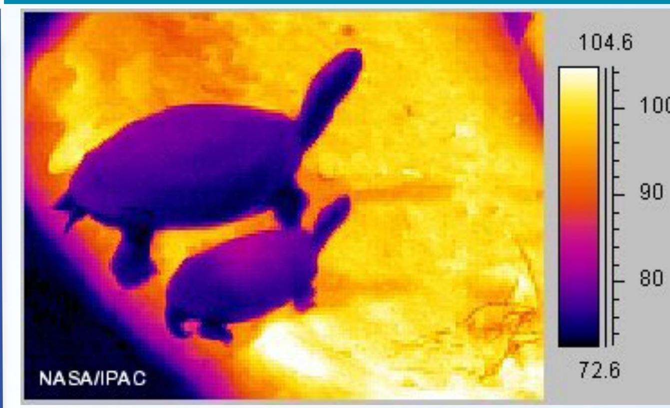
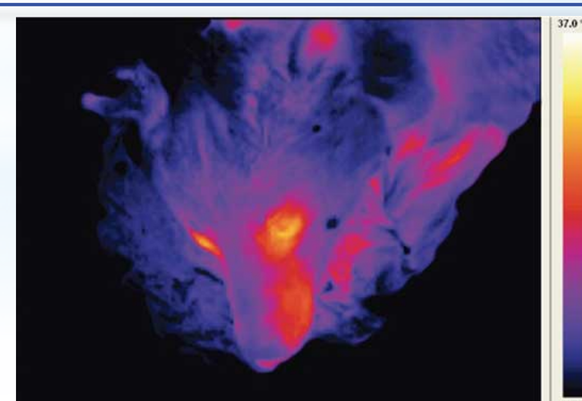
Factor	Response of metabolic rate
Factors that exert smaller effects	
Ingestion of a meal (particularly protein-rich)	↑ for several hours to many hours following ingestion
Body size	Weight-specific rate ↑ as size ↓
Age	Variable; in humans, weight-specific rate ↑ to puberty, then ↓
Gender	Variable; in humans, ↑ in male
Environmental O_2 level	Often ↓ as O_2 ↓ below a threshold, not affected above threshold
Hormonal status	Variable; example: ↑ by excessive thyroid secretions in mammals
Time of day	Variable; in humans, ↑ in daytime
Salinity of water (aquatic animals)	Variable; in osmoregulating marine crabs, ↑ in dilute water

*Energetic cost of transport

- Inverse relationship to size
- Animals adapted to water have lower energetic costs of movement – buoyancy is a huge advantage!!



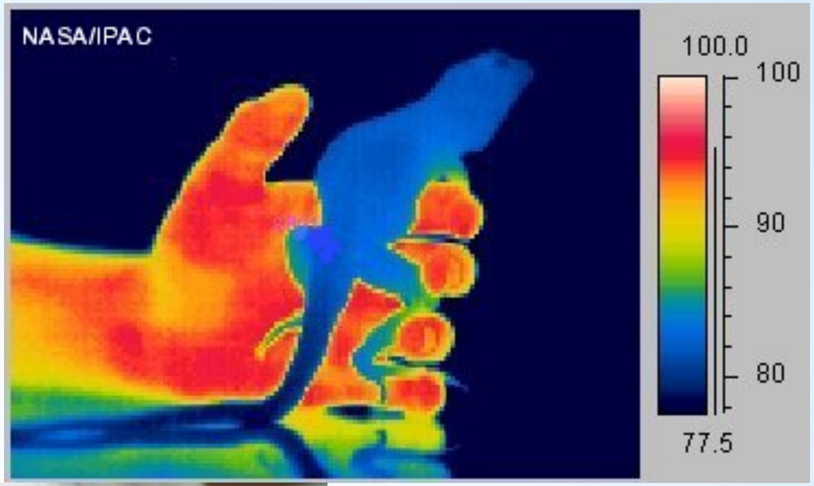
*Thermoregulation

	Maintain a constant body temperature **Homeotherms**	Body temperature changes **Heterotherms**
Gather heat from environment **Ectotherms**	 Tuna, billfish, shark (RARE!)	 Most fish, inverts, reptiles
Generate own heat from inside **Endotherms**	 Most mammals, birds	 Hibernators

*Heterothermic ectotherms

Body temperature changes as environment changes

Heat generated during exercise is lost readily – can't hold on to it



FISH GILLS

↳ **huge surface area!**

Awesome for maximizing O_2 extraction!

Horrible for heat conservation!

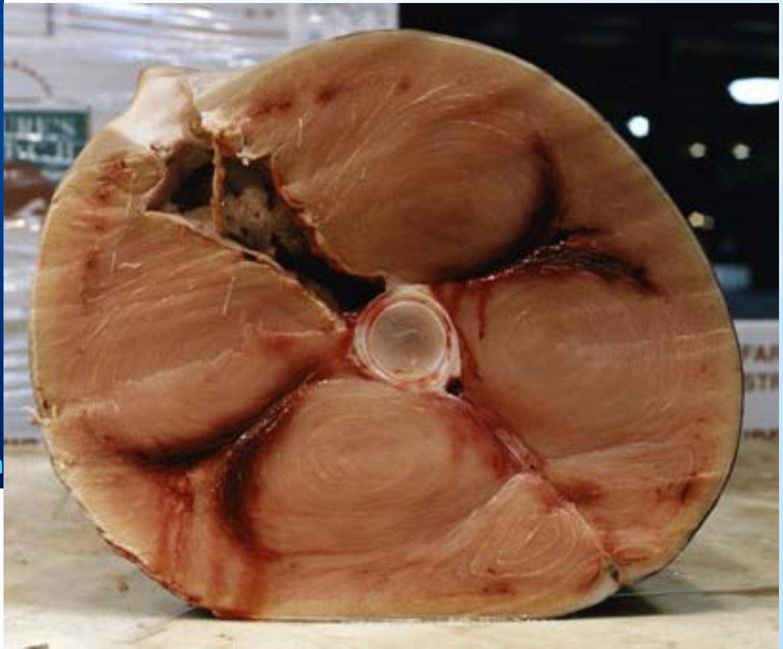
*Homeothermic ectotherms

Maintain body temperature ~14˚C above environment!

- Have to be large
- Have adaptations that allow them to 'hold on' to heat

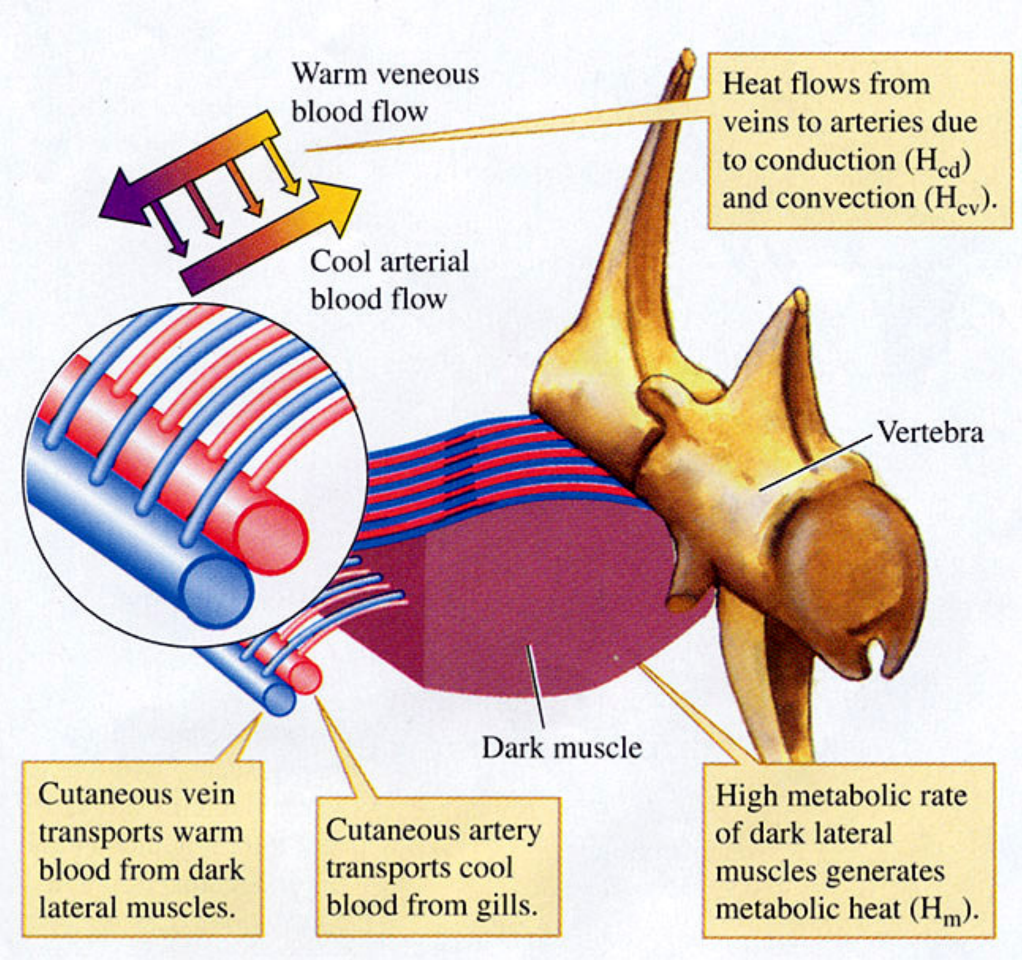
Result: warm muscles, can move fast!

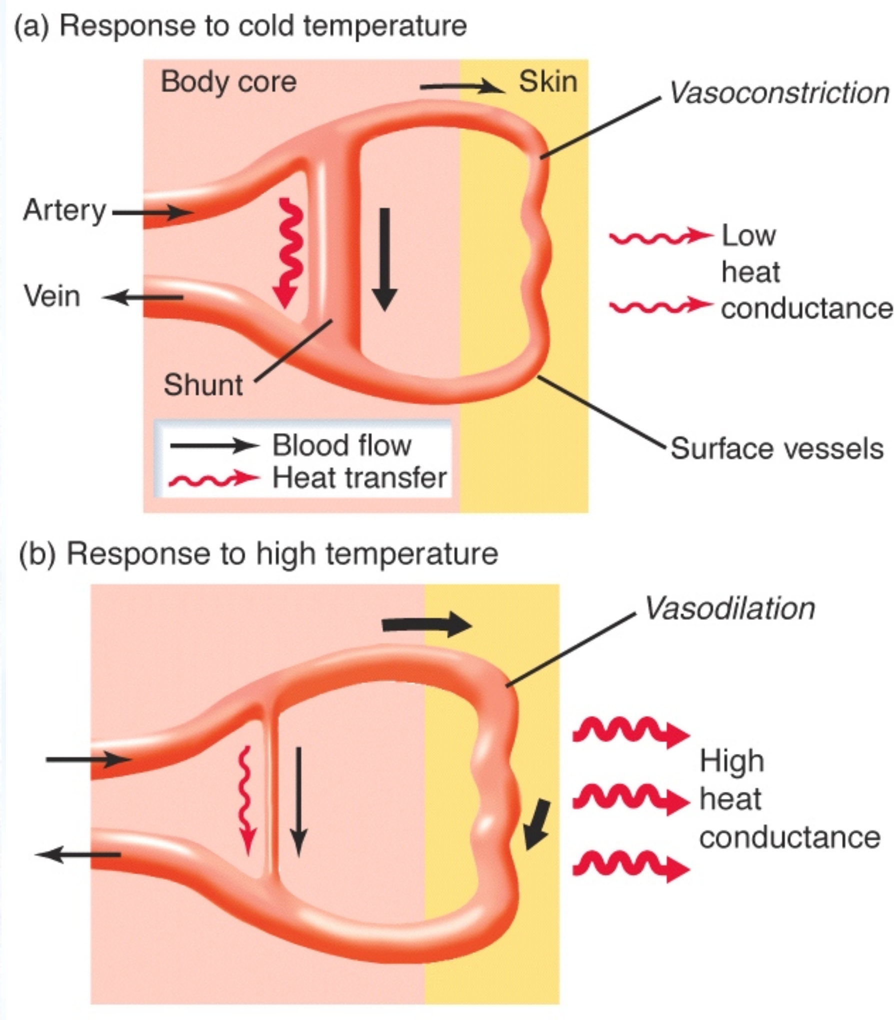
How do they do it?



*Countercurrent heat exchange

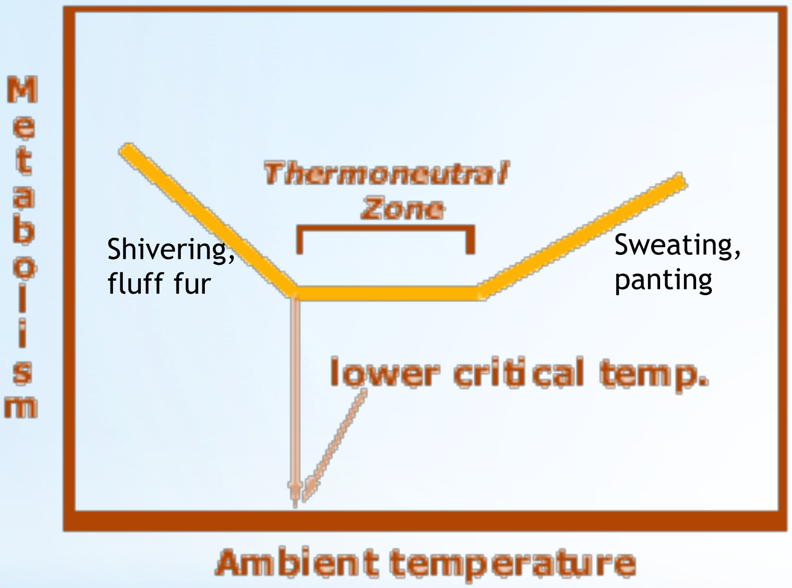
- Warm arterial blood runs close to colder vein blood returning from skin
- Can enhance effect of heat transfer using vasoconstriction when cold
- Or dump lots of heat when it's warm!





*Homeothermic endotherms

Maintain body temperature by generating own heat
Goal: stay in thermoneutral zone – lowest metabolic cost



In order of importance for keeping warm:

1) **BRAIN!**
2) **Body core/guts**
3) **Extremities**

Larger and/or lower surface area:volume retains heat better

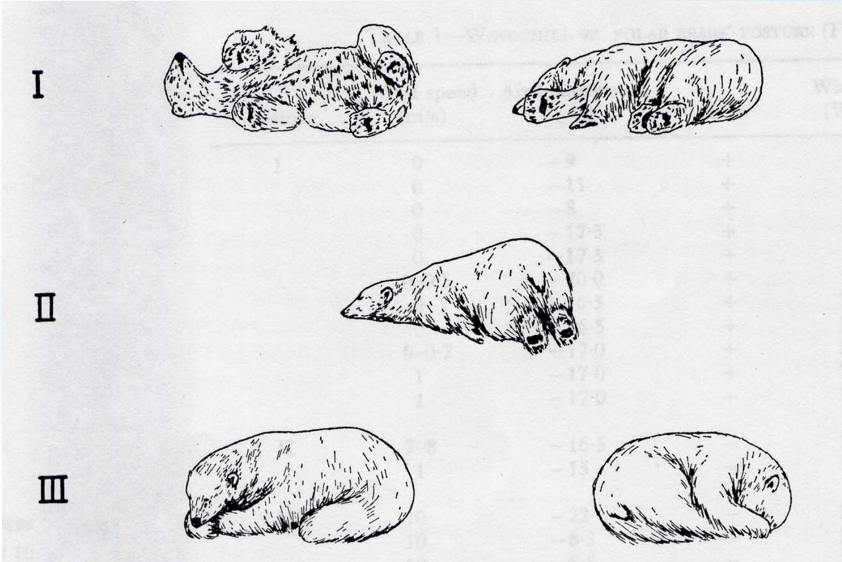


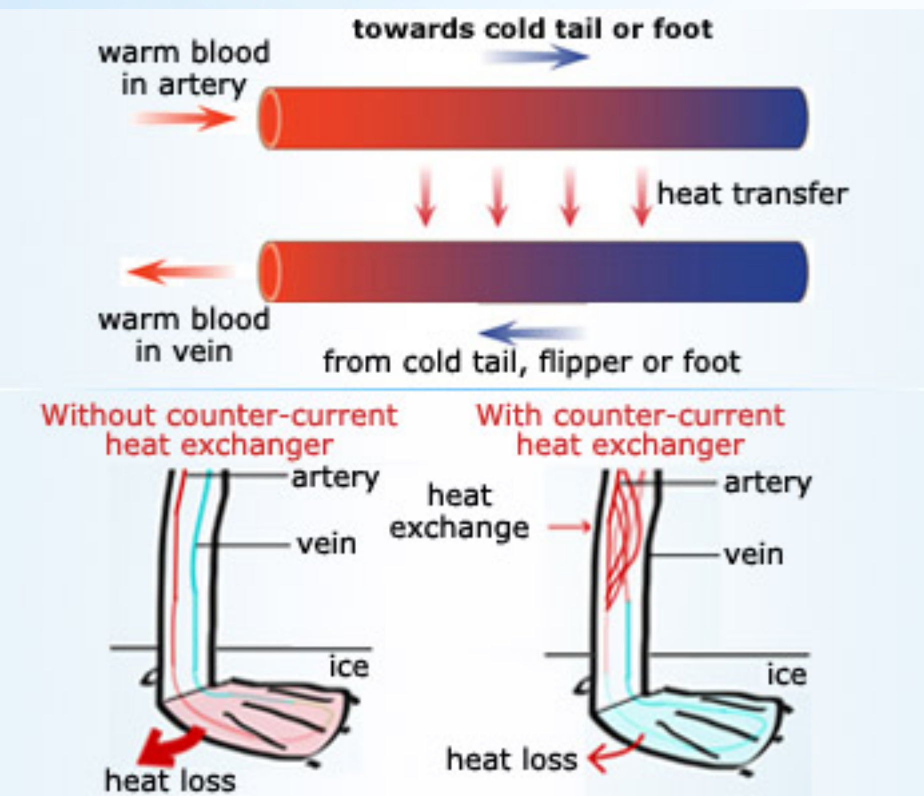
FIG. 5. Polar bears' postures at mean windchills 830 W/m² (I), 1410 W/m² (II) and 1910 W/m² (III). Detailed observations are listed in Table 1.

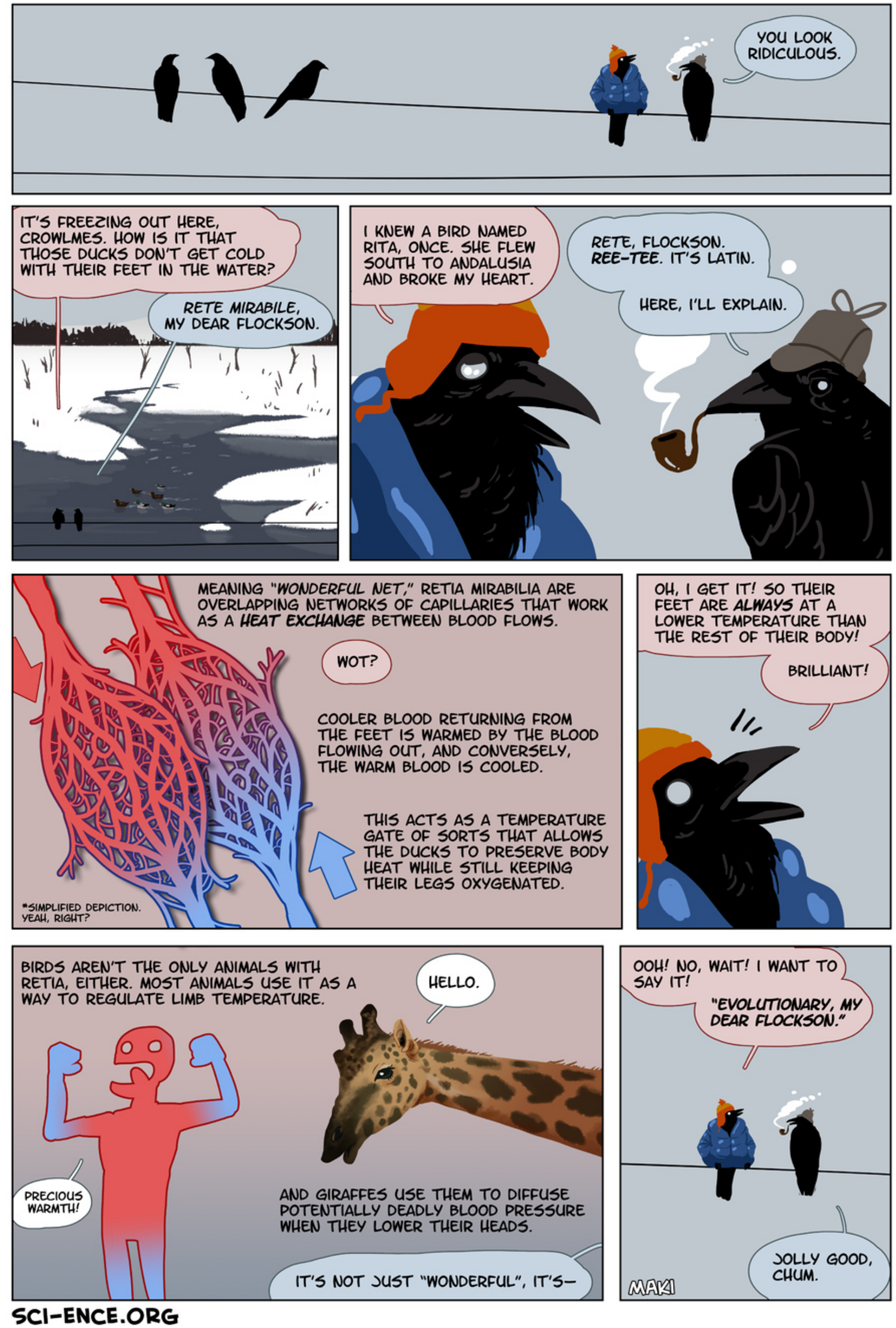
Physical and Behavioral Adaptations

*Rete mirabile

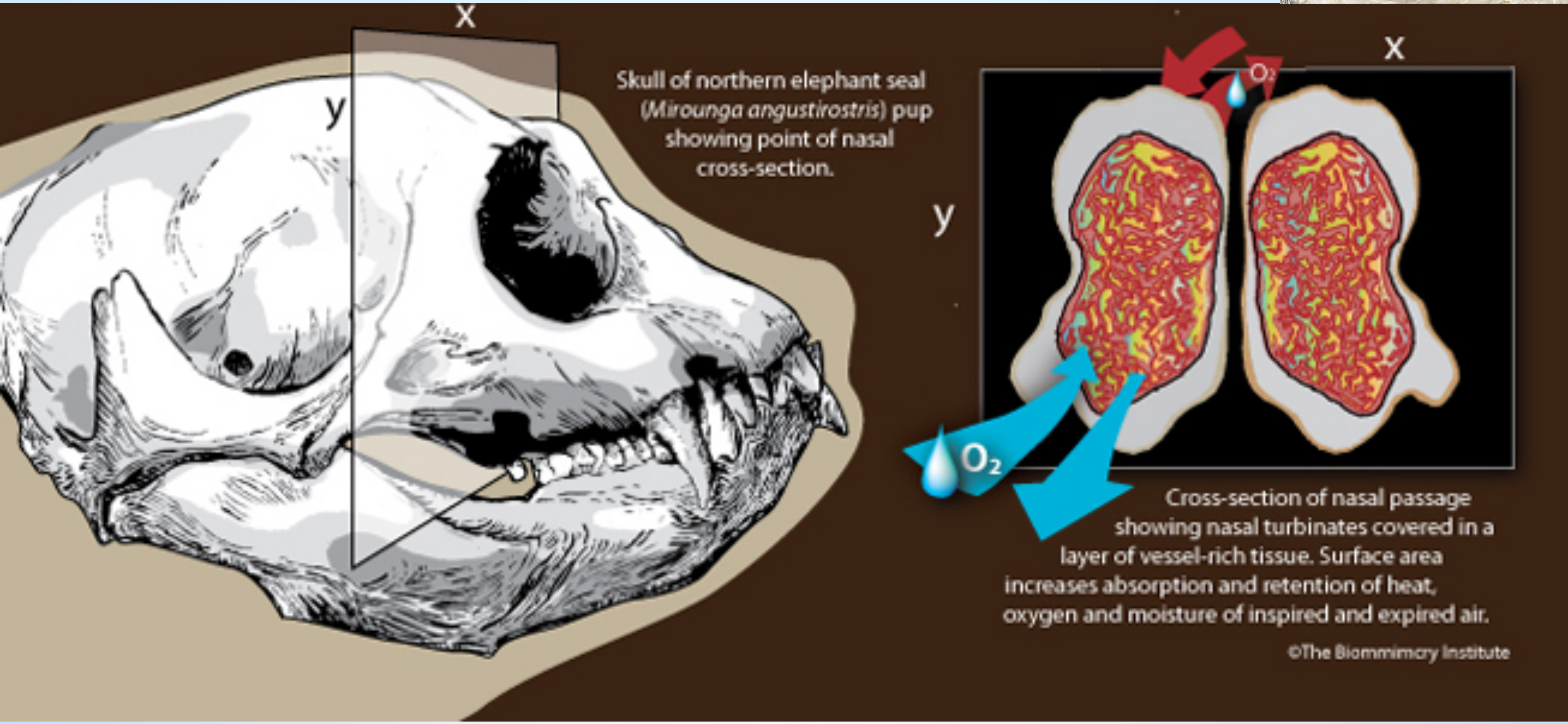
"wonderful net"

- Complex of arteries and veins lying very close to one another
- Allows for exchange of **heat, ions, and gases**





*Nasal rete = turbinates!

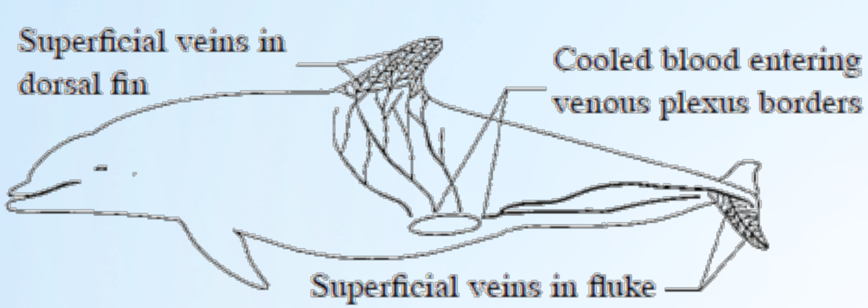


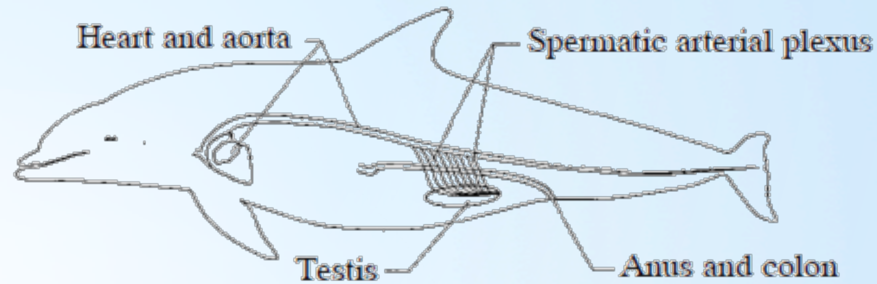
Present in most all tetrapods

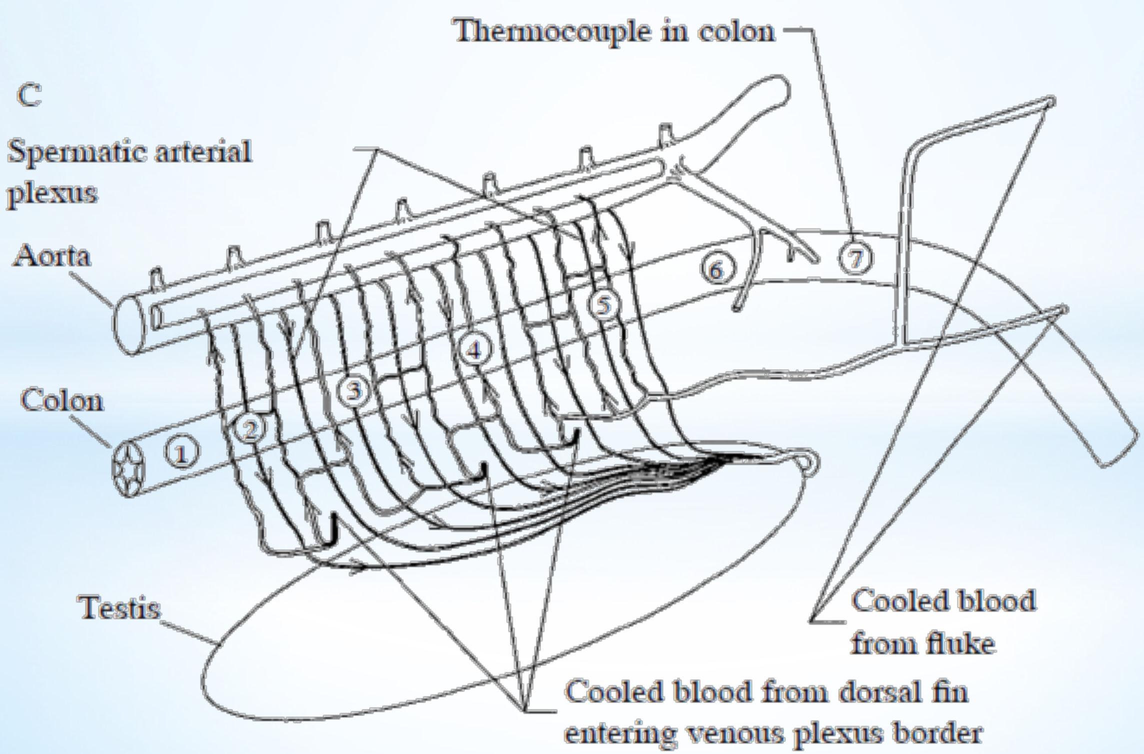
Cools air below body temperature before exhaling:

- Reduces respiratory water loss (otherwise evaporates quickly)
- Conserves heat loss

*Rete in Reproduction







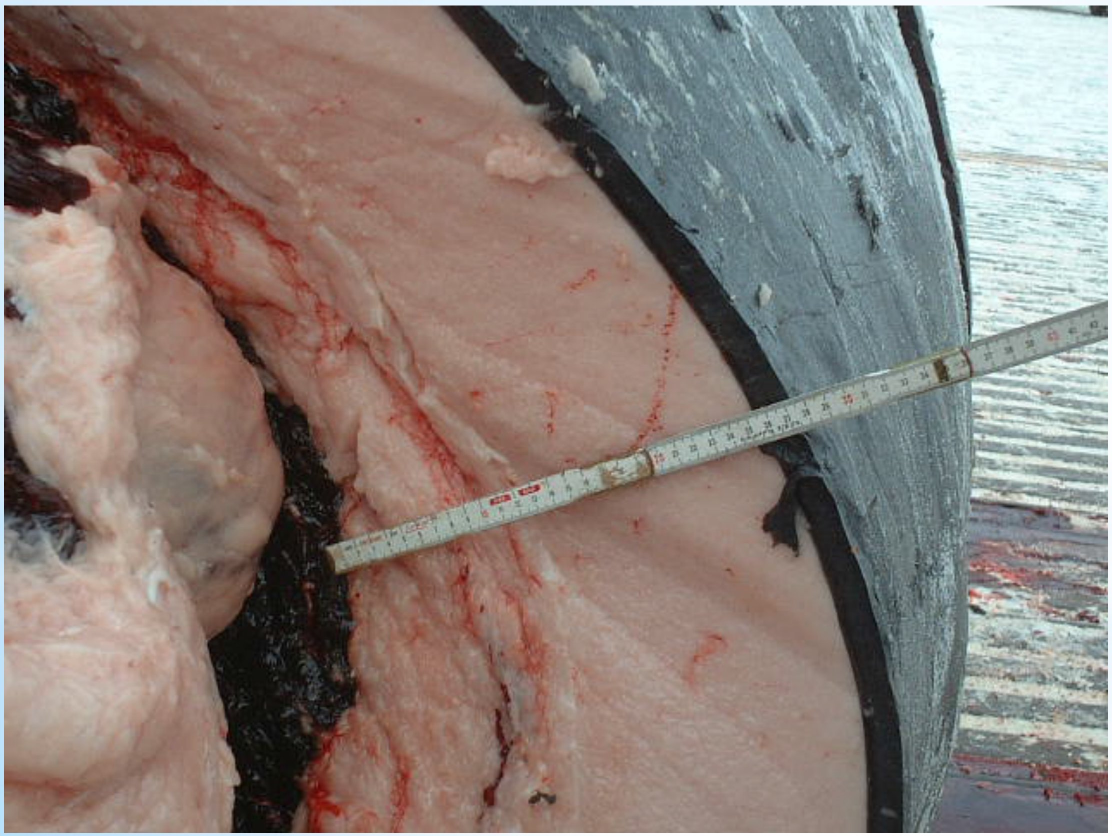
Spermatogenesis is heat sensitive

Can't get too hot! Typically needs to be 1-3°C cooler than core temp

Problem when have internal testes

*Storing energy as insulation

- If INPUTS > OUTPUTS, can store excess energy as FAT
- Lightweight, buoyant, insulation!

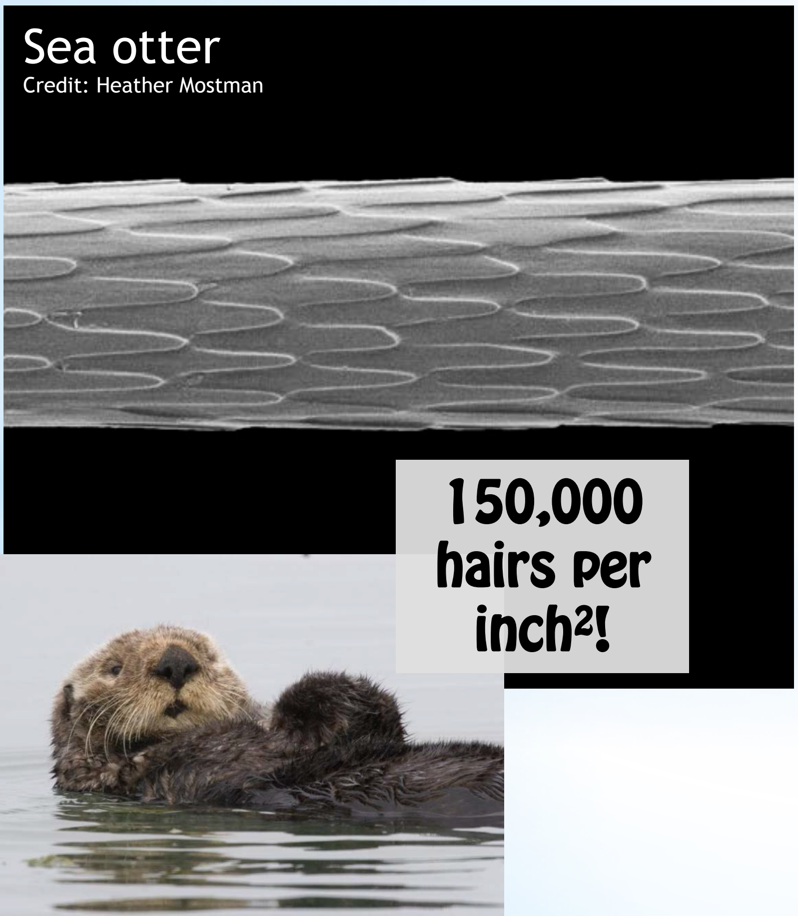


Certain animals choose to store GLYCOGEN rather than **FAT**

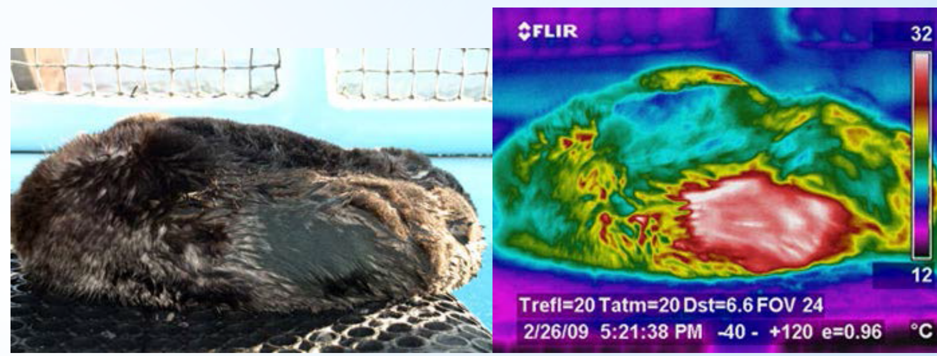
- **Much heavier**
- **Antifreeze properties**
- **Anaerobic conditions** (glycogen can be broken down in absence of O_2, produces lactic acid)

*Insulation with fur/feathers

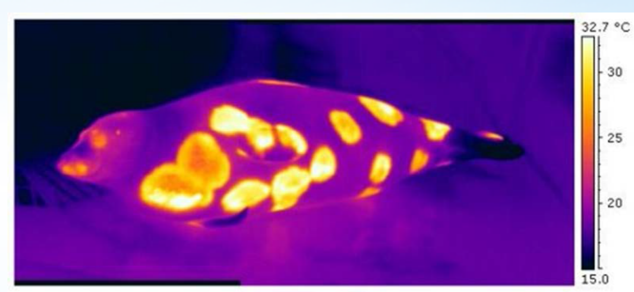
- All about trapping air, skin never comes in contact with water
- Grooming and preening = ~**25%** of resting metabolic rate!
- Allows for hair and feathers to interlock
- Also leads to vulnerabilities….



Oil spills preventing air trapping = rapid heat loss



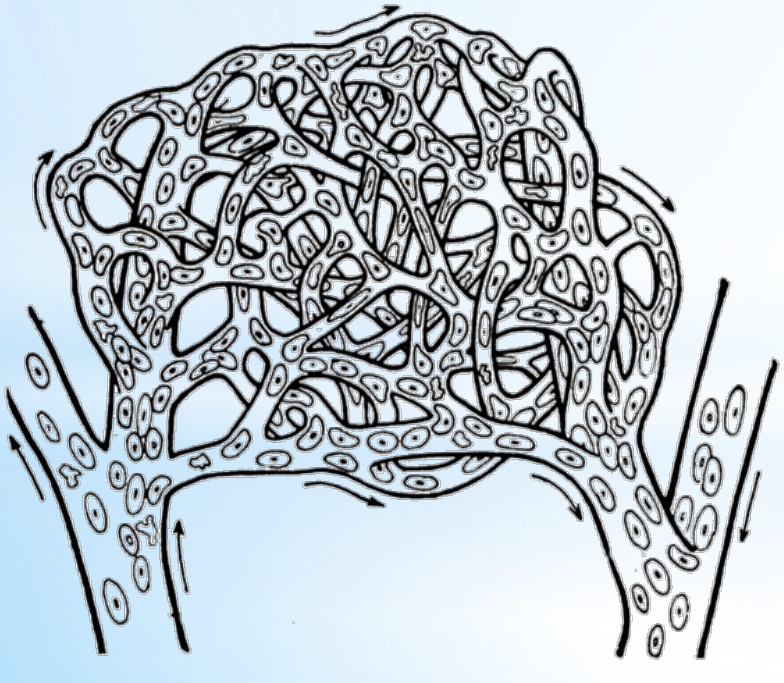
Molting period – perfusion of blood to skin HAS to be warm and dry



*Respiration / Oxygen supply

What is needed to efficiently acquire oxygen from air or water?

- Large surface area
- Thin interface
- Moist
- Large blood supply



Capillary network near the surface of the skin. Gases are exchanged to and from the capillaries, through the thin epidermal layer.

Respiration through skin

WHICH MARINE TAXA?

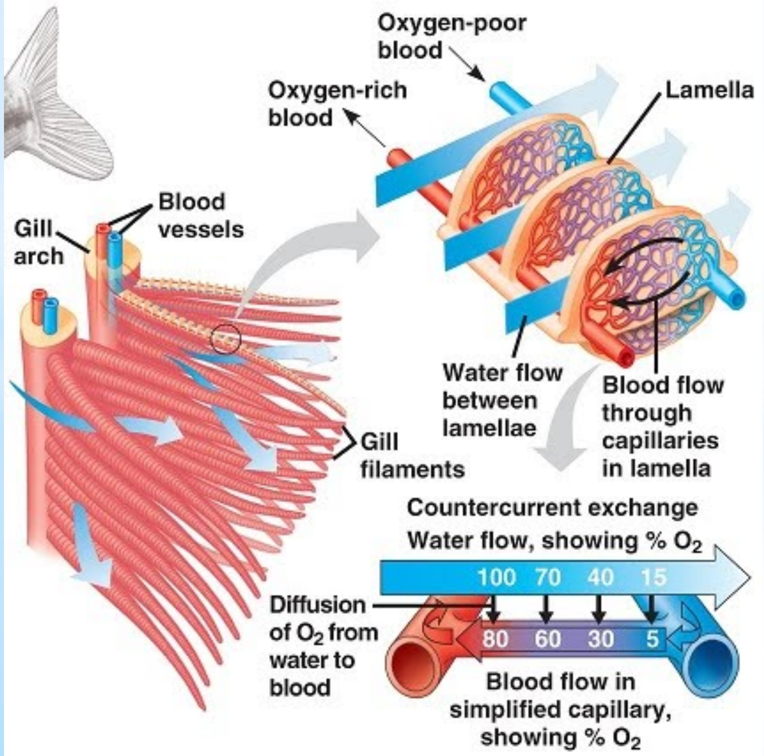
- Dense capillary beds near skin
- Slow metabolism means low O2 demand
- Shape maximizes gas-exchange interface and ease of transport through body

*Gills vs. lungs

Which is more efficient?
DEPENDS ON CIRCUMSTANCE!

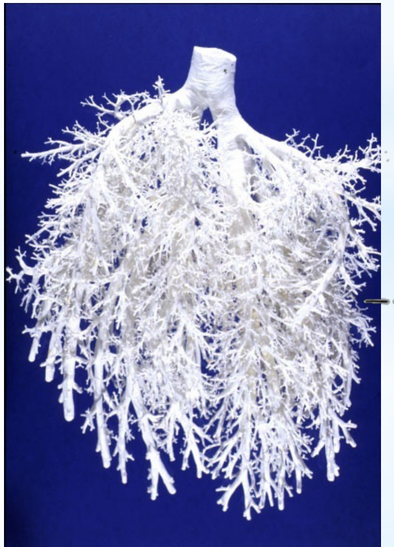
Gills

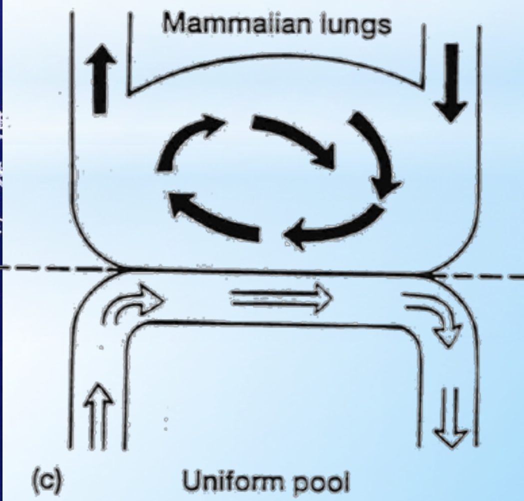
- In direct contact with media
- Can be ventilated continuously
- Can use counter-current gas exchange for maximum efficiency



Lungs

- Prevent drying out
- Can only be ventilated through same entry/exit
- Results in dead space, stale air that can't be exhaled
- Only efficient if surface area high & help with carrying oxygen

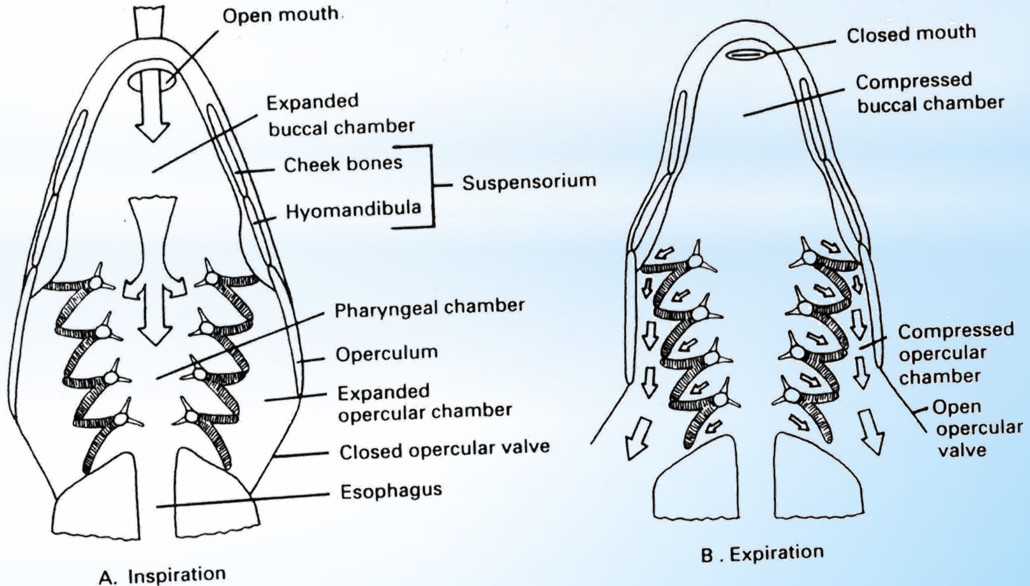




*Gill ventilation

Have to maintain flow over gills, otherwise deplete O_2 !!

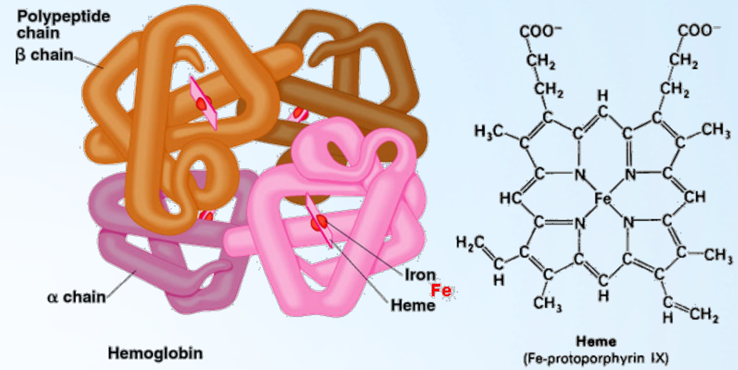
- Can move gills through water – nudis! (why is this not preferred?)
- Most move water over gills
  - ✧ Cilia
  - ✧ Ram ventilation
    - Use velocity of body movement to maintain flow
  - ✧ Buccal ventilation
    - Close mouth to increase pressure, force water over gills
    - Cheek muscles used to move water



*Hemoglobin (Hb)

binds 100x more O_2 than diffusion alone

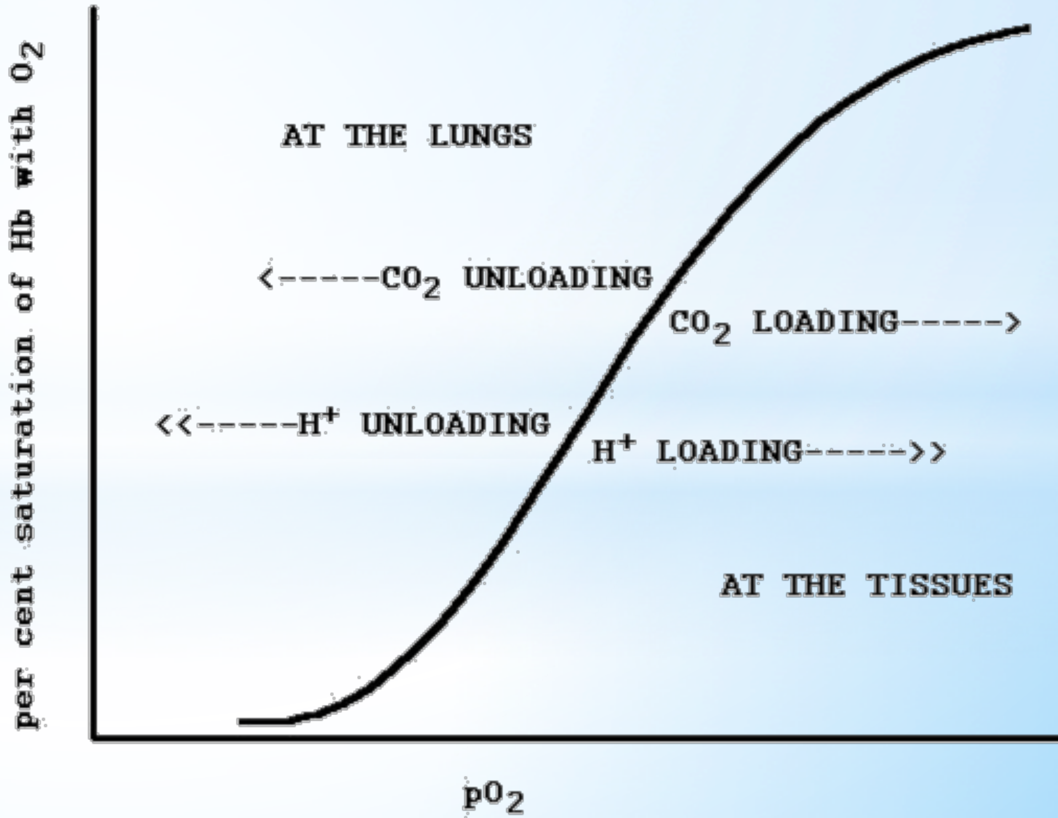
- Protein with metal core
- Binds O_2 and CO_2 **reversibly!**
- Binding of first O_2 molecule facilitates binding others
- Removal of O_2 increases affinity for CO_2



Rise in CO_2 causes respiratory drive, NOT DECLINE IN O_2!!!!

Increased CO_2 causes more acidity = O_2 is released more readily

NOT counter-intuitive, allows blood to move CO_2 out FAST



*Help from all the 'globins

Myoglobin

- O_2 carrying pigment of **muscle**
- Increased affinity to O_2 compared to Hb

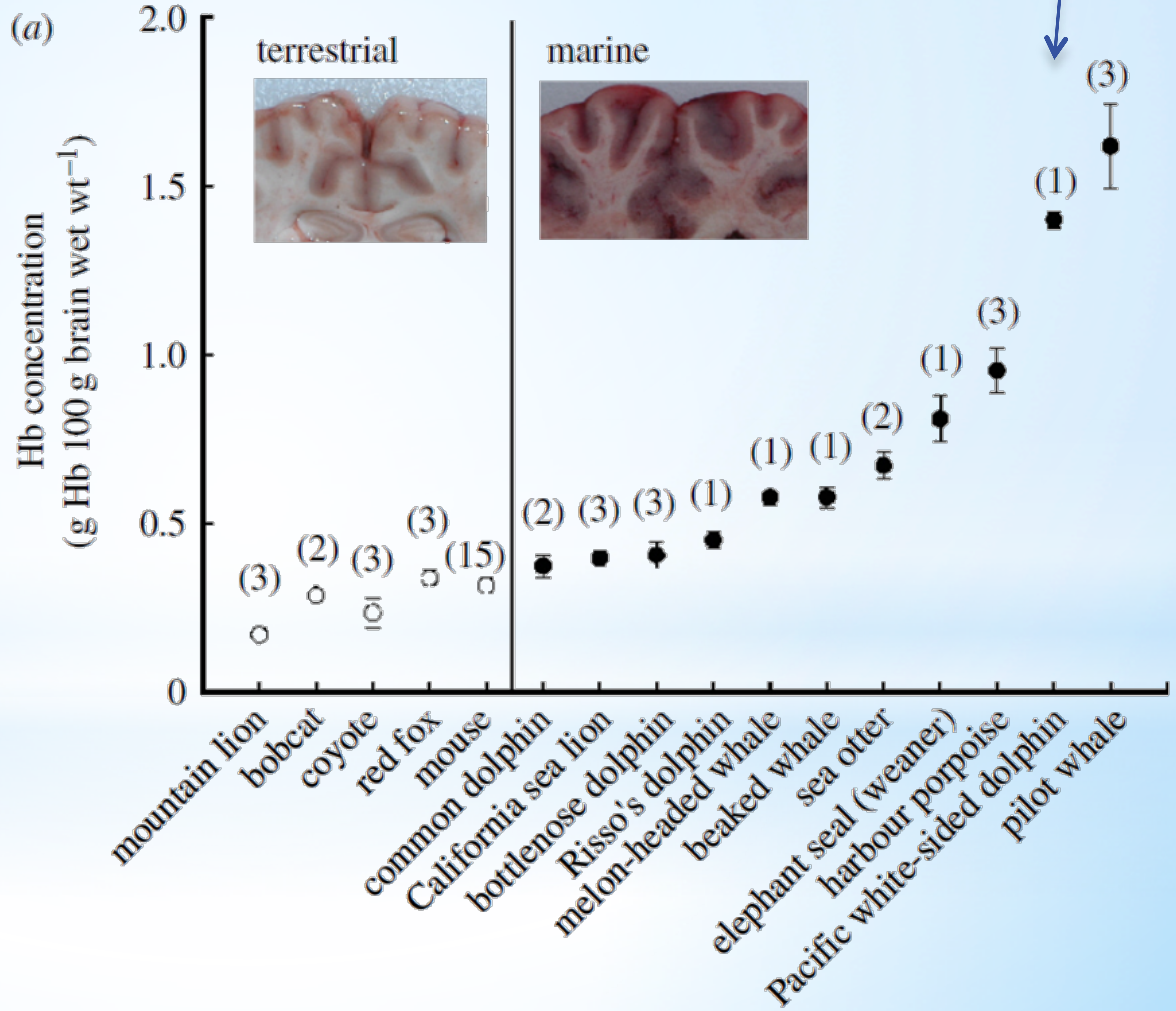
Neuroglobin

- O_2 carrying pigment of **the brain**
- Increased affinity to O_2 compared to Hb

Cytoglobin

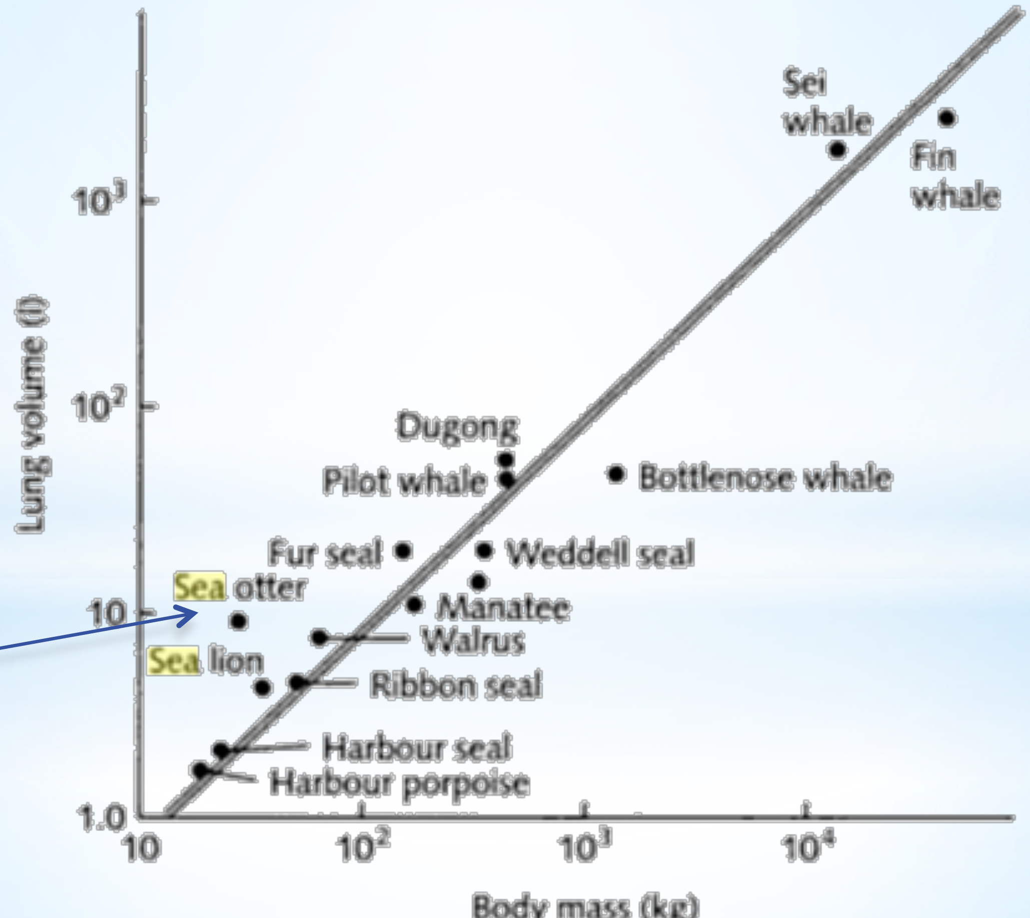
- O_2 carrying pigment of **various tissues**

Why?



*Downside of lungs in ocean

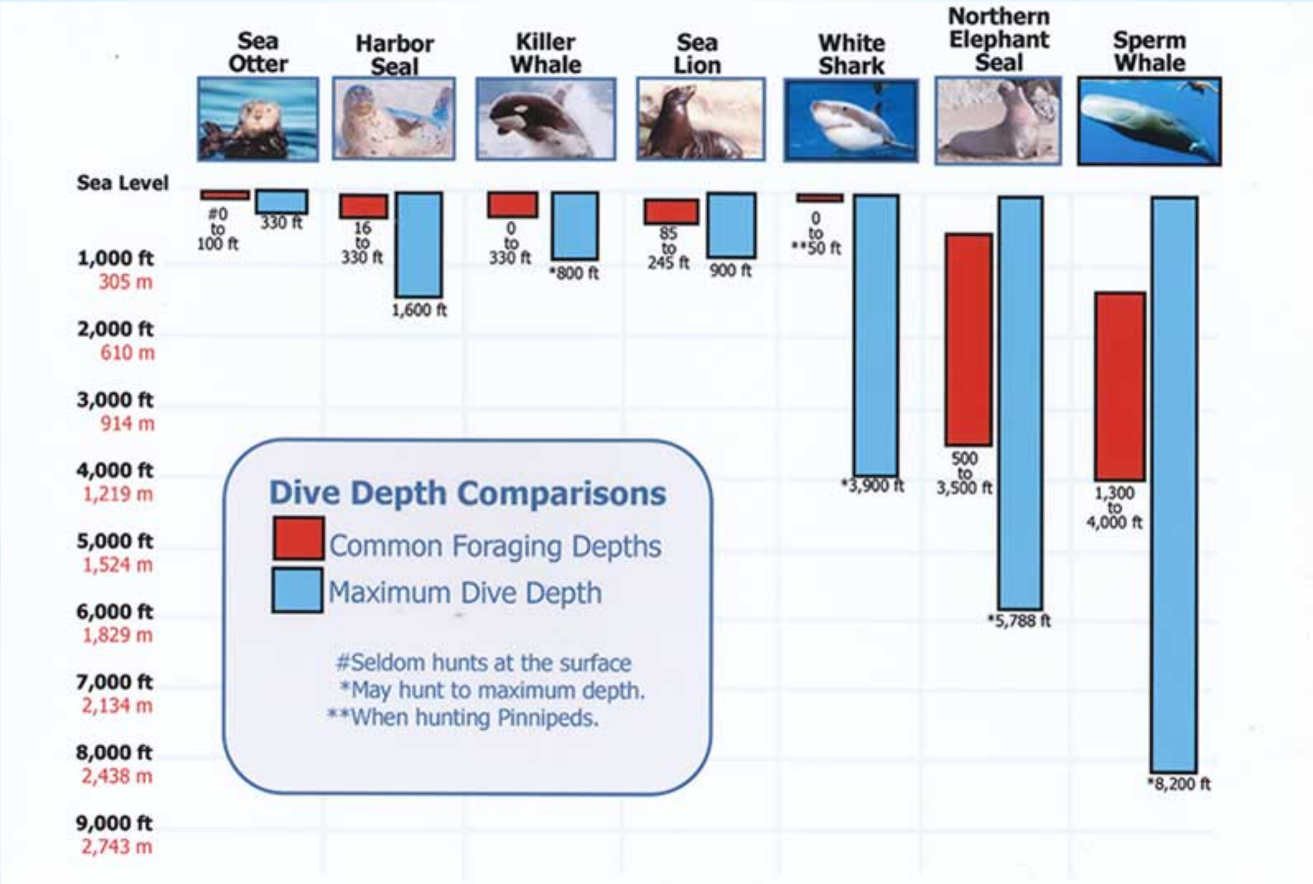
Don't do anything when diving!
Collapse completely under pressure
Increasing lung volume no use to diving animals



Why are sea otters the exception?

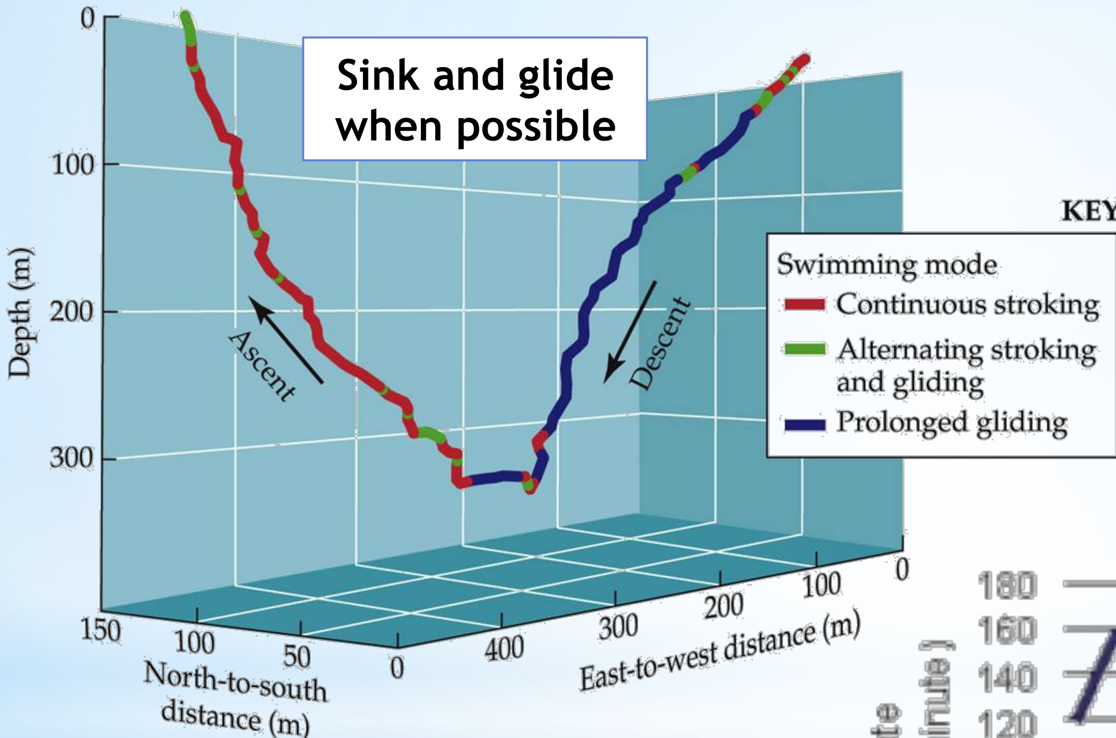
*Options for low O_2 enviros

1) Consume less oxygen!
2) Take O_2 with you!
3) Switch to anerobic (no O_2) metabolism

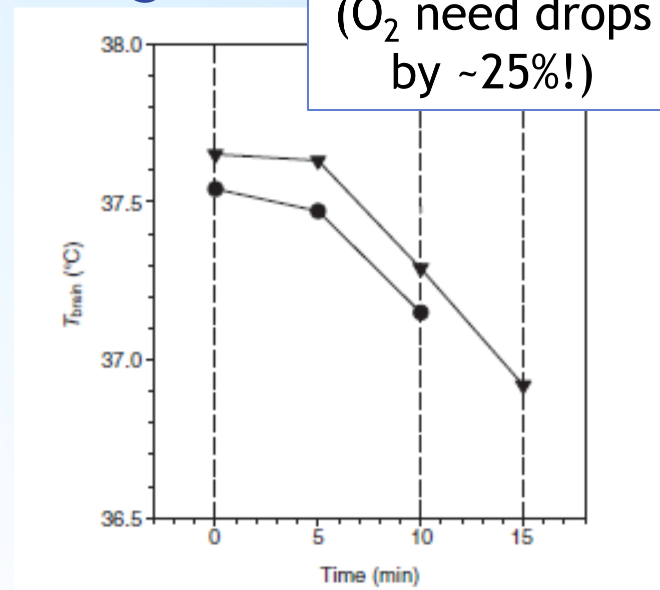


*1) Consume less oxygen!

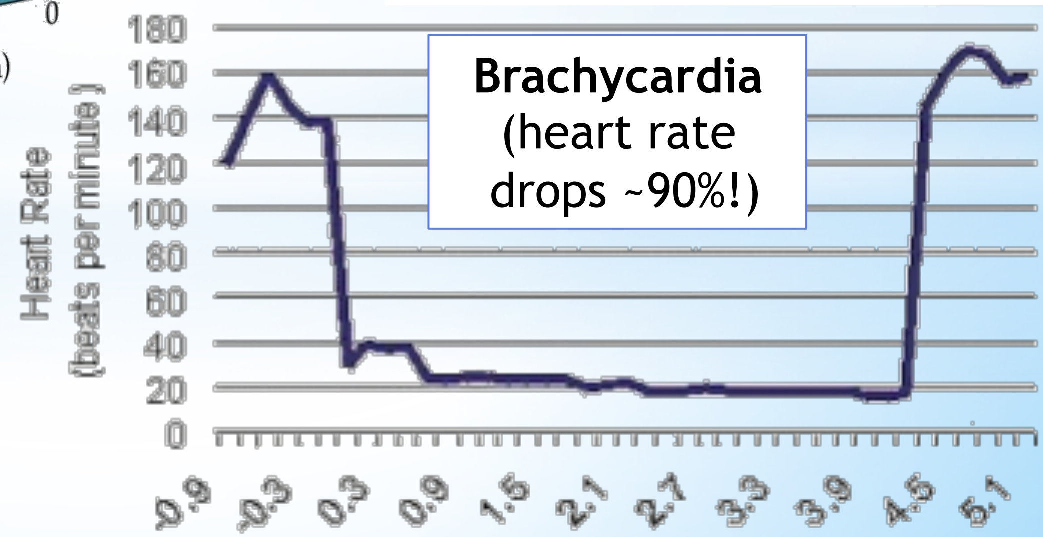
How to lower metabolism during diving?



Sink and glide when possible



Brain cooling
(O_2 need drops by ~25%!)



Brachycardia
(heart rate drops ~90%!)

Take peripheral blood flow off-line
Heart, lungs & brain only organs with direct flow

*2) Take O_2 with you!

More blood per body mass

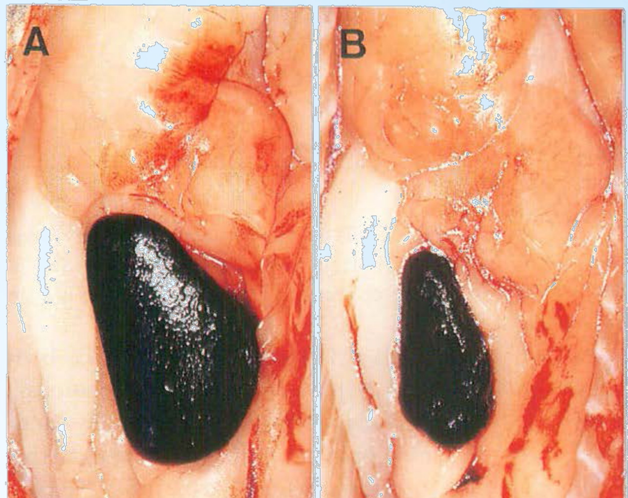
- Diving mammals = 20%
- Other mammals = 10%

More red blood cells per blood volume

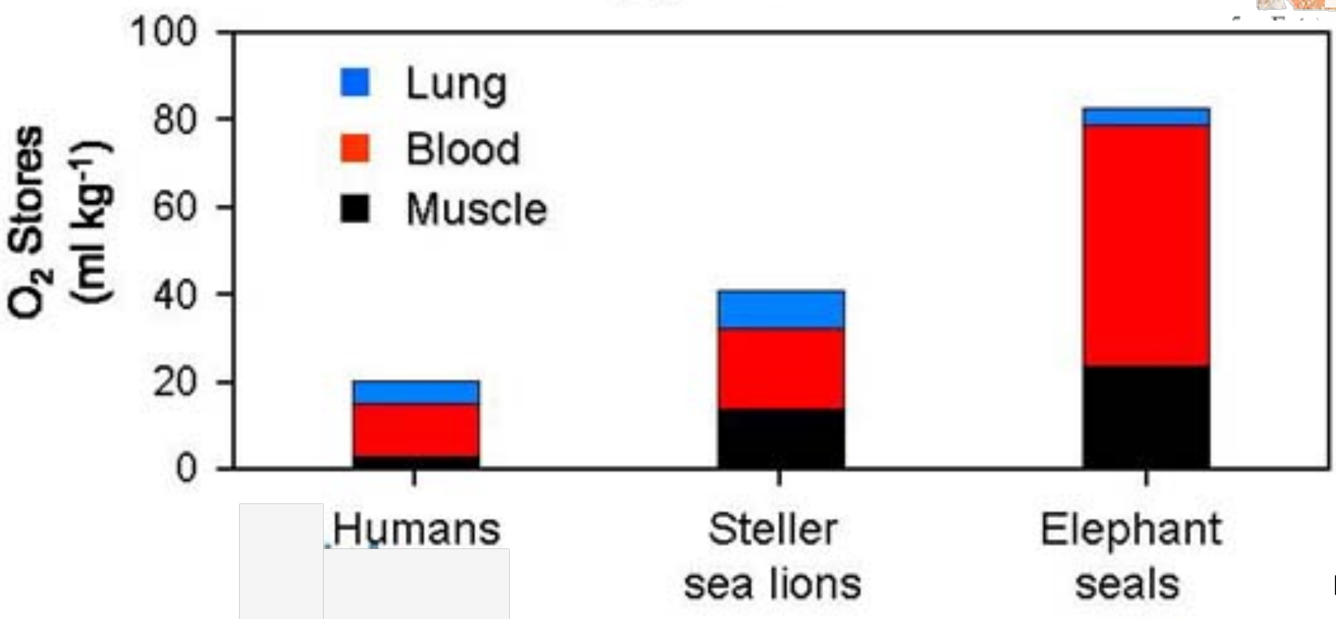
- Diving mammals = 75%
- Humans = 45%

More hemoglobin per red blood cell

- Diving mammals = 45g Hb /100mL RBCs
- Humans = 33g Hb / 100mL RBCs



Spleen of rainbow trout (A) at rest, and (B) after adrenaline



Store extra RBCs in spleen when not needed!

(don't forget about neuroglobin & cytoglobin, too!)

A LAST RESORT!!

*3) Switch to anerobic metabolism

When no O_2 available, body starts to "ferment"

- Only 1/19th as efficient as aerobic metabolism
- Can still use glycogen stores (often in liver)
- Can either produce lactate or ethanol

Lactate:

Increases acidity of body, have to be able to buffer!

Used by turtles, who can buffer blood pH with calcium carbonate from shell!

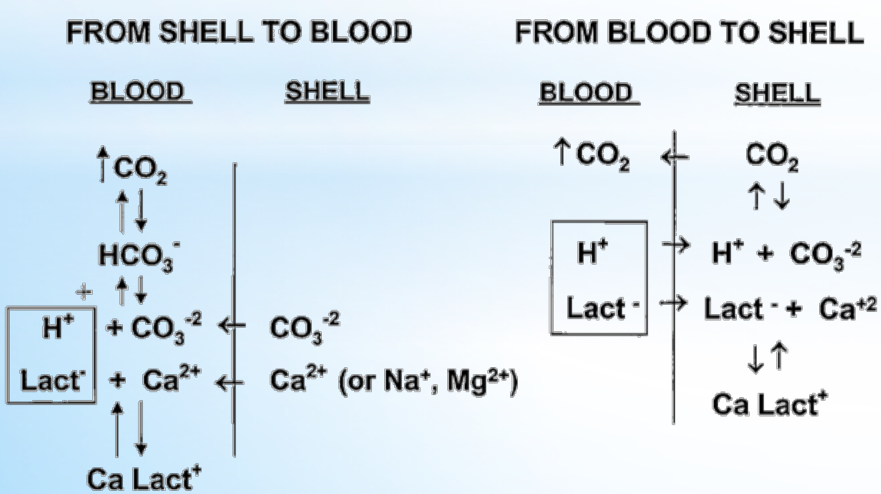
Lactate can be turned back into glucose one O_2 is available again!

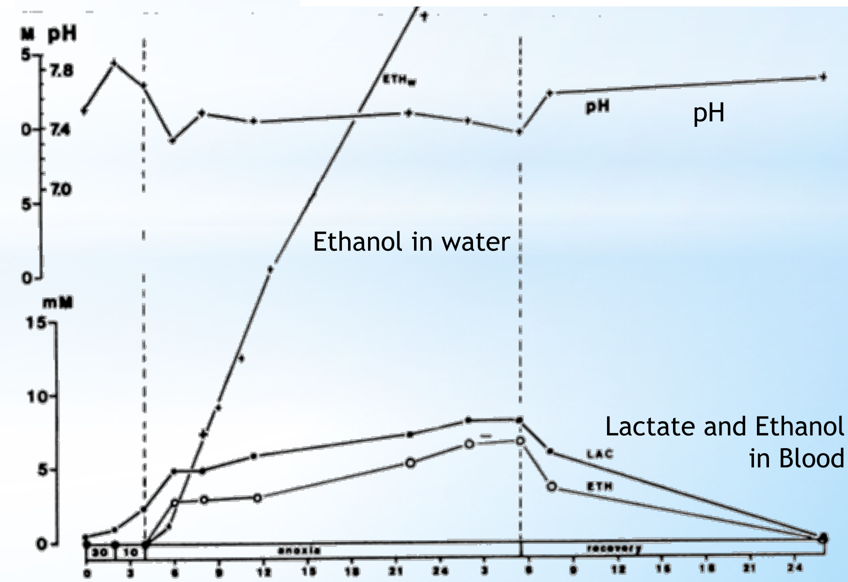
Ethanol:

Doesn't increase acidity, but can be toxic…

Can't regenerate as energy when O_2 returns…

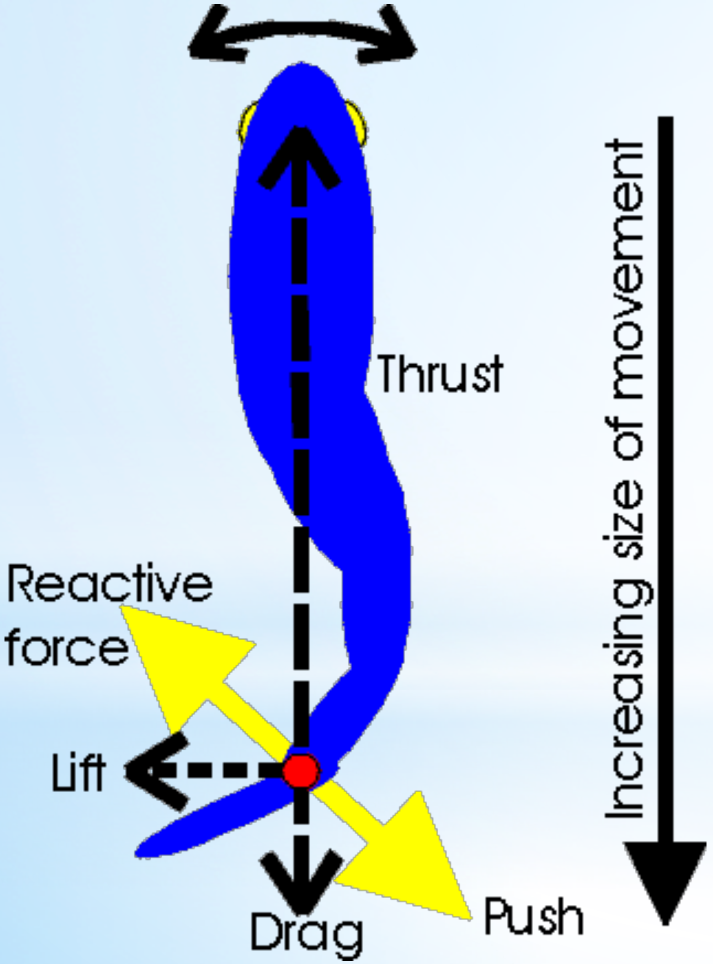
Used by fish, who can get rid of ethanol over their gills!

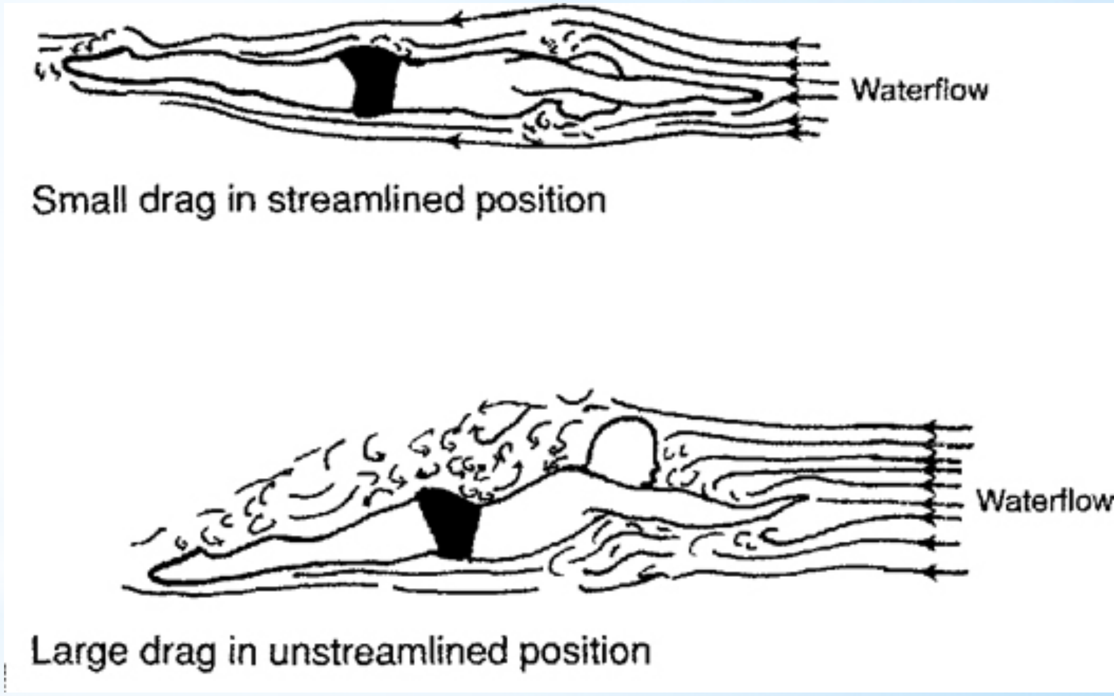




*Hydrodynamics

GOAL: minimize drag & energy cost!

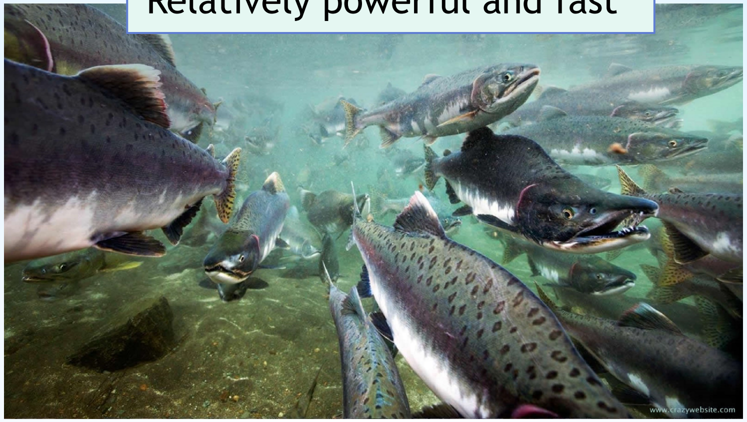




*Styles of locomotion in fish

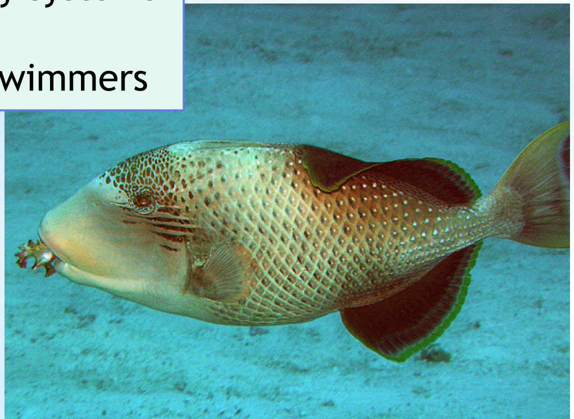
Anguiliform
Whole body movement
Fast, quick turns
Not super powerful

Carangiform
Rigid body
Caudal fin = propeller
Relatively powerful and fast



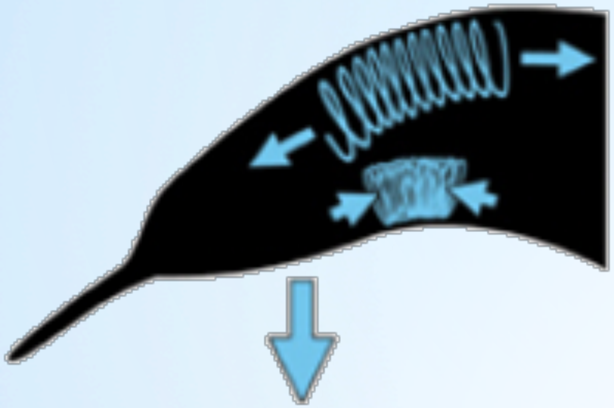
Thunniform
Extreme carangiforms
Caudal fin = propeller
Fast, powerful!

Balastiform
Great sensory systems
Median fins
Slow, weak swimmers

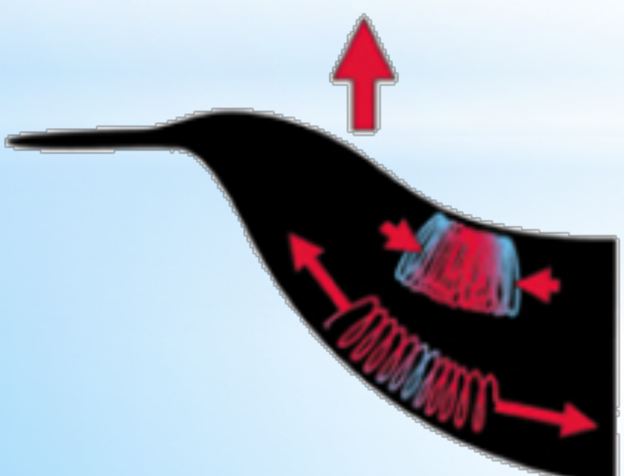


Labriform
Pectoral fins = breaking/steering
Powerful breast stroke
Quick reactions

*Styles of locomotion in mammals



Spring loading
"temporary energy storage"
Collagen in tail capable of elasticity



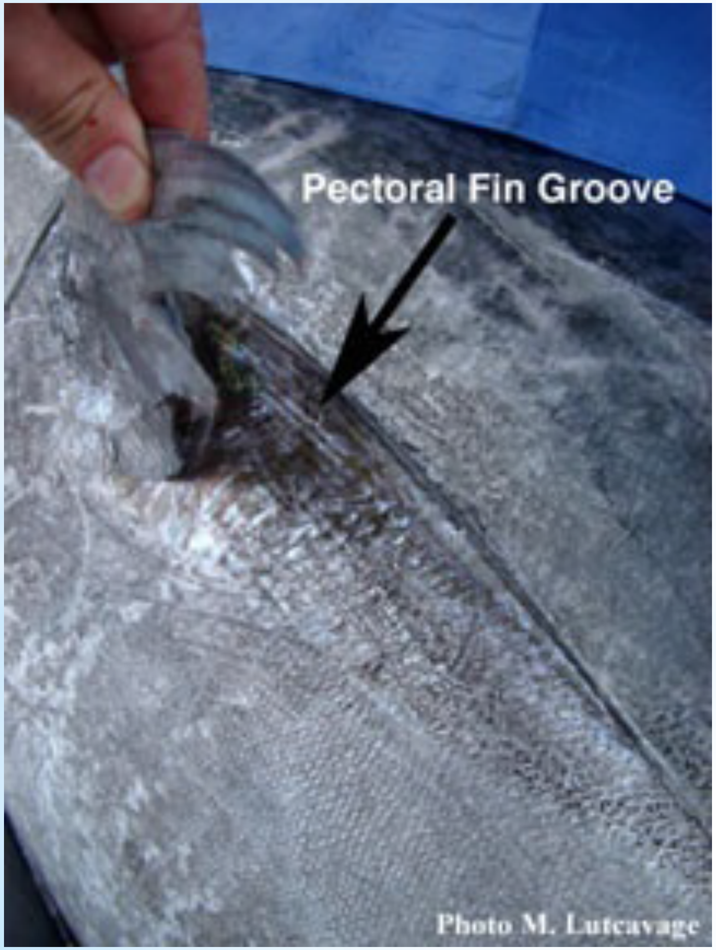
Seals (Phocoids)
Propel with rear flippers
Front flippers for steering, or not at all

Sea lions (Otariids) and marine birds
"Fly" through water – use front flippers/wings
Steer with rear flippers or feet

*Minimizing drag

1) Reduce appendages

Fusiform body
Fold fins into 'grooves'
Internalize ears, nipples, testes



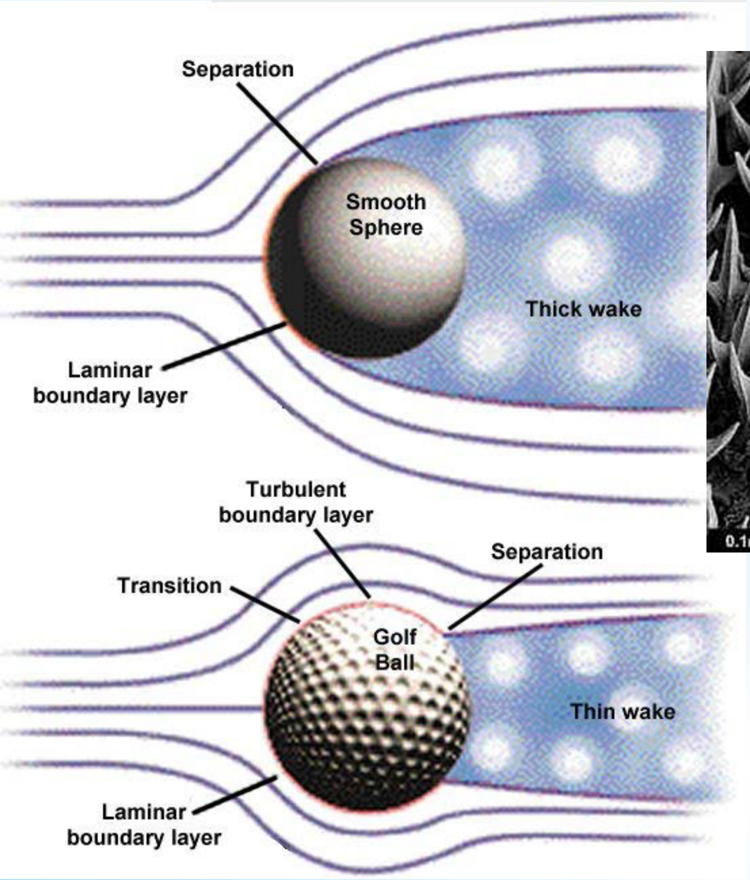
2) Fly!

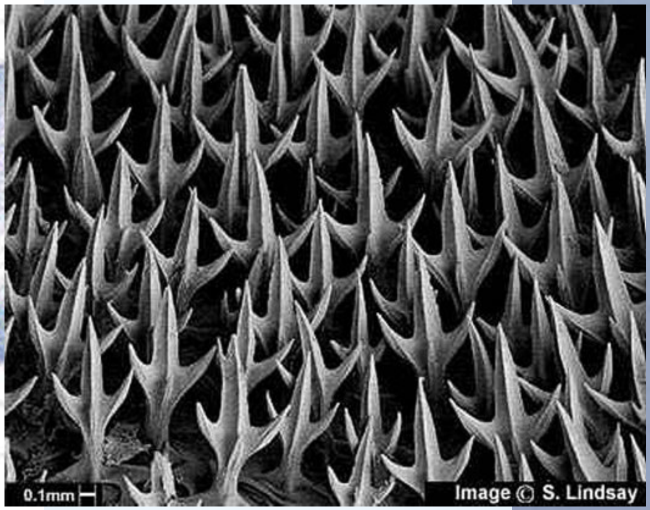
High speed through water = high energy demand
Drag is less through air
Also helps when get a "push"

*Minimizing drag

3) Scale/skin structure

Creates microturbulences on surface
Maintains laminar flow
Reduces flow separation = **QUIET**





Adding slime can do the same thing!

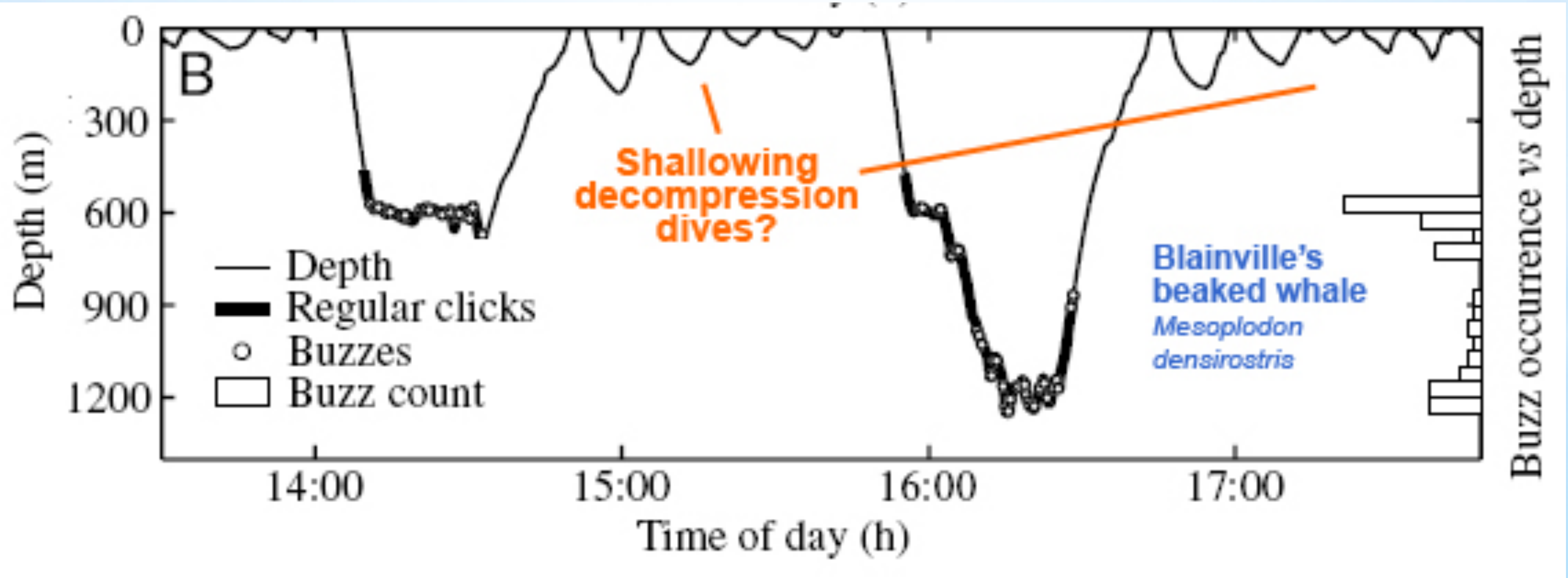
*Pressure

“The bends”

Under pressure, N_2 dissolves into blood

When pressure quickly reduced, N_2 can bubble out into bad areas

- Most marine animals exhale before diving
- Little amount of air left in absorptive areas
- Undergo controlled ascents
- Shallow decompression dives??



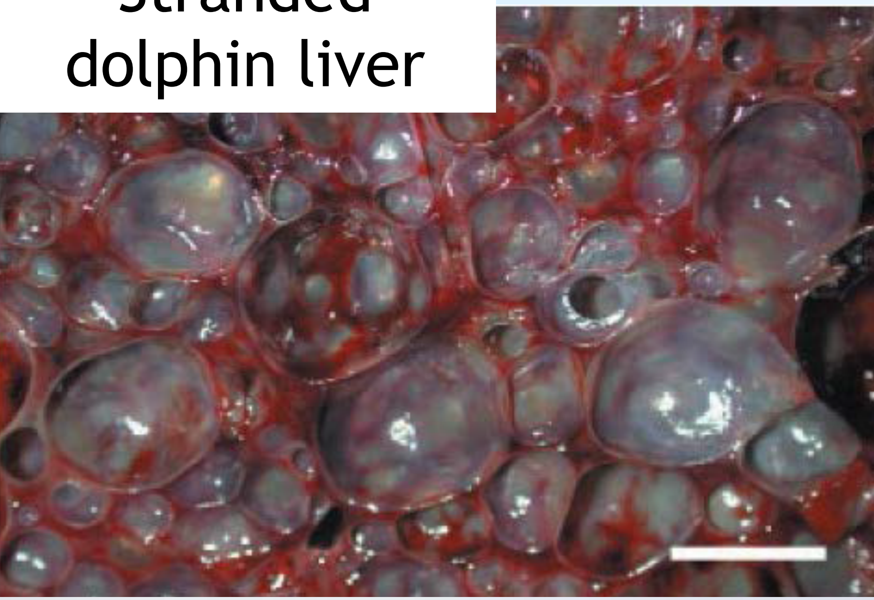
*Bends and Baby

- Adult animals rely on lung surface area to release bubbles from blood circulation
- Fetal lungs are non-functional
- Can be fatal to baby humans if mom dives while pregnant
- **In whales, fetus has enormous network of capillaries (rete mirable!) around whole body**

→ **May be key to allowing adequate off-gassing!**

*Do they always avoid it?

Stranded dolphin liver



Theory that disturbances (e.g., noise!) could induce rapid ascent….

death via decompression illness

Stranded whale rib

* PHYSIOLOGY OF MARINE ORGANISMS

Good luck on midterm if you haven’t taken yet

No assignment for next week

Be thinking of your topic! DUE NOV. 2nd.

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