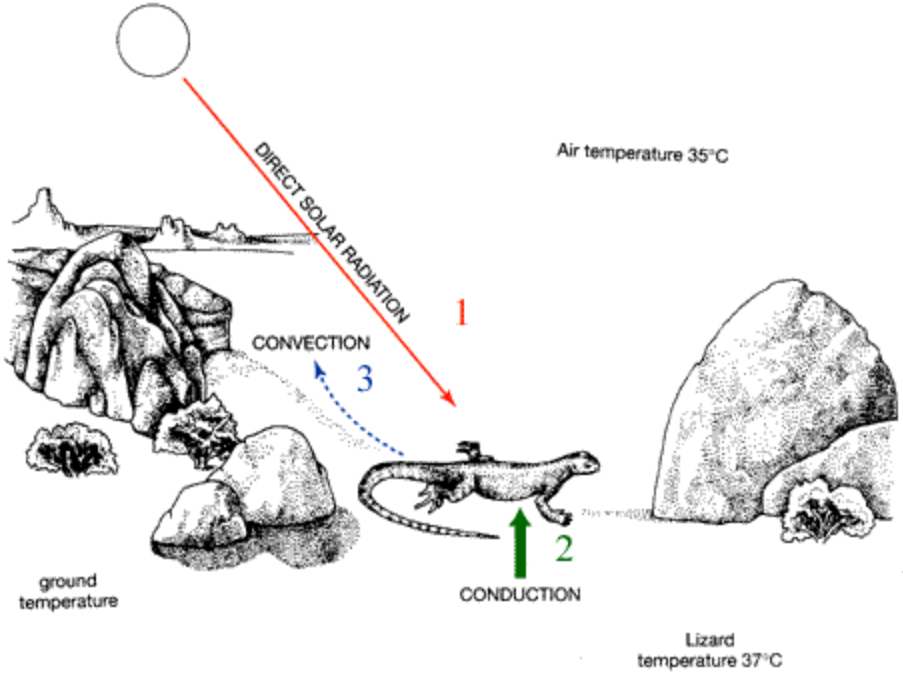
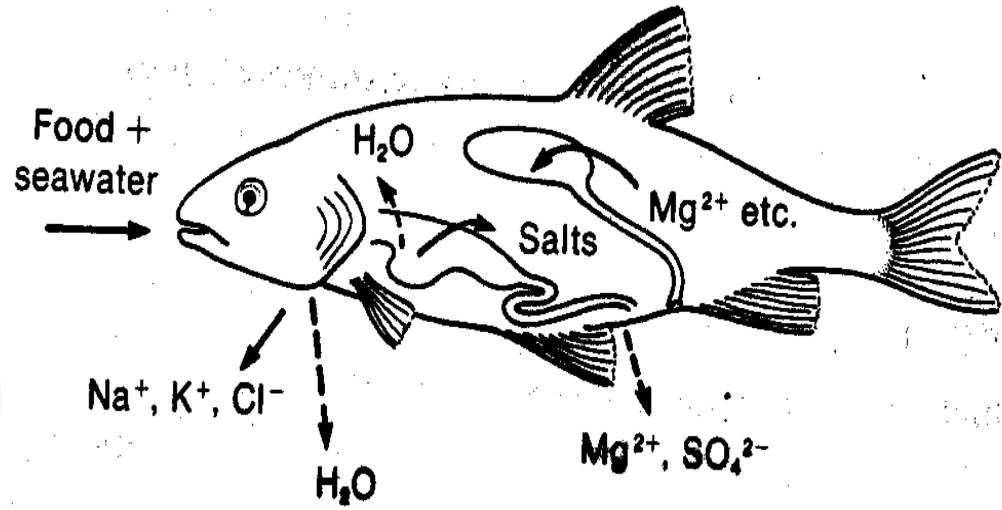




Ecology – Physiological Ecology

Hydro-mineral Balance and Thermoregulation

Focal Areas

- When considering physiological ecology, we tend to focus on two areas
  - Osmoregulatory activities and
  - Thermoregulatory processes
- The adaptations observed in organisms reflect the environmental conditions in which each is found
- The environment impacts more than just these features, but these two are big ones, at least physiologically. What other aspects of the organism are influenced by their environment?

Osmoregulation and Water

- If we look at water and the importance of this molecule to life on Earth, water exhibits several properties that contribute to the functions of life
  - 1) Cohesion
  - 2) High heat capacity
  - 3) Density of the states
  - 4) Solvent characteristics

Properties Continued

- Each one of these properties of water contributes to the ability of organisms to survive on earth
- From the cohesive properties that contribute to the functioning of the xylem elements in plants to the ability of water to dissolve other polar compounds, cellular processes and life itself would cease to exist in the absence of these characteristics

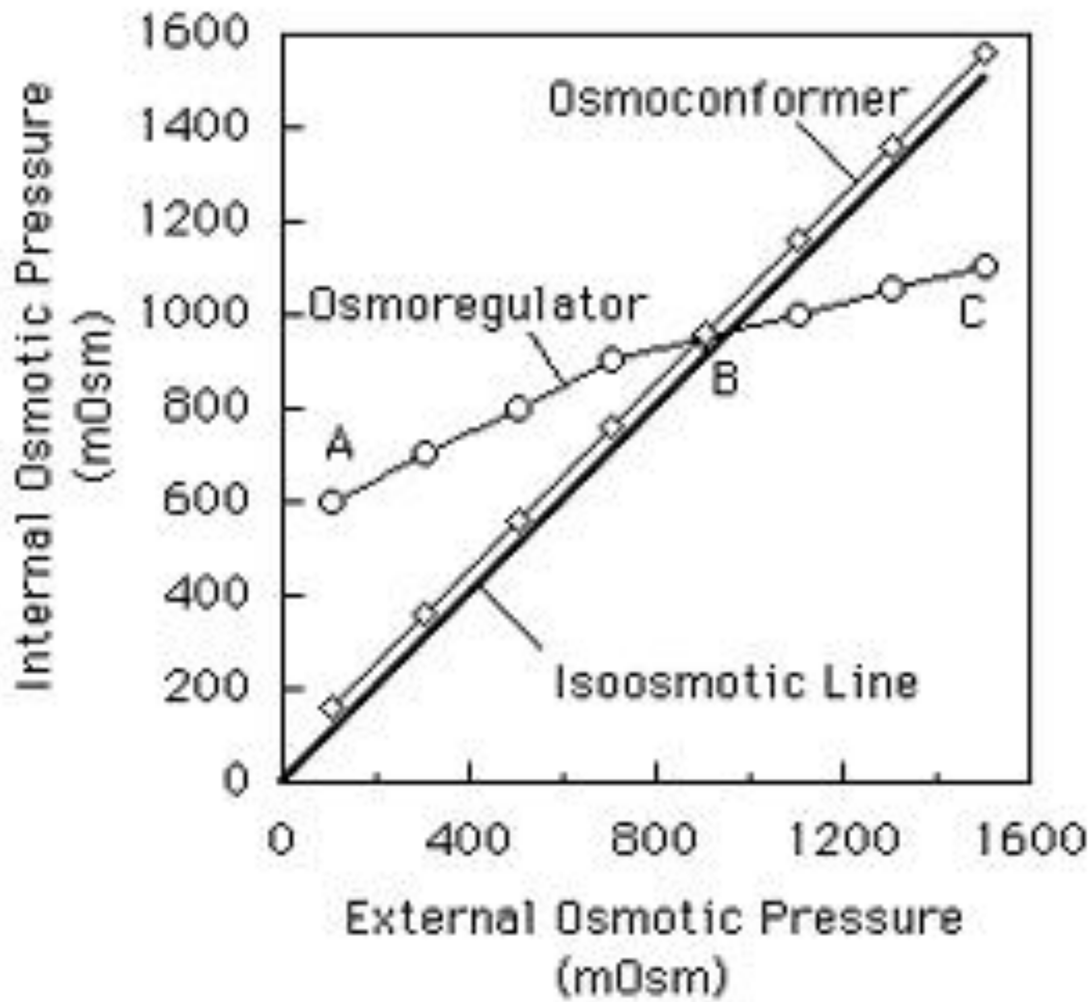
Water as a Solvent

- The polar nature of water contributes to the ability of water to dissolve a wide range of compounds and molecules
- Ionic compounds dissolve readily in water and are generally found in *free ion form*
- Therefore, aquatic organisms will experience a potentially broad range of ions in the aqueous environment that influences their body and cellular composition
- This in turn influences much of the physiological issues associated with being aquatic

Aquatic Organisms

- From a definition standpoint, organisms can be either regulators or conformers (called osmoregulators and osmoconformers, respectively)
- In addition to consideration of the strategies, we must also evaluate the abilities of the organisms to tolerate variation in the solute concentrations in the environment – they can either be stenohaline (withstand a very narrow range of environmental salt concentrations) or euryhaline (a broad range of salt concentrations)

Plots of the two strategies



Some really are Osmoconformers

- That is, body salts are the same as the environmental salt concentrations, and some are even euryhaline (for example some **estuarian** invertebrate species). Please note the restrictions at very low environmental salt concentrations however. Most are stenohaline – adapted to a narrow range of salinities and unable to tolerate significant changes
- The other strategy of "osmoconformers" is to fool the concentration gradients, at least in terms of the water flow across the permeable membranes

What are the issues here?

- We need to look at this from a couple of perspectives – first the pressure from the solutes are exerted because of permeability of the membranes
- Many aquatic organisms have impermeable coverings, either in the form of scales or elements that prevent movement of material across that barrier
- However, what *must* remain permeable?

Plants *and* Animals

- However, the source of all nutrients is their environment - for gasses, ions, minerals and, perhaps most importantly, water
- Thus the problem, *control of the chemical processes of diffusion/osmosis while still obtaining the materials we need to survive*
- One method is inclusion of compatible solutes into the body tissues

Many marine species “fool” the forces of diffusion

- For these forms - total salt concentration of body fluids are just about that of seawater
- *Compatible* solutes allow the inclusion of non-toxic compounds or ions in the body tissues to help handle the regulation activities
- This can be seen in many marine and salt marsh plant species, and even the hagfishes
- The hagfishes do regulate some ions, particularly divalent ions, and this is accomplished by the kidneys, but the total body salt concentration is about that of seawater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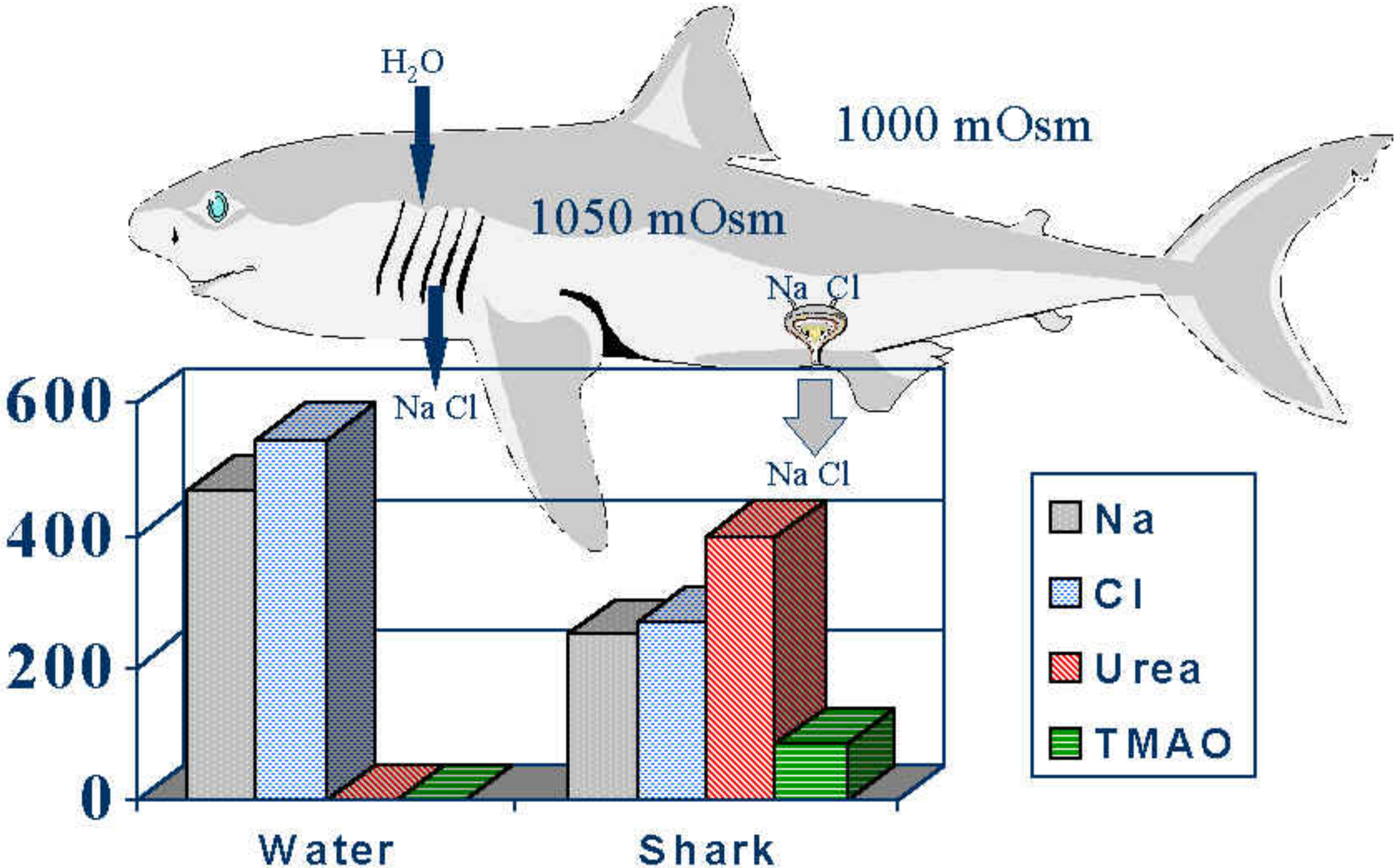
Chondrichthyes – do it a different way

- Like most vertebrates, inorganic salt concentrations are about 1/3 that of seawater
- The balance to make total salt concentrations equal is incorporation of organic salts, urea and trimethylamine oxide
- This does the trick for water, but the salts are regulated mainly by two structures
  - Gills and Rectal salt gland for sodium and chloride
  - Kidneys for all ions

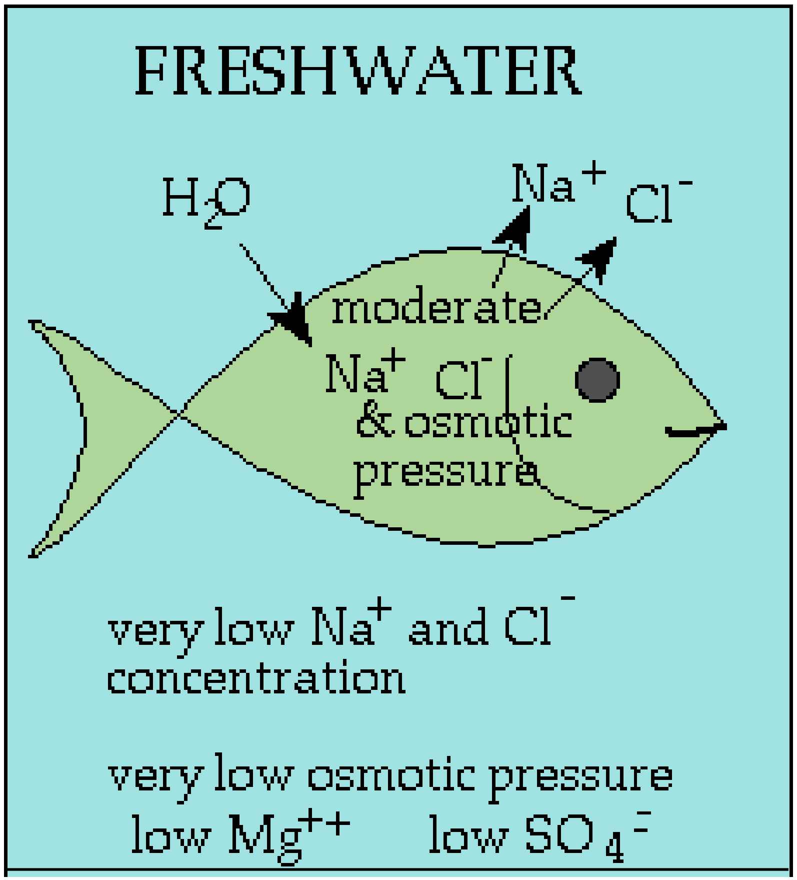


H_2O
1000 mOsm
1050 mOsm
Na Cl
Na Cl
Na Cl
600
400
200
0
Water
Shark
Na
Cl
Urea
TMAO

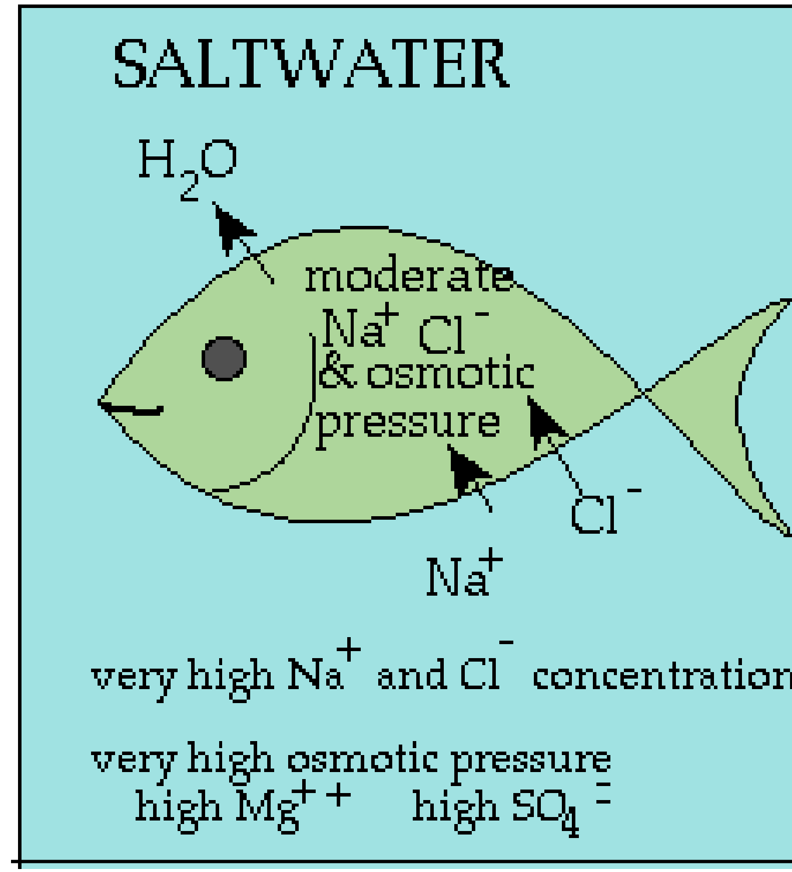
Now, lets look at the bony fishes

- One good thing, at least for them, the integument is basically impermeable
- Alternatively, the gills are permeable to everything. This is a very important area for exchange of gases, heat, ions *and* water
- The kidneys are the other major organs involved in the osmoregulatory process

Body is Hypertonic to environment



Body is Hypotonic to environment



Summary of Processes

- Freshwater bony fishes
  - Drink very little (only with food intake)
  - Pee a lot given that we cannot pump water
- Saltwater bony fishes
  - Drink a lot, the only way to get water inside
  - Pee very little (concentrated)
- Diadromy is generally an ontogenetic “thing” with associated hormonal shifts and therefore regulatory mechanisms and strategies

Now, when we move on land

- We no longer need to be concerned regarding the loading of ions due to diffusion from the medium
- But, we now need to consider the loss of water from body surfaces, the respiratory surfaces, excretions and even defensive adaptations
- If you are of the green persuasion, water is also a required component for the process of photosynthesis

Water becomes a limiting factor

- We see the adaptations with regard to respiratory structures and counter-current heat exchangers to retain moisture inside these invaginations
- We see adaptations for water conservation in plants, such as what is observed with the alternative photosynthetic pathways
- We also see adaptations with regard to the excretory products that animals produce for regulation of the hydromineral balance of the organism

By-products of protein metabolism

- Chemically, one of the main components of proteins is nitrogen
- And when proteins are broken down, the easiest product to produce is ammonia
- This requires very little energy to produce, but, ammonia is very toxic, and it is highly soluable in water, i.e., it takes large amounts of water to eliminate ammonia from the body

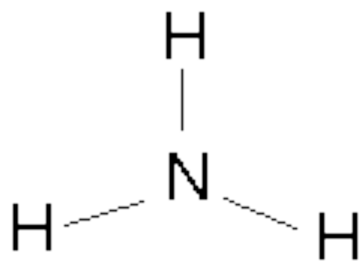
For aquatic organisms

- Ammonia works fairly well as a by-product because we are not too worried about using water
- But, water ***is*** limiting in most terrestrial environments
- We see two alternative by-products of protein metabolism, urea and uric acid
- Both products are less toxic and they exhibit limited soluability in water

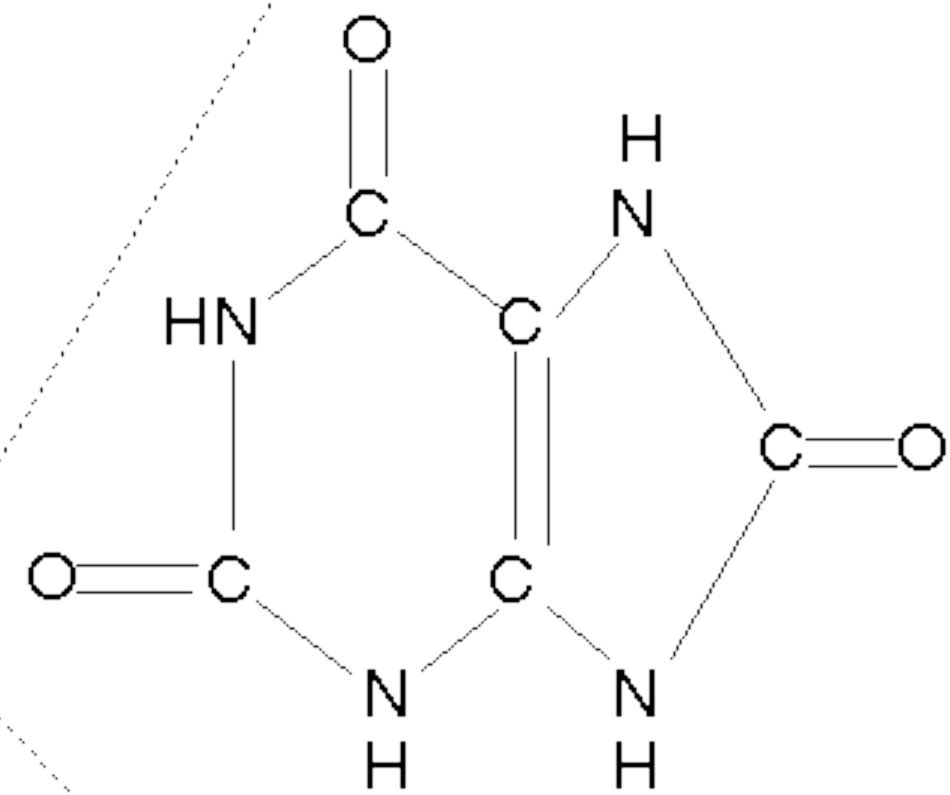
But uric acid is the best?

- Uric acid is a crystalline material, insoluable in water, and represents the best answer in terms of water conservation
- We see this in terrestrial arthropods, reptiles, avian reptiles, and even some desert anurans
- So, why do only some taxa do this?

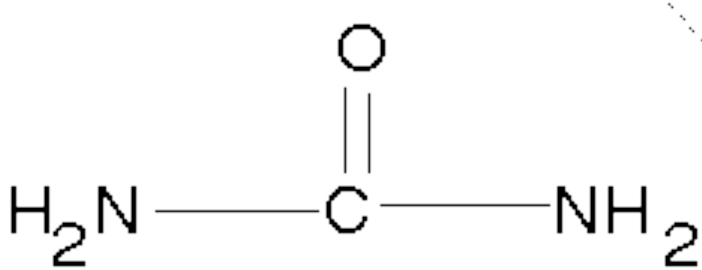
Nitrogenous Excretory Products



Ammonia



Uric Acid



Urea

Salts also become an issue (or remain an issue for the body)

- We see many taxa also exhibit adaptations with regard to excess salt loads – particularly in species that are found in coastal or completely marine environments
- In plants *and* animals, we see salt glands as specialized structures that concentrate and excrete (primarily) sodium chloride from the body tissues to handle the excess salt from the body tissues
- These features, like so many others have evolved several times – addressing and answering the pressures from the physical environment in the same manner

There are many other features

- The environment places restrictions on the manner in which organisms do things, at least within reason, based upon the *capacity* of the organism (i.e. the evolutionary history of that species)
- One of the most interesting aspects are the sensory adaptations exhibited by forms based upon the environmental conditions

Aquatic vs. Terrestrial

- Think about this in terms of the of the aquatic medium
- Water is about 800 times the density of air
- Therefore, movement “in” and “of” this material becomes of primary importance, but in addition to that, this density also limits certain characteristics and enhances other features

Sensory Biology

- The sensory systems of organisms are profoundly influenced by the organism's environment – survival depends upon the organism's ability to sense the environment
- Water is interesting from the the perspectives that it – limits visual information due to dissolved substances; it also limits the diffusion of olfactory cues (slows and localizes); and it *speeds* sound transmission 4 – 5 times – What does this mean??

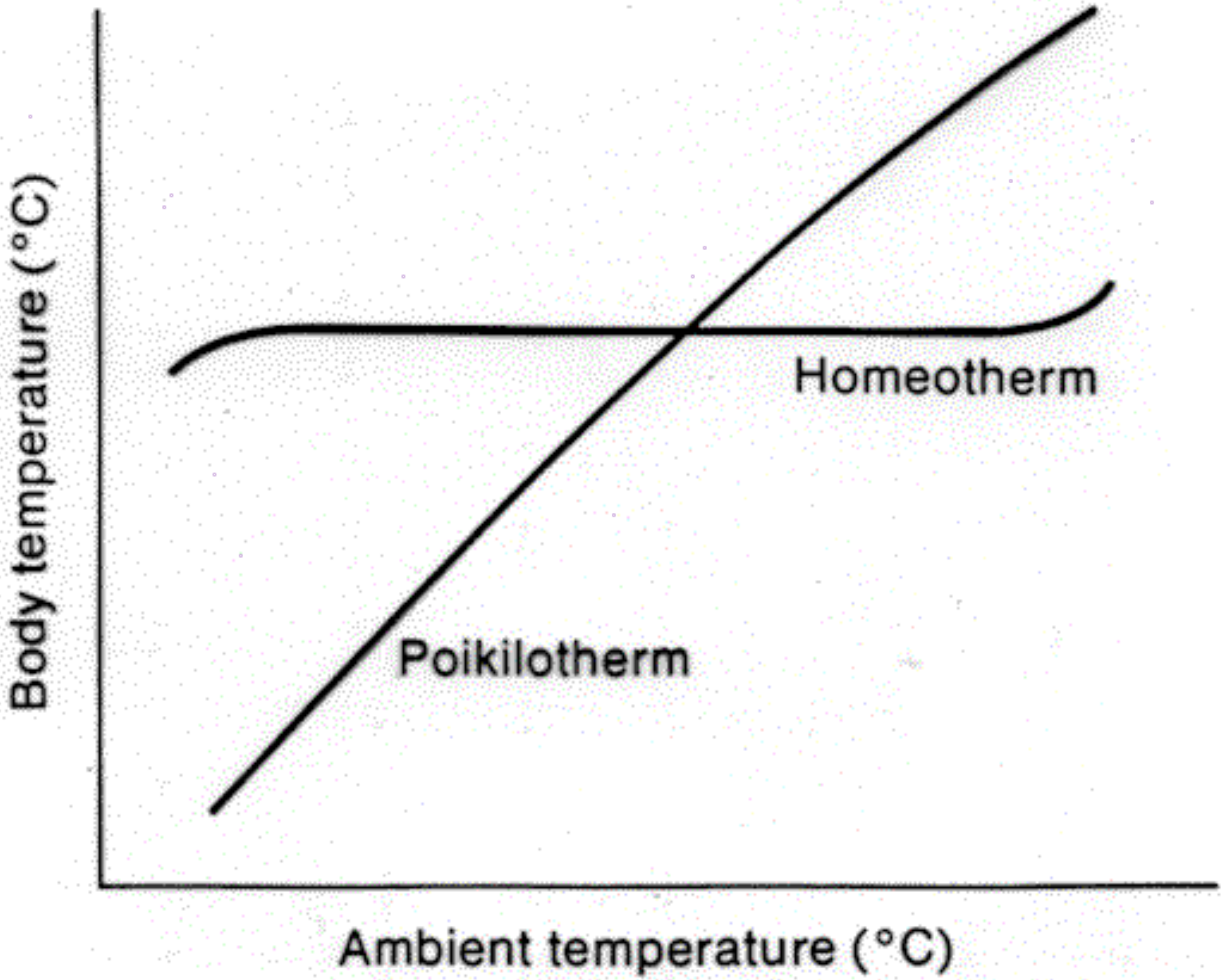
Break Time

Homeostasis from a thermal perspective

- Much like we could evaluate the characteristics of organisms with regard to their water and salt concentrations, we can view the thermal characteristics of these same forms
- One of the most fascinating areas of physiology is a look at the organisms and how they adapt **thermally** to various environmental stresses
- This often involves adaptation at several levels, physiologically, morphologically and in many cases, behaviorally

Do you, or don’t you?

- We can look at the strategies of organisms with regard to the question of whether or not these species regulate their body temperatures to something other than the ambient temperature
- Those that *do* are thermoregulators, those that *do not* are thermoconformers
- Consider this on a general level, when we look at organisms facing thermal stress, one of three options exist – you can move (migrate), you can deal with it, or, quite simply, you do not survive


Body temperature (°C)
Homeotherm
Poikilotherm
Ambient temperature (°C)

Homeotherm/Poikilotherm

- These terms simply refer to the stability of the body temperature – homeotherm is constant or the same and poikilotherm is variable, mirroring the environmental temperature
- Another pair of terms, ectotherm and endotherm refers to the source of the heat energy used to maintain a favorable body temperature

What is it about temperature?

- When we are evaluating this in a general way, why bother with attempts to maintain a high, constant body temperature?
- We need to look no farther than rates of chemical reactions – can anyone tell me about the Q_{10} effect?
- But also the efficiency of rxns
- Any others?

Other temperature considerations

- An organism that is able to regulate its internal thermal environment has an advantage over those that cannot
- Simplistically, it will be able to inhabit regions not suitable for organisms with low body temps
- Selection will be able to “focus” on forms of enzymes that operate within this regulated region of temperatures, enhancing efficiency of the functions of the enzymes

Do organisms fit our categories?

- Certainly we find many exceptions
- These are most appropriately described as heterothermic organisms implying that there is variation in the temperature of the organisms
- This variation can be in time (temporal) heterothermy (any good examples??), or this can reflect the parts of the body – regional heterothermy

Treatment of Adaptations

- We will treat this in terms of the general categories of endothermic forms and ectothermic forms
- As we look at the ways of answering the challenges, keep in mind the evolutionary history of the species under consideration, the "norm" for that taxon and the functional significance of the adaptation
- The earth is not a static entity, *often* on a daily basis, *generally* on an annual basis and *certainly* on a geological basis

Endothermic Organisms

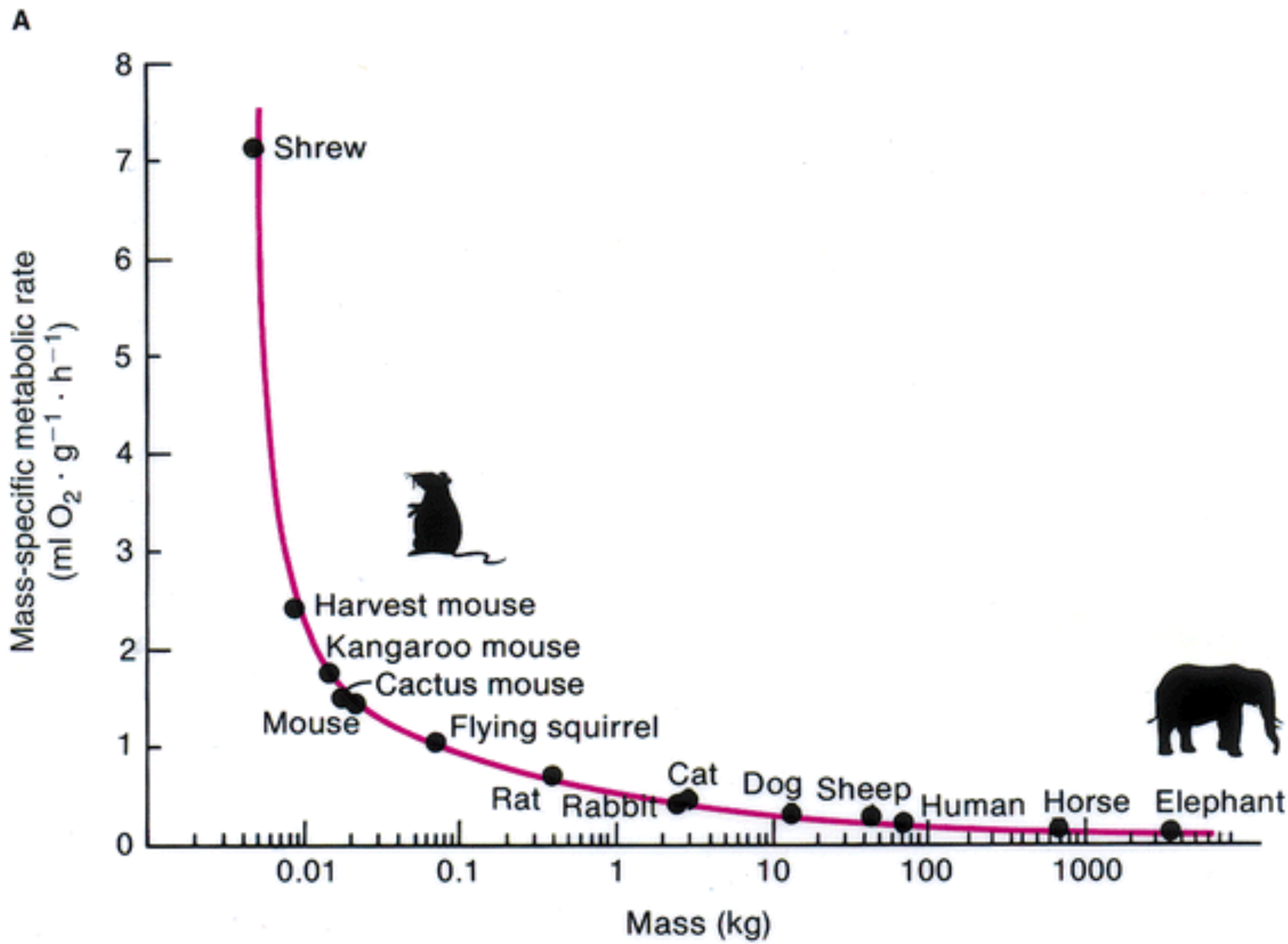
- Endothermy has evolved independently at least twice (true endothermy) and those organisms that are endothermic have become dominant forms of life on earth, from a size and ecological importance perspective
- These forms exhibit higher basal metabolic rates than ectothermic organisms yielding the higher body temps

Size of endothermic organisms

- This increased metabolic rate, actually poses limits on the size of endothermic organisms – not in terms of too large, rather too small
- Observations tend to support the proposal that endothermic organisms, are on the average, larger than ectothermic organisms (reading)
- It is not difficult conceptually to note that the energy requirements of larger endotherms are greater than smaller forms

However,

- It is not immediately obvious that the mass specific relationship is inverse as exhibited by the mouse-to-elephant curve for a variety of different mammals
- This is a measure of the metabolic rate per unit mass plotted against the log of the total body mass of the organism



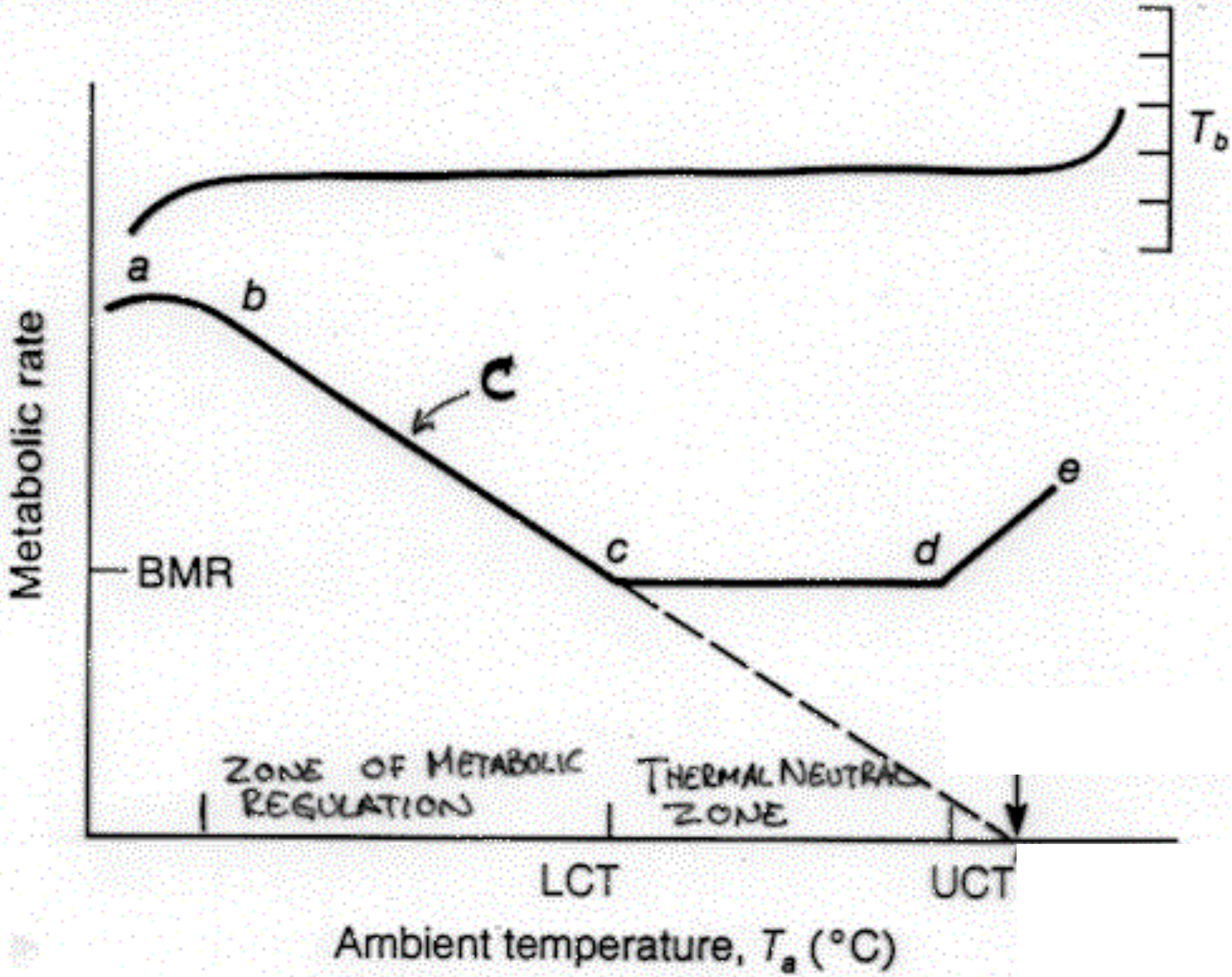
A
Mass-specific metabolic rate
(ml O2 · g−1 · h−1)
8
7
6
5
4
3
2
1
0
Shrew
Harvest mouse
Kangaroo mouse
Cactus mouse
Mouse
Flying squirrel
Rat
Rabbit
Cat
Dog
Sheep
Human
Horse
Elephant
0.01
0.1
1
10
100
1000
Mass (kg)

Theoretically

- This graph suggests some lower limit on the size of an endothermic organism
- Why? What sorts of characteristics might contribute to this relationship between mass and metabolic rates?
- What has size got to with it?
- What about support structures for those larger bodies?

For homeothermic endotherms…

- We know what the body temperature does with increasing or decreasing environmental temperatures
- But what happens to the metabolic rate over a wide range of environmental temperatures?
- How does the metabolic rate change in response to the variation in ambient temperatures?



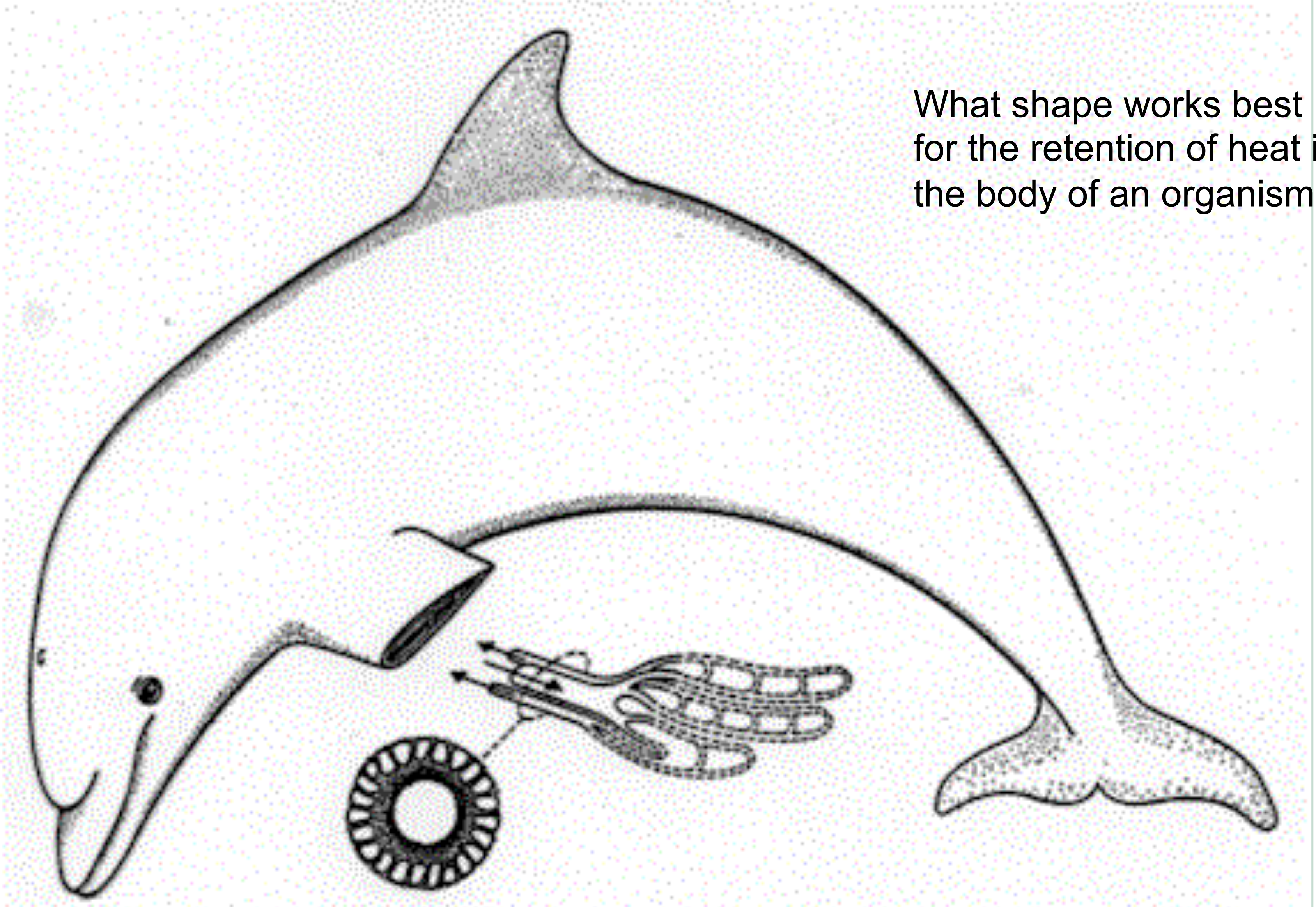
Metabolic rate
BMR
Ambient temperature, T_a (°C)
LCT
UCT
T_b
a
b
C
c
d
e
ZONE OF METABOLIC REGULATION
THERMAL NEUTRAL ZONE

The important quantities here

- LCT and UCT, lower critical temperature and upper critical temperature, respectively
- These define the region as the thermal neutral zone, the range of environmental temperatures in which no modifications of the metabolic rate are required to maintain a constant body temperature
- This ***is*** the minimum level of energy expenditure and the organisms are always producing at least some endogenous heat (that is why the TNZ is at a lower temperature than body temperature)

Other morph mechanisms

- Certainly, insulating mechanisms play a key role in the ability of endotherms to “keep” the heat that they have produced internally – what are the common forms? What was the basis for the evolution of feathers??
- One of the most fascinating displays of heat retention by endothermic organisms is in the evolution of counter-current heat exchangers in both terrestrial and aquatic species (regional heterothermy!)



What shape works best for the retention of heat in the body of an organism?

Regulatory mechanisms

- We have looked at this from the perspective of heat gain/retention or dumping if you are endothermic
- These adaptations include forms of morphology, behavior and/or physiology
- But, when we consider the ectothermic organisms, we see selection for this high constant body temperature, and answering the pressures with many of the same mechanisms, and even some that are more interesting

The Aquatic Environment

- Given the packing of molecules, conduction of heat is more rapid in this environment
- Primary site of heat loss?
- Most aquatic species are good ectothermic poikilotherms (body temperature = environmental temperature)
- And realistically, there is little in terms of physiological/morphological mechanisms

Lifestyles of the Benthic and Pelagic

- Benthic or inactive forms – the regulating mechanisms do not exist primarily because the energy needed would be immense to maintain any body temperature significantly above the ambient
- Alternatively, if you are pelagic (swimming most or all of the time) a by-product of the muscular contractions is heat – why not make the most of it!

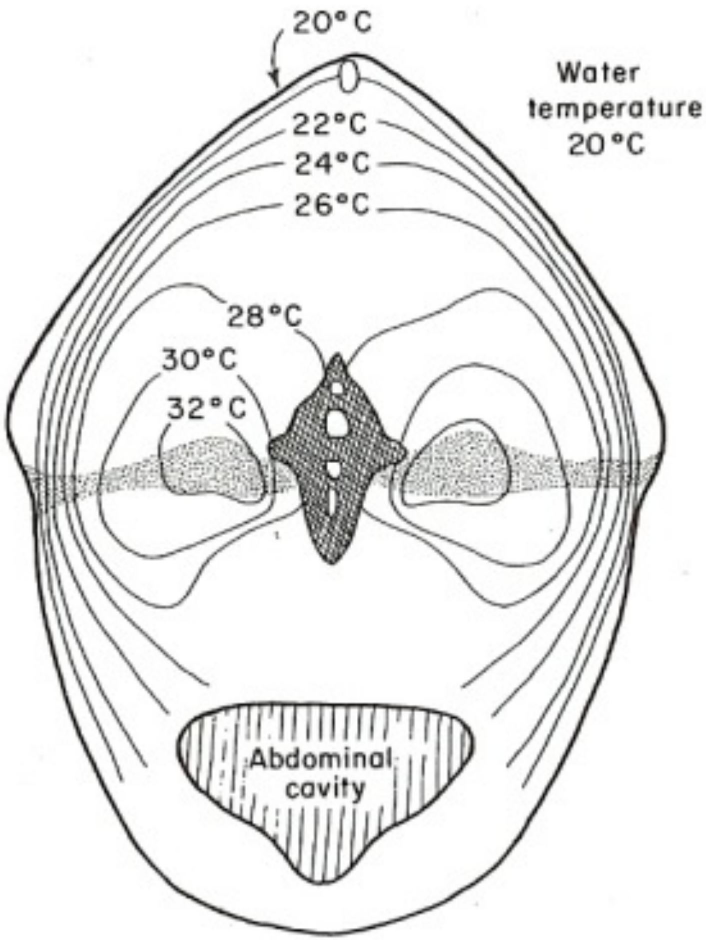


Figure 8-28
Distribution of temperature in the muscle of a freshly captured 70-kg big-eye tuna (*Thunnis obesus*). Water temperature 20°C. Isotherms are plotted at 2°C intervals. Stippling indicates the distribution of red muscle. [From F. G. Carey and J. M. Teal. *Proc. Nat. Acad. Sci. U.S.*, **56**, 1464–1469 (1966).]

Regional Heterothermy

- We see this feature in several large, pelagic fishes, particularly in the Scombridae and Lamnidae
- In most fishes, we see paired arteries and veins radiating from the dorsal aorta and back medially to the center of the body after delivery of materials to the tissues – there is some heat conservation due to proximity, but not too much

Terrestrial Habitats

- These issues with freezing temperatures are not unique to aquatic organisms – we see this in terrestrial species as well (and sometimes much colder than experienced in the aquatic habitat)
- There is a wide variety of responses of terrestrial organisms, but perhaps the most interesting is observed in freeze tolerance in amphibians

Popsicles

- As the temperatures decrease, most amphibians seek protection buried in the substrate, preferably below the frost line
- Others, however, hibernate at very shallow depths. As the temperature falls, the bodies of these species are exposed to freezing temperatures
- Extracellular fluids freeze under these conditions (not completely, but partially) whereas the intracellular fluids remain liquid due to the inclusion of anti-freeze compounds

Low Density Compounds

- This is very similar to what we see in polar fishes that are exposed to freezing temperatures
- Glycoproteins make up the majority of the anti-freeze compounds
- These chemicals prevent ice formation in the body of the fishes as well as the intracellular fluids of many other forms

Temperature Extremes

- Regardless of the nature of the organism, extremes in temperatures require special adaptations that will allow them to survive harsh conditions – otherwise it is death
- The selective pressures here are rather intense, but much like we attribute positives with endothermy, if the organisms can survive these harsh conditions, there are rewards