# BIOL 454

# ENVIRONMENTAL PHYSIOLOGY (PART II)

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# ADAPTATION

# RECALL:

- *Homeostasis*
  - `Stability of inner medium is actively regulated
- *Stress* *and* *strain*
  - An external force—*stressor* or *adaptagent*—sufficiently intense to exceed a threshold and invoke a biological response produces *strain.*
- *Tolerance*
  - Adaptation to a stimulus of constant intensity allows the intensity of the response to decrease over time. Also called *habituation*.
- *Fatigue*
  - A diminishing strength of response under the repeated or prolonged influence of a constant stimulus

# ADAPTATION

- **Definition:** Refers to some characteristic of an organism (structural, physiological, behavioral, etc.) that increases the fitness of the organism possessing it (i.e., increases its likelihood of survival and reproduction)

- **The adjustment or changes in structure, physiology and behavior of an organism to become more suited to an environment.**

- Adaptations enable living organisms to cope with environmental stresses and pressures.
- These can be structural, behavioral or physiological.

- ***Structural adaptations*** are special body parts of an organism that help it to survive in its natural habitat (e.g., wing, skin colour, shape, body covering).

- ***Behavioural adaptations*** are special ways a particular organism behaves to survive in its natural habitat (e.g., phototropism).

- ***Physiological adaptations*** are systems present in an organism that allow it to perform certain biochemical reactions (e.g., making venom, secreting slime, homeostasis).

The basis for adaptation over the *long term* for *populations* is genetic variability.

- Natural selection acts on this genetic variability to preserve favorable traits that increase organismal fitness (these traits are termed adaptive traits)

- Thus, adaptation is a basic process in evolution → changing environments or circumstances result in long-term, or *evolutionary*, alteration of organismal characteristics (including physiology) to meet new demands.

- In this type of adaptive change, the genotype of the organism is modified over time to meet the demands of expected conditions (e.g., organisms native to high altitude show characteristics that are favorable in high altitude situations)

# How to detect adaptation?

- **Correlation between a character and an environmental gradient or a functional response**
  - ??? Correlations do not tell you about actual cause-effect relationships
  - Traits can be linked so that the trait you are measuring actually follows variation in another trait on which selection is acting
  - Correlations also don't tell you which trait is driving the correlation

- **Comparisons of individual differences in a character within a species along an environmental gradient**
  - Also provides only correlative evidence, so no cause-effect relationship can be established

- **Experimental alteration of a character, followed by observation of the impacts of that alteration on organismal function** (e.g., experimental modification of a phenotypic character, gene knockout experiments).
  - Provides better cause-effect information, but often doesn't measure actual fitness effects of the change

– The difficulty with most studies of “adaptation” is that

– actual measurements of the effect of the trait of interest on *fitness* are not usually undertaken.

  – To do that requires following populations over time and noting changes in allele frequencies that occur in response to the experimental treatment.

**Adaptation is usually thought of as a change in response to a long-term change in the environment that an organism faces.**

**How do animals respond to changing environments?**

**I. Compensators vs. Regulators**

**a.** **Compensators**: allow internal environment to change along with the external environment, yet are able to compensate for these changes and *function in spite of them*. Compensators generally show a *wide range of internal conditions* that allow survival. However, *function may not be optimal over the entire range that is tolerated*.

**b.** **Regulators**: maintain the internal environment within a narrow range of conditions, even in the face of changing external conditions. Regulators generally show (or tolerate) only a *narrow range of internal conditions* over which function is possible. *Function is optimal, or near optimal, over this narrow range*.

**Tolerance and Resistance**

– **<u>Tolerance</u>**: the amount of change in the internal environment (brought about by changes in the external environment) that an organism can withstand
– **<u>Resistance</u>**: after tolerance levels are exceeded, an animal can resist changes in the internal environment for a certain period, depending on how greatly the tolerance levels are exceeded, but will eventually succumb → death.

**Phenotypic Plasticity and Phenotypic Flexibility**

– **<u>Phenotypic Plasticity</u>**: environmental conditions during development fix a particular phenotype from a given genotype. Different environmental conditions during development can fix a different phenotype from the same genotype.
– **<u>Phenotypic Flexibility</u>**: physiological adjustments within individuals (usually adults) in response to variation in environmental conditions.

- Changes in temperature tolerance with climate changes are called **Acclimatization**

- **Acclimation** is the response to experimental conditions distinguishing adaptations or adjustments in lab experiments from those of acclimatization

- Acclimatization and acclimation can take place in response to many environmental factors such as temperature, oxygen tension, nature of the food, moisture etc.

- May be a discrete occurrence or may instead represent part of a periodic cycle.
  - such as a mammal shedding heavy winter fur in favor of a lighter summer coat

# ADAPTATION TO HIGH TEMPERATURE

## RECAP: Temperature regulation

### <u>TEMINOLOGIES</u>

- ***Homeotherms*** (warm blooded)
  - maintain their body temperature above that of the environment - Birds and mammals
- ***Poikilotherms*** (cold-blooded)
  - temperature of animal fluctuates with that of its surroundings

- ***Heterotherms***-
  - animals that occasionally have high and well regulated body temperatures but at other times are more like cold-blooded animals - deep sea fishes eg. cookiecutter shark, bristlemouths, anglerfish, and viperfish.

- ***Ectothermy***
  - do not produce heat through physiological means
  - Body temp depends on environment
  - eg. Invertebrates, fishes, amphibian and reptile
  - may maintain their constant body temp at all times

- ***Endothermy***
  - can produce enough heat internally to warm themselves
  - eg. Bird and mammal

# Effects of temperature change

- Temperature has striking effects on many physiological processes

- Each metabolic reaction generates heat.
  - what will happen if heat accumulates internally?
    -core temperature will rise

- Van Hoff's law : If body temperature increases by 10°C, chemical reaction will increase 2-3 times

- E.g. Rate of oxygen consumption and all rate processes affected by temperature

- The increase in a rate caused by a 10°C rise in temperature is called the $Q_{10}$

- Significant variation in the internal temperature could have damaging effects on the body's enzymes

# Heat gain and heat losses

- The heat content of any complex animal depends on the balance between heat gains and losses

| Change in Body heat | = | Heat Produced | + | Heat Gained | - | Heat Lost |
|---|---|---|---|---|---|---|

- Heat is gained and lost through exchanges at the skin and other places by different processes

- Four (4) process drive these exchanges
  - Radiation
  - Conduction
  - Convection and
  - evaporation

- **Radiation**:- heat is gained after being exposed to radiant energy (sunlight) or to surfaces warmer than the animals body surface temperature.

- **Conduction**:- heat is exchanged between an animal and an object in direct contact in response to a thermal gradient between them. Heat is lost when the object is cooler then the body and heat is gained when the objet is warmer than the body.

- **Convection**:- movement of air or water next to the body aids conductive heat loss.

- **Evaporation**:- heat is lost as a liquid converts to a gas. Energy for the conversion comes form the heat content of the liquid

- Evaporation - has a cooling effect,
    - -rate depends on humidity and the rate of air movement

- Animals adjust to heat losses or gains by changing their behavior and physiology

- When outside temperatures change, ectotherms use behavioral temperature regulation.-lizards bask on warm rocks (gain heat by conduction)

# Responses to stressful temperatures

- Animals differ in the range of temperatures they can tolerate and this may change with time
- Some organisms are more sensitive to extreme temperatures during certain periods of their lives
  - Survival temperatures
  - Temperatures required for entire life cycle

- Diurnal variation (sleep and awake)
  - Nocturnal animal has higher body temp at night but the Diurnal animal has a higher temp during day time
- Normal core body temperature : range of changes
- Variation of body temperature depends on environmental temperature

- The hypothalamus has control for maintaining the core temperature of mammals
- Input is always from peripheral thermoreceptors in skin and other places
- Once there is a deviation from the set point, the centers integrate responses made by skeletal muscles, arterioles in the skin and in some cases sweat glands.

- Negative feedback loops to the hypothalamus stop the responses when suitable temperature return

# Adaptations to high temperature

- Most animals are known to live and carry out their entire life cycle at temperatures below 50°C.
  - Unicellular blue green alga in hot springs (73-75°C)
  - Thermophilic bacteria (100°C)
  - Some animals (fly larva-*Polypedilum*) get into the state of dormancy

- When a mammal gets too hot, the hypothalamus signals for **peripheral vasodilation.**

- Blood vessels in the skin dilate and more blood flows to the skin.
- **Evaporative heat loss** occurs at moist respiratory surfaces and across skin
- Humans and other mammals have sweat glands that release water and solutes through pores at the skins' surface

# Sweating:

- Evaporation of water from the skin
- One gram water will remove heat 0.58 cal
- Insensible water loss 50 ml/hr will remove heat 29 cal
- For every 1litre of sweat produced, 600Kcal of heat is lost through evaporative heat loss
- Types of sweat gland
  - Eccrine gland (cholinergic sympathetic nerve): in human
  - Apocrine gland : in animals

- During strenuous exercise sweating helps balance heat production in skeletal muscle
- Extreme sweating may lead to collapse as the body looses vital salt as well as water.
- Sometimes peripheral blood flow and evaporative heat loss cannot counter heat stress leading to *hyperthermia* (core temp rises above normal)
    - What happens in mammals that sweat little or not at all?

# Mechanism of sweating:

- Reflex via warmth receptor at the skin
- High temperature will increase blood temp and this will stimulate warmth receptor in Hypothalamus and Thermo-regulatory Center
- Horse : sympathetic nerve and epinephrine
- Cattle : high temp will cause sweating
- Dogs : sweating contributes minimally to heat loss
- Human : sweat helps to dissipate heat well

- Contain HCl, urea, lactic acid, $K^+$
- Composed of coil (active secretion of sweat) and duct (open to dermis and epidermis)
- High sweating, non- acclimatize : High NaCl
- Low sweating : Low NaCl

# Evaporative cooling:

- Heat dissipation by panting-shallow rapid breathing that increases evaporative water loss from the respiratory tract.
- licking fur, polypnea and salivation
- Reflex arc or Central effect (hypothalamus)
- Found in animals that have no sweat gland eg. Dog, cat, chickens
- Useful in sheep and goat than cattle
- In cattle : involves upper respiratory tract

# Lethal temperatures and cause of heat death:

- Lethal temperature is defined as that temperature at which 50% of the animals die and 50% survive ($T_{L50}$)

Some factors contributing to heat death are:

- Denaturation of proteins, thermal coagulation
  - Proteins are denatured at temperatures above 45-55°C
- Thermal inactivation of enzymes at rates exceeding the rates of formation
- Inadequate oxygen supply

- Different temperature effects ($Q_{10}$) on interdependent metabolic reactions

$$\begin{tikzcd} A \arrow[r] & B \arrow[r] \arrow[d] & C \arrow[r] & D \\ & E & & \end{tikzcd}$$

  - If the process C-D is accelerated by increased temperature more than B-C then the intermediary C will be depleted at high temperature.
  - If C is needed for the production of E then it will no longer be available.
- Temperature effects on membrane structure
  - Lipid bilayer with functional proteins

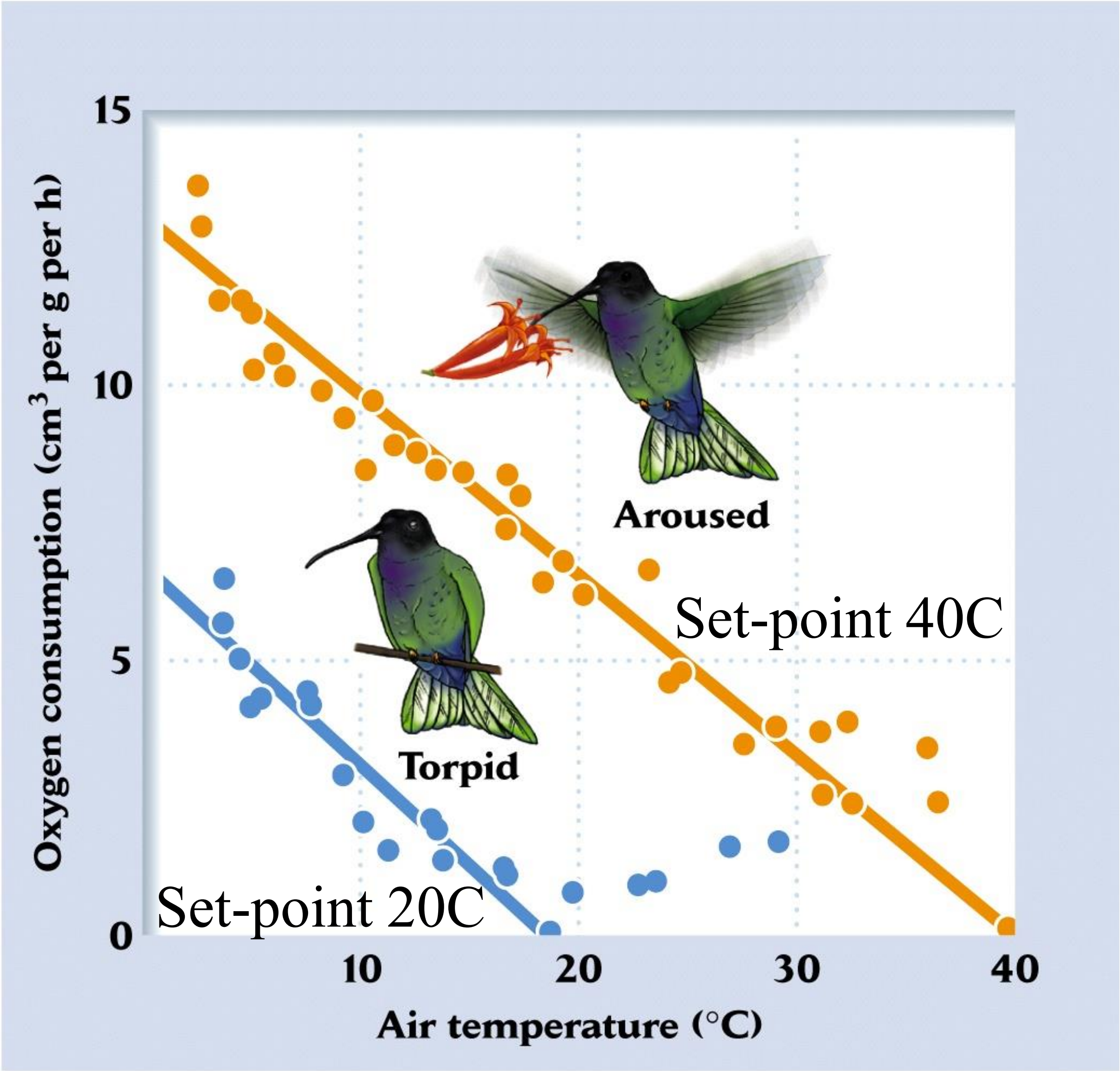
## Physiological change during heat stress:

- Peripheral vasodilation : skin
  - Temperature gradient : non-evaporative cooling
  - Inhibition of sympathetic vasoconstrictor nerve
  - Stimulation of Ruffini's end organ (thermoreceptor)

  - Arterio-venous shunt, bypass the capillary
- Release of bradykinin : vasodilator, aid non-evaporative cooling

- Evaporative cooling from skin and respiratory tract
- Temperature > 90  F (32 °C) : evaporative cooling increase to 75%
- Non-evaporative cooling is not effective if the environmental temperature is high
- Rectal temperature is important indicator

# Maintaining a constant internal temperature warmer than the external environment is costly—the bigger the gradient the bigger the cost




This West-Indian hummingbird, conserves metabolic energy by setting its thermostat down at night

- Assignment I:
  - Write briefly on the physiological responses of humans in relation to prolonged diving in a swimming pool.

# ADAPTATIONS TO THE COLD ENVIRONMENT

- For each species (endotherms) there is a range of environmental temperature, referred to as the **Thermoneutral zone** within which the heat produced remains fairly constant and does not change as ambient temperature increases or decrease.

- Hence, it is the range in which the animal is `comfortable', having neither to generate extra heat to keep warm nor expend metabolic energy on cooling mechanisms, such as panting.

- The lower and upper limits of the range, are referred to as the **lower and upper critical temperatures**.

It is in the relatively narrow range of temperatures between the freezing point of natural waters and 40° C, that most poikilothermal animals carry on their vital activities.

In any one species this range may be considerably less, and vary according to conditions in the environment.

If a species can tolerate a wide range of temperatures it is said to be eurythermal.

If the difference between the maximum and minimum limiting temperatures is small, this condition is referred to as stenothermy.

Ecologists have appreciated in a general way that stenothermal animals are characteristic of environments where temperature fluctuations are small and

eurythermal animals of environments where temperature fluctuations are great, but….

it is only in recent years that satisfactory experimental work has begun to appear on this subject;

- Animals adapted to **cold environments** tend to have **broader** thermoneutral zones than ones living in hot environments.

- **Eurythermy: The tolerance by organisms to a wide** range of environmental temperatures, or the accommodation to substantial changes in the thermal environment.

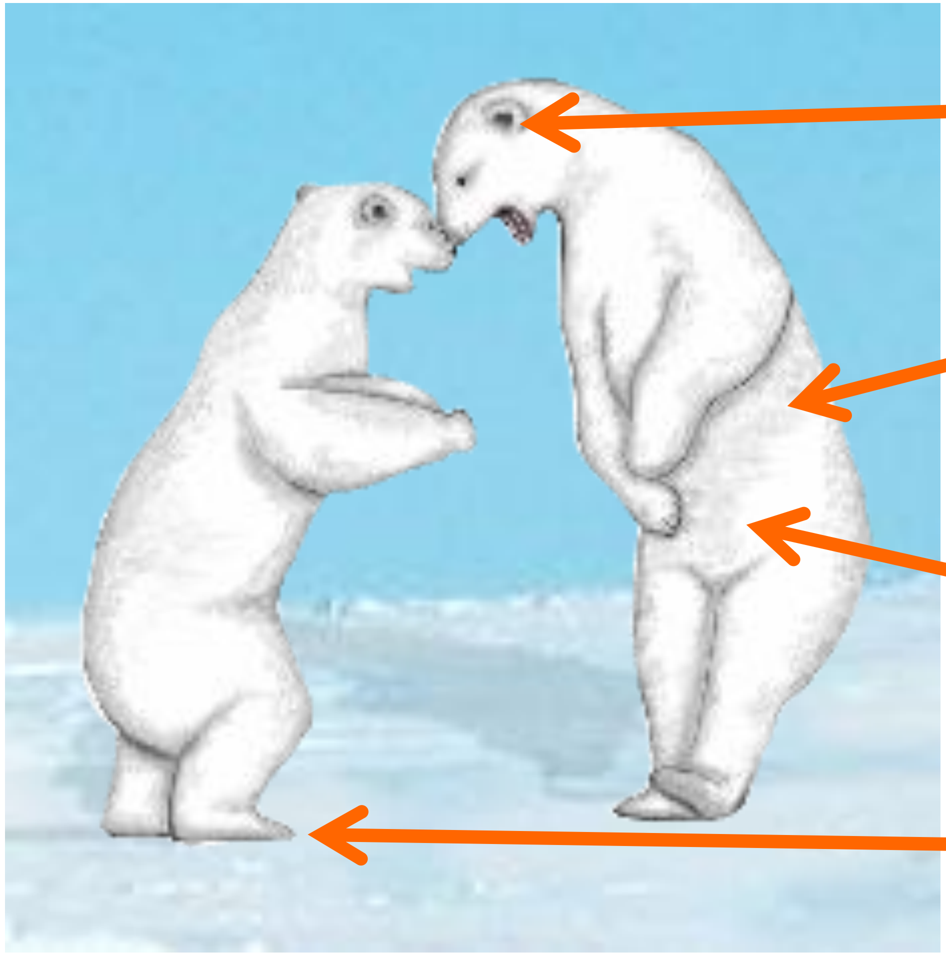
- **Stenothermy:** capable of surviving over only a narrow range of temperatures

- As environmental temperature decreases adjustments in thermal conductance (rate at which heat is lost to the outside environment) and metabolism are necessary to maintain **eurythermy.**

- Living in a cold climate involves adaptations of many physiological systems: appetite, diet, energy storage and reproductive habits as well as thermoregulation.

# How are polar bears adapted?

- How are polar bears adapted to life in an extremely cold climate?



**Small ears help to reduce heat loss.**

**Thick fur and a thick layer of body fat insulate from the cold.**

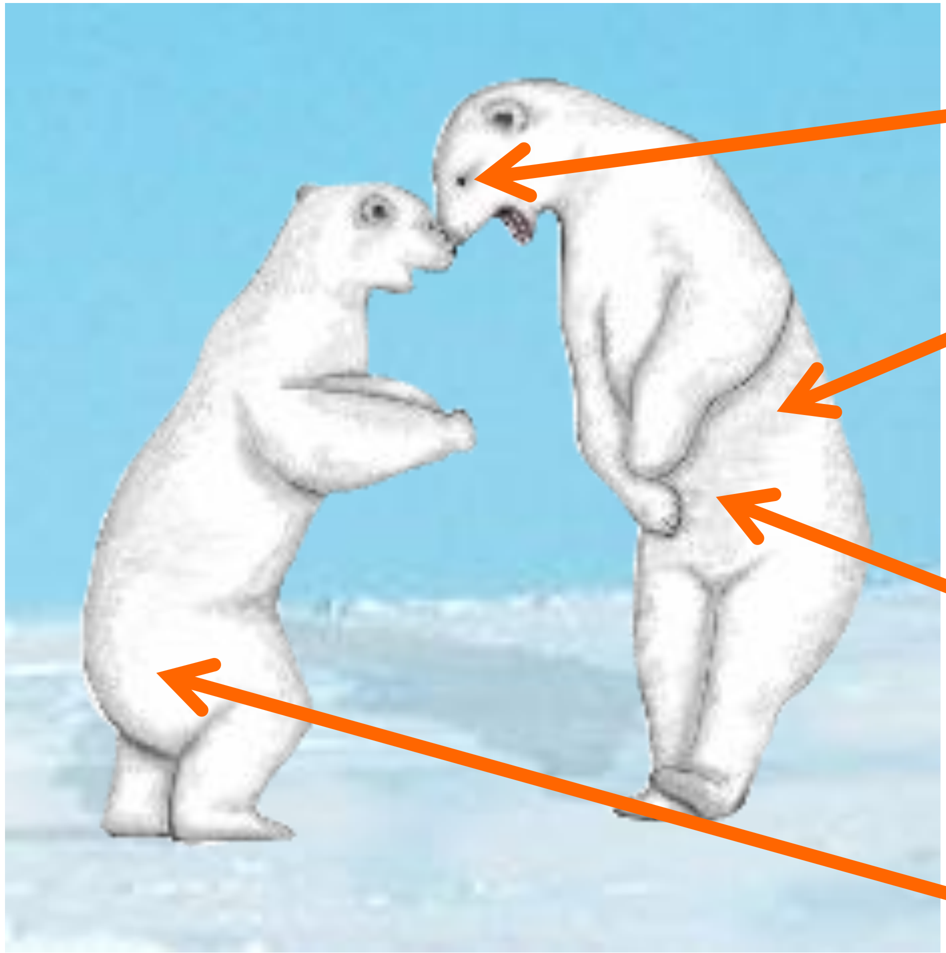
**White fur acts as camouflage.**

**Large feet spread the body's weight. The wide paws act as good paddles**

**and snow shoes.**

# How are polar bears adapted?

- Other adaptations that polar bears have evolved to cope with conditions in the harsh polar environment are:



**Eyes have brown irises to reduce the glare from sunlight reflection.**

**Greasy fur repels water and keeps the bear dry.**

**Skin is actually black to absorb any heat transmitted through the hairs.**

**Body surface area is small compared to volume**

**to reduce heat loss.**

- When humans move from a cool or temperate environment to a hot, dry desert environment or vice versa, they may spend up to seven days acclimatizing to the change in their environment.

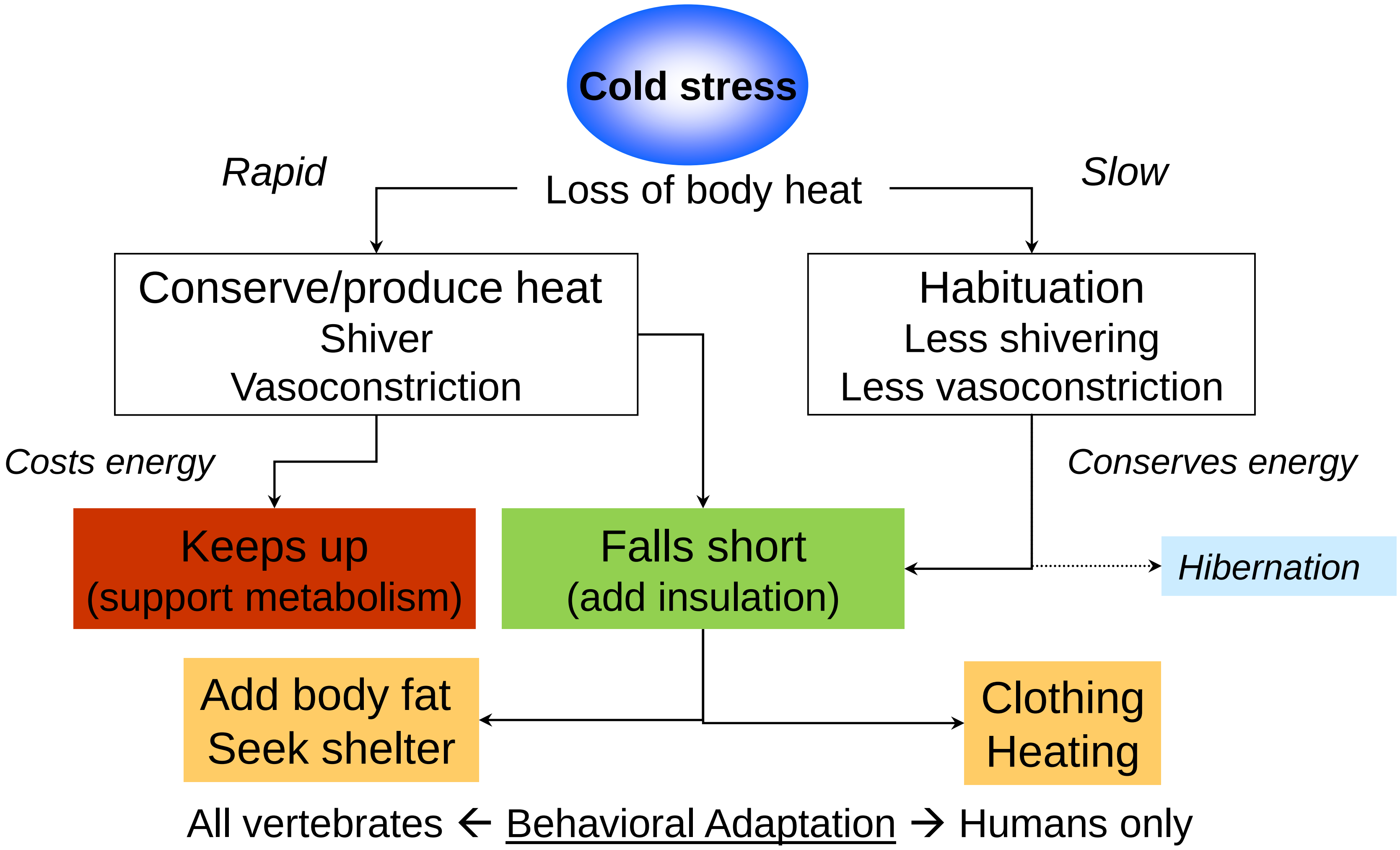
- This allows the body make internal adjustments to compensate for the change in environment conditions.

- **Cold Acclimation**
  - Acute (within 2-3 wk)
  - Change from shivering to non-shivering
  - Hormones involved : epinephrine, T4, corticosteroid
- **Cold Acclimatization**
  - Delayed response : change from summer to winter
  - Improve insulation : fur, decrease critical temp.
  - Adapted vasomotor mechanism : reduce heat loss
  - No change in heat production compared to summer

# Physiological change during cold stress

- Decrease heat loss
  - decrease body surface exposed to cold : huddling, piloerection, shorten the body
  - Peripheral vasoconstriction : less blood come to skin, temp gradient between skin and air
  - Counter-current heat exchange at skin and testis
  - Peripheral venous blood drain into deep vein

- Muscle shivering
  - Effect of epinephrine, nor-epinephrine, Thyroxin, T3 and adrenocortical hormone
- Gene transformation
  - Natural selection of animals : gene changes



Cold stress
Rapid
Loss of body heat
Slow
Conserve/produce heat
Shiver
Vasoconstriction
Habituation
Less shivering
Less vasoconstriction
Costs energy
Conserves energy
Keeps up
(support metabolism)
Falls short
(add insulation)
Hibernation
Add body fat
Seek shelter
Clothing
Heating
All vertebrates ← Behavioral Adaptation → Humans only

# Tolerance to cold and freezing

- Effects as perplexing as those of high temperatures
- Some animals can tolerate extensive freezing but most animals cannot
- Guppies (*Lebistes reticulatus*) kept at 23°C or above dies if cooled to about 10°C

**Cold Hardiness**

Survival of cold-blooded animals at subzero temperatures depends on physiological and biochemical characteristics

- Two strategies are possible
  - Freeze-tolerant
  - Freeze-intolerant

- **Freeze-tolerant:-** animal survives extensive freezing and ice formation in the body
- **Freeze-intolerant:-** animal dies if there is any internal ice formation (such animals must be able to avoid ice formation even at -40°C or -50°C.
- The probability of freezing is dependent on three variables:
  - Temperature
  - Presence of nuclei for ice formation
  - Time

- An animal may be exposed to a temperature far below freezing of its body fluids but remains super cooled unless ice formation begins through nucleation
- Reptiles and amphibians whose body fluids begin to freeze at –0.6°C have been supercooled  to as low as -8°C without freezing
- **Glycerol** is the compound effective in lowering both the freezing point and also supercooling point
- Occurs in high concentration in overwintering insects

- e.g. The willow gallfly-survives the winter in Alaska by extreme supercooling to -60°C
- The immature gallfly has 50% glycerol and there by avoids freezing
- It also improves the tolerance to freezing in animals that tolerate ice formation
- The icefish- *Trematomus borchgrevinki* contains a glycoprotein that acts as an antifreeze substance
    - It acts by preventing the addition of water molecules to the crystal lattice of ice and therefore the growth of ice crystal

- The freezing point of body fluids of polar fishes is a degree or two lower than their melting point explaining why they don't freeze in cold water
  - substance responsible-"anti-freeze" substance
- Fully aquatic marine invertebrates have their osmotic concentration same as the surrounding water and their freezing point the same
- Invertebrates in the intertidal region-alternation between freezing and thawing (low and high tide)

- Intertidal animals may be exposed to air temperatures as low as -30°C for 6hrs – their body fluids freeze rapidly as internal temperature nears that of air
- At -30°C more than 90% of their body water is frozen and the remaining fluid contains solutes in extremely high concentrations
- The cells in addition to losing water to the ice crystals, must be able to tolerate exceptional increase in osmotic concentration
- Formation of ice causes a distortion of muscles and internal organs

- But the ice formed are **outside of the cells** , which are shrunken with probably no ice formed within them. Once thawed, the tissues assume their normal appearance and function normal
- Glycerol is known to protect red blood cells and mammalian spermatozoa from injury caused by freezing
- Its high concentration in insects gives them ability to survive very low temperatures
  - **By lowering the supercooling point thereby increasing the probability that an insect will completely avoid ice formation**
  - **By its protective action against freezing damage once ice formation takes place**

# Ice nucleating agents

- Supercooling and subsequent damage caused by freezing can be avoided by the presence of nucleating agents that aid in ice formation.
- Most freeze tolerant animals have nucleating agents in their hemolymph
- Nucleating agents purified from the bald-faced hornet was found to be a protein with molecular weight of 74000
- This protein is highly hydrophilic with glutamic acid and /or glutamine making up 20% of the amino acid residue

- Supercooling protects an organism against ice formation but not advantageous once freezing occurs
- Natural freeze-tolerance involves mechanisms that restrict ice formation to the extracellular fluid.
- When ice begins to form in the extracellular compartment, the unfrozen fraction becomes osmotically more concentrated and withdraws water from the cells.
- This leaves the intracellular fluid more concentrated so it remains unfrozen

# Freeze-tolerant vertebrates

- The tree frog (*Hyla versicolor*) can tolerate ice formation and in winter has 3% glycerol in its body fluids but the common leopard frog (*Rana pipiens*) has no glycerol
- The wood frog (*Rana sylvatica*) rapidly increases its blood glucose level in response to beginning ice formation
- Some turtles (the painted turtle, *Chrysemys picta*) may be freeze-tolerant as they may survive with more than 50% of their extracellular fluid frozen to ice
- Birds and mammals do not tolerate freezing

How do animals in Antarctica cope with the extreme cold conditions that are found there?

- Antarctic birds and mammals - penguins, whales and seals - are warm blooded animals and they maintain similar internal body temperatures to warm blooded animals in any other climate zone - about 35-42°C.
- They have to keep high body temperatures to remain active. Tropical animals with more variable body temperatures such as reptiles and amphibians can warm up by basking in the sun if they cool down - and they never cool down that much.

- A large (bigger than a small insect) Antarctic animal will never get enough energy from the surroundings to become active if it allows itself to cool) so they have to stay warm to be active.

**Size:**

- Warm blooded animals in cold climates are pretty large, even the smallest Antarctic birds are on the large side and the smallest Antarctic penguin, the Rockhopper is 2.5kg (5.5lb).

- The Adelie and Emperor penguins of the deep south are large. Adult weighs 5kg (11lb) for the Adelie and 30kg (66lb) for the Emperor.
- The larger the animal, the smaller the surface-area : volume ratio and so the less relative area there is to lose heat.
  - **Being big means being warmer.**

**Wrap up warm**

**Don't touch unless necessary**

- Overlapping densely packed feathers make a surface almost impenetrable to wind or water.
- tuck in their flippers close to their bodies
- fat layer (blubber) improves insulation in cold water
- Cold climate penguin species usually have longer feathers and thicker blubber
- The dark colored feathers of a penguin's dorsal (back) surface absorb heat from the sun

# Cont'd…

- King and emperor penguins are able to tip up their feet, and rest their entire weight on a tripod of the heels and tail
- Emperor and king penguin chicks and adults huddle together to conserve heat
- On land in warmer weather, overheating can be a problem
- Emperor penguins can recapture up to 80% of the heat escaping through their breath

# HIGH ALTITUDE

# Acclimatization to high altitude

- People who live at sea-level and ascend to high altitude are exposed to hypoxia;
- Followed by a suite of physiological and biochemical changes that maintain an oxygen supply to the respiring tissues.
- physiological changes are possible because of phenotypic flexibility.

- Sudden exposure to high altitude (4000 m), may result in a set of symptoms known as mountain sickness (HACE/HAPE)

- However more than 22 million people live permanently at high altitude, with domestic animals grazing the alpine pastures, where crops such as barley can also be grown.

- Animal species have lived at high altitudes for much longer than humans.

- Acclimatization to high altitude continues for months or even years after initial ascent, and ultimately enables humans to survive in an environment that, without acclimatization, would kill them.

- initial failure of the respiratory system to respond to hypoxia is to some extent ameliorated by responses in the blood and the cardiovascular system.

- red blood cells which are stored mainly in the spleen are released. This increases the level of haematocrit, so thus increasing the capacity of the blood to carry oxygen.

- Followed by an increase in the rate at which red blood cells are formed

- mediated by the glycoprotein hormone, erythropoietin, which stimulates cell division in haematopoietic stem cells in the bone marrow.
- is an increase in heart rate and therefore **cardiac output**.
- Cardiac output is increased by up to five times the resting level at sea-level.

- Humans who migrate permanently to a higher altitude naturally acclimatize to their new environment by developing an increase in the number of red blood cells to increase the oxygen carrying capacity of the blood, in order to compensate for lower levels of oxygen in the air

# Aestivation

- Aestivation in animals is a state of dormancy usually to assist in water regulation, where minimal activity results in retaining more water during the hottest parts of the day.

- These animals find a shaded/underground area to do this.

- In Plants:- the arrangement of sepals and petals in a flower bud before it opens.
- In animals:- cessation or slowing of activity during the summer; especially slowing of metabolism in some animals during a hot or dry period.

# Hibernation

- Cessation from or slowing of activity during the winter; especially slowing of metabolism in some animals. The act of retiring into inactivity
- The torpid or resting state in which some animals pass the winter.
- A state of dormancy used by animals in the colder winter months where metabolism is slowed down and expenditure of energy is therefore reduced.

- This is done mostly due to the fact that food sources are scarce at this time of the year, and if the animal did not hibernate, it would more than likely have a greater expenditure of energy looking for food than the energy gained by finding it.

# Diapause

- **Diapause** is a physiological state of dormancy with very specific triggering and releasing conditions.
- It is used as a means to survive predictable, unfavorable environmental conditions, such as temperature extremes, drought or reduced food availability.
- The most common application is in arthropods, especially insects

- a neurohormonally mediated, dynamic state of low metabolic activity.
- Associated with this are reduced morphogenesis, increased resistance to environmental extremes, and altered or reduced behavioral activity

- Diapause occurs during a genetically determined stage(s) of metamorphosis, and its full expression develops in a species-specific manner, usually in response to a number of environmental stimuli that precede unfavorable conditions.
- Once diapause has begun, metabolic activity is suppressed even if conditions favorable for development prevail.

- It is primarily important to note that diapause is not only induced in an organism by specific stimuli, but once it is initiated, only certain other stimuli are capable of releasing the organism from this state.
- The latter is essential in distinguishing diapause as a different phenomenon from other forms of dormancy such as hibernation

- A similar phenomenon occurs in the seeds or other resting stages of various plants.
- In the eggs of various vertebrates there is a phenomenon sometimes known as "**embryonic diapause**", also termed "**delayed implantation**," and is not directly equivalent to the phenomenon in arthropods, although in both cases there is a cessation of metabolic activity.
- Some mammals that undergo embryonic diapause include rodents, bears and marsupials, (e.g. kangaroos).

- Activity levels of diapausing stages can vary considerably among species.
- Diapause may occur in a completely immobile stage, such as the pupae and eggs, or in very active stages that undergo extensive migrations, such as the adult Monarch butterfly, *Danaus plexippus*.
- In cases where the insect remains active, feeding is reduced and reproductive development is slowed or halted.

# Phases of insect diapause

- Diapause in insects is a dynamic process consisting of several distinct phases

**The induction phase** occurs at a genetically predetermined stage of life and occurs well in advance of the environmental stress

- This sensitive stage may occur within the lifetime of the diapausing individual, or in proceeding generations, particularly in egg diapause

- During this phase, insects are responsive to external cues called token stimuli, which trigger the switch from direct development pathways to diapause pathways.
- Token stimuli can consist of changes in photoperiod, thermoperiod or allelochemicals from food plants.
- These stimuli are not in themselves favorable or unfavorable to development, but they herald an impending change in environmental conditions.

**Preparation:** During this phase, insects accumulate and store molecules such as lipids, proteins and carbohydrates.

**Initiation:** This phase begins when morphological development ceases

- In some cases, this change may be very distinct and can involve moulting into a specific diapause stage, or be accompanied by colour change.
- Enzymatic changes may take place in preparation for cold hardening.

**Maintenance:** During this phase, insects experience lowered metabolism and developmental arrest is maintained.

- Sensitivity to certain stimuli which act to prevent termination of diapause, such as photoperiod and temperature, is increased.

**Termination:** In insects that undergo obligate diapause, termination may occur spontaneously, without any external stimuli.

- In facultative diapausers, token stimuli must occur to terminate diapause.
- These stimuli may include chilling, freezing or contact with water, depending on the environmental conditions being avoided

# Biological Rhythms

- The world changes in cyclical patterns:, the seasons, day and night, tides etc.

- These changes are often accompanied with several adaptive responses from living organisms.

- Many animals have acquired a variety of endogenous physiological, biochemical and behavioral rhythms whose periodicity is matched to the relevant rhythm(s) in the environment.

- The behavioural pattern is attributed to the presence of in-built time device - the biological clock.

# Definitions

- Biological clock is an internal timing system which continues without external time clues, and controls the time of activities of plants and animals

- Period of the rhythm the time it takes to complete one cycle of activity

- Phase shift when the onset of the period of the rhythm is changed either earlier or later. This occurs when you travel around the earth into different time zones. It can be artificially induced by controlling the light and dark periods

- Free running period this is the time when the clock is running without any clues from the environment, so it ‘runs free’

- Entrainment this is the resetting of the clock on a regular basis, forcing it to take up the period of the environment

- Zeitgeber – the environmental agent that resets the biological clock eg light or temp

- <u>Circa</u> – because each of the rhythms is not exactly the time length stated, eg daily is not 24 hours, their names start with **circa** (which means ‘about’)

- <u>Photoperiod</u> – the responses of plants and animals to the lengths of day and night

# Biological Timing responses to the abiotic world

- All organisms respond to various cues
- The responses can be:
  - Annual cycles – yearly changes of the season
  - Daily – night and day
  - Lunar – monthly, often related to the moon
  - Tidal – related to the ebb and flow of the tides
- It is to an individual's advantage to synchronise its activities to these rhythms
- This can be in three basic ways;

# Synchronising to rhythms

- *Exogenous* - A rhythm that is control by the external, environmental stimulai detected by the organisms

- *Endogenous* – A rhythm that is controlled by an internal biological clock

- *Combination* – of both endogenous and exogenous

# Endogenous

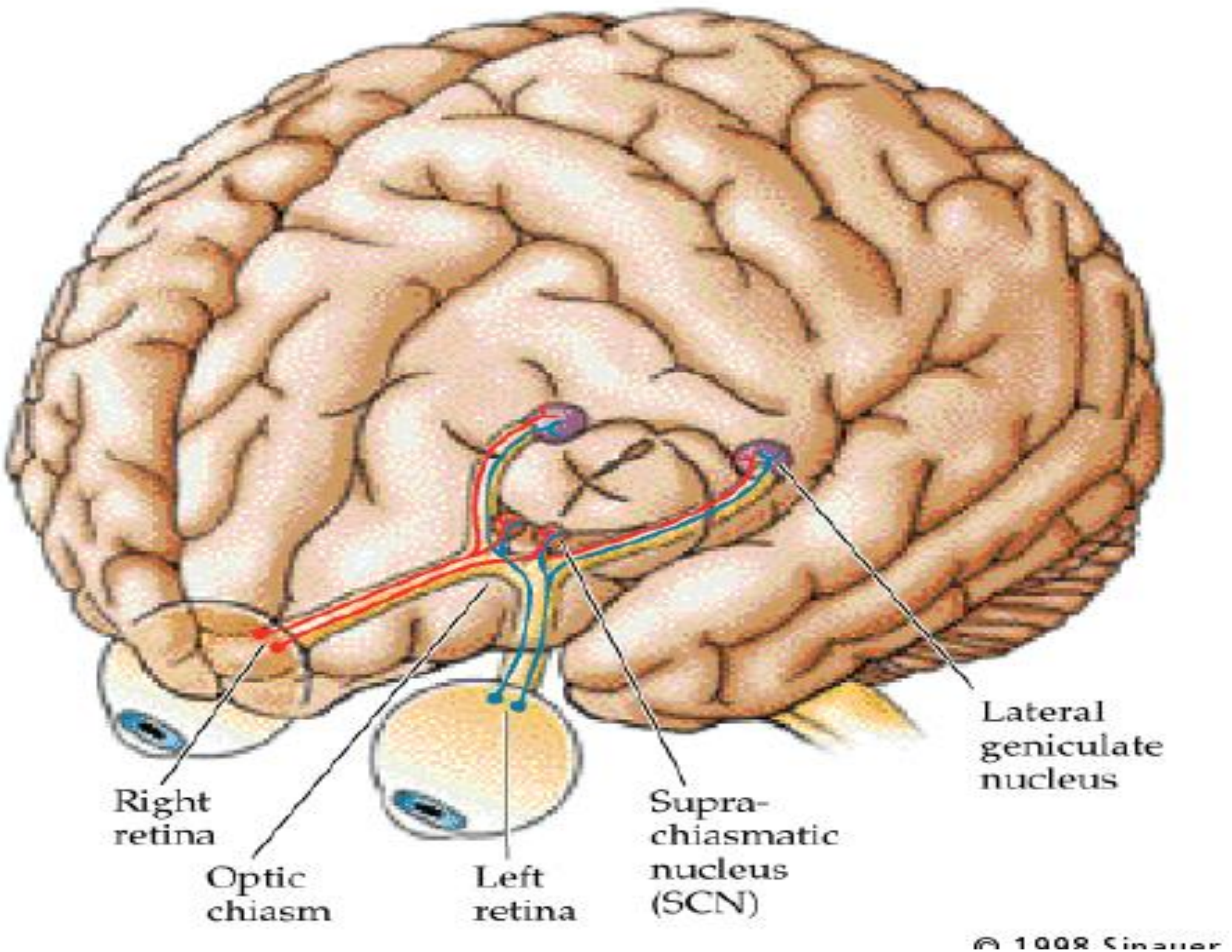
- Sometimes it is hard to tell if a rhythm is endogenous or exogenous. It is endogenous if it can be shown that one of the following criteria apply:
  - **The rhythm may have a frequency that is not exactly the same as the period of an external environmental factor, eg light, temperature etc**
  - **The period of the endogenous rhythm usually deviates from the natural rhythm when studied under constant laboratory conditions**
  - **The rhythm may persist when the organism is moved from one part of the world to another**

# Biological Clocks

- The existence of circadian and circannual rhythms means that animals must have a way of keeping track of time
- They have an internal clock which lets them predict and prepare for changes to come
- The biological clock in animals is found in the hypothalamus of the brain
- It is
  - Sensitive to environmental cues
  - Can be stopped and reset
  - Is very accurate
  - Is inherited

# SUPRACHIASMATIC NUCLEUS (SCN) IS MASTER PACEMAKER

- Circadian clock consists of a group of nerve cells in the brain
- Suprachiasmatic nucleus (SCN).
- The SCN contains about 20,000 nerve cells (hypothalamus)
- An area of the brain just above where the optic nerves from the eyes cross.


Right retina
Optic chiasm
Left retina
Supra-chiasmatic nucleus (SCN)
Lateral geniculate nucleus
© 1998 Sinauer

Activity in suprachiasmatic nucleus correlates with circadian rhythms

Lesions of suprachiasmatic nucleus abolish free-running rhythms

Isolated suprachiasmatic nucleus continues to cycle

Transplanted suprachiasmatic nucleus imparts rhythm of the donor on the host

- Biological clocks are used for:
  - Control of the daily rhythms of the body
  - Reproduction timing
  - Preparing for migration by eating of plenty of food
  - Preparing for winter by storing of food, increasing thickness of coat and hibernating
  - Navigating by the sun or stars

# Circadian Rhythms

- Animals are active at different times of the day
  - Diurnal – active during the day, inactive at night
  - Nocturnal – active at night, inactive during the day
  - Crepuscular – active at dawn and dusk
  - Arrhythmic – no regular pattern – tend to be found where changes in the microclimate are negligible

# Examples of rhythms

- Periods of sleep
- Physiological processes
- Endocrine system rhythms
- Temperature changes
- Heart rate rhythms
- Pain rhythms
- Alcohol metabolism rhythms
- Times of births and deaths, etc

# Epicycles (Ultradian) Rhythms

- cycles of repeated activity that are less than 24 hours

*Arenicola marina* - feed on surface every 6 -8 mins

# Circamonthly Rhythms

- Some animals synchronise their behaviour with the phases of the moon
- Changes associated with tidal patterns are also considered circamonthly (lunar)
- Menstral cycle of female mammals.
- The spawning behaviour of some marine worms is synchronised by the moon so that the egg and sperm are released at the same time
- Grunion fish also uses this method of spawning, using the tides

# California grunion *(Leuresthes tenuis)*

- -spawn between 10 pm and 4 am on the night before a full or new moon

# Circannual Rhythms

- These result from the rotation of the earth around the sun
- Another factor is seasonal changes caused by the tilt of the earth and the seasons produced as it rotates around the sun
- Examples of circannual rhythms are:
  - Migration to and from breeding sites
  - Reproduction cycles
  - Hibernation (Ground squirrels varying b/n 228-445 days)
  - Aestivation

- Our bodies are controlled by endogenous clocks
- We therefore have to pay heed to these clocks and environmental cues as well.