

## The Chemical and Physical Environment

1. Measure of physiological performance
2. Temperature
3. Salinity
4. Oxygen
5. Light
6. Cycles

These are the most important abiotic factors in the marine ecosystem that can cause important changes, in the coastal area these parameters change very quickly

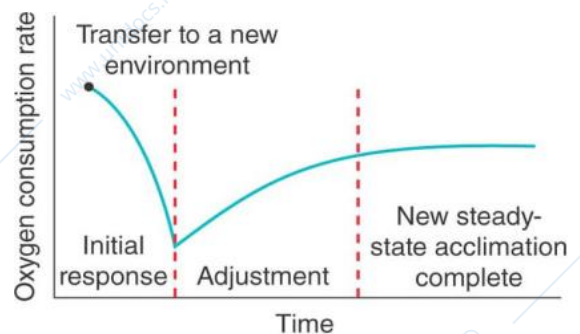
### 1. Measure of Physiological Performance (what happen when a stress occur)

- They are **Receptors to sense the change**: these receptors are very important for the reception, e.g. Eyes, chemical receptors, antennae, there are useful for the adaptive response (the second step).
- They start an **Adaptive response** (there are different types of response depending on the extremity of the environmental change)
  1. **BEHAVIORAL** → is the most important for the vigil, mobile organisms. first the organisms understand the change with the receptors, after they have an adaptive response, so they for example escape, but a lot of organisms are sessile, so they have to develop different responses, e.g. biochemical
  2. **BIOCHEMICAL** → changes of [CONCENTRATION] enzymes, hormones, ions within specific cell types
  3. **PHYSIOLOGICAL** → cellular changes at large systemic level requiring energy (transport across membranes), these processes need ATP (energy), e.g. transport across membrane
  4. **GENE REGULATION** → is a genomic response, activation of genes, pathways

They are able to reach a new equilibrium passing from the acclimation

**Acclimation**: after an environmental change there is an initial response (decrease of O<sub>2</sub>), but after a specific time there is an adjustment period that is followed by a new steady state acclimation complete, so bring the organisms to reach an equilibrium, an O<sub>2</sub> consumption rate that probably is the same before the stress.

The organisms try to adapt themselves with the acclimation that is the change of function and tolerance that results in a change of response to new physiochemical conditions is known as acclimation: NEW EQUILIBRIUM but this is not always possible in fact sometimes they can also die.



There are 2 types of organisms:

- **Regulators organisms**: organisms that can maintain constancy in their parameters despite environmental change, the internal homeostasis even if the external parameters change. *Change in the seawater salt content, the regulator organisms can keep constant the body fluid salt content*
- **Conformers organisms**: organisms whose parameters and internal state change in conformance to environmental change, e.g. if the salinity of the water increases, also the salinity of the body increases. *If the seawater salt content increases, also the body fluid salt content increases*

We can measure different metabolic parameters:

**Cost of metabolism** is the greater energetic cost of overall cellular reactions (consumes and digest food) → is this cost and less energy available for growth and reproduction

**Scope for growth:** consume and digest food is the greater energetic cost of overall cellular reactions, this cost is called COST OF METABOLISM, is due to the consume and digest food. The scope of growth is the difference between the amount for energy assimilated (food) and the cost of metabolism, it can be:

- 0 : maintenance metabolism for organism
- + : is positive, so there is energy available for growth and reproduction
- - : is negative, so the cost of metabolism is greater than obtained by energetic intake of food

e.g. Scope for growth of a *muschel* under conditions of high, medium, and low food and varying temperature. As temperature increases or food decreases beyond a certain point, scope for growth, in terms of energy balance, falls below zero.

**Food** and **T** can be considered the **main factors that affect the scope of growth for an organism**. If food is abundant, the scope of growth usually increase, but if the T increase, the scope of growth decrease because also the energy needs by the cells increase.

**MORTALITY RATE** → we can measure this parameter after an environmental change. We use experimental laboratory procedures, in particular experimental populations, after the acclimation, the population is subject to a gradual change of the environmental parameters, in the example, T. Due to this change, we will observe the change in the mortality % of the population. The **LETHAL DOSE**, or LETHAL T, or LETHAL SALINITY... (different from the parameters that we are studying) is the amount of T, salinity, O<sub>2</sub> level... require to kill the 50% of the experimental population after a specific time, is called **LD50**.

## 2. TEMPERATURE

*The range of T in the ocean is lower than in the terrestrial environment:* (in the ocean the T go from **-2 to +40 °C**) less than typical terrestrial range (-88 to +58 °C); the sea water T in more STABLE than the land T, for 4 reasons:

- *Higher heat capacity of water*
- *Ocean warming reduced by evaporation*
- *Solar radiation penetrates deeply into ocean layers*
- *Ocean mixing*

In the coastal water there is a range of 42°, in the open ocean there is a range of 34° → coastal ocean ecosystem can be very stressful for the habitants.

T is the most important parameter which determinate the distribution and the abundance of the organisms

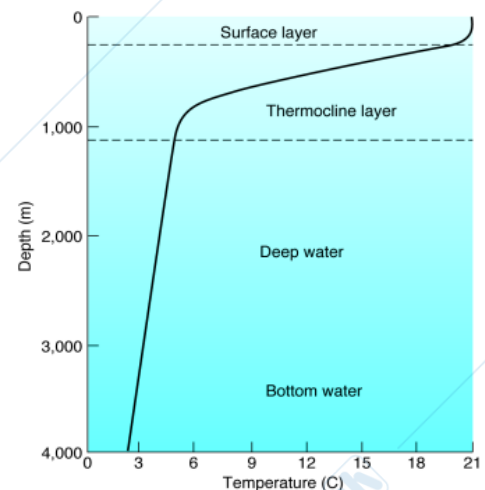
T variation is common in marine environment, there are 5 different T variations:

**1. Latitudinal temperature gradient:** (high T in the lower latitude, tropical, and lower T at the high latitude, polar). The T of water in high latitude is lower than the T of water in low latitude, for this reason the Indian Ocean reach the heist T in the sea, 25°C (is the hottest ocean in the world), the Atlantic Ocean is a bit colder, at the end the Artic Ocean is the coldest one. The polar water still about 0°C, Tropical water are constantly above 25°C, the marginal seas (e.g. Mediterranean Sea) have great annual T ranges due to the restricted circulation and shallow depth.

Depending on the latitude and the season, the water has different characteristic:

- **Low latitudes:** (TROPICAL WATER) always, in winter but also in summer, the T in the upper layer is more or less around 25°C, with the depth the T decreases but earlier than in the mid latitudes. There isn't a thermocline
- **Mid latitudes:** (TEMPERATE WATER) there is a strong THERMOCLINE (variation of T during the hot periods, the T remains around 25°C and then starts to decrease in the deep part). BUT this thermocline disappears in winter because the difference of T above the lower and the upper layer of the water is not so high
- **High latitudes:** (POLAR WATER) T is always constant even in the shallow part, there is a sort of stratification without a thermocline

**2. Vertical gradient (depth):** change in T with an increase of the depth. There are different layers of water, starting from the upper one there is the SURFACE LAYER → in this part of the ocean where are the winds that created waves, clouds, and currents. Moving to the deep layer there is the THERMOCLINE LAYER (until 1000m) → this is separated from the layer above because the T remain constant but is very different from the T of the close layers. The thermocline is not always present, but it depend on the latitude. Then there is the DEEP WATER (from 1000m to the bottom water) → is characterized by a low T that continue to decrease with the depth. BOTTOM WATER (close to the seafloor) → is the deepest layer in the ocean. There are different T profile depending on the season and on the latitude. In the tropical latitude there are no seasons, we have a no too specific thermocline, VS temperate latitude there is a strong seasonality, and the T can change a lot.



### 3. Regional Differences

#### 4. Seasonal temperature change

#### 5. Short term changes (e.g., weather changes, tidal changes)

How can we classify the organisms using T? (In term of internal regulations)

- **Homeotherms** are organisms that *regulate body temperature to a constant level, usually above the T of the ambient environment* (they are regulators organisms), e.g. marine mammals, sea birds
  - Advantages: constancy of cellular and biochemical reaction at high rate, so they are able to keep constant the reactions
  - Disadvantages: sometimes, marine mammals have higher T than seawater, so this lead to a rapid heat loss (marine mammal can reach body t° of 38°C)
- **Poikilotherms** are organisms whose *body temperature conforms to that of the ambient environment* (they are conformers organisms), e.g. fishes, marine invertebrates
  - Advantages: no cost of keeping high and constant t° (they don't need ATP for maintain this T constant)
  - Disadvantages: low metabolic efficiency
- There is another intermediated category, an intermediate behavior: **not true homeotherms**: *the body T is usually higher than the ambient sea water*, e.g. Strong-swimming fishes have an intermediate status because some part of the body (central muscular portion) have higher T than seawater, e.g. Tuna that swim very fast, has the central muscle part hotter than the water.

- There is another intermediated category: **not true poikilotherms**: they have an *internal temperature lower than the T of the sea water*, e.g. Some intertidal animals are not true poikilotherms since they have T lower than seawater.

In fact, they **respond to heat stress** during low tide on hot day to **avoid being heated**:

1. **Circulation of body fluids** → brings heat to surface of body so it can be dissipated
2. **Evaporation** → also allows heat loss to avoid overheating
3. **Behaviour** → mobile forms can move to burrows, subtidal

## HOMEOTHERMS:

The most important problem is **Heat loss** (THEY NEED TO REDUCE THE HEAT LOSS) → problem for homeotherms who maintain high body T

There are different *strategies to reduce this heat loss*:

- a. **Insulated body surface**: used by many vertebrates, e.g. **big layer of blubber** (grasso) in whales, **feathers** (piume) in birds
- b. **Counter current heat exchange**: in marine mammals, or in the birds that have limbs, e.g. flipper for a Dolphin are the principal sources of heat loss, however, is minimize thanks to a counter current heat exchange. The arteries are surrounded by veins, within which the blood return to the core of the animal. At any contact points among veins and arteries, **the arteries are warmer than the veins**, so heat is lost to the returning veins blood flow. Heat is reabsorbed by the veins and return to the limbs body core. The circulating venous and arterial blood in opposite directions while vessels (vasi) are in contact to reduce heat loss. **Limbs** (arti) are the main source of heat loss, e.g. a lot of marine mammals and birds have this system for minimize the heat loss, *they transport the heat into the body without dissipate the heat in the environment* (distribution of the heat into the venous)

e.g. strong homeotherms: **Leatherback turtles** have body temperature as much as 18°C, *over the ambient temperature, which is maintained by a combination of*:

- A large heat-retaining mass → big layer of subcutaneous fat, blubber
- A counter current exchange mechanism in the flippers → arteries and veins

## POIKILOOTHERMS:

The most important problem is that **an increase in T, increases the metabolic activity** (O<sub>2</sub> consumption). AN INCREASE OF T, INCREASE THE METABOLIC ACTIVITY, SO THE CONSUMPTION OF O<sub>2</sub> INCREASE.

With an increase of 10°C, the corresponding change in metabolic activity and o<sup>2</sup> consumption is called Q<sub>10</sub>... **Q<sub>10</sub>**: the change in metabolic rate with an increase of 10°C

- For many poikilotherms Q<sub>10</sub> range from a factor of 2 to 3
- Metabolic rate and performance will increase as temperature increase to a maximum followed by a decline caused by physiological limitations: > T, > metabolic rate, but at a certain point the organisms find an **OPTIMAL TEMPERATURE** and after < metabolic rate caused by physiological limitations

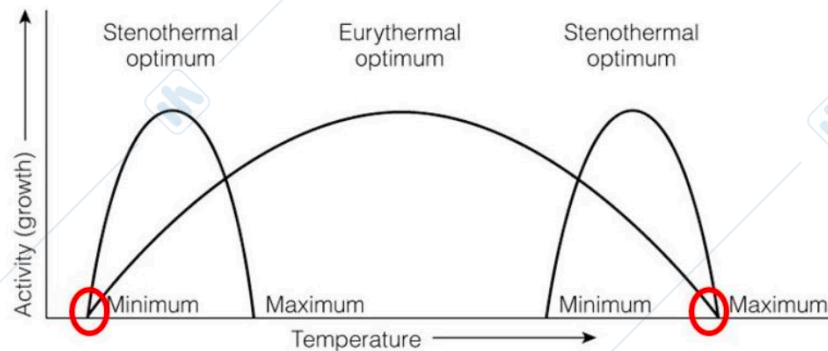
e.g. *Uca pugilator* (crab): the peaks for both these performances reach the same T (25-30°C) which also represent the optimal T in which the crab prefer to live, so crab prefer to live at T° where their performance (metabolic activity) is maximal.

## Tolerance to T changes:

Temperature tolerance varies tremendously among marine organisms, so *we can classify the organisms watching the tolerance to T changes*

- **Stenothermal** → Organisms withstand small variation in temperature (narrow tolerance zone: stretta zona di tolleranza), Typically live in open ocean, e.g. corals → **tolerate SMALL variation in T**

- **Eurythermal** → Organisms withstand large variation in temperature (wide tolerance zone: larga zona di tolleranza), Typically live in coastal waters because in this habitat the T changes are more evident → **tolerate LARGE variation in T**



### CONSEQUENCES...

#### High-Temperature shock: **cause physical and chemical damage**

- Failure of a series of interdependent metabolic reactions
- Loss of physiological integration, or decrease in the degree of coordination among interdependent biochemical reactions
- In a cellular level there are dysfunctions in enzyme activity (to high T, the binding site for substrate are too open and the enzyme function is inefficient)
- Unfolding of the proteins: the high T affects the structure of the protein
- Protein denaturation and degradation... to prevent these, the cells have different mechanisms: **Up regulation of HSPs and ubiquitin**
- In the membrane level there are: Disruption of membranes - disrupts packing of structural phospholipids in cell membranes (membrane order) which disrupts transport of ions, other cell functions

There are several mechanisms for adapt to these changes:

- To prevent damage to the cellular proteins, the cells have a specific family of proteins... **HSPs** (Heat-shock proteins) that protect the other proteins of all organisms (from bacteria to humans) against thermal stresses
- Molecular chaperones which maintain protein homeostasis, they are involved in:
  - de novo folding of proteins
  - prevention of oligomeric assembly
  - refolding of stress-denatured proteins
  - assistance in proteolytic degradation
- **Up-regulation of their expression** following a wide range of environmental stresses (it represent an emergency response)

#### Low -Temperature shock: **cause physical and chemical damage**

- In tropical fishes → cold depress the respiratory system leading to anoxia and death
- Freezing → is a problem in winter in some habitats and in high latitudes where sea ice forms, the freezing can destroy cells as cell cytosol freezes. They use anti-freezing products:

Some fish have **glycoproteins and glycopeptides**, which function as antifreeze and depress the freezing point of the cellular fluids.

e.g. The Antarctic "ice fish" *Pagothenia borchgrevinski* lives in Antarctic waters, just beneath (sotto) the ice. It has antifreeze glycoproteins in the blood, which help to prevent freezing of tissue fluids.

e.g. Black cod (merluzzo), *Notothenia angustata* (New Zealand) → No Hsp response!!

**TEMPERATURE EFFECTS:** T will control...

- **Controls the rate of chemical reactions**, metabolism and performance thus **affecting the rate of growth**, e.g. the polar organisms grow lower than the tropical organisms
- **Controls the feeding rates**: change the rapidity to obtain the food, so the feed. The activity of the Cirri increase when the T increase, but after decrease.
- **Controls the reproduction and sex**:
  1. Spawning (depose): some invertebrates species spawn only when the given T is reached.
  2. switch from asexual to sexual reproduction
  3. embryo sex: in *Chelonia mydas* the sex of the embryo is determinate by the T, if is lower than 29.5°C they are male, instead they are female. In our situation of CC, there will be a problem in the abundance of female

e.g. *green turtle*: if the environmental T during embryo phase of live is < 28°C the young generation will be males, instead is the T is > 29,5°C females... with the global warming the sex ratios may be skewed toward (inclinati verso) females.

**3 – SALINITY**

Def. *Number of grams of dissolved salts per 1000 gr of seawater (ppt or 0/00)*: part per thousand

- **Major elements** (> 100 ppt, 100 mg/l): Chlorine (55%), Sodium (30%), Magnesium, Sulphur, Calcium, Potassium.
- **Minor elements** (between 1 and 100 ppt: low [ ] ): Bromine, Carbon, Strontium, Boron, Fluorine
- **Trace elements** (less than 1 ppt): Nitrogen, Phosphorus, Iron

*The ratio of the major elements is constant throughout the oceans (in all the ocean), even if the total salinity varies* → if in one ocean there is 33 ppt of salt and in other sea there is 35 ppt of salt, the ratio of the major element never change, is always the same: 55%, 30% ...

**Salinity range in the ocean change between 33 - 37 ppt, salinity average is 35 ppt**, but sometimes can reach also 40 ppt, e.g. death sea or sometimes could be lower than the average, e.g. in the estuary 33ppt

The salinity could change linked with:

- **Dilution processes**: river input, rainfall that can decrease the salinity
- **Concentration processes**: evaporation, sea-ice that can increase the salinity

**SOURCES OF SALT IN THE OCEAN:**

There are different sources of salt in the earth, the salt reaches the marine habitat from different sources:

- *Biological processes*
- *From the river*
- *Hydrothermal vents*
- *Precipitation*
- *Vulcanic precipitation*
- *Sea spray*
- *Vuclanic discharge*
- *Weathering*

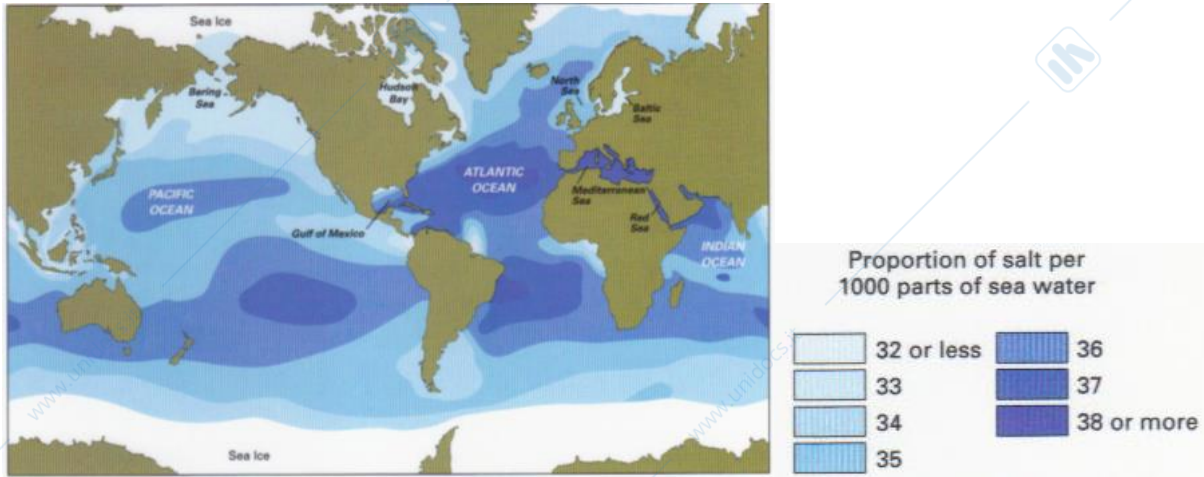
**There are many processes that remove and reduce the salinity, not only the creation of it**

Like the T, also the salinity could change in different ways, there is a **LATIDUTINAL GRADIENT OF SALINITY**:

- In the **equator/tropical region**: excess of precipitation over the evaporation, so the salinity in this area is not so high

- In the **mid latitudes**: e.g. in the Mediterranean Sea, there is an excess of evaporation over the precipitation, so the salinity is higher than in the equator and in the high latitude, around 36-37 ppt
- In **high latitude** the salinity is less than 32 ppt, especially in the pole

In general: 94% of the Earth water is salted



### Salinity variations in the environment

There is also an **ENVIRONMENTAL GRADIENT OF SALINITY**:

Starting from the FRESHWATER, we have river, low salinity, then increase going to estuary or in BRACKISH WATER, in the mangroves, sometimes we can have same salt close lake (BRINE WATER > 50 ppt) and then the water reach the sea (30-50 ppt) where usually remain constant. Sessile organisms must cope with the change of salinity, otherwise they will die, instead the vagile organism can move among the spaces.

- In many habitat, especially intertidal and near-shore habitat, *salinity may change rapidly* over very short spatial scales
- In open ocean salinity remain constant
- In an estuary zone there is a *variation of salinity*, entering in the terrestrial environment the salinity drops down

**Organisms** that are **mobile** can migrate offshore if they cannot tolerate a certain salinity, but **sessile organisms** must cope (in order to avoid damage) with the changes or die

### WHY SALINITY IS SO IMPORTANT?

*To operate efficiently, marine organisms must maintain constant chemical conditions within cells* because significant change in salt could affect different molecular processes:

Significant changes in dissolved cellular inorganic constituents affect:

- Function of proteins
- Catalytic rate of enzymes
- Interaction of substrates with enzymes
- Biochemical reactions
- Membrane transport

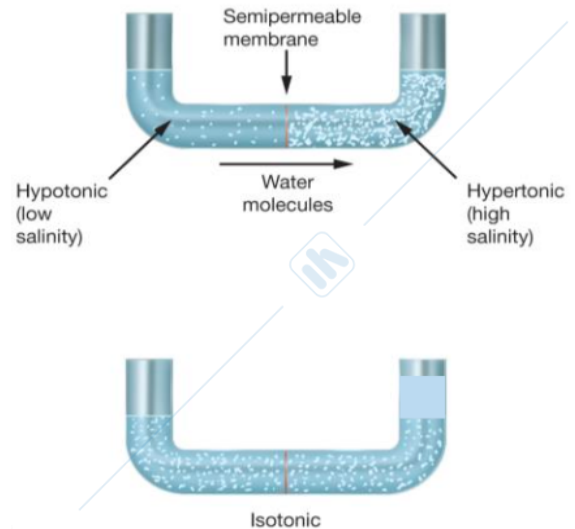
Changes in salinity affect marine organisms through the processes of:

- OSMOSIS
- DIFFUSION

**2 processes that create damage to the marine organisms (due to the salinity)**

## OSMOSIS

1. Osmosis is the *movement of pure water across a membrane which is permeable to the water but not to solute* (that is permeable to water but not to solute) due to difference in total dissolved material on either side of membrane → **semipermeable membrane**
2. Due to osmosis, the **water molecules move from less concentrated** (HYPOTONIC or HYPOOSMOTIC: low salinity) **to more concentrated solutions** (HYPERTONIC or HYPEROSMOTIC: high salinity) until reach an equilibrium with the same amount of solute
3. This movement creates an **osmotic pressure** that is the hydrostatics pressure (created by the water) that prevent the passage of water molecules through the membrane. **The osmotic pressure is a problem and develops when an organisms is expose to a change in salinity**, it continues until both the solutions are ISOTONIC → when the dilution of salt in both the solutions is the same



*Osmotic pressure develops when an animal is exposed to a change in salinity.*

→ the osmotic problems can result as: **dehydration** (lost of water: if the surrounding water is more saline, the water go outside) or **rupturing of cells** (add of water: if the surrounding water is fresh, with low salt, the water go inside the cells, and they can explode)

### Example of osmosis problem

e.g. Sipunculid *Golfingia gouldii* in diluted seawater (15 psu). This is a worm with a certain cellular salt content is placed in water with lower salinity:

- water will enter animal if it is permeable, the body volume of the body starts to increase (add water), but after can create an explosion (with no any regulation), but this doesn't happen to the worm because the organisms have specific adaptation: **nephridiopores** to excrete salt (loss in the water) and the body volume return to normal.

## DIFFUSION

- Diffusion is random and passive movement of dissolved substances (SOLUTE) across a permeable membrane; is not the water that move, but the solute until when the concentration equalize the other side of the membrane (VS Osmosis)
- *If seawater salinity decreases suddenly, solutes leave the body for the external seawater, if the salinity in the seawater increases, the salt we will go inside the body of the organisms.* This is bad because, for cells and biochemical reactions, the overall cellular [ ] of salts must keep be constant.

**Diffusion tend to equalize the [ ] of physiologically important ions.**

### Response to Salinity Changes

Marine organisms regulate the cellular concentration of inorganic constituents using **2 different techniques for excrete or obtain salt**:

1. **Ions (salts) regulation – ACTIVE** (they need energy to do this) → **Cell membranes-channels and active pumps (Na/K)**

When body is isolated and not completely permeable (e.g., crab carapace, chitinous body, outer skin of fish) exchange and regulation localized at special excretory sites: many organisms have organs, or other special structures to excrete or absorb salt, e.g.

- Fish: gills

- Crayfish: antennal glands
- Annelida: nephridium

(Directly changing the amount of salt, but we need ATP)

2. **Cell volume regulation – PASSIVE** (don't need energy) → **without regulate the concentration of the salt and without use ATP, but inorganic molecules.** They regulate the concentration of a variety of organic osmolytes.

**Organic Osmolytes:** *small carbon-based molecules generated by cellular reactions, organic substitute for inorganic ions that allows regulation of cell volume and maintenance of inorganic ion concentrations, so they use these organic osmolytes as false inorganic ions, false salt in order to regulate the volume of the cells,* the are:

- **Free amino acids:** used by many invertebrates, bacteria; uncharged amino acids that have little effect on protein function (e.g., glycine, alanine, taurine)
- **Urea and trimethylamine oxide (TMAO):** used by sharks
- **Glycerol, mannitol, sucrose used by seaweeds, unicellular algae**

## 2 DIFFERENT CATEGORIES OF ORGANISMS

### OSMOTIC REGULATION

- **Osmoconformers:** organisms that **change internal osmolarity in according to surrounding seawater.** E.g. Mussels, shrimp
- **Osmoregulators:** organisms that **can adapt to changes in salinity of the surrounding seawater.** E.g. *green crab* is an osmoregulator until a certain level of salt, after this level it is an Osmoconformer that has intermediate behaviors among Osmoconformers and Osmoregulators

### OSMOCONFORMERS

- The osmotic concentration of body fluid vary with environmental concentration
  - **Advantage:** these organisms **don't use energy,** is a passive process, they don't use an active regulation. It's a passive transport to keep osmolarity
  - **Disadvantage:** organisms withstand only small variation in salinity, they are **stenohaline** so they **can tolerate only small variation of salinity**

#### **If the salinity increases, also the osmolarity increases**

- they match their body osmolarity to their environment
- Internal salinities rise and falls with the waters surrounding them

#### **Osmoregulation In sharks**

*Adjust their internal osmolarity according to the osmolarity of the sea water* (Osmoconformer the internal amount of salt is like the external one, 35%)

- Produce high concentration of **urea** (is an organic osmolyte) in the blood that regulate the amount of water in the cells, creating a diffusion gradient which permits to absorb water in order to equalize the concentration difference. They also accumulate the trimethylamine oxide as osmolyte, not only urea → PASSIVE MECHANISM
- Rather than (invece di) ingesting sea water in order to change their internal salinity, sharks are able to **absorb sea water directly by gills and skin**
- Have a **rectal gland** that excrete salts.

### OSMOREGULATORS

- Regulate their body osmolarity, maintaining constant osmotic internal conditions independently of the environmental external osmotic concentration
- They are organisms that maintain constant their internal concentration of salinity

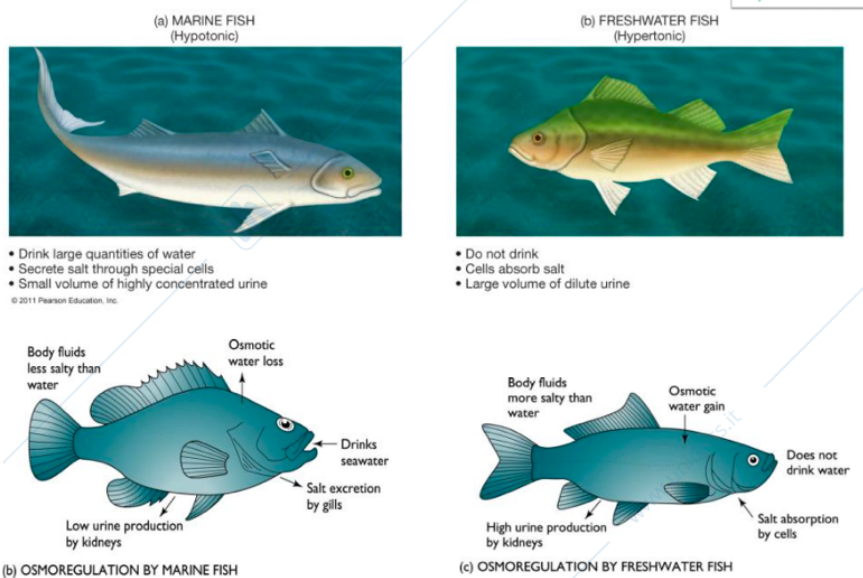
- **Disadvantage:** Osmoregulators use active transport to maintain a stable internal salinity, so this requires the use of energy
- **Advantage:** could be **Euryhaline** so they are able to tolerate big variation of salinity, *could live near the estuary*: organisms withstand large variation in salinity, typically *live in coastal waters*, e.g., estuaries, tidal pools

Example: **most vertebrate fish and marine reptiles**

### Osmoregulation in marine fishes

**Bony marine fishes = teleost fishes** (not cartilaginous fishes) are Osmoregulators and HYPOTONIC to seawater, the concentration of cell fluids is 1/3 respect of the water concentration, but the reason is unclear. They maintain this condition because are Osmoregulators, they **continue to drink water** (food) to maintaining the water balance and continue to **eliminate the salt with special cells close to the gills** to maintain a lower level of salt, they **excrete a little amount of urine**. They drinking seawater ingest ions, e.g. Na<sup>+</sup> and Cl<sup>-</sup> thanks to the gills, so they try to reach the osmotic equilibrium.

**Freshwater fishes** have a body fluid that is osmotically less dilute than the surrounding seawater, so the body fluid is saltier than water, they are HYPERTONIC to seawater, they use another approach to obtain an osmotic balance, they must release water, they **don't drink** but they do the opposite process in fact they **produce a large amount of water** to excrete the high-level salt, moreover they have **cells that absorb salt** and they **produce a large volume of dilute urine**.



### Osmoregulation in marine mammals

They obtain freshwater from feeding on fish and invertebrate and metabolism (from cellular respiration). These mammals are HYPOTONIC, so the internal fluid is less rich of ions than the seawater, for this reason they have to **produce very salty, concentrated urine** thanks to **very efficient kidneys** (reni). They **don't drink** directly, but they obtain fresh water from **feeding** (on fish and invertebrate) obtaining water, also from metabolism (= from the cellular respiration), e. Whales

### Osmoregulation in marine reptiles and birds

These animals are HYPOTONIC, so they have to **ingest seawater** to obtain nutrients, e.g. turtles. They have also **salt glands** that **excrete** the excess salt and highly concentrated salt solution. These **glands** have **different locations**, for example the glands are close to the eyes for the turtles, or near the nose for the birds.

There are many **strange fishes**, which are able to tolerate more than high level of salt:

- The Atlantic eels (*A. rostrata* and *A. anguilla*) reproduce in the Sargasso Sea and juveniles return to salt marshes and other inshore water habitats. they migrate but when mature, they can live in freshwater.
  - Salmon hatch in rivers, migrate to ocean for 1-3 years then return to river to spawn
  - American killifish (*Fundulus heteroclitus*) can live in freshwater and in seawater
- Great capacity of osmoregulation coordinated hormonally through the pituitary gland.

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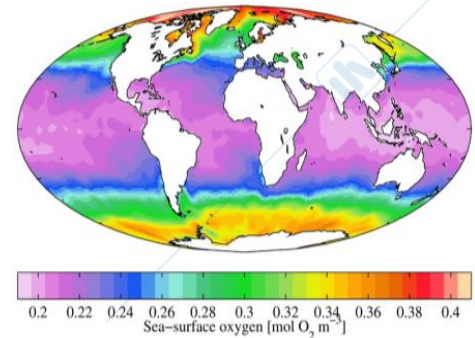
## 4 – OXYGEN

There are 3 main processes in which the oxygen is involved:

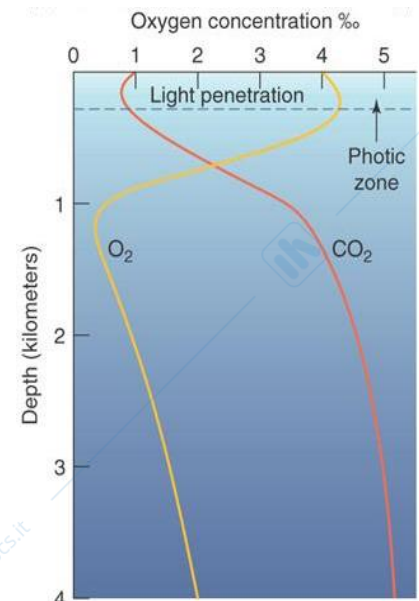
1. **Mixing with atmosphere:** the O<sub>2</sub> arrives to the sea mostly through the atmosphere: O<sub>2</sub> decreases when the increase of the T and the salinity; O<sub>2</sub> increases when the increase of the winds that allow the atmospheric oxygen to better penetrate (relation between the oxygen amount in the sea and the parameters) → **input process of oxygen**
2. **Photosynthesis:** ( $6 \text{ CO}_2 + 6 \text{ H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2$ ) is a biological process related with the presence of the organisms. There are a lot of photosynthetic organisms: corals, seagrasses, plants, algae, phytoplankton... → **input process of oxygen**
3. **Respiration:** ( $\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2 \rightarrow 6 \text{ CO}_2 + 6 \text{ H}_2\text{O} + \text{energy}$ ) and **decomposition** driven by bacteria and other microbiological organisms → **removal process of oxygen**

As for T and salinity, also for the oxygen there are 2 different gradients of oxygen:

**Latitudinal gradient** → moving from the equator to the polar region there is an increase of the oxygen concentration in the upper layer of the sea because near the equator the T is high, so the O<sub>2</sub> is less, instead in the polar region the sea-surface oxygen is high because the T is cold. Also, the salinity is less in mid and tropical latitude than in the high latitude (where the mixing is high because there are a lot of winds). A lot of autotrophic organisms in high latitude and a smaller number of heterotrophic organisms (that remove O<sub>2</sub>). Also there is higher concentration of autotrophic organisms (algae, phytoplankton) in the high latitude and lower amount of herbivores, carnivores (eutrophic organisms)



**Vertical gradient** → the oxygen is high and maximum at 10-20 m of the sea column = PHOTIC ZONE where there is light and photosynthetic organisms (max photosynthesis). Sometimes the light is too strong and creates damages → PHOTOINIBITION, so usually the O<sub>2</sub> is lower. After this there is a decline with depth of the oxygen reaching the lower amount of O<sub>2</sub> in an area called: OXYGEN MINIMUM ZONE (OMZ) located from 200 to 1000 m of depth. This OMZ is the areas in which the organic matter accumulates at the end of the thermocline, between these 2 water masses with different density. Due to this strong thermocline the organic matters produced in the surface fall down and accumulate here, without going down, so this zone is created by bacteria that consume oxygen to decompose the organic matters. Also, in this zone, the composition activity is high, in fact we can find a lot of bacteria or decomposer organisms which cause a zone with low oxygen. Under this level the O<sub>2</sub> concentration increases a bit thanks to the cold water, thanks to the decrease of respiration and the deep currents (there are less organisms), precisely in this point (OMZ) there is the lowest level of oxygen in the sea. Also, the respiration and the T decrease, so the amount of oxygen increases.



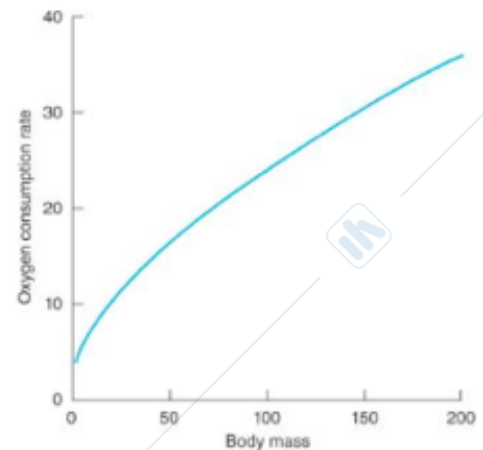
**Oxygen is necessary for the manufacture of necessary reserve of ATP**, the availability of oxygen and the mechanisms for its uptake are of great importance in understanding the function and distribution of marine organisms. O<sub>2</sub> is a critical factor in the sea, in order to determinate the distribution and the processes that characterize the marine communities.

Some habitats are low on oxygen: (difficult habitats)

- Low tide for many intertidal animals → The animals must face some period when they are exposed to a very low concentration of oxygen
- Within sediment: often anoxic pore water
- Oxygen minimum layers in water column where organic matter accumulates at some depths → in another habitat with low O<sub>2</sub>
- Seasonal oxygen changes as in estuaries: hypoxic zones are created, also “dead zones”

### CONSUMPTION RATE OF OXYGEN

- It is measure in: ml consumed per unit time per unit body mass (ml O<sub>2</sub>/h/g)
- This is also called **mass-specific oxygen consumption rate**
- There is not a linear relation because at specific point and mass the consumption rate of oxygen, after starts to decline, large snail consumes less O<sub>2</sub> that thin nail → Oxygen consumption increases with increasing body mass (> **body mass**, > **oxygen consumption**), BUT in a long turn, the oxygen consumption rate declines with increasing total body mass → there is a general relationship of oxygen consumption rate to body mass in a typical animal. Line will rise but it is concave down, indicating that the rate of oxygen consumption decelerates with increasing body mass. In fact the O<sub>2</sub> consumption rate is not a linear relationship, but is a function of a constant K, body mass (W) and a fitted exponent (b). → ml O<sub>2</sub> consumed =  $K \cdot W^b$  This means that **small organisms can consume more oxygen than large organisms**, but **the rate of the O<sub>2</sub> consumption decline with the increasing of the total body mass**.
- **Active species VAGILE** (that move on the sediment or swim VS sessile) **require more oxygen for energy and therefore consume more O<sub>2</sub>**, compered to benthic organisms, e.g. **sponges, bivalve, corals consume much less oxygen than crustaceans, cephalopods, fishes**
- Activity may change within the life span of single individual, e.g. **species moving and feeding during the day require more oxygen during that time**.



The organisms are classified in 2 main categories looking the oxygen:

- **AEROBES**: organisms that *require oxygen* during their life, they are more or less all eukaryotic organisms.
- **ANAEROBES**: organisms that *live in absence of oxygen* and need other molecules to obtain ATP; usually are very small and sessile organisms that need a little amount of O<sub>2</sub>, e.g. bacteria, small and slaw moving organisms

Some organisms use a mix of metabolic pathways with and without use of O<sub>2</sub> to manufacture ATP → some aerobic organisms are able to shift to anaerobic behaviour, e.g. *during the low tide these organisms switch their metabolism to survive*. E.g. Invertebrates in intertidal zone at low tide subjected to period of O<sub>2</sub> depletion; in high latitudes during winter, there is a lower transport rate of O<sub>2</sub> to cells, so during this time, the anaerobic metabolism produces alanine and succinic acid that finally produce ATP.

The **glycolysis** is less than 10% of the efficiency of the aerobic processes but is absence of O<sub>2</sub> glycolysis is a way to produce energy.

### OXYGEN UPTAKE MECHANISMS

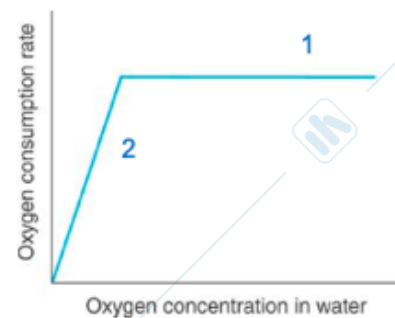
1. **Diffusion from the surface:** is the most used process by small and thick organisms, e.g. flatworm thanks to the surface are able to uptake O<sub>2</sub>
2. **Gills:** large respiratory surface for oxygen exchange with water current, they are surrounded by an efficient circulation system (arteria and vanes). They occur also in the mussels, not only in the fishes; in the fish the gills are composed by gill arch that surround the blood vessels, from gill arch starts different gills filaments that increase the absorption surface of the O<sub>2</sub>. Between the different lamella (that characterize each gills filaments) there is a counter current exchange, as for the temperature.
3. **Lungs:** more developed animals have lungs, they are enormous surface areas to acquire rapidly O<sub>2</sub>, e.g. whale has a big lung area to breath (1000 meters square)

Larger animals have **circulatory systems** that circulate oxygen to tissues.  
Many have oxygen-carrying **blood pigments**, e.g. haemoglobin

### RESPONSE TO DECREASE OF OXYGEN CONCENTRATION

What happen when an aerobic organism cope to low oxygen concentration

1. There is usually a broad range of relatively high environmental oxygen concentration within which the animal can regulate the respiration rate, keeping the oxygen consumption relatively constant (1).
2. At a lower threshold of environmental oxygen concentration (2), the rate of respiration decreases with decreasing oxygen. Beyond the point, the animals cannot regulate the O<sub>2</sub> concentration efficiently, but there is a decrease in the oxygen concentration rate



What could be the solutions?

- **Escape to a more oxygenated habitat**, is not always possible, e.g. sessile organisms
- **Reduce the activity levels**, which in turn reduces the requirement for oxygen to fuel aerobic muscular metabolism

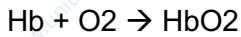
### OXYGEN BINDING PIGMENTS = BLOOD PIGMENTS

Blood pigments are substances that greatly **increase blood capacity for transporting oxygen o the tissues**, there are different types of blood pigments:

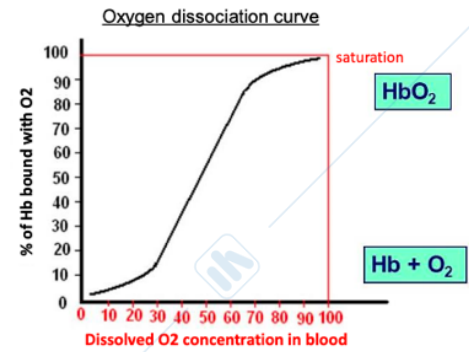
- **Hemocyanin:** Cu-containing protein (mollusks, arthropods), give the blue color
- **Hemerythrin:** Fe-containing protein (sipunculids, some polychaetes, brachiopods), give purple color
- **Chlorocruorin:** Fe-containing protein (some polychaetes), give green color
- **Hemoglobin:** is composed by a protein unit (GLOBIN, is the core) and iron-bearing unit (HEME GROUP), found in many phyla (chordates, mollusks, arthropods, annelids, nematodes, flatworms, protozoa); is present nearly in all the phyla, give the red color  
Hemoglobin sometimes is not present in the Antarctic fishes, high latitude, where there is so much oxygen, so hemoglobin and other blood pigments are not necessary, they don't have a red blood,

There is another blood pigment: **myoglobin**, similar to the hemoglobin, but is smaller

Binding and release of O<sub>2</sub> with Hb (hemoglobin)

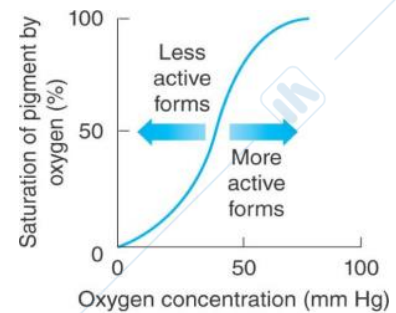
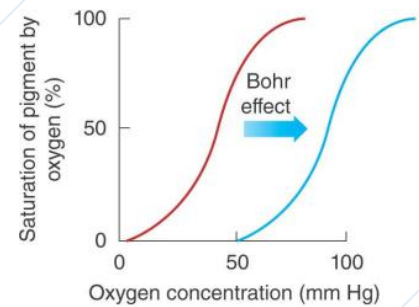


This is the **oxygen dissociation curve**: show the % of hemoglobin bound with the oxygen as function of the dissolved oxygen concentration in the blood. When O<sub>2</sub> increase, also the concentration of Hb (bound with oxygen) increase until reach a SATURATION (where all oxygen in the blood is bound with hemoglobin). If the O<sub>2</sub> concentration is lower, the hemoglobin release the oxygen, so we have Hb + O<sub>2</sub> separated.



There are 2 different parameters that can affect the hemoglobin binding characteristics:

1. The **pH of the blood** (if the pH decrease, the curve shifts to the right: **BOHR EFFECT**: Hb ability to bind oxygen decreases with decreasing of the pH → with low pH, Hb need more O<sub>2</sub> for saturation. Reduce the Hb capacity to bind the O<sub>2</sub>, so it is release to the blood and is available alone)
2. The **activity of the animals** (with animals that are not able to move, the curve shift to the left, so the Hb is able to bind the O<sub>2</sub> also when there is a low concentration of O<sub>2</sub> in the blood) affect Hb-O<sub>2</sub> binding characteristics. **Inactive animals**: in environments low in O<sub>2</sub>, have dissociation curve shifted to left which allows the Hb to bind to O<sub>2</sub> at low blood [O<sub>2</sub>]



### Oxygen binding pigments – HIGH OXYGEN CONDITION

Pigments are not necessary and not present in species living in environments highly oxygenated (Arctic and Antarctic) → they haven't hemoglobin, the blood is white, but they use *anti-freeze glycoprotein* (AFGP).

### Oxygen binding pigments – LOW OXYGEN CONDITION

Intertidal zone, anoxic barrows... the oxygen is very low, so:

- Pigments are highly present and serve as oxygen reservoirs: there are organisms with a lot of pigments
- Pigments can change their chemical structure to bind more efficiently oxygen

E. g *Limulus Polyphemus* moves to beach for reproduction facing low O<sub>2</sub> period. During oxygen shortage, calcium and lactate increase in the blood and have a direct effect on hemocyanin (blue blood) changing its the three-dimensional structure of the hemocyanin and the **new structure has higher affinity with oxygen**. Has very important anti-cancer properties, and unfortunately are very overexploit.

## 5 – LIGHT

- There is a **VERTICAL GRADIENT OF THE LIGHT** → is high in the first meters depth **PHOTIC ZONE**, than starts to decrease until go away.
- *Much of the light is reflected and scattered by the ocean*, not all the light has absorbed by the water (surface loss due to the waves)
- There is an *exponential decline* of light going to the sea floor
- The light that penetrates is used by the photosynthetic organisms for their metabolisms
- *There are different patterns of light change with the depth*, but usually there is a high amount of light in the first meters and then decrease with the depth
- In the **open ocean** usually there is a high amount of light that can reach deepest places because the water is clear VS in the **coastal water**, due to the turbidity and the present of the organisms that use the light, there is a low high penetration
- **Light is crucial for life**, in particular for → **photosynthesis, predation and moving**
- *Also the quality of the light change with the depth*
- Moreover, *high intensity and UV light could be harmful* (especially in the clear water of the tropics) → too much light and UV rate, in the clear water ca create problems to the photosynthetic apparatus : **PHOTOINIBITION PROCESS**

Moving from the top to the bottom there are different layers in which there are different levels of light:

We can see the red color only in the photic part of the water because is not absorbed...

- **Light is sufficient for photosynthesis** → from the top to 100 m deep (**photic zone**), where the light is enough for the photosynthetic activities
- **Light is too weak for photosynthesis, less than 5% sunlight** → from 100 m to 200 m deep (can reach 500m) (twilight, **dysphotic zone**)
- **There isn't light** → from 500 m to the seafloor (**aphotic zone**), all the organisms must develop other organs to move and understand where they are because there isn't light. E.g. organs that are able to create own light: **BIOLUMINESCENCE, very developed eyes**

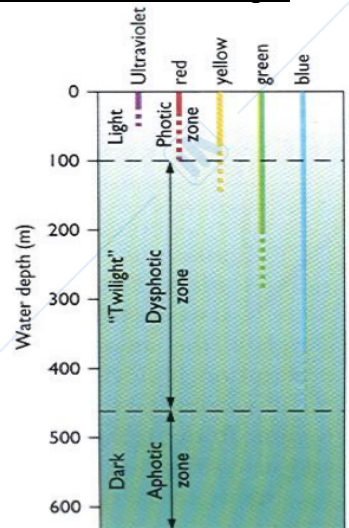
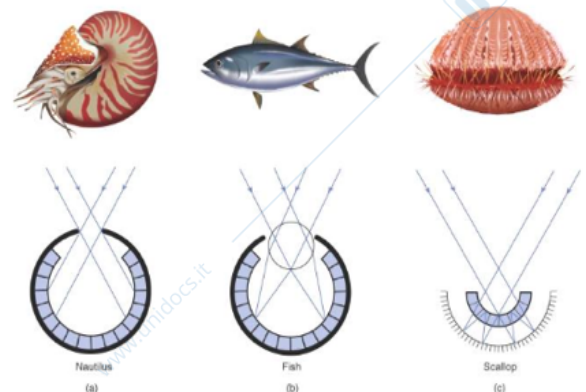
All marine environments depend upon the production of the surface photic zone

The light allows to use **VISION** in order to:

1. Detect pray
2. Avoid predators
3. Find mates (reproduction)
4. Help in navigation

### LIGHT DETECTION

- Many animals detect light with aid of a simple layer of **sensory cells** (scallops have little spot used to see), but many species have **complex eyes** with focusing mechanisms.
- There are 3 ways used by marine animals to focus an image:
  - (a) **pinhole camera**, used by the nautilus
  - (b) **lens**, used by fish, squid, and lobsters
  - (c) **curved reflector**, used by scallops



## A – PINHOLE CAMERA

- Light enters through a tiny hole and rays directly hit the retina
- The hole acts as a pinhole camera, permitting an inverted image to form on the back of the eye
- The nautilus uses muscles to adjust the pinhole opening
- The major disadvantage is that the design allows a vision only in high light.

## B – LENS

- Use lens or a series of lenses to focus light
- A fish lens differs from a glass lens and consists of material of continually increasing density in the direction of the centre of the lens
- This variation allows the lens to bend light and focus an image in a very short distance reducing distortion
- Fishes have muscles that move the lens forward and back to adjust for focus
- They have a brain, or some other part of the nervous system must integrate all the individual images into a mosaic image

## C – CURVE REFLECTORS

- Light passes first through a crude lens, then through a nearly transparent retina (layer of receptors) and reflects from the shiny layer, to be detected on return by the retina.
- Scallops have hundreds of shiny bluish spots around the periphery of the shell that are eyes

Other characteristic of the vision:

- Photoreceptor pigments (**rhodopsin**) in the retina
- Vertebrate retinas contain **rods** (more sensitive, but don't discriminate wave length) and **cones** (less sensitive, allowing the color vision)
- Many marine animals can identify almost 2 colors (Crustacean can discriminate between blue and green-yellow light)

Light is important in behavioral adaptation of marine organisms:

- a. **Zonation** → green algae lives in the upper part of the rocky shore, then there are brown algae and red algae (different ability to use different waves length)
- b. **Find mate** → for the reproduction activity, e.g. Fiddler crab has bride color to help the choice among male
- c. Migration and navigation → can occur only thanks to the light, e.g. Turtles

## **BIOLUMINESCENCE**

- Many organisms are able to produce own light
- Occur in **bacteria, algae, protozoans, sponges, jellyfishes, annelids, crustaceans, cephalopods, echinoderms, and fishes**
- Light produced by the organisms, especially in the deep ocean
- 3 different way of bioluminescence:
  - a. **Intracellular luminescence** (squid and cuttlefish) with PHOTOPHORE cells with focusing lenses and reflectors → most common
  - b. **Luminous mucus secretion**
  - c. **Symbiotic luminescent bacteria** (fishes) → is not the fish, but the bacteria
- Bioluminescence happens thanks the reaction of **luciferins** which emits light when it reacts with the enzyme luciferase.

- Is not very clear why the organisms have bioluminescence, but we make hypothesis...  
**Confusing predators, find mates, camouflage**, perhaps other as yet undiscovered functions

## 6 - CYCLES

Seasonal, tidal, and diurnal changes exert both direct and indirect effects on organisms

**Seasonal cycles** → these changes are more pronounced in shallow water and in middle to higher latitudes (for T° and light). Tropical regions are seasonally the most constant environment:

- **Norther latitudes:** WINTER is the time of low T and low food, is very difficult to survive for the marine organisms
- **Mid latitudes:** SUMMER is the time oh high T and low food, is the most difficult time to survive for the marine organisms

Due to these things there are different (negative) EFFECTS in these 2 environments:

- The growth is reduced*
- The metabolism is altered*
- Many invertebrates rely more on anaerobic pathways*

BUT THEY ARE ABLE TO SURVIVE BECAUSE THEY ADOPTED DIFFERENT STRATEGIES

- **Norther latitudes:** SUMMER is the time of higher T and more food. Is the best period
- **Mid latitudes:** SPRING is the time oh medium T and more food. Is the best period

Due to these things there are different (positive) EFFECTS:

- Growth is increased*
- Reproductive activity is high*

**Tidal cycles** → these cycles *affect the physiology and behaviour of organisms* living only in intertidal zone. Exposition to air (**low tide**) can be a challenge or an opportunity depending on the organism type, this is the most difficult period, but some organisms are able to cope to the low tide:

E.g. *Mercenaria mercenaria*:

High tide: the bivalve actively respire oxygen

Low tide: anaerobic pathways predominate

E.g. *Geukensia demissa* is capable of breathing air at low tide

**EXPOSURE TO AIR (cause to the low tide)** presents contrasting **challenges to animals' burrowing and feeding behaviour**:

- Crustaceans and polychaetes **retreat into burrows** to avoid desiccation
- Bivalves (as *Tellina*) can **protrude their inhalant siphons** and **feed in the sediment-water interface** because predators and grazers are inactive during low tide and exsiccation. Bivalves, when submerged, **secrete CaCO<sub>3</sub> + organic matrix**. Exposed: anaerobic metabolism produce acid that dissolve CaCO<sub>3</sub>. Alternating series of growth increments consisting of organic matrix-CaCO<sub>3</sub>

The general increase of feeding activity for burrows organisms during low tide suggest a cycle of growth.

**Diurnal changes (Diel cycle)** → daily changes in light have a strong influence:

- on *photosynthetic organisms* (in zooplankton and phytoplankton)
- on *animal dependent on light for detection of prey*
- on *prey whose visibility is heightened (increased) during the day*

The zooplankton migrates during the day and the night to come to these diurnal changes

