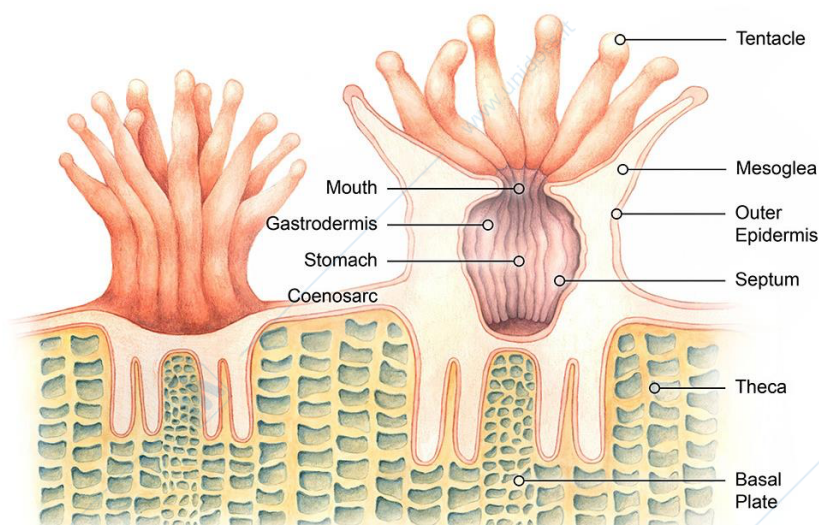


8.0 - CORAL REEFS

- They represent the most diverse ecosystem in the ocean
- They are biogenic structures deposited by living organisms → created by something that is alive, corals are animals, they create structures called **BIOGENIC STRUCTURES**
- They support an incredible variety of organisms, in fact are also called **MARINE RAINFOREST**
- Coral reef ecosystem **occupy less than 0.1% of the ocean surface** but **host more than 25% of all the marine species of fishes**; e.g. 6000 species of fishes, more than 1000 species of corals...
- Coral reefs are very high productivity ecosystem, they create through the photosynthesis organic materials
- It is a 3D structure ecosystem
- If coral reefs are in a good situation, they are **topographically complex** with many strata as well areas of strong shade due to the towering coral colonies, with different niches and the biodiversity >>

CORAL POLYP



- Corals are **colonial animals**, created by different organisms which are all **clones**, called **SINGLE POLYPS** (= the animals of the colony)
- The polyps are little organisms, animals, like jellyfish but with opened tentacles in the upper part of the structure which together formed the coral
- They are transparent, not have any color
- *Depending on the species of corals, polyps can change a little in term of morphology, size, number of tentacles...* e.g. some polyps have 6 or more multiple of tentacles in this case they are **EXACORAL**, e.g. other corals have 8 or multiple of 8 number of tentacles and are called **OCTOCORAL**
- They can be classified in: **HARD CORAL** (have a hard calcium carbonate skeleton outside the structure) or **SOFT CORAL** (are not surrounded by calcium carbonate skeleton, but have some structure inside the tissue: **SPICULE**) looking their capacity to create calcium carbonate skeleton
- They are simple organisms, compose only by 2 types of tissues:
 - 1) OUTER EPIDERMIS= **ECTODERMIS** (outer tissue)
 - 2) GASTRODERMIS= **ENDODERMIS** (inner tissue)
 Between these 2 tissues there is a gelatinous matrix called **MESOGLEA**
- They have a mouth surrounded by tentacles, all of them are provided by urticant cells, called **CNIDOCYTES** that give the name of the phylum of the corals → **CNIDARIAN** (with urticant cells)

Function of tentacles:

 - **Provide food** (corals mainly use the light to do the photosynthesis, but during the night they feed on zooplankton thanks to the extroflexion of the tentacles)
 - **For defence**
- The base of the polyps is called **BASAL PLATE** with which they stay attach to the substrate and to create then the calcium carbonate skeleton
- They do a **symbiotic relationship with photosynthetic unicellular algae: zooxanthella** that **give the color to the polyp** which normally is transparent

There are exception of corals, not all corals are colonial...



Familia **Fungiidae** → **solitary coral** → similar to the terrestrial mushrooms, are composed by only 1 big polyp with a single mouth opened in the middle of the structure and surrounded by the tentacles that can be extro-flected, are not always extro-flected, but in different situation they go outside, e.g. during the night

SYMBIOSIS WITH ZOOXANTHELLAE

- All the polyps, in order to live, need to stay in symbiosis with unicellular algae commonly known as zooxanthellae
- They stay in the inner tissue, gastrodermis, they live within the coral cells, so the symbiosis is the most important symbiosis present in the ocean and it a **mutualistic symbiosis** because both provide benefits to the other →
 1. **polyps acquire food** from the zooxanthella that do the photosynthesis using the light (Zooxanthellae provide up to 90% of a coral's energy requirements). The polyps acquire the coloration, otherwise they remain transparent
 2. **zooxanthella provide protection, shelter, a good position** in the ocean and they **use the products of the respiration of the polyps as sources of food**, nutrients use for the photosynthesis.
- **Dinoflagellate single-celled alga (genus Symbiodinium)**
- **There are 7 different types of zooxanthella, called not species, but CLADES** → there are clades more sensitive to T change, other more resistant to the heat stress... the capacity of the corals to cope with the stresses depend on also the type of zooxanthellae present in the tissue of the corals
- Coral can acquire zooxanthella **directly from the water ingesting them**, in other cases they can be **transmitted directly in the coral eggs, in the planulae** during the reproduction
- PROBLEM → The algae of the zooxanthella live the coral polyp tissue, so if the zooxanthella go away, that don't have food anymore, loss the color and there is bleaching → the BREAKDOWN OF THE SYMBIOSIS is commonly known as CORAL BLEACHING... the coral became completely white.

If the algae live the coral polyp tissues, they don't have food anymore, loss the color and the coral became white, so the skeleton is visible. If the situation remain like this, so the algae are not able to come back to the corals or the coral is not able to acquire them, after few days or weeks, the entire colony can die, so the habitat will be completely occupied by macroalgae because there was a competition of the space in the coral reef habitat for the light and the space between corals and algae. (remain only the skeleton which will be colonized by algae).

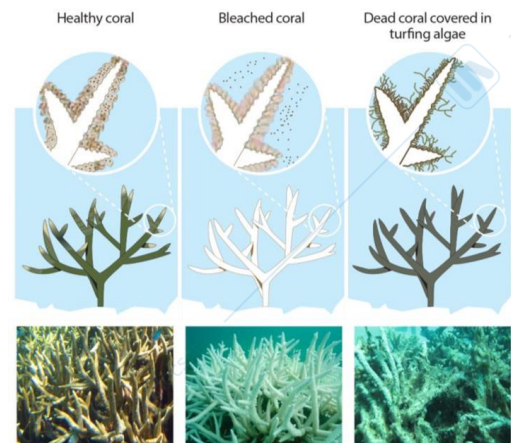
Which are the causes of the coral bleaching?

TEMPERATURE → corals are *stenothermal organisms*, they can live in a very narrow range of T, they are not present in the Mediterranean Sea because there is a strong minimum T, they need to stay always in warm water, around 25-28°C during all the year → **tropical latitude**

When the T exceed the maximum threshold of tolerance, there are 2 possible outcomes:

1. The corals can decide to release the algae because became toxic for them
2. The algae decide to leave the coral polyps

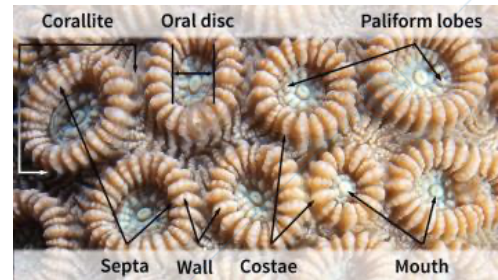
Both create the breakdown of the symbiosis and the bleaching happened



Other phenomena that can cause the breakdown of the symbiosis... SALINITY, POLLUTION, TOO HIGH UV LEVEL, but the global warming is the most important cause

CALCIFICATION

- Corals are animals surrounded by calcium carbonate, produce by the corals thanks to the zooxanthellae which are **fundamental in the process of biomineralization in the seawater because they provide to accelerate the deposition of the carbonate skeleton in corals.**
- The chemical reaction that lead to the biomineralization in the ocean $\rightarrow \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3$
- The water reacts with CO_2 to create carbonic acid, then this acid, in particular the bicarbonic ion (which is released during the dissociation of the carbonic acid) combine with the calcium Ca^{++} , normally present in the ocean, creating calcium carbonate, so the material that create the skeleton of the corals $\rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{CaCO}_3 \leftrightarrow \text{Ca}^{++} + 2\text{HCO}_3^-$. The zooxanthellae, using the CO_2 for the photosynthesis, tend to promote the formation of calcium carbonate because they quickly eliminate the carbonate anhydride produced by the coral metabolism, which would otherwise dissolve the calcium being formed, shifting this reaction toward left.
- **pH** is important (contributes to the calcification of the coral) to maintain the balance of this reaction, if the **pH increase** (ocean acidification, $> \text{CO}_2$ emission) it could be a problem for the corals because **the skeleton can melt**, so zooxanthellae, eliminating CO_2 , reduce the possibility that the pH can increase and dissolve the skeleton during the reaction
- the skeleton can be used to identify the corals because a single animal, a single polyp is able to create incredible calcium carbonate structures.
- For of all, the coral polyp creates its home around it, called **CORALLITE**, it is the place where each singular coral polyp lives on the coral surface. It is then composed by different structures: WALL, COSTAE, SEPTA... but the macrostructures of wall, septa... are different for all species of corals (using electronic microscope), the shape and the structure of the corallite are important for the classification.
- Many corals can be very similar in term of morphology, but at reality they are 2 different species, so now to classify them we can use 2 main approach:
 - A. DNA approach
 - B. Analyzing the corallite structure with the SEM (scan electronic microscope)

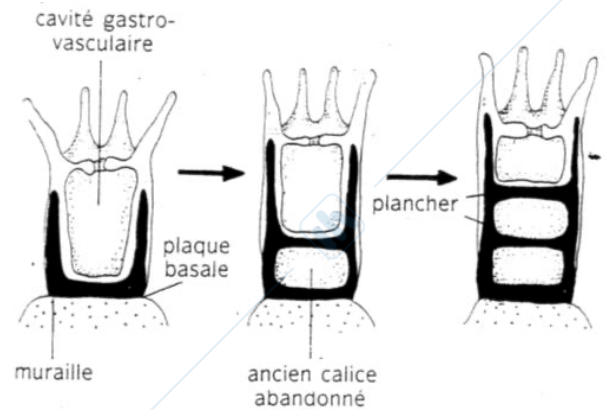


2 different corals:

- **Hermatypic corals** or "stony corals" or HARD CORAL are reef organisms that deposit aragonite structures and contribute to coral reef development \rightarrow fully surrounded by calcium carbonate skeleton. Are the primary contributors of the coral reef ecosystem, are called **reef building corals species**
- Corals that do not contribute to coral reef development are referred to as **ahermatypic corals** (non-reef-building) species. They can be soft coral but also hard coral, but they don't contribute to the construction of the coral reef ecosystem, e.g. Fungiidae corals are hard coral, but since they are not attached to the surface are not contributors of the tridimensional structure of the reef, they are accessories corals, or called also **not reef building corals species**

7.1 - CORAL GROWTH

- **Upward growth of coral polyps is generally between 1-10 cm a year** → They can grow vertically in a very slow process. The polyp is able to create different step, different basal plate that allows it to grow upward (image)
- **Linear extension of individual corals can reach 20 cm a year**
- **The diameter of the coral polyp grow through the budding**, the asexual reproduction.



The corals can reproduce both by sexual and asexual reproduction:

SEXUAL REPRODUCTION: the fertilization can occur within a coral known as *brooding* or outside of a coral known as *broadcasting*. It is called **SPAWNING**, happens 2 times per year (April and November) and those days all corals in the ocean decide to spawn together, the gametes are released, the fertilization occurs creating a larvae, planula which is transported the currents for days, weeks, until encounters a suitable substrate, settles there and a new polyp grow. Starting from this single polyp the asexual reproduction can occur through budding.

ASEXUAL REPRODUCTION: budding occurs when a new zygote grows onto another one and remains attached, separating only when mature

8.2 - FEEDING

The feeding, during the day and during the night is different:

About 90% of the food it is provided by the photosynthesis, so *during the day* they stay height within their home, corallite. In fact during the day we see only the skeleton, the polyp are retracted inside but enough light arrive in order to provide the photosynthesis.

During the *night* there is no light, they must extroflex the tentacles in order to feed on zooplanktonic animals and injecting them through the mouth.

8.3 - FACTORS LIMITING REEF GROWTH

1 - Temperature

- The most important factor affecting the coral reef development and presence
- Corals can usually survive in a narrow range of T; the **perfect range is 26-28 °C** but some corals can be found also in colder and warmer water
- The T helps to explain the absence of reef in some areas of the tropic latitude, e.g. in the tropical coast of the west Africa and west America as Senegal → there are not coral reef because these areas are characterized by huge productivity, upwelling with cold water, a lot of turbidity and less light, so they cannot live there
- In **sub-tropical areas**, with season, corals, where are present, are characterized by **intermittent pattern of growth**, they grow faster during the warmest period, less during the cold periods
- The T influences the pattern of coral growth because warm water enhance the calcification process increasing the **rate of aragonite (is the carbon carbonate form mainly present in the coral skeleton) deposition** → increasing the T, also increase the calcification rate. It was demonstrated that the optimum calcification rate is 27°C. so even we increase the T of water, the calcium calcification rate doesn't increase linearly with T, but it continues to increase. So the T is not a big problem for coral, in fact coral polyps can tolerate high T, the problem is connected with the zooxanthellae that are not able to tolerate high T.
- Corals have quite **low tolerance to temperature variation** (mainly **stenotherm**), but at reality there are **super corals** that are able to live in areas with a high T variation, they evolved some mechanism, these organisms are not so stenothermal, but can be consider eurythermal.
- Tolerance is species and site specific → **Depending on the species and the situations there are different tolerant threshold in term of temperature for corals**

- Extreme or moderate but prolonged increase or decrease of temperature beyond a specific **thermal threshold** can cause **coral bleaching** → Those corals that have evolved in a very stable temperature regime, are typically less tolerant in change in T. An increase of 1°C can cause coral bleaching. Those corals that have evolved in a various T regime, are typically more adapted to the change in T and a minimum change in T doesn't cause coral bleaching.
- Corals present different grow forms: corals with **branching grow form**, corals with a **tabular grow form**, corals with a **massive grow form**... usually the branching and the tabular ones are the *more sensitive*, so they have very thin tissues VS the massive grow form has a thick calcium carbonate structure that with thicker tissue allow the organisms to be *more resistant* to the change in T. Starting from this, we know that when the T increase in a specific area, the first species that start to bleach usually are the branching and the tabular ones, but usually at the same time they are the most ready to recover after a stress because have a higher and faster grow compared to the massive species that are more tolerant, but slow in the recovery.

2 - Light

- Determine the *lower limit of reef development and reef composition* because corals depend on the light for the photosynthesis. So depending on the turbidity and on the clearness.
- Maximum depth for coral growth depend on clearness of water (usually max 50 m)
- **Skeletal growth** (coral linear extension and calcification) and **photosynthesis drops dramatically with depth** in response to a decrease in total light → going in depth the light decreases, so also the photosynthetic efficiency and the skeletal grow of the corals are affected. For this **reason is difficult to find big colonies after a specific depth**
- Due to the photoinhibition, also in the shallower part of the reefs sometimes the corals can be affected by light stress → **High levels of UV radiation are dangerous for corals and especially for zooxanthellae**
- *The most important mass coral bleaching event is due to the increase of synergic impact of high T and high UV rate.*

3 - Salinity

- Corals are **osmoconformers** → are not able to change the internal osmolarity independently, but they use the surrounded area
- Prefer high salinity levels (around 35 ppt)
- **Tolerance is species and site specific**
- In the vicinity of estuaries extensive coral reefs do not develop, where the salinity is too low and there is a high level of turbidity

4- Sedimentation

- *Turbidity intercepts light and reduce the photosynthesis*
- Sediment cause smothering, abrasion, shading, decrease of feeding inhibiting the extension of polyps tentacles
- Sediment cause recruitment inhibition → the larvae cannot find a good substrate where attached if the sediments are too much
- Sediment can encourage the growth of disease-causing bacteria

5- Wave Action

- Coral reef tend to be located in areas of high energy wave energy → not too high hydrodinamism because it can avoid the recruitment of the larvae, but an **intermediate high level of wave action is important to moving water bring nutrients**, also **for increasing the O2 level** and to **enhance larval dispersal**.
- Some corals cannot withstand the turbulence induced by waves → the Caribbean are usually affected by hurricane and powerful waves that every year create damage to the coral reef
- Wave action has an important structuring force on coral communities

A colony can change a little bit the morphology of the skeleton depending on the conditions in which its live. The grow form depend on 3 factors: light, hydrodinamism and sediment

VARIATION OF THE LIGHT

1. If a coral colony lives in an area **full of light** it tent to acquire more **massive structure** in order to be resistant to the wave action, to be more resistant in the change in T
2. **Decreasing the light level** the colony tent to acquire a more **branchy morphology** because allow the coral to go toward the light.
3. When the **light is very low**, the colony tent to became **tabular, plate**, in order to increase as much as possible the surface to obtain the light.

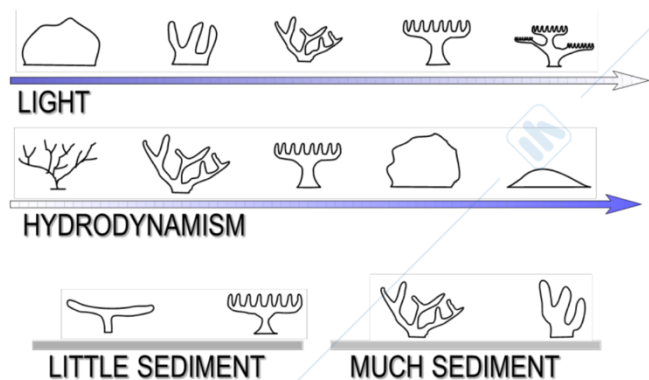
VARIATION OF THE HYDRODINAMISM

1. In areas where the **hydrodinamism is low**, the coral can acquire the **branchy morphology** because this structure is the one that tent to maximize the amount of light absorbed and since the hydrodinamism is low, this structure is not affected
2. When the **hydrodinamism starts to increase**, it tent to acquire a **massive morphology**, more resistant o the waves action
3. In areas where the **wave action is particularly strong**, the corals acquire an **incrusting morphology**, no specific grow form, it tent to incrust the sediment in order to be more resistant to the wave action

VARIATION OF THE SEDIMENT

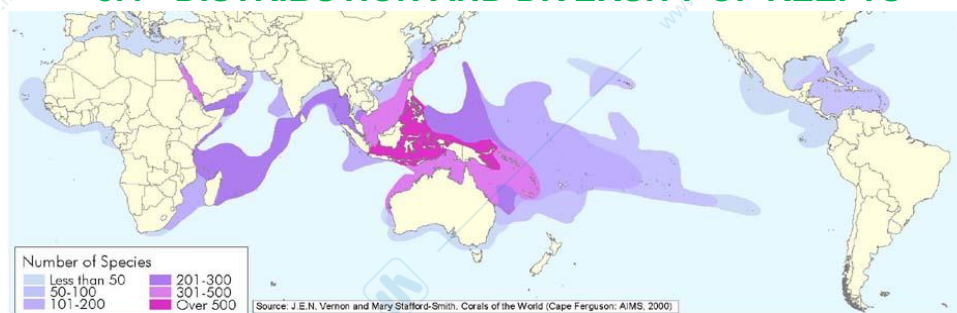
1. If the coral lives in an area with **little sediment**, it can acquire a **tabular grow form** to maximize the amount of light absorbed
2. If the coral lives in an area with **many sediments**, the place will be covered by the sediment, so. For this reason the coral tent to grow vertically, going outside the sediment acquiring a **vertical branching grow form**.

→ the same species of corals can acquire different morphotypes or ectomorph depending on which habitat its live, the corals have a **GREAT MORPHOLOGICAL PLASTICITY**, it can change a little bit the structure depending on in which part of the coral reef ecosystem it lives. E.g. *Pocillopora damicornis* live in the lagoon, has a vertical branching structure because is the most useful structure to combat the sedimentation



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8.4 - DISTRIBUTION AND DIVERSITY OF REEFS

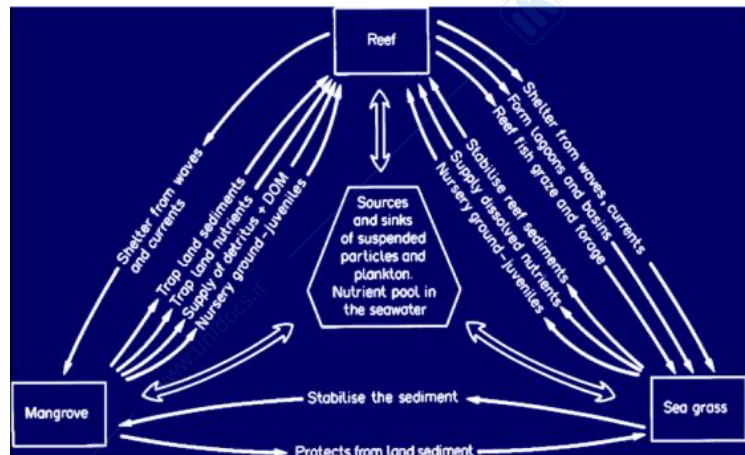


- Are not so widespread in the ocean, but are confined to the tropical and subtropical waters (25-30° N and 25-30° S) → tropical and subtropical latitude (high light, high T, no seasonality, clear water, low sedimentation rate, low productivity, and primary production due to low level of phytoplankton, suitable salinity around 35-36, high biodiversity level)
- Cover less than 0.1% of the global ocean surface
- Indo-Pacific reefs higher richness and diversity:
 - **Coral Triangle** (we find more than 500 species of corals), is the center of origin of the coral
 - **Great difference in coral composition and diversity between Caribbean and Indo-Pacific**, the biodiversity is higher in the Indian Ocean, in the Red Sea, in the west side of Australia, Fiji, Indonesia, there is low biodiversity in the Caribbean Sea (less than 50 species of hard corals, but there are a lot of soft corals). We can call them "ocean province"

- The mangrove and the seagrasses distributions are similar to the coral reef distribution, they show the highest biodiversity in the Coral Triangle (Philippines, Australia, Malaysia, Indonesia, Papua New Guinea) → they are strictly related from different points of view, they provide ecological services which determinate also the presence of other related ecosystems...

8.5 - RELATION BETWEEN CORAL REEFS – SEAGRASSES – MANGROVES

- Sea grasses trap sediment and slow water movement thus benefits coral by reducing sediment loads and provide clear water
- Mangroves trap sediment, reduce the load on seagrass and corals
- Barrier reefs form lagoons protected from waves (reduce the hydrodinamism), which allows mangrove and seagrass communities to develop
- Seagrass sediments form substrate that can be colonized by mangroves
- They are also important from a tourism point of view



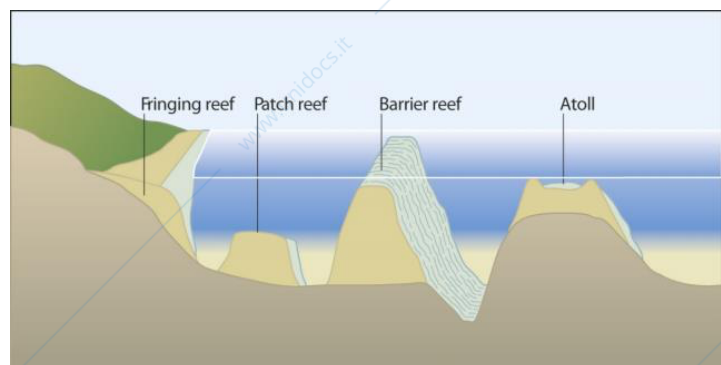
8.6 - REEF DEVELOPMENT AND TYPES

Corals form **several types/structures of reef** depending on 4 factors:

- The availability of underlying substratum → type of the substrate on which the coral grow, depending on geological processes happened in the Area
- Long-term changes in sea level
- Light levels
- Wave action

Combining these factors, the coral reefs can create 4 tridimensional structures:

1. Fringing Reef
2. Patch Reefs
3. Barrier Reefs
4. Atolls



Fringing Reefs

- Coral reef which develop directly attached to the shores of rocky islands, with a shallow and short lagoon (this is a sandy environment between the shore and the coral), the LAGOON should be very small and shallow → < 500 m width < 5 m depth.

STEPS:

1. Coral settle and grow towards the surface on illuminated and shallow rocky substratum, creating a shallow platform exposed by low tides
2. The upward growth of the reef stops because the corals cannot tolerate drying and intense wave action, so...
3. Fringing reef may continue to grow horizontally until the base of the platform is too deep and poorly illuminated, for this reason they are not so wide in dimension because a specific distance from the shore, they stop to grow horizontally but continue to grow vertically

- The reef should be or directly connected to the shore, or a little bit far, but with the following conditions: less far than 500 m from the land and less deep than 5 m. if the conditions are not respected, it can be classified as fringing reefs, but barrier reef

Barrier Reef

- Reef parallel to the coastline and separated from a mainland or island shore by a deep and large lagoon with patch reef
- e.g. the *Australian barrier reef* → parallel to the coast line, separated from the mainland or the island shore with a very big, far (more than 500 m) and deep (more than 5 m) lagoon which can also contain some patches of reef. In this case it's so far that we need few days to reach its.
- The windward side is strongly affected by waves that are visible from land and satellites
- It represent an evolution of the fringing reefs, so in Australia, millions years ago there was fringing reefs, not barrier reefs → **due to the subsidence and the rise of the sea-level processes the barrier reefs was formed.**

Patch Reef

- Small, isolated reef formation that usually is circular or oval in shape, which are mostly located in the lagoon, in the sea portion between the land, the shore and the reef (both fringing of barrier reefs).
- There is a sandy bottom with calm and protected water thanks to the reef that stay behind
- They may grow upward until they are just below the surface at low tide, but they are often deeper
- They are not so developed because since the water is not so active, hydrodynamic it will become worm, there aren't the perfect conditions to the growth of the coral reef growth
- They can create aggregation of patch becoming big aggregations of patch reefs.

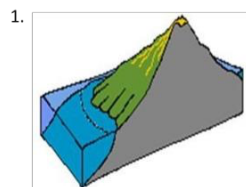
Atoll

- Ring of barrier reef, more or less circular, with low-lying islands surrounding a central lagoon
- Open-ocean structures, not usually found near a continental coast, but they are far from the shore, e.g. Belize, Indonesia, Maldives, Micronesia...
- There are many atolls in Indo-Pacific, less in the Caribbean
- They can be very big
- The emergent part of the reef is often covered with accumulated sediments and some vegetation that are old corals which died before, so are only calcium carbonate structures covered by vegetation, there were corals before, but now white sand made by coral skeleton
- There are many **channel** between the open ocean and the main lagoon, they provide fresh and colder water, rich of nutrients to the lagoon, in fact in these channels we can find strong currents that identify these places as the best places in which dive.

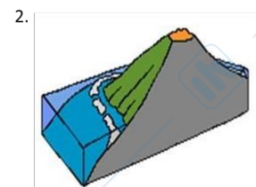
Which is the process that create these atolls?

The theory of the atolls formation derive from the Darwin theory:

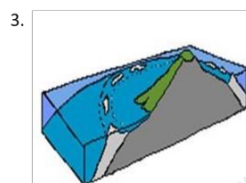
1831 (the Darwin's theory) it could be considering the theory of the formation of the atolls. A fringing reef directly attached to an active volcanic island started to be created. Then the island subsides, the sea level rise, so the corals continue to grow upward and horizontally so starting from a fringing reef, a barrier reef was created. Was created this ring shape structure, the island disappear under the water and there was the formation of an atoll in the middle, the depth is not so huge because there is the volcanic island below, max 5m, instead outside in the open ocean the depth can reach 100-1000m. when the corals continue to grow vertically and horizontally, they can go outside the water, they die and there could be also the formation of an island with white sand.



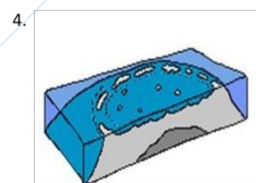
Active volcanic island



A fringing reef surrounding the island
Subsidence of the seafloor or rising sea levels



Subsidence continues
Fringing reef becomes a larger barrier reef

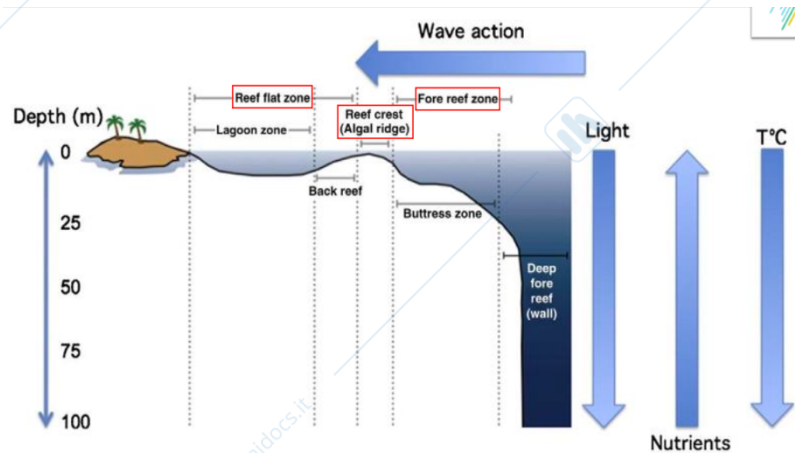


An atoll results when the island has disappeared

e.g. *Bora Bora*: in some case the volcanic island can remain, is not the normality, but it could happen as in this case.

REEF ZONATION

- As the mangroves ecosystem, also the coral reef shows a zonation which can change depending on geographical region, condition...
- **Different grow form of corals need different habitats creating a zonation**, so we can define different areas characterized by different types of corals, not in term of species, but in term of morphology, structure.

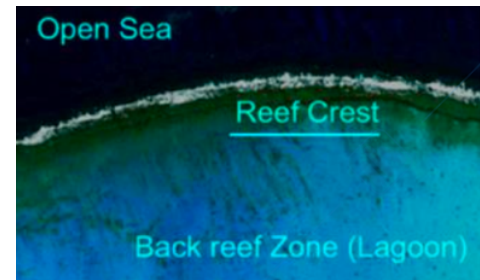


- Is based on varies degrees of **wave energy**, **T °C**, **light** and **nutrients** → the zones of corals are created by the interaction of these physical factors

- These patterns are different depending on the geographical area and the type of reef

- We mainly define 3 important zones within the coral reef: REEF FLAT ZONE, REEF CREST ZONE, FORE REEF ZONE (also called REEF SLOPE)
This zonation can be easily detected from the satellite, or using aerial photography

- Also using the color we can distinguish these 3 main zones: the first area with a sandy lagoon, back reef, and reef crest, is the border where the waves break. The last part is not visible, is the open sea, characterized by the 4-reef zone.



Reef Flat

- Is the first part of the reef directly attach to the shore, or close to its
- It is composed by 2 subzones: lagoon and the back reef (this is not always present)
- **Is the shallow water area that extends from the shore to the reef crest**
- Is characterized by a **shallow depth, high light intensity, high salinity, high temperature** create an environment at the edge of coral tolerance range, so is not so optimal for the coral growth
- Extremely variable in size, width, depth, and composition depending on location and reef type
- Due to the shallow depth of this region of reef these areas are often exposed during low tides
- The **low number of corals** in this region is protected from the majority of the wave stress
- It is divided in 2 subzones:

Lagoon:

- Is the first subzone close to the land.
- Is a shallow pool of seawater with a substrate of coral rock and sand
- There are small patches of scleractinians corals
- Sometimes there are huge seagrasses beds
- constantly supplied with nutrients and sediment from both the reef front and mainland outlets

Back Reef :

- **sometimes moving far from the land we can find this zone**
- **is the shoreward side of a reef, the inner side of the reef between the reef crest and the land, in particular between the lagoon and the reef crest**
- there is a protection from the majority of the wave stress
- principally **branching or globular** (submassive) **corals** sheltered from wave action, so there is a huge coral cover

- This zone varies widely in structure and composition depending on the prevailing wave energy and the substrate morphology
- In **high energy reefs** (where there is a high hydrodinamism), the lagoons (the sandy bottoms) are composed mainly of accumulated **dead coral fragments** called **coral rubble**
- In many **fringing reefs** the reef flat doesn't have the sandy lagoon → e.g. in the *red sea* most of the reefs are attached to the land, so there is not the lagoon

Reef Crest

- **Is the ridge of the reef between the lagoon and the fore reef** (reef slope)
- Its exposed during the low tide, and is consider the highest part of the reed
- Is an area characterized by an *intense stress* because all the waves break there, there is a very intense light, high T
- Due to these stresses, this zone is characterized by little corals, sometimes if the area is characterized by a **very strong wave energy** **no corals can live** and they can be **replaced by calciphyte red coralline algae** and **brown algae** creating the **algal ridge** → they are incrusting algae so can resist
- *From higher altitudes it can be located by the bright line of breaking waves along its outer margin*
- There are some corals that can survive on reef crests with less severe wave action, **typically short branching corals, massive or incrusting corals**

Fore Reef

- This is the last zone, of the reef, is the most far zone from the land, when the reef start to go down developing in depth
- Is also called seaward slope or reef slope, it is the **oceanic side of the reef crest**, and it slopes downward
- Host the **higher number** and the **largest corals** on the reef, due to the most hospitable environment with limited wave action → the condition are perfect: not so much hydrodinamism, perfect light, T, especially after 10-15m of depth because in the first m there are these stresses.
- It can be subdivided in w subzones:

Buttress Zone:

- Is the first subzone close to the reef crest
- Is the shallow part of the outer reef (**reef slope**)
- The most densely populated and the most diverse zone of the reef (15-20 m)

Deep fore reef:

- Is the deeper part of the reef
- where the edge of the reef drops off into the depths (similar to a **wall**)
- in the first m of these zones we still encounter corals because there is light, but going in depth, the morphology of corals change acquiring a **plate morphology** to absorb much light as possible
- going more in depth, scleractinians corals can be replaced by: ahermatypic forms, solitary corals, sea fans and sponges, so corals that don't live in symbiosis and are called A-ZOOXHANTELLATE, so corals that are heterotrophic 100%, not need light and feed just using the tentacle

Open sea

BIOLOGICAL INTERACTIONS IN THE CORAL REEF ECOSYSTEM

The main biological interactions that exist in coral reef ecosystems are:

- **Competition among coral species:** in competition only one of the 2 components receive an advantage, it can be both intraspecific and interspecific. Coral species compete for **space** and **light** because are the 2 main limiting factors. There are different mechanisms adopted by corals to compete:

1. Overgrowing and shading the neighbors → because of the symbiosis with zooxanthellae, reef corals are strongly light limited so growing vertical can reduce the grow rate of neighbors by shading them out. It can be:
 - Intraspecific: when colonies of the same specie compete, they can come into contact and fuse together (forming **chimera**). Fusion may enhance survival by reducing the perimeter open to attack to competitors and predators. It is also a genetic advantage because can increase the resistance to perturbation.
 - Interspecific: when 2 different species compete, usually the specie with the highest grow rate will dominate and overgrowth the other one but this not always occur in fact sometimes is the slow growing species (massive one) to dominate (because are chemically stronger).
 2. Extrusion of mesenterial (digestive) filaments → in several hours the **mesenterial filaments** (extrude by the polyps) of one colony can completely digest part of the second colony, leaving the underlying skeleton exposed. The outcomes is the formation of a **bare zone** between the 2 competitors. The most aggressive species at digesting their neighbors are in general the slowest growing forms (massive one).
 3. Elongated polyps or tentacles (sweeper tentacles) → some slow-growing species (massive) also have long **sweeper tentacles** that damage neighbors with **stinging cells**, that maybe are longer than the other and are only use for this function. The cnidome of these tentacles are different from the one present in the other tentacles and probably are more urticant. For example, are present in *Goniopora*.
 4. Chemical mechanisms (allelopathy) → production of aqueous soluble toxic compounds (**allelochemicals**) that can physically damage the other corals (can affect the survival, growth rate or settlement of larvae according to the different bioactive compounds).
 5. Mucus deployment → all coral polyps produce mucus that is full of bacteria, and it is very important because protect the corals from different stressors (eg coral disease) but sometimes can be used to compete. In fact, Fungiid mushroom corals actively release nematocysts into their surface mucus and these nematocysts may be their major mechanisms of competitive damage to neighboring stony corals.
- **Avoid competition:** there are many different mechanisms adopted by corals to avoid competition for examples:
 1. Redirect their growth away from areas of contact with competing corals.
 2. Alteration of their angle of growth leading the formation of coral domes so massive morphology (eg stony corals to avoid competition with sponges).
 3. Formation of skeletal barriers.
 4. Evasion responses: some corals are able to move in particular Fungidi corals because are not attached to the bottom.
 - **Competition with other sessile invertebrates:** the main competitors are
 1. Sponges → sponges and corals compete for space. Sponges invasion and overgrowth on corals in enhances by environmental conditions that are stressful to corals but tolerable for sponges (low irradiance, high level of sedimentation, coral bleaching and disease). Sponges may compete with corals by:
 - Overgrowing corals: they can colonize coral tissue and the skeleton. This reduce the photosynthetic efficiency and respiration process reducing the coral growth.
 - Producing allelochemicals: they are produce only when the sponges are in contact with the coral tissue or are release through the sponges mucus or directly in the water column.
 2. Ascidians (tunicates) → when the environmental condition change, they can increase in population size and overgrowth corals. They can compete with corals due to their:
 - Rapid growth rates

- Early sexual maturity
 - High fecundity
 - Lack of successful predators
3. Vermitids → secrete a mucus net to entrap food completely covering nearby corals and damaging them. Mucus prevent coral feeding and may allow the vermitids to consume photosynthetically derived coral metabolites.
- Competition between corals and seaweeds → algae and corals compete for light and space. Algae can inflict competitive damage to stony corals using 7 major types of mechanisms:
 - Inferring with the settlement and survival of larval and juvenile corals.
 - Shading.
 - Allelopathy.
 - Attraction of setting larvae to ephemeral algal surfaces.
 - Abrasion.
 - Basal encroachment.
 - Sedimentation due to reduced water flow.

There is a great variability in the processes and outcomes of coral-algal interactions, even within an algal family, and coral life forms and genera.

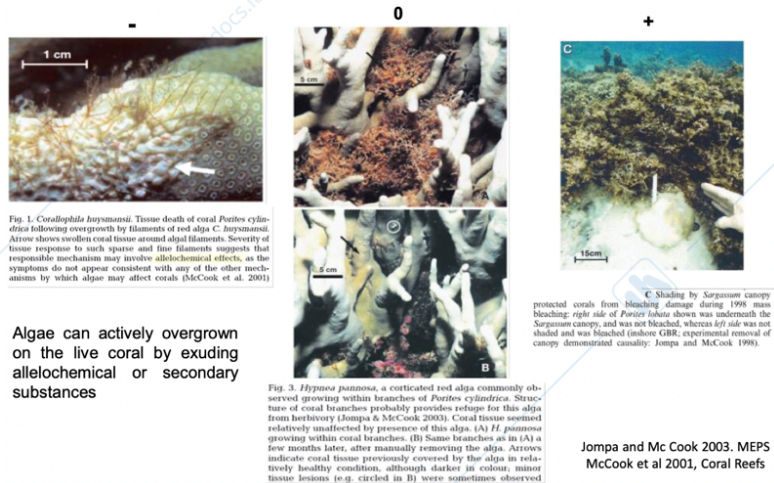
- Bioerosion: describes the erosion of hard ocean substrates by living organisms causing the reef regression and decline. The bioerosion affect the skeleton of coral reefs (reducing the volume of the coral reefs) and we have 2 main type of erosion:

1. Mechanical erosion
2. Chemical erosion

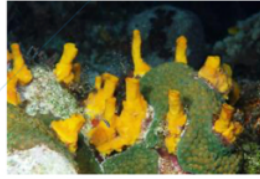
The bioeroders (don't eat coral polyps) are divided in 2 categories:

1. Internal bioeroders (borers): erode the skeleton from inside. That are divided again into:
 - Microborders: like algae, fungi and bacteria.
 - Macroborders:
 - Sponges: sponges in the family Cilionidae send out pioneering filaments (pseudopods) that:
 - ◆ Release acid compound able to dissolve CaCO₃ (use chemical erosion).
 - ◆ Perforate and dig the coral skeletons (mechanical erosion)
 - ◆ Excavate below the live tissue layers, thus avoiding tissue-based defense mechanisms
 - ◆ Eventually they can undermine coral skeletal support and induce polyp retraction and death.

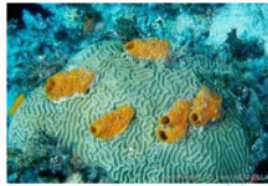
These sponges use the coral as shelter and produce structure similar to chimneys in order to feed (eg *Siphonodictyon coralliphagum*).



- Bivalves: release acid compounds able to dissolve CaCO_3 . The most perforating bivalves belong to the genus *Lithophaga*.



- Sea urchins: sea urchins are herbivores and grazers (feed on algal turf and coralline algae that sometimes grow on corals) but sometimes can feed on coral recruits and juveniles (not first source of food). They erode with mechanical and chemical processes.



Siphonodictyon coralliphagum

Species of the bioeroding sponge *Siphonodictyon* bore deeply into living coral heads, leaving only the **oscular chimneys** exposed and surrounded by live coral tissue.

This was the first sponge proposed to use allelochemicals to prevent growth and reduce respiration rates of adjacent coral polyps.

Siphonodictyon sp. secretes toxic mucus that acts as a carrier for the secondary metabolite **siphonodictidine**, which inhibits coral growth around the base of the oscular chimneys

- At intermediate densities, sea urchins can prevent the overgrowth of macroalgae providing space for coral settlement and juvenile growth (advantage for corals because remove competitors of algae). While at high densities, sea urchins can have a negative effect on the calcium carbonate budget.
- Fish: fish also erode coral while eating algae and algal turf on coral surface (grazers). Eg: Parrotfish, Triggerfish.
- Humans: also humans cause erosion through trampling or coastal development.

2. External bioeroders (grazers): erode the skeleton from outside.

- Sea urchins: sea urchins are herbivores and grazers (feed on algal turf and coralline algae that sometimes grow on corals) but sometimes can feed on coral recruits and juveniles (not first source of food). They erode with mechanical and chemical processes.

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- Corallivory: describes the predation of coral polyps (tissue, mucus, or skeleton) by other marine organisms, contributing to reef regression and decline. The corallivore can be obligate (feed only on corals) or facultative (eat also other organisms). There are many taxa that include fish, echinoids, crustaceans, mollusks, and annelids.

They have a very important role in modelling coral community and in determine the structure of the coral reef (some corallivore are specie-specific). In general, their presence is not a problem for corals but when increase in number (outbreaks) they represent a big issue (increase predation pressure). Some examples are:

1. *Coralliophila* (sea snail)
2. Fish
3. *Acanthaster planci* → reported outbreaks (cause are still unknown) and aggregations in other localities. It feed on *Acropora* and *Pocillopora*. They suck the coral polyps leaving only the skeleton.
4. *Culcita* spp (cushion star) → not able to create outbreaks. It feed on *Acropora* and *Pocillopora*. It is a facultative corallivore, feed also on coral, rubble, sea grasses and sponges.
5. *Drupella* spp → reported outbreaks. It is an obligate corallivore and feed on *Acropora* and *Pocillopora*.