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FOOD WEBS AND MICROBIAL ECOLOGY: THE DECOMPOSITION PROCESS

- The microbes are mostly involved in the decomposition process, not only in the terrestrial environment, but also on the marine ecosystem
- The biomass of micro-organisms is comparable to that of the whales or fish
- The microbes genetic and metabolic diversity far exceeds the diversity of other groups of organisms

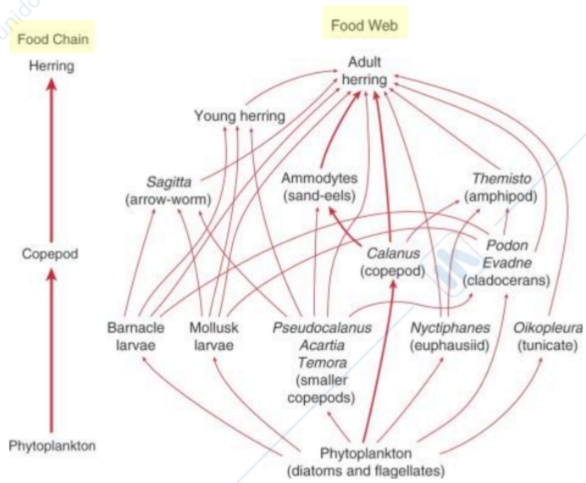
Eukaryotic marine species: ~230.000 (in the ocean)
Prokaryotic marine species: from 1.000.000 to 1.000.000.000 (in the ocean)

- Metabolic versatility allows bacteria to occupy many niches and to carry out multiple fundamental processes vital for ecosystem functioning in the ocean:
    1. Decomposition
    2. recycling of the organic material
    3. utilization of dissolved organic matter
    4. nitrogen fixation
    5. denitrification

Microbes play a central role in the metabolism of organic material in the ocean

The flow of organic material can be treated in the context of feeding interactions between organisms sharing the same habitats and forming food chains and food webs

- **Food web** is a diagram that shows the overall pattern of feeding among organisms
- **Food chain** is a semplificated linear version of the food web, which takes into account the main species through which organic matter cycles



Each main species or group of species that feed on one or more other species represents a **trophic level**

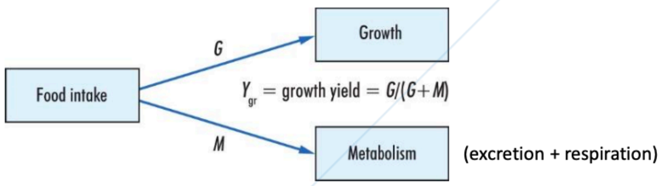
Different processes than can regulate the food web/ chain

- Bottom-up control**:** effects of fluctuations of species at a given trophic level on the levels **above**
- Top-down control**:** effects of fluctuations of species at a given trophic level on the levels **below** (predators control abundance of preys)

Transfer Between Trophic Levels

- Transfer of production (organic material) from one trophic level to the next **is not complete** → considering carnivores that ear herbivorous, not all the material is completely transfer between these 2 levels, there is a loss of material
- Loss of material must be considered:
    1. Some material not eaten (phytoplankton with spines, toxins, too small or big)
    2. Not all eaten is converted into growth with 100% efficiency
    3. Some food egested or excreted (skeletal material, fecal pellets)
    4. Some of the energy obtained by food is lost as respiration
- **Respiration** and **excretion both represent metabolic losses** that result from converting food into new organism tissue (i.e. growth)

For an organism, the **food intake** is used both for growth but also for the metabolic process, which include respiration and excretion. This concept introduce a new concept of the **growth yield** (Y) of an organism, it is the proportion of assimilated food used for growth, is the ratio between the growth and the food intake (how much food intake allow me to growth).



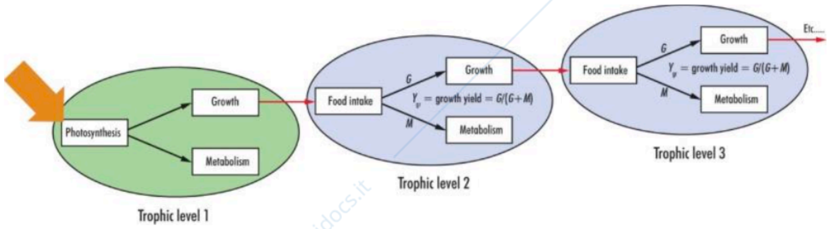
1. **Growth yield (Y_{gr})** of an organism $= \dfrac{\text{Growth}}{\text{Food intake}} = \dfrac{G}{G + R + E}$ or $\dfrac{G}{G + M}$

Food intake= growth + metabolic process (M) = growth (G) + respiration (R) + excretion (E)
Growth yield= is not a fixed value, it's depended on the organism, the type (multicellular, unicellular), behavior (sessile, vagile) and the stage of life (larva, juvenile, adult)

If we consider a SIMPLE LINEAR FOOD CHAIN:

We consider the process between 1 trophic level and the next level; we can extend the concept of the growth yield to the concept of the **trophic yield** → all the organisms that belong to a specific trophic level. If we compared 2 trophic levels (herbivore and carnivore), the trophic yield is the result of the proportion of the growth of a specific level (carnivore) divide the production (growth) at the trophic level just below (herbivore).

2. Trophic yield (Y_t) = $\frac{\text{production (growth) at trophic level } i+1}{\text{production (growth) at trophic level } i}$
2 trophic levels



3. Overall efficiency = $Y_{t=2}$ x $Y_{t=3}$ x $Y_{t=4}$ x ....
all the food chain
= $(Y_t)^n$

- $Y_{t=2}$, $Y_{t=3}$ ..: yields at the various trophic levels
- Y_t: representative trophic yield
- n: number of steps in food chain

If we link all together all the trophic levels that compose the food chain or the food web, we may calculate the **overall efficiency** of the food chain → addiction of the trophic yield of each trophic level, using this formula= Y^n.

In the food chain there is part of energy that us used to growth and part for the metabolism, the energy use to growth will represent the food intake for the next trophic level that use the energy to growth and for the metabolism (respiration and excretion), which represent the food intake for the next level and so on…

In general:

- Overall efficiency of a food web is about 10 – 30%
- We have not the maximum efficiency because there is a loss of material in the environment
- In higher latitude planktonic systems have higher values because they have less trophic levels, there is not a complicate trophic food web because there are not so many organisms, e.g. just 2 levels: phytoplankton and anchovy (that eats phytoplankton) → less trophic level we have, lower is the amount of energy that is loss, the overall efficiency is higher

Areas of **high productivity have less trophic levels**, therefore less energy is lost, and more energy is available to the next trophic level, **high efficiency in energy transfer.**

- **The natural food webs are, and need to be, energetically inefficient,** otherwise
  1. the cycle of nature cannot be completed
  2. the flow of material between the different trophic levels would stop
- The inefficiency is a consequence of the very large fraction respired and recycled to form inorganic C, N and P used during phytoplankton production
- Without this efficient recycling of nutrients the food webs would rapidly stagnate → **without this loss of material we don't have another process, the decomposition process** (another food web)

Before we have studied the process of production (use of inorganic compounds, light and E to transform these compounds in O2 and nutrients, they must be recycled and they must go back to the inorganic form, for this reason, part of the energy used by the metabolism is those included in the remineralization or mineralization of the organic compounds → transformed of organic compounds to inorganic form passing through the decomposition process.

DECOMPOSITION PROCESS

- **Decomposition** is the breakdown of organic material by heterotrophic metabolism as a consequence of respiration, resulting in the reformation of inorganic carbon (CO_2), nitrogen (ammonium) and phosphorus (as phosphate)
- This process is also called **remineralization** or **mineralization**
- **Prokaryotic microorganisms** (bacteria, archaea, protist) play a dominant role in the process
- This is another food web (dominated by bacteria) that go in parallel to the first food web that we have studied

Two parallel food chains (**dual food chain**) with separate starting points:

- one based on the photosynthesis
- the other starting from detritus, which involves the microbial community → the detritus-based food chain can start from bacteria and other organisms capable of consuming both POM and DOM.

Decomposition process start from biological particulate material

3 stages of decomposition process:

1. Everything start with biological material, organic material that is also called insoluble biological particulate material, it is formed principally by cellulose (in the algae, in all the vegetables), chitin (is a compound present in the skeleton or exoskeleton of many organisms), proteins, fats that in this first stage are CONVERTED in low molecular weight (LMW) dissolved material (e.g. aminoacids, sugars, fatty acids):
    - This conversion occur outside the cell, usually in particular vesicles, in the gut or in the external environment
    - This conversion is made by bacteria that are obligate **osmotrophs organisms** which are able only to take dissolved substrate into the cell
    - The conversion in the gut, in the vesicles or in the external environment usually occur thanks to some digestive enzymes which are secreted extracellular and are called hydrolytic enzymes
2. The LMW products once created, may DIFFUSE, or be ACTIVELY TRANSPORTED into the single cell of the bacteria or protist and are metabolized and used for the respiration (final stage)
3. The final stage is the RESPIRATION that occur within the cell

Both soluble and particulate biological material is collectively known as ORGANIC MARINE DETRITUS:
The excretion of the heterotrophic organisms is classified as “marine detritus” and can be also called WASTAGE or WAST PRODUCT which are included in the food web model with the term excretion. They are produced both **during the growth of the organisms**, e.g. fecal pellets… or also **by the metabolic activity** of the organisms.

A food chain is always an open system, because **there is always a wastage of food** along the way

- Fecal pellets
- Incomplete digestion of the food
- Release of soluble organic material from algae or heterotrophic (**exudates**)
- Incomplete feeding of preys (**sloppy feeding**)

Together with these products there are also additional sources of marine detritus:

- **Mucilage** (mucus, polysaccharide) → e.g. algae can produce mucus or polysaccharide that can form these mucilaginous aggregates, also corals use this mucilage to protect themselves from infections or also to captured zooplanktonic organisms. These aggregations are part of the marine detritus
- **Dissolved organic material** released from the algae (both alive and moribund cells) → are important in the creation of the mucilaginous composed

We can distinguish the organic material in 2 different categories depending on the size:

1) DOM → all the organic material able to pass through a filter of 0.5 micrometer (**dissolved organic material**)

2) POM → all the organic material that is not able to pass through a filter of 0.5 micrometer, is bigger (**particulate organic material**). It is also called MARINE SNOW because it generally appears as snowflakes in the sea. Usually it is composed by:
   - Small living organisms
   - Pieces of organic material, of meal
   - Material created by physicochemical processes from soluble detritus (destroy bigger organic material creating this particulate, that from the shallow part of the ocean sink to the bottom and is called snow).
   - The marine snow is very important and can be very huge in same part of the sea → it host a lot of microbes, bacteria, they are oasis of nutrients in place where the nutrients usually are not present in high concentration. Moreover are important for the carbon cycle in the ocean. Sometimes the marine show can also reach huge size, especially in the norther Adriatic Sea, where they can appear in different forms, not only as snow but also as big mucilaginous aggregations.

In term of microbial food web, which are the most important ecological groups of this decomposition process? The most important organisms which actively decompose the organic material converting them in inorganic material?

The marine planktonic microbic community can be classify in different categories depending on the approach that we select…

From a taxonomy point of view:
The life can be classified in 3 major phylogenetic groups:
1) **Prokaryotic bacteria**
2) **Prokaryotic archaea**
3) **Eukaryotic organisms** → all the macroscopic organisms (fungi, plats, protists, and animals)

+ 4) there is another separated group, the **viruses**, which are not included in the 3 groups below

PROKARYOTIC ORGANISMS:

Speaking about the decomposition, we are interested on them
- They are all microscopic organisms
- They are single-cell organisms (unicellular)
- They don't have organelles in their cells (NO nucleus, mitochondria, chloroplast)
- The cell reproduction occurs by mitosis

The most important ecological groups present in the marine plankton and comprising the oceanic food webs, in particular in the decomposition processes, are not only the prokaryotic organisms, but:
1. **Marine prokaryotes** (bacteria and archaea)
2. **Viruses**
3. **Algae**
4. **Protozoa**
5. **Multicellular zooplankton**

Marine Prokaryotic Microbes: **Eubacteria** and **Archaea**

- They are fundamental in the organic material degradation and nutrient remineralization in the ocean
- They are unicellular organisms or can create colonies
- The size is from 0,2µm–30µm
- The reproduction occurs by binary fission and sometimes by budding
- They appear with different shapes, for these reason they're classified in different categories
- They live both in the water column, in the sediment or attached to other organisms, places or particles
- Bacteria and Archaea belong to 2 distinct evolutionary lineages, groups: the 2 groups are similar in term of cellular characteristic because they both lack in nucleolus, they reproduce themselves by fission, but they have different genetic, cellular, and biochemical features.
- Archaea (prokaryotic microbes) tend to live in extreme environments (deep water, high temperature, e.g. hydrothermal vents) and are less abundant than bacteria

Marine prokaryotes have major taxonomic groups that characterize their communities which are commonly found world-wide:

Some marine bacterial groups have defined niches in organic matter degradation:

- **BACTEROIDETES**: are able to degradate just protein and chitin, so organisms with these skeletons
- **α-PROTEOBACTERIA:** take up dissolved aa and comprise up to 25-30% of total abundance of pelagic prokaryote communities
- **β-PROTEOBACTERIA:** they utilize simple sugars molecules

Marine bacterial populations

bacterial cells that belong to same species, in a given environment form a population, in a bacterial population, the cells can face (have variable) different physiological states:

- same cells are dead, but the population is still intact
- same cells are dormant but capable of growth after a certain period
- same cells are starved (inactive) but the metabolism is only partially shut down

In a bacterial population, only a little fraction of the population is active, grow and reproduce (usually are the **larger bacteria**), in fact most of the time the smaller bacteria are starved

Two main categories of **CONTROLLING FACTORS** (affect the different activities of the different bacterial cells within a bacterial population)

1. Growth-controlling factors→ factors that affect the rate by which new cells enter in a population, e.g. T, salinity, pressure, nutrient type, nutrient availability
2. Mortality-controlling factors → determine cell removal from the population, e.g. protozoan predation (the most important predator of bacteria), competition, starvation (lack of nutrients), presence of viruses

Persistence of bacterial populations despite unfavorable conditions → they are present everywhere and always also if the conditions are not good. This condition of a bacterial population is obtained thanks different factors:

- High reproductive rate (allow the population to be always present)
- They are adapted also to spend moments (long or short) without eating (survive to the starvation)
- They have dormancy strategies that allow them to survive and growth during these periods

Marine Bacterial Populations - **Ecological Strategies**

They are used to survive, to grow and colonize new habitats, environments…

- **R - ecotype (patch exploiters)**
  - Species that respond to a sudden increase in food availability growing and multiply becoming dominant
  - Under unfavorable condition they rapidly become scarce, they decrease, for this reason are called PATCH EXPLOITERS (colonized new patches)
  - These organisms usually form colonies
  - They are associated with high productivity habitats
  - Are mainly composed by: Y-Proteobacteria and *Roseobacter* of α-Proteobacteria
- **K- ecotype (oligotrophs)**
  - Mainly composed by single cell (they don't create colonies)
  - They are adapted to oligotrophic open ocean (where the nutrients are not so high)
  - Can utilize these scarce resources efficiently
  - They maintain a stable population size that fluctuate near the carrying capacity (higher capacity that the environment limited condition can sustain), they don't increase the population depending on the availability of the resources
  - They are composed by: α-Proteobacteria

Interaction between Bacterial Populations

- **Allelopathy**
  - Is an antagonistic interaction → prevention of the growth of another bacteria by production of bactericidal compounds (I don't want any other bacterial species in the same environment, so I produce toxic compounds), occur not only among bacterial but also among different algae or algae and corals

- More common in particle-associated bacterial populations than free-living bacterial populations

- **Quorum sensing**
    - Is a system of stimuli and response correlated to population density → when there are favorable condition for the growth of bacteria, this lead to a gene expression producing signals (signaling molecules) called **autoinducer** which suggest an increase of the reproduction in order to increase the cell density of the species
    - E.g. bacteria that colonize the same marine snow regulate the timing of their production of extracellular enzymes that solubilize particles in DOM by leaking Autoinducer

VIRUSES

- They are submicroscopic biological entities, the littlest organisms, from 20 to 200 nm
- Replication by infecting cellular life and using the cellular machinery of the host
- They **are NOT organism**, although they contain genetic material in the form of DNA and RNA they don't have an independent metabolism or reproduction activities, they depend on the host for the survive and reproduction
- Capable to infecting all marine organisms from bacteria to whales
- The most abundant entities on Earth (several hundreds of thousands of marine species)
- Important function as regulation → they control the bacteria population, [ ] of bacteria (bacteriophages)
- Significant influence on the fate of primary and secondary production

Virus Infection

There are 10 billions of viruses in 1 ml seawater

1. **Small** virus infect bacteria and are call **bacteriophages** → they act as bacteriophages; they can adhere on the bacteria cell (they find the host thanks to specific receptors on the cell surface) in which they will inject some DNA or RNA into the cell taking control of the host cellular machinery.
2. **Large** spherical viruses (130-200 nm) in the ocean surface **infect phytoplankton**

Some virus are **host-specific** whereas VS others seem to have a **wider host range**

- A key factor in infection is the host-virus contact rate, which is a function of the amount of host cells and viral particles in the water.
- Viruses limit the abundance of bacterial species that become dominant in the microbial community since the viral infection rate increases as the concentration of host cells increases, for this reason they have a important control function on the bacterial community… if a specific bacteria became abundant, also their activity, the viruses infection rate, decrease, so controlling the spread of this specific bacteria group following the → **''Kill-the-winner'' hypothesis** base on this hypothesis there is an important mechanism that control both prokaryote and algal populations

Role of viruses in the coral reefs:

Virus important in recycling nutrients, releasing DOM and nutrients available for other organisms, such as zooxanthellae and corals

KINGDOM PROTISTS

- This is another important component of the oceanic microbial food web
- The protist are eukaryotic organisms, they are not plants, animals, or fungus
- They can be unicellular or multicellular
- They can be microscopic or very large
- Autotrophic or heterotrophic (or mixotrophs)
- They can follow an asexual or sexual reproduction

    → are composed by various different groups of organisms that show great different in term of size, reproduction mode, physiology, metabolism…
- They can be classified by the **way they obtain food**
    1) Animal-like protists: **Protozoa** (heterotrophic and unicellular) → there are 3 main groups of protozoa in the sea water: AMOEBAS (have not specialized structures, they use the pseudopods to move, but are not defined structures), FLAGELLATES (single, located on the top of the cell to move), CILIATES (have cilia that surround the body, are used to move, to capture food)
    2) Plant-like protists: **Algae** (autotrophic and unicellular/multicellular)

3) Fungus-like protist: **Slime Molds, Water Molds** (are mostly decomposer organisms)

FLAGELLATES

- Heterotrophic nanoflagellates (HNF) are the **bacterivores flagellates**
- Size range from 2 to 20 μm
- Characterized by 1 to 4 flagella that serve:
  1) for movement
  2) as a device to generate feeding currents
  3) to collect preys (bacteria)
  4) for sensing the environment
- They generate feeding currents by undulating their flagellum and collect the prey particles through contact with the flagellum or by using filter structures
- Flagellate grazing is an important limiting factor for bacterial production and is a selective force in marine bacterial assemblages as large-size bacteria are more vulnerable to grazing

CILIATES

- 20 -200 μm
- Characterized by cilia
- Bacterivorous, herbivorous, predatory (other ciliates), mixotrophic (using chloroplasts captured from algal prey)

DINOFLAGELLATES

- 2 differentiated flagella (one for motility and one for grazing
- Some species covered by cellulose plates (theca)
- Can prey upon large organisms by extending **pseudopods**

METAZOAN ZOOPLANKTON

- Little organisms which belong to the groups of zooplankton, in particular include **larva of crustaceans**
- Are very district taxonomically from the microzooplankton protists, but very similar in size and function

ALGAE

- Include both prokaryotic and eukaryotic organisms
- From 1 μm to 200 μm diameter → we are not speaking about the macroalgae because we are looking the microbial food web
- Prokaryotic belong to **cyanobacteria** (blue-green algae) that can be unicellular, filamentous, or colonial
- Eukaryotic algae are taxonomically and morphologically more diverse
- Both the groups are autotrophic primary producers