Zooplankton in the context of marine life

Zooplankton is considered the most important link between planktonic primary producers and large carnivores, amongst them fish species subject to human exploitation. Zooplankton can also contribute the role of marine systems as sinks of CO₂, the main greenhouse gas. When feeding, zooplankton compacts small, slowly settling particles into larger ones (fecal pellets) that can reach the bottom before being recycled, so that biogenic carbon can be sequestered in the sediment, thus enlarging the time for CO₂ to return to the atmosphere.

Nutritional modes in zooplankton:
All zooplankton -indeed all animals and some micro-organisms- are \textit{heterotrophic}. That is, they require organic substrates as sources of chemical energy in order to synthesize body materials. Animal species differ in how their energy is obtained: as follow:

- \textbf{Herbivores}: feed primarily on phytoplankton
- \textbf{Carnivores}: feed primarily on other zooplankton (animals)
- \textbf{Omnivores}: feed on mixed diet of plants and animals and detritus
- \textbf{Detrivores}: feed primarily on dead organic matter (detritus)

\textbf{Crustacean Zooplankton}

\textbf{Phylum Arthropoda}

Crustaceans comprise a class of the phylum Arthropoda, whose distinctive features include

1. an external skeleton of chitin, a flexible but stiff material, that is relatively impermeable to the external environment, and
2. some degree of segmentation, with paired, jointed appendages (e.g., legs, antennae).

The crustaceans possess antennae, mandibles, and maxillae as head appendages, and usually have compound eyes. They are notable for their mobility, armored exoskeleton, and generally good vision.

- \textbf{Copepods (oar-footed)}

The word Copepoda derives from Greek, from \textit{koipe}, that means oar, and \textit{podos}, which means feet Hence Copepod = oar-footed, referring to the pair of swimming legs that are moved together, like the oars.

Copepods are covered by a chitinous carapace. Generally, the body is elongated and has two distinct parts, the anterior, the \textit{cephalothorax} or prosome and the posterior, the abdomen or uroosome. The last somite which is called the anal somite is ending in a two branched structure called \textit{furca} or caudal rami (singular ramus). In the cephalothorax two filiform appendices are laterally widespread, the \textit{antennae}. These are sometimes modified into a sexually modified grasping organ in the males. Following the antennae, there are several feeding appendages, plus four to five double branched swimming feet.
Copepods represent the **largest group of crustaceans** in the zooplankton and the most abundant zooplankton in all the oceans and seas, they are called “insects of the sea” and can be found in all seasons and marine environments in the plankton, generally forming the bulk of holoplankton communities both in biomass and in number of individuals.

- They range in length from less than 1 mm to a few millimeters.
- They are either herbivorous, carnivorous or omnivorous species; in fact there is no clear separation between feeding habits, the **size of food** items being usually more important than their possible animal or vegetal origin.
- Development involves twelve different stages (after egg), each separated by moulting, or casting off of the exoskeleton, and marked by the appearance of new segments and additional appendages. The first six stages are **nauplius** (plural, naupli) larvae (designated NI to NVI); the last six are **copepodite** stages (CI to CVI), with CVI being the sexually mature adult.
- Females can lay eggs free in the water, or carry them in egg sacs.
- Copepods are classified into three major groups (or orders, with three other minor orders) – calanoid, cyclopoid and harpacticoid copepods

The **calanoid** (Suborder Calanoida) are the most of marine planktonic species. Calanoids are usually larger, barrel shaped and the body is composed of head, thorax, and abdomen

- They have long first antennae that almost reach the length of the animal and a thinner abdomen.
- Copepods have two swimming speeds. The first is slow, steady, and accomplished using their mouthparts. The second looks like a succession of jumps separated by stillness. This jumpy form of swimming is accomplished by the appendages on the thorax.
Calanoids have a median naupliar eye but lack the compound eyes found in many other crustaceans.

Females often retain eggs in one egg sac until they hatch or they scatter their eggs into the water. In the genus *Calanus*, the female lays eggs in clutches of about 50, every 10-14 days.

The first stage in identifying them is the number of segments behind the head (three, four or five).

Calanoids feed mainly on phytoplankton, some organic particles, and smaller zooplankton. Detection of food occurs first on the first antennae, which are festooned with sensory hairs. They trap particles on hairlike maxillary setules, located on setae, which, in turn, are located on the maxillipeds. The animal flaps four pairs of appendages (Figure) to propel water past itself. As a diatom comes near the copepod, the maxilliped reaches out and grabs it, rather than sieving it through the setules (as was originally thought). Actually, because of the viscosity of its environment, the animal grabs the diatom with a surrounding envelope of water, which may have to be strained off the particle before it is passed to the mouth parts. In the larger copepods, sieving by the setules may occur. The animal must detect the presence of a diatom by means of chemosensors on the feeding appendages before reaching out for the food.

Another copepod group, the Order *Cyclopoida*, differs in that members are often smaller with relatively shortened antennae and more segments in the posterior third of the body. Females often retain eggs in two ovisac. The order contains over 1000 species, but the majority live among benthic algae or in bottom sediments; only about 250 species are planktonic.

The third group, the *harpacticoids* are smaller still, elongate and with no difference in width between the thorax and abdomen. They have short antennae, two egg sacs and are typically benthic – although they may be found in the plankton at night or on drift algae.

The harpacticoids usually have benthic adults, but the larvae of some species may dominate the estuarine zooplankton.

Members of the Lernacopodoida are wormlike copepod that *parasitize* marine mammals and fish.
• **Krill**

Family Euphausiidae,

Next to copepods in importance are the Euphausiacea. They are shrimp-like creatures from one to a few centimeters long (from 15 mm up to 5 cm long) that form enormous swarms in high latitude seas.

- They are fast swimmers, often undersampled by nets because of their visual perception and avoidance capabilities.
- They dominate the zooplankton of much of the Antarctic Ocean.
- Euphausiids are generally omnivorous with food consisting of detritus, phytoplankton, and a variety of smaller zooplankton.
- They are a crucial link between primary producers and carnivores of high latitude (both arctic and antarctic) food webs, and the main food source of food for baleen whales, penguins, seals, etc.
- They are important as prey for commercial fish (e.g. herring, mackerel, salmon, sardines, and tuna).
- They harvested commercially
- Adult krill have bioluminescent dots along their abdomen, stalked eyes, a loosely fitting carapace around the abdomen and their long and setose feeding limbs.

| **Euphausia superba,** Antarctic Krill | **Gnathophausia zoea,** a mysid. |
• **Mysids** (Figure ) they seldom are important components of the plankton community. Many of these shrimp-like animals spend part of the time on the seafloor, but rise into the overlying water at night or when forming breeding swarms. They have been introduced in some lakes for increasing large particle food availability for fish. Instead, they sometimes became competitors for young fish and even predators for newly hatched fish!

• **Cladocera** (water fleas براغيث الماء) are more important in fresh water than in seawater, but they are sometimes abundant in estuaries. Eight marine species worldwide. The genus *Podon* preys on other zooplankton. Because they are capable of producing by parthenogenesis (i.e. reproduction without males and without fertilization), Cladocera are able to rapidly increase their numbers when environmental conditions are favorable. Cladocera are often found on the surface of samples, which may be due to trapped air inside the carapace.

• **Ostracods** (القشريات الصدفية) (Figure ) are usually minor components of the zooplankton community. These crustaceans have a unique, hinged, bivalved exoskeleton into which the animal can withdraw. Most species are rather small. Little work has been done on feeding habits in this group, but some species are regarded as scavengers.

• **Cumaceans** are truly planktonic but rarely dominate the zooplankton. They look superficially like a large calanoid copepod, but with a bulbous head and thorax, and a slender abdomen (Figure ). At night the normally benthic living cumaceans can swarm into the water column to mate and moult.
- **Amphipods** (مذدوجات الأرجل) (Figure) are distinguished from other Crustacea by having laterally compressed bodies. They usually constitute only a small fraction of the total zooplankton. A few amphipods are holoplanktonic (such as the genera *Euthemisto* and *Hyperia*) and are at times important members of the zooplankton in many parts of the world.

- **Gelatinous Zooplankton**

- **Coelenterates**
  
  **Phylum** Coelenterata or Cnidaria

  **Three classes** Hydrozoa, Scyphozoa, and Cubozoa (a fourth class of cnidarians, the Anthozoa contains all the benthic anemones and corals).

  - Cnidaria are primitive group of metazoans; some holoplanktonic, others have benthic stages in their life cycle and thus their medusae are part of the meroplankton.
  - They range in diameter from just a few millimeters to 2 m for *Cyanea capillata*, a common northern species with 800 or more 30-60 m-long tentacles.
  - Although jellyfish belong to several different taxonomic groups within the Phylum Cnidaria, all are characterized by a primitive structural organization, and all are carnivorous, capturing a variety of zooplanktonic prey by tentacles equipped with stinging cells called nematocysts.
  - Medusae are single organisms of few mm to several meters.
  - The medusae known as box jellyfish are much more dangerous. *Chironex fleckeri* of tropical Australia is the most venomous animal on Earth, and this 'sea wasp' has caused at least 65 human fatalities in the last century. The stings of a large individual, with up to 60 tentacles stretching some 5 m, can cause death within four minutes. In nature, *Chironex* uses this potent venom to quickly kill prey such as shrimp.

  ![Velella velella](image)

  ![box jellyfish](image)

  Some well-known pelagic Cnidaria are colonial forms, like *siphonophores*, in which many individuals with different morphology and specialized functions (feeding, reproductive, swimming or floating) are united to form the whole organism.

  *Physalia physalis* (Portuguese man-of-war), is a tropical siphonophore that floats at the surface with its tentacles extending as far as 10 m below; it is
capable of capturing sizeable fish, and its stings can be painful to swimmers.

- The by-the-wind sailor *Velella velella* other colonial hydrozoans, has remarkable sail-like structure, which catches the wind. The animal has a prominent skirt around the gas-filled float, which stabilizes the animal as the wind hits the sail.
- Dried jellyfish is eaten in many Asian nations.

**Figure**  Siphonophores: (a) a surface floating species, *Physalia physalis*, the Portuguese man-of-war, with tentacles up to 10 m long; (b) a swimming species, *Nanomia* sp. ca. 10 cm long. Both species use their long trailing tentacles to capture prey.

**JELLYFISH BLOOMS**

The interest in jellyfish blooms—the sudden increase of jellyfish to large numbers—and their causes have increased worldwide in recent decades. In Mediterranean waters, approximately 12 species of scyphomedusae form dense blooms. Example include; *Pelagia noctiluca*, *Cotylorhiza tuberculata*, *Rhizostoma pulmo* and *Aurelia aurita*.

Sometimes the most damaging type of jellyfish increase has been caused by populations of new, nonindigenous or alien species such as the nomadic jellyfish, *Rhopilema nomadica*, the upside-down jellyfish (*Cassiopea andromeda*) and the Australian spotted jellyfish (*Phyllorhiza punctata*) in the eastern Mediterranean.

The Mediterranean Pink Jellyfish (*Pelagia noctiluca*) in the early 1980s stimulated international meetings on environmental degradation. In February
2014 a significant numbers of Pink Jellyfish has arrived to Eastern Mediterranean along the Palestinian’s coasts and were much larger than usual. Jellyfish blooms raised the concerns about over-fishing and climate change. In 2002, large swarms of medusae, which were tentatively identified as *Crambionella orsini*, bloomed in the Gulf of Oman blocking seawater intakes at the Oman Liquefied Natural Gas plant and clogging commercial fishing nets. In these cases, the blooms seem to be attributable to population fluctuations of endemic species. However, all too often, the causes for blooms remain unclear. Integrating data on weather patterns, biological, chemical, and physical oceanography, and jellyfish population dynamics (of both polyps and medusae) should increase understanding of the causes of jellyfish blooms and help mitigate future impacts. In the case of *C. orsini*, there may even be a silver lining because it is an edible jellyfish.

HANDLING JELLYFISH: A NOTE ON SAFETY
Most jellyfish stings are not lethal, but a few are. Many more cause rashes, swelling and other symptoms such as nausea, sweating, muscle and joint pain and difficulty breathing. Wear rubber gloves when handling jellies and avoid water into which cnidocytes might have been released. Wear a wet-suit (with gloves, booties and hood) if swimming with them. As jellyfish are generally fragile, avoid taking them out of water. Instead capture and move them in bags and buckets. An effective and practical treatment for pain from stings is immersion in warm to hot water (45°C for 20 minutes), which is more effective than the traditional icepack method. Many marine venoms are heat labile and are quickly denatured by moderate heat.
The Comb Jellies

Phylum Ctenophora

- Ctenophores are gelatinous, nearly transparent, and egg shaped.
- They range in size from a pea to a golf-ball.
- They don’t have nematocysts
- Comb jellies swim by means of fused cilia arranged in eight rows (called comb plates)
- Some have long tentacles. Tentacles of ctenophores may be retracted into sheaths within the body, especially after being caught in a plankton net.
- They are carnivorous, eating over 10 times their body weight per day, despite their body composed of 96% water.
- They are major predators of copepods and larval fish, using sticky cells on their pair of tentacles, or lobes around the mouth, to catch their prey.
- The feeding mechanism is very efficient, and comb jellies are believed to cause strong declines in shellfish larval populations, they have significant impacts on fish populations and fisheries as they feed directly on fish eggs and fish larvae, and they also compete with young fish for smaller zooplankton prey such as copepods.
- A recent invasion of *Mnemiopsis leidyi* into the Black Sea resulted in the decline of a number of species of fish, owing to predation on eggs and larvae.
- Gametes are usually shed into the water, and the embryo develops into a larva that resembles the adult.
- Comb jellies are often strongly bioluminescent and light up like flashing bulbs when disturbed.
- Ctenophores may sometimes bloom (up to one per litre) and may fill a plankton net making it difficult to retrieve into the boat.
- Two invasive Ctenophora (comb jellies) species were reported along the Mediterranean coast of Palestine, *Beroe ovata* and *Mnemiopsis leidyi*. The latter species set in motion a dramatic chain of events that culminated in a collapse of the major fishery and massive economic losses in the Black Sea.
Planktonic Urochordates
Phylum Urochordata

Close relatives of the vertebrates, among the Chordata there are four interesting planktonic groups of Urochordata, Larvacea (Appendicularia), Doliolids, Salps and Pyrosomes. They are the specialized pelagic relatives of benthic sea squirts, and indeed ourselves (because these animals possess a notochord – the precursor to a ‘backbone’, at least during larval development, they are all within the Phylum Chordata

- Larvacea (ذوّات النّيل)
  - Appendicularians are very common in all marine environments, being especially abundant in coastal waters and over continental shelves where densities may reach 5000 m⁻³.
  - The 70 or so species are distributed in all the oceans.
  - Larvaceans are so called because they closely resemble the larval stages of these bottom-dwelling relatives.
  - They are small (few millimeters), tadpole-like, with a small body that contains all the organs, and a swimming tail.
  - Most species secrete a spherical balloon of mucus, called a house, in which they reside.
  - The body is generally only a few millimetres long, whereas houses range from about 5 mm to 40 mm long.

- Movements of the animal's tail create a current of water that enters the mucoid house through mesh-covered filters which remove larger particles of suspended material. As water flows through the house, it passes another feeding filter where nanoplanктон and bacteria are collected and transported to the mouth. Periodically the filters become clogged with particles and the house must be abandoned, an activity that can be repeated up to several times per day; new houses can be secreted within a few minutes.
  - Discarded houses can reach densities of more than 1000 m⁻³, and they contribute to the formation of marine snow, a term applied to
macroscopic aggregates of amorphous particulate material derived from living organisms.

- Also, abandoned houses represent rich sources of food and surfaces for attachment by other organisms in the water column and, for these reasons, they are rapidly colonized by bacteria and protozoans.
- The discarded house may sink to the sea floor and – because six or more houses may be made per day – they are regarded as important components of the global carbon transport, from the atmosphere to the deep ocean. Therefore they have central role in the microbial loop and the global carbon flow
  - Larvaceans grow rapidly, and have been described as the fastest growing animals on the planet, and have short generation times of 1-3 weeks.

- **Doliolids and Salps**
  - Doliolids and Salps are transparent, barrel-like organisms.
  - They have no limbs, tentacles or eyes.
  - They are specialized for a free-swimming planktonic existence
  - Each individual salp has a cylindrical, gelatinous body with openings at each end, intake (inhalant) and exit (exhalent) siphons at opposite ends of the body.
  - Locomotion is achieved by muscular pumping which propels water through the body.
  - This water current also brings food particles into contact with an internal net of mucus that is continuously secreted by the animal. Cilia transport food entrapped in mucus to the esophagus where it is ingested. Food consists primarily of phytoplankton and bacteria, ranging in size from about 1 µm to 1 mm.
  - Because salps often form dense swarms and have high feeding rates, their feeding activities may significantly reduce the concentrations of small-sized organisms in the surrounding water.
  - Some salps are important predators on fish larvae.
  - Salps have an unusual **life cycle** (Figure ) in which sexual reproduction alternates with asexual budding. Each species of salp has two different forms: the asexual form is a **solitary** individual (1-30 cm long) that buds to produce a chain of up to several hundred individuals and as long as 15 m; each **aggregate** in the released chain is an hermaphrodite and will produce both sperm and a single egg. Self-fertilization does not usually occur because the egg and sperm ripen at different times. Following cross-fertilization, the single embryo grows within the parent and eventually breaks through the parental body wall to become a young, free-swimming, solitary individual which once again will continue the cycle with asexual budding.
• **Pyrosomes (from pyros, fire and soma, body)**

  - Pyrosoma, are bioluminescent and colonial organism which are closely related to salps.
  - They are cylindrical- or conical-shaped colonies made up of hundreds to thousands of individuals, known as zooids.
  - Colonies range in size from less than one centimeter to several metres in length.
  - Each individual in the colony has its intake siphons oriented outside, whereas its exit siphon empties into the central cavity.
Other Zooplankton: Snails and worms

Holoplanktonic snails
Holoplanktonic snails include the heteropods and pteropods (Mollusca, Gastropoda)

- **Pteropods (‘winged foot’)**
  - Pteropods swim by means of lateral projections (paired wings) from the foot which is divided into two flaps for swimming.
  - Pteropods may be shelled (thecosomate) or naked (gymnosomate).
  - Pteropods are sometimes quite abundant, and the shells of one group—the thecosomes sink to the bottom in great abundance and form sediments known as pteropod ooze.
  - Pteropods are all predatory, capturing prey and eating it with a rasp-like tongue (radula).

- **Heteropods**
  - Heteropods are small group of pelagic relatives of snails.
  - The foot modified into a single ventral fin (i.e. they swim upside down).
  - Heteropods are visual predators with well-developed eyes and a long proboscis containing a radula.
  - They feed on small crustaceans, other mollusks or gelatinous organisms, such as salps and doliolids.
• **Arrow Worms**

Phylum Chaetognatha

- Arrow worms have transparent, elongate and streamlined bodies, and most are less than 4 cm long, with one or two pairs of lateral fins.
- They often remain motionless in the water, but are capable of swift darting motions when in pursuit of prey.
- They swim by means of rapid contractions of longitudinal trunk muscles.
- Armed with grasping spines, the head is well adapted

![Arrow Worm](image)

• **Planktonic Polychaetes**

- A few families of polychaetes are holoplanktonic and have well-developed locomotory appendages (parapodia) and sense organs (e.g., the genus *Tomopteris*).

![Planktonic Polychaetes](image)

• **MEROPLANKTON**

- Meroplankton are temporary members of the zooplankton. They are organisms that live as plankton for only part of their life cycle.
- Meroplankton are the planktonic larvae of animals from a wide variety of habitats: rocky shores, subtidal communities such as kelp beds, and coral reefs, estuaries, and the deep ocean floor.
- While living as meroplankton these organisms feed on yolk sacs retained from the eggs they hatched from or on other plankton.
- These larvae often bear almost no resemblance to their adult forms and have entirely different lifestyles.
- Meroplankton are seasonally abundant, particularly in coastal waters.
- The larval phase may last only a few hours or a year or more.
- The larvae play a vital role in the dispersal phase of the life cycle.
Figure  Meroplanktonic larvae of benthic invertebrates, (a) snail veliger; (b) polychaete trochophore; (c) late larva of a polychaete; (d) bipinnaria of a starfish; (e) echinopluteus of a sea urchin; (f) barnacle nauplius; (g) barnacle cypris; (h) crab zoea; (i) crab megalopa.
**Crustacean meroplankton**
Crustaceans are by far the most abundant members of the zooplankton (including meroplankton) in both species and number of individuals. Common crustacean meroplankton include the larvae of:

- **Decapoda**: shrimps and crabs produce **zoëa** larvae (Fig. h); they turn into **megalopa** larvae (Fig. i) in crabs before settling to the sea floor
- **Cirripedia**: Sessile barnacles have free-swimming **nauplius** (Fig. f) stages, usually six, which are similar to the nauplii of copepods and other planktonic Crustacea, but with characteristic pointed projections on the anterior edges of the exoskeleton; these naupliar stages are succeeded by a **cypris** (Fig. g) which attaches to a substrate and metamorphoses to the adult.

**Non-crustacean meroplankton**
Common noncrustacean meroplankton include the larvae of starfish, sea urchins, snails, polychaete worms, and fish.

- **Echinodermata**: sea urchins, starfish and sea cucumber produce **pluteus** larvae (Fig. e) of different shapes, which turn into **brachiolaria** larvae (starfish); metamorphosis to adult is very complex
- **Mollusca**: clams and snails produce shelled **veliger** larvae (Fig. a); ciliated velum serves for locomotion and food collection
- **Polychaeta**: brittle worms and other worms produce **trochophora** larvae (Fig. b), mostly barrel-shaped with several bands of cilia
- **Pisces**: fish eggs and larvae referred to as ichthyoplankton; fish larvae retain part of the egg yolk in a sack below their body until mouth and stomach are fully developed

**Adaptations of planktonic larvae**

**Larval dispersal**
Regardless of its duration, the larval stage plays a critical role in the overall life cycle. **Dispersal** by means of planktonic larvae reduces overcrowding, allows colonization of new and potentially unexploited habitats, and promotes genetic exchange between populations. Other potential advantages conferred by having planktonic larvae are listed in Table 4, but there are considerable risks as well. Very few survive to settle in a favorable habitat and assume the adult form. Perhaps this is why many benthic species are so prolific.
Larval transport

Sometimes larval development takes place at a considerable distance from the adult habitat. The life cycles of fishes and invertebrates often exhibit movements between coastal, ocean and estuarine systems. The successful transition between larval and adult habitats requires **precise timing and, often, long-distance transport**. Because larvae cannot swim against most tidal currents, **behavioral responses** to advantageous tidal and wind-driven currents are keys to successful transport and settlement.

Larval selection of favorable habitat for settlement

For benthic invertebrates, the planktonic larval phase ends as the larvae settle and take up the adult lifestyle. Because most invertebrates have specific habitat requirements, the location of the final settlement is crucial for adult survival. A few decades ago, we assumed that larval settlement was largely a chance event where only those fortunate enough to be in the right spot at the right time survived. Although serendipity is indeed a factor, **many larvae have surprisingly sophisticated physical and chemical sensory capabilities employed solely for selecting a favorable habitat**. Often larvae approaching settlement will explore and evaluate several prospective substrates before selecting one. If no suitable substrate is found, some larvae can postpone the final metamorphosis to the adult form, thus giving a wider temporal window to finding a suitable spot.
Protist plankton

Protists are of major importance in the plankton, especially because they consume very small creatures, such as bacteria, that are largely unavailable to most other zooplankton. Protists are consumed by larger zooplankton and are therefore a major link between microbial forms and the rest of the planktonic food chain.

- Ciliates
  Phylum Ciliophora
  - Ubiquitous in the plankton and often very abundant.
  - They are feed on bacteria, phytoplankton and heterotrophic nanoflagellates
  - Some species may take up phytoplanktonic cells but retain the chloroplasts, which remain functional within the ciliate.
  - While most ciliates are naked forms, there is a group, the Tintinnids have vase-like external shells that are composed of protein or chitinous shell, the lorica (see Figure below). Because this substance is biodegradable, the shells are not present in sediments.

![Figure](image_url)

Despite their small size (about 20-640 µm), tintinnids are of considerable ecological significance as they are widely distributed in both open seas and coastal waters, where they feed primarily on nanoplanktonic diatoms and photosynthetic flagellates. In coastal waters, tintinnids may consume 4-60% of the phytoplankton production. In turn, they are prey for a wide variety of mesozooplankton.

- Foraminifera
  Phylum Foraminifera
  - They are relatives of amoeba, which are characterized by having a calcareous perforated shell, or test, that is usually composed of a series of chambers.
  - They are range in size from 30 µm to 1-2 mm.
  - Food, consisting of bacteria, phytoplankton or small zooplankton, is captured by specialized slender pseudopodia (called rhizopodia) that project through the pores of the test.
  - After death, the shells of these protozoans sink and accumulate in large quantities on the seafloor. In depths less than 2,000 m, they form deep-sea sediments known as foraminiferan ooze.
  - They are most abundant 40°N – 40°S
Radiolaria
- They are spherical, amoeboid protozoans with perforated silica capsule;
- they have branched pseudopodia (called axopodia) for food capture
- Most are omnivorous, feed on bacteria, small phyto- and zooplankton
- The size of individual organisms ranges from about 50 µm to as much as several millimeters in diameter
- The colonial forms can attain several centimeters.
- Radiolarians are contribute to silica ooze sediments called radiolarian ooze in some parts of the ocean in cold water and deep-sea.

Microbial loops
The microbial loop refers to the activities of marine bacteria and protozoa (heterotrophic flagellates and ciliates) in breaking down detritus or non-living particulate organic matter (POM) and dissolved organic material (DOM) derived from living cells, faecal pellets and dead and decomposing bodies. Energy and nutrients from dead organisms are returned to the main food web through the microbial loop. This is especially true for DOM which cannot be directly ingested and absorbed by larger organisms.

The bacteria convert organic matter to dissolved inorganic nutrients (DIN), such as nitrogen, phosphorus and potassium, which are then available for rapid uptake by phytoplankton. The bacteria themselves are consumed by protozoans (ciliates and nano-flagellates), which are in turn food sources for other zooplankton. The recycling of POM by the microbial loop also serves to reduce the sedimentation of faecal matter and detritus. This is particularly important in warm, low-nutrient
waters, where microbes rapidly and efficiently recycle materials and thus limit the sinking of large amounts of organic matter to the bottom.

Thus the microbial loop is of particular importance in increasing food chain efficiency through utilization of both the very smallest size fractions of particulate organic material (POM), as well as of the dissolved organic matter (DOM) which is usually measured as dissolved organic carbon (DOC).

In cold waters – and during the winter months in many temperate regions – microbial activity is suppressed. The effects are that most of the carbon reaches
higher trophic levels directly via the grazing activities of zooplankton, and a large fraction of the carbon fixed during photosynthesis sinks to the bottom where it is then used by benthic communities.

FACTORS AFFECTING ZOOPLANKTON DISTRIBUTION
Factors acting on many scales influence zooplankton distribution.

- **Water temperatures** primarily determine geographic ranges, a function of both latitude and major ocean currents.
- Within a given temperature range, **salinity** is probably the largest factor affecting distribution. Within each salinity division (freshwater, brackish water, seawater, and hypersaline), many species show preferences for specific habitats or hydrographic conditions.
- Differences in **depth, current velocity, wave energy, and turbidity** affect local distributions.
- Proximity of certain habitats such as salt marshes, oyster beds, and submerged vegetation also affects plankton distribution.
- The distribution of individual planktonic taxa change over time as **abiotic and biotic factors change**. These factors include the distribution of food, abundance of predators, and changes in temperature or salinity. Different larval or other life stages of a taxon can have different distributions within the same water body.

Vertical Zonation of Zooplankton

- **Epipelagic**: upper 200-300 m water column; high diversity, mostly small and transparent organisms; many herbivores
- **Mesopelagic** = 300 – 1000 m; larger than epipelagic relatives; large forms of gelatinous zooplankton (jellyfish, appendicularians) due to lack of wave action; some larger species (krill) partly herbivorous with nightly migration into epipelagic regimes; many species with black or red color and big eyes with maximum sensitivity to blue-green light (why?);
- **Oxygen Minimum Zone**: 400 – 800 m depth, accumulation of fecal material due to density gradient, attract high bacterial growth, which in turn attracts many bacterial and larger grazers; strong respiration reduces O₂ content from 4-6 mg l⁻¹ to < 2 mg l⁻¹
- **Bathypelagic**: 1000 – 3000 m depth, many dark red colored, smaller eyes
- **Abyssopelagic**: > 3000 m depth, low diversity and low abundance
- **Demersal or epibenthic**: live near or temporarily on the seafloor; mostly crustaceans (shrimp and mysids) and fish.