PLANKTON
1-Introduction

WHAT ARE PLANKTON?
The term plankton is taken from the Greek verb meaning “to wander” and refers to any small organisms (from microns to centimeters) living in the water and drifting at the mercy of currents – ranging from bacteria to jellyfish.

Or; Plankton are organisms whose powers of movement are insufficient to prevent them from being moved by water currents. They form the first few trophic levels of most ocean food chains.

Plankton are neither attached to the bottom (benthos) nor able to swim effectively against most currents (nekton).

Types of plankton

Bacterioplankton are planktonic bacteria and cyanobacteria. They are prokaryotic organisms that have simple cellular organization and are less than 2 μm long.

Phytoplankton are photosynthetic planktonic protists and plants, and usually consist of single-celled organisms or of chains of cells. They range in size from single cells about 2 μm long to chain cells of up to 2 mm long.

Zooplankton all heterotrophic plankton that feed on phytoplankton (herbivorous zooplankton) or other zooplankton (carnivorous zooplankton); size range from 2 μm (heterotrophic flagellates, protists) up to several meter (jellyfish)

Mixoplankton are photosynthetic protists, but also can ingest other plankton.

Meroplankton are zooplankton that are the larval stages of nonplanktonic creatures (benthos or nekton), i.e. they spend only part of their lifetime in the plankton. They include the planktonic larval stages of many benthic invertebrate groups and fish.

Holoplankton, are zooplankton that remain as zooplankton throughout their life cycles. They range in size from heterotrophic protists about 2 μm long to jellyfish about 1 m across.

Neuston are those organisms that associated with the water surface, i.e. those that inhabit the uppermost few to tens of millimetres of the surface water.

Pleuston are those species that live permanently at the sea surface and whose bodies project partly into the air above the sea surface e.g. Portuguese man-of-war.

Demersal zooplankton are those organisms that spend much of their time on or near the bottom but periodically swim upward into the water column, especially at night.
Classification of Planktonic organisms according to their size

The various size categories of plankton are as follows:

- **Ultraplankton or picoplankton** (0.2-2 μm), are mostly bacteria (called bacterioplankton). They require at least 400× magnification for detection and counting. Marine viruses are even smaller (less than 0.2 μm).
- **Nanoplankton** (2-20 μm), include small phytoplankton (mostly single-celled diatoms), flagellates (both photosynthetic and heterotrophic), small ciliates, radiolarians, coccolithophorids and others
- **Microplankton** (20-200 μm), include large phytoplankton (large single-celled or chain-forming diatoms, dinoflagellates), foraminiferans, ciliates, nauplii (early stages of crustaceans such as copepods and barnacles), and others
- **Mesoplankton** (0.2-20 mm), are very common and visible to the naked eye; they are diverse and include copepods, cladocerans, small salps, the larvae of many benthic organisms and fish, and others
- **Macroplankton** (2-20 cm), include large visible organisms such as krill, arrow worms, comb jellies and jellyfish
- **Megaplankton** (20-200 cm), include large floating organisms. They are represented by very large jellyfish, salps and their relatives.
- The term net phytoplankton refers to phytoplankton retained by a 20 μm mesh, primarily larger diatoms and dinoflagellates.

<table>
<thead>
<tr>
<th>PLANKTON</th>
<th>FEMTO-PLANKTON 0.02-0.02μm</th>
<th>PICO-PLANKTON 0.2-2μm</th>
<th>NANO-PLANKTON 2-20μm</th>
<th>MICRO-PLANKTON 20-200μm</th>
<th>MESO-PLANKTON 0.2-20 mm</th>
<th>MACRO-PLANKTON 2-20 cm</th>
<th>MEGA-PLANKTON 20-200 cm</th>
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<td>METAZOO-PLANKTON</td>
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**Fig. 1.1** Size spectrum of different taxonomic-trophic compartments of plankton including the size range of nekton.
Why study Plankton?
In short, we need to examine and monitor the plankton because:

- Some phytoplankton produce toxins that become concentrated in filter-feeding animals such as oysters, mussels and even fish.
- Phytoplankton may assimilate surplus nutrients, which may be grazed by zooplankton and productively pass them up the food chain to fish.
- The early life stages of mussels, oysters, prawns and fish all live in the plankton.
- Some species of phytoplankton or zooplankton can be indicator species of environmental health by, in effect, integrating the conditions of the past few days or weeks.

Collection methods
No single sampler is capable of capturing all zooplankton within its path. Zooplankton larger than 200 µm traditionally have been collected by towing relatively fine-mesh nets through the water column. Plankton nets vary in size, shape, and mesh size (Figure  ), but all are designed to capture drifting or relatively slow-moving animals that are retained by the mesh. The simplest nets are conical in shape, with the wide mouth opening attached to a metal ring and the narrow tapered end fastened to a collecting jar known as the **cod end**.

![Plankton nets placed overboard.](image)

![A towed Batfish plankton sampler which simultaneously estimates phytoplankton and zooplankton abundance while recording environmental parameters. F, fluorometer for detecting chlorophyll a; L, light sensor; OPC, optical zooplankton counter; PI, intake for zooplankton sampling; SB, stabilizer; STD, salinity-temperature-depth sensor; T, towing arm.](image)

Such a net will filter water and collect animals during an entire towing period. More sophisticated nets are equipped to be opened and closed at selected depth intervals.
All nets can be equipped with a flowmeter that estimates the total volume of water filtered during a tow; this permits a quantitative representation of the zooplankton collected. The newest towed samplers, such as the *Batfish* shown in Figure, simultaneously measure salinity, temperature, depth, and chlorophyll *a* concentration while counting and sizing zooplankton that pass through an optical sensor. Zooplankton smaller than 200 µm (nano- and microplankton) and phytoplankton cannot be satisfactorily sampled in nets; instead, a known volume of water is collected in sampling bottles or by pumps from defined depths and the smallest plankton are concentrated and removed by filtration, centrifuging, or settling and sedimentation. Both planktonic protozoans and phytoplankton can be counted in the concentrated water samples.

**Plankton Life**

**Life in liquid medium challenges**

Life in the plankton poses many challenges. Zooplankton live in a viscous liquid medium in which locomotion is difficult. There is no place to hide from drifting or swimming predators. Survival in the plankton requires specific adaptations to remain in the water column, to secure suitable food, and to avoid predators. Solutions to these challenges have evolved separately in different groups of zooplankton.

**Survival challenges**

For most planktonic organisms, whether phytoplankton, holozooplankton or merozooplankton, their life in the plankton is usually short. Phytoplankton live for only a few days or weeks, either dying when they are eaten, after they become infected by viruses, or when nutrients are insufficient to support their growth, in this last case they may either die or produce resting spores. While some zooplankton may live longer, up to well over a year in the case of many euphausiids and large copepods, their lives are often also ended abruptly by predation. For all holozooplankton the goal is to survive long enough to reproduce, and for the merozooplankton it is to survive the planktonic phase and find somewhere to settle on the seabed where they will live their adult life. To aid their survival, the zooplankton have therefore evolved several adaptations to sense their environment.

**Feeding**

While some benthic invertebrates release *lecithotrophic* larvae with sufficient yolk reserves to complete their planktonic phase without feeding, all of the permanent zooplankton and most of the temporary larval stages feed actively in the water column and are thus *planktrophic*. Most coastal zooplankton graze on *detritus*, these particles are usually less than 1 mm long. Their task is to collect or to concentrate the food. Most of these particle grazers are loosely termed *suspension feeders*. With the major exception of
crustaceans, cilia represent the tool of choice for most suspension feeders. Cilia create feeding currents to move water and food over a mucus-covered surface. As small particles become stuck, cilia move the mucus and trapped food to the mouth. Feeding using cilia and mucus is well suited to removing nanoplankton and other particles too small to be caught by crustacean setae. Lacking cilia, the crustacean grazers sweep their setae through the water and remove phytoplankton and detritus particles.

The active, mobile predators such as larger crustaceans, chaetognaths (arrow worms), and larval fishes, detect and attack individual prey. Medusae and ctenophores are more passive “ambush” or “entanglement” feeders but equally efficient predators. They drift or cruise slowly through the water as their trailing tentacles subdue and collect zooplankton.

**Locomotion**

By definition, plankton are swept to and fro by currents. However, it would be a mistake to think of them as passive drifters. Many are accomplished swimmers capable of rapid escape maneuvers and extensive vertical excursions. While overall swimming speeds seldom exceed 5 cm per second, these speeds are more impressive when we consider the animals’ sizes. For example, some ciliates and rotifers, though propelled by cilia, can attain speeds of more than 10 body lengths per second. The fastest copepods swim at more than 100 body lengths per second when in escape mode. By contrast, human Olympic swimmers reach only reach about 1 body length per second. These high relative speeds become even more remarkable when we consider that the viscosity of water has a far greater impact on motion as size decreases. Swimming resistance due to viscosity may be minimal for a fish but becomes the dominant form of resistance for smaller plankton of a millimeter or less in length. Some people suggest that for smaller plankton swimming might be like swimming in syrup. Zooplankton use widely varying mechanisms to move. Cilia, jointed appendages, or whole-body contractions generally accomplish swimming, but each group has its distinctive form of locomotion.

**Vertical Migrations**

Oceans are three-dimensional worlds. Waters at different depths differ in light level, temperature, salinity, oxygen availability, and concentrations of food and predators. Most zooplankton can actively control their vertical position through directed swimming or slight changes in buoyancy. Extensive vertical migrations of entire planktonic communities are common in the open ocean but are seldom seen in shallow coastal and estuarine areas where dramatic vertical excursions by individual species occur.

**Planktonic Surface area and volume**

All phytoplankton and many zooplankton are microscopic in size.

- Their small size result in a high surface area-to-volume ratio.
A high surface area-to-volume ratio favors the rapid exchange of gases by diffusion and creates a high frictional resistance, which means they sink slowly.

It also facilitates the rapid excretion of wastes across the body surface, light trapping, and nutrient absorption.

**Planktonic Cell density**

Planktonic organisms usually depend upon the surface waters for survival. Phytoplankton will die unless they are near a source of sunlight for photosynthesis. Zooplankton on the other hand, depend upon phytoplankton, or at least upon animals that consume phytoplankton. Zooplankton, therefore, also must remain in the surface waters.

A particle will remain suspended in water if it is less dense than seawater. Many planktonic organisms however are somewhat denser than seawater and will therefore sink in a quiet water column.

**Factors affecting cell density, and thus rate of sinking**

1. **Cell** size has a significant impact on the ability of phytoplankton cells to maintain their position at depths with adequate light and nutrients to sustain growth. In general, an increase in cell size results in an increase in sinking rate – with dead cells sinking at faster rates than live cells. Large phytoplankton cells (such as diatoms) are disadvantaged by being highly susceptible to sinking, and may require strong vertical mixing (for example, caused by upwelling or strong winds) to maintain their position in surface waters.

2. **Cell** density, and thus rate of sinking, is also affected by the composition of cells and the skeletons which consist of silica, calcium carbonate and cellulose. Silica-laden diatoms are particularly heavy.

3. **Cell** aging and nutritional state of phytoplankton cells are physiological conditions that affect cell density. Post-bloom nutrient-starved diatoms tend to sink significantly faster than nutrient-rich diatoms. This effect is frequently demonstrated in temperate and polar waters, where mass sinking of phytoplankton blooms occurs following nutrient exhaustion. A large proportion of bloom material may settle to the bottom as diatom flocs or aggregates (> 0.5 mm) composed of algal cells, zooplankton remains, faecal pellets and other forms of detritus. These highly visible settling flocs are commonly referred to as ‘marine snow’.
How do plankton keep near the surface or avoid sinking?

Plankton reduce their density relative to that of the surrounding water and avoid sinking to the bottom or to depths greater than a depth at which they can photosynthesize or survive by following one or more of the following mechanisms:

1. **By storing (accumulating) oils, fats, gases and other fluids of low density**
   - Many plankton have buoyancy aids. For example, phytoplankton, notably diatoms, and zooplankton such as copepods, fish eggs, and larvae, contain buoyant oil droplets which reduce their density and can also serve as food reserves.
   - Some blue-green bacteria and radiolaria have vacuole-like structures that contain low-density gases such as nitrogen or CO₂ respectively.

2. **By having flattened body shapes and appendages, spines, or other body projections that provide a high surface area: volume ratio and increase their frictional drag, thus reducing their settling velocity (i.e. make them sink more slowly).**
   - The bell-shaped jellyfish has flat bottom and tentacles combine to create a drag that slows sinking relative to a sphere of the same shape and bulk composition.
   - Some plankton are flattened. They sink slowly, moving back-and-forth in a “falling-leaf” pattern.
   - Chains of individuals can assume shapes that encourage sinking in a slow spiral or zigzag path.
   - Long projections and spines increase surface area and slow sinking - just like it is easier for humans to float on their back if we extend our arms and legs. They may also deter potential grazers or predators from consuming the individual.

3. **By reducing the total density of body fluids by means of replacing heavier ions with lighter ones**
   - Certain dinoflagellates, and various zooplankton replace dense magnesium, calcium, and sulfate ions with lower-density ammonium, sodium, and chloride.

4. **By accumulating ions of low specific gravity**
   - The dinoflagellate *Noctiluca*, for example, accumulates ions of low specific gravity, which reduces their density.
5. By having Flotation structures

- Portuguese man-of-war *Physalia* for example have a large gas-filled sac that acts as a float from which the rest of the colony is suspended.

6. By having the ability to swim

- Motile phytoplankters, like most dinoflagellates, may actively swim to compensate for sinking.
- Pteropods (sea butterfly) for example, has two lateral winglike projections, and the snails flap through the water.
- Jellyfish move in pulses, through rapid compressions of circular muscles, which compress the bell and force water backward.
- Crustaceans such as copepods use assorted appendages to push against the water to move forward.
- Arrow worms swim by undulation, as do many fish.

All these swimming methods are effective means of counteracting sinking. It is worth to mention however that swimming to stay afloat in the plankton is energetically expensive, so it is more easily following other mechanism in order to save more energy available to grow quickly.

7. By having small sizes

Cell size has a significant impact on the ability of phytoplankton cells to maintain their position at depths with adequate light and nutrients to sustain growth. In general, an increase in cell size results in an increase in sinking rate – with dead cells sinking at faster rates than live cells. Large phytoplankton cells (such as diatoms) are disadvantaged by being highly susceptible to sinking, and may require strong vertical mixing (for example, caused by upwelling or strong winds) to maintain their position in surface waters. Small size produce a high surface area-to-volume ratio which creates a high frictional resistance, which means they sink slowly.

8. By depending upon water turbulence which keeps organisms suspended in the water column.
Defense against Predation

Various planktonic predators feed on herbivorous zooplankton and on one another. The other major threat to zooplankton comes from planktivorous fishes. In fact, the most abundant fishes in coastal and nearshore waters (anchovies, sand lances, herrings, and silversides) are zooplanktivores. Most are selective visual feeders on zooplankton. Despite the absence of hiding places, zooplankton reduce predation in a variety of ways.

- The development of body spines and armature in many phytoplankton and zooplankton is probably an adaptation to increase the difficulty of capture and ingestion. Common diatoms, such as those of the genus Chaetoceros, have large projecting spines that increase the effective body size (and may also aid in flotation). Many planktonic crustaceans are similarly armed with sometimes elaborate spines. The presence of spines may place the prey out of the size range of predators or may make the prey difficult to handle and seize.

- Several animals also possess sensory bristles and antennae that are both mechanosensory - able to detect vibrations - and chemosensory - able to detect smells.

- **Transparency:** Many planktonic organisms are nearly transparent. Jellyfish, comb jellies, arrow worms, and many other groups are difficult to spot in turbulent water.

- **Bioluminescence** is a common feature of many planktonic phytoplankton and zooplankton species. Dinoflagellates commonly luminesce. Calanoid copepods avoid luminescent dinoflagellates and favor grazing on nonluminescent forms. As copepods feed or as they swim among swarms of luminescent dinoflagellates, the resultant microturbulence induces flashes of light. These flashes may endanger the copepods by making them visible to fish predators.

- **Production of distasteful or toxic chemicals:** Many phytoplankton species, notably the cyanobacteria and dinoflagellates, are toxic to grazers. This toxicity undoubtedly influences the distribution of species of phytoplankton in grazed systems. Species of the chrysophyte alga *Phaeocystis* produce large amounts of acrylic acid, an effective antibiotic capable of sterilizing the guts of consumers. It may inhibit microbially mediated digestion and could induce future avoidance of the alga. Bioluminescence in some dinoflagellates may serve as a “warning” system that has coevolved with the production of toxins and the presence of grazers.

- Some zooplankton have well-developed predator-detection capability and escape responses. Some zooplankton have some form of photoreceptor, varying from simple ones that just detect light- these may help them to avoid predation by detecting the shadow cast by a predator, for example - to complex eyes, which, in the case of some predatory species, are used to locate their prey.

- Last, some zooplankton have so little nutrient value that most selective predators ignore them.
Table 3. Summary of adaptations to deter predators

<table>
<thead>
<tr>
<th>Antipredator tactics</th>
<th>Representative taxa</th>
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<tbody>
<tr>
<td>Transparency</td>
<td>Arrow worms, hydromedusae, comb jellies, fish eggs and larvae</td>
</tr>
<tr>
<td>Protective spines</td>
<td>Crab zoeae, polychaete bristles</td>
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<tr>
<td>Detection and escape. Detection of minute pressure waves followed by evasive maneuvers</td>
<td>Copepods and some fish larvae</td>
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<tr>
<td>Distasteful or toxic</td>
<td>Some crab larvae</td>
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<tr>
<td>Diel swimming rhythms, usually with nocturnal excursions into the plankton</td>
<td>Late shrimp and crab larvae, mysids, gamma-ridean amphipods, estuarine calanoid copepods</td>
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<tr>
<td>Synchronized mass spawning; timing of larval release; limited planktonic phase</td>
<td>Many bivalves, echinoderms, some polychaetes; many crabs and shrimps; sea squirts</td>
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<tr>
<td>Bioluminescence; sudden flashes may startle predators, but this hypothesis needs confirmation</td>
<td>Ctenophores and some dinoflagellates</td>
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Note: For specific information, see the “Suggested Readings” at the end of this chapter, including Ohman (1988), for an overview.

LIFE CYCLES OF ZOOPLANKTON

In general, the smallest plankton have the shortest life cycles: bacteria and flagellates generally multiply within a few hours to one day. Most mesozooplankton have life cycles of a few weeks, while the macro- and megaplankton usually have life cycles spanning many months and longer. Many zooplankton spend their entire life cycle as part of the plankton (for example, copepods, salps and some jellyfish) and are called holoplankton. The meroplankton, which are seasonally abundant, especially in coastal waters, are only planktonic for part of their lives (usually at the larval stage). Most bear little, if any, resemblance to the adult form and drift for days to weeks before they metamorphose and assume benthic or nekton lifestyles. Examples of meroplankton include the larvae of sea urchins, starfish, crustaceans, marine worms and most fish. Planktonic and sessile life stages of some common zooplankton types are described below.

The general copepod life cycle includes six nauplius stages (larvae) and five copepodid stages (juveniles) prior to becoming an adult. Each stage is separated by a moult and, as the stages progress, the trunk of the copepod develops segmentation. Sexes are separate, sperm is transferred in a spermatophore from the male to the female, and eggs are either enclosed in a sac until ready to hatch or released as they are produced. Development times from egg to adult are typically in the order of 2 to 6 weeks, and are significantly affected by temperature and food availability. The life-span of adults may be from one to several months.
Barnacles also have free-swimming nauplius stages, followed by a carapace-covered cyprid stage after the final naupliar moult. Cyprid larvae are attracted to settle on hard substrates by the presence of other barnacles, ensuring settlement in areas suitable for barnacle survival and for obtaining future mates. After settling, the cyprid releases a substance to permanently cement itself to the substrate. Calcareous plates then grow and surround the body. The appendages face upwards to form cirri which sweep food particles into the organism. The adults are hermaphroditic (each with both male and female parts) and reproduce sexually by cross fertilisation. The adult broods the fertilized eggs within the shell until they develop into nauplius larvae. Over 10000 larvae may be released by a single adult.

Life cycles of jellyfish are complex, with generally two adult morphologies: polyp and medusa (typical jellyfish form). The sexes are separate and mature adult medusae release eggs and sperm, which, upon fertilization, form free-swimming, hair-covered larvae known as planulae. After a few days to weeks, the planulae settle on hard substrates and metamorphose into tiny sessile polyps (which look like upside-down jellyfish), which clone themselves and bud (strobilate). Juvenile jellyfish (ephyrae) peel off from the stack, float into the plankton as young jellies and grow into adult medusae. This transformation can take a few weeks up to a few years, depending on the species of jellyfish.