CHAPTER 16
THE OCEAN DEPTHS

***G-SLO 7**. The student will be able to list the unique physical and chemical characteristics influencing communities of ocean depths, explain the outstanding adaptations of organisms occupying the deep-ocean water bodies, and describe the different benthic communities occupying the great ocean depths.*

The student will be able to…

- **SLO 7.1** … to list the most important physical and chemical characteristics influencing communities of the ocean depths.
- **SLO 7.2** … to outline the most outstanding biological adaptations of organisms occupying the great ocean depths.
- **SLO 7.3** … compare and contrast between animals living in the epipelagic, mesopelagic, and abyssalpelagic zones.
- **SLO 7.4** … compare and contrast the organisms associated to the deep-sea benthos with particular attention to the communities occupying the hydrothermal vent.

- Chapter 16 examines life in the ocean depths below the epipelagic zone i.e. the mesopelagic and the deep sea (bathypelagic; abyssopelagic and hadopelagic). These depths comprise the largest but least known environment on earth.

Division (zonation) of the waters below the epipelagic zone:

- **Deep-sea** – part of the marine environment which lies below the level of effective light penetration for phytoplankton photosynthesis ("photic zone") in the open ocean and deeper than the depth of the continental shelves (>200m) [i.e. below the epipelagic zone]
  - The upper part of the "deep-sea" zone is a "transitional zone" that receives some light (**disphotic zone**) – this corresponds to the **mesopelagic zone**
  - The entire area below it is permanently dark and is known as the "aphotic zone". (it includes -- bathypelagic; abyssopelagic; hadalpelagic)
- The deep-sea realm can be divided into 2 primary areas:
  - Benthic zone
    - Bathyal; Abyssal; Hadal (ultra-abyssal)
  - Pelagic zone
    - Mesopelagic (disphotic/twilight zone) (200-1000m)
      - Inhabited by many species of animals with well-developed eyes and a variety of light organs (bioluminescence); the dominant fishes are silvery black; the crustaceans are usually red
    - Bathypelagic (1000-4000 m) & Abyssalpelagic (4000 – 6000m)
      - boundaries between both zones are uncertain; low number of species; individual organisms then to be white or colorless with reduced eyes and few biolumincescent organs
    - Hadalpelagic (6000m+)
      - The trenches zone; do not know much about them to set them off from the other zones

- Life in the mesopelagic and deep sea:
  - All share an important feature: the lack of food production by photosynthesis (no photoautotrophs). Consequently, the amount of food available gets lower the further away from the surface zone. In turn, life is equally reduced compared to life in other marine communities.

SAMPLING THE DEEP SEA
(pass – for your information only – and to place in a "perspective context")

- Various means are used – dredges; nets of different kinds… **(Fig. 16.7, p.366)**
- Major issue with the amount of cable needed to let out to sample deep zones – and the time it takes to set the sampling gear out and pull it in
- Major issue regarding – quantifying samples (most of the data is of qualitative nature)
- Major "pressure issue" – because of the large pressure differences – organisms are in bad conditions once they have reached the surface (only dead animals – cannot withstand the differences in pressure)
- Since the 1970s – the use of remote cameras **(Fig. 16.23, p.375)** and man submersibles has permitted to explore better the deep-sea zones
- But still little is known about these depth – less than 1% of this realm has been explored (we know more about the surface of the moon that the great ocean depths)

1. THE TWILIGHT WORLD

- The mesopelagic zone lies just below the well-lit epipelagic. It extends from about 200 m to about 1,000 m deep. It is a world of twilight. In this world of "dim light", photosynthesis is not possible; thus, there is no "primary productivity" at least from "photoautotrophs"
- This is the zone where the main thermocline occurs, so organisms that move up and down in the water column encounter large changes in temperature. Changes in pressure must also be tolerated as well

1.1 The Animals of the Mesopelagic

- The mesopelagic supports rich and varied community of animals, which are often called **midwater** animals.
- In the epipelagic, the primary production is abundant and phytoplankton and zooplankton abound
  - Due to this, many species that reside in the mesopelagic take part in vertical migrations
  - Days are spent in the mesopelagic and nights are spent feeding in the epipelagic

1.1.1 Zooplankton and other animal groups of the mesopelagic

- The dominant zooplankton groups are generally the **Krill** and **copepods**. Several different kinds of shrimps are relatively more common in the mesopelagic than in the epipelagic **(Fig. 16.2, p.363)**
- Krill and mesopelagic shrimps have a common adaptation of midwater animals: **photophores** or **light organs**, which are specialized structures that produce light called **bioluminescence** ("living light")
- Ostracods **(Fig. 16.3, p.365)** can be abundant in the mesopelagic.
- **Arrow worms** (or **chaetognaths**) are important midwater predators.
- Jellyfishes, siphonophores, comb jellies, larvaceans, and pteropods are also common.
- **Squids (Fig. 16.4, p.365)** are prominent members of the midwater community.
  - Mesopelagic squid usually have photophores, typically arranged in a different pattern in each species.
  - Other cephalopods equally include various octopus and even the chambered nautilus.

1.1.2 Midwater Fishes

- Nearly all mesopelagic fishes are quite small, about 2 to 10 cm long.
- Bristlemouths and lanternfish **(Fig. 16.6, p.366)** are by far the most abundant fishes in the mesopelagic. These two groups may account for 90% or more of the fishes collected by midwater trawl.
- Other groups include the hatchetfishes, viperfishes, dragonfishes, sabertooth fishes… Many have photophores, usually in rows on the ventral surface. Most are less than 30 cm but there are exceptions.

1.2 Adaptations of Midwater Animals

- Species from the same depth often have very similar characteristics even though they are unrelated.

1.2.1 Feeding and Food Webs

- Only 20% of surface primary production sinks to the mesopelagic mainly in the form of Particulate Organic Matter (POM). This means that the mesopelagic is chronically short of food, which is why there are fewer organisms in the mesopelagic than in the epipelagic.
- Many of the characteristics of midwater animals are directly related to the lack of food in the mesopelagic.
  - *Small size* of mesopelagic fishes (less energy required).
  - *Large mouths* with *long sharp teeth curved towards the throat* and *large "hinged", extensible jaws* – this allows them to feed on most any prey (even if the prey is larger than they are!) i.e. they have unspecialized diets and eat about anything that can fit into their mouths. **(Fig. 16.10, p.367)**

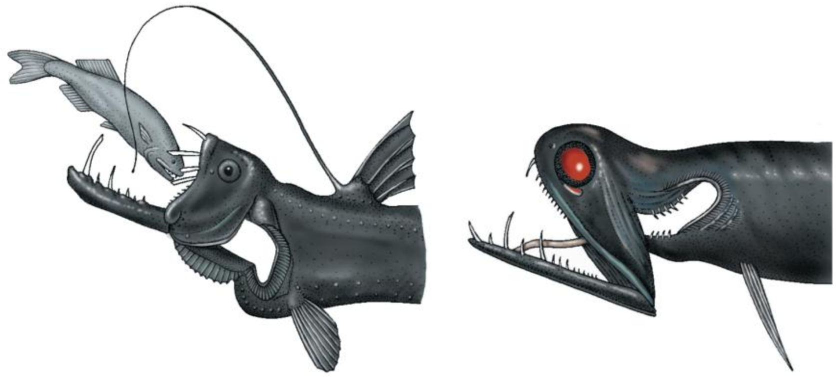

Fig. 16.10 (p.367) – (a) The viperfish (*Chauliodus*) has hinged jaws that can accommodate large prey. (b) The rattrap fish (*Malacosteus*) has a similar jaw arrangement.

- They can be divided into two major groups: the non-migrating fishes and the vertical migrating fish.

Non-migratory group:

- Most of the non-migrating fish are *sit-and-wait predators* that lurk in the dim light, gulping down anything that comes within range. With food hard to come by, these animals are adapted to conserve energy.
  - Tend to have soft, weak bones and flabby, watery muscles. They also have lost defensive structures like spines and scales which permit to reduce weight. These adaptations help to make them neutrally buoyant and require less energy.
  - Many of these fish lack a swim bladder as adjusting the pressure in the swim bladder takes precious energy.
  - Since they do not swim much, they have little need for streamlining that is so characteristic of epipelagic fishes.

1.2.2 Vertical Migration and the Deep Scattering Layer

- On the other hand, some midwater animals fall into the group of those that migrate to the surface at night rather than being non-migratory and staying in the mesopelagic (as described above).

The midwater animals that migrate to the surface at night:

- Many mesopelagic organisms make **vertical migrations**. They swim up at night to feed in the rich surface layers and descend during the day to depths of several hundred meters or more.
- Vertically migrating fishes differ in several important ways from those that stay in the mesopelagic **(Fig. 16.9, p.367)**
  - Well-developed muscles and bones are needed to make the daily swim up and down the water column. These structures are heavy, so these fishes have retained the swim bladder for buoyancy.
  - As they move up and down, they experience dramatic changes in pressure. Many, have a swim bladder filled with fat instead of gas (fat does not compress like gas), making it much easier for the fishes to regulate their buoyancy.
  - They show wide temperature tolerances to be able to move up and down across the thermocline.

Migrating Vs. Non Migrating Fish of the Mesopelagic

- To the right is a comparison of fish that migrate versus those that do not.

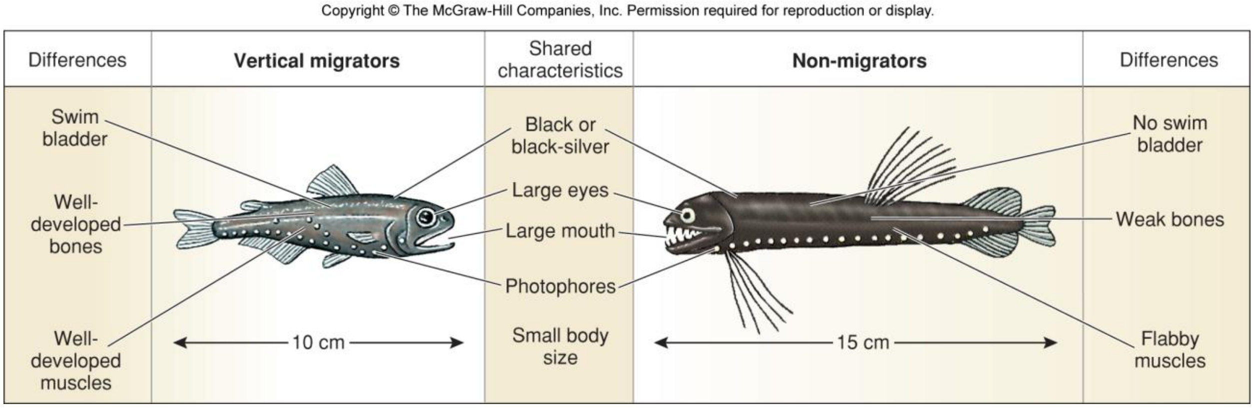

Fig. 16.9 (p.367) – Some adaptations of typical mesopelagic fishes, including some differences between vertical migrators like lanternfishes (left) and non-migrating dragonfishes (right).

Deep scattering layer (DSL)

- The deep scattering layer (DSL) is a sound-reflecting layer made up of vertically migrating midwater animals. Lanternfishes, krill, shrimps, copepods, jellyfishes, and squids are the dominant organisms of the DSL.
  - Vertical migration by mesopelagic animals was discovered during World War II, when sonar come into use.

- Vertical migration greatly increases the food supply in the mesopelagic. Many non-migratory midwater predators feed heavily on vertically migrating species.

1.2.3 Sense Organs--EYES

- Many midwater animals have evolved large, light-sensitive eyes that provide good vision in dim light.
- *Tubular eyes*
  - A complex visual system that is almost like having two pairs of eyes. The eye is a short black or silver cylinder topped with a spherical, transparent lens. This gives the animals (fish) two main visual fields corresponding to two parts of the retina. **(Fig. 16.13, p.369)**
    - Tend to give the animal wide binocular vision – permitting the fish to see to the side and below.
- *Among the invertebrates:*
  - In some krill, they have **bilobed eyes**. **(Fig. 16.14 & 16.12c, p.369)**

1.2.4 Coloration and Body Shape

- Like their epipelagic counterparts, mesopelagic predators rely heavily on vision.
- Like fish in the epipelagic, these fish have **countershading** or **transparency**, and reduction of silhouette to escape notice from prey or predators.
- Transparency is particularly common in the shallower and better-lit parts of the mesopelagic (Copepods; jellyfishes, shrimps, bristlemouths…)
- Deeper in the mesopelagic, fishes tend to be more silvery.
- In the deepest, darkest part, black or red dominate.
- Many crustaceans are often red, orange, or purple in the darkest zones. Red light does not penetrate to mesopelagic depths, however, the red pigment absorbs the blue light that does reach such depths, so the organism appear dark against the dark background of the surrounding water.
- To reduce their silhouettes, some mesopelagic fishes, like the hatchetfishes, have laterally compressed bodies. This reduces the size of the body outline whether the animal is viewed from above or below.

1.2.5 Bioluminescence

- **Bioluminescence** – is the chemical production of light by living organisms
- Bioluminescence is a widespread phenomenon in the sea
  - Dinoflagellates – produce "phosphorescent seas" (Ex: *Noctilica*)
- But in the mesopelagic and the upper bathypelagic zones, bioluminescence is the most widespread; up to 90% of the organisms have the ability to produce light
- **Photophores** – the light producing organs causing bioluminescence
  - Photophores are particularly abundant in fishes and squids but can equally be present in other invertebrates.

Functions of bioluminescence:

- Serves different functions in different animals (several alternative hypothesis have been suggested)
- Most are used primarily as a means of food capture or defense against predators

  Defense mechanism ---
  - In mesopelagic zones, many fish and squids have photophores concentrated ventrally; the dim light produced by photophores is similar to the light down-welling from above; thus a predator looking up at them cannot see their silhouette **(Fig. 16.15, p.370).** This adaptation, which functions in a similar manner to countershading, is called **counterillumination**.
  - Photophores may also be used to produce a "*blinding*" flash of light, which momentarily startles a potential predator and allows the prey to dart away.

  To capture prey --
  - Photophores might also be employed as **lures** to attract prey within range of the predator; for example, the light organ (esca) on the modified dorsal fin (illicium) of the anglerfish; the lures of other midwater fishes as well act in a similar manner **(Fig. 16.19, p.373)**
  - Some have light organs (photophores) around their eyes that may help them see and pick out prey.

    - Photophores under the eyes of a few species of midwater fishes produce red light (instead of the usual deep blue color). The red light is invisible to most other midwater organisms, but these fishes can see it and probably use it to detect “red” preys.

Used for recognition ---

- Particular patterns of distribution of photophores over the body of the animal that is visible at a distance – can permit organisms to recognize their own species; this is an important adaptation in communicating and finding mates. **(Fig. 4.33, p.165)** – this is commonly observes in fish and squids.

1.2.6 The Oxygen Minimum Zone

- Surface waters are rich in oxygen, because oxygen both enters from the atmosphere and is released by photosynthesis. In the mesopelagic zone neither the atmosphere nor photosynthesis can contribute oxygen to the water. The oxygen supply drops to a minimum at a fairly-well defined layer at around 500+ m depth. This is known as the **oxygen minimum layer (OML)**. This drop is linked to the **high bacterial activity** in decomposing the dead organic matter (POM). The bacteria contribute largely to deplete the oxygen supply at this level. Also contributing to the respiration is the biomass of mesopelagic organisms concentrated in this layer. **(Fig. 16.18, p.372)**
    - This layer usually corresponds to the “pycnocline zone”.

    - **Oxygen Minimum Zone (OMZ) –** A layer of water at a depth of approximately 500 m where oxygen is depleted.

- Animals that live in the OMZ have adapted to survive in low oxygen levels.
    - These animals usually have large, well-developed gills to help extract what little oxygen there is.
    - They also tend to be relatively inactive, which lowers their oxygen consumption.
    - Many also have complex biochemical adaptations, like **hemoglobin** that functions well at low oxygen concentrations.

- *Below the oxygen minimum zone (corresponding to the pycnocline zone):*
    - The oxygen supply is constantly replenished from the currents of the **thermohaline circulation** (the great ocean conveyer belt system).
    - Since that water no longer gains oxygen after sinking, the reason these deep masses are not depleted of oxygen by the respiration of deep-water organisms is that the **density** of such organisms is so low and they have such low metabolic rates that, together, the two factors are insufficient to deplete the oxygen supply.

2. THE WORLD OF PERPETUAL DARKNESS

- Conditions in the Bathypelagic (1,000-4,000m), Abyssopelagic (4,000-6,000m), and Hadopelagic (6,000m to the bottom of trenches). The deep sea also includes the deep-sea floor.
    - **Uniformly dark**
        - Absence of light means that the organisms have to rely on “senses other than vision” to find food and mates and to maintain various interspecific and intraspecific associations
        - Absence of light – can have a “selective effect” on the locomotory habits of the animals and on their propulsive systems (reduce the intensity of predators-prey interactions, hence, more “sluggish locomotory habit..)
    - **Uniformly cold** (isothermal typically 1° to 4°C) and homogenous – below the pycnocline/thermocline
        - There are no “seasonal changes” or “annual changes” in the temperature
        - Two areas where rapid temperature changes occur
            - Transitional zone between the surface water and the deep water (pycnoclin/thermocline zone) – this is within the “mesopelagic zone”
            - Transitional zone between the deep-sea floor and the hot-water flows at the hydrothermal vents (temperatures can go from 400^{o}C down to 2-4^{o}C within a short distance)
    - **Uniform salinity** (constant throughout the water depth)
    - **Water chemistry is also relatively consistent**

Characteristics of organisms of the Bathy-, Abysso- and Hadopelagic

- No countershading/counterillumination is needed as no light is present
    - Bioluminescence becomes less common in the deeper parts of the deep sea.
- Many animals, especially zooplankton, are a drab gray or off-white. Deep-sea fishes are generally black. Shrimps are often bright red, which in the deep sea has the same effect as being black. A few deep-sea fishes are also red.

- Bioluminescence is also present in the upper portions of the deep sea; however, the occurrence of this decreases with increasing depth.
    - Bioluminescence is thought to be used for courtship, communication or prey attraction. It is not used for counter illumination, since there is an absence of light at these depths to create silhouettes.
- Unlike the organisms in the mesopelagic, the photophores are normally located near or on the head as opposed to on the ventral side. (used for prey attraction, communication, and courtship)

- The large, light-sensitive eyes of mesopelagic animals are not needed in the aphotic zones. Below 2000m, eyes are small, degenerate, or lost. (eyes are only used to detect bioluminescence)

2.1 The Lack of Food

- Most of the communities beneath the photic zone depend for food on organic material produced in the surface layers of the ocean.
    - They face a continual shortage of food. Only about 5% of the food produced in the photic zone makes it to the deep sea.
- Because of a **paucity** of food supply trickling from above (marine snow), pelagic life forms become scarcer at greater depths:
    - There are typically 5 or 10 times fewer organisms at 500 m, than there are at the surface, and perhaps 10 times fewer again at 4,000 m.
    - The density of deep-sea animals is relatively low and the size of most of them small (generally 50 cm or less)
- Fish in this area are similar to those in the mesopelagic in lack of swim bladders and flabby, watery muscles and light, weak skeletons.
- They are sedentary, and have poorly developed respiratory, circulatory, and nervous systems.
- The mouth is also large with long, pointed teeth. **(Fig. 16.19, p.373)**
- To go along with their large mouths, many species have stomachs that can expand to accommodate the prey once it has been engulfed.
- **Fig. 16.21 (p.374)** shows pictures of some deep-sea fished and their approximate maximum length.

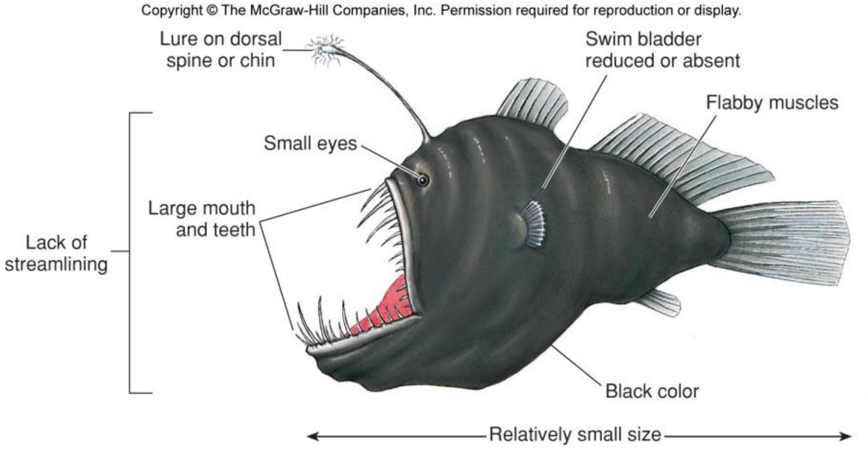

Fig. 16.19 (p.373) – Some typical characteristics of deep-sea pelagic fishes.

<u>Example of a Deep Sea Fish</u>

- The angler fish **(Fig. 16.19, p.373)** is one of the more interesting fish of the deep sea
- Anglerfish possess a "lure" on the head that contains symbiotic bioluminescent bacteria to attract prey

2.2 Finding mates in the Deep Sea

- Finding a mate can be difficult in such a vast, sparsely populated world.
- Many deep-sea fishes have solved the problem by becoming **hermaphrodites**.
    - This strategy ensures that reproduction can occur if encounters occur between members of the same species:
        - *Bioluminescence,* may send a signal that draws other members of the same species. Individuals may be able to recognize potential mates by the pattern of light.
        - *Chemical attraction/cues* can be important as well.
            - In anglerfishes, the females release a special chemical (**pheromones**) that the male can detect and follow.
- Some anglerfishes have evolved an extreme solution to the problem of finding mates:

  - When a male locates a female, who is much larger, he bites into her side, where he remains attached for the rest of his life (ectoparasitism). The female ends up nourishing the male. In return, the male is always available to fertilize the female's eggs.

2.3 Living under Pressure

- The pressure augments 1 atmosphere/10 m
  - Most of the deep sea is under pressures between 200 to 600 atmosphere (2000 to 6000m)
- Biochemical adaptations are significant in establishing depth distributional pattern among species
- Both proteins and biological membranes are strongly affected by pressure
  - Ex: deep-sea organisms, have enzymes that are much more resistant to the effects of pressure
- Under high pressure – calcium tends to dissolve; thus much harder for organisms to secrete hard parts such as shells
- The absence of a functional swim bladder in most deep-sea fishes, is probably due to the high energetic cost of filling the bladder with gas under extreme pressure.

3. THE DEEP-OCEAN FLOOR

Benthic organisms:

- The biological communities of the deep-sea floor are very different from pelagic communities because of one key factor: **the presence of the bottom**.
- One benefit of the benthos is that food that falls from above can become trapped on the bottom
  - This allows these organisms to have a greater chance at finding food.
  - Food particles that reach the bottom tend to be those that sink fairly rapidly. Fecal pellets (primarily from copepods), for example, are an important source of organic matter for the deep-sea benthos. Other sources are "moults" (the hared parts of the plankton, including dead intact small organisms), and, in particular, amorphous aggregates (termed "marine snow").

3.1 Feeding in the Deep-Sea Benthos

- Food shortage is critical on the floor of the deep sea. Very little of the surface production makes it all the way to the bottom. Only about 1 to 3% of the surface net primary production reaches the abyssal seabed. Therefore, food supply is the major limiting factor for deep-sea organisms and is the main reason there is a comparatively low abundance and biomass of animals on the deep-ocean floor.
- The deep sea ocean is composed of soft ooze (fine, muddy sediment).
  - Decomposing bacteria can be found in the deep sea sediments, but they decompose at a much slower rate than bacteria at the surface (as much as 1000 times slower)
    - This is likely due to the extreme pressure present in the deep sea
- A wide variety of **meiofauna** also live here. They graze on bacteria and absorb dissolved organic matter.
- Due to the bacteria and meiofauna, **deposit feeding** organisms are common both as infauna and epifauna. (There are few suspension feeders.)
- The main groups of large, mobile organisms are echinoderms, decapod crustaceans, and fish, many of which show remarkable adaptations to deep-sea life.
- The bottom dwelling fishes and crustaceans tend to be "scavengers", adapted for cruising along the bottom in search of the occasional meal.
  - Numerous "scavengers" will quickly aggregate if a "**baitfall**" (large food falls – whole bodies of dead animals and large fractions of plants) reaches the bottom. These bottom scavengers tend to be larger on average than deep-sea pelagic fishes, relatively muscular, and active, unlike bathypelagic fishes. **(Fig. 16.27, p.377)**. They seem to be adapted for cruising along the bottom in search of large bait. Their olfaction is highly developed. Thus, they likely rely a lot on their sense of smell.
- Predators in the deep-sea benthos are fairly rare.
  - <u>Tripod fishes</u> are an interesting group of deep-sea benthic predators. Nearly blind, these fishes sit on the bottom on their elongated fins, facing into the current and snapping up passing plankton. **(Fig. 16.25, p.376)**
- There is a trend for large sizes in some deep-sea organisms. This is known as **deep sea gigantism**. This trend is also apparent in polar seas, suggesting this phenomenon may be a function of "cold temperature" rather than depth.

3.2 The Nature of Life in the Deep Sea Benthos

- Not only do organisms tend to grow larger but they also tend to grow slow (probably because of the lack of food) and have an exceptionally long life
  - They tend to reproduce late in life and have few, large well developed eggs, with enough yolk to see the larva through its early stages without eating (indication of a more direct or abbreviated development).

- Perhaps the low temperature and high pressure slow down the processes of life in the deep sea.

3.3 Microbes in the Deep Sea

- Bacteria, archaea, and viruses play many important roles in deep-sea benthic ecosystems that we are only beginning to understand.

4. HOT SPRINGS, COLD SEEPS, AND DEAD BODIES

Hydrothermal Vent Communities

- **Hydrothermal vents** – A deep-sea hot spring where heated seawater forces its way up through the crust.
- Discovered in 1977, deep-sea hydrothermal vents harbor rich communities (tube worms; mussels, crabs, shrimps, fish…). The primary production that supports these communities comes from **microbial chemosynthesis**, not photosynthesis **(Chemoautotrophic bacteria)**
- These vents contain large amounts of hydrogen sulfide that serve as the energy source for these bacteria.
- These bacteria are the first link in the food chain in this unique community.
- Not only can they utilize this normally toxin substance, but they can withstand temperatures over 120°C, the highest temperature at which life is known to occur.
- Water near the vents contains so many microbes that they cloud the water.
- These “black smoker” vents and the cooler “white smokers” support a **WIDE** variety of organisms besides bacteria such as fish, shrimp, tube worms, clams, crabs, snails, barnacles, sponges, corals, etc.
- Interesting, one group of these organisms – the tube worm (*Riftia*)– actually harbors the chemoautotrophic bacteria in their body to support their metabolic needs. Other groups of organisms, such as large clams (*Clyptogena*), equally contain symbiotic bacteria, though they can filter-feed as well.
- These vents may come and go as geologic activity in any given area may change.
- For as long as they last, the vents support a level of life not seen elsewhere in the deep sea.

Cold seeps:

- In 1990, scientists have discovered another community oasis that depends on bacterial chemosynthesis as energy supply. These are the **Cold Seeps**.
- **Cold seeps** are places, mostly along continental margins or in sediment-rich basins like the Gulf of Mexico, where **hydrogen sulfide** and **methane** produced by the decay of organic matter seep out from the sea floor.
- Primary production by chemosynthetic prokaryotes that can use one or the other of these energy-rich molecules supports communities that are similar in many ways to those at hydrothermal vents, though the individual species are mostly different.

Deep-sea “graves”:

- Occasional baitfalls like dead whales are an important source of food for deep-sea scavengers. When the scavengers are through, the decomposing remains produce hydrogen sulfide and methane, supporting a community similar to those at vents and seeps.