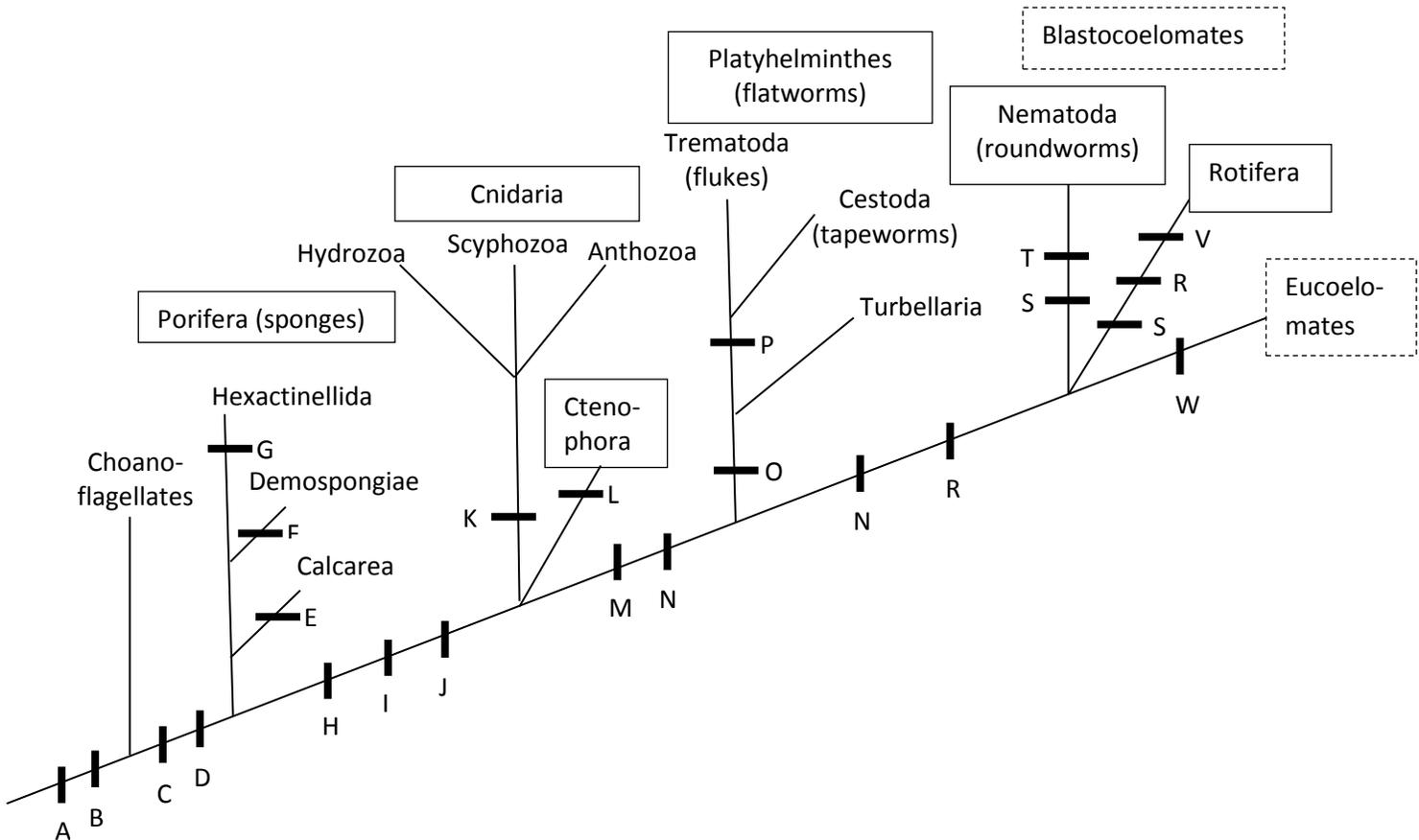


Question 1

Phylogeny of selected taxa showing homologies among sister groups



Key to homologies:

- | | |
|--------------------------------|------------------------------|
| A = Heterotrophy | M = Mesoderm (triploblasty) |
| B = Motility | N = Bilateral symmetry |
| C = Multicellularity | O = Flat form |
| D = Aquiferous body system | P = Tegument |
| E = Calcium carbonate spicules | Q = Complete digestive tract |
| F = Spongin network | R = Coelom |
| G = Silicon spicules | S = Blastocoelomate |
| H = True tissue | T = Cuticle |
| I = Diploblasty | U = Corona |
| J = Radial symmetry | V = Mastax |
| K = Cnidocytes | W = Eucoelomate |
| L = Ctenes (combs) | |

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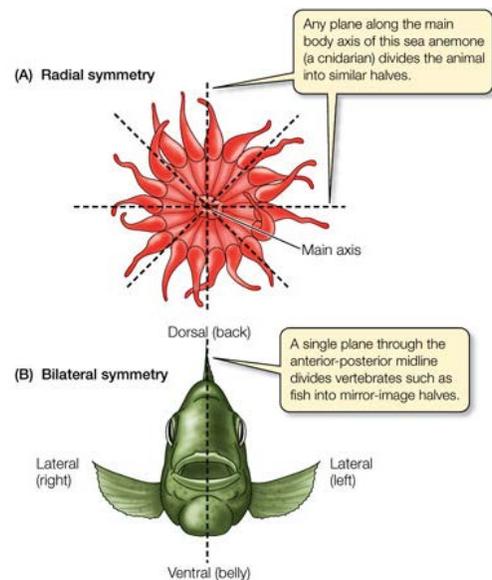
Figure 1 shows homologies, or similarities based on descent from a common ancestor (Lab Manual, Lab 1), for several selected taxa we have studied so far. Some of the taxa asked for are on the level of phyla (ex: Cnidaria, Ctenophora), some are on the level of class (ex: Trematoda, Cestoda, Turbellaria), and some are requested by their common name (ex: sponges). In some cases, I have indicated both the formal phylum or class name as well as the common name. Phyla are indicated by a solid box. General characteristics are indicated by a dashed box.

Starting at the far left, the outgroup on the phylogenetic tree is the choanoflagellates. These are single celled and colonial organisms thought to be the sister taxa to the metazoa, or animals (Hickman, p. 98-99). They share many characteristics with metazoa, including heterotrophy and motility. However, they are not truly multicellular organisms.

Porifera, or sponges, begin the truly multicellularity of the animal kingdom. The most important characteristic of sponges is their aquiferous body system, which uses millions of modified choanoflagellate cells called choanocytes to pump water through their bodies for the purpose of gathering nutrients and oxygen, eliminating waste, and reproducing. Sponges are divided into three classes: Calcerea, which gain their shape from spicules made mostly of calcium carbonate; Demospongiae, whose softer exterior is due to a protein called spongin; and Hexactinellida, or “glass sponges,” with spicules made of silicon. Sponges will be discussed in Question 3.

Metazoa, or animals, are often divided into two groups, the parazoa and eumetazoa (Hickman, p. 112). Sponges are the only members of the parazoa, or “beside animals” group, that we have studied, classified as such because they have no true tissue, defined as cells organized in layers and connected by a basal membrane that allows for cell communication. All the other taxa in the metazoa do have true tissue, and so are sometimes called the eumetazoa, or “true animals.”

Starting off the eumetazoa are the cnidarians, which consist of the classes Hydrozoa (hydras), Scyphozoa (jellyfish), and Anthozoa (sea anemone and corals), as well as ctenophores, or comb jellies. Cnidaria and Ctenophora are often shown as sister taxa because both are diploblastic with radial symmetry (right, Fig. 31.3 in Sadava et al., *Life: The Science of Biology*, 9th ed., <http://bcs.whfreeman.com/thelifewire9e>). Diploblasty means they have two tissue layers, an endoderm and ectoderm, while radial symmetry means they could be cut in half from any angle and would still display mirror images. These two phyla are the only ones we have studied with these characteristics. However, the relationship between cnidarians and ctenophores is not known, and they may have evolved diploblasty and radial symmetry independently (Hickman, p. 144).



The main characteristic of all classes of Cnidaria are millions of cnidocytes found in the ectoderm. One type of cnidocyte called a nematocyst is found throughout the tentacles of cnidarian animals; these are the stinging cells they use to defend themselves and capture prey. The evolutionary relationship between the classes of Cnidaria is not fully understood as there is physical evidence to support sister group relationships between any two of the three classes. A

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more detailed discussion of the bauplan of cnidarians can be found in Question 6. The main characteristic of Ctenophora is the rows of combs, or plates of cilia they use to move in water.

Next in the phylogeny are the Platyhelminthes, or flatworms, made up of the classes Turbellaria, Cestoda (tapeworms), and Trematoda (flukes). This phyla marks the beginning of animals that have bilateral symmetry and are triploblastic. Bilaterally symmetrical animals can be cut sagittally to display right and left mirror images, but cannot be cut in half in any other direction. Triploblastic animals have three tissue layers, the endoderm and ectoderm of the diploblasts, but also a mesoderm, or middle layer. All other phyla on the tree have these characteristics.

The major characteristic of Platyhelminthes is that they are flat (“platy” means flat, “helminth” means worm). Of the three classes of flatworms, Turbellaria are free living in marine and freshwater environments, while Cestoda and Trematoda are parasitic in the digestive tract and organs of vertebrates. Because they must survive in a hostile environment, the parasitic flatworms have evolved a tegument, or multinucleated non-ciliated body covering that provides protection while still allowing for lateral expansion (Hickman, p. 151).

Cnidarians, ctenophores, and flatworms all have an incomplete digestive tract, meaning that they have only one opening that functions as both a mouth and anus. Subsequent taxa on the phylogenetic tree, however, have a complete digestive tract, or a tube system with a mouth on one end and an anus on the other. Subsequent taxa also have a coelom, or body cavity, though this can be found in different forms (see Fig. 31.4 below). The next two phyla in the tree, Nematoda and Rotifera, are both blastocoelomates (also called pseudocoelomates), while the remaining animal taxa not yet considered in this class are all eucoelomates (also called coelomates). In blastocoelomates, the mesoderm is arranged near the ectoderm and does not surround the endoderm or any of the organs in the coelom. In eucoelomates, the mesoderm surrounds both the ectoderm and endoderm, as well as organs housed in the coelom.

A coelom can only occur in triploblastic animals, and not all of them have one. Platyhelminthes, for example, are acoelomates, without a body cavity. Instead, the mesoderm is packed directly against the endoderm and ectoderm. The acoelomate and blastocoelomate condition is considered by many scientists to be a form of neoteny, or the retention of developmental traits. It may be that all triploblastic animals start as acoelomate, with no body cavity, then move into the blastocoelomate or eucoelomate condition. Eucoelomates do go through a blastocoelomate phase during embryological development. However, this does not mean one form of triploblasty is more primitive than another, as all three types of animal evolved during the Cambrian.

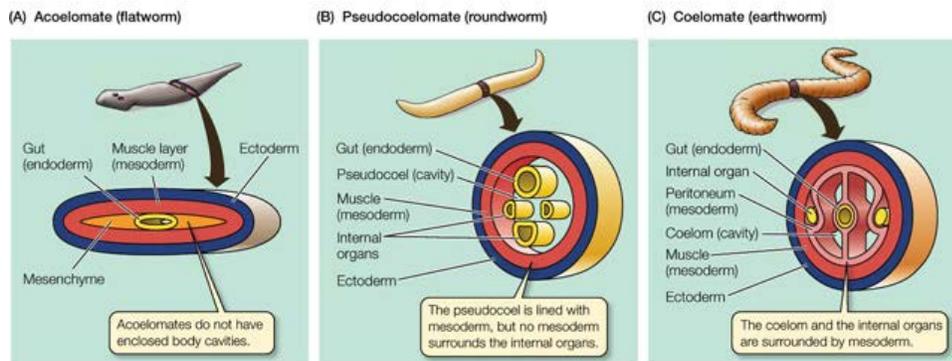


Fig. 31.4 in Sadava et al., *Life: The Science of Biology*, 9th ed., <http://bcs.whfreeman.com/thelifewire9e>

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The final two phyla on our phylogenetic tree are the nematodes and rotifers. Both, as mentioned previously are blastocoelomate. The relationship between various blastocoelomate phyla is not well understood, and it is likely these phyla evolved this condition independently. Thus, the blastocoelomate condition is indicated separate on the tree for these two phyla.

The major characteristic of nematodes is an outer body covering called a cuticle, made of the structural protein collagen (Hickman, p. 224). Unlike the flatworm's tegument, the cuticle does not bubble off from below the surface but is a complete outer body covering. Its function is to provide protection from elements on the outside as well as the high hydrostatic pressure on the inside. The cuticle also serves as an antagonist for the nematode's longitudinal muscles. Without circular muscles, nematodes are unable to squeeze around the body to lengthen it. Longitudinal muscles contract the body first on one side then the other, causing it to lengthen on the opposite sides. High hydrostatic pressure increases the efficiency of these movements, resulting in the nematode's characteristic thrashing and whipping movements.

Rotifers are also blastocoelomates, but again, likely evolved this condition independently of nematodes. Their major characteristics are the corona, or wheel-like ciliated organs at the top of the head used for locomotion and to create a water current that pulls food into the mouth, and the mastax, or toothed area behind the mouth used for mechanical and chemical digestion. Rotifers are tiny organisms that push the limit on how small an animal can be. They range in size from 40 μm to 3 mm and live mostly in freshwater environments (Hickman, pp 167-168).

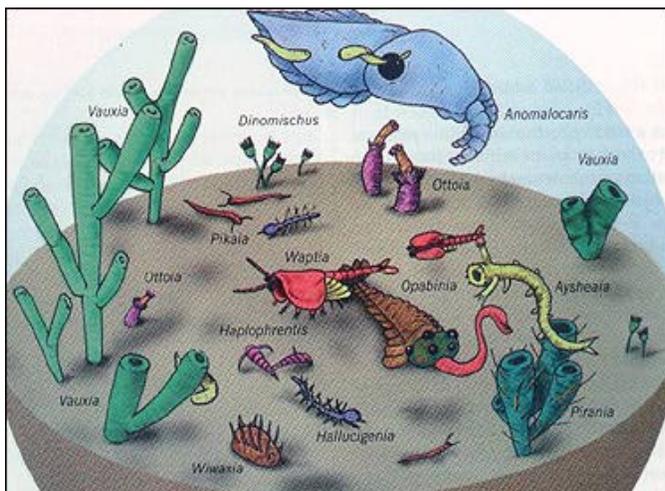
Question 2

According to Edward O. Wilson, biodiversity is “the variety of organisms considered at all levels, from genetic variants belonging to the same species through arrays of species to arrays of general, families, and still higher taxonomic levels; includes the variety of ecosystems, which comprise both the communities of organisms within particular habitats and the physical conditions under which they live” (Wilson, p. 393).

As Wilson indicates, biodiversity can exist on several levels. Molecular-level biodiversity refers to the variety of genes, or heritable units in the sexual reproduction of organisms, and includes all the different alleles and interaction of alleles among different genes within a species. It is important for a species to display a high level of diversity on the molecular level because that increases the fitness. A species that has little diversity among alleles of its genes is less fit for several reasons. First, it is more likely that to members of the species that reproduce may both be carriers of a recessive gene, leading to deleterious homozygous traits such as mutations, deformities, diseases, or even death. Second, if most or all members of a species have alleles that are not resistant to a pathogen or disease, it is more likely the species could go extinct.

Biodiversity can also exist on the ecosystem level. Ecosystems are communities of species that evolve complex interactions among each other and with the abiotic components of the environment. Examples are coral reefs, rainforests, and deserts. The more biologically diverse the ecosystem is, the less likely it is to fail. For example, studies in forests have shown that multiple plant species help ensure more even distribution of leaves to gain energy from the sun and roots to gain nutrients from the soil (Wilson, pp. 308-309).

Many people picture the tree of life becoming ever more diverse, with branches splitting and multiplying evenly across the ages. However, evidence shows this is not the way it happened. As mentioned in the previous answer, most phyla of animals got their start during an “explosion” in the Cambrian period between 505 million and 570 million years ago (Wilson, p. 188). This explosion may have been made possible by the amount of oxygen available. After billions of years of photosynthesis by first prokaryotic and then eukaryotic single-celled organisms, oxygen levels reached their current levels of 21 percent in the atmosphere and oceans, and a protective ozone layer was formed that kept ultraviolet solar radiation from bombarding the earth’s surface.



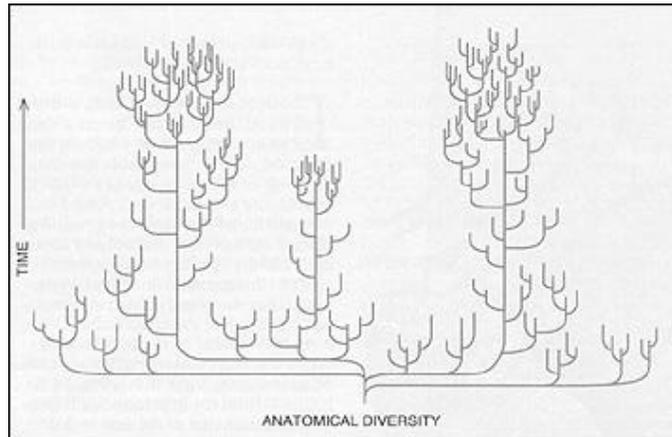
It is thought that a large variety of multicellular heterotrophic organisms – animals -- were able to rapidly proliferate during this period. Fauna found fossilized in the Burgess Shale of British Columbia show that that Cambrian was a time of great experimentation in body plan and phyla. All the creatures in the illustration below date to the middle Cambrian, about 540 million years ago. Some forms, such as the vauxia sponge, survived to present times, while others such as anomalocaris, did not. Many of the species that did not survive are so peculiar in form that they

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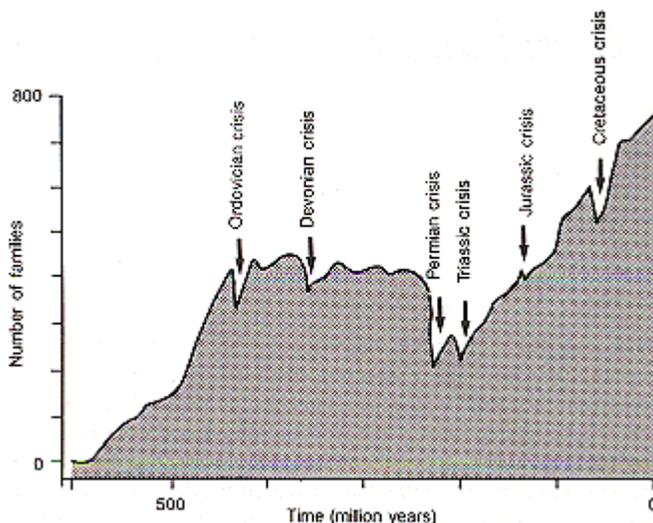
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cannot be classified under any of today's known phyla. We do not know why they died out. Perhaps their body plan was too bizarre to adapt to the planet's changing environment, or perhaps others were able to outcompete them in gathering food and reproducing (Stephen Jay Gould, "Evolution," *Scientific American*, October 1994, accessed at <http://brembs.net/gould.html>)

Regardless of the reason, many of the body forms that originated during the Cambrian did not last long. Among arthropods, for example, 20 body plans dating to the Cambrian period have been identified, but of those only four survive today. However, this does not mean that there is less diversity today than 540 million years ago. Back then, there was a diversity of body plans but not of species. Today, a diversity of species has developed among the few surviving body plans. Among the four body plans for arthropods, there are over 1 million described species.



Thus, the pattern is not one of even diversification through time, but of diversification followed by decimation. For a time, a range of body plans were developed among relatively small number of species, but most of these body plans were decimated. However, the surviving body plans go on to diversify by evolving a large number of species, creating a tree of life that has had many of its branches pruned, as in the illustration below. Today we have fewer body plans than we did during the Cambrian period, but a greater number of species than ever before. (Figure from Gould, 1994, accessed at <http://brembs.net/gould.html>)



What causes this pruning of the branches of the tree of life? A gradual pruning occurs through the process of natural selection, as some body plans and species are selected for and against by the environment. But more important are major extinction events, or spasms, that may knock out entire families, orders, or classes of organisms. The history of the planet has seen five such extinctions, and many scientists believe we are currently in a sixth mass extinction event. (Figure from M.J. Farabee, "Paleobiology: The Late Paleozoic," 2001, accessed at <http://www.emc.maricopa.edu/faculty/farabee/biobk/BioBookPaleo4.html>)

Of the five mass extinctions in earth's history, the most important were the Permian event, 250 million years ago, and the Cretaceous event, 65 million years ago. The Permian extinction killed 95 percent of all marine species and 70 percent of terrestrial species. An early arthropod taxa called trilobites, numerous until this point, completely disappeared. The cause of this extinction

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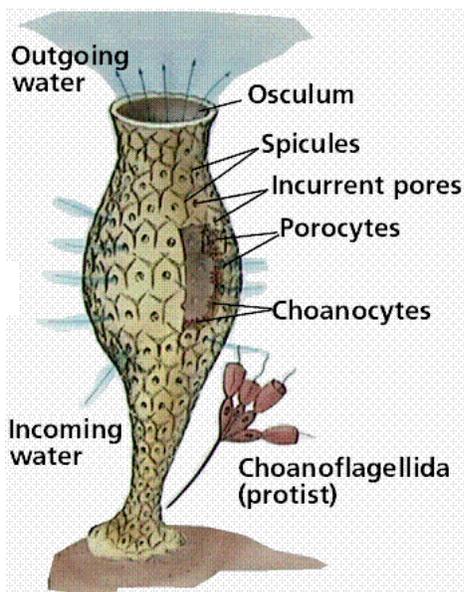
event is not known. The Cretaceous extinction event, which wiped out 75 percent to 80 percent of species on earth, is thought to have killed the dinosaurs. (Farabee, 2001). Its cause is believed to be a large meteor that slammed into the earth near the Yucatan peninsula in Mexico.

Despite these extinction events, the overall trend in biodiversity in terms of numbers of species on earth is an inexorable march upward. Still, that does not mean we can be complacent about the current extinction event, the first thought to be caused by human activity. First, it takes the planet tens of millions of years to recuperate the number of species it once had after an extinction event. It takes even longer for the planet to evolve the rich and complex ecosystems we see today. New species may evolve fairly quickly, but they have not been fine-tuned to adapt to a niche environment and may be pushed out by competition with sister species. Rich stable ecosystems take much longer to develop (Wilson, pp. 73-74). Second, an extinction event changes the course of evolution forever. For example, the extinction of the dinosaurs paved the way for the diversification of mammals, which until then had been relatively unimportant. Moreover, had an extinction event wiped out early primates, they would not have been able to evolve into humans (Campbell et al, *Biology*, 8th ed, 2007, p. 522). Humans now must guard against a new extinction event not just for our own sake, but for the sake of our descendants.

Question 3

A sponge is considered to be an animal because it has all of the major characteristics of animals: it is multicellular, heterotrophic, and motile, though most of its motility occurs among the larvae. Yet sponges are so different from other animals that they are classified as parazoa, or “beside animals,” while all other animal phyla are classified as eumetazoa, or “true animals.” The main reason for separating sponges into their own phylogenetic category is that unlike all other animal groups, they lack true tissues, or organized cell layers connected by a basal membrane.

The most important characteristic of the sponge bauplan is their aquiferous body system. Essentially, sponges are built to pump and filter water. Sponges have no blood circulatory system, no waste elimination system, no respiratory system, and no reproductive system. They rely on water pumped through their bodies to carry out all these life processes.



How do sponges pump water through their bodies? This is accomplished through the coordinated beating of choanocytes, or flagellated collar cells that line the interior of the sponge's body. As the flagella beat, they pull water in through millions of tiny pores called ostia on the sponge's surface. These ostia, or incurrent pores, are what give the sponge its phylum name Porifera, or “pore bearer.” Water flows through the ostia into the hollow middle the sponge called the spongocoel and out through a hole called the osculum. One-way flow is ensured because the total diameter of all the ostia put together is larger than the diameter of the osculum. This builds water pressure coming out of the osculum, much like covering part of the opening of a hose increases water flow. Sponges are capable of pumping large amounts of water through their bodies; some large sponges can filter 1500 liters of water per day (Hickman, p. 118). (Figure from “Porifera,”

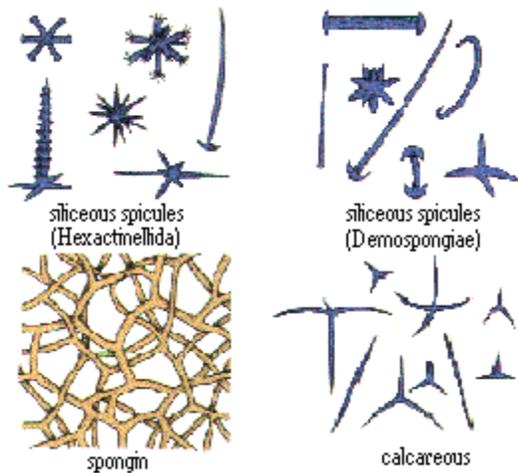
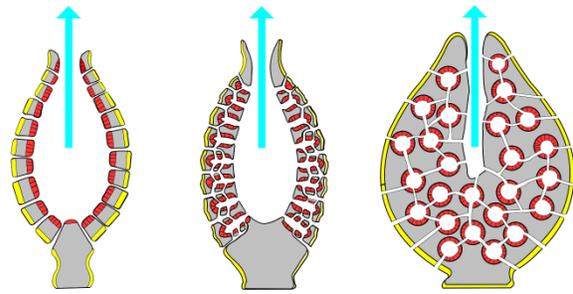
Zoology Quest, 2009, <http://www.zoology-quest.net/wiki/index.php?pagename=Porifera>)

Sponges accomplish everything that an animal needs to do through this one-way flow of water. Nutrients are acquired by the choanocytes, then passed on to amoeboid cells called archaeocytes for intracellular digestion and distribution. Oxygen is also absorbed by diffusion and carried by amoeboid cells throughout the gelatinous matrix called the mesohyl. Nitrogenous wastes and carbon dioxide are also removed from the sponge's body by diffusion into the outflow of water.

Sponges are monoecious, meaning they have both male and female parts. In some cases, reproduction is accomplished when one individual releases sperm into the water so that it can be pumped into the body of another individual. The sperm are phagocytized by choanocytes and then carried through the mesohyl to the ova. In other cases, sponges release both sperm and eggs, which meet in the water to form a zygote. The zygote develops into a parenchymula larva with outward flagellated cells that help it swim to a new location, where it inverts to put the choanocyte cells on the inside and settles down to grow into an adult sponge (Hickman, p. 118).

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The body plan of the sponge comes in three types arranged in increasing complexity: asconoid, syconoid, and leuconoid. Asconoids are the simplest, essentially a tube-like structure with a central cavity called a spongocoel lined with choanocytes. Syconoids also have a central spongocoel, but the choanocytes line a series of smaller cavities coming off the spongocoel called radial canals. Leuconoids are the most complex. They lack a central spongocoel. Instead, the choanocytes line a series of chambers filled with water from incurrent canals and connecting to a series of excurrent canals that lead to the osculum. The advantage of this increasing complexity is that it allows the sponge to increase in size because water bringing nutrients and oxygen can get to all parts of the animal. However, these body types do not represent a chronology of evolutionary development, as all have evolved independently many times (Hickman, pp. 114-16). (Figure: Porifera body structure. Colors: yellow: pinacocytes, red: choanocytes, grey: mesohyl, pale blue: water flow. Structure types: left: asconoid, middle: syconoid, right: leuconoid. From Ruppert, E.E., Fox, R.S., and Barnes, R.D., *Invertebrate Zoology*, 2004, 7, 78. Accessed at <http://en.wikipedia.org/wiki/Sponge>.)



Sponges also have three types of skeletal structures, which provide support and prevent the canals and chambers from collapsing in on themselves. These skeleton types are the basis for differentiating the three classes of sponges, Calcarea, Demospongia, and Hexactinellida. Most sponges secrete minute hard parts called spicules that float in the mesohyl and stiffen the body. Calcarea has spicules made primarily of calcium carbonate while Hexactinellida has spicules made primarily of silicon.

Demospongiae, which comprise 80 percent of known sponge species, has spicules of both types. However, its skeleton is made primarily of a protein unique to sponges called spongin, which is a form of the

connective tissue collagen. While sponges whose skeletons are made mostly of spicules have a hard exterior, those whose skeletons are made mostly of sponging are soft; these are the so-called “bath sponges” (Hickman pp. 117, 119). (Figure: Oceanlink, “Images from the Deep: Reef-building Sponges,” accessed at http://www.oceanlink.info/LEYS/reef_research2.html.)

One final characteristic of the sponge bauplan that it shares with no other animal group is totipotency. Essentially, every cell in a sponge’s body acts as a stem cell, meaning that it can give rise to any other type of cell even after the sponge reaches maturity. Even in adult sponges, one type of cell can change its form and function to become another type. This means that if a piece of a sponge is disassociated from the main body, it can grow and reproduce into a whole sponge again even if the piece does not contain all the necessary cell types. No one understands how sponges accomplish this, though it is thought to be related to the lack of true tissue.

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Question 4

Jellyfish are radially symmetrical animals of the phylum Cnidaria. Their form explains much of their movement through water. Radial symmetry means they can be bisected along any plane through the main body axis to result in mirror image halves. It is an especially useful form for organisms that live in the ocean, where the environment is similar regardless of direction.

Jellyfish do not move with purpose toward an object the way that cephalized bilaterally symmetrical animals do. Unlike bilaterates, jellyfish have no head. Their sensory organs are arranged primarily around the ring canal of the bell, and instead of a central nervous system, jellyfish have a nerve net spread evenly across the body. Rather than scavenging for food or hunting for prey as bilaterally symmetrical animals do, jellyfish float in the water and use their tentacles to snatch whatever comes by, regardless of the direction it comes from.

Jellyfish do very little actual swimming. They move by contracting the bell, which moves water out from under the subumbrella, causing them to rise. This movement is made possible by the jellyfish's diploblastic tissue layers and hydrostatic skeleton. A layer of epitheliomuscular cells line the animal's surface, connecting to a series of longitudinal myofibrils next to the mesoglea, a gelatinous matrix layer between the ectoderm and endoderm. Using the hydrostatic skeleton and mesoglea as an antagonist, the epitheliomuscular cells contract and shorten, moving water out from under the bell and causing the jellyfish to rise (Hickman, p. 127-128.)

After moving upward by contracting the bell several times, jellyfish then allow themselves to sink slowly. As they float down, jellyfish are able to gather small plankton in the mucus of the subumbrella, or to transfer food into the mouth via the tentacles and oral arms. The food may be carried to food pockets by cilia and from there transferred into the mouth by the oral arms and then into the gastrovascular cavity for extracellular digestion (Hickman, p. 134).

Jellyfish use the nematocysts in their tentacles or oral arms to capture prey and transfer it into their mouths and gastrovascular cavities. Nematocysts are specialized stinging organelles unique to cnidarians. They have a barb and long filament that can be discharged to penetrate the prey item and deliver a neurotoxin. Millions of nematocysts line the tentacles of a jellyfish, and are thought to be discharged upon tactile or chemical stimulation (Hickman, p. 129).

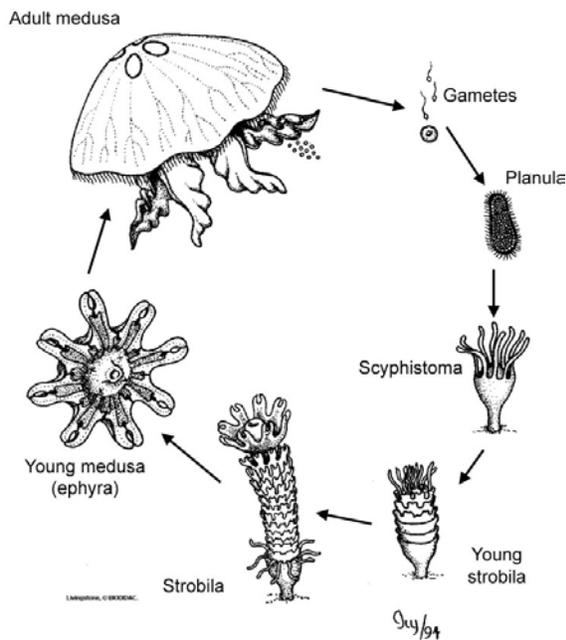
Many jellyfish have sense organs called rhopalia spread evenly around the rim of the bell. *Aurelia*, for example, has eight of these organs, each of which contains a statocyst for balance as well as sensory cells including, in some species, an ocellus. The ocelli do not form images but do allow the jellyfish to sense light and dark (Hickman, p. 134).

Jellyfish tend to remain in well-lit regions because that is where their food sources can be found. However, some species of jellyfish have another reason to seek out light: Like corals and sea anemones, they share a mutualistic symbiotic relationship with single-celled algae called zooxanthellae. The marine lakes of Palau in the South Pacific feature this type of jellyfish. (Photo: Snorkeling with jellyfish at Jellyfish Lake in Palau, by tata aka T, Creative Commons)



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Most famous are the golden jellyfish found only in Jellyfish Lake. While most closely related to the spotted jellyfish that inhabit nearby lagoons, the golden jellyfish is different enough in appearance and behavior that scientists have proposed designating them as a separate species. Each day, these jellyfish migrate in a fixed pattern across the lake to take the greatest advantage of sunlight possible. They live in part from the energy supplied through photosynthesis by the zooxanthellae in their tissues. In return, they provide protection and some nutrition to the algae they harbor (National Geographic, “Great Migrations: Golden Jellyfish,” accessed at <http://channel.nationalgeographic.com/channel/great-migrations-animals-golden-jellyfish>).



The life cycle of many jellyfish includes an alternation of generations in which they switch between polyp and medusa forms (see left). The scyphozoan jellyfish *Aurelia*, for example, is a medusa in adult form. Reproduction is started when sperm from the male fertilizes eggs on the oral arms of the female. The zygote develops into a ciliated planula larva, which breaks away from the female and settles into the substrate to develop into a hydra-like form called a scyphistoma. Through the process of strobilization, the *Aurelia* forms a series of cup-shaped buds called ephyra which eventually break away to develop into an adult jellyfish (Hickman, p. 135). The advantage of this dimorphic life cycle in jellyfish is the same as in other life forms that go through a metamorphosis such as butterflies and frogs: It reduces competition between juvenile and adult forms, thus increasing

chances that the young will survive into adulthood and perpetuate the species. (Figure from Marine Life Information Network, Descriptions of Major Taxonomic Groups, Phylum Cnidaria, Superclass Scyphozoa, <http://www.marlin.ac.uk/taxonomydescriptions.php#scyphozoa>)

Question 5

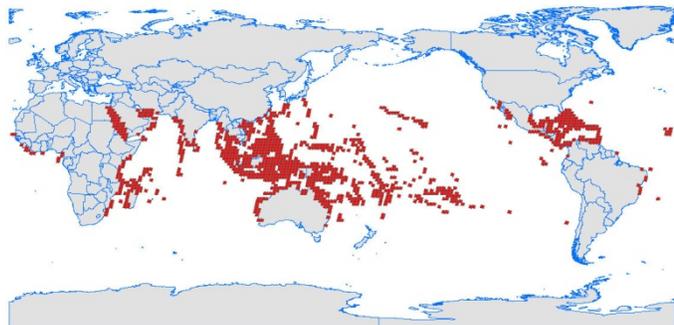
Often described as the “rainforests of the sea,” coral reefs are among the most diverse ecosystems in the world. Although they make up less than 0.1 percent of the oceans, they are home to 25 percent of all marine species, including members of most known phyla such as fish, mollusks, worms, crustaceans, echinoderms, sponges, tunicates and cnidaria (Marjorie Mulhall, “Saving rainforests of the sea: An analysis of international efforts to conserve coral reefs,” Duke Environmental Law and Policy Forum, 2007, 19:321-351. Accessed at <http://www.law.duke.edu/shell/cite.pl?19+Duke+Envtl.+L.+&+Pol'y+F.+321+pdf>)



Central to coral reefs are stony corals, a cnidarian organism in the class Anthozoa that secretes a calcium carbonate exoskeleton for protection. Appearing much like a small sea anemone, these corals occur in large colonies. Each polyp secretes a calcium carbonate exoskeleton which grows into its neighbor’s skeleton, resulting in a geometric pattern unique to each species. As one generation of coral polyps dies, the next builds its exoskeletons on top of the previous layer, creating a tall coral reef. Many coral reefs are thousands of years old (Wilson, p. 179). (Photo: A blue starfish (*Linckia laevigata*) rests on hard acropora coral on the Great Barrier Reef. Richard Ling, 2004.)

Because of their production of oxygen and carbohydrates, coral reefs are a focal point of primary productivity in the ocean. Oxygen and carbohydrates are produced not by the corals themselves, but by symbiotic algae called zooxanthellae that live in the coral’s tissues. It is these algae that give the coral its bright colors. They are unicellular and autotrophic, meaning that they use solar energy to make their own food and nutrients from carbon dioxide through the process of photosynthesis. The oxygen and carbohydrates they produce can support an entire ecosystem. The relationship between the corals and their zooxanthellae is mutualistic: the corals gain an energy and food source while the zooxanthellae gain protection through the coral’s nematocysts.

Because the zooxanthellae function best in warm waters with lots of sunlight, coral reefs are found in shallow waters close to the equator. These ecosystems occur between 30 degrees north and south of the equator, where sunlight most directly hits the earth’s surface year round. Coral reefs do not occur in deep water where sunlight cannot penetrate, cold water, or areas of low salinity or high turbidity, such as where a river flows into the ocean (Hickman. p. 140). (Map from Susan M. Wells, Coral Reefs of the World, UNEP, IUCN, 1988, accessed at <http://www.coralreefinfo.com>)



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Why do biologically diverse ecosystems such as coral reefs and rainforests occur mainly in the tropics? Wilson discusses the Energy-Stability-Area, or ESA, Theory of Biodiversity: The more solar energy, stability in climate, and surface area a region has, the more biodiversity it is likely to develop. Species in temperate regions must adapt to four seasons, giving them a larger geographical range. Species in the tropics have a smaller range, but more of them can be packed together. Rather than trying to be a jack of all trades, tropical species specialize to inhabit a single niche, including, in some cases, living on another species (Wilson, pp. 199-201).

Because the species in coral reefs are so specialized, that also make them vulnerable to any changes in the environment, and over the past few decades, human activity has brought many changes that threaten these fragile ecosystems. Recent studies show that 20 percent of the world's coral reefs have died and an additional 50 percent are endangered (Juliet Eilperin, "Yes the Water's Warm ... Too Warm," *Washington Post*, July 15, 2007, accessed at <http://www.washingtonpost.com/wp-dyn/content/article/2007/07/13/AR2007071300531.html>).

Most of the threats to coral reefs, whether on a local or global level, are a result of human activity. On a local level, overfishing can remove fish that make their home in coral reefs and control the growth of algae. Destructive fishing practices such as blast fishing or cyanide use also destroy life on the reef. Pollution from agricultural, municipal and industrial runoff affects reefs, especially as 40 percent of the human population lives on the coast. Irresponsible tourism in the form of anchoring boats and discharging wastewater are a threat, as is mining reefs for limestone or for coral to sell for aquariums, decorations, and jewelry (Mulhall, p. 326-328).



An even greater threat to coral reefs in the long run is global climate change. It takes a rise in water temperature of only 1.8 to 3.6 degrees to trigger coral bleaching, in which the coral polyps expel their symbiotic zooxanthellae algae. Without the zooxanthellae, the coral die, and the oxygen and nutrient production of the coral reef ceases to exist. Yet water temperatures in the tropics have climbed steadily since the 1950s, resulting in mass coral bleachings around the world (Eilprin, 2007; Mulhall, pp. 330-331).

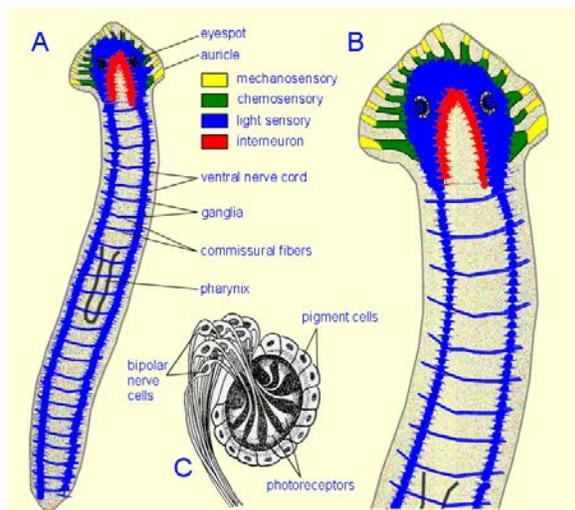
(Photo from Oceanic Defense, "Coral Bleaching Likely in the Caribbean," 2009, accessed at <http://oceanicdefense.blogspot.com/2009/07/coral-bleaching-likely-in-caribbean.html>)

In addition to higher temperatures, climate change has brought a greater incidence of extreme weather patterns such as hurricanes that can devastate coral reefs. Finally, the unprecedented levels of carbon dioxide that humans release into the atmosphere each year settles into the ocean, causing ocean acidification. The oceans have absorbed half of the anthropogenic carbon dioxide since 1750 (World Resources Institute, September 2007 Monthly Update: Ocean Acidification, the Other Threat of Rising CO₂ Emissions, *Earthtrends Environmental Information*, Oct. 2, 2007, accessed at <http://earthtrends.wri.org/updates/node/245>). These acidic conditions make it harder for coral polyps to build their calcium carbonate exoskeletons, and could even dissolve them.

Question 6

Animals in the phylum Cnidaria (jellyfish, hydra, coral, anemones) and Platyhelminthes class Turbellaria (free-living flatworms) live mostly in the water. However, their bauplans provide a contrast in body symmetry, nervous and sensory structures, and osmoregulatory ability that allow these two taxa to pursue different lifestyles and exploit different types of habitat.

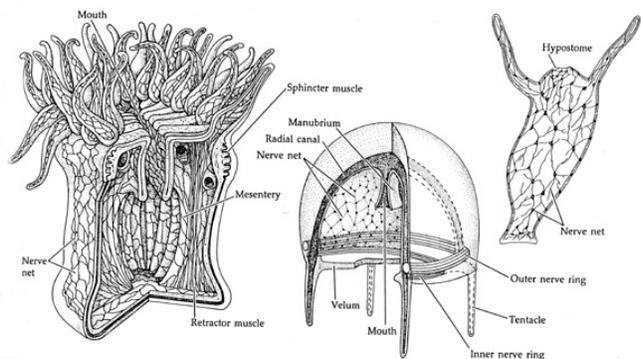
In terms of body symmetry, cnidarians have radial symmetry while free-living flatworms are bilaterally symmetrical. Radial symmetry means cnidarians can be bisected along any plane through the main body axis to result in mirror image halves. In bilateral symmetry, the only bisection that results in mirror image halves is through the sagittal plane.



Bilateral symmetry is associated with cephalization, or the formation of a well-defined head where much of the nervous tissue and sensory structures can be found. Cnidarians have no head, while free-living flatworms clearly do. In Turbellaria, the head usually contains ocelli (“little eyes”), or small eyespots with photoreceptors that allow it to sense light and dark. (Image from Bill Tietjen, “Platyhelminthes,” The Spider Lab, Bellarmine University, accessed at <http://cas.bellarmine.edu/tietjen/images/platyhelminthes.htm>)

Turbellaria also often have auricles, or flares on the side of the head with tactile and chemoreceptive cells that allow them to sense changes in the chemistry of water. Free-living flatworms also have a rudimentary brain made of a mass of ganglia congregated in the head that lead to one to five pairs of longitudinal nerve cords that run the length of the body and are connected by transverse nerves in a ladder-like structure (Hickman, p. 152).

Cnidarians, by contrast, do not have a central nervous system with a defined brain or nerve cords. Instead, they have a nerve net, a diffuse network of nerve cells distributed evenly across the body. These cells are different the nerve cells of bilaterate animals in that rather than transmitting impulses in one direction, they have neurotransmitter vesicles on both sides of the cell, allowing nerve impulses to flow both ways (Hickman, p. 129). With the exception of some Scyphozoa species, cnidarians do not generally have eyespots or chemoreceptors. (Image from Ms. Kraftsen, “Cnidaria,” Eco SE, 2010, accessed at <http://myclasses.naperville203.org/staff/NNHSBiology/KraftsonEcoSE/Animal%20Kingdom%20%20Period%204/Cnidaria.aspx>)



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Osmoregulation also functions differently in Cnidaria and Turbellaria. Cnidarians do not have an osmoregulatory system. Instead, they are osmoconformers, meaning they allow their body chemistry to match the environment. Cnidarians such as jellyfish are 95 percent water, so little additional water could flow into their cells anyway. (Novel Guide, “Osmoregulation,” http://www.novelguide.com/a/discover/biol_03/biol_03_00323.html). Most cnidarians live in marine rather than freshwater environments, making osmoregulation less of a concern.

Free-living flatworms, by contrast, have a complicated osmoregulatory system made of canals with tubules that end in flame cells. Flame cells, named because their movement resembles a flickering flame, have a series of flagella that beat in unison to create negative pressure to draw in excess water through an opening called a weir. The water is then channeled through the tubule into collecting ducts that open to the outside through exit pores (Hickman, p. .152).

These differences in body symmetry, nervous and sensory structures, and osmoregulatory ability allow cnidarians and free-living flatworms to exhibit different lifestyles and exploit different environments. Cnidarians are opportunists that wait for food to float by so they can collect it with their tentacles, or in the case of medusa, they collect food as they sink from near the water surface. Either way, the environment they live in is the same from all directions, making a radial symmetry and a diffuse nerve net the best forms for the functions they need to carry out.

Turbellaria, on the other hand, are built to move with a purpose. They have a predatory or scavenging lifestyle, and they need to be able to sense what is in their environment so they can move either toward it or away. Their bilateral symmetry allows them to move easily in a specific direction, while their brain allows them to gather sensory information, process it, and formulate a response. Their osmoregulatory system allows them to expand to freshwater environments.

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Question 7

Nematodes, or roundworms, are ubiquitous across the earth. There are about 12,000 described species of nematodes but many scientists believe the real number is more like 500,000. Nematodes live in every conceivable type of environment including oceans, freshwater, soil, polar regions, tropical forests, deep mines, and mountain tops. A handful of soil contains thousands of microscopic roundworms, and an acre of fertile soil may contain billions (Hickman, p. 224). Nematodes account for 90 percent of all life on the ocean floor, and outnumber all other animals, with an estimated 10^{21} to 10^{22} on earth (“What is the most numerous animal?”, Wise Geek, accessed at <http://www.wisegeek.com/what-is-the-most-numerous-animal.htm>)

Nathan Cobb, founder of the USDA Nematology Laboratory in Washington, DC, illustrated the ubiquity of nematodes in this way:

“In short, if all the matter in the universe except the nematodes were swept away, our world would still be dimly recognizable, and if, as disembodied spirits, we could then investigate it, we should find its mountains, hills, vales, rivers, lakes, and oceans represented by a film of nematodes. The location of towns would be decipherable, since for every massing of human beings there would be a corresponding massing of certain nematodes. Trees would still stand in ghostly rows representing our streets and highways. The location of the various plants and animals would still be decipherable, and, had we sufficient knowledge, in many cases even their species could be determined by an examination of their erstwhile nematode parasites.” (Nathan A. Cook, Nematodes and their Relationships, USDA Yearbook, 1914, p. 472, accessed at http://naldr.nal.usda.gov/NALWeb/Agricola_Link.asp?Accession=IND43748196.)



The most famous nematode is probably *Caenorhabditis elegans*, commonly used as a model organism in laboratory experiments. *C. elegans* is highly suited to this purpose for several reasons. It is easy to breed and maintain, and with lifespan of just a few weeks, an entire life cycle can be studied quickly. It can be frozen and will remain viable when thawed out later. Its body is transparent and can be stained easily, so scientists can easily see its biological processes with no need for dissection (Photo: An adult *Caenorhabditis elegans*, by Zeynep F. Altun, wormatlas.org, http://en.wikipedia.org/wiki/Caenorhabditis_elegans)

C. elegans has been used as a model organism to study an incredible array of biological processes and phenomena. Riddle et al.’s book *C. elegans II* (Cold Spring Harbor Laboratory Press; 1997), has chapters on areas of *C. elegans* research that include the genome; chromosome organization, mitosis and meiosis; mutation; transposons, RNA processing and gene structure; transcription factors and transcriptional regulation; mRNA and translation; sex determination; developmental genetics; spermatogenesis; male development and mating behavior, fertilization and establishment of polarity in the embryo; cell fates in the early embryo; cell death; muscle structure, function and development; extracellular matrix; heterochronic genes; development of the vulva; patterning the nervous system; cell growth and cone migrations; synaptic transmission; mechanotransduction; feeding and defecation; chemotaxis and thermotaxis; genetic and environmental regulation of larva development; neural plasticity; environmental factors and gene

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activities that influence lifespan; and evolution (Bookshelf, U.S. National Library of Medicine, National Institutes of Health, accessed at <http://www.ncbi.nlm.nih.gov/books/NBK19997/>)

C. elegans was the first multicellular organism to have its genome completely sequenced. Its genome has about 100 million base pairs that make up about 19,000 genes. More than 40 percent of the proteins encoded by these genes are similar to proteins in other organisms. (*C. elegans* Sequencing Consortium, “Genome sequence of the nematode *C. elegans*: a platform for investigating biology,” *Science*, December 1998, 282 (5396): 2012-2018, accessed at <http://www.sciencemag.org/content/282/5396/2012.abstract>)

Because of its transparency, *C. elegans* has been used to study cellular differentiation, or the process in which embryonic stem cells are determined to become a particular type of adult body cell such as a muscle cell or neuron. *C. elegans* has exactly 959 somatic body cells, and the fate of every single one has been examined. Because *C. elegans* has many additional cells that are eliminated during development, it also been used to study apoptosis, or programmed cell death. (Sulston and Horvitz, “Post-embryonic cell lineages of the nematode, *Caenorhabditis elegans*,” *Developmental Biology* 56 (1): 110-56, <http://www.sciencedirect.com/science/article/pii/0012160677901580>).

Another area of study in *C. elegans* is its simple nervous system comprised of 302 neurons, which have been completely mapped. Scientists have examined the neural mechanisms for behaviors such as chemotaxis, thermotaxis, mechanotransduction, and mating behavior. (Kosinski and Zaremba, “Dynamics of the Model of the *Caenorhabditis elegans* Neural Network.” *Acta Physica Polonica B* 38 (6):2202, <http://th-www.if.uj.edu.pl/acta/vol38/pdf/v38p2201.pdf>.)

Yet another area of research is RNA interference, in which the expression of specific genes is disrupted, or “silenced,” so the scientist can see what the gene does. This type of research can be done easily by feeding bacteria that has been genetically modified to disable the gene of interest. Scientists have used this method to study 86 percent of the genes in *C. elegans* (Kamath, et al., “Systematic functional analysis of the *Caenorhabditis elegans* genome using RNAi,” *Nature*, 421 (6920): 231–237, <http://www.nature.com/nature/journal/v421/n6920/full/nature01278.html>)

Meiosis is also easy to study in *C. elegans* because unlike in higher organisms, the sperm and egg move in lock step through the gonads, reaching the same stages at the same time. The organism has also been used in nicotine studies because it exhibits the same addiction, tolerance, and withdrawal patterns as found in higher animals. (Feng, et al., “A *C. elegans* Model of Nicotine-Dependent Behavior: Regulation by TRP-Family Channels,” *Cell* 127 (3):621-33, <http://www.cell.com/retrieve/pii/S0092867406012955>)

Several major prizes have been given to scientists who use *C. elegans* to study biological processes common to other animals. In 2002, Sydney Brenner, Robert Horvitz, and John Sulston won the Nobel Prize in Medicine for their work on the genetics of organ development and programmed cell death in *C. elegans*. In 2006, Andrew Fire and Craig Mello won the same prize for their discovery of RNA interference in *C. elegans*. And in 2008, Martin Chalfie won the Nobel Prize in Chemistry for his work on green fluorescent protein in *C. elegans*. (“All Nobel Prizes,” Nobelprize.org, accessed at http://nobelprize.org/nobel_prizes/lists/all/)

Question 8

Ecology as a science is only about 50 years old, and our understanding of biodiversity and the biosphere is still quite limited. In recent years scientists have made several discoveries that show just how little we understand about the earth's systems. These include an entire new type of ecosystem (whale falls), a group of organisms that permeate the ocean and may be the most numerous on the planet (prochlorococcus bacteria), and a new phylum of anaerobic animal that plays an important but still unknown role in the ocean sediment (loriciferans).



Whale falls occur when a whale dies at sea and his body sinks to the ocean floor. Over a period of decades, a succession of other species from the very large to the very small gain nourishment and living space from the carcass,. More than 400 species have been documented at whale falls, at least 30 of which were previously unknown. (Crispin T.S. Little, “The Prolific Afterlife of Whales,” Scientific American, Feb 2010, p. 78-84, <http://www.scientificamerican.com/article.cfm?id=the-prolific-afterlife-of-whales>)

Whale falls as an ecosystem were not discovered until 1987. There were previous hints at their existence, such as in 1854 when a zoologist described a new species of mussel found in whale blubber collected near South Africa. Industrial trawler fishing nets started scooping up whale bones with living species of mollusk attached in the late 20th century. The first definitive whale fall was found by Craig Smith of University of Hawaii, who was mapping the Santa Catalina Basin off Southern California. Although the whale had been dead for years, its skeleton was teeming with life (Little, 2010). (Photo: Skeleton of a 35-ton, 13-m gray whale on the sea bottom, Craig Smith and Mike Degruy, 2004, http://en.wikipedia.org/wiki/File:Whale_fall.jpg)

Smith began studying whale falls by towing whales that had washed up on shore out to sea and letting their bodies sink. By visiting the remains at regular intervals, Smith and his colleagues were able to establish fairly constant stages of whale fall ecosystems. In the first stage, called the mobile scavenger phase, hagfish and sleeper sharks bite off large chunks of meat, stripping away most of the soft tissue at the rate of 40 to 60 kg per day. The whale may be stripped to the bone in just a few months (Little, 2010; Kim Fulton-Bennett, Monterey Bay Aquarium Research Institute, “Whale Falls: Islands of abundance and diversity in the deep sea,” 2002, http://www.mbari.org/news/news_releases/2002/dec20_whalefall.html).

In second stage, the enrichment opportunist stage, the whale bones and the sediment around the carcass are infested with polychaete worms, crustaceans, mollusks, and other invertebrates. For up to two years, they feed on the blubber and other organic material left behind by the larger scavengers that came before them (Little, 2010; Fulton-Bennett, 2002).

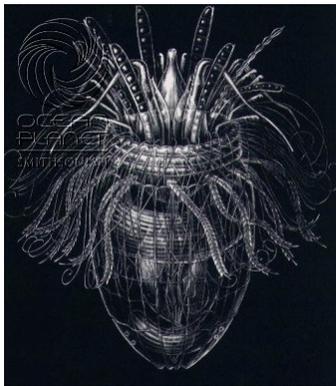
Once all the soft tissue is gone, the third phase, called the sulfophilic stage, begins. Sulfur reducing bacteria break down the lipids locked in the whale bones, using SO₄ as their source of oxygen and releasing hydrogen sulfide as waste. The H₂S attracts chemosynthetic bacteria that

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use oxygen from the water and sulfide for energy and growth. Some animals such as mussels and clams can live symbiotically with the chemosynthetic bacteria, while others such as snails and limpets can feed on them. Because whale bones contain so many lipids, the sulfophilic stage can last several decades or even a century (Little, 2010; Fulton-Bennett, 2002).

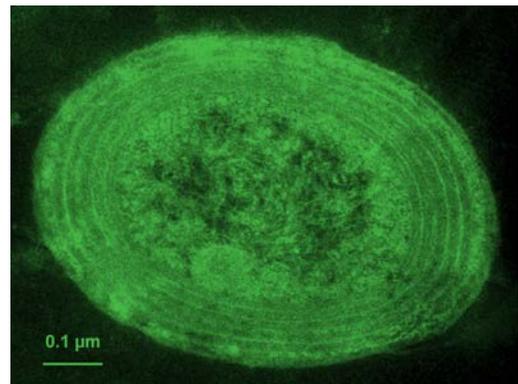
Whale falls are not the only major discovery that scientists have made in recent years. In 1983, Danish zoologist R.M. Kristensen described an entire new phylum called loriciferans (“girdle bearing”). Loriciferans are microscopic animals about the size of a single-cell protozoan, but they are multicellular, with a brain, digestive and waste-removal system, sense organs, muscles, separate sexes, and a protective external cuticle (Elaine Soulanille, “Loriciferans,” Encyclopedia of Life, 2010, <http://www.eol.org/pages/1537>)



As of 2010, about 100 species of loriciferans had been collected, but only two dozen had been described. Loriciferans live between the particles of ocean sediments. They use adhesive glands to attach firmly to sand grains and gravel, which is why it took so long to discover them. Although first found in the 1970s, it took until 1983 to work out the complex life cycle (R.M. Kristensen, “An Introduction to Loricifera, Cycliophora, and Micrognathozoa,” *Integrative and Comparative Biology*, 42: 641-651, <http://icb.oxfordjournals.org/content/42/3/641.full>). (Photo: NASA, EM image of *Pliciloricus enigmatus*, accessed at http://en.wikipedia.org/wiki/File:Pliciloricus_enigmatus.jpg.)

Loriciferans are found at all depths, sediment types, and in all latitudes. Now that their existence is known, researchers continually find new species, which indicates that the animals are abundant and distributed worldwide (Soulanille, 2010). They are thought to play an important role in the ocean sediment, but scientists don’t know what they do. Of special interest are three obligate anaerobe species discovered in the sediments of the Mediterranean Sea. These species lack mitochondria, which use oxygen to generate the body’s energy, but instead rely on anaerobic organelles similar to hydrogenosomes previously seen only in single-celled organisms (Charles Q. Choi, “Animals Living Without Oxygen Discovered for First Time,” *Live Science*, 2010, <http://www.livescience.com/6307-animals-living-oxygen-discovered-time.html>).

A third example of how little humans know about the natural world is the discovery of a tiny marine cyanobacteria called prochlorococcus in 1986 by Sallie W. (Penny) Chisholm of the Massachusetts Institute of Technology, Robert J. Olson of the Woods Hole Oceanographic Institute. The organism was found first in the Sargasso Sea, then in the Mediterranean. At first it was assumed to be related to prochloron, another bacteria that contains chlorophyll b, but the two were later demonstrated to be from separate groups (Chisholm, et al., “A novel free-living prochlorophyte occurs at high cell concentrations in the oceanic euphotic zone.” *Nature* 334 (6180): 340–343, 1988, <http://www.nature.com/nature/journal/v334/n6180/abs/334340a0.html>). (Image: SPB



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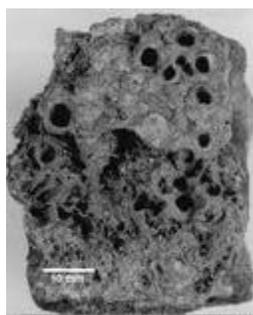
Bioimaging Workshop, Transmission Electron Microscope image of Prochlorococcus, accessed at <http://xray.bmc.uu.se/spb/>)

Measuring about 0.5 to 0.8 μm , Prochlorococcus are among the tiniest organisms on the planet, which is why it took so long for them to be discovered. Yet they are among the most numerous, with more than 100,000 in a milliliter of water, and several octillion (10^{27}) estimated worldwide. Prochlorococcus may be responsible for over half the photosynthesis of the oceans as well as 20 percent of the earth's oxygen ("The Most Important Microbe You've Never Heard Of," Science Friday, June 13, 2008, <http://www.sciencefriday.com/program/archives/200806132>).

Question 9

The origin of life – how organic living matter came about in a largely inorganic world – has long fascinated scientists. In the 1950s, Stanley Miller and Harold Urey did a lab experiment in which primordial earth conditions were simulated in an enclosed chamber and an electrical current was run through, simulating a bolt of lightning. The result was the formation of early organic molecules such as amino acids and fatty acids; however, Miller and Urey did not say how these molecules might have been organized into cells. Other scientists have theorized that the meteors or asteroids hitting the earth during its early years may have brought the molecules of life. Extraterrestrial objects are known to be coated with organic molecules, but again, this theory does not explain how these molecules formed into complicated cellular structures.

One recent theory that has been gaining widespread attention does explain how the organized cells that make up the basis of all living beings came about: the iron sulfide theory of the origin of life, developed by William Martin and Michael J. Russell. This theory is discussed by Kendall Morgan in “A rocky start: Fresh take on life's oldest story” (*Science News*, April 26, 2003, 163 (17): 264-66). According to the iron-sulfide theory, the cells that make up the basis modern life originated in deep-sea hydrothermal vents. These vents occur across the ocean floor, spewing iron sulfide into the water. As the hot iron sulfide meets the cooler water, chimney structures form. Some chimneys as tall as 15-story buildings have been found. (Image: NOAA. Hydrothermal vent. Accessed at http://www.phschool.com/science/science_news/articles/rocky_start.html)



What interested Martin and Russell about the chimneys was not their height but their internal structure. Rather than being a solid mass of stone, they turned out to be honeycombed with millions of tiny compartments. These compartments could have acted as an incubator of the first life forms, with the rock walls serving as the first cellular membranes. Cellular membranes are key to the functioning of life because they concentrate organic molecules into a small space and enclose the processes that make life possible. (Images: Russell and A. Hall. A hunk of iron sulfide, with a close-up of the honeycombed chambers. Accessed at http://www.phschool.com/science/science_news/articles/rocky_start.html)

One issue in this theory is where the energy of life comes from: How would such prototype cells manage to reproduce? The answer lies in the difference between the iron-sulfide solution coming out of the hydrothermal vent and the ocean water surrounding it. The two have different ion concentrations, creating a voltage that could have catalyzed the early reactions of life.

Previous evidence for such a scenario exists. German chemist Gunter Wächtershäuser found that metal sulfides can catalyze the formation of active thioester, which may have preceded ATP as the biochemical fuel inside cells. Later, geophysicist George D. Cody showed that iron sulfide can lead to the synthesis of pyruvate, a molecule found in cellular metabolism. In lab experiments, Cody found that iron sulfide mixed with early earth ingredients such as carbon

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dioxide and hydrogen resulted in “cycles that look a lot like metabolism.” In addition, many enzymatic co-factors that catalyze metabolic reactions are based on iron and sulfur.



For Martin and Russell’s theory to work, at some point the prototypical cells inside the compartments of the iron-sulfide chimneys would have to form cell membranes of their own and venture into the larger world. True cell membranes could have formed as lipids were synthesized inside the early incubators. Martin and Russell theorize that this happened not once but twice in the history of life, forming two types of bacteria: archaeobacteria and eubacteria. Research by Yosuke Koga into the genetic makeup of the membranes of archaeobacteria and eubacteria show that the two are so different, they had to have evolved separately. (Image: Martin, Royal Society of London. A model of how two types of cells could be formed in

the rock formed around deep-sea hydrothermal vents. Accessed at http://www.phschool.com/science/science_news/articles/rocky_start.html)

Although archaeobacteria and eubacteria are thought to have formed separately 4 billion years ago, Martin and Russell believe they came back together 1.5 billion years later when an archaeobacterium swallowed a eubacterium. Other scientists have found evidence for this bacterium-bacterium collaboration as well. Joan M. Bernhard has found protists near deep sea vents that house bacteria internally or on their surface. Ante Boetius has found archaeobacteria surrounded by eubacteria feeding on methane in the deep ocean and forming mats up to 4 feet deep. The bacterium within a bacterium structure has also been found inside mealybugs.