SMILE Summer Teacher Workshop Tues August 2nd 2008

High School SMILE Club Activities Summer 2008

Ocean Science: Microbes to Whales

Teacher Resources Booklet

Pick Your Plankton
The Life Aquatic
A Whale of a Scale
Dissolving Issues
Project Brine Shrimp

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Plankton 101

General
- Drifting organisms
- Pelagic
- Derived from Greek word meaning ‘wanderer’
- Subject to current movement
- HOLOPLANKTON - spend entire life cycle as plankton e.g. algae, copepods, salps, some jellies
- MEROPLANKTON - only part of life cycle spent as plankton, e.g. urchins, seastars, crustaceans, worms, fish
- Abundance and distribution dependant on factors such as nutrient level, physical state of the water, abundance of other plankton

Groups
- **Phytoplankton** - planktonic plants, live near the water surface for sufficient light to support photosynthesis - basis of oceanic food webs
  - AUTOTROPHIC - organisms that use energy from light (photoautotroph) or inorganic chemical reactions (chemoautotroph) to produce complex organic compounds from simple inorganic molecules
  - PROKARYOTIC - organisms that lack a cell nucleus. 2 domains: bacteria and archaea (also bacterioplankton)
  - EUKARYOTIC - organisms whose cells are organized into complex structures enclosed within membranes
  - Most common: DIATOMS, CYANOBACTERIA & DINOFLAGELLATES
- **Zooplankton** - ‘Small animals’ which feed on other plankton and are non/weak swimmers (drift with the current flow), e.g. eggs/larvae of fish, copepods (crustaceans). Range in size from microbes to jellies
  - PROTOZOANS - ‘first animals’ e.g ameobas, ciliates. Often unicellular and heterotrophic (rely on consumption of other organisms for carbon), eukaryotic
  - METAZOANS - multicellular, eukaryotic, heterotrophic, mostly motile
  - Most common: FORMINIFERA, RADIOLARIANS, CILIATES, COPEPODS, EUPHAUSIIDS
- **Bacterioplankton** - include bacteria and archaea (single celled microorganisms), play an important role in nutrient recycling and remineralization of organic material in the water column
<table>
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<th>Size Groups:</th>
<th>Group</th>
<th>Size range (ESD)</th>
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<td></td>
<td>Megaplankton</td>
<td>&gt; 2×10⁻² m</td>
<td>metazoans; e.g. jellyfish</td>
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<td></td>
<td>Macroplankton</td>
<td>2×10⁻³→2×10⁻² m</td>
<td>metazoans; e.g. Pteropods; Chaetognaths; Euphausiacea (krill); Medusae; Tunicata;</td>
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<td>Mesoplankton</td>
<td>2×10⁻⁴→2×10⁻³ m</td>
<td>Cephalopoda; metazoans; e.g. copepods; Medusae; Pteropods; Tunicata; Chaetognaths;</td>
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<td>Microplankton</td>
<td>2×10⁻⁵→2×10⁻⁴ m</td>
<td>large eukaryotic protists; most phytoplankton; Protozoa (Foraminifera); ciliates; Rotifera; juvenile metazoans - Crustacea (copepod nauplii)</td>
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<td></td>
<td>Nanoplankton</td>
<td>2×10⁻⁶→2×10⁻⁵ m</td>
<td>Small Flagellates; Pyrrophyta; Chrysophyta; Chlorophyta; Xanthophyta</td>
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<td></td>
<td>Picoplankton</td>
<td>2×10⁻⁷→2×10⁻⁶ m</td>
<td>small eukaryotic protists; bacteria; Chrysophyta</td>
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<td></td>
<td>Femtoplankton</td>
<td>&lt; 2×10⁻⁷ m</td>
<td>marine viruses</td>
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Common Phytoplankton

DIATOMS:
- Mostly unicellular
- Eukaryotic
- Exist in colonies in the shape of filaments, ribbons, fans, zigzags or radial patterns
- Unique cell wall made of silicia (frustule)
- Commonly use in water quality studies
- ‘Bloom and bust’ lifestyle
- Important in carbon export to bottom ocean waters

CYANOBACTERIA:
- Blue-green algae
- Important in the marine nitrogen cycle
- Colonies form filaments, sheets or even hollow balls
- Have thick gelatinous cell wall
- Reduce nitrogen and carbon in aerobic conditions

DINOFLAGELLATES:
- Population distribution dependant on temp, salinity and depth
- Some endosymbionts, e.g. zooxanthellae (found with corals)
- Have flagella (tail like structures) for locomotion (water travel)
- Linked to ‘Red Tide’ – sudden marine algal bloom

Common Zooplankton

FORMINIFERA:
- Amoeboid protists
- Have pseudopods (false feet) for locomotion
- Feed on diatoms, small bacteria
- Calcareous tests (shells)
- Primarily marine, although some can survive brackish conditions

RADIOLARIANS:
- Amoeboid protozoans
- Produce intricate mineral skeletons
- Many needle-like pseudopodia to aid buoyancy

CILIATES:
- Often symbiotic
- Large protozoa
- Have hair-like organelles, cilia, used for swimming

COPEPODS:
- Small crustaceans
- Biggest source of proteins in the ocean
• Sometimes used as bioindicators
• Usually dominant members of the zooplankton in a region
• Often teardrop-shaped body with large antennae

EUPHAUSIIDS:
• Krill - small crustaceans
• Food for e.g. baleen whales, manta rays, whale sharks
• Feed on phytoplankton and lesser extent zooplankton
• Have a chitinous (glucose polymer) exoskeleton

BACKGROUND INFORMATION

Plankton by definition are organisms that are unable to swim against water currents. Most plankton are so small they can only be seen using a microscope. They are very numerous and form an extremely important part of the marine food chain. Phytoplankton are producers, transforming sunlight into food energy. Producers provide food for many different primary consumers. Zooplankton is food for many secondary consumers. Detritus is typically not considered plankton or a producer because it is not living. It is placed in its own category. The amount of detritus in the water depends on how much dead and decaying plant material is going into the water.

The species composition of the plankton when observed, can provide an indication of environmental health. The classic example is algal blooms associated with eutrophication, especially during large phytoplankton blooms known as "red tides." During red tides, some organisms disappear completely as water quality deteriorates, and the number of species and total overall number of different organisms found in the plankton decline. Plankton are usually categorized one of two ways:
1) Feeding mode: Phytoplankton = autotroph, Zooplankton = heterotroph or
2) life cycle: holoplankton (entire life cycle in water column as plankton), meroplankton (part of life cycle as plankton).

The amount of phytoplankton in the water depends on light availability, the amount of nutrients available, and the relative proportions of nutrients available (nitrogen and phosphorous are usually the limiting nutrients) and the temperature of the water. The amount of zooplankton in the water depends generally on the amount of phytoplankton and detritus available to feed on. As spring approaches and sunlight is available for longer hours and the temperature of the water rises, holoplankton and meroplankton become more abundant. Generally plankton are more abundant in coastal waters than the open ocean, and they are most abundant in estuaries and bays that can serve as nutrient traps and nursery grounds. Nearshore environments also have more terrestrial and marsh plant material to supply the detritus. Detritus can be food for primary consumers.

The community of life in the sea can be likened to a pyramid. At the base of the pyramid is a multitude of microscopic plants and animals called plankton, a word that
means "to wonder or drift". These living specks that range in size from a thousandths of a millimeter to some that are 2 millimeters or more in size, include all of the sea organisms that are too small or too weak to do anything but drift or wander about at the mercy of the currents and tides. This plankton supports a smaller number of larger forms which feed on them, and these in turn, a still smaller number of larger organisms, are fed upon by still fewer and larger organisms. Finally, at the top of the pyramid are the relatively few large fish and other sizable sea creatures that could not exist without all of the intervening layers of organisms in the pyramid. An example of the life and death involved in a single food chain would be to look at the stomach of the Hump-back Whale, which needs a ton of herring (5000 or more individuals) to feel full. Each herring in turn may well have six or seven thousand small crustaceans in its own stomach, each of which may have as many as one hundred and thirty thousand diatoms in them. In other words, some four hundred billion yellow-green diatoms sustain a medium-sized whale for only a few hours at most. Not only do the numbers of organisms increase as you go down the pyramid, so does the size of each organism get smaller.

At sea, as on land, the whole animal kingdom depends upon the plant kingdom for food. Plants alone are able to capture the energy of sunlight and use it in making sugars, starches and proteins that animals live on. The seaweeds found along the shores play a part in this process, but in the total chain of sea life it is a small part. More than 99 percent of all plant life in the sea consists of the microscopic phytoplankton floating in the upper hundred feet or so of the ocean. Of the thousands of different kinds of drifting single-celled plants, many will live only in water of certain temperatures or salinity.

By far the most important of the drifting phytoplankton are the single-celled algae known as diatoms, which constitute six-tenths of all planktonic life. Each diatom is a transparent crystal case with a single plant cell inside which viewed under the microscope look like a collection of tiny flashing bracelets, pendants, needles and anchors. Each tiny creature manufactures its own "house" from the minerals in the sea around it, building the walls from the same silica that sand is made of. Many odd projections help them float in the water.

Just as land plants depend upon minerals in the soil for growth, these tiny sea plants depend upon the nutrient salts and minerals in the seawater. In the spring, the oceans having been deeply stirred by winter storms, bringing to the surface a rich supply of bottom water. This nutrient rich water plus the increasing hours of sunlight, rouses the diatoms into a fierce intensity of growth. Hundreds of square miles of oceans surface will be tinged yellow or brown or green as the sea takes on the color hue of the grains of color contained in each tiny plant cell. The creatures have taken off on a veritable binge of diatom guzzling.

Also present in the thick planktonic soup are swarms of equally minute animal forms called Zooplankton. These animal forms include representatives of almost every phylum of the animal kingdom, including larvae and fingerlings of thousands of kinds of invertebrates and marine fish. Many of the zooplankton are found as plankton for only a brief part of their life. Only an infinitesimal fraction of all the eggs and young larval forms of life ever reach adulthood. About one creature in 10 million escapes a violent death, and that is usually inside the stomach of another sea creature. This fact
gives testimony to the prolific propagation rates of sea creatures. Some scientists have calculated that if all of the eggs laid by codfish were hatched and grew to maturity, the Atlantic would be packed solid with codfish within six years. Of course, nature doesn't let this happen. Probably the most numerous of the zooplankton organisms are the copepods. The copepods may be of either the herbivorous or carnivorous type, with the plant eating herbivores most numerous. These plankton types thus provide food for many larger animals.

Another type of plankton that is important to note are the radiolarians, which have skeletons that resemble tiny “snow crystals”. There are over 4,000 different types of radiolarians, which live, from the surface waters to the mid-depths of the oceans. These tiny “snow crystals” are made up of a dense inner layer of cytoplasm, which is separated from an outer frothy layer and by a central capsule pierced by systems of pores. Outside the capsule is the skeleton, usually made of silica. Radiating from the capsule are fine threads of moving cytoplasm, a trap for small planktonic organisms, which are digested in the outer cytoplasm. Foraminiferans have a similar means of catching food. They have fine threads of cytoplasm, which emerge through a calcium carbonate shell. There are nearly 1,200 species of marine foraminifers which range from 20 thousands of a millimeter to a size of 15 millimeters. Today calcareous sediments that are rich in their shells exist on over nearly half of the deep-sea floor.

The remains of the coiled foraminifers shells can be found in core samples from the sea floor. One fossil species, *Globochalina menardi* is found only in warm water sediments and can be used as a climate indicator for dates in the geologic past. Their absence can indicate a cold climate trend, such as times of glacial activity. Other foraminiferans are used as climate indicators due to their change in coiling direction with change in water temperature.

Plankton also includes the plant-animal, dinoflagellates, which are tiny specks that can move with whip-like feelers and eat other things but are also able to make their own food. Some dinoflagellates radiate an eerie glow of luminescence (a chemical reaction touched off in organisms by the disturbance of the sea).
Interesting Facts About Food Chains

(from ArchyTech.org)

Introduction

In an ecosystem, plants capture the sun's energy and use it to convert inorganic compounds into energy-rich organic compounds. This process of using the sun's energy to convert minerals (such as magnesium or nitrogen) in the soil into green leaves, or carrots, or strawberries, is called photosynthesis.

Photosynthesis is only the beginning of a chain of energy conversions. There are many types of animals that will eat the products of the photosynthesis process. Examples are deer eating shrub leaves, rabbits eating carrots, or worms eating grass. When these animals eat these plant products, food energy and organic compounds are transferred from the plants to the animals. These animals are in turn eaten by other animals, again transferring energy and organic compounds from one animal to another. Examples would be lions eating deer, foxes eating rabbits, or birds eating worms.

This chain of energy transferring from one species to another can continue several more times, but it eventually ends. It ends with the dead animals that are broken down and used as food or nutrition by bacteria and fungi. As these organisms, referred to as decomposers, feed from the dead animals, they break down the complex organic compounds into simple nutrients. Decomposers play a very important role in this world because they take care of breaking down (cleaning) many dead material. There are more than 100,000 different types of decomposer organisms! These simpler nutrients are returned to the soil and can be used again by the plants. The energy transformation chain starts all over again.

Here is a figure showing one such food and energy chain:
Producers. Organisms, such as plants, that produce their own food are called autotrophs. The autotrophs, as mentioned before, convert inorganic compounds into organic compounds. They are called producers because all of the species of the ecosystem depend on them.

Consumers. All the organisms that can not make their own food (and need producers) are called heterotrophs. In an ecosystem heterotrophs are called consumers because they depend on others. They obtain food by eating other organisms. There are different levels of consumers. Those that feed directly from producers, i.e. organisms that eat plant or plant products are called primary consumers. In the figure above the grasshopper is a primary consumer.

Organisms that feed on primary consumers are called secondary consumers. Those who feed on secondary consumers are tertiary consumers. In the figure above the snake acts as a secondary consumer and the hawk as a tertiary consumer. Some organisms, like the squirrel are at different levels. When the squirrel eats acorns or fruits (which are plant product), it is a primary consumer; however, when it eats insects or nestling birds, is it a tertiary consumer.

Consumers are also classified depending on what they eat.

Herbivores are those that eat only plants or plant products. Examples are grasshoppers, mice, rabbits, deer, beavers, moose, cows, sheep, goats, and groundhogs.

Carnivores, on the other hand, are those that eat only other animals. Examples of carnivores are foxes, frogs, snakes, hawks, and spiders.

Omnivores are the last type and eat both plants (acting as a primary consumers) and meat (acting as secondary or tertiary consumers). Examples of omnivores are:

- Bears -- They eat insects, fish, moose, elk, deer, sheep as well as honey, grass, and sedges.
- Turtles -- They eat snails, crayfish, crickets, earthworms, but also lettuce, small plants, and algae.
- Monkeys -- They eat frogs and lizards as well as fruits, flowers, and leaves.
- Squirrels -- They eat insects, moths, bird eggs, and nestling birds and also seeds, fruits, acorns, and nuts.

Trophic level. The last word that is worth mentioning in this section is trophic level, which corresponds to the different levels or steps in the food chain. In other words, the producers, the consumers, and the decomposers are the main trophic levels.

Food Webs

In looking at the previous picture, the concept of food chain looks very simple, but in reality it is more complex. Think about it. How many different animals eat grass?, how
many different foods does the hawk eat? One doesn’t find simple independent food chains in an ecosystem, but many interdependent and complex food chains that look more like a web and are therefore called food webs. A food web that shows the energy transformations in an ecosystem looks like this:

As you can see from this picture, food webs, with all their dependencies, can be very complex, but somehow nature balances things out so that food webs last a long time. Many species share the same habitat, their populations survive for many years, and they all live happily together.

The Ecological Pyramid

We described in the previous sections how energy and organic compounds are passed from one trophic level to the next. What was not mentioned is the efficiency of the transfer. In a highly efficient transfer almost all of the energy would be transferred -- 80% or more. In a low efficiency transfer very little energy would be transferred -- less than 20%. In a typical food chain, not all animals or plants are eaten by the next trophic level. In addition, there are portions or materials (such as beaks, shells, bones, etc.) that are also not eaten. That is why the transfer of matter and energy from one trophic level to the next is not an efficient one.
One way to calculate the energy transfer is by measuring or sizing the energy at one trophic level and then at the next. Calorie is a unit of measure used for energy. The energy transfer from one trophic level to the next is about 10%. For example, if there are 10,000 calories at one level, only 1,000 are transferred to the next. This 10% energy and material transfer rule can be depicted with an ecological pyramid that looks like this:

This pyramid helps one visualize the fact that in an ecological system there need to be many producing organisms at the bottom of the pyramid to be able to sustain just a couple of organisms at the top. In looking at the pyramid, can you guess how much larger the volume of each layer is as compared to the one just above it? Take a guess. It might not look like it but they are close to 10 times larger.
Microbial Food Webs

(From Ocean World Resources http://oceanworld.tamu.edu/resources)

Importance

Life in the ocean is microbe based. A large fraction of the biomass and biological activity in the ocean is microscopic, and it is an important part of earth's carbon and nitrogen cycles. There are 100 million times more bacteria in the ocean than stars in the known universe, and there are a thousand times more viruses than bacteria. Yet we know little about the relationships between microbes and their environment because only one tenth of one percent of the bacteria have ever been cultured. The traditional marine food web exists in a sea of microbes and dissolved carbon-based matter.

The pelagic food web is microbe-centric...The ‘diatom-copepod-fish’ food web is a relatively minor component. - Barber & Hilting (2000). The entire microbial food web, including protozoan microzooplankton, is typically some five to ten times the mass of all multicellular marine organisms. The potential metabolic dominance of microorganisms is even greater than their biomass suggests ... Put in more understandable terms, a mass of B. natrigens [a bacteria] equal to 100 humans would have an energy throughput of about a gigawatt, much the same as a nuclear power station. This metabolic potential under optimal circumstances would be rarely, if ever, achieved in nature for a number of reasons, notably the low concentrations of organic nutrients ... - Pomeroy et al (2007).

The microbial food web...has been a major theme of biological oceanography over the past two decades... - Ducklow (2000).

1800 genomic species based on sequence relatedness, including 148 previously unknown bacterial phylotypes. We have identified over 1.2 million previously unknown genes represented in these samples, including more than 782 new rhodopsin-like photoreceptors. - Venter et al (2004).
Organisms Comprising the Microbial Food Web

The microbial web includes bacteria and archaea (organisms without a cell nucleus) and very small eukaryotes (organisms having cells with a nucleus), ranging in size from 0.01 micrometers for viruses to 20 micrometers for ciliates, living in a dilute broth of carbon-based matter ranging from individual molecules to tangled polymers to colloids to clumps of dead matter called marine snow.

Here is an impressionistic view of microbial life in the sunlit waters of the ocean.

*The microbial loop: impressionist version.* A bacteria-eye view of the ocean’s sunlit layer. Seawater is an carbon-based matter continuum, a gel of tangled polymers with embedded strings, sheets, and bundles of fibrils and particles, including living organisms, as “hotspots.” Bacteria (red) acting on marine snow (black) or algae (green) can control sedimentation and primary productivity; diverse microniches (hotspots)
can support high bacterial diversity. From Azam (1998).

Some Vocabulary

Organisms can be classified by how they obtain energy and nutrients. Note -troph means to nourish. From Greek trophos = "nourishment." Phototrophs are nourished by photons of sunlight.

- **Autotrophs** synthesize their own nutrients. Phototrophs such as phytoplankton use sunlight and inorganic nutrients to synthesize carbon-based nutrients. Chemotrophs get energy from inorganic chemical reactions, such as the oxidation of methane (methanotrophs).
- **Mixotrophs** are organisms that can both photosynthesize (phototrophic) and ingest particulate carbon-based matter and bacteria (phagotrophic).
- **Heterotrophs** are organisms that must eat other organisms to obtain nutrients. People are heterotrophs.
  - **Bacteriovores** eat bacteria.
  - **Herbivores** eat plants.
  - **Carnivores** eat animals

Microbial Web

Microbial food web. DOM = Dissolved Organic Material. POM = Particulate Organic Material
The Marine Food Web

(by Tony Corey with Dave Beutel, taken from Rhode Island SeaGrant Factsheets, http://seagrant.gso.uri.edu/factsheets/)

Big fish eat little fish; that’s how the food cycle works. Of course, there’s more to it than that. A whirlwind spiral up the marine food chain goes like this: Phytoplankton—microscopic plants drifting in the water—feed the copepods and other grazers that feed the small menhaden and crustaceans that feed the stripers and bluefish that feed the tunas and swordfish that feed us.

Taking it a little more slowly and stopping at each trophic level (feeding level), we start with the primary producers. Single-celled plants, microscopically small phytoplankton floating in the upper layers of the ocean, use the sun’s energy to photosynthesize chemical compounds, such as carbohydrates. These carbohydrates can be eaten for energy, and these plants—mostly diatoms and algae—are the foundation of the ocean’s entire biological community.

Taking advantage of this abundant plant life, zooplankton—animal planktonic forms—drift through the water grazing on the phytoplankton. These "grazers" include copepods and larval stages of fish and benthic, or bottom-dwelling, animals that make up the second trophic level.

Zooplankton range from microscopic copepods to more substantial coelenterates, including jellyfishes, all drifting passively on the ocean currents. The larger zooplankton may be food for proportionally larger animals, such as baleen whales and other marine mammals. Still, the most abundant zooplankton are the copepods. By sheer biomass and their trophic position, copepods are the crucial link between the primary producers and the rest of the ocean food web. They make up most of the animal mass in the ocean, and they account for one-half to two-thirds of the zooplankton in Narragansett Bay.

Copepods and other plankton, both animal and plant, nourish filter-feeding organisms that strain their food directly from the water. This third trophic level includes molluscan bivalves, amphipods, and larval forms of many fish and crustaceans as well as small fish such as alewife and menhaden. These finfish are schooling fish, and they can make a significant dent in the zooplankton population. A single adult menhaden, for example, can sift 8 gallons of water a minute. If a school of perhaps 100,000 of these fish passes through an area, it can temporarily decimate planktonic life.

In the same way, a school of bluefish may eat through a school of menhaden, creating the next trophic level. Because menhaden are the food of choice for species all the way up the food ladder to apex predators, they are popular bait fish. It is bluefish, though, that feast most voraciously on the menhaden, wasting as much as they consume. The waste sinks to the bottom, where it may be eaten by bottom-dwelling carnivores, such as lobsters, or decomposed by bacteria and ultimately returned to a nutrient form usable by plants.
The bluefish, striped bass, and fluke that feed on bait fish are among the most popular recreational fishing targets in Rhode Island. Like species at successively higher trophic levels, these predators are food for every level along the way. Not only are they hunted from the water but also from the sky, plucked by ospreys, cormorants, and other sea birds. Their primary predators, though, are larger fish, the game fish that migrate from coastal to deep ocean waters in search of sustenance. Among these high-level hunters are tunas, sharks, and billfishes such as swordfish. These animals are both dominant predators in the marine environment and prey for other large animals at the apex of the food web.

At this level of predation, the hunt is cutthroat and circular. Marine apex predators are opportunistic feeders—they eat what is available. This means they may sometimes eat each other: The bluefin tuna that is such a prize for humans is also a target of toothed whales, swordfish, sharks, and even other tuna. Sharks, depending on the species, eat seals, tuna, and other sharks.

Opportunistic feeders may also eat larval forms of their own predators: Squid, for example, feed on juvenile bluefish but become the quarry for adult bluefish. At the extreme, opportunistic feeders may eat the larval forms of what they eventually become: Lobsters, for instance, are notoriously cannibalistic.

Even animals that have no immediate predators ultimately contribute nutrients to the food web. Large whales and sea turtles, while not specifically targeted for consumption, do produce waste. The waste may be either excretions from digestive processes or dead tissue. It is eventually broken down by decomposers—bacteria, primarily—in a process that releases nutrients that plants can use to start the whole cycle again.

Organisms higher up the food ladder tend to be larger in size and fewer in number than those at lower levels. This is partly a function of the many trophic steps required to meet advanced energy needs. Because the efficiency rate at each trophic level is only about 10 percent, each succeeding level supports a smaller total biomass to compensate for the 90 percent loss of food value.

So if it takes 100,000 pounds of phytoplankton to feed 10,000 pounds of copepods, and these copepods feed 1,000 pounds of silversides, and these silversides feed 100 pounds of mackerel, and these mackerel feed 10 pounds of bluefin tuna, this tuna nourishes only one pound of apex predator at the end of the chain. When all is said and done, that tuna steak on the dinner plate culminates a web of interdependencies that passes sustenance from a one-celled plant all the way up to the most complex organisms on Earth.
Scale Drawings

(taken from Regents Exam Prep Center, http://regentsprep.org/Regents/math/scale/Lscale.htm)

A scale drawing is a drawing that represents a real object. The scale of the drawing is the ratio of the size of the drawing to the actual size of the object. Architects and map-makers are examples of people who use scale drawings in their field. What one does is represent a length by a much smaller figure in order to put a facsimile of it on paper.

Example:

The length of a stadium is 100 yards and its width is 75 yards. If 1 inch represents 25 yards, what would be the dimensions of the stadium drawn on a sheet of paper?

Solution:

You can take an intuitive approach to this problem:

100 yards by 75 yards = 4 inches (HINT: 100 / 25) 75 yards = 3 inches (HINT: 75 / 25) Therefore, the dimensions would be 4 inches by 3 inches. Or you can establish a proportion: (Notice that the inches are all on the top and the yards are all on the bottom for this solution. Other combinations are possible.)

Length: \[25x = 100 \times 4\] inches

Width: \[25y = 75 \times 3\] inches

WHAT IS A CETACEAN?

(taken from American Cetacean Society, http://www.acsonline.org)

At first glance, whales, dolphins and porpoises may appear to be similar but different types of animals. Whales tend to be very large animals that live way out at sea, while dolphins and porpoises seem to be much smaller and can be seen playing with boats, and often from the beach. However, all whales, dolphins and porpoises share certain characteristics that put them together in the scientific order Cetacea (from the Latin word “cetus” (a large sea animal) and the Greek word “kEtos” (sea monster)). They all have a fairly streamlined body, as well as other adaptations that allow them to live a completely aquatic life, without ever having to come onto land. Their front limbs have become paddle-like flippers, and, externally, they have lost their back limbs completely. While these features have caused them to become fish-like in appearance, they also all share a characteristic that strongly separates them from fishes, and links them to otters, cows, dogs, and people. They are all mammals.
WHAT IS A MAMMAL?

So, then, what is a mammal? Mammals share several characteristics with other types of animals. Certainly, mammals breathe air with lungs, which immediately separates them from the fishes. This does not make them a mammal, though, since birds and reptiles also breathe air with lungs. Like birds, mammals are endothermic, which means that they maintain a constant inner body temperature (often referred to as "warm blooded"). For the most part, mammals give birth to live young. However, 3 species of mammals do lay eggs, and several species of fish and reptiles give birth to live young. Hair, or fur, is useful as a determining feature, since no other animals have "true" hair (The "hair" on some arachnids and insects are actually sensory bristles, and are not similar to mammal hair in anything but casual appearance). But many cetaceans are hairless, and some other mammals, like rhinos, are not immediately recognized as having hair. The one characteristic that all species of mammals posses is that the mothers produce milk for their young. No other type of animal in the world does this. It is this feature, in combination with the other characteristics that serve to separate mammals from all the other groups of animals.

Cetaceans, therefore, are referred to as Marine Mammals - Mammals that live in the ocean. Cetaceans aren't the only group of marine mammals, however. There are also pinnipeds (seals, sea lions, and walruses), sirenians (manatees and dugongs), sea otters, and even polar bears! However, from ancient Greek pottery to today's advertisements and movies, cetaceans seem to have most completely captured the hearts and minds of people all over the world.

CETACEAN EVOLUTION

Evolution is the process by which all living things change over long periods of time. This process usually occurs in response to changes in the environment. Whales and dolphins evolved over a period of 55 million years from an animal that looked very different from the cetaceans that live today.

The exact ancestor of cetaceans is still unknown, but recent fossil findings indicate that one of the earliest cetaceans is an animal called a pakicetid. Pakicetids lived on land and resembled a short-legged wolf with hoof-like claws. It walked on four legs and was a meat eater. Some pakicetids may have hunted along the shore, probably to catch fish. They may have begun to find more food in deeper waters or may have begun to escape from predators by swimming. Over time, the pakicetids body began to change to gradually adapt to this new aquatic environment.

Over millions of years, pakicetids evolved into a primitive group of whales, called archaeocetes, which means "ancient whale." Initially, archaeocetes were small, seal-like animals, with four legs and few marine specializations. They may have spent some time on land at first. Gradually, the archaeocetes evolved into large, eel-like animals highly adapted for a marine life. Their limbs were replaced with paddle-like flippers to help them move in water. The archaeocetes ultimately evolved into two groups of whales, mysticetes (baleen whales) and odontocetes (toothed whales), which are still alive today.
Fossils have helped scientists identify the ancient relatives of whales, such as pakicetids and archaeocetes. Fossils are the preserved remains of animals and plants in rocks. By identifying and comparing fossils, scientists can begin to see how different types of animals on earth are related. The fossilized wrist bones of pakicetids, for example, reveal that they most likely evolved from the same ancestor as the modern day artiodactyls (even toed hoofed animals). This is strongly supported by fossils of pakicetids that show a combination of features of both artiodactyls and cetaceans. So although they appear to be very different animals, the closest living relatives to whales and dolphins are cows, hippos, and giraffes!

GENERAL CETACEAN ANATOMY

Cetaceans come in all sizes, and have many adaptations to help them survive in the ocean. They are even broken up into two major groups (based in part on feeding strategies): the Mysticetes and Odontocetes. All cetaceans, however, have a common overall body plan. They have a streamlined, torpedo-like shape that allows them to swim efficiently through the water. It is no coincidence that humans have designed submarines and airplanes in a similar shape. For the most part, they also share a number of common body parts as well.

Cetacean Body Parts

**Flukes:**
The flukes are often referred to as the whale's tail. However, the flukes are large appendages at the end of the tail (also referred to as the caudal peduncle). The flukes are made up of fibrous connective tissue, without any bone or muscle inside. These paddle-like structures serve to help push the whale through the water, much like the swim fins of a human diver. Like a diver's fins, the flukes move up and down to push the whale through the water, as opposed to the side to side motion of fishes. When swimming near the surface, the water displaced by the flukes causes smooth circular patterns to appear on the surface, which observers often call "footprints" or "flukeprints". The whales can actually be tracked by these prints as long as they remain near the surface. (The same effect can be observed in a bathtub or pool by putting your hands under the water and moving them up and down near the surface.)

**Dorsal Fin:**
The dorsal fin is the fin on the back of most cetaceans. Like the flukes, it is made of fibrous connective tissue. Most polar species (beluga, narwhals, right and bowhead whales), as well as gray whales, lack dorsal fins. Many scientists believe it helps keep balance, aids in turning when chasing prey, and assists in thermoregulation (maintaining internal body temperature).

**Pectoral Fins:**
The pectoral fins, or flippers, are used mainly for balance and steering. The bones of a whale's flippers are similar to the bones found in a human hand. Differences in the size or shape of individual bones enhance the whale's ability to steer. Shortened wrist bones and longer finger bones provide added power, better balance, and help the whale to maneuver.

**Blowholes:**
A cetacean’s nostrils, or blowholes, are located at the top of its head. This facilitates the movement of the cetacean through the water since only the top of the head needs to break the surface of the water to allow the cetacean to breathe. Cetaceans are voluntary breathers; meaning that, unlike land mammals, their nostrils are sealed shut in their relaxed state. The whale must open their blowholes to breathe. Mysticetes have two blowholes, and odontocetes have only one.

**Rostrum:**
The rostrum is the very front end of the cetacean, often called the snout or beak. It is structurally comprised of the same bones humans have between the bottom of their nose and their upper jaw. On cetaceans, these bones have been elongated to the rostrum. This gives the cetacean a more streamlined shape, making it easier to move through the water.
What is ocean acidification?

(taken from the Ocean Acidification Network, http://www.ocean-acidification.net/)

The ocean absorbs approximately 1/3rd of the CO2 emitted to the atmosphere from the burning of fossil fuels (1). However, this valuable service comes at a steep ecological cost - the acidification of the ocean. As CO2 dissolves in seawater, the pH of the water decreases, which is called "acidification".

Since the beginning of the industrial revolution, ocean pH has dropped globally by approximately 0.1 pH units.

Past and present variability of marine pH. Future predictions for years shown on the right-hand side of the figure are model-derived values based on IPCC mean scenarios. From Pearson and Palmer (2), adapted by Turley et al. (3) and from the Eur-Oceans Fact Sheet No. 7, "Ocean Acidification - the other half of the CO2 problem", May 2007 (4).

While these pH levels are not alarming in themselves, the rate of change is cause for concern. To the best of our knowledge, the ocean has never experienced such a rapid acidification. By the end of this century, if concentrations of CO2 continue to rise exponentially, we may expect to see changes in pH that are three times greater and 100 times faster than those experienced during the transitions from glacial to interglacial periods. Such large changes in ocean pH have probably not been experienced on the planet for the past 21 million years (5).

How is atmospheric CO2 responsible for ocean acidification?

When CO2 dissolves in seawater, it forms carbonic acid, which releases hydrogen ions into solution. Acidity is a measure of the hydrogen ion concentration in the water, where an increase in hydrogen leads to an increase in acidity (and a decrease in the pH scale used to quantify acidity). These hydrogen ions then combine with carbonate ions in the water to form bicarbonate. Carbonate ions are the basic building blocks for
the shells of many marine organisms. Thus the formation of bicarbonate through this chemical reaction removes carbonate ions from the water, making them less available for use by organisms. The combination of increased acidity and decreased carbonate concentration has implications for many functions of marine organisms, many of which we do not yet fully understand.

The details of the reactions look like this:

When CO2 dissolves in seawater, carbonic acid is produced via the reaction:

$$\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3$$

This carbonic acid dissociates in the water, releasing hydrogen ions and bicarbonate:

$$\text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$$

The increase in the hydrogen ion concentration causes an increase in acidity, since acidity is defined by the pH scale, where $\text{pH} = -\log [\text{H}^+]$ (so as hydrogen increases, the pH decreases). This log scale means that for every unit decrease on the pH scale, the hydrogen ion concentration has increased 10-fold.

One result of the release of hydrogen ions is that they combine with any carbonate ions in the water to form bicarbonate:

$$\text{H}^+ + \text{CO}_3^{2-} \leftrightarrow \text{HCO}_3^-$$

This removes carbonate ions from the water, making it more difficult for organisms to form the CaCO3 they need for their shells.

The oceans are not, in fact, acidic, but slightly basic.

Acidity is measured using the pH scale, where 7.0 is defined as neutral, with higher levels called “basic” and lower levels called “acidic”.

Historical global mean seawater values are approximately 8.16 on this scale, making them slightly basic.

To put this in perspective, pure water has a pH of 7.0 (neutral), whereas household bleach has a pH of 12 (highly basic) and battery acid has a pH of zero (highly acidic).

However, even a small change in pH may lead to large changes in ocean chemistry and ecosystem functioning. Over the past 300 million years, global mean ocean pH values have probably never been more than 0.6 units lower than today (6). Ocean ecosystems have thus evolved over time in a very stable pH environment, and it is unknown if they can adapt to such large and rapid changes.
What can we expect in the future?

Based on the emissions scenarios of the Intergovernmental Panel on Climate Change and general circulation models, we may expect a drop in ocean pH of about 0.4 pH units by the end of this century, and a 60% decrease in the concentration of calcium carbonate, the basic building block for the shells of many marine organisms (8).
Changes in atmospheric CO2 under the “business as usual” scenario to the year 2100 and associated changes in ocean pH and carbon chemistry. Adapted from Wolf-gladrow et al., 1999 (9).

Today, the surface ocean is saturated with respect to calcium carbonate (including its several mineral forms, i.e., high-magnesium calcite, aragonite, and calcite), meaning that under present surface conditions these minerals have no tendency to dissolve and that there is still enough calcium and carbonate ions available for marine organisms to build their shells or skeletons. Colder and deeper waters are naturally undersaturated with respect to calcium carbonate, where the water is corrosive enough to dissolve these minerals. The transition between saturated surface waters and undersaturated deep waters is called the saturation horizon. Because of the increase in CO2 entering into the ocean from the atmosphere, the saturation horizons for calcium carbonate have shifted towards the surface by 50-200 meters compared with their positions before the industrial revolution (10). This means that the zone occupied by undersaturated deep waters is growing larger and the zone occupied by the saturated surface waters is growing smaller.

By 2050, this saturated surface zone will begin to completely disappear in some areas of the ocean. High-latitude surface waters, already naturally low in calcium and carbonate ion concentration, will be the first to have undersaturated surface waters with respect to aragonite, with undersaturations for the calcite phase of calcium carbonate expected to follow 50-100 years later (11).

The figure below by Feely et al. (12) shows aragonite saturation levels from before the industrial revolution to 2100 and how these saturation levels affect the growth of both shallow and deep corals (models based on the work of Orr et al., 2005, (11)). Before the industrial revolution, we see large bands of the tropical ocean that are optimal for growth. By 2040, these same bands are only adequate, and by 2100 most areas are only marginal at best.
Many scientists believe that stabilizing atmospheric CO2 concentration at 550 parts per million (ppm) may avoid the worst impacts from climate change. Atmospheric concentration of CO2 is currently ~380 ppm and, if no precautionary action is taken, is expected to reach 550 ppm by the middle of this century. However, if we consider the impacts of CO2 on ocean chemistry and ecosystems rather than on climate considerations alone, there are strong arguments to be made for a lower stabilization target of 450 ppm.

In order to prevent changes that would lead to undersaturation of aragonite and put marine ecosystems at risk, it has been suggested that the average pH of surface waters should be prevented from dropping by more than 0.2 units below the pre-industrial value. Stabilization of atmospheric CO2 concentrations at 450 ppm by the year 2100 would lead to a pH decrease of about 0.17; stabilization at 540 ppm by the year 2100 would lead to a decrease of 0.23 pH units. With stabilization at 450 ppm, about 7% of the Southern Ocean will still become undersaturated with respect to aragonite. At 550 ppm, about half of the Southern Ocean will be undersaturated (13, 14, 15).

References used in this section


(4) Eur-Oceans Fact Sheet No. 7 (2007), "Ocean Acidification - the other half of the CO2 problem".


How will ocean acidification affect marine life?

Corals, calcareous phytoplankton, mussels, snails, sea urchins and other marine organisms use calcium (Ca) and carbonate (CO3) in seawater to construct their calcium carbonate (CaCO3) shells or skeletons. As the pH decreases, carbonate becomes less available, which makes it more difficult for organisms to secrete CaCO3 to form their skeletal material. For animals in general, including invertebrates and some fish, CO2 accumulation and lowered pH may result in acidosis, or a build up of carbonic acid in the organism’s body fluids. This can lead to lowered immune response, metabolic depression, behavioural depression affecting physical activity and reproduction, and asphyxiation. Since the oceans have never experienced such a rapid acidification, it is not clear if ecosystems have the ability to adapt to these changes (1,2). Effects of ocean acidification on organisms and ecosystems are still poorly understood. Over the last few years, research has intensified significantly to fill the many knowledge gaps.

Corals?

early 500 million people depend on healthy coral reefs for sustenance, coastal protection, renewable resources, and tourism, with an estimated 30 million of the world's poorest people depending entirely on the reefs for food (3).

Coral reefs face two challenges from increasing atmospheric CO2. First, higher CO2 concentrations in the atmosphere are linked to warmer global temperatures, which in turn lead to warmer water temperatures. Corals are very sensitive to temperature change: a 1-2º C change in local temperature above their normal summer maximum can lead to a phenomenon called ‘bleaching’, whereby the corals expel their vital algal symbionts (algae which live in the cells of the coral), leaving the coral tissues translucent.

In 1998, a single bleaching event led to the loss of almost 20% of the world’s living coral. Corals can recover from these events but repeated episodes are likely to weaken the coral ecosystem, making them more susceptible to disease and causing a loss of biodiversity.

The second challenge faced by corals is the increasing acidity of the water caused by higher CO2 concentrations (4). Lowered calcification rates affect the reef’s ability to grow its carbonate skeleton, leading to slower growth of the reef and a more fragile structural support, which makes it more vulnerable to erosion.

By the middle of this century, the estimated reduction in calcification rates may lead to more reef area erosion than can be rebuilt through new calcification (5). See "How is ocean acidity changing? What can we expect in the future?".
Phytoplankton and Zooplankton?

Changes in the carbonate chemistry of the ocean may have a strong negative impact on many plankton and zooplankton species that form the base of the marine food chain.

In almost all calcifying organisms tested, ranging from single-celled organisms up to reef building corals, there is a decrease in the ability of the organism to produce calcium carbonate in more acidic waters (6). One study has documented the changes in two species of coccolithophores grown under conditions expected by the end of this century, where both species show significant decreases (25 - 45%) in calcification rates and clear signs of structural damage in their shells, which may affect their physical functioning and reproduction. However, not all species of calcifying organisms are negatively affected by increased acidity, and more research is needed to understand these mechanisms and possible adaptation pathways(7).

The first two photos on the left show scanning electron microscopy photographs of the calcifying phytoplankton *Gephyrocapsa oceanica* under CO2 conditions of today (top) and under the high CO2 conditions expected by the end of this century (middle).

Pteropods are small "winged snails" that form the basis of the food chain for many commercial fish species. A recent study has observed shell dissolution in living pteropods when exposed to the carbonate content of the ocean expected in the next 50 years in the high latitudes (6).

If ocean acidification leads to disturbances in the populations of these organisms, other non-calcifying organisms may out-compete them for food and nutrients, leading to a change in the ecosystem composition of the system. Although some of the affected organisms are important prey for higher organisms, it is not yet clear how such changes would affect fisheries.

Other Marine Animals?

The rate at which mussels and oysters build their shells is also lower in a high CO2 (low pH) environment, which could have dire consequences on the aquaculture of molluscs, an industry of 12 million tonnes per year and a market value of over $10.5 billion US dollars (8).

Higher marine life forms, animals such as invertebrates and even fish may be affected
by lower pH environments through acidosis (an increase in carbonic acid in the body fluids causing lower pH values in blood) leading to lowered resistance, metabolic depression, behavioural depression affecting physical activity and reproduction, and asphyxiation (9).

Cephalopods such as squid seem to be particularly sensitive to CO2 increases because their energy-demanding way of swimming requires a good supply of oxygen to the blood, which is impaired by lowered blood pH values.

Depending on the effect of other stressors like warmer temperatures, sensitivities may differ between life stages of a species, with larvae possibly being more sensitive. The full range of physiological mechanisms eliciting whole animal responses to elevated CO2 levels is still insufficiently explored. Current experiments address the extent to which genomic information defines sensitivity and if animals can physiologically adapt to elevated CO2 levels.

Direct effect of CO2 on marine mammals (seals and whales) or birds are not expected because they breathe air, and thus will not be directly affected by acidification of the surrounding seawater.

Changing food webs will, however, affect these animals and their well-being in ways that are not fully understood.

**What regions of the ocean will be affected first?**

The first areas to be impacted by ocean acidification are high-latitude regions and deep water areas, where the natural carbonate levels are lowest and closest to becoming undersaturated with respect to carbonate (see How is ocean acidity changing?). Cold water coral communities, which often occur at depths of hundreds of meters and are found in all the world’s oceans, are slow-growing and fragile ecosystems that are thought to be important nursery habitats for many commercially important fish species as well as home to thousands of other organisms, making them hotspots of biodiversity that are still poorly understood. Other benthic ecosystems and organisms such as molluscs, star fish, and sea urchins are also expected to be impacted early owing to the already-low carbonate concentrations in the deep sea environment.

As acidification continues and the carbonate saturation horizons becomes shallower, it is estimated that the surface waters of high latitude regions will become undersaturated with respect to aragonite by 2050, with calcite saturation levels
becoming undersaturated 50-100 years later. This will affect all calcareous organisms in the productive surface waters, including coccolithophores, foraminifera, and pteropods, which form the base of the marine food-web for many species and play an important role in the natural cycling of carbon from the surface to deep ocean. Effects first seen in the high-latitude surface waters will also be seen in the surface waters of other regions as CO2 levels increase, with impacts determined by the composition and functioning of each specific ecosystem.

Coral reef ecosystems in the warm waters of tropical and subtropical regions are among the most diverse and productive of marine ecosystems, supporting hundreds of millions of people directly through subsistence harvesting. These valuable ecosystems, which are found mostly in developing countries, will experience reduced calcification rates as ocean acidification progresses, leading to slower growth rates and a more fragile skeletal structure. It is estimated that by 2050, we may be losing more reef area to erosion than can be rebuilt through new calcification. There is minimal understanding of how the combined effects of warming seas (which cause coral bleaching) and reduced calcification due to acidification will interact.

References used in this section


BRINE SHRIMP

By Christine Duerr (taken from Rhode Island SeaGrant Factsheets, http://seagrant.gso.uri.edu/factsheets/)

Just over a centimeter in size, the adult brine shrimp *Artemia* is an extremely well-known animal because of its importance as a food source for fish and crustaceans raised in home aquariums, aquaculture systems, and in laboratories. One can buy brine shrimp at practically any pet display. It looks like a powdery brown substance but in reality the substance is thousands of cysts—eggs surrounded by protective cases. When added to water, these cysts will hatch into shrimp nauplii within a few hours. Under magnification, the elongated shape and eleven pairs of limbs give this organism a shrimplike shape, but *Artemia* actually falls into an order of primitive crustaceans. Various pigments from the phytoplankton that the shrimp eats give hues of blue, green, and red to the otherwise transparent body.

Because brine shrimp are so desirable as a food source they are found naturally in only about 250 locations around the world, in water bodies so salty that predators and competitors for the same food cannot survive. The only companion life to the brine shrimp in these ponds are a few species of bacteria and algae, which provide forage for the shrimp.

In the United States, in areas such as the Great Salt Lake, the brine shrimp's yearlong life cycle usually begins in early spring. After hatching, the larvae will go through 15 molts before it reaches the adult form. These begin to die by October and most will be gone by December. In the period from May to December females will give birth to either live nauplii or, if conditions are wrong for larvae survival, they will lay a number of cysts. These will be dispersed by winds and waves. Often the cysts drift to shore, where they remain until spring rainfalls wash them back into the water. These will later hatch when water, temperature, salinity, oxygen, and other seasonal conditions are right.

It is this ability of the brine shrimp cysts to remain dormant for long periods of time and then be easily hatched that has made them an easy live food for the use of tropical fish hobbyists and aquaculturist as well as a valuable organism for research. These cysts can withstand wide fluctuations in temperature due to their ability to lose, and regain, practically all of their intracellular water. For at least a century the brine shrimp, because of its characteristics and its short life span, has been useful to a variety of researchers in genetics, histology, toxicology, radio biology, biochemistry, molecular biology, and ecology. Because the cysts are also very small and require no food, they were chosen as test organisms for the early space experiments. Cysts housed both within and outside the U.S. Apollo and the U.S.S.R. Cosmos spacecraft helped scientists determine the effects of ultraviolet radiation on living cells.

Despite the fact that brine shrimp have been studied ever since 1755, when they were first observed in the salt ponds of Lymington, England, there were major gaps in knowledge about the organism, particularly its nutritional value, up to the late 1970s. Brine shrimp have been found to be a critical food for certain fish at early stages to insure good survival and increased growth. An international group of scientists from...
Rhode Island, Wales, Spain, and Belgium investigated many of the still unanswered questions about the differences among brine shrimp strains and found that geographical location and water quality are important factors in determining the organism's composition of fatty acids, proteins, pesticide concentrations, and other substances. If anyone is having trouble with a brine shrimp strain and suspects that it is the cause of problems in survivability and growth of fish, a standard stock is available from the Artemia Reference Center in Ghent, Belgium, which has been determined to be free of pesticides and to maintain good growth and survival in organisms to which it is fed.
Indicator Species

Biological indicator species are unique environmental indicators as they offer a signal of the biological condition in a watershed. Using bioindicators as an early warning of pollution or degradation in an ecosystem can help sustain critical resources. While indicator species is a term that is often used, it is somewhat inaccurate. Indicators are actually groups or types of biological resources that can be used to assess environmental condition. Within each group, individual species can be used to calculate metrics such as percent Achnanthes minutissima (a diatom species) or groups of species (e.g., EPT taxa) or individual orders (e.g., Caddisfly larvae - Order Trichoptera) in an effort to assess water quality conditions.

Marine environments also utilize biological indicators. While this site focuses predominately on freshwater resources, marine/tidal indicators are also quite important in sustaining biodiversity and preserving and restoring marine and estuarine resources.

Invertebrates as Indicators

Aquatic invertebrates live in the bottom parts of our waters. They are also called benthic macroinvertebrates, or benthos, (benthic = bottom, macro = large, invertebrate = animal without a backbone) and make good indicators of watershed health because they:

- live in the water for all or most of their life
- stay in areas suitable for their survival
- are easy to collect
- differ in their tolerance to amount and types of pollution
- are easy to identify in a laboratory
- often live for more than one year
- have limited mobility
- are integrators of environmental condition

Some benthos are found more often, and in larger amounts, in waters that are generally clean, or unpolluted by organic wastes. Without too much organic matter, the waters usually have lots of oxygen for the benthos. This use as an “indicator” of water quality has been occurring for many years. For example, stoneflies are often
considered to be clean water benthos. But when thinking about worms and midges, water quality professionals often view these as indicators of dirty water, especially in rivers and streams.

Unfortunately, it is not always a clear decision to make. Oxygen is only one factor affecting the benthos. Others include toxic chemicals, nutrients, and habitat quality. Some types of stoneflies may actually be found in waters that are not so clean, and likewise some types of worms and midges can be found in cleaner waters. So it is important to understand that there are some more complex methods to make these types of decisions, and to determine whether waters are healthy or polluted for aquatic life. Depending upon the type of aquatic environment, such as standing waters like lakes and wetlands, the categories of clean, somewhat pollution tolerant, and pollution tolerant don't necessarily apply.
Useful Websites

**Plankton**
- The Plankton Net [http://www.biosci.ohiou.edu/faculty/currie/ocean/](http://www.biosci.ohiou.edu/faculty/currie/ocean/)

**Aquatic Food Webs**
- Water on the Web [http://waterontheweb.org](http://waterontheweb.org)

**Whales**
- Pacific Whale Foundation [http://www.pacificwhale.org](http://www.pacificwhale.org)

**Ocean Acidification**
- The Ocean Acidification Network [http://www.ocean-acidification.net/](http://www.ocean-acidification.net/)
- Intergovernmental Panel on Climate Change [http://www.ipcc.ch/](http://www.ipcc.ch/)

**Environmental Indicators**
Other Resources

Videos

Barnacles gathering plankton
http://www.youtube.com/watch?v=ZbUc4u-veZE

Global Plankton Blooms
http://www.youtube.com/watch?v=JloWlDA6ccM&feature=related

Marine Zooplankton
http://www.youtube.com/watch?v=aIFiWrGwAZY&feature=related

Beneath the Surface
http://www.youtube.com/watch?v=UkMK3Wm0oNQ

Plankton
http://www.youtube.com/watch?v=LuXMz3j9E8k&feature=related

Freshwater Aquatic Biomes
http://video.google.com/videoplay?docid=1576105336432750777&ei=-Z-gSOXzB5norQPNxYGxAw&hl=en

Climate Change and the Oceans
http://www.youtube.com/watch?v=yAvtDaCAwR0

Eye in the Sea, deep-sea video footage
http://www.mbari.org/earth/EITS/eits_video2.htm

Whale Video Gallery
http://www.whalewatch.com/photos/video.php

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Articles


Discover Magazine, A Global Case of Osteoporosis, July 2008

http://www.nature.com/nature/journal/v437/n7059/abs/nature04095.html

Aumont, O.; Bopp, L. (2006). "Globalizing results from ocean in situ iron fertilization studies". Global Biogeochemical Cycles 20 (2)

Bugs as Indicators of Water Quality - Florida Department of Environmental Protection
http://www.dep.state.fl.us/water/bioassess/bugind.htm

The Case of the Mysterious Macros! - 2007 ThinkQuest Team, CSI: Cahaba Student Investigators
http://library.thinkquest.org/06aug/00051/index.html

Additional Educational Resources

Brain Pop http://www.brainpop.com/

Hatfield Marine Science Center Education http://hmsc.oregonstate.edu/education/

The Bridge http://www.vims.edu/bridge/

National Marine Educators Association http://www.marine-ed.org/

Northwest Aquatic and Marine Educators http://www.pacname.org/