A Unique Planet

Life would not be possible without large amounts of water. Water has the ability to retain heat, moderate temperature, dissolve many chemicals, and suspend nutrients and wastes. All life, from a jellyfish to a dusty desert weed, depends on saline water within its cells to dissolve and transport chemicals..indicating that simple, self-replicating-living molecules arose somewhere in the early ocean.

How long ago...probably at least 3.4-3.5 billion years ago as the oldest fossils yet found indicate.

- **The most striking and distinctive feature of our planet, when viewed from space, is the amount of water on its surface. Its called the water planet. And, while some is contained in clouds as water vapor and a few percent is present in lakes, rivers ice caps and in cavities of pores of rocks, most is contained within the oceans. The sea probably played a part in man's life and experience from the very earliest times, even his prehuman ancestors are likely to have included shellfish from the shore in their diet.**

- **Water transportation was used at least since 50000 years ago to colonize Australia and maybe even longer but little trace remains because of the materials used for primitive boat building, reeds, wood, skins rapidly decompose. While the Greeks, Pacific Islanders and Vikings were responsible for some of the earlier spectacular maritime achievements, the Portuguese sea men were the first true pioneers of European oceanic exploration. Sent out by Prince Henry in 1420's they continued new discoveries, and charted these with considerable skill. In the 1460's they devised a system of nautical astronomy to improve navigation.**

The map shows the world known to Homer at about that time, and shows that knowledge of the seas was centered in the Aegean, and extended generally throughout the eastern Mediterranean. The Greeks of that time imagined the world to be a large disk with upturned edges, with the center of the disk in the Aegean, surrounded by a river.

Although the Phoenicians had traveled into the Atlantic centuries earlier, the Greeks were probably unfamiliar with the Atlantic Ocean, or any seas beyond the Mediterranean. Between the eighth and sixth centuries BC, Greeks of the historic period began voyaging more extensively beyond the Aegean, although not venturing out of the Mediterranean until the fourth century BC..

Renewed interest in natural history began to increase by the 16th century, and over the next few hundred years there were many studies carried out by what we would today call amateur naturalists.

These were usually professional men in other fields, often physicians or explorers, but generally were individuals not specifically employed to carry out natural history studies.

Notable among these are the explorations of Humboldt and of James Cook, who made extensive voyages and observations of the natural world.

One of the early professional naturalists that made significant contributions to marine biology was Charles Darwin. Darwin, most famous for his later works on theories of evolution, was commissioned early in life as a naturalist on the

The British ship HMS Challenger investigated the oceans worldwide between 1872-1876, finding a large number of new species. Sir Charles Wyville Thomson (Professor of Natural History at the University of Edinburgh, and director of the civilian scientific staff on the Challenger) published the findings of the Challenger expedition in a series known as the Challenger Reports.

Until the middle of last century, marine biologists relied primarily on nets, grabs, and dredges to collect samples in almost every marine habitat except the intertidal zone, where collections could also be made by hand and

organisms could be directly observed. As an example of the ships and techniques, the U.S.S. Albatross of the United States Fish Commission carried out a number of expeditions from 1887 to 1925. Some of the equipment used on the Albatross are pictured below

In 1934, zoologists William Beebe and Otis Barton were the first to observe relatively deep sea habitats directly aboard the "bathysphere", which remained tethered to a surface ship during the entire dive.

They reached a depth of 923 meters (3,072 feet). The advent of modern Self Contained Underwater Breathing Apparatus (SCUBA), underwater photography, and manned submersibles have allowed us to see firsthand much of the marine environment that we previously could not observe.

The development of a wide variety of electronic measuring devices and instruments, unmanned submersibles, and remote sensing by satellites and aircraft has also greatly increased our ability to measure and study parts of the marine environment that are difficult to observe in person.

Even so, because of logistical problems associated with conducting research in much of the marine environment, our knowledge of conditions in most of the seas and oceans lags behind our knowledge of the terrestrial environment.

- **By the 1480's a pilot could calculate his latitude. Longititude could not be measured yet so "running down the latitude" was practiced...sailing to the latitude of landfall, for three to four hundred miles seaward and then sailing due east or west to the landfall. Columbus used his method on his return voyage from the New World.**
- **It wasn't until 1760+ that John Harrison's fourth chronometer and the lunar distance method of calculating longitude provide answers to measure longititude at sea.**

<u>Latitude and Longitude</u>

- **1st and 4th Chronometer by John Harrison**

- ***Albatross***

- **In August 1882, the United States Commission of Fish and Fisheries launched the first vessel built especially for marine research by any government—the steamer *Albatross*. Perhaps even more impressive than being the first government vessel equipped throughout with electric lights, *Albatross* has been credited with discovering more new marine species than any other research vessel.**

- **The American Navy's' ship the Blake carried out research from 1877-80 in the Caribbean gulf of Mexico and coast of Florida and from there the science continued to flourish... Note names!**

- ***Pathfinder* was the first survey ship to have a nautical chart printing press installed onboard. During World War II, the vessel churned out thousands of charts for fleet units. Captain Junius Jarman of the C&GS was instrumental in developing techniques for chart printing in a shipboard environment.**

<u>Latitude and Longitude</u>

Longitude

•On the globe, lines of constant longitude ("meridians") extend from pole to pole, like the segment boundaries on a peeled orange

<u>Latitude and Longitude</u>

•Every meridian must cross the equator.

•Since the equator is a circle, we can divide it--like any circle--into 360 degrees, and the longitude of a point is then the marked value of that division where its meridian meets the equator.

Latitude and Longitude

•Any location on Earth is described by two numbers--its latitude and its longitude.

•If a pilot or a ship's captain wants to specify position on a map, these are the "coordinates" they would use.

Latitude and Longitude

•On a globe of the Earth, lines of latitude are circles of different size.

•The longest is the equator, whose latitude is zero, while at the poles--at latitudes 90° north and 90° south (or -90°) the circles shrink to a point.

- **Did you know that you can use the stars to tell directions at night? The North Star, or Polaris, is usually within 1-2 degrees east or west of true north. Polaris is at the top of the handle of the Little Dipper, a constellation that is easy to find in the Northern Hemisphere.**
- **You can also use the North Star to determine latitude in the Northern Hemisphere. Use an *astrolabe*, used to determine the altitude of objects above the horizon, to find your latitude. You can make your own simple astrolabe using a protractor, plastic straw, 12-inch piece of string, and a metal weight (a small bolt or a washer works well). Tie one end of the string to the hole in the middle of your protractor. (If there is not a hole, drill one in the center of the flat-edged piece on the protractor.)**

Latitude and Longitude

•1st and 4th Chronometer by John Harrison

Latitude and Longitude

•What that value is depends of course on where we begin to count--on where zero longitude is.

•For historical reasons, the meridian passing the old Royal Astronomical Observatory in Greenwich, England, is the one chosen as zero longitude.

Latitude and Longitude

•Old Royal Astronomical Observatory in Greenwich, England,

Latitude and Longitude

•Located at the eastern edge of London, the British capital, the observatory is now a public museum and a brass band stretching across its yard marks the "prime meridian.“

• Tourists often get photographed as they straddle it--one foot in the eastern hemisphere of the Earth, the other in the western hemisphere.

Latitude and Longitude

• A lines of longitude is also called a meridian, derived from the Latin, from meri, a variation of "medius" which denotes "middle", and diem, meaning "day."

•The word once meant "noon", and times of the day before noon were known as "ante meridian", while times after it were "post meridian."

•Today's abbreviations a.m. and p.m. come from these terms, and the Sun at noon was said to be "passing meridian".

Latitude and Longitude

•All points on the same line of longitude experienced noon (and any other hour) at the same time and were therefore said to be on the same "meridian line", which became "meridian" for short.

Latitude and Longitude

•Time Zones

• On the Mississippi river in the 1850s, the leadsmen also used old-

fashioned words for some of the numbers; for example instead of "two" they would say "twain". Thus when there was only two fathoms left under the boat they would call "by the mark twain!". The American writer Mark Twain, a former river pilot, likely took his pen name from this cry.

<u>Sonar</u>

•How does Sonar work?

•Sonar is a device that is used to detect objects through sound waves.

•There are two main types of sonar: Active and Passive.

• Sonar technology enters a signal into the water in a narrow beam which has the speed of about 1500 m/s.

•Ocean Floor Contour using Sonar

•If there is an object in the beam, its sends sound energy back to the sonar dish.

•Then the distance is calculated by range = sound speed x travel time / 2.

• In active sonar a pulse signal is sent to a transducer which changes the electrical signal into a sound signal.

•After that it is put out into the water and it detects returning echos.

• A receiver amplifies the soft echos and measures the range of each object.

•Old Method

•New Method up to 121 beams.

•Geosat from Orbit!

•Geosat Image

Radar

•Radar works by sending out a radio wave at a very high frequency.
•When the radio signal hits raindrops part of the signal bounces back to the radar.
•The signal travels at the speed of light (over 350,000 kilometers per second!).
•Knowing exactly how fast the signal is travelling, means that we can tell how far away the rain is by timing how long it takes for the signal to travel to the rain and then bounce back to the radar.
•This happens so fast that most radars send out about 1000 signals (called pulses) each second!!

Loran

•A long-range radio navigation position fixing system using the time difference of reception of pulse type transmissions from two or more fixed stations.
• This term is derived from the words long-range electronic navigation.

- **All radionavigation systems, including GPS, have their weaknesses. On February 7, 2008, the U.S. Department of Homeland Security (DHS) announced that it would begin implementing Enhanced Loran (eLoran), an enhanced and modernized version of Loran-C, as the U.S. national backup system. This independent, positioning, navigation, timing, and data delivery system would mitigate the safety, security, or economic effects of a loss of GPS for critical infrastructure applications, especially those that require precise time and frequency.**

GPS

•GPS system of satellites--the Global Positioning System. That network of 24 satellites constantly broadcasts its positions, and small hand-held receivers exist which convert those signals into positions accurate within

15 meters or about 50 feet.

•In circular orbits at distances of about 4.1 Earth radii (26,000 km or 16,000 miles), GPS satellites continually broadcast their precise locations, and these can be read by small portable receivers, relatively inexpensive.

•Using a built-in computer, these receivers then derive their own precise position on the ground, within 10-50 meters.

•Russia operates its own system, GLONASS, and European countries are planning a third on

GLONASS constellation status, 13.01.2009г.

Total satellites in constellation 20 SC Operational 16 SC

In commissioning phase 3 SC

In maintenance 1 SC

In decommissioning phase -

•Originally developed by the US Department of Defense (whose users derive from them even more precise positions), the GPS satellites are widely used by the public--by ships at sea, airplanes, hikers in the wilderness, even drivers trying to navigate large cities

- **By means of four or more satellites, an absolute position in a three dimensional space can be determined. A 3D-position fix also gives the height above the earth surface as a result.**
- **By constantly recalculating its position, the GPS receiver can additionally determine the speed and direction of a movement (referred to as "ground speed" and "ground track").**

Introduction To the Oceans

•About 71% of the surface of the planet is covered in salt water.

•Beneath the depth averages 3,8 km giving it a volume of 1370 x 106 km3.

•Since life exists throughout this immense volume, the oceans constitute the single largest repository of organisms on the planet.

•These organisms include representatives of all phylums and are tremendously varied but all are subject to the properties of the sea water that surrounds them.

• Many features common to these plants and animals are the results of adaptations to the watery medium and its movements.

•Its necessary therefore, to examine the physical and chemical conditions of seawater and aspects of its motion (oceanography) and look at the environment where the organisms live.

•The mean depth is 4km (2.5 miles)and its interconnected from the Arctic to Antarctic.

•Seawater flows freely among the basins transporting dissolved materials, heat and marine organisms.

•Seawater mixes from basin to basin/per 1000 years but regional characteristics of the seawater do exist.

•The major basins are the Pacific, Atlantic, Indian, Arctic, Southern ocean and the boundaries are artificially defined.

•Movement of water moderates world climate by distributing heat from equatorial water to the poles.

•Warm currents flow toward the poles from the equator (Gulf Stream) heating northern latitudes.

•Cold water from the Arctic and Antarctic basins flow beneath the oceans surface toward the tropics...cooler water near the equator.

•SEA LEVEL

•The sea level has undergone dramatic changes. 15000 years ago 120m below present level.

•As it fell portions of the continental shelf were exposed changing position of coastline.

•Ice age/Wisconsin glacial period, the ocean water froze into glaciers.

•It is still rising.

•The rise slowed 3000 years ago and has only risen 10m since.

•CO2 is warming the Earth and the ice could melt and flood low lying areas in the next 1000 years.. Green House effect.

•The Ocean Floor

•Prior to the 1920's, they used weighted rope to probe depths.

•1920's the echo sounder (SONAR-(sound navigation and ranging) which analyzed sound waves which bounced off the oceans bottom and returned to the ship.

•The Meteror (1925-7) did the 1st ocean survey with sonar.

•Common topographical features of the oceans include: Continental margin and deep sea as the major divisions. Continental Margin

•Continental shelf-underwater extension of the continental land mass.

• 8% of the total surface area of the world ocean, yet its one of the most productive parts of the ocean.

•It gradually drops down to the 100-200m depth.

•Formation of Continental Shelf

•Continental slope begins where continental shelf plunges down.

•As the steepness decreases, this zone is called the continental rise.

•Locations of Continental Shelfs

•Soft sediment of the shelf exposed to erosion from rivers and then the glaciers started to melt, excess water cut canyons into the shelf.

• Ocean refilled, flooding shelf and forming underwater canyons.

•The rise slowed 3000 years ago and has only risen 10m since.

•Underwater canyons occur in the margins which resulted from when the ocean level was lower with rivers flowing over them eroding the soft sediments making deep gouges.

• Underwater landslides along the sides of the canyons make the canyon bigger

•Types of Reefs

•Fringing-along the land

•Barrier-a lagoon between the land and reef

•Atoll-a reef around a lagoon (formally an island since eroded.

•Trench Formation

• Converge: one plate dives under another, crumples and forms trenches...

•Turbidity Currents

•Avalanche-like sediment movements caused when turbulence mixes sediments into water above a sloping bottom.

•Since this sediment-filled water is now denser than the surrounding water, thick, muddy water can run down the slope at speeds up to 17mph.

•These currents may have been responsible for enlarging submarine canyons

Introduction to Physical Oceanography

Lecture Notes

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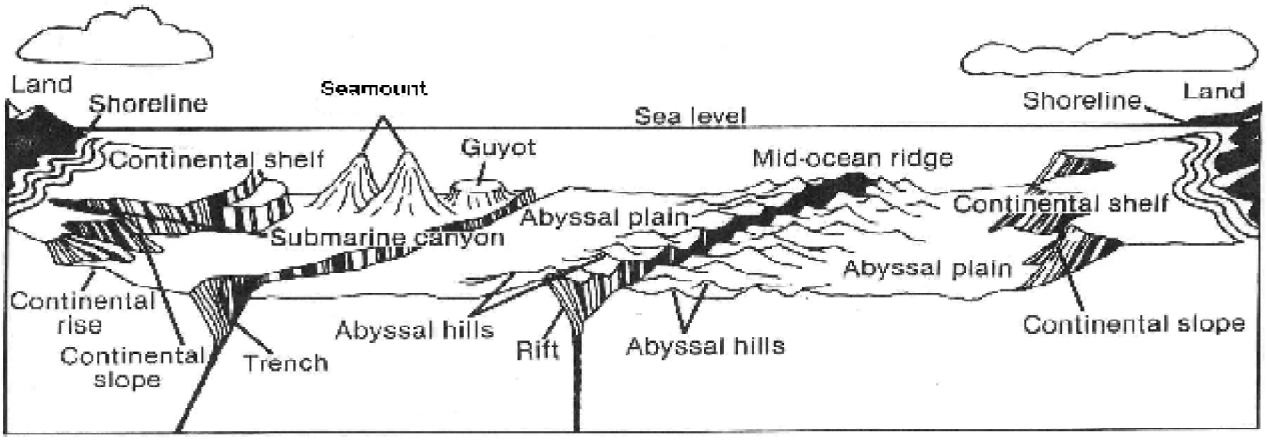

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profiles of the ocean floors developed from wartime advances and these described patterns of underwater trenches, Mt. ranges and volcanoes along the flat abyssal plane. The idea that the earths crust is composed of movable rigid plates floating on a denser mantle formed.

SEA LEVEL

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CO2 warming and will flood in next 1000 years.. Green House effect.

Worksheets

Readings

Ocean Floor Profile

Questions from reading 3

3 "Undersea Birth Throes of a New Hawaiian Island

1. How long has the "Hawaiian jet" been producing lava ?

2. What is the name of the new Hawaiian Island, not yet above the water line?

3. How high is this new " to be" island?

4. What two volcanoes are powered by the Hawaiian jet?

Return to Selections

Back to Home Page

PLATE TECTONICS

There are 8 major plates, up to 100 miles thick and move slowly. They know the direction and speed so can figure out what the continent was like before it moved. The Atlantic has been growing for 150 mil years.

The theory of continental drift or plate tectonics was only established in the 1960's. 200 million years ago, Pangaea fractured and started moving apart 180 mil. yrs ago.

The force that moves the plates over the semi-solid layer of the upper mantle /asthenosphere is the convection currents (large temp. difference between the mantle and crust) and moves plates either 1. apart, 2. together or 3. laterally.

1. apart new material rise as magna /molten rock filling spaces (rifts form mid ocean ridge.

evidence 1965 research vessel Eltanin did magnetic studies

1969 Glomar Challenger did cores from Pacific ant ridge

1977 Project Famous used submersibles

2. Converge one plate dives under another, crumples and forms trenches...usually but not always (mountains) the area is called a seduction zone

Island arcs formed/volcanoes/ from turbulence from the melting of the descending plate.

3. Lateral-sideswipe and cause earthquakes volcanoes and deformations

Mineral deposits in trenches and ridge areas related to tectonic movements.

Geo-sil theory concentration of copper and other metals form as plates melt and separates from crust material, rise in subduction zone near trenches and continues rising until it cools and gets exposed by weathering rocks.

Hydrothermal vents...water percolates into fissures around the rift valley, sinks and heats to 320'C in fissures (pressure) and the heated water dissolves metals and it rises to the seafloor surface, openings flow through the hydrothermal vents, mix with cold water, minerals settle to bottom forming deposits.

Robert Ballard witnessed milky bluish clouds spewing in a Pacific rift zon

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Plates

•ALFRED WEGENER
(1880-1930) German climatologist and geophysicist who, in 1915, published as expanded version of his 1912 book *The Origin of Continents and Oceans*. This work was one of the first to suggest continental drift and plate tectonics.

•He suggested that a supercontinent he called *Pangaea* had existed in the past, broke up starting 200 million years ago, and that the pieces ``drifted'' to their present positions. He cited the fit of South America and Africa, ancient climate similarities, fossil evidence (such as the fern *Glossopteris* and *mesosaurus*), and similarity of rock structures.

•The force that moves the plates over the semi-solid layer of the upper mantle /asthenosphere is the convection currents (large temp. difference between the mantle and crust) and moves plates either

• 1. apart,

•2. together or

•3. laterally.

• Surtsey, Iceland;63.30 N 20.62 W;170 m elevation
This photo, taken on November 30, 1963, shows the sixteen-day-old cone which became the Island of Surtsey, off the southern coast of Iceland. Born from the sea, it has provided scientists a laboratory to observe how plants and animals establish themselves in new territory. The eruption began 130 m below sea level, where it proceeded quietly until the height of the volcano approached the sea surface. Then the explosive activity

could no longer be quenched by the sea. A black column of volcanic ash announced the island's birth on November 14, 1963. Jets of dense black ash shot skyward and the towering eruption cloud rose to a height of 9 km. By April of 1965, ash had blocked sea water from the crater area. Lava flows became prominent, forming a hard cap of solid rocks over the lower slopes of Surtsey. This prevented the waves from washing away the island. The three and one-half year eruption was over in June 1967. Photo credit: Howell Williams

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•Hydrothermal vents...water percolates into fissures around the rift valley, sinks and heats to 320'C in fissures (pressure).

• The heated water dissolves metals and it rises to the seafloor surface,openings flow through the hydrothermal vents, mix with cold water, minerals settle to bottom forming deposits.

•Robert Ballard witnessed milky bluish clouds spewing in a Pacific rift zone.

Global Hotspots

Pacific Plate Motion

- **Moves W/NW at approx. 5-10 cm per year**
- **Currently being subducted beneath the N. American and Eurasian plates (Aleutian Trench)**
- **Moves over stationary hot spot in Earth's mantle**

Hot Spot Theory

- **1963- Proposed by J. Tuzo Wilson**
- **Evidence:**
  - Oldest Volcanic rocks of Kauai (most NW island) are dated at 5.5 million years old and greatly eroded.
  - Oldest rocks of the Big Island are approx. 0.7 million years old.

Hot Spot: magma from within the Earth's mantle pushes up the Earth's crust resulting in the formation of an undersea volcano.

The Next Generation: Loihi

- **Located off the Southwest coast of Hawaii**
- **Currently, 6000 ft above the sea floor (about 1km from the surface)**
- **Predicted to poke through surface in about 1 million years. So, don't make vacation plans just yet!**

Caribbean
Tectonics
Puerto Rican
Tectonics and Seismic Hazard

Puerto Rican
Tectonics and Seismic Hazard

. Seawater Chemistry
Water Chemistry Information

Lecture Notes

Pressure

Air is .1% as dense as water and the ocean pressure is directly proportional to its depth and acts in all directions within the water <- ->^

The atmospheric pressure is 1kg/cm2 (14.7lbs/sq in)= 1 ATM. An increase of 1 atm for each 33' or 10m and at 30m (100') the pressure is 4atm (1atm/10m + 1atm for air). Mariana trench 11,034m (36192')= 1000atm.

This is known as hydrostatic pressure and because of it, many organisms restricted to particular level or depth and those that can go to all areas have evolved adaptations to compensate for the change.

Density

Salt water is 800x greater in density than air (supports big organisms) The density is affected by temperature. As water cools, water molecules move closer, increasing density..2. 4'C max density (1g/cm3) 3. cooler decreases density..ice= .92g/cm3 and is less dense so it floats. Some organisms have glycoprotein in their blood lowering freezing point of their internal fluid.

Temperature: Water has a high heat capacity...ability to resist rapid temperature changes and is transferred by convection. Temperature is the most important physical factor in the marine environment limiting the distribution of ocean life by effecting density, salinity, gas concentration in oceans. There is minimum vertical mixing because warm water (on top) can't replace cold water. The thermocline is a narrow zone between warm surface water and cold bottom water. Temp. effects

ectotherms and endotherms.

It also affects the density as does salinity so both salinity and temp. must be considered to work out density. Variation of -2 (28) to +30 (86). Satellites are now used to monitor water temperatures.

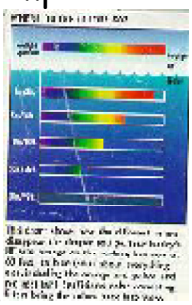
Gases

Gases enter the ocean by diffusion from the atmosphere until it reaches saturation level...different for each gas. The most important are O, CO2 and N. Dissolved O2 = aerobic (use O2 and none= anaerobic...used for respiration and corrosion.

O2 makes up 21% of the atmosphere but in the coldest oceans its less than 1% to as much as 9%. O2 comes from photosynthesis in the ocean and this diffuses into the air because water can only hold small amounts of O2. The ocean provides 50% of atmosphere O2. Turbulence increases the amount of O2 that can dissolve in water. Dissolved O2 declines rapidly as depth increases...why?? At the surface as O2 is used, its replaced quickly by photosynthesis and as it deepens, respiration becomes greater than photosynthesis.

Light

Used for photosynthesis by plants with chlorophyll. Much is reflected back to atmosphere and as wave action increases, more is reflected. Lots are absorbed by water but 65% of all light is absorbed within the 1st meter and only 1% gets to 100m. The sunlit area is the photic zone where 70% of worlds photosynthesis. At the depth where photosynthesis=rate of respiration its the compensation depth.



Lower area (not sunlit) is the aphotic zone =90% of the ocean.

Certain wave lengths are absorbed..blue goes far down and this is vital to photosynthesis as most autotrophs use red and blue light.

Photic zone ranges from 1m in estuaries to 100m in open ocean and depends on turbidity. Turbidity increases along the coast as suspended solids increase. This causes a shift of balance because where blue is the predominant absorbed light in crystal clear water, suspended solids enable wavelengths of green to penetrate deeper than blue in coastal waters. The highly productive water of the coast is greenish and estuaries are brownish. The compensation depth is shallower in coastal waters and below this the autotrophs can't get enough light for photosynthesis to meet the energy requirements.

Seawater Composition

Water...the wonderful stuff held together by hydrogen bonds which causes ice to melt at 0 instead of -90. It causes the absorption of lots of heat to melt ice and same to evaporate water...cooling. It allows water to hold heat...heat capacity and the amount of heat needed to change water temperatures help for cooling of the earth.

Water is a solvent for most substances especially salts. The characteristics of seawater are due to the nature of pure water and the materials dissolved in it. The solids in seawater come from two sources, the chemical weathering of rocks washed to the sea by the rivers and the earth's interior through hydrothermal vents.

Major components of seawater vary slightly. Two processes add salts to the ocean--river discharge and water circulations through hydrothermal vents (hotsprings). All ocean water cycles through these vents every 8-12 million years. These work together making seawater, with the springs adding and removing chemicals.

Salinity is expressed as concentration of ions in a liter of water or # of grams of dissolved solids in 1000g of seawater. Seawater 1000g samples have 34.7g of dissolved matter so salinity is expressed as 34.7 ppt (0/000) or 3.47 % . The remaining 96.5% is pure water. There is a rule of constant proportions and the chloride ions make up 55.27% of however much salt is present in a seawater sample. Also even though organisms may be exposed to changes in salinity...rivers rain etc, they don't have to deal with changes in rations of the various ions dissolved in the

seawater. Today they can measure electrical conductivity in conjunction with temperature of water sample..conductivity is proportional to salinity.

Although constant, the concentration can change with addition or removal of water. Different in local areas depending on rate of evaporation/precipitation and volume of fresh water dumped. (red sea=40, Mediterranean=38 lack of rain fall and high evaporation. Black Sea=18 Baltic Sea=8..low evaporation and high runoff.

Euryhaline=organism can tolerate large salinities and fluctuation.

Stenohaline can't tolerate large salinity changes.

Vertical change surface layer mixed..uniform beneath the halocine layer. large salinity changes above..The salinity changes with depth.

Chapter Questions

Worksheets

Ocean Profile

Return to Selections

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Circulation (CURRENTS)

Lecture notes

Circulation of ocean water has profound effects on organisms living in the open ocean and coastal embayments. Within bays and estuaries, tidal currents circulate and mix ocean and bay water transporting larva from offshore to bays and nutrients from bays to ocean.

Waves break along the shore at angles and the current flow parallel to the coast. This is the longshore current or littoral drift which is the movement of water within the breaker zone and strictly from breaking waves

Currents in the open oceans (Graphic)

Surface and wind driven currents carry plankton. The thermohaline/deep sea circulation brings O2 to abyss and disperses eggs and young of deep sea creatures and transports heat.

The suns irregular heating patterns of the atmosphere creates regular wind patterns around the world. Frictional drag of prevailing wind along the ocean surface waters causes them to move. (friction decreases with depth)

Coriolis effect-wind and water are deflected to the right in the northern hemisphere (left in Southern Hemisphere) due to the earths rotation and causes water to rotate slowly in circular rivers or gyres.

Ekman spiral is formed when wind driving surface currents and the coriolis effect creates additional deflection of water 100-200m below. Each succeeding layer is deflected further to the right. In some cases this spiral is responsible for a phenomenon known as UPWELLING.

Movements of surface water away from the shore enables cold, dense bottom water to rise and mix with warmer surface water (UPWELLING). it carries significant amounts of dissolved minerals to the oceans upper sunlit limit supplying fertilizer to

plants near the surface...grow food for the fish. When upwelling stops, the numerous fish disappear..El nino--- see 2003 Florida East Coast Upwelling Event Information

Deep sea circulation is driven by temperature and density deficiencies within the ocean. these are called thermohaline currents. As the water cools it becomes more saline..some water form ice crystals so salt is left behind. Water is more salty, higher density, sinks to a denser layer, pushes out polar water toward equator, horizontally moving deep water masses are deflected by the coriolis bending. These currents help deliver dissolved O2 to the bottom communities where there is no circulation. Bottom water that is devoid of O2 is called anoxic/deoxygenated water.

Major ocean currents....show..explain where its warm and cold

.Chapter Questions

Readings

Questions for current reading

5,3 UPWELLING Questions

1. **What is upwelling?**
2. **What does it do to the ocean and how does this effect productivity?**
3. **What effect causes this deflection of the water currents?**
4. **Where are major upwelling areas on earth?**
5. **What causes downwelling?**
6. **How does this effect deep waters?**
7. **How is productivity of California coastal waters increased?**

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WAVES

Lecture notes

Waves are of practical significance to us...they may swamp a small boat, smash supertankers, damage offshore structures, force commercial vessels to slow their speed, damage shore structures, make students skip school when they want to surf and determine what adaptations organisms along the shoreline must have in order to exist there.

Exposure to waves, tides, currents and pressure presents significant obstacles to the survival of animal and plants living in the ocean. Waves pound the shore, tides inundate and expose marine organisms severally restricting the distribution of seashore life.

Waves are mechanical energy that has been transferred from wind, earthquakes, landslides, or other waves to the ocean water.

Most of the transfer is by wind and waves travel outward from the energy source. As more energy is supplied, waves become larger.

Properties of waves

3 factors that determine size of wind generated waves.

1. time of contact

2. velocity of wind

3. fetch-distance over which wind is in contact with water.

Particles in the ocean are set into an elliptical motion as wind energy acts on water. The energy of the particles move (is transferred) through the ocean, not the particles. Their movement makes the waves shape.

The highest part of the wave is the crest, lowest is the trough, the distance between successive crests or troughs is the wave length, and the vertical height- from the top of the crest to bottom of trough is the wave height, the time between successive crests/troughs passing a fixed point is the period of a wave. Sharp peaks are called seas and as waves move out of their area, the crests become rounded forming a swell, a long, low wave that can travel thousands of miles.

As the wave approaches the shallow water, it changes shape. -the wave length decreases. -the height increases as particles encounter resistance from the bottom. -pathway of the particles become more elliptical as it gets closer to the coastline. -bottom resistance slows the waves. -shortens wave length when depth is 1/2 wavelength. When depth decreases less than 1/2 wavelength (or 1.3x height) the frictional drag along the bottom and forward motion of the wave and steepness of the crest causes the wave to break or collapse against the shore. Stored energy is released as the water falls against the shore.

Marine organisms along the ocean are affected by wave actions. Sandy and rocky shores, exposed to the direct assault of strong waves are known as a high energy environment, as opposed to beaches in protected estuaries, bays and lagoons which is a low energy environment.

Winter usually has higher crests and shorter wave lengths than summer thus release more energy on the shore.

Tsunami- a wave caused by undersea earthquakes near island arcs and trenches that make enormous waves. Energy is transferred to water as the coastal plates shift. Travel through the sea at 100+ mph with a wave length of 100miles when reaching the coast, wave lengths shorten and heights can increase to 100'. Krakatoa 1883 the wave moved around the world.

HOW A WAVE FORMS

To create a wave, a **generating force** is required. This is a result of a pulse of energy which produces waves (throw a stone etc.) The waves produced by the generating force moves away from the point of disturbance.

When the rock hits the surface, it disturbs and displaces the water surface. As the rock sinks, the displaced water flows back into the space from all sides and its momentum forces it upward resulting in a higher surface. The elevated water falls back causing a depression below the surface, which is filled and in turn sets up a series of waves that move outward and away from the point of disturbance until they are dissipated through friction among the water molecules.

The force that causes water to return to the level of undisturbed surface is the **restoring force**. This has to do with the surface tension (elastic quality of the surface due to the cohesive behavior of the water molecules.) This affects smaller waves, but larger waves are pulled back by the force of gravity and are called **gravity waves**.

The most common generating force for water waves is moving air or wind.

As the wind blows across a smooth water surface, the friction or drag between air and water tends to stretch the surface resulting in wrinkles. Surface tension acts to restore a smooth surface. The wind and surface tension create small waves called **ripples** or **capillary waves**. You can see these as wind moves over a smooth surface of a pond or lake, and are called cat's paws as they move across the surface keeping pace with the wind.

As the wind blows, energy is transferred to the water over large areas, for varying lengths of time, and at different intensities. As waves form, the surface becomes rougher, and its easier for the wind to grip the roughened water surface and add energy. There is an increased frictional drag between the air and the water. As the wind energy is increased, the oscillations of the water surface becomes larger and the restoring force changes from surface tension to gravity. A wave is a result of the interaction between a generating force and a restoring force. Generating forces include any occurrence that adds energy to the sea surface: wind, landslide, sea-bottom faulting or slipping, moving ships, and even thrown objects.

PARTS OF THE WAVE

The portion of the wave that is elevated above the undisturbed sea surface is the **crest**. The portion that is depressed below the surface is the **trough**. The distance between two successive crests or two successive troughs is the length of the wave or **wavelength**, and the **height** of the wave is the vertical distance from the top of the crest to the bottom of the trough. The **amplitude** is equal to 1/2 the wave height or the distance from the crest or trough to the still water or equilibrium surface. The **period** is the time required for two successive crests (or troughs) to pass a point in space.

While the dimensions and characteristics of waves vary greatly, the regularity in the rise and fall of the water's surface and the relationship between wavelength and wave periods allow math approximations to be made giving more insight to the behavior and properties of waves.

WAVE MOTION

The particles of water get set into motion when a wave passes across the water surface. The ocean wave does not represent a flow of water but a flow of motion or energy from its origin to its eventual dissipation at sea or loss against land.

As a wave crest approaches, the surface water particles rise and move forward. Immediately under the crest the particles have stopped rising and are moving forward at the speed of the crest. When the crest passes, the particles begin to fall and to slow their forward motion. It reaches a maximum falling speed and zero forward speed when the midpoint between crest and trough passes. As the trough advances, particles slow in falling rate and start to move backward until at the bottom of the trough they reach the maximum backward speed and neither rise or fall. As the remainder of the trough passes, the water particles begin to slow their backward speed and start to rise again, until the mid-point between the crest and trough passes.

Now they start their forward motion and continue to rise with the advancing crest. The motion creates a circular path or **orbit** for the water particles. This is the motion that causes a boat to bob!

The surface water particles trace an orbit whose diameter is equal to the wave height. The same motion is transferred to the water particles below but less energy of motion is found at each succeeding depth. The diameter of the orbits decrease and become smaller and smaller as the depth increases. At a depth of 1/2 the wavelength, the orbital motion has decreased to almost zero.

All this is based on sine waves and while in the ocean, there is a bit of difference because due to real waves, the crests are sharper than the troughs so there is minimal transport of water in the direction of the waves, the motion is often ignored when studying waves.

WAVE SPEED

It is possible to relate the wavelength and period of the wave in order to determine the wave's speed. The speed of the wave (C) is equal to the length of the wave (L) divided by the period (T):

Speed = length/period or C=L/T

While the period of the wave is not hard to measure at sea, the wavelength is because of no fixed reference point. So the oceanographer determines the period (T) and calculates the wavelength (L) by another equation.

In deep water, the wavelength is equal to the acceleration due to gravity (g) divided by 2p times the square of the wave period (T). The value of the earth's gravity (g) is 9.81 m/sec^2

L=g/2p (T^2) or a simpler one .....**L(in feet)=5T^2 or .L(in meters)=1.5T^2**

interesting!

DEEP-WATER WAVES

Deep water waves must occur in water that is deeper than 1/2 the wave's length so in order for the waves to behave like the description below, it must be a deep water wave.

STORM CENTERS

Most waves at sea are progressive wind waves. They are build up by the wind, restored by gravity and travel in a particular direction. These waves are formed in local active storm centers or by steady winds of the trade wind and westerly wind belts. An active storm may be large, with unsteady winds and varying directions and strength. The winds in the storm flow in a circular pattern around the low-pressure storm center creating waves that move outward and away from the storm in all directions. In the storm center, the sea surface is jumbled with waves of all heights, lengths and periods. There are no regular patterns. Sailors call this a sea. As waves are being generated, they are forced to get larger by the input of energy **forced waves**. Due to variations in the winds of the storm area, energy at different intensities is transferred to the sea surface at different rates, resulting in waves with a variety of periods and heights. Once a wave is created with its period, the period doesn't change. The speed may change but the period remains the same. The period is a constant property of the wave until the wave is lost by breaking at sea, through friction, or crashing against the shore.

SWELL

Once energy or generating forces no longer effect the waves, the forced waves become **free waves** moving at speeds due to their periods and wavelengths. Some waves produced have long wavelengths and long periods and have a greater speed than those with short. They gradually move through and ahead of the slower ones and escape the storm and appear as a regular pattern of undulating crests and troughs moving across the sea surface. Once away from the storm these waves are called **swell**. They carry considerable energy which they lose very slowly..

The movement of the faster through and ahead of the slower waves is called sorting or dispersion. Groups of these faster waves move as wave trains or packets of similar waves with about the same period and speed (sets).

WAVE INTERACTION

Waves that escape, or outrun a storm are no longer receiving energy from the storm winds and tend to flatten out slightly and the crests become more rounded.

As they move out across the ocean, they are likely to meet other trains of swell moving out and away from other storm centers. When two wave trains meet, they pass through each other and continue on. Wave trains may intersect at any angle, and many possible sea surface patterns may result. If 2 trains intersect sharply a checkerboard pattern will be formed, and in some cases two or more trains may phase together so they suddenly develop large waves unrelated to any storms that may become so high they break losing some of their energy.

WAVE HEIGHT

While table 8.1 shows typical wind waves in deep water and their sizes compared to the wave length etc., there are several factors that influence the height of a wave.

1. wind speed

2. wind duration

3. fetch (distance over water that the wind is blowing in a single direction.)

Any one of these factors can limit the wave height. If the wind speed is low, it doesn't matter how far and how long the wind blows over the water, no large waves will be produced. If the wind speed is great but short, again, no large waves will be formed and strong wind over a short area will also not produce large waves. When no single limiting factor is present, large waves can form at sea. (40-50' S).

A typical fetch for a local storm is about 500 miles and with the storm moving, and the storm winds circulation around the low pressure area, the winds can continue to follow the waves on the side of the storm which increases fetch and duration of time over which the wind can add energy to the waves. Waves up to 49feet are not uncommon and the wave lengths can be between 330-600feet.

Wave heights taken in the North Atlantic over the past 25 years show a continuing increase in wave height of about 25%. There is no known reason for this increase.

Giant waves over 100' are rare but a Navy Tanker (USS *Ramapo*)in 1933 encountered a Typhoon and riding on the downside to ease the ride, was overtaken by waves that when measured against the ships superstructure by the officer on watch were 112'high. The period was 14.8 seconds and the wave speed was 90'/sec

(60 mph). While conditions to produce waves of this size occur, none have been well documented (or have survived).

EPISODIC WAVES

Large waves that suddenly appear at sea unrelated to local conditions are called epsodic waves. It occurs due to the combination of intersecting wave trains, depths and currents. Not much is known and when they do occur and swamp ships, witnesses are often removed. They occur near the continental shelf in water about 600' deep and in some areas with prevailing wind, wave and current patterns. (Agulhas Current) p220

WAVE ENERGY

Waves carry considerable energy per each unit width of their crest. The unit is measured in meters or unit width of 1 meter. The wave represents a flow of energy and its present as potential energy due to the change in elevation of the surface water, and kinetic energy due to the motion of the water particles in their orbits. The higher the wave, the larger the diameter of the water particle orbit and the greater the speed of the orbiting particle so the greater the potential and kinetic energy. The wave energy is calculated in a fun math formula and represented in fig. 8.8 basically showing that it increases greatly.

Energy average over one wavelength per unit width of crest from the sea surface to a depth of L/2 and related to the square of the wave height.

WAVE STEEPNESS

There is a maximum height for any given wavelength. This value is determined by the ratio of the wave's height to the wave's length and is the measure of steepness of the wave:

Steepness = height/length or S=H/L

If the height to length ratio exceeds 1:7, the wave is too steep, the crest angle will be sharper than 120' and the wave is unstable and will break. A wave length of 70m will cause a wave to break when it exceeds 10m (1:7).

Whitecaps have very short wavelengths(about 1m) and break because the wind increases their height rapidly...quicker than the wavelength increases. Also when wave trains pass through each other, he quick increase in height can cause these waves to break (even in the middle of the ocean).

Waves sometimes run into a strong opposing current which forces the waves to slow down. Remember the speed =L/T and once a wave is formed, the period doesn't change. so its wavelength will shorten if its speed is reduced so the wave will increase in height to satisfy the direct height-energy relationship. If the increased height exceeds the max. the wave breaks. (entering harbors etc during outgoing tides).

Beaufort Wind Scale p223

SHALLOW WATER WAVES

When the deep water wave begins to approach the shore and shallow water, the reduced depth begins to affect the shape of the orbits. They become flattened circles or ellipses and the wave begins to "feel" the bottom and the resulting friction and compression of the orbits reduce forward speed of the waves. Remember the speed of the wave is equal to the wavelength divided by the period and 2. the period never changes so when the wave slows because it feels the bottom, there is a reduction in wavelength resulting in an increase in wave height and steepness.. When the wave enters water with a depth of less than 1/20 the wavelength the wave becomes a **shallow-water wave**. The speed is now determined by the square root of the product of the acceleration due to gravity (g) and depth (D): c=` /gD

When the water depth is between L/2 and L/20, the speed of the wave is also slowed. Waves in this depth range are called **intermediate waves.** (no simple way to determine speed).

REFRACTION

Waves are refracted or bent as they move from deep top shallow water and begin to feel the bottom. Waves usually approach the shore at an angle and when one end of the crest comes in and feels the bottom and the other end is still in deeper

water, the shallow water end slows and because the deep water part is still traveling the same speed, the wave crests bend, or **refract,** and tend to become orientated parallel to the shore.

When waves approach an irregular coastline, certain refraction patterns occur. Waves will slow over submerged ridges and speed over submerged canyons.

REFLECTION

A steep, vertical barrier in water deep enough to prevent waves from breaking will reflect the waves.. The barrier may be a cliff, steep beach, breakwater, bulkhead or other structure. Waves approaching this barrier at an angle reflect from the barrier at the same angle. These pass through incoming waves to produce an interference pattern and often steep, choppy seas often result.

DIFFRACTION

When a wave passes its energy though a narrow opening, some wave energy will pass through to the other side and once through the energy radiates out and away from the gap. A portion of the energy is transported sideways from the original wave direction it is diffracted. Energy can be transported sideways and around the end of a barrier and energy can be transported behind the barrier but much is lost.

THE SURF ZONE

The surf zone is the area along the coast in which the waves slow, steepen, break, and disappear in the turbulence and spray of expended energy. The width of the zone is related to the length of the arriving waves and changing depth pattern.

BREAKERS

Breakers are formed in the surf zone because the water particle motion at-depth is affected by the bottom, slowed down, and compressed vertically. The orbit speed of the particles near the crest are not slowed too much so particles move faster toward the shore than the wave itself. The crest can curl and eventually break (fall over). There are two types, plungers and spillers.

Plunging breakers are usually found on a steep beach, the curling crest outruns the

rest of the wave curves over the air below it and breaks with a sudden loss of energy and a splash. Spilling waves occur at flatter beaches and consists of turbulent water and bubbles flowing down the collapsing wave face.

WATER TRANSPORT

Waves transport water toward the beach in the surf zone. There is a drift of water in the direction the waves are traveling and is intensified in the surf zone and with the waves approaching the beach at an angle, the transport of water moves both toward and along the beach. This water must flow seaward again and will in a quieter zone with smaller waves. Because these regions may be some distance apart, and narrow, the water may flow out quickly forming a rip current.

TSUNAMI

Earthquakes are often responsible for producing seismic sea waves or tsunamis. They are called tidal waves (incorrectly) and formed if in an area the earths crust suddenly raised or lowered. The displacement causes a sudden rise or drop of the sea level and gravity causes the water to quickly fill it in. Waves with long wave lengths are produced (100-200km) and periods of 10-20 min. Since the aveg. depth is 4000m it is less than 1/20 the wavelength so it acts like a shallow water wave. Because of this they may be refracted, diffracted, or reflected in mid-ocean.. p230

STORM SURGES

Periods of excessive high water due to changes in the atmospheric pressure and the wind's action on the sea surface are called storm surges or storm tides. These are not typical waves but share characteristics of curving sea surfaces and produce like effects to that of tsunamis.

Chapter Questions

Questions for Tsunami Reading

TSUNAMI READING QUESTIONS

1.What does tsunami mean?

2. How is a tsunami (A) the same as (B) different than regular ocean waves?

3. What happens to a tsunami as it travels into shallow water?

4. How would a tsunami appear to an onlooker in (A) the open ocean (B) along the shore?

5. What is meant by the term run-up?

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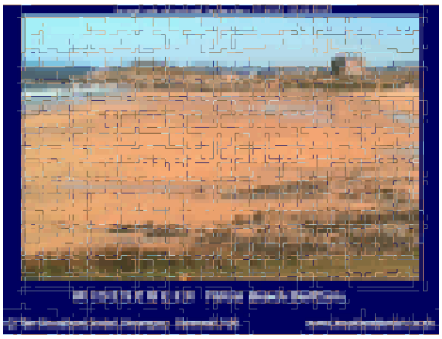
TIDES



Lecture notes

The rhythmic rise and fall of the oceans water at a fixed location is known as the tide. Changing water levels create hardships for coastal organisms by exposing them. Tides are long waves moving through the ocean. When the crest of the moving tide reaches a location, high tide occurs. Low tide is when the trough reaches the location.

Best known as the rise and fall of these around the edge of land, the tides are caused by the gravitational attraction between the earth and the sun and between

the earth and the moon. While tides go unnoticed far out at sea, they are easily observed along the shoreline.

TIDE PATTERNS

Three types of tides occur.

- 1. Semi-diurnal 2 high and low tides per day about equal range. Most.EC
- 2. Diurnal 1 high and 1 low tide per day (24hrs) Gulf of Mexico/Vietnam/Manila
- 3. Mixed 2 high and 2 low tides per day but different ranges...1 high high, 1 low low 1 high 1 low west coast

Tides behave differently in different places. In some coastal areas there is a regular pattern of one high and one low tide each day known as a **diurnal tide**. In other areas there is a high-low water sequence repeated twice a day...semidiurnal **tide** and these tides usually reach about the same level at high and low tides each day. The third type of tide has two high and low tides a day but the tides reach different high and low levels during a daily rhythm. This is called a **semidiurnal mixed tide**. It is caused by a diurnal (daily) inequality by combining a semidiurnal and diurnal tide. Tides are charted on a marjoram which shows the height of the tide above mean low water (sea level) and the time of the peaks of the high/low tides.

In the uniform tidal system (semi and diurnal) the greatest height to which the tide rises on any day is known as high water and the lowest point is low water. In a mixed system it refers to higher high and lower high water and higher low and lower low waters.

Tidal observations made over a period of time are used to calculate the **average or mean tide** levels.

Since the depth of coastal waters is important for navigation, an average low-water reference is established: depths are measured from this level and recorded on navigational charts. This area is usually established at mean low water and the zero reference or **tidal datum**, is established at this point. In mixed tidal areas, mean lower low water is used as the tidal datum. Sometimes the low tide level may fall below the mean value used as the tidal datum producing a **minus tide**.

When the tide is rising, it is called a flooding or **flood tide** and when its falling it is an **ebbing tide.**

TIDAL CURRENTS

Currents associated with the rising and falling of the tide in coastal waters is a **tidal current**. They can be very swift and dangerous. When the tide turns, reverse direction, there is a period of **slack water** during which the tidal currents slow and then reverse.

TIDAL THEORY

Oceanographers analyze tides in two ways. One is using universal laws of physics called **equilibrium tidal theory** and the other is studying them as they occur in nature called **dynamic tidal analysis** which study the oceans tides as they occur modified by the land masses, geometry of the ocean basins and earth's rotation.

The effect of the sun and moons gravity on tides is easily explained using the equilibrium theory. 9.3 A water covered planet with its satellite moon orbits the sun. The moon is held in orbit about the earth by the earth's gravitational force (B). There is also a force pulling the moon away from the earth and send it spinning into space (B') and is considered **centrifugal force** in this discussion. The earth and moon are held in orbit by the gravitational attraction between the center of mass between the moon and earth system and the sun (A). The centrifugal force pulls the center of the mass away from the sun (A'). To stay in orbit A must equal A'. (like twirling a string with a weight on it around your head and the string is gravitational attraction.

In the earth moon sun system, the mass of the sun is great but its very far away and while the mass of the moon is small, its closer and therefore has a greater attractive effect on water particles than does the sun, so the moons effect will be considered first because its greater.

MOON TIDE

Water particles on the side of the earth facing the moon are closest to the moon are acted on by the larger moon gravitational force and because water is liquid and

deformable, the force is applied to water particles toward a point directly under the moon. It produces a bulge in the water covering. At the same time, the centrifugal force of the earth moon system acting on the water particles at the earths surface opposite the moon creates a bulge too. Now a model would show 2 bulges on opposite sides of the earth but that is on a uniformly deep water covered planet.. The area between bulges (opposite each other) would be low water areas or depressions (or 2 crests and two troughs--high tide and low tide).

TIDAL DAY

The moon and earth are moving in the same direction along its orbit during a 24 hr period but the earth must turn an extra 12' or 50 minutes for the moon to be directly over the same place. Therefore the **tidal day** is not 24 hours long but 24 hr and 50 minutes explaining why tides arrive at a location about an hour later each day.

TIDE WAVE

The equilibrium tides produced are semidiurnal or two high and two lows a day. The tidal distortion of a models water covering produce a wave form known as the **tide wave**. The crest of the wave is high water (tide) and the trough is low water (tide). The wavelength of this wave is 1/2 the circumference of the earth and period 12 hr and 25 min.

The SUN TIDE

While the moon plays a greater role in tide producing, the sun also produces its own tide wave. Though it is large, the long distance away means its tide raising force is only 46% that of the moon and the average time is 24 hours not 24h50m. The tide wave produced by the moon is greater magnitude and continually moves eastward relative to tide wave produced by the sun and therefore the tide forces produced by the moon are greater and more important than that of the sun (therefore tidal day 24h50m).

SPRING AND NEAP TIDES

During the 29 1/2 days it takes the moon to orbit the earth, the sun, the earth and

the moon move in and out of phase with each other. During the period of the new moon, the moon and sun are lined up on the same side of the earth so that the high tides, or bulges, produced independently of each, coincide. Since the water level is the result of adding the two wave forms together, tides of maximum height and greatest depression, or tides with the greatest **range** between high and low water are produced. These are **spring tides**. The vertical displacement of the tide may also be described as amplitude or 1/2 the range (distance above or below sea level.)

In a weeks time, the moon is in its 1st quarter and moved about 12' per day, until its at a right angle to the sun wave. Now the crests of the moon tide will coincide with the troughs produced by the sun and the same is true of the sun's crests and moons troughs. They tend to cancel each other out and the range between high and low water is small. These are low-amplititude **neap tides**.

At the end of another week, the moon is full and the sun, moon and earth are again lined up, producing crests that coincide and tides with the greatest range between high and low waters, or spring tides. These are followed by neap tides seven days ;later and the cycle, 4 weeks, continues with a spring tide every two weeks...etc. This 4 week progression creates a tidal cycle of changing tidal amplitude.

DECLINATION TIDES

If the earth and moon are aligned so that the moon stands north or south of the earth's equator, one bulge is in the Northern Hemisphere and one in the Southern Hemisphere. A point in the middle latitudes passes through only 1 crest and one trough during the tidal day. This type of diurnal tide is called a declination tide, because the moon is said to have declination when it stands above or below the equator.

The sun also influences these tides as it sits over 23.5N/S at summer and winter solstice and the variation causes the bulge created by the sun to oscillate north/south (making a more diurnal sun tide during winter and summer. The moons declination is at 28.5N/S and because the orbit is inclined 5' to the earth sun orbit, it takes 18.6 yrs for the moon to complete its cycle of max. declination. When the sun and moon coincide, both tide waves become more diurnal. Also the moon doesn't move around the Earth in a perfectly circular orbit or even does the earth circle the sun at a constant distance. In the Northern Hemisphere, the earth is closer to the

sun so the solar tides play a greater role as a tide producer in the winter than summer. see p254 tide charts

TIDE TABLES

Because of all the combinations, its not possible to predict the earths tides from our knowledge of tide raising bodies alone. But with a combination of actual local measurements with known astronomical data, tide predictions are quite accurate.

Water level recorders are installed at coastal sites and the rise and fall are measured over a period of years...at least 19 years are needed to allow for the long 18.6 year period of declination of the moon. Tide Tables are published annually by NONA. The tables give the dates, times, and water levels for high and low water at a primary tide station. There are only 196 of these but consulting a list for other 6000 auxiliary stations applying corrections to the times and heights of the primary stations helps more localities get accurate tide predictions.

Tidal predictions are based on recorded high measurement from past records which are used in the future.

Tide Current Tables

Like tides, these currents are measured at primary locations and data is published similar to tide tables. Useful for moving in and out of estuaries.

Summary

Without land, 2 bulges , 1 on side of the earth closest to the moon, 1 on the other side would appear. Bulge is high tide from mutual attraction between earth and moon. Moon gravitational attraction pulls and moves the water. The opposite bulge, centrifugal (I know, there is no such thing,) force created as the earth and moon revolve around a common point...barycenter-4670 km (2900miles) from earths center.

Tides occur at different times because the moon goes around the earth in 24h50m or 1 lunar day. (freq 12h25m)

Due to friction between earth and tidal bulges, High tide is given about 50 minutes after the moon passes over that point. known as a lunar semidiurnal tide.

Vertical height ...high to low water is the tidal range and varies day to day because of the sun and the moon. Solar tides are 1/2 the size of lunar tides. When the sun and moon line up (2x per month) tides are higher and lower than usual...spring tide. When the moon is at right angles to the sun, there is less gravitational effect that lessens the tidal range (neap tides) Between these tides the height varies throughout the month.

Differences in tidal frequencies and range occur because of the shape of the ocean basins and coastline (Hawaii is a few cm while the Bay of Fundy is 20m.

Check Larger slide show

Show tide tables

Lecture Questions

Readings

Reading questions for tides

11. Tide readings

1. What is a tide?
2.. How much stronger is the gravitational force of the moon on the earth than the sun on the earth?
3. What is the average interval between tides?
4 What is a amphidromic point?
5 How does shallow water effect tides?
6. Where do diurnal tides occur?
7. What is a cause that effects the range of tides?

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SANDY BEACHES

Lecture Download

Florida Beach Page

Sand Dune Page

video of African beach

The sand beach is a hostile environment, forming a boundary between the ocean and the land . The beach is subjected to harsh conditions such as breaking waves, changing tides, salt laden winds, extreme temperature changes etc. The sand beach is a temporary habitat.

The texture changes seasonally. Winter beaches contain **course sediments** while summer beaches contain **fine sediments**. The removal of beach sediment is **erosion** and addition of material is **deposition**. The changes in steepness is the **slope**.

The beach is a region between the high and low waterlines that is covered by sand or some other unconsolidated material.

Some materials along the coastline are more susceptible to weathering than others. Granite, a crystaline rock, is much more resistant to erosion than sandstone. Regions

made of sand are quite susceptible to erosion. Quartz sand is common in beaches along the continental shorlines (Gulf from Tampa to Pensacola almost pure quartz sand) La Jolla, the oxidation of iron in mica give the sand a gold cast and the high iron and magnesium content in some sand account for dark patches seen on beaches especially in winter when heavy sediments are left behind while lighter quartz is removed by larger winter waves. Some sand in many tropical and subtropical beaches is predominantly calcium carbonate secreted by marine organisms (shells, algae coral) and in Hawaii and Iceland, black beaches from basalt lava are common. Minerals like gold and diamonds have been found in certain areas of the world on the beaches.

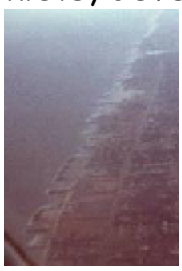
Tides produce short-term fluctuations along coastlines but sea level changes are long-term. Tsunamis have changed coastlines.

Turbulant waves along the shore usually remove mud from the beaches and hold it in suspension. As the fine particles of mud are transported to deeper or less turbulent water, they settle on the bottom. A beach is described in terms of the average size of its sand particles, the range and distribution of these particles, the elevation and with of the berm, the slope of the foreshore and the slope of the inshore. Generally the larger the sand particles, the steeper the beach.

Waves are primarily responsible or moving sand away from river mouths and along the coast. As a wave breaks, the sudden release of energy within a small area causes turbulence that dislodges sand particles. If waves moved in perpendicularly to the beach, then the particles would only move in and out. However, waves approach the coast from almost any angle and if it comes in from the north say, then the water runs back to the sea in a southernly direction. This forms what is known as the **longshore current or littoral drift**. This current provides longshore transport that carries sand along the shore. Beach sand is always in transit from one place to another. Size and power of waves affect the rates of longshore transport. On the east and west coast, LST runs in one direction usually, and thats south because most waves come from northern storms. Sand is transported south at a rate of 150,000 to 1,600,000 m3/yr.

Large scale earth movements...well an earth quake or the collision coasts where two plates run into each other can affect the coast, but thats covered in plate tectonics.

Human activities have had both benificial and harmful effects on the coastline. Damming of rivers, land recovery programmes, dredging of inlets, development of



dune areas and construction of erosion control structures.

Dams-when a river is dammed, deposition occurs upstream of the dam instead of at the river mouth where coastal currents could carry he sand down the beach starving the currents and causing erosion of the beach and coastline.

Land recovery-in the Netherlands, this expensive way to get land has destroyed sensitive marsh lands which were regions of life.

Dredging Inlet dredging has become popular so boats can go out into the ocean. Here each area can be looked at. San Diego bay when dredged did not have any real effects on the area while the dredging of a channel in Matanzas Inlet in fla (st Aug.) to enhance land values at Crescent beach and Marineland, had disastrous results. The tidal currents rushing from the new channel, have diverted the strong longshore current,causing sediment to be deposited on the inlets north side and the starved current sweeps by the south side eroading the shorefront property and highway to boot!

Erosion Control Structures

Jetties built to prevent longshore currents from filling inlets or to bring about the deposition of sediments benefit the property immediately upcurrent but may cause the downcurrent shoreline to recede. Groins, small piles of rocks at right angles to the beach transform the longshore current into a zig zag current that destroys the linear form of the coast. Wherever it encounters nonresistat rock, it erodes the shore.

The precarious stability of the shoreline and of the transition zone between the nonmarine environment and the delicate matrine environment suggests that the shoreline should be left undeveloped except where development poses no hazards. Developers should consider the long term consequences of massive shoreline development programs before proceeding.

THE SHORE

The **shoreline** is the region bounded by high and low tide and by the farthest landward reach of the waves.

The **backshore** is the area of the shoreline above the high water or high tide mark. This can contain cliffs or sand dunes or a berm (flat upper beach).

The **foreshore** is the area that is exposed at low tide. It may have a beach scarp (vertical slope produced by wave erosion) and a low tide terrace (broad flat area exposed at low tide.

The **offshore region** extends from the low tide mark seaward beyond the wave breaking zone. It has a **shoreface** (slope below the low tide mark) and a **longshore trough** (a depression parallel to the beach between the low tide mark and wave breaking zone).

Longshore bar is a sand ridge parallel to the beach.

5 factors interact along the coastline:

- **rock materials present along the shore**
- **changes in sea level**
- **the energy of certain natural processes**
- **large-scale earth movements**
- **and human activities.**

Zonation.

Boundries are difficult to locate because of shifting sand and changing heights of waves.

Upper beach-supratidal zone ranges from high tide mark to sand dunes. Animals live below the sand to avoid sunbaked surface. The sand contains almost no food or water so the animals feed at the surface. The most common animals in this zone are amphipods called sand fleas, which are found under driftwood and seaweed during the day. A crustacean, the ghost crab, also lives here and both animals consume dead plant and animal material. This is the fastest crab and blends in with the environment. It breaths air but must return to water to moisten gills and casts fertilized eggs into the surf where they develop as drifting larva in the ocean and return to the beach when they grow. These are consumers of decaying plant and animal material and sea turtle eggs. Some insects and plants also live here but also live in the dunes so fall under sand dunes. At night, insect eating bats, rats, mice run along the tide mark searching for food.

Strand-line. highest place where the ocean washes the beach. This area collects stranded material called beach wrack which provides a cool, moist environment for small invertebrates (biting fleas, centipedes, earwig beatles, amphipods.). Gulls and sandpipers scavenge here and whats left, bacteria breaks down. The organic materials provide food for scavengers and decay bacteria break down the rest to release nutrients_ back into the ocean for the primary producers to use thus

completeing the cycle of life. 

Intertidal zone:

- 1. Exposed to atmosphere at low tide, covered at high tide...
- 2. absorbs direct assult of waves.
- 3- sands shift, grinding organisms.

The surface remains wet at low tide from capillary action. Sand grains stay wet and draw water up towards the surface to evaporate. Organisms can now thrive near the surface of the sand. These organisms belong to the **interstitial sand community** which vary from minute bacteria to worms and copepods.The bodies of these are thin and long and can move easily among the grains. They have adhesive organs allowing them to stick to grains and not be washed away. Diatoms and dinoflagellates are the main producers living in the sand and can migrate deeper and shallower in the sand.(color the sand). There are great quanities of detritis for food and consumers from protozoa to annelids to nematodes which can number 2-3 million per meter2

Subtidal zone..from the lowest part of the intertidal zone to as far out as sand is moved by wave action. Environmental factors change slowly but there is still no substrate which means living under the sand. Fish have adapted a burrowing lifestyle (eels, flounders, soles, rays, skates.) The number of species living in this soft-bottomed subtidal zone usually outnumbers the number of species on the soft bottom of the intertidal zone because of the stability below the low tide mark. Desiccation, rapid temperature changes, salinity variations are not as much a problem.

While the zonation is not as easily seen as on rocky shores, it does exist in ernst but is usually absent from muddy water where there is no change between high and low water marks.

These soft bottoms are unstable and constantly shift in response to waves, tides and currents so the soft-bottomed organisms don't have a solid place to attach. Very few seaweeds/plants adapt to this (except seagrasses) so most of these organisms will burrow in the sediment to keep from being washed away. These are called i**nfauna.** T he kind of sediment on the bottom, size of grains etc have an effect on the kinds of organisms living as infauna. Sizes of grains/rub between fingers/gritty = sand...silt and clay are smooth (mud)...silt and clay clay is smooth between teeth and silt gritty! Yum

Living in the sediment has advantages in the intertidal. The soft bottoms hold moisture when the tide is out so desiccation is not that much of a problem. However, the corser the sand, the quicker it dries out! Also because of the lack of plants, oxygen availability is a main concern to the organisms living in the sediments. Also, most are detritus/deposit feeders because of lack of plants and this environment is also home to decay bacteria to help break down sediments (detritus) and these also use oxygen. The finer the sand, the more stuff it holds (more smelly) and courser, the less and therefore cleaner. Water flow through the fine sediments is restricted therefore, less oxygen circulation. The i**nterstitial** water is deficient of oxygen. This anoxic or anareobic condition is usually no problem to many bacteria (giving off hydrogen sulfide), but the animals must pump water from above the sediment and have developed long tubes for this.


Sand Dunes



Development of Dune areas

The commercial development of dune areas has also deterioated the ecology. Dunes are impermanent formations that rarely survive the building of houses and other structures. As the dunes are destroyed, the shoreline migrates deeper into the

land.

Sand Dunes

Coastal dunes form where sand is deposited onshore by the sea at river mouths, or exposed by a dropping sea level as in past glacial times, dries out and is blown landward by the wind. (Tinley, 1985)

Coastal dunes exhibit unique processes of genesis () dynamics and zonation determined by the fluctuating sand supply/wind energy ratios related to daily, seasonal and long term changes in sea level and climate, soil changes and plant succession and exposure to salt spray.

Dunes are a mobile physical medium and ecological environment, frontal dunes are part of sediment exchange, increase in age and complexity as it gets farther from the coast, and contains an endemic and/or specialized plant and animal community.

- **Dune**- Hill, mound or ridge of sand composed of particles transported and heaped up into accumulations by wind.
- **Dune Base**--compact base of dune
- **Dune Trough**- linear depression between dunes
- **Slack or swale**- a seasonally or perennially wet depression between dunes.
- **Hollow**- a dry depression between dunes.
- **Primary dunes** The first line of dunes
- **Secondary dunes** The second line of dunes leading to the forrested area

There are 7 determinats to dune development along a coast.

- 1.**wind regime**
- **2.sand supply**
- **3.degree of coastal exposure and deflection of winds**
- **4.rainfall**
- **5. plant colonization**
- **6. sea (wave action and longshore drift)**
- **7. river mouth dynamics.**

Coastal dunes are populated by plants and animals that are exposed to hot blasts of

salty wind, scorching sunlight and almost no water, meager food supplies, little or no firm footing, and wind blown sand.

Dune plants-few specialized plants can live on the upper beach and adaptations include; waxy coverings on the leaves, large root systems, small leaves and few stomata, thick stems and leaves to store water.

How do each of these adaptations help? List them!

Sand Dune Formation...an essay

Sand dunes form along the coast as sand is blown away from the beach. Grain by grain, the dune grows as onshore winds slow and drop their load of fine, sugary sand. The growth of coastal dunes begins as wind_movement across the open beach is obstructed by blades of grass, a fence etc. Dunes grow and gradually move inland away from the beach. The windward side of the dune usually has a gradual_slope because wind velocity slows and deposits sand along the face of the dune. Strong winds often carry sand over the crest and falls abruptly behind the dune where wind speed is much less. A steep slope forms on the backside of the dune. The first line of dunes are primary dunes which deflect ocean breezes and create a semi-protected environment on the backside of the primary dune. Plants that can't withstand direct blasts of salty wind on the dune face, grow in the protected lee of the primary dune. The area behind the primary dune is the swale which because of the deflection of the wind by primary dunes, can heat up to temperatures of 50'C. The second line of dunes, secondary dunes, are often thickly vegetated, which allows a coastal forest to often develop behind it.

Dune development/ fences to collect sand and walkover to protect the dune grass

Beach Comparisons



Keys


Gulf

Gulf

Gulf

Atlantic

Atlantic


Atlantic


Atlantic


Atlantic/Indian


Indian

Summary

Sand Beaches

What to look for: zonation, environment, Composition, Ecology of Dunes, formation of barrier Islands, Populations of beaches and TERMS

One-Line Glossay

Beach and Sand Lab

- BEACH
- COURSE AND FINE SEDIMENTS
- EROSION
- DEPOSITION
- SLOPE
- UNCONSOLIDATED MATERIAL
- LONGSHORE CURRENT
- SHORELINE
- BACKSHORE
- FORESHORE
- OFFSHORE
- SHOREFACE
- LONGSHORE TROUGH
- LONGSHORE BAR
- SUPRATIDAL ZONE
- STRAND-LINE
- INTERTIDAL ZONE
- INTERSTITIAL SAND COMMUNITY
- SUBTIDAL ZONE
- INFAUNA
- DUNE
- DUNE BASE
- TROUGH

- SWALE
- HOLLOW
- PRIMARY AND SECONDARY DUNES
- WIND/SAND/DEGREE OF COASTAL EXPOSURE
- RAINFALL/PLANTS/SEA/RIVER MOUTH

Beach Readings

Beach Reading Questions

Sand Helps Revive shore 4

1. How do Florida's beaches benefit from beach renourishment projects?

2. Why are these projects 50 year projects?

3. How much will these projects cost the taxpayer for the next 50 years?

4. How much of the Florida Beaches are critically eroded?

5. Give evidence that the beach renourishment is working and not unravelling.

6. How can Brevard County defend the use of federal money to rebuild its beaches?

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ROCKY SHORES

Cape Point, South Africa

Lecture notes

The rocky intertidal habitat has a very rich diversity of organisms especially in temperate climates. Attachment is critical and competition for space is a prime factor. The organisms are well adapted for withstanding tremendous SURF-EXPOSURE. Also tolerance to DESICCATION (low tides during the summer days), temperature changes, and salinity changes(rainfall during low tide).

When the tide goes out, the phenomenon of ZONATION is manifested - horizontal bands or zones of organisms. This is true for both plants and animals. Each zone has a particular color or texture from the organisms inhabiting that particular zone. UNIVERSAL PATTERNS of zonation, occurring throughout the world, have been recognized, such that no matter where you might be observing the exposed intertidal, the middle littoral zone will often have a community of barnacles, mussels, and rockweeds.

The nature of the rock between the tide marks may exert a certain selective influence on the organisms that attempt to colonize it, in the sense that some rocks are more susceptible to the activities of boring organisms and others are not and

certain minor variations in zonation may also be attributed to it. Rocks between the tidemarks include GRANITE, HARD QUARTZITIC SANDSTONES, SOFT SANDSTONES (calcareous or not), DOLERITE, CONGLOMERATES, LIMESTONES, SLATELIKE ROCKS, and various other materials. You see, porous sandstone will hold water longer during low tide than granite and other non-porous rocks and therefore may exhibit a different type of zonation than other rocks nearby. Rock texture/rough and smooth does not really seem to have much of an effect unless friability is considered where pieces of rock (bearing attached organisms) may break off.

The proximity of sand also affects populations of adjacent rocky areas. In some cases, sands shift a good deal, so that a low rocky reef may be buried under sand at one, and emerged at another time. This does not always kill everything on the reef unless it lasts for a long time.

Desiccation / drying out plays a role in organisms to the degree which they can withstand exposure to the air between the tidemarks. I may affect organisms in two ways: it may be intense, but for short duration, or less severe, but of repeated occurrence. It can be intensified by increased temperature and air movement (and light).

Factors controlling the distribution of organisms on the PACIFIC coast: Predation is #1; also competition, exposure to the waves, desiccation, and rain water. On the Washington coast the yearly water temperature change is only 5.5'C (10F).

East coast intertidal populations are affected dramatically by the relatively LARGE SEASONAL TEMPERATURE CHANGES: Predation is also important but less so than in the Pacific.

The Upper intertidal zone: usually termed the LITTORINA ZONE, named after the small herbivorous gastropods (periwinkles) that occupy this zone that must survive long periods of exposure. This zone extends higher than the highest tide where there is great exposure with spray from the various waves causing the organisms to extend higher into the littoral zone.

There may be several species of these snails but each species occupy their specific niche..species 1 are the most tolerant and occupy the highest level, species 2, less tolerant and occupy the next and so on. (one lower species mimics the air bladders of rockweed). There is even a higher zone than the periwinkles and it is occupied by LICHENS (Verrucaria) which occupy a dark zone above the periwinkles and/or blue-green algae (covered with mucilage to prevent total desiccation.

Middle intertidal zone: barnacles (upper part), rockweed (middle), & mussels (lower) occupy this zone and each will have one distinct advantage in regard to their area over the others. Mussels and seaweeds can crowd out the barnacles but the barnacles can tolerate surf and desiccation better, giving them the upper position in the Mid-littoral.

Barnacle life cycle

- eggs hatch into napulus larva
- molts 6 times and turns into cypris larva
- cypris larva finds place to attach
- secretes cement from cement glands on the 1st antennae to attach
- develop into adult

The rockweeds in the middle of the mid-littoral zone provide a nice moist protective canopy when the tide is out, so many inverts. can survive underneath. The green crab hides under it during the day and comes out at night.

Below the rockweed are beds of mussels (Mytilis) using their byssal threads to attach. Their shape allows them to adapt well to the wave force and adductor muscles tightly hold them closed at low tide...protecting them from predators and desiccation. Mussels release sperm and eggs into the water, (external fertilization) and environmental cues affect members of the population to bring about a synchronous release of gametes, resulting in maximum opportunity for successful fertilization. The eggs turn into a VELIGER larva which exists as plankton until it finally settles down and crawls around looking for a favorable site (strongest currents to bring lots of food). Mussels will be preyed on by certain snails, seastars, crabs, shorebirds, lobsters etc. but while the mussels are uncovered for a

while, the marine organisms can only get them while they are covered (and birds vice versa) Tough life!

FORAGING RUNS...the Predation above, which opens up the habitat for other species and thus increases species diversity. The greater the diversity, the more links in the food chain of that community.

LOWER INTERTIDAL ZONE

There is less time of exposure to air as you get lower into the zone. These organisms while less tolerant of air are better adapted to wave exposure. Dense strands of kelp can occur here and all this provides living and hiding spaces for a variety of inverts. (hydroids, bryozoans, nudibranches, worms, crabs, tunicates. Some are more conspicuous like the sea anemones, sea urchins, and sea stars.

Some anemones have algae living with them but all capture food, sea urchins graze on the algae in this zone which increases species diversity. Exceptions are that often only one or two species of algae grow when the urchins are very active but then control of urchins by sea otters and sea birds, lobster and fish all return things to normal.

A filter feeding gastropod, the slipper shell (Crepidula), filter feeds and can change sex. They grip the substrate tightly with their foot and filter feed and can fertilize the females below them and eventually transform into females. If the area is lacking females, they will stay longer as males.

Some inverts. can BURROW or BORE into hard substrates: rock, coral, wood by either mechanical abrasion or chemical dissolution. Some mussels, date mussels, secrete acid and dissolve limestone, gribbles are small wood-boring isopods that simply chew into wood. Teredo (shipworm) are also filter feeders as well as eat wood.

Tide pools are depressions of varying size in the intertidal such as when the tide is out, standing water is left behind like an oasis for algae and animals. They are subjected to great fluctuations in regard to temp. salinity, acidity, dissolved oxygen content... The higher the pool is in the littoral zone, the longer the pool will be exposed, or isolated from the flush of the oceans waves. Depth in the pool is

important, as is the overall size. If then tide is out at night, the release of CO2 from the respiring animals and plants will increase (NO Ps) and increase the acidity of the pool. During the day, PS will cause the pH to increase. The larger pools in the mid zones allow the inverts, seastars etc. to live higher up on the rocks and therefore be able to feed in the upper areas longer. In California. some kelps get started in these pools but once a series of spring tides in June arrive (esp. sunny days), the species living beyond their limits will be killed off.

South African Shores----------Florida

Rocky Beaches of North Florida (Near Marineland)

Biological succession: going from bare rock to a mature, or climax community, although nothing is permanent. Predation brings about open areas or physical abrasion by logs often destroy communities in the intertidal. The term conditioning is used to refer to the process by which a bare rock surface must go through a sequence of first being settled by bacteria and algae and such slime-producing organisms before the larva of barnacles and zygotes of rockweeds will be able to attach themselves. Then mussel larva will settle down and crowd out the barnacles and rockweeds restricting them to higher areas. Predators and mussels will next move into the picture.

Trophic structure on the rocky beach community: Primary production is the Ps activity of the BENTHIC seaweeds and also a good part from the phytoplankton being washed over the area whenever the tide is in. Also dissolved organic matter and detritus will be a source of nourishment for filter feeding/suspension feeders/sponges, barnacles, mussels, while the grazers, chitons, periwinkles, limpets, sea urchins are scraping off the benthic flora. Tidal fluctuations make for a good contribution coming from outside the narrow confines of the littoral zone and this results in a large biomass or carrying capacity and the numerous predators at various levels that enter this ecosystem and the rich diversity of species and high density of individuals inhabiting the intertidal zone of the rocky coastlines.

Competition

Some observations and experiments:

The ochre star, *Pisaster ochraceus*, and the 6 armed star which is smaller.

3 sites were chosen along the coast..site 1..all ochre stars were removed and added to site 2 and 3 was left as a control. After 15 months, the 6 armed had gotten larger, 2 their size had decreased and 3 stayed the same.

Size-selection Predation The whelk eat the barnacles but can't withstand too much desiccation. Barnacles, after about two years, get too big for the whelks to eat in the time allotted out of the water between tides so mostly 2 year old and younger are eaten but experiments where older barnacles are put in cages, they were eaten.

Zonation

Few features of the shores are more obvious than zonation. All shores, no matter how large or small the tidal range (max. 17m Bay of Fundy) have at least some degree of zonation or vertical banding of the organisms living on them. Just as plant communities occupy definite bands or zones on mountains corresponding to tolerances to decreasing temperature with increasing elevation, so intertidal communities occupy definite zones on the shore. Compared to the mountains though, the shorelines are much compressed vertically. Generally where the range of tides is small or where the slope of the beach is steep, the zones are generally narrow. Where the slope of the beach is flat and the range of tides is great, then the zones are wide. Heavy wave action widens the zones, both above and below the calm water limits and the upper and lower borders of the zones are less distinct.

An example of the coast of Vancouver Island where the algae, *Porphyra* is the highest level (above the highest barnacles) and grows best in the winter because of the high storm surge and nighttime low tides and its burned off in the summer. The barnacle zone is the first clearly demarcated zone at the top of the shore and this zone occurs on almost every shore in the world.

This is followed by a zone of mixed barnacles and seaweeds, the mid tide region is marked by mussels and goose barnacles and beneath this zone is another of barnacles and algae and several whelks and limpets. Below this zone and marking the beginning of the lower intertidal zone is the clearly marked zone of brown algae (kelp) interspersed with chitons,starfish, and surf grass.

The zones are by no means constant in composition, number, width and these factors vary from season to season, year to year, shore to shore, and even rock to rock.

The "Universal" scheme of zonation

After 30 years of studying intertidal zonation throughout the world, (tough job), husband and wife team T.A. and Anne Stephenson published their findings (1949) in which they presented their "universal" scheme of zonation. They attempted to formulate general zonation patterns for the whole world. They studied coastlines in various parts of the world including Great Britain, S> African, Indian Ocean, Red Sea, Mauritius, Great Barrier Reef, North America on both sides (Fla. and

Vancouver Island) and looked for features of zonation that were of universal occurrence and universal application and came up with the following terminology for rocky coasts:

- 1. **Supralittoral zone** ..near sea but above the high tide mark with some marine influence (spray)
- 2. **Supralittoral fringe**...upper limit of barnacles (in quantity) to nearest higher convenient landmark (upper limit of Littorina or lower limit of land lichens. Spring tides invade part of this zone.
- 3. **Midlittoral zone**: the entire intertidal areas, from the upper limit of barnacles to upper limits of large brown algae at the lower part of the shore. The barnacle demarcation is an important reference point in the universal scheme.
- 4. **Infralittoral fringe**: the lower fringe of the intertidal ..an area extending from the upper limit of whatever organism sets the lower limit of the midlittoral zone, to the ELWS (extreme low water spring) tide mark, or in areas of waves, to the lowest level visible between waves. Organisms living here cannot tolerate complete emersion but can live in an area of broken emergence through wave action.
- 5. **Infralittoral zone**: the area between ELWS tidal level and corresponding more or less to the more commonly used "sublittoral" term.

This pattern pointed out by the Stephensons is sensitive to such factors as wave effects, slope of rocks, differing amounts of sun and shade. However, while shores may differ in relatively minor details as a result of such factors, most still adhere to the basic pattern.

One of the main points of contention of the Universal scheme is that it does not rely on tidal levels as such in the defined zones but rather on the deposition of organisms. So in their 1949 paper they recognized that certain zones may be related to tidal level but not specifically caused by tides. In a 1972 article, they changed the "universal " to general scheme. Their theory was based and related to the air-water interface, gradients of moisture/light penetration/sedimentation etc. Thus even in areas lacking a tidal cycle, the factors producing zones would still be

present. Tides serve to emphasize the zones not to create them.

ZONATION AND CRITICAL TIDE LEVELS

This figure of a two week tidal curve for a site on the coast of British Columbia. The difference between the extreme lower water spring (ELWS) and the extreme high water spring (EHWS) represents the greatest tide of the cycle.

So organisms like a barnacle, located at or just below the EHWS level would be in the air for about 13 days until covered by the next spring tides. On the other hand, an organism at the ELWS level would be continually submerged for the same period. EHWS would be at the 4.5m level on this BC coast and ELWS would be at the -0.3 m level. These two tidal levels, along with others relating to various points on the daily and monthly tidal cycles, are considered by M. Doty to be CRITICAL agents in governing the vertical distribution of marine organisms. Other factors however cause problems with Doty's hypothesis such as an environmental override, like low salinity of surface water, storm surges, as well as tidal levels which vary from year to year.

Chapter Questions

Reading and Rocky Shore Questions

1 What types of animals dominant the intertidal rocks?

2.What is the most striking feature of any rocky shore?

3. How is one zone different from another?

4. What are 3 ways rocky intertidal zones vary?

a)

b)

c)

5. What conditions may alter the bands or zones?

6. In the Stephenson's scheme, there are three main divisions. What are they?

Reading

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THE CORAL REEF SYSTEM 

Lecture Notes

Single coral reefs may cover over 100 sq km: massive structures that have been built almost entirely by marine plants and animals. The material of the reef is calcium carbonate: limestone derived from the surrounding waters by the reef organisms. The living reef forms the top layer of the reef adding new limestone to these massive structures at rates that can be measured annually at KG's for every square meter of the reefs surface.

The corals are probably the most obvious life forms on the reefs. All the different colors and shapes made up of thousands of individual polyps,

each secreting its own small cup of coral limestone, which provide the building blocks for reef construction. But plants are also important in the development of this system as many secrete limestone! Coralline algae, in particular, form cementing crusts that act as 'mortar' for the coral 'blocks'. Innumerable other plants and animals also contribute, forming fine sand and courser skeletal material which ends up as either sediments on the reef surface or as infill in the many cavities that develop within the reef.

Coral reefs have existed in the earth's shallow seas for a long time, probably in excess of 450 million years; a clear indication of how successful a life form they are. Although the original corals, called 'rugose' corals, became extinct about 200 million years ago, the reef that they formed were probably very similar to modern coral reefs.

HISTORY

The scleractinian corals that succeeded the rugose forms probably evolved in the warm waters of the Tethys sea, a massive ancient ocean that existed between the northern European and Asian land masses and the Southern African and Indian continents. It was eventually closed by the gradual northward migration of the southern continents, a process known as continental drift. The closing was earliest in the west and latest in the east so that the evolving corals were slowly pushed eastwards into the shallow peninsulas and island studded seas of the western Pacific. It is in this area which has by far the greatest diversity with more than 500 coral species known in this region.

The worlds modern reef's systems began to develop during the tertiary period (about 25 million years ago). Reefs have existed and grown successfully many times in the past. This explains why there are reefs and fossils in cold water areas of the world.

The Australian continent was also on the move and slowly drifting northwards from the cold polar latitudes and into the warmer waters of the tropics and by chance ventured into this area rich in coral growth...its northeastern shores in particular were bathed in the ocean waters passing

through the coral rich seas. (great Barrier Reef)

With the great environmental fluctuations in the earth's history, sea levels have oscillated from positions slightly higher than the present to at least 150m below the present level. Corals and associated life forms were able to survive these changes showing how resistant to natural disturbances this ecosystem is.


Florida is the only state in the Continental US to have extensive shallow coral reef formations near its coasts. The reefs extend from near Stuart on the Atlantic east coast to the Dry Tortugas, west of Key West in the Gulf of Mexico. The best reef development occurs in the Florida Keys. These reefs may rival some of the Caribbean areas and number about 6000 between Key Biscayne and the Dry Tortugas.

These reefs came into existence 5-7000 years ago when the Wisconsin Ice Age ended and the sea level rose. The growth is slow and estimates range from one to 16' every 1000 years.

Live-bottom biota's

WORM REEFS Aggregations of the tropical reef worm (Phragmatopoma lapidosa) construct low reefs of tubes consisting of sand grains cemented together by protein. The reefs expand as worm larva settle on existing tube masses. The reef growth is controlled by waves bringing planktonic food and sand to the worms. Found from Cape Canaveral to Key Biscayne and best developed off St. Lucie and Martin Counties...Bath Tub Reef.

Oculina Banks

Coral banks that occur offshore from JAX to St Lucie inlet at depths of 50-100m are another of FLA little known reef types. The banks are constructed by the ivory tree coral (Oculina varicosa).

GEOLOGY The Fla.-Bahamas region is part of an extensive carbonate platform that once extended into the Gulf coast region. The Florida platform is a massive southward-thickening wedge of limestone's that is at least 6000 m thick beneath Cay Sal Bank. These limestone's have been accumulating for about 150 million years. About 15 million years ago, cooling occurred in the northern latitudes, climates cooled and sea levels began to drop...coral reefs retreating to lower latitudes...and during the past million years with each continental glacial advance, sea level dropped further and coral reef communities withdrew from Florida. During interglacial episodes, sea level rose, waters warmed, and corals returned. The Key Largo Limestone , a fossil coralline rock found in the upper keys, provides evidence of coral reef development during the last glacial period before the present. This formation extends from Miami to the dry tortugas and into the straits of Florida. It varies in thickness from 23m to 61m. the last glacial period ended about 18000 yrs ago and sea level began to rise. Modern reef development began about 5000-7000 yrs ago.


Stony corals are the major reef architects. These small marine animals, called polyps, remain in one place throughout their adult lives and produce a hard skeleton made of calcium carbonate, which they extract from the seawater and combine with CO2 for limestone, constructing elaborate limestone skeletons which are left behind when the animal dies. Some corals grow in colonies that continue to enlarge year after year, and some are solitary and live alone. Together they can form enormous colonies that are called coral reefs, coral islands and coral atolls. The largest, being the GBR, is 1,250 miles long. They can exhibit many shapes, sizes, and colors

and reefs look like underwater gardens (although they usually lose their colors when removed from the water except red coral). These shapes and patterns are characteristic for the species and are a result of growth patterns of millions of tiny individual polyps that make up the colony.

And though reef corals are classified as animals, there is a complex of microscopic plants called zooxanthellae, which live within the animal tissues (symbiosis) and the animals benefit from the energy that the plants provide through photosynthesis. These dinoflagellates gain nutrients from the corals nitrogen and phosphorus wastes. They are also responsible for most of the colors of the reef.

These specialized habitats provide shelter, food, and breeding sites for numerous plants and animals and form a breakwater for the adjacent coast, providing natural storm protection. They are also important to SE Fla's economy.

Reef development occurs only in areas with specific environmental characteristics:

1. a solid structure for the base,

2.warm and predictable water temperatures and oceanic salinities,

3. clear, transparent waters low in phosphate and nitrogen nutrients,

4.and moderate wave action to disperse wastes and bring oxygen and plankton to the reef.

Corals live in all oceans of the world from the Arctic and Antarctic to the tropics. The largest reefs occur in the warmer portions of the Pacific and Indian oceans however they are also found in the Caribbean and gulf of Mexico and southern Florida.

Numerous species occur in the different areas ranging from 40 or more in the West Indies to 200 or more on the Great Barrier Reef (because of their great skeletons, their fossils have yielded more than 6000 extinct species.) Corals can live in water below 68-70 degrees (reef min. temps) but don't form reefs, just like some corals which can live 19,000 feet below the surface, but reef building corals are in water usually less than 300'.

There are three types of reefs, 1. fringing, which follow the coastline and form along the coast, 2. barrier reefs, which lie parallel to the coast and separated by a narrow lagoon, and 3. atolls, which are associated with rims of extinct volcanoes which sunk back into the ocean leaving a circular rim of coral around a deep lagoon.

Great care must be taken to minimumize human damage and though the reefs are well marked on the charts, every year careless boaters run aground destroying coral colonies hundreds of years old. From the surface reefs have a unique golden brown color. If you see brown, you may be about to run aground. Anchors, hooks traps and touching all injure or damage or destroy corals by leaving it vulnerable to infection by microscopic organisms that can kill the animals.

The Animal

The adult coral, stationary at this stage in life is called a polyp which can reproduce in two different ways. One is by means of eggs that, when fertilized by sperm, develop into tiny swimming larval organisms called planulae. They eventually settle down on the bottom of the ocean, on a rock etc. and develop into polyps. Each polyp builds a limestone skeleton attached to the surface on which the polyp has landed. After establishment, the upper part of the polyp becomes domed shaped, develops a body and a mouth with tentacles around the mouth used to draw

in food from the surrounding waters. The tentacles are armed with specialized stinging cells called nematocysts that paralyze tiny prey. (mostly at night)

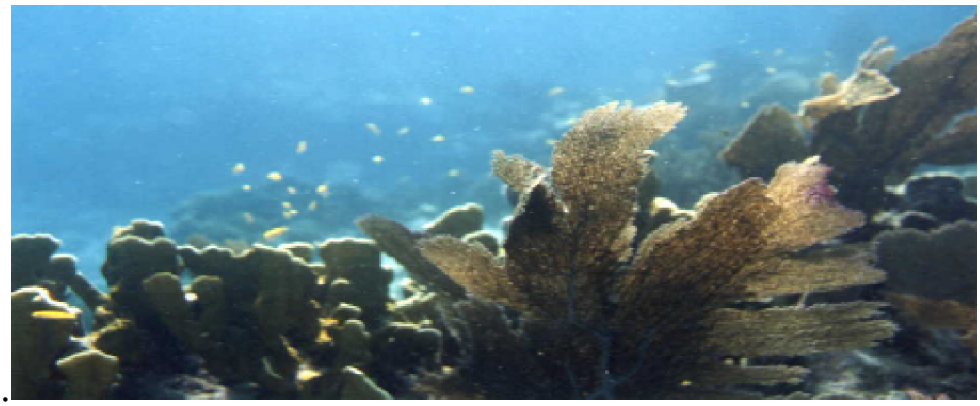
Another process is by budding which offshoots called buds grow out from the body and remain attached sending out more buds. Some corals, the buds break off to become separate individuals. The largest solitary polyps grow to a diameter of 10 inches (25cm) while polyps of colonial species form from .04-1.2inches in diameter.

(comptons CD Rom1990)

The coral reef has a very high order of internal organization, greater even than the tropical rain forests they are often compared to. Both receive high levels of solar radiation, the ultimate source of all ecosystem energy. (p63 Great Barrier Reef).

CORAL BIOLOGY 63 coral taxa in keys

2 CLASSES of reef corals exist, HYDROZOA AND ANTHOZOA. In the keys, Millepora (fire coral) is the only hydrozoan coral on shallow reefs. Stylaster and Distichophora are found in deep habitats. The anthozoans include octocorals, zoanthids, stony corals, false corals, and anemones. Reef corals are colonial, often containing thousands of individual members

or polyps. 

---------Fire Coral-*(M. complanata*)----------Fan Coral....Keys

FIRECORAL...MILLEPORINA The stinging/burning comes from nematocysts. 2 species of firecoral are found in Florida reef. The bladed is a keel shaped (*M. complanata*) restricted to shallow windward reef tops. Crenulated (*M. alcicornis*) is a branching species found in a much wider range of reef habitats. Fire corals are successful in colonizing living octocoral branches.

In 1842, Charles Darwin devised a scheme to describe coral reefs that still dominates their classification. He described them as "fringing reefs" attached to the mainland or island, "barrier reefs", and open ocean atolls. Fringing reefs, the simplest reef landforms, are built upwards and outwards in shallow seas adjacent to islands or continents. Barrier reefs occur further offshore, separated from the mainland shore by a shallow lagoon. In contrast, atolls are found in the deeper oceans, having usually developed over volcanic foundations that have subsided beneath the sea. Coral growth in this case produce saucer like reefs with central lagoons.

Coral reefs can only grow up to about the level of a low spring tide, and reefs (as opposed to individual corals) will probably not develop in water more than 40m deep. Reefs are, therefore, strongly influenced by sea level. Over the time that most of the world's reefs have grown, there

have been major sea level changes. There were two main reasons for sea level changes. One, the worlds ocean basins have changed in size and shape because of sea floor spreading and plate tectonics and the other is the ice ages.

ZONES OF THE MODERN REEF.

In the last 8000 years, reefs have grown to what they are today. They have grown from the older reef platforms about 15-20m deep. The modern reefs are relatively thin and their shape reflects accurately the shape of the surface over which they are growing.

To understand the growth of modern reefs, its best to begin at the surface, where five easily defined zones can be identified:

1. the reef front,

2. the reef crest,

3. the coral flat,

4. the sand flat, and

5. the lagoon.

The upper slope of the modern reef front extends from the mean low-water level of spring tides down to a depth of 10 to 20m. Fairly steep, sometimes vertical, sometimes terraced, and often serrated by coral covered spurs and channels, the area has a lot of coral cover. On some reefs, the front is protected by a line of patch reefs, many of which are joined to form an outer front.

The exposed windward reef crest, or outer reef flat, lies above the mean low-water level of spring tides. It is composed of either a seaweed, stepped surface of encrusted coralline algae and devoid of corals, or a flat coralline-encrusted surface that may reach half a meter above the

mean low-water level of spring tides, as on a ribbon reef. The upper surface of the reef crest is sometimes covered by a green turf of fleshy algae, which provide a home for countless small organisms, particularly foraminifera. These algae pavements can reach 200-300m wide and form in response to the high energy conditions typical of windward edges. These algal pavements are replaced by extensive coral development in lower energy or more leeward parts of the edge of the reef.

The coral flat or reef flat, occurs on the sheltered or lee side of the algal flat. It usually consists of an aligned coral zone where most corals are encrusted by coralline algae. These aligned corals occur in patches 1 to 2 m wide and 20m long formed by coral growing parallel to the direction of waves refracted across the top of the reef. The water movement is channeled across the grooves between the aligned assemblages of coral and in this way, coral growth on the reef top controls the backward flow of water across the reef. Nutrients and sediments are carried back through these channels to the sand flat and lagoon areas. This zone is usually separated from the lagoon by a sand flat, sometimes up to 500m wide. The sand flat is made up of broken skeletons of corals, coralline algae, and other reef organisms derived from the reef front and coral flat and transported toward the lagoon as sands and gravels. Foraminifer from the algal turf of the reef crest also form part of this sediment.

Sand flats have been built by prevailing swell and waves that continually destroy the reef front and transport the broken products backwards. The surface of the sand flat, covered by one half to two meters of water, depending upon the tides, is often sparsely covered by small colonies of branching corals which can grow from fragments brought from the coral flat which grow when they come to rest. What can happen is that as these pieces start to grow a small solid patch eventually forms after larva of massive corals settle and grow. In this way, the coral flat extends backward across the sand flat, and the sand flat will migrate into the lagoon.

The lagoon is best seen in platform reefs, where they reach 5-10m deep with the deepest part on the leeward side of the reef. Lagoons are

sometimes open with very few patch reefs rising from the floor or often very crowded with patch reefs making navigation of the lagoon difficult.. These patch reefs whether they form discrete circular or network-like structures, usually rise vertically from the lagoon floor. They are made up of many species of branching and massive corals, the dead parts of which are encrusted by coralline algae. The lagoon floor consists of coral sand, which becomes finer away from the windward margin and patches of mud (very fine) sometimes occur in the quiet waters of the leeward margins. Because the lagoons are depositories for sediments and organic material created on the windward margin, they are slowly filling up.

About 6000 yrs ago, sea level established and maintained a position close to what it is today. In ten meters of water, corals grow upwards toward the light, so that the reef surface grows upward from the deeper, quiet water to the high energy surface environment characterized by heavy pounding of the surf. The types of corals that make up the reef change as the environment changes.

The composition of the reef also varies with the position of the reef on the continental shelf. The structure of the outer shelf-reefs generally reflects the influence of powerful waves, and here most of the reef consists of coral skeletons forming a porous, but relatively stable framework. Reefs in the middle and inner parts are dominated by accumulations of sand, and the coral framework forms a much smaller proportion of the reef, reflecting the calmer sea, or lower energy conditions compared with the outer reef.

3 stages of reef development can be seen.

1. vertical growth to sea level...a reef growing slowly from a deep substrate may not yet have reached sea level or only recently have reached sea level and is characterized by vigorous growth of free-standing branching or massive corals upwards to sea level. Such a reef is

termed juvenile.

A reef growing from relatively shallow substrate, or one growing rapidly from a deeper substrate, will reach sea level quickly and will be subject to the influences of shallow water for a long time...many have been at sea level for 4 to 6000years. Swell, waves and currents help develop these and these reefs are called mature.

Reefs growing from very shallow substrates, or small reefs that have grown rapidly from deeper substrates, may have been at sea level even longer than mature reefs and because a long time at the surface leads to destruction of the reef, lagoons will have been filled in and the typical zonation destroyed. Erosion is thought to exceed production, and such reefs are called senile.

Its believed that reefs progress through the growth stages from juvenile to mature to senile. Different reefs require different lengths of time to follow this progression, the time being dependant on depth and size of substrate, rates of growth, length of time at sea level, and intensity of the processes operating at sea level. As reef growth has seldom lasted for more than 5000-15000 years, some large lagoon reefs may not have sufficient time to progress through the complete cycle in one high-sea-level growth phase and could need more than one growth phase to reach a senile condition.

Maintenance and Destruction

Reefs come in a vast array of shapes and sizes and many of these differences result from erosion while periodically exposed during low-sea-levels rather than from growth differences. While the reefs are biologically complex with the many plants and animals, they are also ecologically organized with a series of zones across the reef, each serving a specific role in providing food, consuming wastes, recycling nutrients, and creating and maintaining the limestone structure that is the reef.

The clear boundaries and isolation make coral reefs excellent examples of the natural order of things.

Many of the worlds tropical oceans have few plant nutrients, which result in little plankton growth (the absence which results in the beautiful blue color usually associated with tropical seas), but coral reefs show no particular preference for the most barren areas of the ocean and can live in water very low in plant nutrients and plankton to water that is quite enriched. The enriched environments often find the reef not being able to compete with other marine systems dense beds of large algae populated by filter feeding animals such as barnacles. Though reefs don't prefer to struggle for nutrition, they have developed the ability to thrive in barren areas of the ocean more effectively than other marine systems by creating and recycling their own internal food supply.

Chemical runoffs can either be destructive such as herbicides and insecticides or enriching, such as fertilizers. In either case the viability of a coral reef community is threatened. Inshore reefs whether they be stable or in decline, do not develop the structured zonation and balanced communities of the outer reefs because they exist in enriched and biologically active waters and internal recycling of the food supply in not essential.

Needs

A coral reef requires only the basic plant nutrients plus a copious supply of calcium for the construction of the calcium carbonate of the coral skeletons and other limestone forming materials of the reef. Carbon dioxide and calcium are abundant in sea water. N, P and some trace elements may only be present in limited quantities in the clear oceanic waters and the reef must recycle these materials to maintain its intense biological activity. All plant and animal matter grown must be totally consumed or fully degraded within the reef community to prevent the loss of any nutrients. Extensive mats of blue-green algae on the reef may provide the reef with N by converting the N in the atmosphere to the soluble inorganic N nutrients.

There are very small but important losses and gains from any reef system and that is the exchange of larval forms with other reefs. This ensures

inbreeding and that any species depleted by disease or other stress will be replaced by larval input from another reef or reefs.

About 3/4 of the CO2 that is removed from sea water by a coral reef in each 24hr period is used directly in photosynthesis within the reef algae. This creates about 20g of new organic matter for every square meter of shallow, reef-flat environment per day and can be up to 50g a day in areas of intense biological activity. This is the reefs food supply.

Most of the limestone making up the solid underlying mass of the coral reef consists of skeletons of once living corals. This material may remain where it grows, though it is perhaps more commonly broken off and redeposited in other parts of the reef. One thing certain, corals cannot cement their skeletons together in a solid reef structure, they mearly form a vast quantity of limestone. They provide the aggregate of the reef concrete. At least some of the corals in this rich surface growth are likely top add to the structural framework of their own reef when they die.

The encrusting coralline algae hold together the sand and framework materials of the reef to create a solid surface. They have a role in building a real reef rather than a pile of uncemented coral debris and sand. Once the reef has been totally consolidated by these algae, chemical precipitation of more carbonates in the reef structure provides additional cementing of the remaining loose calcium carbonate materials. Its a slow process but it makes the entire structure more rigid. The final reef material is a porous but strong limestone, though it frequently contains uncemented regions.

NUTRIENTS AND REEF PRODUCTIVITY

Direct feeding by the polyps usually only supplies only 10 per cent of the corals energy needs. In such cases, most energy comes from photosynthesis by zooxanthellae, which obtain nutrients from metabolic waste products of the coral host as well as from the seawater or detritus. Coral reef primary productivity is usually very much higher than areas where these nutrients are more abundant but recycling rates of the corals and zooxanthellae are high but the harvestable primary productivity is low

because most of the organic matter produced is metabolized and nutrients are freed to be reused in photosynthesis.

Almost every gram of organic matter created by a coral reef is consumed and eventually finds its way back to the sea water as carbon dioxide. Before most of the organic matter is finally degraded back to CO_2, it may move through all or part of the complex and finely balanced coral reef food web.

What is the result of a reef creating and totally consuming so much food material? First, it allows the continuing maintenance by reproduction of the coral reef community by feeding the sun's energy into the system. Second, and perhaps most significantly, it provides the energy needed to remove the other quarter of the total of CO_2 used by the reef in a 24-hour period. This additional CO_2 is used in the biological formation of calcium carbonate or limestone. The limestone created us mostly retained by the system, giving rise to the physical growth of the reef structure.

Reefs may be thought of as assemblages of beautiful animals but in fact they are dominated by the activities of plants. The whole system is driven by the photosynthetic activities of plants, just like most ecosystems existing in light. Even the corals function principally as plants, deriving as much as 90% of their total and energy requirements from the tiny algae, known as ZOOXANTHELLAE, contained within their coral tissues. The remaining requirements are met through feeding on reef plankton.

Apart from the corals, the major plants providing the food supply of the reef are fine filamentous algae that form a rapid growing fuzz or turf over almost all available surfaces within the reef. This turf is grazed by animals, which in turn are preyed on by larger animals and so the food web expands. Also, all living materials die and undergo microbial decay, forming the basis of yet another component of the complex food web. The reef also creates and consumes its own plankton. Each animal and plant serve a vital role in the reef's finely tuned balance.

The Factory

The 10 to 30 grams of calcium carbonate or limestone created everyday for each square meter of the active parts of the reef are retained somewhere within the general reef environment. The reef thus exhibits real, measurable growth over hundreds of years. The energy to enable the creation of all this limestone comes into the system through algal photosynthesis. Much of the limestone originates as growing coral but other organisms, such as many algae, tiny single celled forams, and shells make major contributions. The cements in the limestone rock are partially deposited by algae and partially chemical precipitation.

Photosynthesis by zooxanthellae also promotes production of skeletal limestone's that make up the reef framework. Zooxanthellae provide coral with the energy needed to calcify. (They also prevent phosphate poisoning of calcification by removing phosphatic wastes and any phosphates from the microenvironment (phosphate inhibits the precipitation of aragonite crystals, the skeletal building blocks of corals))

Photosynthesis uses CO_2 and water from respiration raising the pH of the system end enhancing aragonite precipitation.

During calcification, calcium ions, which are abundant in sea water, combine with bicarbonate ions, also found in the environment and the following reaction occurs...

1 $Ca_2 + 2HCO_3$ -----> $Ca(HCO_3)_2$ and then calcium carbonate and carbonic acid are produced...

2 $Ca(HCO_3)_2$----->$CaCO_3 + H_2CO_3$

but carbonic acid can't exist so carbonic acid must be ionized

3 H_2CO_3---> $H^+ + HCO_3^-$ or converted to water and CO_2

4 H_2CO_3----> $H_2) + CO_2$

Reactions 3 and 4 are catalyzed by the enzyme carbonic anhydrase, which is found in the calicoblastic epithelium the corals tissue layer where calcium metabolism is most active. Calcium Carbonate is apparently stored then actively transported in a system of microvessels to the deposition sites where it is deposited as aragonite crystals. It has also been suggested that the zooxanthellae provide glycolate, which is converted to glyoxylate and combined with urea to form allantoic acid. This may be the medium by which calcium and CO2 are transported to sites of calcification.

Destruction

One of the obvious of all reef destroying processes are storms. But not all reef destruction is caused by physical forces. Many animals and even some algae live out their lives inside the reef structure and even in the skeletons of still-living corals and other organisms with hard skeletons. Some of these graze off of the reef surfaces and remove considerable amounts of the limestone at the same time. These boring and grazing organisms weaken the structure of their host or the reef itself by physically disrupting the limestone materials. This in turn, forms more fine sand and calcium carbonate detritus in the reef system. But the boring organisms also dissolve, using acid secretions, much of the calcium carbonate they remove (about 5-25% of total CaCO3 deposited by the reef)..

Readers digest Great Barrier Reef pp64-86.

CORALS EXTRA

BIOLOGICAL INTERACTIONS

Of course, grazing and predation can be readily observed but on coral reefs, disease, competition, chemical warfare, bioerosion and symbioses are also common.

Pathogens may injure and kill corals, and black band, one such pathogen usually attaches to a coral following tissue damage.

Competition include overgrowth denying light and water movement.

Allelopathy (chemical defense and offense) is also used to prevent overgrowth and gain living space.

Damselfish destroy coral tissue and farm/defend algae on the dead coral.

The black sea urchin crops algae from the reef and this provides settlement habitat for coral larvae.

Sponges bore into coral skeletons, weakening them, some bind to them and some protect the undersurface from attacks by boring organisms.

Chapter Questions

Coral Reading with Questions

1 **State Of Coral Reefs in ..by Carlos Goenaga**

1.How old is the recent Caribbean Coral Reef System?

2 List 5 socioeconomic importance's of coral reefs and give an example of each.

3. How are reefs a buffer for the CO2 cycle?

4. What 3 human activities threaten Caribbean reefs? How do they occur?

5 How does upland clearing effect coral reef?

6 How does sewage discharge effect coral reefs?

7. The discovery **of what** about coral has made the destruction of reefs an international interest?

Coral Readings

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Estuaries 

Lecture Notes

Estuaries are of immense importance and are frequently areas of high fertility and large phytoplankton and zooplankton populations. Its been estimated that 60 to 80 % of the commercial marine fisheries resources depend on estuaries for part of or all of their life cycle.

An estuary is a semi-enclosed coastal body of water which has free connection with the sea, thus is strongly affected by the tidal action. Sea water is mixed with freshwater from land drainage. The estuary is not part of the coast but is a coastal feature with a continuous exchange of water between it and the sea. It typically contains marine plants and animals having anatomical, physiological, or behavioral adaptations to the changing conditions found in estuaries. They produce numerous kinds and vast amounts of sport and commercial fishes and provide numerous other ecological services of direct and indirect value to humans.

Positive estuaries...the precipitation and runoff exceed evaporation and sea water is diluted.

Neutral estuary...runoff+prec. =evaporation

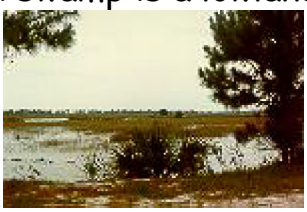
Negative or inverse estuaries...almost no freshwater runoff.

Currents in the estuaries come from tides, river runoff, transport by wind generated surface waves, direct stress by wind on water surface , variations in density distributions, and internal waves.

Plants and animals possess different tolerances for such physical parameters as salinity, consequently an estuary may be divided on the bases of salinity, each part corresponding to certain biotic classifications.

Several terms are used interchangeable with estuary: wetlands, lagoon, slough, salt marsh, marsh, swamp. The term wetlands refers to land on which water dominates the soil development and thus the types of plants and animals that will live there.

The term lagoon is the region between a barrier island or spit and the mainland, a slough is a shallow estuary with large areas of the bottom exposed during low tides, a salt marsh is a shallow tidal estuary protected from ocean waves and inhabited by plants and can withstand submergence. The term marsh (used interchangeable with salt marsh) but in precise sense refers to a region with zero salinity upstream from a salt marsh. A swamp is a lowland area saturated with water often quite large and farther inland.



> It is common for coastal nekton to use estuaries as nursery grounds where young growth stages can take advantage of the protection and abundance of food. Since man often harvests such species offshore, the vital life history and energetic connections with the nearby estuary have not always been appreciated and the dependency of so many important commercial and sport fisheries on estuaries is one of the major economic reasons for preservation of these habitats. Its estimated that 60-80% of the commercial marine fisheries resources depend on estuaries for part or all of their life cycle.
>
> The intertidal and adjacent shallow water zones are the most productive and most important and also the 1st to suffer the ill planned encroachment of man Estuaries tend to be more productive than either the sea on one side or the freshwater drainage on the other.

The estuary is a nutrient trap, partly physical and partly biological. Retention and rapid recycling of nutrients by benthos, formation of organic aggregates and detritus, and the recovery of nutrients from deep sediments by microbial activity, and deep plant roots create a self-enriching system. Pollution can also get trapped.

There are three types of producers in the estuaries...macrophytes, benthic microphytes, phytoplankton.

Detritus...involves accumulation and decomposition of dead materials.

Spartina is the major producer and the microbial enriched grass detritus feeds

consumers in creeks and sounds. The role taken by eel grass *Zostera* or seaweeds in colder water, Turtle grass (*Thalassia*) in warm waters...make contributions to productivity of sub-tropical and tropical lagoons. These sea grasses often support a large population of epiphytic algae and small fauna.

 Spartina

Terrestrial and freshwater vegetation that lived in the low lying coastal regions during the ice age were killed as the advancing seawater moved inland. Grasses that could thrive in brackish estuarine environments colonized the salty mud and as the the roots of the plants grew down, trapping more particles, the estuary grew. With each tide, planktonic larva of clams, mussels, crabs and worms settled among the plants and fish, birds insects and animals migrated to the young estuaries for food and living space.

 St. Aug. FL

The salt marsh community is a relatively flat grass covered coastal area occurring within the estuarian ecosystems in temperate climates. Its partially flooded by tides (tidal march or wet land). The marsh can be thin or very wide and is one of most productive habitats in the marine environment. Vast quantities of food are produced by marsh grass (*Spartina*) and algae that live on the surface of the mud. Photosynthesis. is fastest at low tide and an ample supply of nutrients (nitrates,

phosphates and sulfates) in the estuary make a high rate of food production possible. (nutrient rich water bought in each high tide). Blue-green algae convert atmospheric Nitrogen into nitrates .

Salt marsh producers grow rapidly and absorb minerals at a fast rate. *Spartina* grass and other marsh producers have a short life. Floating seaweed and debris are dumped onto the marsh at high tide and as this and the marsh grass dies, teeming masses of bacteria break down the complex plant material into detritus. Isopods, insects, fiddler crabs, marsh snails eat the decaying plant tissue, digest it, and excrete wastes that include nitrate, phosphate and sulfate. By quickly converting the decaying material into inorganic material, these detritus feeders speed the growth of living marsh plants.. Each tide carries much of the detritus and minerals into the offshore water with phytoplankton using the minerals, clams, mussels, worms, and sponges eat pieces of detritus. (these excrete minerals when they break down the detritus adding more..and this rapid cycling of minerals is a unique feature of the tidal salt marsh, making the high rate of primary productivity possible. Wetlands near cities also have an additional source of minerals for producers with the billions of gallons of sewage/treated and untreated, discharged into coastal waters (as well as PCBs bacteria, viruses heavy metals, which can be ingested by marine organisms and be passed on to humans).

Food web

Communities within estuaries are linked by overlapping food chains as energy flows from primary producers to consumers. (food wed). Many primary producers are first converted by bacterial decomposition into organic detritus which serves as a major food source for the majority of consumers living in the estuarine community. An important group of primary consumers living in estuaries are animals that feed on plankton and these are the most abundant species of vertebrates in estuaries because of the large supply of food available to them. The carnivores (predators) occupy the highest level obtaining energy by eating animals that feed on plankton and detritus.

Predators are important to the estuary because of their end position in most consumer food chains. Part-time and full time residents feed there. Many migrating

animals stop over for refuge and food in the estuary thus exporting the energy to other environments. One aspect of the estuary food web is that there are more different species of consumers than species of primary producers. A few provide nutritional needs to many. Thus the usual trophic pyramid is inverted because most carnivorous species are at the top of the food web!

Salt Marsh Page

Chapter Questions

Reading With Estuary Questions

2 Florida Estuaries (What are Estuaries)

1.What conditions do estuarine plants and animals have to put up with?

2. What can upset the balance of estuarine organisms?

3. Why are estuaries special to Florida?

4 List some producers and consumers of the estuaries.

5. How is Florida mapping their estuaries?

6. What percent decline in estuaries has been noted from Sebastian inlet to St. Lucie inlet along the Indian River?

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Marine Ecology

Lecture Notes -

Marine ecology is the branch of ecology dealing with the interdependence of all organisms living in the ocean, in shallow coastal waters, and on the seashore. The marine environment for all organisms consists of non-living, abiotic factors and living, biotic factors.

Abiotic The abiotic factors include all the physical, chemical and geological variables that have a bearing on the type of life that can exist in an area. Included are

- water
- light
- temperature
- pH
- salinity
- substratum
- nutrient supply
- dissolved gases
- pressure
- tides
- currents
- waves
- exposure to air.

Biotic The biotic factors are the interactions among living organisms. **Zonation** Two major divisions in the marine world.

- Pelagic zone...waters of the world and benthic zone..the ocean bottom.

The pelagic zone include the productive coastal waters..neritic zone and deep waters of the open ocean..oceanic zone. Another division in the pelagic zone is related to light penetration..the photic and aphotic zones.

The **benthic zone** extends from the seashore to the deepest parts of the sea. The material that makes up the bottom is the substratum and the organisms living there are the benthos.

Tides uncover parts of this zone and the area uncovered is the intertidal zone, above is the supratidal zone, affected by salt spray but not covered by sea water and below the intertidal zone is the subtidal zone..submerged and extending seaward. The elevation and slope determines the length of time its exposed. This affects organisms living there because some are restricted to zones according to their adaptations to this type of zone (intertidal etc.).

Organisms living in pelagic waters also put up with changes in salinity, temperature etc. and inhabit the coastal areas etc. which fit their adaptations. (can withstand large changes (eury-- prefix) and narrow tolerance (steno))

Other zones include the surface waters of the coastal areas called the neritic zone and the waters of the ocean called the epipelagic zone.The open ocean is less productive than the neritic zone which contains plant plankton, fish larva, invertebrate larva that will eventually end up near the coast.

The open ocean is divided into zones depending on the amount of light it receives...from the **epipelagic** layer to the **mesopelagic** zone 200-1000m in which daytime inhabitants migrate upwards during the night, bringing back nutrients and some exhibit bioluminescence (light producing organs called photophores). The deep sea layers **bathypelagic** 1000-4000m and the **abyssopelagic** zone (below 4000m) have limited food supplies although bacteria have been found that can make their own food.

TROPHIC (FEEDING) RELATIONSHIPS Energy transfer is accomplished in a series of steps by groups of organisms known as autotrophs, heterotrophs, and decomposers. Each level on the pyramid represents a trophic level.

Autotrophs absorb sunlight energy and transfer inorganic mineral nutrients into

organic molecules. The autotrophs of the marine environment include algae and flowering plants and in the deep sea are chemosynthetic bacteria that harness inorganic chemical energy to build organic matter...AUTOTROPHIC NUTRITION..supply food molecules to organisms that can't absorb sunlight.

HETEROTROPHS Consumers that must rely on primary producers as a source of energy...heterotrophic nutrition. The energy stored in the organic molecules is passed to consumers in a series of steps of eating and being eaten and is known as a food chain. Each step represents a trophic level and the complex food chains within a community interconnect and is known as a food web.

DECOMPOSERS The final trophic level that connects consumer to producer is that of the decomposers. They live on dead plant and animal material and the waste products excreted by living things. The nutritional activity of these replenish nutrients that are essential ingredients for primary production. The dead and partially decayed plant and animal tissue and organic wastes from the food chain are **DETRITUS**. This contains an enormous amount of energy and nutrients. Many filter/deposit feeding animals use detritus as food. Saprophytes decompose detritus completing the cycle.

ENERGY TRANSFERS IN MARINE ENVIRONMENTS Primary producers usually outnumber consumers and at each succeeding step of the food chain the numbers decrease. The numerical relationship is called the pyramid of numbers. (base as opposed to each step.) The energy pyramid is the energy distribution at each trophic level as it passes from producers through the consumers. Some energy is lost as it passes to the next level because

- (a) consumers don't usually consume the entire organism
- (b) energy is used to capture food
- (c) organisms used energy during their metabolism
- (d) energy is lost as heat.

Generally only 10% will pass on to the next level. (The shorter the better..)

FOOD RELATIONSHIPS Predator-prey..predator kills and eats another organism... the prey. Antipredator defenses have evolved LIKE

- POISONOUS SECRETIONS,
- SHARP SPINES AND THORNS
- THE HARD SHELL-LIKE CONSTRUCTION of Coralline algae also deters grazing sea urchins

.

Scavengers..feed on dead plants and animals that they have NOT killed...crabs ripping chunks of flesh from fish on the beach are scavengers. Most scavengers consume detritus rather than flesh and deep sea animals can feed on both.

Symbiotic...refers to close nutritional relationship between two different species...

- commensalism- one benefits
- mutualism both benefit and parasitism
- one benefits at hosts expense.

Population Cycles ..density or numbers of individuals depends on

- 1. natality or rate of production of new organisms and
- 2. mortality..rate of death in a population.

Now to be stable the two must be in equilibrium but under favorable conditions, populations can increase numbers (can be seasonal and geographical) but this also increases mortality because of decreased food supply and living space and increased predation. If mortality is greater, then the population decreases. These favorable conditions depend on

- high concentration of nutrient rich water,
- rapid cycling of materials by decomposers,
- high numbers or rapid turnover of producer organisms
- Light
- nutrients including nitrate, phosphate, silicon, potassium, magnesium, copper, iron.

Silicon dioxide needed for outer glass covering of diatoms and forms internal structural parts of sponges, K and NO4 and PO4 needed in plant proteins, lipids and carbohydrates during photosynthesis. and the nutrients can be considered a limiting

factor as well as pH temp. light , depth salinity nesting sites and predation.

Distribution Pelagic world include the drifting organisms...**plankton** and the swimmers...**nekton**.

Plankton comprise the large and small organisms that drift or float while tides and currents move them through the water. Most plankton do have a limited ability to move and can migrate vertically through the water from day to night. Some drifters can photosynthesize while others are consumers.. Plankton is very important as it occupies the first two or three links in the marine food chains.

Nekton use fins, jets of water, strong flippers, flukes and flippers to swim through the water.

Benthic If the organism resides primarily in or on the substrate and doesn't swim or drift for extended periods as an adult it is considered benthic. They either burrow , crawl, walk, (motile) or are sessile..permanatly affixed to the substrate or each other. Demersal organisms, such as flounder alternate between swimming and resting on the bottom. Living on the bottom are epifauna and living within are infauna. The substrate could be a source of food.

PLANKTON Phytoplankton, plant plankton,are the important primary food producers in the pelagic environment. The animal members of the plankton are the zooplankton which range from bacteria size to 15m jellyfish. Phytoplankton are the trees of the sea which float near the surface to make the most of the sunlight for photosynthesis.Two forms of phytoplankton, dinoflagellates and diatoms are particularly important as founders in the planktonic food webs because most of the animal life in the oceans depend on these. The dinoflagellates are usually found in warmer waters, and the diatoms are usually more abundant in cooler waters. Other plankton, coccolithophores and silicoflagellates are also abundant as well as blue-green algae (in certain locations it can become the dominant) and green algae but usually in the coastal water (some are in the open ocean as findings of chlorophyll b indicate. Phytoplankton have adaptations which deal with methods of keeping them in the upper zones to stay in the sunlight.. Size...small sizes retards sinking, structure...shape/structure of the diatoms effects sinking rate and density...decrease by storing droplets of oil in the cytoplasm. Blooms Although unknown, the availability of nutrients, amount of vertical mixing, salinity, density,

temperature, and depth of water affect phytoplankton growth rates. Blooms called red tides have occurred in almost all oceans. Red tides usually refer to the discoloration of the waters as a result of the absorption of light by pigmentation in planktonic organisms. The red water usually results from actions of non-toxic organisms and the term red tide is inadequate when used with reference to PSP (paralytic shellfish poisoning) and toxic dinoflagellates will not always discolor the water (too few) but may be numerous enough to toxify shellfish. Some mysteries have been solved but evidence that PSP may be increasing in intensity and spreading to new areas is surfacing. About 60 species of dinoflagellates may color offshore waters however only 6 have been shown to produce toxic substances. Some toxins, saxitoxin, is 50x more poisonous than curare (used by SA Indians). Repeated cell divisions as result of long period of dry weather following a violent storm which stirs up bottom sediments, reach concentrations of 25,000 dinoflagellates /ml of water. Bioluminescent phytoplankton bloom in the ocean and produce a bluish-green light. Phosphorescent Bay in Puerto Rico contains high concentrations of bioluminescent phytoplankton throughout the year. One type, Noctiluca sp. Disturbing water, passing of boat, wave breaking, initiates bioluminescence. Zooplankton..500,000 per gal and range in size from single cell to jellyfish. Almost any animal phylum can be found wandering through the sea but the most common are Copepods (95%). Two types of zooplankton....Holoplankton or permanent members of the community and temporary residents called Meroplankton. Holoplankton have evolved efficient means of remaining adrift...special appendages, droplets of oil and wax, tread water, jelly-like layer, gas-filled float. A majority of inverts and many verts. have planktonic stages (meroplankton) Drifting eggs and larva of fish, crabs, barnacles, worms, clams, snails, sponges, lobsters, etc. They use the water mass to feed and disperse their planktonic young to new habitats. The reproductive cycles often coincide with maximum concentrations of food and favorable currents. EX. polar oceans, spring phyto. bloom triggers increases in zooplankton coinciding with migration patterns of whales, seals and penguins. Vertical migrations refers to Copepods and other zooplankton moving up toward the surface to feed in the evening responding to the changing light reducing predation during the day because they are in deeper layers. This varies among species but light, shadows and pigments of phytoplankton (color) helps zooplankton locate food. Thus buoyancy, mobility, vertical migration, and chemical sensing enables Copepods to search open water for concentrations of food. Trophic levels in zooplankton communities Energy

incorporated in organic molecules by marine plants flows to the zooplankton community in a complex series of interconnected food chains. Each chain or part of the web serves to link phytoplankton to larger pelagic animals through the zooplankton. Herb. zoo eat phytoplankton while carniv. zoo occupy the third level as secondary consumers. Nekton Free swimming organisms equipped to direct their movements through the sea including cephalopods, fishes, marine mammals, sea turtles and marine birds. Many are at the top of the trophic levels either as carnivores or herbivores without natural predators..except man. Swimming allows escape or movement toward food and methods of locomotion are very diverse, from jets of water, flippers, large tail fins and flukes. Planktivorous nekton are animals that feed directly on plankton such as baleen whales and some fish. Herbivorous Nekton are ones that feed on large seaweeds ad sea grasses (turtles and manatees) Carnivorous Nekton are the dominant carnivorous animals of the pelagic environment and generally these animals migrate great distances in search of food. Production Food production occurs mainly through Photosynthesis. It is measured and called Primary food production which will occur in the photic zone as phytoplankton manufacture organic matter during photo. The primary productivity varies seasonally and geographically. It is measured as g of Carbon/m2/year. (Long Island Sound 500g, Antarctica. 2-400g etc.) . It seems that the more vertical mixing that occurs in an area, the higher the primary production is because in the tropics where there is little vertical mixing, their Primary Productivity is low because of the depletion of nutrients in the surface waters. Primary productivity decreases as depth increases as there is less light and less photo. Accessory pigments in algae enable them to make the most of the little light that does get to them. The boundary where the food production (photo) is balanced out by the rate of respiration (the use of the food) is called the compensation depth. Copepods metabolize droplets of diatom oil to liquid waxes and fats which can be used as long-term energy reserves. (waxes; long/fats short). It is these waxes and oils that get used for blubber when the Copepods/krill are fed on by marine birds and mammals. Detritus food chains are also secondary when decaying material enter the detritus chain as decaying materials, wastes, pieces of animal tissue. The swarms of Copepods feeding on diatoms excrete packets of partially digested matter called fecal pellets. These pellets usually aren't eaten by other pelagic organisms and provide food for bacteria when they settle as well as a host of detritus feeders on the bottom (transfer of energy from the top to the bottom). While there is a loss

of energy to the grazers, many consumers are adapted to feed on detritus thereby returning energy to the food chains. Chitionolytic bacteria can break down chitin which represents an enormous source of organic carbon. Some are even symbiotic and found in the intestines of certain pelagic organisms to help them digest chitin. These bacteria play a big role in making sure the billions of tons of chitin produced in the marine environment each year get broken down and their nutrients are returned to the primary food makers.

Chapter Questions

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Scientific Classification

Systems

Why a Scientific Classification System?

- **Ambiguity of terms**
- **Latin "dead language"**
- **Categorization of relationships:**
- **Evolutionary**
- **Structural**
- **Biochemical**

- (NOT habitat)

7 Classification Groups:

- Kingdom (most inclusive)
- Phylum
- Class
- Order
- Family
- Genus
- Species (most specific)

- King
- Phillip
- Came
- Over
- From
- Greece
- Singing

5 Major Kingdoms:

- Monera
- Protista
- Fungi
- Planta
- Animalia
- 1 cell, prokaryotes
- 1 cell, eukaryotes & algae
- Multicelled, absorptive feeders
- Multicelled, autotrophs
- Multicelled heterotrophs

Cellular Tree of Life

Which is the most difficult to assign?

- Species:
- Most specific
- Successful interbreeding
- Fertile offspring

Which group has the largest # organisms?

- **Kingdom:**
- **Cell types**
- **Prokaryotes**
- **Eukaryotes**
- **Cell number**
- **Nutrition**
- **Structures**

Plant Kingdom*
***Division* replaced by Phylum**
PLANT SYSTEMATICS

- **Common names**
  - **Have evolved over centuries in a multitude of languages**
  - **Sometimes used only in a limited geographical area**
  - **Problem with common names:**
- One plant may be known by several names in different regions, and the same name may be used for several different plants…

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- **Phycology by fiat**
- **The blue-greens are not algae any more ... any more.**
- **It seems that they're not lost, but gone before.**
- **By a stern decree despotic,**

- **Since they're all prokaryotic,**
- **The poor blue-greens can't be algae any more.**
- ***Euglena's not an alga any more ... any more,* are not algae anymore.**

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- **Whatever people thought of it before.**
- **Its form is somewhat plastic**
- **And its pellicle's elastic,**
- **So *Euglena's not an alga any more.***
- ***Spirogyra's not an alga any more ... any more,***
- **Though it passes nuclei from pore to pore,**
- **Since it hasn't swimming gametes**
- **It's reclassified with *Trametes.***
- ***Spirogyra's not an alga any more.* ore.**

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- **Red algae are not algae any more ... any more,**
- **Though the reddest weeds abound on every shore.**
- **Since their microsporulation**
- **Is devoid of flagellation,**
- **The red algae can't be algae any more.**

- You cannot regard an alga as a plant ... as a plant.
- However much you want to, you just can't.

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- If it's not to late to switch
- You should throw away your Fritsch,
- For the algae are not algae anymore.

Scientific names

- Similar plant species form a group called a genus (plural: genera)…
- Genera are grouped into families…
- Families into orders, classes, divisions and kingdoms

- Kingdom-Division (Phylum)-Class-Order-Family-Genus-Species

- "King David Came Over For Great Spaghetti"
- "King David Conquered Our Fifty Great States"

Species name

- Each species has a single correct scientific name in Latin called a binomial (two names) – it is always *italicized* or <u>underlined</u>.

- First name is genus name.

- **Second name is species name**

- **Human:** ***Homo sapiens***
- **Cat:** ***Felis catus***
- **Dog:** ***Canis familiaris*** **Wolf:** ***Canis lupus***

- **Through the lens of a high-powered microscope, Karen Steidinger of the Florida Fish and Wildlife Conservation Commission stares down at her nemesis of the past 43 years.** ***Karenia brevis, as a*** **Danish colleague renamed this plantlike speck of algae in tribute to Steidinger's groundbreaking contributions toward unraveling the mysteries of it cloverleafshaped body, twin tails and – under normal circumstances –laid-back lifestyle in the warm Gulf waters off western Florida.**

Examples

- **Genus of maple trees is** ***Acer***

- **It has many species including:**

Common name	Scientific name
"Red maple"	*Acer rubrum*
"Sugar maple"	*Acer saccharum*

- "Black maple" *Acer nigrum*

Taxonomic hierarchy

- Species that have many characteristics in common are grouped into a genus.
- Related genera that share combinations of traits are grouped into families.
- Families are grouped into orders.
- Orders into classes
- Classes into Phyla
- Related phyla are grouped into kingdoms

- (e.g. house, street, city, county, state, country, continent, planet)

What is a species?

- Species: a set of individuals that are closely related by descent from a common ancestor and ordinarily can reproduce with each other, but not with members of any other species.

- Biological species: group of interbreeding populations. Offspring are fertile.

- *Pleonosporium flexuosum (C.Agardh) Bornet ex De Toni*

- *Plocamium coccineum var. flexuosum Hooker & Harvey*
- *Plocamium flexuosum (Hooker & Harvey) Harvey*
- *Plocamium leptophyllum var. flexuosum J.Agardh*
- *Pseudophormidium flexuosum (Gardner) Anagnostidis & Komárek*
- *Sargassum oligocystum var. subflexuosum Grunow*
- *Schizonema flexuosum (Cleve) Kuntze*
- *Pinnularia flexuosa Cleve*
- *Scytonema flexuosum Meneghini*
- *Stigonema flexuosum W.West & G.S.West*
- *Triceratium flexuosum Greville - Unchecked*

Species

- **Some members of same species look very different…**

Definition of species

- Or, plants look the same, but due to polyploidy (more than the diploid number of chromosomes), they cannot interbreed.
- For example: Ferns; evening primrose

Carolus Linnaeus

- Swedish scientist – Carl von Linne
  - (doctor and botanist)
  - born in 1707.
- Called the "Father of Systematic Botany"
- Established modern system of nomenclature

Linnaeus legacy

- His binomial system of nomenclature, in which the genus and species names are used.
- He classified 12,000 plants and animals, and many of the names he first proposed are still in use today…

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- *Hypoglossum subslmplex* **Wynne sp. nov.**

- ***Fasciculus lamina rum simplicium aut subsimplicium erectarum delicatarum e base disciformi orientium; ranNflcatio tantum ad unum ordinem; laminae tantum usque 6 mm altae; margins laminae laeves; costa corticata destituta; omnes cellulae serierum cellularum secundi ordinis series cellularum tertii ordinis procreant; tetrasporangia tantum in una lamina procreant, cellulis ambo serierum secundi ordinis et tertii ordinis abscissa, vicina costa laminae, sic laterales cellulas pericentrales includentibus; sorus tetrasporangiorum non discretus in longitudino sed ad aliquot distanciam currens; sori spermatangiorum plerumque in turmis diagonaliter aut irregulariter dispositi, parvi et sejuneti aut confluentes; uno aut duo cystocarpiae in quoque femina lamina, in costa locatae.***

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- **Diagnosis: A cluster of simple or subsimple erect, delicate blades arising from a discoid base; branching to one order only; blades only up to 6 mm tall; margins of blade smooth; corticated midrib lacking; all second-order row cells producing third-order rows; tetrasporangia produced in only the primary layer, cut off by cells of both second- and third-order rows in vicinity of midline of blade, thus including lateral pericentral cells; tetrasporangial sorus not discrete in length but running continuously for some distance; spermatangial sori arranged usually in diagonal or irregular groups, small and isolated or becoming confluent; I or 2 cystocarps per female blade, located on the midline.**

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- **Holotype: Wynne 9959 (slide in MICH), on *Halimeda tuna,* collected by M. D. Hanisak, 19 June 1994, Content Keys, lee side of Florida Keys, Florida, U.S.A. Isotypes: slides deposited in MEL, PC, UC, US.**

Animal Kingdom

Scientific Name:

- Latin
- Italics or underlined
- *Genus species*
- *Homo sapien*

Classification Criteria:

- Biochemistry

- Behavior
- Hair Color
- Genetic System
- Evol. History
- Nutrition
- Molecular Make-up
- Most (DNA)
- Not very
- Not very
- Most
- Most
- Most
- Not very

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Chimpanzees: distant relatives
Walking upright:
Homologous or Analogous Stuctures?
Homologous Structures:

- Shark/Dolphin fin
- Seal flipper/Fish fin
- Fish tail/Whale fluke

- **Bat wing/Cat limb**
- **Bird/Insect wing**
- **Bird wing/reptile limb**
- **Seal flipper/human arm**
- **Dog limb/whale flipper**

- **No (cartilage/rays)**
- **No (bones/rays)**
- **Yes (bones/bones)**
- **Yes (bones/bones)**
- **Yes (bones/no bones)**
- **Yes(bones/bones)**
- **Yes(mammal bones)**
- **Yes(mammal bones)**

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- **Bacteria and Archaea constitute two of the three known taxa placed at the level of Domain, the most inclusive of all catagories. All other names and taxa in the figure are in the third domain: Eukarya**

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- Excavata
- the single characteristic that unites them is the presence of certain sequences of DNA not seen in other groups. The name is derived from a feeding groove present on one side of the cell in some species, but not common to all members of this group.
- Chromalveolata
- This is an extremely diverse group, Based upon molecular and cellular data, species share a common plastid origin and pigment structure, and cellulose cell walls.
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- Alveolates
- A common feature of this clade is the presence of membrane-enclosed spaces beneath the cell membrane called alveoli.
- • Haptophytes
- Members of this clade have a haptonema, a unique cellular structure resembling a flagellum, but differing in both structure and function.

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- Stramenopiles
- A common feature of this clade is the presence of tubular hair-like structures covering one of their two flagella (called a "tinsel flagellum").
- Rhizaria
- . Although diverse, many species (not all) have thread-like cytoplasmic extensions. This grouping is controversial.
- Include Forams (Foraminiferians) and Radiolarians

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- Archaeplastida
- Based upon comparative molecular and cellular structural data, members of this group share a common ancestor.
- Red algae form a monophyletic clade. Most are multicellular and marine. They have chlorophyll a, but also have large amounts of the pigments phycocyanin and phycoerythrin, which give them their distinctive red, brown, and purple colors. No flagellated cells have been found in red algae. Life cycles in some are very complex.

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- • Green Algae This name refers to the bright green color of a pigment within the photosynthetic structure called a chloroplast. The pigment is common to these organisms.
- True plants are paraphyletic with the green and red algae. They are

multicellular and have chlorophyll a. All exhibit life cycles with alternation of generations where the fertilized egg develops into a multicellular embryo within protective cells on the female plant.

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- Unikonta
- Molecular data support the hypothesis that this diverse collection of organisms should be placed in a single group. It is the least controversial of the groups presented.
- Amoebozoa as a Clade is based principally upon comparative molecular data. Members vary widely in morphology. The name is derived from their ability to change shape..

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- • Opisthokonts -Comparative molecular and cellular morphology data support the Opisthokonts as a clade. The name is derived from the common feature of a flagellum, when present, being located at the "rear" of a moving cell (opisthios-rear, posterior, kontos-pole).

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- Parazoa
- The organisms included in this group do not have true tissues (See Eumetazoa). However, parazoan's structural organization shows a definite pattern, and that pattern is often one of layers.
- Eumetazoa

- These organisms have true tissues. A true tissue is defined as a group of cells, generally having the same morphology and organized in such as way as to perform a common function.

- Radiata

- Radiatans show radial symmetry or some variation of radial symmetry. They are also diploblastic, meaning that only two layers of cells form in the developing embryo. All adult radiatan cells are derived from one of these layers.

- Bilateria

- These organisms show bilateral symmetry or some variation of bilateral symmetry. They are also triploblastic, meaning that three layers of cells form in the developing embryo. All adult bilaterian cells are derived from one of these

- Acoelomates

- Any organism that is bilaterally symmetrical, triploblastic and does not have a body cavity is an acoelomate/

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- Pseudocoelomates

- Organisms that are bilaterally symmetrical, triploblastic, and have a body cavity that is not entirely lined with cells from the mesoderm are placed in this group

- Coelomates

- The organisms included in this group are bilaterally symmetrical, triploblastic, and have a body cavity that is entirely lined with cells

from the mesoderm

- Protostomia
- These organisms are bilaterally symmetrical, triploblastic coelomates in which the mesoderm (middle tissue layer) originates from cells near the blastopore
- Lophophorates
- Three animal phyla have developmental and molecular characteristics that are ambiguous. They possess characteristics of both Protostomia and Deuterostomia. Their placement in Figure 1-2 is highly controversial and since all possess a feeding structure called a lophophore, they are labeled Lophophorate (consistent with traditional classifications).

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- Deuterostomia
- These organisms are bilaterally symmetrical, triploblastic coelomates in which the mesoderm (middle tissue layer) originates from cells at the end of the primitive gut opposite the blastopore
- Gnathostomata (Craniata with jaws)
- Tetrapoda (four-limbed vertebrates)
- Amniota (tetrapods with embryos having extraembryonic membranes)

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Marine Plants

Lecture Note to download

Members include seaweeds, sea grasses, mangroves, marsh grass, microscopic algae etc. If you don't include blue-green algae (prokaryotic)

- they are eukaryotic
- contain organelles enclosed by a membrane
- photosynthesis takes place in chloroplasts--green,brown, or red organelles.
- lack flowers, roots stems and leaves.

While most are referred to as plants, some have flagella and show animal characteristics...and some are actually claimed by both botanists and zoologists as theirs! Taxonomically, a compromise has placed them in the Kingdom Protista..the unicellular forms.

Seaweeds...dominant marine plants containing chlorophyll and additional pigments from blue to red. Seaweeds (exc. noted) are all eukaryotic and most are multicellular but even some that are unicellular or simple filaments are considered seaweed because the classifications of seaweeds is based not only on structure, but also on other features such as types of pigments and food storage products.

Classification characteristics used to classify are;

- 1. form which starch is stored
- 2. composition of cell wall
- 3. presence of motile with flagella
- 4. level of complexity
- 5. sometimes, reproductive patterns (reds)

Red Algae is Rhodophyta

Green Algae is Chlorophyta
Brown Algae is Phaeophyta

Algae are **Thallus**, meaning they lack true roots, stems, and leaves, fruits, connecting tissue etc. and photosynthesis occurs throughout the plant, not just the leaves.

Parts: Holdfast, stipe, blade, air bladders (pneumatophores). (list functions)

Brown Algae...Phaeophyta..microscopic to 60' make up the largest and structurally most complex. Colors range from olive green to dark brown, due to yellow pigments fucoxanthin dominance over chlorophyll. Pigments are xanthophyll and carotene and chlorophyll.

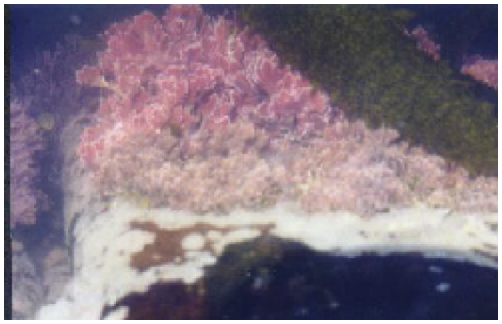
The simplest brown algae have a finely filamentous thallus as in *Ectocarpus*. There is the fan shaped *Padina*. Many species of brown algaes are found in the intertidal zone and known as rockweeds and in deeper areas of the cool coastal zones are the kelps, the largest and most complex of all brown algaes. As mentioned before, kelp plays an important i the coastal production with many organisms finding homes around the kelp beds. Some kelps consist of a single blade, *Laminaria*, which are harvested for food. Kelps have been estimated to grow up to 50 cm (20 inches) per day. Note these have the pneumatocysts.

Alginic Acid, a gummy, slimy layer in cell wall, is used as an emulsifying agent (algin).. (Know uses)

Red Algae..Rhodophyta has more species of these than green and brown combined. It has the highest commercial value, and don't get as large as brown algae.

- absence of flagellate stages
- presence of other pigments mainly phycobilins
- floridean starch as food reserve (scattered throughout cells)
- Existence of special female cells (carpogonia) and male gametes (called spermatia) for sexual reproduction.
- Cell walls with inner rigid component and outer mucilage or slime layer. This is like the alginates and very valuable.
- They can also deposit calcium carbonate (lime) into the walls of some species

(Coralline algae) (Coralline algae)<



Coralline Algae

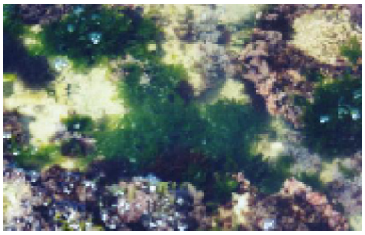
The structure of the thallus of red algae does not show the wide variation in complexity and size that is observed in brown algae. Most reds are filamentous but thickness, width and arrangement of the filaments vary a great deal. There are many variations in the shapes, sizes colors etc. of the reds. One important in marine environments are the red alga Corallines. These are characterized by deposits of calcium carbonate around their cell walls. These can be encrusting on the rocks or articulated, branching plants, with colors from light to reddish pink-white when dead. Warm water corallines are active in reef development.

Green Algae CHLOROPHYTA. The great majority of green algae are restricted to fresh water and terrestrial environments. Only 10% are marine but they are dominant in environments with wide variations in salinity such as bays and estuaries, tide pools (sewage outfalls) . ..stock from which land plants derived and in full agreement in regards to pigment, starch, cellulose etc. May exist as single cells, simple or branched filaments, blades, organized into tubes that are intertwined and usually grass green in color.

Few green algae are as complex as the other groups but their pigments and food reserve are the same as in higher plants. (evolved from green algae.) chlorophyll b in green and land but not other algaes). They are unicellular, filamentous

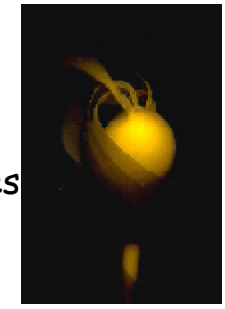
multicellular, shapes can vary in the same species according to their environment. *Enteromorpha* is a thin hollow tube, *Ulva*, sea lettuce is leafy-like, *Valonia*, forms huge spheres /clusters of them in tropical waters., some branch and *Caulerpa* and *Cladophora* have tubes with many nuclei, spongy, branching thallus *Codium* and segmented with deposits of calcium carbonate in their walls to ward off predators but end up cementing the reef together in reef areas...*Halimeda*... a Coralline green algae!

Life Histories of seaweeds involve an alternation of gamete producing phase (gametophyte) and spore producing phase (sporophyte). (Video of Gamete release)



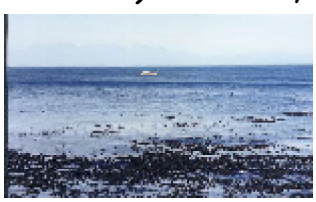
Green algae...*Ulva* (sea lettuce) have two identical phases. 1. Sporophyte (diploid) produces flagellated zoo spores (haploid) (meiosis) and these 2. swim briefly and settle on the bottom and 3. grow into a gametophyte phase (male or female) and produce motile gametes which 4. fuse to form zygotes (diploid). ....*Codium*, another green algae is more like animals and produces gametes by meiosis which fuse and form a zygote and grows into the familiar plant.

Brown algae...*Nereocystis* (bull kelp). The kelp is the sporophyte or diploid phase and



- 1. certain areas of the fronds (sori) become darker
- 2. meiosis occurs and haploid zoo spores are formed.
- 3. They settle to the bottom and grow into microscopic gametophytes.
- 4. The female produces eggs but holds them and the male produces sperm which are released and
- 5. attracted to eggs, fertilize them and
- 6. zygotes are formed which germinate into the sporophyte plant.

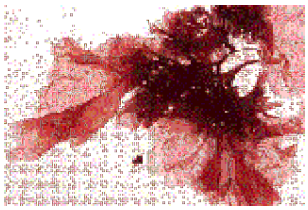
Kelp (how are chances for fertilization increased?) ....*Fucus*, another brown algae or rockweed, is again, like animals where the



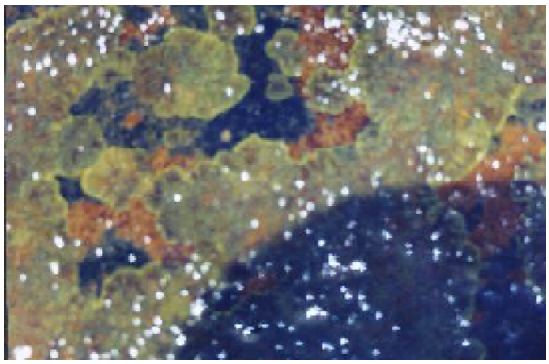
- 1. diploid plant forms gametes through meiosis
- 2. fertilization occurs
- 3.the zygote immediately germinates back to the sporophyte

Gametes are produced in cavities called CONCEPTACLES.

Red algae *Porphyra* or nori is a valuable food source but has an atypical life history with the gametophyte being the large leafy plant and the sporophyte being the tiny "conchocelis" found living in discarded shells. The Typical red cycle is that of Polysiphonia.



- 1. Sporophyte produces tetrasporangia (site of meiosis) which produce 4 haploid tetraspores.
- 2. Gametophytes grow from the spores and their gametes (spermatia and carpogonia) fuse and
- 3. are retained and develop into a special mass of diploid cells (the carposporophyte)
- 4. which breaks up into many carpospores (diploid) and
- 5. these grow into a sporophyte generation which resembles the gametophyte (isomorphic) and..(go to 1)



- Red Algae *Plocamium corallorhiza* and an encrusting *Ralfsia verrucose*

Marine Angiosperms (flowering plants)...few occur in the marine environment but those that do are usually very productive and adapted for their lifestyle. Of the 3 groups, mangroves, marsh grass and seagrass, only the sea grasses are adapted to live completely submerged in water. Pollination occurs under water.

Seagrasses are not grasses, and thrie closest relatives are probably lilies. Pollen is carried by water currents and seeds are dispersed by water currents and feces of fish and other animals that browse of the plants. Eel Grass (*Zostera*) is the most widely distributed of the 50 species and found in shallow, well-protected coastal waters such as bays and estuaries. It has distinct flat ribbon like leaves. Surf grass *(Phyllospadix*) is on rocky coasts exposed to waver action. Turtle grass (*Thalassia*) is common in the keys. (Manatee Grass (*Halophila*)).

Mangroves..80 unrelated species of flowering plants adapted to various ways to survive in the salty environment. Mangroves have a special root system using aerial roots to ventilate the system below the substratum (especially in anaerobic mud and under water). Some genera have seeds that germinate on the parent plant and drop as seedlings rather than seeds.

Saltmarsh plants, true members of the grass family, usually consists of succulent shrubs and herbs and grass-like species which can tolerate large salinity fluctuations. Cord grass inhabits the zone above the mud flats and can be submerged, and have salt glands to get rid of excess salt. Halophytes are found in higher levels of the marsh (pickleweed).

Phytoplankton...plankton..Greek for wanderer meaning that they are passively transported. Nekton are those that swim. Size categories of plankton:

- ultraplankton: less than 2 um
- nanoplankton: 2-20 um
- microplankton: 20-200 um
- macroplankton: 200-2000 nm
- megaplankton: greater than 2 mm

Types:

- Holoplankton...spend entire life in open waters
- Meroplankton...spends part of life as plankton and part as a benthic or bottom dweller.
- Tychopelagic...normally attached but break off and can then be found in the plankton.

Divisions

- Cyanobacteria (Cyanophyta) Blue-green algae (Monera)
- Chlorophyta green algae
- Chrysophyta golden algae/silicoflagellates
- Haptophyta coccolithophores
- Xanthophyta yellow-green algae
- Bacillariophyta diatoms
- Dinophyta (Pyrrophyta) dinoflagellates & zooxanthellae
- Cryptophyta cryptomonads
- Euglenophyta euglenas

Division Cyanophyta/Cyanobacteria Blue green Algae are prokaryotic cells specialized to carry on photosynthesis. Chlorophyll, phycobilins, phycocyanin, beta-carotene and xanthophylls are the pigments so color range is great..red, blue-green, black, olive, yellow, violet. The only other prokaryotes that carry out photosynthesis are some Autotrophic bacteria. There are hemosynthetic bacteria too that release stored energy in chemical compounds (H_2S) . Blue-green algae contain a bluish pigment, PHYCOCYANIN. (Considered bacteria). Photosynthesis occurs on folded membranes within the cell (rather than chloroplasts). They do produce O_2 etc. and probably played a role in the oxygen in the atmosphere. The presence of this ultraplankton is only being discovered .

Responsibilities of blue greens include forming dark crusts along wave splashed zones , exploiting polluted sediments and even forming a few types of red tides (*Trichodesmium erythraea*).(skin rashes). Blue-greens also carry out nitrogen fixation in the oceanm, converting N into nitrates to be converted to proteins. Some blue-greens live on the surfaces of seaweeds and sea grasses (epiphites) and some are known to lose their ability to photosynthesize, becoming heterotrophs.

Chlorophyta..few marine planktonic reps. but lots of macroscopic, benthic types

. **Chrysophyta**...golden/yellow color because in addition to chlorophyll. a & c there is a dominant carotenoid, fucoxanthin and many members have a cell covering of small siliceous scales. The silicoflagellates have an internal glass skeleton. Rare today.Characterized by star shaped internal skeleton made of silica and a single flagellum.

Haptophyta.. or Coccolithophorids, flagellated spheric cells covered with button like structures called coccoliths made of calcium carbonate. This was broken off the above class because of different types of flagella. Phaeocystis forms gelatinous clumps, visible and can effect migration patterns of fish. Also, blooms long ago followed by anaerobiosis, caused them to sediment and gave rise to oil deposits in the North Sea. The coccolithophores have small calcareous plates covering them and the patterns go way back in fossil records and are used by oil companies.

Xanthophyta...like Chrysophyceae but have no fucoxanthin pigment.

Euglenophyta...euglena..class contains only unicellular flagellates, chlorophyll. A and B and a flexible cell covering...no wall!

Fungi There are at least 500 species of marine fungi, most which are decomposers of dead organic matter. Some are parasites causing diseases in fish , shellfish, seaweed and sponges. Also some form associations with algae forming lichens and marine lichens may be found as thick, dark-brown/black or even orange patches on the wave splashed zones on rocky shores.

Bacillariophyta...diatoms...most important group in terms of primary productivity. The characteristic yellow-brown color is due to CAROTENOID pigments in addition to two types of chlorophyll (a and c). Half of the 12,000 species are marine. The

brownish scum in a fish tank consists of millions of diatoms.

Diatom Characteristics

- 1. Usually unicellular but chains do occur
- 2. Pigments chlorophyll. a & c and fucoxanthin (gold/brown)
- 3. Food reserve is chrysolaminarin and oils (buoyant)
- 4. Only flagellate cells in reproduction (uniflagellate.)
- 5. Walls made of glass called frustule.
- 6. Looks like petri dish
- 7. Two symmetries..radial and bilateral which divide diatoms into 2 sub-divisions..Centric & Pennates

Reproduction...valve to valve...one product of the division retains the parental epivalve (top) and the other the parental hypovalve (bottom) which results in the bottom being slightly smaller than the parent because a new inside always grows back. Continued vegetative reproduction reduces the size until it gets to its smallest size and this diploid cell produces gametes which fuse to form a full size zygote. Only the small cells will undergo sexual reproduction and if they get too small, they can't even do that.

Dinophyta /Pyrrhophyta or the Dinoflagellates Mostly unicellular with 2 unequal flagella , one that wraps around a groove in the middle of the cell, and the other that trails free, and include the non-motile zooxanthellae (found in corals). The are most abundant in warm waters and second to diatoms in cold water.

Characteristics of Dinoflagellates

- 1. Most are marine
- 2. Chlorophyll a, c, peridinin. Starch, oils , but can ingest food stuffs
- 3. Distinctive flagella pattern
- 4. Some without walls (naked) and others with walls (Armor) with cellulosic plates fitting together like armor which may have spines,
- pores or other ornaments.(pattern and shape of plates used in classification)
- 5. Half are colorless, some heterotrophic, sparophitic, phagocytic, parasitic and some photosynthetic. It is thought that through
- evolution they have gained the ability to function as primary producers by

"capturing" and using chloroplasts from other algae.

- 6. some bioluminescent
- 7. some responsible for red tides and 20 spp.. secrete toxins. They reproduce by simple cell division and form blooms that often color
- the water red, redish-brown, yellow or unusual shades.
- a. all toxic ones are photosynthetic
- b. all are estuarine or neritic forms
- c. all probably produce benthic, sexual resting stages
- d. all capable of producing monospecific blooms (suggest competitive advantages through exclusion
- e. all produce bioactive-watersoluable or lipid soluble toxins that are hemolytic, or neurotoxic in activity. (NSP, PSP, Dsp)

The Zooxanthellae are a variety of dinoflagellates which have developed a close association with an animal host. The hosts range from sponges to giant clams but the most important are the ones in the stony corals. They help fix carbon through photosynthesis, release organic matter to be used by the coral, help in formation of the coral skeleton.

THE IMPORTANCE OF CORALLINE ALGAE

(from Nongeniculate coralline algae @ http://196.21.43.2/clines.htm)

Corallines as carbon stores

Coralline algae take up carbon for use in the process of photosynthesis, as do most plants, but they have an additional mechanism of carbon uptake, the calcification process. Calcium is deposited in the cell walls of coralline algae in the form of calcium carbonate. One of the most exciting pieces of information which I have recently received came from a Brazilian marine biologist, E.C. de Oliveira, who has presented evidence that coralline algae may be one of the largest stores of carbon in the biosphere. If this is so, then they urgently need to be studied, since we know so little about even their basic ecology, particularly in the Indo-Pacific region.

Corallines in community ecology Many corallines produce chemicals which promote the settlement of the larvae of certain herbivorous invertebrates, particularly abalone. This is adaptive for the corallines as the herbivores then remove epiphytes

which might otherwise smother the crusts and pre-empt available light. This is also important for abalone aquaculture, as corallines appear to enhance larval metamorphosis and the survival of larvae through the critical settlement period. It also has significance at the community level, as the presence of herbivores associated with corallines can generate patchiness in the survival of young stages of dominant seaweeds. I have seen this in eastern Canada, and I suspect the same phenomenon occurs on Indo-Pacific coral reefs, yet nothing is known about the herbivore enhancement role of Indo-Pacific corallines, or whether this phenomenon is important in our coral reef communities.

Some corallines slough off a surface layer of epithallial cells, which in a few cases may be an anti-fouling mechanism which serves the same function as enhancing herbivore recruitment. This also affects the community, as many algae recruit on the surface of a sloughing coralline, and are then lost with the surface layer of cells. This can also generate patchiness within the community. The common Indo-Pacific corallines *Neogoniolithon sp*. and Sporolithon ptychoides slough epithallial cells in continuous sheets which often lie on the surface of the plants looking so much like wet tissue paper. Not all sloughing serves an anti-fouling function. Epithallial shedding in most corallines is probably simply a means of getting rid of damaged cells whose metabolic function has become impaired. Sloughing in the South African intertidal coralline algae, *Spongites yendoi*, was studied and it was found it sloughs up to 50% of its thickness twice a year. This deep-layer sloughing, which is energetically costly, does not have any effect on seaweed recruitment when herbivores are removed. The surface of these plants is usually kept clean by herbivores, particularly the pear limpet, Patella cochlear. Sloughing in this case is probably a means of getting rid of old reproductive structures and grazer-damaged surface cells, and reducing the likelihood of surface penetration by burrowing organisms.

Some coralline algae develop into thick crusts which provide microhabitat for many invertebrates. For example, off eastern Canada, ,juvenile sea urchins, chitons, and limpets suffer nearly 100% mortality due to fish predation unless they are protected by knobby and under-cut coralline algae. This is probably an important factor affecting the distribution and grazing effects of herbivores within marine communities. Nothing is known about the microhabitat role of Indo-Pacific corallines. However, the most common species in the region, *Hydrolithon onkodes*,

often forms an intimate relationship with the chiton *Cryptoplax larvaeformis*. The chiton lives in burrows that it makes in *H. onkodes* plants, and comes out at night to graze on the surface of the coralline. This combination of grazing and burrowing results in a peculiar growth form (called castles) in *H. onkodes* in which the coralline produces nearly vertical, irregularly curved lamellae.

Non-geniculate corallines are of particular significance in the ecology of coral reefs, where they provide calcareous material to the structure of the reef, help cement the reef together, and are mportant sources of primary production. Coralline algae are especially important in reef construction, as they lay down calcium carbonate as calcite. Although they contribute considerable bulk to the calcium carbonate structure of coral reefs, their more important role in most areas of the reef, is in acting as the cement which binds the reef materials together into a solid and sturdy structure.

An area where corallines are particularly important in cobnstructing reef framework is in the algal ridge that characterizes surf-pounded reefs in both the Atlantic and Indo-Pacfic regions. Algal ridges are carbonate frameworks that are constructed mainly by nongeniculate coralline algae (after Adey 1978). They require high and persistent wave action to form, so are best developed on the windward reefs in areas where there is little or no seasonal change in wind direction. Algal ridges are one of the main reef structures that prevent oceanic waves from striking adjacent coastlines, and they thus help to prevent coastal erosion.

Economic importance

Despite their hard, calcified nature, coralline algae have a number of economic uses. One use dates back to the 18th century, and involves the collection of unattached corallines (maerl) for use as soil conditioners. This is particularly significant in Britain and France, where more 300 000 tonnes of *Phymatolithon calcareum* and *Lithothamnion corallioides* are dredged annually. Several thousand kilometres of maerl beds, composed of as-yet undetermined species belonging to the genera *Lithothamnion* and *Lithophyllum,* exist off the coast of Brazil, and have been subjected to a low level of commercial exploitation. Maerl is also used as a food additive for cattle and pigs, as well as in the filtration of acidic drinking water.

Corallines are also used in medicine, where the earliest use involved the preparation

of a vermifuge from ground geniculate corallines of the genera *Corallina* and *Jania*. This use stopped towards the end of the 18th century. Modern medical science has found a more high-tech use for corallines in the preparation of dental bone implants. Apparently, the cell fusions provide an ideal matrix for the regeneration of bone tissue. Since coralline algae contain calcium carbonate, they fossilize fairly well. They are useful as stratigraphic markers of particular significance in petroleum geology. Coralline rock has also been used as building stones, with the best examples being in Vienna, Austria.

Chapter Questions

Readings

Questions for algae reading

. Uses of Algae

1. How do algae structurally differ from land plants?
2. Where does the brown algae "Fucus" get its name from?

3. Today, there are over 450 species of useful algae. What are some of the uses?

4. What is Carrageenan and what are its uses…how does it work??
5. How was bull kelp used to get rid of headaches?

Algae Reading 1 with questions

Farming 4 feet under worksheet

Extras

Algae Photos Indian River Lagoon 1	Algae Photos Marco Island 3	Algae Photos Keys 2
		Berkeley Indian Ocean

Algae Photos-clist 4	Algae Slides-African	Berkeley Indian Ocean Algae Database
Mangrove Page	Algae ID Reference Lists	Phycological Society of America
Herbarium Sheets from Marco Island Collection (2/2000)	Nongeniculate coralline algae	Algae ID Reference Lists

Return to Menu

Marine Mammals

Lecture notes

Anyone who has ever witnessed the early morning feeding at sea on a calm day has also seen the superiority of the warm-blooded physiology over the cold-blooded way of life. While the sardines, anchovies and other schooling fry are chased around by faster fish, sea birds, like dive bombers take their share of the feast. But even the predators, bonitos and bass, are easy prey for the second circle of divers, the dolphins. Sharks roam farther away to scoop up remains but don't venture in too close because of the dolphins...from the air and from below, the fish are no match for the warm-blooded birds and mammals.

The warmer the blood the higher the efficiency of the living thermodynamic machine. Birds and sea mammals have acquired their power while evolving out of the oceans; their physiology has coped with such problems as keeping their central temperature constant or holding their breath during deep, prolonged dives. The heat exchanging system present in their flukes, fins, wings, or webbed feet is ingenious. Some powerful fish, tuna, have also developed this system but this is only to keep their muscles a few degrees warmer than the surrounding water while the marine mammal and bird must keep their temperature constant whatever

outside polar or tropic temperatures may be.

The warm blooded animals have no feeding problem. They have to eat a lot more compared to the same size fish. Colonies of millions of seabirds pile up on islands, feeding twice a day in less than half an hour and gorging themselves to a point of hardly being able to fly. In the sea, whales fill up on crustaceans in a few daily dives, pilot whales dive deep and fill up on squid or cuttlefish, and porpoises and dolphins and sea lions spend less than an hour a day to quench their appetite.

Having no difficulty in finding food, these warm blooded animals have lots of leisure time, explaining why they play, travel for no apparent reason and some, like the sea elephant, are so fat that they can afford to fast for several months when they come ashore to breed.

Leisure time has been used by the sea mammals that have a large brain to develop wit, intelligence, communication, and even some unnecessary feelings such as faithfulness, tenderness, and friendship.

This warm-blooded superiority has some severe limitations. Because of the high combustion of the excess food, excess oxygen is also needed (from the air) and this limits the duration of their dives. Some birds and cetaceans have modified their organs to perform dives of extended duration.

No birds, except the penguin, is at home in the sea like the pelagic mammals but many spend their life at sea except form that one short period of the year when they come ashore to mate, nest and raise their young. Whalebirds, prions, sea hawks, jaegers, and the albatrosses and shearwaters are among these pelagic birds. Other birds live in open waters just offshore, coming ashore little more than pelagic birds but remaining closer to land. (sea ducks) and some remain close to shore and

seek haven in stormy weather on land or in shoreside ponds. (gulls terns, skimmers.)

The largest group of marine mammals are the Cetaceans. There are over 90 species. These have the most complex transition to marine life.

Cetaceans are shaped like fish but are not fish. There are 90 different species . They are all marine except a few freshwater dolphins. They are all totally dependent on support afforded by the water and can't survive on land. The whales, dolphins and porpoises are born live, suckle their young, and breath air. From the 4 ft. harbour porpoise to the 110ft blue whale these mammals have no need to come on to land. They have a pair of front flippers, but the rear limbs have disappeared and though there are rear limbs present in the embryo, they are small useless bones in the adult. There is a dorsal fin and the tail ends in a pair of fin like horizontal flukes. Blubber provides insulation and buoyancy and body hair is almost absent. The nostrils form a single or double opening called a blow hole on the head

There are two sub-orders...Odontoceti (toothed whales) equipped with pegshaped, spadelike teeth for grasping food, using biosonar or echolocation to locate prey at great depths (sperm whale) and include toothed whales, dolphins, porpoises and killer whales.

The second sub-order is Mysticeti (mustache G) or toothless baleen whales which scoop up minute plankton and small drifting fish with overlapping flaps of baleen (made of similar material as your hair and nails. They feed by taking in a big mouthful of water, squeezing it through the bristles and licking the food left behind. Included are the blue whale and divide into three families; rorqual whales...blue, humpback, fin, sei, Byrds and minke which feed on dense swarms of krill, 2. Right whales inc. black, Greenland, pygmy which feed on swarms of Copepods and the 3. gray whale which feed on worms, small crustaceans and other bottom organisms by sucking up sediments and filtering its food from the mud.

Pinnipeds, seals, sea lions and walruses while they need to come ashore to breed, they go to sea only to feed. They evolved from early forms of terrestrial carnivores/cats,dogs,bears and they are all predators. They also have blubber which acts as insulation, food reserve, and buoyancy. There are 19 species of seals, distinguished by having rear flippers that cannot move forward. On the land they pull themselves forward with their front flippers. Elephant seals are the largest with males reaching up to 20' in length. Monk seals live in warm regions, the exception to the relatively cooler regions where seals inhabit.

Sea lions or eared seals are similar to seals except they have external ears and can move their rear flippers forward so they can use all 4 limbs to walk or run on land. The head of the sea lions look doglike while the seals look more like a cat. There are 5 species of sea lions and 9 related fur seals.

Walrus is a large pinniped with a pair of distinctive tusks protruding down from the mouth. It feeds mostly on invertebrates, clams but there is no evidence that the tusks are used to dig up the clams and they travel along the bottom sucking up their food, with their stiff whiskers acting as feelers.

Sea otters, the member of Carnivora, the smallest of the marine mammals. They lack blubber and their fur traps air there to act as a layer of insulation.

Sirenia- dugongs and manatees, descendants from elephants, sluggish, with forearms modified as flippers and no hind limbs, may have been the source of the mermaid legend, thus the name Sirenia (sailors probably had been at sea too long)

Adaptations;

Streamlining..in the evolutionary process of streamlining the shape,

cetaceans have undergone a distortion of their skulls so the nostrils are pushed back atop the head. This enables the animal to breathe at the surface without lunging out of the water. It only needs to break the seas surface with the top of its head, open the blow hole quickly and exhale, then inhale quickly, close its blow hole, and submerge. It takes only two to three seconds and may be repeated several times before a deep dive. In large whales the moisture of their warm breath condenses when it hits the air and together with a little mucus and seawater a characteristic spout or blow which sometimes can be used to identify the whale. Cetaceans have all but lost their necks as the cervical vertebra are compressed and blubber fills in the natural constriction behind the head.

Adaptation of bones that make up the flippers

Bones in cetaceans are also lighter as a result of being buoyed up by water and blubber. Beached cetaceans can suffer serious injuries because of the lack of support.

Seals: Eared seals (Otariidae) including fur seals and sea lions use front flippers for swimming and can turn their hind flippers forward to walk on land, have visible ear flaps and usually found in warmer waters. True seals (Phocidae) are propelled through the water by their hind flippers and these can't support their weight on land and get drug helplessly behind.

Walruses (Odobenidae) use both front and hind flippers for swimming. The upper canine teeth in both males and females develop into large tusks used to hoist them onto the ice and dig clams and mussels in 300'water.

Sea Otters (Mustelidae) uses stone tools when it feeds cradling them on

their abdomens and smashing open shells of clams or sea urchins. They also have no blubber and with dense fur and oil secreted from numerous glands, a layer of air is trapped under the fur to prevent excessive loss of heat. Also otters eat urchins which feed on holdfasts (supporting structures of kelp) and have helped kelp forests survive. With the decreased population of otters, the kelp forests showed marked destruction.

Polar bears (Ursidae) Have white fur to help them blend into the snow/ice around them, possesses thick fur a layer of insulating hair on their paws, and a thick layer of blubber and are streamlined more than other bears to help them swim better.

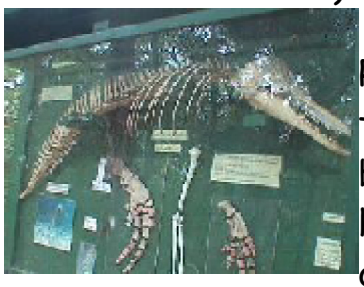
Streamlining in birds allows them to pass through the air and water with least effort and best fuel economy. Gannets are quick strong flyers and can dive into the water going down 30 feet to capture their food.

Fur, except in otters which trap air bubbles under their fur, is generally used for insulation in the air . Most marine mammals have to depend on blubber for insulation. Blubber is a thick layer of fatty tissue between the skin and muscles. The amount depends on the species and the season. Species living in ice latitudes have thicker blubber than those in warmer latitudes. Its buoyant and helps keep whales and dolphins afloat. Right whales have blubber 28" thick and float when killed. Besides insulation, its a food reserve. Whales feed on fatty shrimp-like krill in colder waters and as they move to warmer waters where food is less abundant, they draw on their blubber as food reserves, thinning their layer out.

Pinnipeds have a fat layer usually thinner than cetaceans (3"). Male fur seals when they come ashore to breed, have flaps of fat hanging from them but after the season, are relatively thin. During nursing, females draw from these reserves for milk production.

Birds also have fatty tissue within them that serve as a food reserve when they are migrating. With little time to eat when heading towards their feeding grounds, they get their energy from their reserves. (duck hunters know there are fat deposits on the ducks in the early season but not late in the season)

Teeth -- Dolphins and porpoises and sperm whales are well equipped with teeth 42-300) They use them to hold their quarry not to chew.

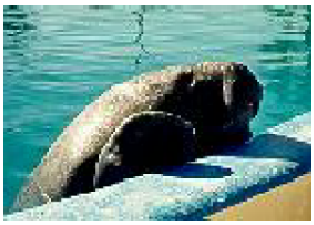


Rorquals have bony plates with hairy edges inside their mouths instead of teeth. The plates are called baleen and are made of the same substance as our hair and fingernails. They feed by straining the food out of the water, swimming with their mouths open.

Seals and sea lions also use their teeth to hold their prey rather than chew while manatees use lips to gather plants that make up their diet.

Bird bills range from the huge bill and pouch of the pelican to tiny bills of the sandpipers to the broad bill prion which has strainers on the edges of the bill like baleen.

Ears Most Marine mammals have no external ears but fur seals and sea lions do but they lay back while swimming. Small openings mark the ears in birds and true seals. In cetaceans and sirenians, a crease shows where the ear is.



Nostrils Cetaceans have nostrils (blow hole) on the top of their heads. Toothed cetaceans have had both nostrils merge as one blow hole which remains sealed during its dive. The sperm whale the nostril has its blow hole located on the left side of the head. Pinnipeds have nostrils that close when relaxed so they, like cetaceans must make a conscious effort to breathe.

Water Fish eating dolphins get their water from the fish they eat, Orcas, feeding on birds and mammals, get water from them but both groups take in some seawater with their food. Seals and sea lions take no seawater in with their food but whales walrus and sea otters eat invertebrates whose body fluids are close to the salinity of sea water. One reserve is the fat because when it is burned up, water is a by-product.

Water conservation. Cetaceans have no sweat glands and lose little water to the atmosphere when breathing because of the humid air near the surface of the sea. Kidneys also dispose of excess salt.

Birds have a pair of glands near the nasal passages in the head which help secrete excess salt. These are found in all birds but not always functional and usually only work when excess salt is present (after feeding).

Temperature control:

Body temp. regulation in most marine mammals occurs through the flippers/forelimbs, and flukes or hind limbs. These flattened hands/feet are thin sheets of flesh with no blubber but are abundantly irrigated and allow cooling of the blood. Each artery that feeds these limbs is surrounded by veins that join to form a sheath through which the blood returns to the heart. The blood in the veins, cooled by having circulated in

the cold limb, is warmed by the transfer of heat from the arteriole blood, which is cooled in the process. As the venous blood returns to the heart it is progressively warmed and there is little heat loss to the outside of the body, as the flipper/fin is irrigated by blood that is already cold. To the other extent, the venous blood can bypass the heat exchanger and return through another network of veins close to the skin that have no insulation.

The rest of the body is insulated by a layer of blubber and the peripheral blood circulation can slow /reduce during each dive.

Seals use their skin as a heat exchanger opening or closing tiny blood vessels in the skin capable of exchanging heat with the air. Sea otters are the least adapted but has developed a way to use the properties of its coat to trap small air bubbles which engulf the otter when it dives.

Birds with their greased feathers can control individual feathers in positions that allow precise degrees of ruffling to imprison air either before or after a dive. The feet can cool the animal off easily if needed or to retain heat, be retracted within the belly feathers.

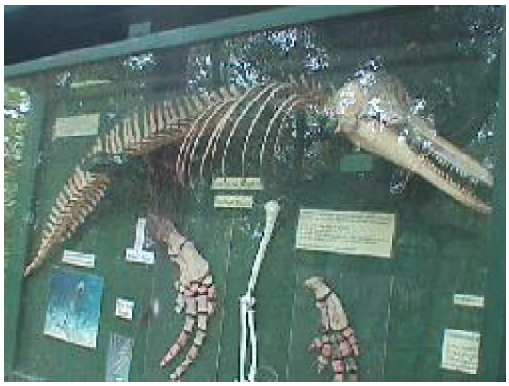
Digestion The marine birds and mammals swallow their food whole, none is equipped for chewing.These whole shrimp, fish etc. are dissolved by gastric juices and possibly ground up by gravel and stones in the stomach or crop.

Cetaceans have a three part stomach (cattle etc.) with the 1st part a great widening of the esophagus. In whales this part has stones to grind up food. the second section of the stomach is like the human stomach, secreting HCl and pepsin. The third stomach is smoothed-walled but has a few glands that secrete digestive juices. Rorquals can hold up to a ton of krill in the 1st two stomach sections. After the stomachs, the food then passes to the small and large intestines.

Pinnipeds also have stones in their stomachs but one mystery is the huge length of their intestines which is usually short in carnivores/ its 3x longer

than a cow.

Breathing: Cetaceans exhale up to 80-95% of the air in their lungs (man 15-25%) and pinnipeds about 35%, sirenians, 50%. Exceptional development of the diaphragm muscles (compared to man) in cetaceans and more floating ribs, may give them a more flexible and powerful breathing pump. It takes a rorqual two seconds to exhale and inhale 1500 gallons of air and man 4 seconds to exhale and inhale a pint.



Diving: When mammals dive, the heart beats slower (bradycardia) 15-50% slower, and blood supply to less essential areas of the body is shut off by sphincter muscles in some arteries (goes to heart, brain, lungs, muscles not stomach and kidneys). By shutting down, less O2 is needed for the dive. Oxygen is also not stored as a gas but is either accumulated as chemical combinations as oxides in blood or muscles or dissolved in organic liquids and tissues.

Cousteau, The Ocean World, Chp 9 pp 196-210, 1979.

Special adaptations include substantial amounts of myoglobin and large volumes of blood. Myoglobin in the muscle tissues binds a large amount of oxygen. The large pool of blood allows for a storage place for Oxygen. the blood is also a storage site for glucose (more because more blood). Small twisted blood vessels forming spongy masses in fatty tissue (retia mirabilia) seem to regulate blood pressure during the dive so brain, heart

and lungs are supplied with constant blood pressure. The pressure on the blood stored in the RM forces blood into the vital organs.

During deep dives, the outside pressure squeezes their ribs as the volume of air in the lungs decrease. The ribs of many diving mammals are designed to collapse inwardly. Human divers as they dive deeper, take air in under the pressure which dissolves in their blood. As they ascend, this gas must get out of the solution in the blood or air bubbles will form , embolism or the bends. cetaceans take very little air down in their lungs, rather it is in solution as above and it can't expand beyond its original volume when ascending because the original volume was taken in at the surface rather than at the bottom under pressure.

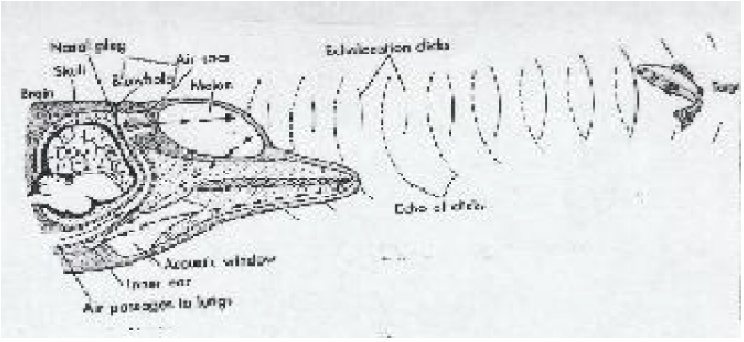
Using Oxygen, glucose is broken to CO_2, water and energy but once the O_2 is used up, glucose is broken down anaerobically to lactate releasing a little energy, so they can use glucose in a mixed anaerobic/aerobic metabolism..one of the most important modifications ...oxidize lactate!

Echo-location and vocalization

Because their sense of smell is so limited, any marine mammals have developed echolocation, natures version of sonar. The animal emits sound waves which travel 5x faster in water and listens for echoes reflected back from the surrounding objects. The echoes are analyzed by the brain. Most toothed whales , some pinnipeds and some baleen whales may also echolocate. (Bats Too)!

The sounds of echolocation consists of short bursts of sharp clicks repeated at different frequencies. Low frequency clicks have high penetrating power and can travel long distances. The clicks, squeaks and whistles of cetaceans are produced and air is forced through air passages and air sacs while the blow hole is closed..no vocal cords so the

frequencies are changed by contracting and relaxing muscles along the air passages and sacs. A fatty substance on the forehead, the melon appears to focus and direct sound waves..this gives them the rounded forehead. In toothed whales incoming sound waves are received primarily by the lower jaw. Ear canals are reduced or blocked in most cetaceans. The jawbone is filled with fat and oil and transmits sound to the two very sensitive inner ears...each independently.



Behavior..the brain has evolved into complex behaviors like learning..not instinct dominates...they rely on past experiences.

Most live in groups at least part of the time. Vocalizations play a prominent role in communications loud barks, whimpers, sedate grunts, whistles, chirps, moos, barks...there have been over 70 calls identified of the killer whales. and there are different dialects. Cetaceans show play behavior and the great whale breaches, some stick their heads out of the water to spy.

Migration

Most migrate from cold polar waters to warmer areas in response to amount of food. In the fall, the food in the polar waters becomes scarce and most cetaceans migrate to warmer waters. The pacific gray whale migrates 11,000 miles from the Aleutian to the Baja Peninsula.

Reproduction

Migration and reproduction are closely interrelated: and adaptations are...birth of seal pup must be exactly timed to coincide with the mothers return to the breeding area 11 months later because the pup would drown if born at sea. Whales must reach war water prior to giving birth. Therefore, gestation must be timed exactly.

In certain fur seals, the period is lengthened by stopping development of the embryo for several months. The embryo does not attach to the wall of the uterus after descending from the fallopian tube. the delayed implantation of the embryo lasts 4 months. It then attaches to the wall and begins to develop. The delayed implantation enables the mother to complete nursing her pup, and gives her body a chance to build up the necessary food reserves to ensure the developing fetus will be supplied nutrients during gestation.

In streamlining the body the sex organs became internal. The penis is inside the body held by retractor muscles attached to the pelvis. Connective tissue and a penis bone or baculum keep the penis rigid. Copulation in cetaceans is belly to belly and is brief being difficult to maintain contact in the sea.

Baby whales are born tail first and guided to the surface for its first breath by its mother. Gray whales weigh 907 kg at birth and 19 ft. long. Baby blue whales gain 90 kg each day. The high fat and protein content of the milk (10x fat of cow milk) milk is pumped into the young 9.5l/2-3 sec. 50x /day makes 490 l of milk daily.

Birth rate is low one / 3 years and offspring are looked after for some time.

Chapter Questions

Reading

MARINA MAMMALS-ADAPTATIONS

ADAPTATIONS

• We'll look at structure and mode of locomotion for major taxa before returning to the implications for

energetic costs

Polar bear

• Largest bear species, but smaller than recent ancestors

• Large feet aid in swimming

• Pulls through water with forelimbs, hindlimbs trail behind

– Position aids in pulling heavy body for swimming (climbing in other bears)

• Large paws distribute body weight on land

–

–

Osmoregulation

• Refers to maintaining salt (electrolytes) and water balance in internal environment

• Marine mammals are hypoosmotic

– Body fluids have lower salt concentration than surrounding water

– In danger of losing water through osmosis

Balancing salt and water

• Feeding and water ingestion alter osmoregulatory balance

– Most (or all) water ingestion from food intake

• Reestablished by urine, feces, evaporation; Kidneys are organ responsible for balance

Kidneys of marine mammals

– Many species have large kidneys, but not all (e.g. elephant seals)

– Kidney:body mass ratios

• 0.44-1.0% cetaceans; 0.3-0.4% terrestrial mammals

– Pinnipeds, cetaceans, polar bear and sea otter have *reniculate kidney*

– Many small lobes (reniculi)

– Each lobe functions as mini-kidney

– Cetaceans have 100s to 3000 reniculi in kidney

– Number of reniculi depends on salinity of diet

• Sirenian kidneys are not reniculate

• Dugong kidneys are elongate, smooth, and have some characteristics of ungulate kidneys

• Dugongs are physiologically independent of freshwater

• Manatees must have access to fresh or brackish water to maintain osmotic balance for prolonged periods

Drinking and water sources

- **Marine mammals will drink freshwater when it is available**

– Some pinnipeds in polar areas eat ice

– Is it needed? Not really

- **Water sources**

– Drinking

– Water in food

- **Fish/invertebrates 60-80% water**

– Water from own stores (catabolism)

- **1.07 g water/g fat; 0.4 g water/ g protein**

- **Used extensively during fasting**

Drinking saltwater

- **Allows high rate of urea production to get rid of more wastes**

- **Associated with high protein diet**

– Need to get rid of more nitrogen

- **Sea otters drink lots of seawater**

- **Cetaceans and pinnipeds will drink seawater (especially adult male otariids that have prolonged fasting)**

Reducing water loss

- **Few salt glands present in pinnipeds and none in cetaceans**

• Reduced urine output

• Countercurrent moisture exchangers in respiratory tract

Maintaining water balance

• Water loss from exhalation can be extreme (especially on land)

– Some pinnipeds (elephant and gray seals) conserve water during breathing

– Countercurrent blood flow in the nose sets up temperature gradients

– Increased surface area in nasal passages

– Moisture in exhalation condenses on epithelium then humidifies inhaled air on way to the lungs

Adaptations: Sensory Systems

Marine mammal sensory abilities

• Life underwater presents unique challenges in trying to navigate, find food, avoid predators, and interact

with conspecifics due to low light and visibility conditions

• Most species rely heavily on numerous sensory systems working in concert

• Many marine mammal systems highly modified from terrestrial mammals

• In this lecture, we'll look at all but sound production and echolocation

Mechanoreception

• Includes:

– Touch

– Hydrodynamic reception

– Sensing vibration and water disturbance

– Audition

– Sensing sound waves

Touch

• Other than whiskers, receptor units are distributed across entire body

• Head area most sensitive for tactile information

– Skin sensitivity in dolphins may be used to help with drag reduction, but most interest in other

species focuses on whiskers

• Most specialized mechanoreceptors are vibrissae (whiskers or sinus hairs)

– Specialized sensory hairs

– Diameter and structure reflect *does not* reflect importance but adaptation to signals received and

transmitted (sensitivity and function)

– Used for tactile information but may also detect vibrations

– Stiffer hair in pinnipeds

– Follicles surrounded by 3 (not 2) blood sinuses

• Three types of vibrissae

– Rhinal

• 1 or 2/side just posterior to nostril (phocids only)

– Supraorbital

• Above eye, mostly immobile

– Mystacial

• Upper lip, mobile

• Most prominent and numerous

• Walruses have most (600-700)

Pinniped vibrissae structure

– Number of nerve fibers (1000-1600) passing through capsule in *Phoca hispida* is 10x greater than terrestrial species with sensitive whiskers

• Extremely sensitive

– Baltic seal vibrissae have 10x nerve fibers of terrestrial mammals

– Size discrimination abilities of harbor seals and CA sea lions are similar to primate hands and close to visual capabilities of the seal which shows the importance of this sensory system (Denhardt andKaminski 1995)

– Move head side to side when object is small but don't need to for large objects (touch multiple vibrissae simultaneously)

Pinniped Vibrissae function

• Tactile receptors

– Mystacial vibrissae used for discrimination of textured surfaces (location, shape, size, surface

texture)

• Navigation

– Can help navigation in total darkness and low visibility conditions

– Use as speedometer, sense direction changes

• Prey detection and capture

– Even blind seals found to be well-fed in wild

– Often used to scan for benthic prey

Cetacean Vibrissae

– Only on head along margins of upper and lower jaws

– Structure and innervation suggest sensory role

– Mysticetes have ~100 very thin (0.3 mm dia) immobile vibrissae on upper and lower jaw

– Most odontocetes lose hair postnatally; 2-10 follicles on either side of upper jaw

– Exception are river dolphins which possess many well developed immobile vibrissae on both jaws,

but not yet shown if they are true vibrissae

Sirenian Vibrissae

– Entire muzzle covered with flexible *bristle-like hairs*

– Used for discrimination of textured surfaces

– Also have *perioral bristles* on the upper lip, oral cavity and lower jaw that are very rigid and moveable

– Manipulation of objects, further exploration once grasped

– Manatees can control facial vibrissae which may have role in feeding

– Sinus hairs also lightly scattered over body

The Sirenian mouth

• Combination of muscular lips and different types of facial vibrissae form a unique system

• Manatees can use this "haptic" system in a prehensile fashion to investigate objects and manipulate food

into mouth

Sea otter and polar bear vibrissae

• Sea otters have all three types of vibrissae

– Mystacial whiskers most numerous

• Few vibrissae in polar bears

Hydrodynamic Reception

– Can vibrissae of pinnipeds detect pelagic fish through water disturbances? (Denhardt et al. 1998)

– Vibrissae respond to vibrations, but took an experiment to show that this worked for water

disturbances

– Vibrissae are tuned to frequency range of fish-generated water movements

– Fish leave trails of disturbance that last minutes

– Harbor seals can detect and tract trails up to 40m long (based on blind-folded seal following

minisub)

– Sensory abilities of vibrissae help explain success of pinnipeds in dark and murky water

Audition (hearing)

• Some changes in marine mammals

– Closing mechanisms to protect the ear from penetrating water under pressure at depth

– Loss or reduction of external ear flaps to increase streamlining

– No real tradeoff for underwater hearing since external ear tissue is acoustically transparent

underwater

• A major problem is how to transmit sounds to the inner ear and localize sources

Sound localization

• In horizontal plane, determined by interaural time and intensity differences

• Sound travels 4.5x faster in water so information processing must be better

!

How do marine mammals localize sounds?

• Terrestrial mammals underwater can't localize sounds

– Bone conducts sound to both ears almost simultaneously

• Auditory organs of odontocetes are largely isolated from the skull to avoid bone conduction (less so in other MM)

– How does sound reach the inner ear in odontocetes?

Sound reception in odontocetes

• Two pathways

– Ear canal functions to detect low frequency sounds

– Mandible (lower jaw) can detect high frequency sounds

– Fat channels in lower jaw have impedance close to water and channel sound over pan bone to

petrotympanic bullae

Sound reception in other MM

• Mysticetes still unknown, but conventional pathway of terrestrial mammals is functional

– Distance between ears makes localization less problematic with bone conduction

• Manatees have lipid-filled zygomatic process which appears to transmit sound to squamosal-periotic

complex (mechanism similar to odontocetes)

Sound reception in pinnipeds

• Appear to use conventional pathway

• Bone conduction probably most important for sound transmission

– Should limit directional sensitivity with sound through skull

– good sound-localization in some sp (*Phoca vitulina*)

– Poor and variable in others (*Zalophus califonianus*)

• Ear functional in air sensitivity depends on species

– California sea lion: best in air

– Common seal: equal

– Northern elephant seal: better underwater

Hearing ranges and discrimination

• Odontocetes have widest hearing range

– *Tursiops* best hearing 12-75 kHz but up to 150 kHz detected

– Can discriminate frequency difference of 0.2-0.8% from 2 kHz-130 kHz

• Frequency discrimination is less precise and operates over a lower frequency range in pinnipeds and

sirenians

Weeding out background noise

• Marine mammals superior to terrestrial mammals in detecting signals in noise

• However, this is often not enough and vocalizations may be used to reduce masking effects

Vision

• Electromagnetic radiation changes intensity and composition as it moves deeper in water

– Becomes more monochromatic and spectrum shifts to shorter wavelengths as depth increases due to

scattering and absorption

• Eyes of marine mammals adapted to see in water and in air

Habitat and vision

• Spectral sensitivity of visual pigments should correspond to the habitat where vision is most important

– Deep-sea fishes have blue-sensitive pigments

– Shallow water fishes are green-sensitive

• Generally fits for marine mammals

– Shallow diving species green or blue-green

• E.g. spotted seal, manatee, gray whale

– Deep-diving species tend to have blue

• E.g. elephant seal, Baird's beaked whale

– Reflects habitats as well (e.g. open ocean is bluer; arctic is greener, Weddell Seal)

Marine Mammal Eyes

• Generally resemble nocturnal mammals

– Dilatable pupil maximizes light collection

– Choroid located between retina and outer coating of eye with tapetum lucidum (light reflecting

layer)

– Retina dominated by rod-like receptors but cone-like receptors (or second type or receptor) strongly

suggested or verified

• Two types of cones in mammals

– S: short wavelength sensitive

– M/L: medium to long wavelength sensitive

• Absence of S cones associated with nocturnal habits

• Cetaceans and pinnipeds lack S cones, which appears to be adaptation for redder coastal waters

– Loss may have occurred early in evolution or should see S-cones in pelagic species (we don't)

Do marine mammals see in color?

• Mixed results from psychophysical methods

– Demonstrated in spotted seals, California sea lions, manatees

– Failed in bottlenose dolphins

– Fur seals can discriminate blue and green but not red and yellow from grey shades

• Color discrimination and adaptive nature of vision is still unclear

Adaptations to seeing in water

– Cornea and encased fluids have about the same refractive index as saltwater; optically inefficient

– Refractive power restricted to lens when submerged

– Most pinnipeds and cetaceans have a large almost spherical lens with high refractive power allowing

normal vision underwater

– Trade-off: when cornea regains power in air, results in extreme

near-sightedness

River dolphin eyes

- **Most river habitats extremely murky**
- **Sensing light and dark for orienting to surface is all that is important**
- ***Platanista indi* and *P. gangetica* have lost the lens of the eye and are essentially blind**

Visual Acuity

- **Perception of fine detail at various distances**
- **Visual acuity degrades faster in air than in water**
- **Acuity underwater is poorer than in-air acuity of many primates, but better than many terrestrial**

mammals with good vision

– e.g. elephants, antelope

Chemoreception: Olfaction

- **Relatively little attention in marine mammals**
- **Relative to terrestrial mammals, marine mammal olfactory systems**

– Somewhat reduced in pinnipeds and sirenians

– Very reduced in baleen whales

– Absent in odontocetes

Olfaction in pinnipeds

- **Olfactory systems well-developed**
- **Have vomeronasal organ**

– Can detect scents of food in mouth

- **Olfaction may function in mother-pup recognition**
- **More research needed to understand role of olfaction in pinnipeds**

Chemoreception: Gustation

- **Taste buds in oral cavity provide information about dissolved substances**
- **Taste appears to be limited in pinnipeds and small odontocetes**

– Fewer taste buds that terrestrial mammals

– They can discriminate some chemicals in sea water and can detect the four primary tastes (sour,

bitter, salty, sweet) but for most of them, detection thresholds are much higher (especially salty)

- **More taste buds present in sirenians**

Taste in pinnipeds and other marine mammals

- **Use of taste in marine mammals poorly known**
- **May be highly specialized for detecting salinity differences at high (marine) salinities**

– Harbor seals shown to be very good at this

– Could be used for finding vertical layers

– For navigation to/along oceanic fronts?

Ring Species

- **There are several ring species, but the most famous example is the herring gull. In Britain, these are white. They breed with the herring gulls of eastern America, which are also white. American herring gulls breed with those of Alaska, and Alaskan ones breed with those of Siberia. But as you go to Alaska and Siberia, you find that herring gulls are getting smaller, and picking up some black markings. And when you get all the way back to Britain, they have become Lesser Black-Backed Gulls.**

- **So, the situation is that there is a big circle around the world. As you travel this circle, you find a series of gull populations, each of which interbreeds with the populations to each side. But in Britain, the two ends of the circle are two different species of bird. The two ends do not interbreed: they think that they are two different species.**

Evolution and Systematics

Convergence, Divergence and Parallel Evolution

– Distantly related taxa can come to resemble one another through the process of convergence (wings)

– Closely related taxa may quickly develop very different morpholgies through divergence

– Species may have diverged in the distant past can maintain similar morphologies through parallel

evolution

–

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Adaptations

• An adaptation is a character or suite of characters that helps an organism cope with its environment

• A preadaptation (or exaptation) is an adaptation that performs a function other than previously held

– e.g. the lower jaw of odontocetes is used to transmit high frequency sounds underwater but first

evolved to transmit low frequency sounds from the ground

Adaptive Radiation

• Rapid diversification of a lineage into many forms

• Can obscure relationships due to rapid evolutionary change if in distant past

• If recent, may be hard to detect differences: what *is* a species??

<u>What is diphyly, with regards to monophyly vs diphyly?</u>

- **If whales are monophyletic, that means a single common ancestor gave rise to all whales. If it is diphyletic, that means the whales have two different ancestors and that they are only similar because of convergent evolution. There are 2 great groups**

of whales: toothed whales and baleen whales. There is strong evidence that baleen whales evolved from a toothed whale, therefore there is strong evidence that whales form a monophyletic group

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– Biological Species Concept

– Inability to interbreed

Studying evolutionary relationships

• *Systematics* – the study of defining evolutionary relationships among organisms both extinct and extant

• A *phylogeny* is a hypothesis about evolutionary relationships

– Often shown on a tree

– Can never be "proven" only strongly supported!!!

Phylogenetic Trees(Cladograms)

• Tree representing best estimate of phylogenetic lineages

– Lines are clades or lineages (groups of related taxa from a common ancestor)

– Nodes = branch points = speciation events

–

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Cladistics

• Organisms can be deemed related based on *shared derived characters* (synapomorphies)

• Characters

– any feature useful in phylogenetic analysis

– May be ancestral (primitive) or derived (apomorphy)

– Characters may be primitive or derived but taxa are not

• Taxa are all endpoints of evolution

• Character State

– Condition of the character

Homology and Analogy

• Cladistics relies on finding synapomorphies

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• Homology

– Characters that arise from similar ancestry

– Bats' wing bones and human fingers

• Analogy

– Similar characters that do not share evolutionary history

• Bird wing and bat wing

• *Do analogies help in resolving evolutionary relationships?*

Determining Character States

• It is critical to determine which character states are ancestral and which derived

– Can use outgroups or closely related lineages; often use sister group

– the most closely related

lineage

– Character states shared with outgroup likely are ancestral

–

Types of groups on cladograms

- **Monoplyletic**

– includes hypothetical ancestor and *all* descendents

- **Paraphyletic**

– does not include all descendants of an ancestor

- **Polyphyletic**

– Collection of descendants from >1 ancestor not including all ancestors

Types of characters

- **Behavioral**
- **Physiological**
- **Mophological**
- **Molecular**

–

Molecular vs Morphological Characters

- **Molecular**

– Huge number of possible characters (down to each nucleotide)

– Can find parts of genome not under environmental selection

– Long time periods can obscure due to saturation (problems with parallel evolution)

– Time to saturation depends on rate of evolution at each locus

• Morphological

– Evolve more slowly (little saturation)

– Can include extinct taxa

– Can have problems with convergence

– Defining characters can be difficult

• Use of both types of data best!

–

Fossil Taxa

• Contribute most when they help plug holes in long divergent lineages

• Can complete morphological series, help determine homologies

• Can help determine earliest occurences

• Can't Use many characters – results in poloytomy (unresolved nodes)

Constructing a Cladogram

• Select group, define all taxa

• Select and define characters and character states

• Create data matrix

• Use outgroup comparison to determine ancestral and derived states

• Construct all possible cladograms

• Select best cladogram using parsimony

• Principle of Parsimony – the best cladogram is the one involving the fewest evolutionary transitions

(steps)

–

Uses of phylogenies

• Character mapping

Pinniped Evolution and Systematics

The pinnipeds

• Monophyletic group with 3 monphyletic families

• 18 phocids, 14 otariids, walrus

• Diversity was once much greater (13 species of walrus are extinct)

• First pinnipeds arose in Oligocene (27-25mya)

• Much speciation in last 2-5 million years

• Poor fossil record generally

Major pinniped synapomorphies

• Large infraorbital foramen (hole below eye to allow vessel and nerve passage) (1)

• Short, robust humerous (6)

• Digit I on hand emphasized (7)

• Digit I and V on foot emphasized (8)

–

Mono or diphyly?

• Evidence for diphyly

– Biogeorgaphy and morphology

– Otarrids (eared seals) and odobenids (walrus)close to bears; phocids (earless seals) close to mustelids (otters, weasels)

• Evidence for monophyly: the best explanation

– Molecular, karyological, morphology

– All support close ties to ursids (bear), mustelids, otters (sister group unclear)

– Diving behavior and breeding patterns suggest eared seals evolved first (Costa 1993)

• Phocids are most aquatically adapted (diving, breeding, body plan)

Early Pinnipeds

– Find describe in 2009 sheds new light on early evolution

–

– *Pujila darmwini* was "walking seal" ~24 mya

– Otter-like body, webbed feet, lived in freshwater lakes of Canadian Arctic

– Suggests pinnipeds went through a freshwater phase

– High productivity associated with cold water upwelling probably

supported prey base early pinnipeds

exploited

– First found from cool waters and rocky coasts of eastern N. Pacific during late Oligocene

– Pinnipedimorpha clade

– Show ancestral, heterodont (having teeth of different shapes, such as the molars and incisors of humans), dentition

– Many similarities to archaic bears

– Later forms show derived homodont dentition

Early Pinnipeds

–

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- **• Pinnipedimorpha clade**
- **– Lateral and vertical movement of vertebral column possible**
- **– Both sets of flippers modified for aquatic locomotion**
- **– Still very capable on land, probably spent more time there than modern forms**
- **Modern Pinnipeds: Otariidae**

–

- **• Seal lions and fur seals**

- • **Shallow divers often targeting fast-swimming fish**
- • **Monophyletic group first appeared late Miocene (11 mya) but all modern forms in last 2-3 my**
- • **Two subfamilies**
- **– Otariinae (seal lions)**
- – Arctocephalinae (fur seals)

–

- **In cladistics, a synapomorphy or synapomorphic character is a trait that is shared ("symmorphy") by two or more taxa and their most recent common ancestor, whose own ancestor in turn does not possess the trait.**

–

- **Some Otariid synapomorphies**
- **– Frontals extend anterior between nasals (9)**
- **– Uniformly spaced pelage units (primary and secondary hair)**
- **– Trachea subdivides close to voicebox (13)**
- **– Secondary spine on scapula (11)**
- **– External ear flaps "pinnae"**
- **– Can turn hindflippers forward; use to walk**
- **Otariid systematics**
- **– Otariinae (sea lions) monophyletic (single stock) , not**

Arctocephalinae (fur seals) which are still poorly resolved

- – Hybridization and Introgression may cause problems
- – aggressive sexual behavior of male sea lions directed at other species

–

- Modern Pinnipeds: Odobenidae
- • Current 2 subspecies relicts of once diverse group
- – Modern walrus large-bodied, shallow diving mollusk feeder
- • Monophyletic family, origin middle Miocene (16-9 mya) eastern North Pacific
- Odobenid synapomorphies
- • Five synapomorphies
- • Modern walrus distinguished by squirt-suction feeding
- • TUSKS ARE NOT A SYNAPOMORPHY
- – They evolved in only one lineage leading to modern walrus
- – Many ancient odobenids did not have tusks
- Where do the odobenids fit?
- • Molecular evidence points to otariids, but morphological data suggests a close association with phocids

–

- – Middle earbone enlarged
- – No pinnae

- – Well-developed thick subcutaneous fat
- – Abdominal testes
- – Similarities in hair and venous system
- • What gives?
- – Still unclear where walrus fit in pinniped clade
- – Odobenids probably branched off from basal pinnipeds very early leading to a long branch
- – Subsequent long-branch attraction causes molecular similarities
- Odobenid movements
- • Origin in eastern North Pacific
- • Invaded Atlantic through Carribean
- • 600,000 ya modern walrus reinvades Pacific through Arctic and diverge into subspecies

–

–

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- – No pinnae
- – Well-developed thick subcutaneous fat
- – Abdominal testes
- – Similarities in hair and venous system
- • What gives?

- **– Still unclear where walrus fit in pinniped clade**
- **–Modern Pinnipeds: Phocidae**
- **– "True" seals, lack ear flaps**
- **– Generally larger than otariids**
- **– Some fantastic divers**
- **– Weddell and elephant seals over 1000m**
- **– Late Oligocene origin (29-23mya) in N. Atlantic**
- **– Monphyletic family with two subgroups**

–

- **– monoachines and phocines**
- **Some phocid synapomorphies**
- **• Unable to turn hindflippers forward**
- **• Inflated entotympanic bone (21)**
- **• No supraorbital process (10)**
- **Subspecies, hybridization and a misplaced genus**
- **– Five subspecies of harbor seal recognized based on morphological, molecular, behavioral differences**
- **– Eastern and western sides of Atlantic and Pacific, lakes of northern Quebec**
- **– Harp seal *Phagophilus groenlandicus x* hooded seal *Cystophora cristanta* hybird – what does this mean**

- for biological species concept
- – What is the status of the gray seal genus?

—

- Phocid systematics
- • Are traditional subgroups monophyletic?
- • Monk seals *Monachus* often considered most basal of phocids due to ancestral characters (some moreso
- than fossil taxa)
- Pinniped Evolution: Summary
- • Morphologic and molecular data support monophyly
- • Derived from arctoid carnivores, probably close relatives of bears
- • Earliest appear 27-25mya in north Pacific
- • Modern lineages diverged quickly
- • Position of the walrus unclear

—

- Cetacean Evolution and Systematics
- Cetaceans
- • Monophyletic group with 3 suborders
- – Archaeoceti (extinct)
- – Odontoceti (~76 species)

- – Mysticeti (11 species)
- • Earliest marine mammals (with sireneans) 53-54 mya
- Cetacean Origins
- • Currently some questions about origins: several competing hypotheses
- • Evolved from small primitive ungulate group
- – Could share common ancestor with hippos
- – Could be sister group of other artiodactyls (even-toed; hippos, camels, antelope, pigs, giraffes, etc)

<u>Archaeoceti (extinct)</u>

–

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- – Could be another ancestor not closely related to moder artiodactyls
- Cetacean Origins: The old favorite
- • 1. Decendent of Order Condylartha, Family Mesonychidae
- • Wolf-like with digitigrade stance (walk on toes), possibly hoofed
- • Massive crushing dentition; early skulls suggest similarity
- Cetacean Origins: close to hippos?
- • 2. Some molecular data points to close affinity with hippos; recent skull finds disagree – more like
- mesonychids

- **Cetacean Origins**
- **3. Sister group to clade including hippos and artiodatyls; not particularly close to mesonychids**
- **–**

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- **– Probably all derived from mouse-deer like ancestor**
- **Cetacean Origins: *Indohyus* brings us closer to an answer**
- **• 4. Sister group to cetaceans more primitive than other artiodactlys**
- **– Recent finds in India suggest cetaceans closest ancestor is an ancient artiodactyl group (raoellids)**
- **– Similarity to cetaceans based on morphology of inner ear, the arrangement of incisors, and**
- **morphology of premolars**

–

- **– *Indohyus* was an aquatic wader based on bone density and oxygen isotopes**
- **– Carbon isotopes suggest feeding on terrestrial vegetation or omnivores on land but escaped to water**

when in danger like modern African mouse deer

- **– Adaptation to aquatic habitats did not occur first in early cetaceans, but more basal species –**

–

- **cetacean branch probably driven by switching to aquatic prey (unique dentition and oral skeleton)**
- **– Early cetacean ancestors went through a hippo-like stage**
- **– Study published in 2009 suggests that hippos are, in fact, closest living relatives of cetaceans.**
- **Archaeocete cetaceans**
- **• Paraphyletic group of ancient whales that gave rise to modern whales**
- **– lack telescoped bones of the skull**
- **– Elongate snout**
- **– Narrow braincase**
- **– Large temporal fossa**
- **– Well defined sagital and lambdoidal crests**
- **• Earliest from Early Eocene (>50 mya)**
- **• Extinct by end of Eocene**

—

- **• Pakecetoids are most ancient group (50 my)**
- **– *Pakecetus* – earliest whale; India and Pakistan**
- **– Ear morphology gives them away as cetaceans**
- **– Lived in an arid environment with ephemeral streams and floodplains**
- **• Always found in river deposits**

- • At best site, 60% of mammal remains are pakicetids!

–

- •– Quadropedal and probably mainly terrestrial but not swift runners (dense bones that may have
- been for ballast)
- – Long thin legs and short hands and feet suggest they were poor swimmers (quadropedal
- paddling) and many deposits were rivers that were too shallow for swimming
- – Teeth vary greatly – some hyena-like
- • may have been scavengers or predators

–

- • Probably ate freshwater aquatic organisms and land animals near water
- • Ambulocetids
- – Found in middle Eocene rocks of India and Pakistan
- – Most basal amphibious marine cetaceans
- • Nearshore marine (estuaries and bays) but tied to freshwater for drinking
- – *Abulocetus natans* and others close to size of male sea lion

–

- – Show first signs of hearing adaptations

- – Eyes above profile of skull
- • Ambulocetids
- – Likely slow on land
- – Elongated hind feet and tail that would aid in locomotion
- • Probably swam like modern otter swinging tail and feet
- – Probably ambush hunter like modern crocodiles

–

- • Remingtonocetidae
- – Short-lived group from Middle Eocene of India and Pakistan
- – Nearshore tidal environments, but more aquatic than ambulocetids
- – Long narrow jaws
- – Probably swam with tail like Amazonian giant otter
- – Captured fast-swimming aquatic prey

–

- •– Protocetids
- – Globally distributed during the middle Eocene
- • First group to leave South Asia
- – Expanding niches inhabited including deep offshore waters but probably restricted to tropics
- – Nasal openings more caudal than earlier species

- • Could breath with much of head underwater
- – No fluke

–

- •– Lifestyle probably very similar to modern pinnipeds
- – Hindlimbs may not have been able to support weight in some species
- • Basilosaurids
- – Middle to late Eocene/early Oligocene
- – large-bodied family with elongated vertebral bodies (Basilosaurinae)
- – Very reduced hind limbs – fully aquatic
- – *Basilosaurus* grew to 25m
- – Throughout the tropics and subtropics
- – Had fluke, but back undulations rather than the fluke provided propulsion
- – Piscivorous
- • Dorudontids

–

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–

- Archaeocete trends
- – Rapid evolution (few million years) from
- – Quadropedal to flukes (hindlimb reduction)
- – Freshwater dringing to seawater drinking
- – Land animal to not able to move on land and giving birth in water
- – Movement of nostrils to the top of the head
- – Extinction probably tied to changes in food supply driven by oceanographic change

–

- Modern Cetaceans
- – Diverged from Archaeocetes about 37 mya

- – Monophyletic clade derived from dorudontids
- – Split between mysticetes and odontocetes probably 35 mya
- – Synapomorphies
- – Telescoping of skull: movement of blowholes to the top of skull
- • Migration of premaxillary and maxillary bones forms a rostrum (beak)
- – Fixed elbow joint not present in archaeocetes
- Mysticetes (Baleen whales)
- – Modern forms distinguished by baleen plates, but early mysticetes had teeth
- – Origin probably tied to Oligocene development of Circum-Antarctic current and generation of nutrientrich

—

- upwelling that led to huge zooplankton shoals
- – Early mysticetes were small 4-5 m
- – Major evolutionary transition is from raptorial predation (single prey item at a time) with teeth to batch
- or filter feeding with no teeth (baleen present by Oligocene, but decomposes so record poor)
- – Other trends include increased body and head size, shortening of the neck
- Mysticete Synapomorphies

- • Maxilla extends posteriorly to form infraorbital process
- • Mandibular symphysis (lower jaw connection) unfused

—

- Modern Mysticete Relationships
- – Four extant families?
- – Balaenopteridae,
- – Balaenidae
- – Eschrichtiidae
- – Neobalaenidae
- – Taxonomy not well-resolved
- Mysticetes: in order of divergence
- – Balaenidae
- – Right whales and Bowhead
- – First appear in early Miocene (23 mya)
- – Heavy body, cavernous mouth, no throat grooves
- – Head 1/3 of length
- – Long baleen plates

—

- – Only mysticetes with 5 digits on forelimb
- – Monopyletic

- • Support for two separate genera poor
- – Neoalaenidae
- – Anatomical data places as separate family outside Balaenidae
- – More anteriorally thrust occipital shield
- – Shorter, wider mouth for shorter baleen
- – Separate from balaenids due to presence of dorsal fin, throat furrows, different type of baleen,
- relatively smaller heard, four digits on hand, shorter humerous)

–

- – Eschrichtiidae-grey
- – Current species has 100,000 year fossil record (only one for family)
- – North Atlantic population extinct in 17th or 18th century
- • No dorsal fin
- • 2-4 throat grooves
- • Baleen is thicker, fewer in # and whiter than rorquals

–

- – Balaenopteridae
- – Fossil record extends 10-12 mya from Americas, Europe,

Asia, Australia

- – Hybrids occur
- – Dorsal fin
- – 14-22 (humpback) to 56-100 (fin) throat grooves extend beyond gular (cooling)region

–

- – Short baleen
- Odontocetes
- • Diverse array of toothed forms from freshwater rivers to deep-diving in pelagic habitats
- • First appear in fossil record 28-29 mya
- • Major Miocene radiation of pelagic forms appears to be linked to changes in currents and thermal
- gradients
- • Monophyly well supported despite well-publicized argument against with early genetic data
- Are odontocetes monophyletic?
- • Most morphological characters argue that they are, but one of the supposed synapomorphies has come
- been disputed: presence of a single blowhole
- – Odontocete facial structure serves a number of functions
- – Respiration cause of much skull rearrangement

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- – Sound production (echolocation) and detection another major force
- – Buoyancy control, at least in sperm whales
- – Some of the 20 Synapomorphies
- – Concave facial plane
- – Asymmetric cranial vertex
- – Premaxillary foramen present
- – Maxilla overlays supraorbital process (frontal bone)
- – Antorbital notch present
- – Asymmetric skulls (except possibly most primitive)
- – Asymmetric soft tissues in modern forms due to enlargement on right side
- – Fatty melon in front of nasal passages for echolocation

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- Ziphiidae
- • More than 20 species in 5-6 genera extant
- – Found in Mocene and Pliocene, including one freshwater form; extant species mainly pelagic
- – Trend towards loss of teeth with exception of 1-2 pairs anteriorly which become enlarged (only
- Shepard's beaked whale has full functional dentition)

- • Possible sexual display/weapons
- – Pair of throat grooves that converge anteriorly
- – Phylogeny unclear; no rigorous cladistic review
- Physeteridae
- • Long fossil record (29-21 mya), once diverse but only one extant species
- • Loss of one or both nasal bones
- • Deepest known divers
- • Have spermaceti organ

–

- – in supracranial basin
- – may occupy 30% of length and
- 20% of weight
- – May control buoyancy but still unclear
- Kogiidae
- • Linked into a superfamily with sperm whales because of supercranial basin and spermaceti organ
- • Lack both nasal bones
- • Have short rostrum and are much smaller than sperm whales (<4m; <2.7m)
- • Oldest known from late Miocene (8.8 mya)
- "River Dolphins"

- • Once put into a single family, but similarities (reduced eyes, elongated snouts) are due to convergent

evolution

–

- – freshwater/estuaries have
- been invaded at least 4 times
- Platanistidae
- • Asiatic river dolphins
- – Ganges and Indus Rivers
- – Reduced eyes in Ganges form
- – Long narrow beak with numerous narrow pointed teeth
- – Broad paddle-like flippers
- – No known fossil record, time
- of freshwater invasion unknown
- – Bony facial crest
- Pontoporiidae • Fransiscana
- – Coastal waters of western S. Atlantic
- – Long rostra, tiny teeth – Close relative of Iniidae

–

- Iniidae

- • Amazon river (botu)
- – Reduced eyes
- – Extremely elongated rostrum and mandible
- – Conical front teeth, molariform rear teeth
- – Greatly reduced orbital region
- – Maxilla forms crest
- – Fossils from late Miocene originated in Amazonian basin
- Lipotidae
- • Yangtze Tiver (baiji)
- – Narrow, upturned beak
- – Triangular dorsal fin
- – Broad round flippers
- – Reduced eyes
- – One fossil, one extant species from China

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Delphinidae

- – Most diverse cetacean family 36 sp, 17 gen
- – Open ocean to some into freshwater (*Orcella brevirostris*, *Sotalia fluvatilis*)
- – Most small to medium 1.5-4.5m, killer whale to 9.5m
- – Loss of posterior sac of nasal passage

- – Reduction of posterior end of left premaxilla: does not contact the nasal
- – Oldest from late Miocene (11 Ma)
- • Systematics are still a mess
- – Some genera are not monophyletic
- – Diversity likely to increase (e.g. *Tursiops*)
- – *Stenella* is polyphyletic
- Phocenidae

–

- – Six small extant species
- – Synapomorphies
- – Raised rounded protuberances on premaxillae
- – Premaxillae do not extend beyond anterior half of nares
- – Spatualte (not conical) teeth
- – Sister taxa of delphinids
- – First appeared in late Miocene, eastern Pacific
- Monodontidae
- • Delphinoids with flat or convex facial planes in profile
- • Extant species in Arcitc
- • Miocene/Pliocene some species found in E. Pacific to Baja California

–

- **Sirenians, Sea otters, Polar Bears, and other marine mammals: Evolution**
- **Sirenians**
- **• Monophyletic group with two extant familes**
- **– Trichechidae (manatees)**
- **– Dugongidae (dugongs)**
- **• Unique in strictly herbivorous diet**
- **• First appear in early Eocene (50 mya)**
- **Sirenian Origins**
- **– Monophyly strongly supported**
- **– Syapomorphies**
- **– External nares retracted and enlarged reaching beyond the level of the anterior margin of the orbit**
- **– Premaxilla contacts frontal**
- **– Lacks sagital crest**

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- **– Bones dense and compact (for buoyancy regulation)**
- **– Closest living relatives are proboscideans (elephants)**

- – Teeth and skull morphology unite the groups
- – Extinct Desmostylians form clade with sirenians and elephants (monophyletic "Tethytheria")
- – First arose in Old World, but quickly spread to New World 50 mya
- Ancient Sirenians
- • *Prorastomus* (50mya) first (Jamaica)
- – Had functional hindlimbs
- – Dense bones, swollen ribs and presence in marine deposits suggest partially aquatic; riverine and
- estuarine selective browser

—

- • *Protosiren* (middle Eocene) (Egypt)
- – Functional terrestrial locomotion but auditory, olfactory, and visual systems appear modified for
- aquatic lifestyles
- • Much of the spread of sirenians tied to the spread of seagrasses in the temperate Pacific
- Modern Sirenians: Trichechidae
- – Appear to be derived in late Eocene/early Oligocene, possibly from dugongids
- – Monophyletic, united by features of the skull and reduction of neural spines on vertebrae

- – Mainly freshwater/estuarine
- – Ability to produce new teeth as old ones are worn down

—

- • 3 modern species
- – West Indian manatee (*Trichechus manatus*)
- • 2 subspecies: Antillean (*T.m. manatus*); Florida (*T.m. latirostris*)
- – Amazon manatee (*Trichechus inunguis*); freshwater only
- – West African manatee (*Trichechus senegalensus)*
- Modern Sirenians: Dugongidae
- • Paraphyletic family with Caribbean/W. Atlantic origins spreading to Pacific
- • More marine than manatees
- • Two extinct subfamilies and one extant
- – Hydrodamalinae (includes Steller's sea cow) appears to have split from Dugonginae (dugong) in
- late Eocene
- • Includes Stellar's sea cow (extant into historical times)

—

- • Some temperate species
- • Large body size
- • Loss of tusks

- • May have fed on kelp high in the water column
- Steller's sea cow
- • Named after Georg Steller
- • 7.6m long, 4-10 tons
- • Lacked teeth, had bark-like skin
- • Cold waters near islands of the Bering Sea
- – Prehistorically from Japan to Baja California (to Montery 19,000 years ago)
- • Extinct by 1768 (27 years after discovery)
- – Mainly Russian hunting, but possibly exacerbated by aboriginal hunting

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- Dugonginae
- • Currently one species, but once many genera
- • Tropical and subtropical
- • Once widespread; 15 mya from North and South America, Caribbean, Mediterranean, Indian Ocean,
- North Pacific
- • Some extinct species used tusks to dig up seagrasses
- • Modern dugongs use tusks socially, not for feeding
- Sirenian evolution in the Caribbean (Domning 2001)

- • From Oligocene onwards, there was a great diversity of sirenians in the Caribbean, especially dugongids
- • Seagrass communities were similar to extant ones but were more diverse
- • Habitat could be partitioned along several axes
- – Rhizome size

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- – Location of feeding in water column
- • Morphology of sirenians reflects partitioning of seagrass resources
- – Body size differences lead to differences in access to shallow waters and ability to consume more
- fibrous seagrasses (bigger are better)
- – Rostral deflection influences ability to feed on the bottom or on midwater or surface plants and
- ability to dig
- – Tusk size influences ability to dig out largest rhizomes
- – Interaction of tusk size and defection can be complex
- • Why so few species today?
- • Close of Central American Seaway about 3 mya led to major shifts in habitats

–

- – Dugongids died out along with large rhizome seagrasses

- **– Manatees were able to disperse into open marine habitats to move into North America and to West**
- **Africa**
- **Desmostylia: Sirenian Relatives**
- **• Only extinct Order of marine mammals**
- **• Confined to North Pacific (Japan through N. America)**
- **• Late Oligocene to Middle Miocene (33-10mya)**
- **• Hippo-like amphibious quadropeds**
- **• More closely related to elephants than sirenians**
- **• Probably fed on algae and seagrasses in subtropical and cool-temperate waters**
- **• Locomotion probably like polar bears**

–

- **–*Thalassocnus***
- **• Aquatic ground sloth!**
- **• Pliocene marine rocks of Peru**
- **• Medium to giant sized herbivores**
- **• Aquatic or semi-aquatic grazer on seagrasses or seaweeds (well developed lip for grazing)**
- **• Probably swam with tail**
- ***Kolponomos***
- **• Bear-like carnivore (early Miocene)**

- • Massive skull, down-turned snout, broad crushing teeth
- • Coastal habitat feeding on marine invertebrates on rocks and crushed their shells

–

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- • Sea otter only marine mammal that may be similar in habitat
- • Relationships problematic
- – Appears to be closely related to basal ursids and forms leading to pinnipedimorphs
- Sea otter *Enhydra lutris*
- • Smallest marine mammal but largest mustelids
- • Three subspecies across northern Pacific
- • *E. lutris* arose in North Pacific early Pleistocene (1-3mya)
- • Several extinct species from Africa, Europe, and Eastern United States that appear to have
- consumed extremely hard prey items like modern otters

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- Polar Bear *Ursus maritimus*
- • Most recently derived marine mammals
- • Descended from lineage of brown bears during middle Pleistocene (300,000-400,000 ya)
- • Brown bears of southeast Alaskan islands closest relatives

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- **This phylogenetic tree for the sea otter contains all the sea otter genera. The sea otter is the only member of the genus *Enhydra*. Each genus is a monophyletic group, meaning that the organisms in each genus share a common ancestor. The sea otter is sister to the speckle-throated otter (*Hydrictis maculicollis*) and is by far the closest relative to the sea otter. This also shows that the sea otter shares a common ancestor with the Eurasian otter (*Lutra Lutra*), African clawless otter (*Aonyx capensis*), small-clawed otter (*Aonyx cinerea*), and the speckle-throated otter (*Hydrictis maculicollis*).**

MARINE MAMMAL DISTRIBUTION

Zoogeography

–

Zoogeography

- **Study of the distribution of extant species**
- **Water temperature critical for marine mammals**

– Directly on animals physiology

– Indirectly on prey

– Species often occur in latitudinal bands

- **Shape of nearby land/shelf**

• History is Critical

– When did lineages arise and diversify?

– Continental Drift and Climate Change

–

– *The early and middle*

Miocene

Basic Climatic Zones

• Polar

• Subpolar/Cold Temperate

• Temperate

• Subtropical

• Tropical

Basic Types of Distribution

• Cosmopolitan- a taxon is said to have

a cosmopolitan distribution if its range extends across all or most of the world in appropriate habitats. For instance, the killer whale has a cosmopolitan distribution, extending over most of the world's oceans.

• unknown for many species

–

–• Pan Tropical In biogeography, a pantropical ("across the tropics") distribution is one which covers tropical regions of all of the major continents, i.e. in Africa, in Asia and in the Americas

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- **Temperate/Subpolar**
- **Circumpolar**
- **Anti-tropical**
- **Regional (Endemic)**
- **still unknown for many species**

–

Horizontal Habitats

- **Nearshore**

– Lakes and Rivers

– Estuaries

– Freshwater and saltwater mix, high productivity and low visibility

– Bays

– Relatively protected waters

– Coastal

– Shallow waters, often high energy (wave action)

• Offshore

– Continental Shelf

• Relatively shallow but deeper than nearshore habitats

• Light usually penetrates to bottom over much of this habitat

–

– Continental Slope

• Depth changes rapidly, light penetration begins to diminish

• Often associated with high productivity

– Pelagic

• Extremely deep, no light at depth

• Generally low productivity except in areas of relief (seamounts, etc)

• Frontal dynamics and current features may be very important

Vertical Marine Habitats

• Vertical Distribution of Habitats

– Light, temperature, pressure, salinity, and water density change considerably as depth increases

– Deep-water habitats can be divided into photic and aphotic zones

–

– Depth where these start varies considerably with water visibility

Ice Habitats

• Many pinnipeds rely on ice as habitat

– Haul outs

– Breeding

• Polar bears use the ice to stalk seals

• Cetaceans must navigate the ice to access many polar habitats

– Fast ice

– Ice attached to shore that does not move

– Pack ice

– Ice that forms at sea and moves with currents

– Covers central Arctic, surrounds Antarctica

– Largely melts in summer, especially in Antarctica

–

– Ice floes

– Large pieces of sea ice broken by wind or waves

– Leads

– Open water formed when floes move apart

Current Distributions: Mysticetes

• Typified by seasonal shifts from high latitudes (feeding in summer) to low latitudes (breeding in winter)

• Bowhead: arctic

• Right whales: temperate

• Gray whale: warm temperate

• Rorquals: cosmopolitan

– *B. edeni*, *B. brydei* pantropical (<40°)

Current Distributions: Odontocetes

• Not limited by temperature in general

• Sperm whales – pelagic, cosmopolitan

–

– 2 smaller species more tropical

• Narwhal and Beluga – coastal, arctic

– Move with sea ice

• Beaked whales – pelagic, regional or antitropical

– In general, very poorly known

• Delphinidae – coastal and pelagic forms; tropical, anti-tropical, cosmopolitan, regional all found

• Porpoises – coastal, sometimes freshwater, regional/endemic

• "River Dolphins" – large tropical river drainages; one coastal species in SA

– Indus, Ganges, Yangtze, Orinoco, Amazon

Current Distributions: Sirenians

• Tropical/Subtropical; Regional

– Recently extinct Stellar's Sea Cow was cold temperate

–

• Dugongs: fully marine

– Limited by marine plant distributions

– Prefer >18°C, <6m depth

• Manatees (Trichechids): tend towards freshwater sources

– Amazon manatee: obligate fresh water

Current Distributions: Pinnipeds

• Cetaceans more successful in low latitudes, pinnipeds more successful at high latitudes

• Odobenids

– disjunct circumpolar

• Otariids

– cool temperate/subpolar (except N. Atlantic)

– lower latitudes where cold currents occur

–

•– *Arctopcephalus* (fur seals) have 6 species only in southern ocean

– Distributions highly influenced by sealing

– Some species highly endemic, but others widespread

– *Zalophus* (sea lions) mainly in north with California sea lion most widespread

• Phocids

– Most widespread pinnipeds

– Northern group Phocinae

• Many give birth on ice or in ice lairs

• Temperate, Arctic, subarctic, some landlocked lake seals

–

– Monachinae

• Warm water seals, elephant seals, Antarctic ice seals

– Some ice seals can maintain holes (Ringed seal) in ice, others must stay near ice edge (Bearded seal)

– Monk seals only true warm water seals

Current Distributions: Sea otters and Polar Bear

• Sea Otter

– North Pacific

– Tied to shallow waters

– Poor dispersal ability

• Polar Bear

– Circumpolar

– Track seal distribution (mainly ringed seals)

–

Current and historical distributions

• May have been modified greatly by human activities both ancient and modern

• Pinnipeds in central and northern California are a perfect example

Pinnipeds of central California

• Currently dominated by CA sea lions and N elephant seals with northern fur seals (NFS) rare and only

breeding in recent and small colonies on offshore islands

• Most NFS breeding is in Alaska and may forage in pelagic waters as far south as Baja

• A strange observation: remains of NFS extremely common in archeological sites in California.

Explanations of NFS abundance in ancient times

• Always had northern rookeries and foraged closer to shore where they were available or were hunted

–

more commonly

• More abundant on offshore rookeries of California

• Were historically more abundant and had mainland rookeries

Burton et al (2001)

• Used archeological data, stable isotopes to address these hypotheses: what did they find?

– Differences in hunting or foraging location did not explain remains

– NFS were mainland breeders in CA during mid-late Holocene

– NFS were extremely abundant historically compared to other pinnipeds and may have limited the

abundance of other pinnipeds

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Range of Polar bears

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- **Philos Trans R Soc Lond B Biol Sci. 1999 January 29; 354 (1380): 193–201.**
- **doi: 10.1098/rstb.1999.0371**
- **PMCID: PMC1692474**
- **The evolution of cost efficient swimming in marine mammals: limits to energetic optimization**

- **T. M. Williams**

–

- **One of the most characteristic features of marine mammals is a streamlined body shape.**

- **This is not surprising when one considers the forces that the animal has to overcome in order to move through water.**

- **When a swimmer moves through water a force, termed drag, acts backward on it, resisting its forward motion.**

- **The equation describing total body drag is given by**

- **Total Drag = 1 / 2ρ V^2ACd (1) where ρ is the density of the fluid, V is the velocity of the fluid relative to the body, A is a characteristic area of the body, and Cd is the drag coefficient (a factor that takes into account the shape of the swimmer).**

–

- **The primary mode of locomotion for marine mammals with the possible exception of polar bears (*Ursus maritimus*) is swimming. For dolphins, porpoises and whales, it is the**

- **only form of locomotion.**

- **The duration of swimming among these mammals may be as short as several seconds when moving between**

- **prey patches or as long as several months during seasonal migrations across entire ocean basins.**

- **Although swimming by marine mammals often appears effortless, it is in reality a delicate balance between precise body streamlining, exceptional thrust production by specialized propulsive surfaces, and locomotor efficiency**

–

- **The optimum fineness ratio that results in minimum drag with maximum accommodation for volume is 4.5.**

- **Calculations of the fineness ratio for a wide variety of marine mammals show that many species have body shapes that conform to the ideal hydrodynamic range**

- **A review paper by Fish (1993) showed that many cetaceans, pinnipeds, and sirenians have body shapes with Fineness**

- **Ratios that range from 3.0 to 8.0.**

- **The species examined included seals, sea ions, and odontocete whales that are considered by many to typify a streamlined body profile.**

- **Even mysticete whales with enlarged heads**
- **and jaws specialized for filter feeding maintain a streamlined body profile when swimming .**

–

- **There are four primary types of drag that contribute**
- **to total body drag:**
- **(1) skin friction drag which is a tangential force resulting from shear stresses in the water sliding by the body,**
- **(2) pressure drag which is a perpendicular force on the body associated**
- **with the pressure of the surrounding fluid,**
- **(3) wave drag that occurs when a swimmer moves on or near the water surface, and**
- **(4) induced drag that is associated with water deflection off hydrofoil surfaces such as fins, flukes, or flippers.**
- **Of these, pressure drag is the component most influenced by body streamlining in marine mammals.**
- **The more streamlined a body, the lower the pressure drag and consequently the lower the total body drag of the swimmer.**

–

- **Mammals whose lifestyles or foraging habits involve prolonged**

periods of swimming have streamlined body shapes.

- In contrast to the lanky appearance and appendages of terrestrial mammals, marine mammals tend to have a reduced appendicular skeleton and characteristic tear drop body profile.

- External features that may disrupt water flow across the body are also reduced or absent in many species of marine mammal.

- These features include the pinnae (external ears), limbs, and long fur.

- In highly specialized swimmers such as dolphins the skin contains microscopic ridges that help to direct the flow of water in a controlled manner down the body.

- All of these adaptations prevent the onset of turbulence in the water surrounding the swimmer and thereby reduce total body drag.

–

- Hydrodynamic theory describes the streamlined body shape as one in which a rounded leading edge slowly tapers to the tail, and total length is 3–7 times maximum body diameter.

- The ratio of these morphological measurements, termed the Fineness ratio

  - Specifically, it is the ratio of the length of a body to its maximum width; shapes that are "short and fat" have a low

fineness ratio, those that are "long and skinny" have high fineness ratios.

- **Aircraft that spend time at supersonic speeds generally have high fineness ratios, a canonical example being Concorde.**

–

- **However, the loss of this hydrodynamic profile when the animals open their mouths quickly results in a marked increase in drag, a reduction in forward speed, and a concomitant elevation in energetic costs**

- **Despite nearly ideal body streamlining, all marine mammals must contend with drag forces when moving through the water.**

- **These forces can be a considerable challenge for the swimmer and will influence how quickly the animal will be able to move.**

- **It is apparent that the velocity of the swimmer will have a large impact on total body drag.**

- **As the swimmer moves faster, body drag increases exponentially.**

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- **Whether the sea otter swims on the water surface or submerged, body drag increases with velocity.**

- **However, body position clearly affects the level of total body**

drag encountered by the sea otter.

- **At all comparable swimming speeds, body drag is higher for the otter moving on the water surface than when it is swimming submerged.**

- **The same results have been found for other swimmers, including humans and harbor seals (*Phoca vitulina*).**

- **In general, body drag for a swimmer moving on or near the water surface is 4–5 times higher than the level of drag encountered by the submerged swimmer moving at the same speed**

–

- **A hallmark of marine mammal swimming is the use of lift-based propulsion that allows thrust to be generated through the entire stroke cycle.**

- **This capability is found in highly adapted marine species such as pinnipeds and cetaceans.**

- **It contributes to an increase in locomotor efficiency in marine mammals, especially when compared to the inefficient drag-based swimming styles of humans and terrestrial mammals**

- **Marine mammals use a wide variety of swimming styles to move through the water.**

- **The most terrestrial species of this group, the polar bear and sea otter, swim by alternate strokes of the**

- **forelimbs or hind limbs, respectively.**

- **Polar bears use a dog style of forelimb paddling with the hind limbs dragged passively behind or used as an aid to steering.**

–

- **Sea otters are unique among marine mammals in their ability to lie on their backs during surface swimming.**

- **Propulsion is provided by either the simultaneous or alternate strokes of the hind limbs.**

- **When on the surface, sea otters can also swim ventral surface (belly) down using the hind paws for propulsion.**

- **The front paws are held against the submerged chest and do not play a role in propulsion during this mode of swimming.**

- **Stroke frequency has been measured for swimming sea otters and ranges from approximately 30 to 80 strokes per minute while swimming on the water surface**

- **Polar bears and sea otters are the only marine mammals that rely primarily on drag-based modes of swimming.**

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- **These modes of swimming have two distinct phases during the stroke cycle, a power phase when thrust is produced, and a recovery phase when the foot or paw is repositioned for the next stroke.**

- **During the power phase, the foot is moved backward relative to the body.**

- **Drag created by this motion is subsequently translated into thrust and the animal moves forward through the water.**

- **The enlarged hind flippers of sea otters and fore paws of polar bears enable the animals to increase propulsive efficiency by moving a large mass of water during this power phase.**

- **The recovery phase of the stroke is only used to bring the limb back to its starting position, and occurs without the generation of thrust.**

—

- **Because thrust is produced only during part of the stroke cycle, drag-based modes of swimming are comparatively inefficient.**

- **When sea otters want to move quickly through the water, they switch to an undulatory (wave-like movement patterns) mode of swimming involving dorsoventral body flexion and simultaneous movements of paired hind flippers.**

- **The tail and hind flippers are held straight back and trail the undulatory movements of the trunk.**

- **Stroke frequency of sea otters remains relatively constant at 55 strokes per minute during submerged undulatory swimming, which suggests that underwater speed is elevated by**

increasing stroke amplitude.

- **As observed for submerged swimming sea otters, dolphins and whales use undulatory modes of propulsion.**

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- **The primary propulsive movements of all cetaceans occur in the vertical plane with the posterior third of the body undulating in a dorsoventral direction.**

- **" Semi-lunate " refers to the crescent shape of the flukes.**

- **This mode of propulsion is shared by other fast swimming vertebrates including tuna.**

- **" Undulatory propulsion in cetaceans is considered highly efficient and can generate high levels of thrust on both the upstroke and downstroke.**

- **There is no recovery phase and propulsion can be**

- **produced throughout the stroke cycle.**

- **Stroke frequency using this mode of swimming varies with the speed and size of the cetacean.**

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- **The range of stroke frequencies for bottlenose dolphins (*Tursiops* spp.) swimming in a pool is 60–180 strokes.min _ 1 .**

- **Stroke frequency decreases with increasing body size among**

the cetaceans.

- **Thus, we find that the largest species of swimming mammal, the 100 ton blue whale (*Balaenoptera musculus*), uses stroke frequencies that are only one-tenth of the range observed for bottlenose dolphins.**

- **A measurement of the stroke frequency of blue whales ascending during a dive was 6–10 strokes.min.**

- **Swimming by pinnipeds differs markedly between the eared seals, the otariids, and the true seals, the phocids.**

- **Otariids use pectoral appendages to generate propulsive forces during swimming, with the hind flippers trailing passively or occasionally used for steering**

–

- **IV. Energetics Fineness Ratio=maximum body length/maximum body diameter**

- **The energetic cost of swimming has been measured for numerous species of semi-aquatic and marine mammals using a wide variety of techniques.**

- **Smaller swimmers such as sea otters, seals, and sea lions have been studied while they swam against a current in water flumes.**

- **Similar to placing a human on a treadmill, flume studies have enabled scientists to measure how much energy a swimmer expends while moving at different speeds.**

- **Often oxygen consumption is measured during these tests by using a face mask or metabolic hood connected to an oxygen gas analyzer.**

–

- **By training animals to breathe into a metabolic hood, expired respiratory gases can be collected and analyzed for oxygen content.**

- **For larger, more powerful swimmers like dolphins and whales, most flumes are not adequate in terms of size or challenging water speeds.**

- **Instead, investigators have relied on a variety of novel techniques for determining the energetic cost of swimming in cetaceans.**

- **Techniques have included using trained dolphins that match their swimming speed to that of a moving boat in open water or having whales swim to metabolic stations where expired gases can be collected for analysis**

- **To compare swimmers of different size, it is useful to convert the metabolic measurements into a cost of transport.**

–

- **Defined as the amount of fuel it takes to transport one unit of body weight over a unit distance, the cost of transport is analogous to the fuel rating of an automobile.**

- **In this case, the cost of transport indicates the " gas**

- per mile " used by the swimmer rather than the " miles per gas " achieved by automobiles.

- The total cost of transport is calculated from the following equation:

- Total Cost of Transport

- Oxygen Consumption

- Swimming Speed where oxygen consumption is in ml O_2 /kg /sec and speed is in m/sec which results in a cost of transport in mlO_2 /kg /m

—

- These values are usually converted to an energetic term and expressed as Joules expended per kilogram of body mass per meter traveled .

- The conversion calculation assumes a caloric equivalent of 4.8 kcal per liter of oxygen consumed and conversion factor of 4.187×10^{3} J per kcal.

- Comparisons of the cost of transport for a wide variety of mammalian swimmers indicate that swimming is energetically expensive for mammals compared to fish. The total cost of transport for swimming mammals can also be divided into two distinct groups, the semi-aquatic mammals and the marine mammals .

- **Swimming costs for semiaquatic mammals such as minks**

- **(*Mustela* spp.), muskrats (*Ondatra zibethicus*), and humans are 2–5 times higher than observed for marine mammals.**

_

- **These high energetic swimming costs are attributed to a wide variety of factors including elevated body drag associated with a surface swimming position and low propulsive efficiency associated with drag based propulsion.**

- **Mammals specialized for swimming demonstrate comparatively lower energetic costs.**

- **Total cost of transport in relation to body mass for swimming marine mammals ranging in size from a 21 kg California sea lion to a 15,000 kg gray whale (*Eschrichtius robustus*) is described by Total Cost of Transport _ 7.79 mass_0.29 (4) where the cost of transport is in J/kg/1/m/1 and body mass is in kilograms.**

_

- **Interestingly, the style of swimming used by marine mammals did not affect the cost of transport relationship.**

- **Species and swimming styles represented in this equation include sea lions using pectoral fins for propulsion, phocid seals using lateral undulation of paired hind flippers, and odontocete and mysticete whales using dorso-ventral undulation of flukes.**

- **The energetic cost of swimming for marine mammals is greater**

than predicted for salmonid fish of similar body size.

- **Despite specialization of the body and propulsive surfaces for aquatic locomotion, the cost of transport for swimming by seals and sea lions is 2.3–4.0 times higher than predicted for swimming fish.**

- **Values for cetaceans are somewhat lower, and range from 2.1 to 2.9 times values predicted for fish.**

- **Differences in the total cost of transport between marine mammals and fish are due in part to the amount of energy expended for maintenance functions, particularly thermoregulation and the support of a high core body temperature.**

- **As endotherms, mammals expend more energy to support the production of endogenous heat than ectothermic fish.**

- **In addition, many marine mammals show exceptionally high metabolic rates while resting in water in comparison to terrestrial mammals resting in air.**

- **A consequence of these high maintenance costs is an overall increase in the total energy expended during swimming, especially when compared to fish.**

River Dolphins

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Marine Protozoa

Lecture notes

Protozoans

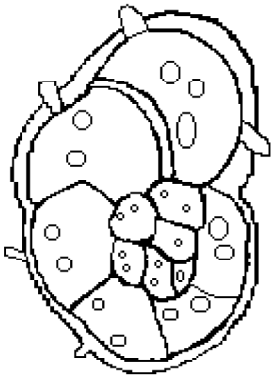
Sub kingdom: protozoa of Kingdom Protista 31,250 species in 7 phyla Features: unicellular, freeliving or parasitic, mostly solitary though some colonial (ciliate and flagellates) move by pseudopodia, flagella, or cilia, some amoeba with tests,or shells, ciliates possess a mouth (cystostome) and nuclei of two sizes, reproduction mainly asexual, sexual reproduction in some groups.

Special marine ones... **Subphylum Sarcodina** (including amoeba) produce so-called pseudopodia-flowing extensions of the cell which can extend one or more at a time (depending what species) . Amoeboid marine protozoans, the Foraminiferans and Radiolarians build cases around themselves. Forams secrete a calcium (chalky) carbonate shell or test, which resembles a microscopic snail shell. Their pseudopod extend through pores to form a network used to trap diatoms and other minute organisms suspended in water. Most live on the bottom either free or attached. The covering of forams is potmarked with numerous holes which the pseudopods extend through to capture smaller ciliates and detritus. As these die, they sink to the ocean floor to form ooze which makes up thousands of square miles of the ocean floor. (white cliffs of Dover are foram tests). Scientists use the fossil tests to measure variations in the worlds temperatures as the structure and sizes of the tests change with water temp. changes. Forams living in cold water have fewer pores than those in warm water.

FORAMS ETC. There may be over 20,000 species of the order Forminiferia, which are characterized by having a rhizopodia and a one chambered or multi- chambered


gumbelina (Cushman, 1955)

test that may be calcareous or siliceous with various substances such as sand or sponge spicules cemented together by pseudochitinous or gelatinous materials. They are among the largest protozoans with some reaching 100mm but usually .5 to 1.0 mm The tests are various shapes--oval, tubular, branched, spiral, etc. Most shells are multi chambered consisting of a series of successively larger chambers which are separated internally with pores or canals connecting them. The cytoplasm is found in all the chambers and is continuous through pores connecting the chambers. By passing though the pores of the test, the cytoplasm forms a layer (ectoplasm) over the test which connects to the endoplasm through the pores. As the animal grows it adds successive chambers to the initial chamber.


Hastigerina (Cushman, 1955)

They capture their prey by means of their pseudopodal network which exhibits active streaming movements. They are found in marine and brackish water and only a few in fresh. A few are pelagic or sessile but most are creeping bottom dwellers (benthonic). A third of the ocean bottom is covered with Globigerina ooze, made mainly of the accumulation of the tests of this common foram. (usually in water under 4000 m deep because tests dissolve in the high concentration of CO_2 in deep water.) Good fossils and important in detecting oil bearing strata.

(From Bio of Inverts Hickman Mosby Co ST Louis 1973)

Radiolaria (Subclass) Radiolarians form a glass like test composed of silica which is studded with long transparent spines to increase buoyancy and ward off predators. Typical shells are spheric with radiating spines though the structure varies...thin needlelike pseudopod capture food.

The radiolarians also form ooze, though radiolarian ooze and is usually found deeper being able to resist more pressure than the calcium carbonate foram tests.Radiolarian Web page

Ciliates are some of the protozoans that use cilia for locomotion. ..creeping over the

bottom, living in gills, attached etc. The Tintinnids build their own quarters that drift in the water.

Reproduction is usually asexual binary fission whereby each effort results in two identical daughter cell (MITOSIS). This occurs when conditions are favorable...warm, lots of food etc.,. but sexual reproduction can occur in some when adverse conditions (drying up) occur as a survival method. The forams have alternation between sexual and asexual generations, having asexual reproduction to produce many organisms which secrete shells around themselves and when mature, they produce identical gametes which are liberated into the sea and fuse in pairs to produce individuals which in turn secrete a shell grow to maturity and repeat the cycle.

Life cycles are known for a few foraminiferans. They have two phases, one asexual and the other sexual. They are also dimorphic, having two types of individuals in each species, based mainly upon the size of the initial chamber (proloculm) of the test. The megalospheric type (gamont) has a large chamber (proloculum), one nucleus and is small in size while the microspheric type (schizont) has a small chamber, many nuclei and is relatively large. This is due to reproductive cycles which alternate between sexual and asexual generations.

Ecology Its complex as it would be for organisms found in every environment . They occur commonly in plankton...benthic communities, marine depths (13,000 ft for a foram) and since many protozoans exploit bacteria as a food source, they form part of the decomposer food web in nature. It is thought that they stimulate the rate of decomposition by bacteria by grazing on bacteria and keeping the bacteria community in a state of physiological youth and hence at the optimum level of efficiency. Ciliates can cause illness sees in some organisms.

Chapter Questions

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ORIGINS OF THE INVERTS and SPONGE LECTURE

Lecture notes

Early invertebrate records are scarce because of the lack of fossil evidence until about 570 million years ago (Cambium) when organisms with external skeletons appeared. All phyla that had hard outer parts existed 530 million years ago and many soft bodied animals belonging to modern phyla of worms appeared as well.

During the jellyfish-worm stage of animal evolution, the various basic designs of animal bodies evolved. First came the jellyfish, a blind sac with only two layers of cells and a single opening serving as both mouth and anus. They have radial symmetry, meaning they have no front or hind end which is adaptive to only two types of habitats...floating on the surface of the sea or attached in an immobile position on the ocean floor. Great masses of jellyfish cover wide stretches of the ocean and corals and sea anemones line tide pools in warm waters. The jellyfish phyla are dominant in these habitats and while their basic body plan adapts them admirably to certain ecological niches, it severely limits their options for colonizing others.

This body plan was also successful in flatworms but nowhere reached the dominance of the body plan of a tube within a tube design.

There are three plans, bilateral symmetry, a diversity of tissues and organs, spaces or body cavities (coelom) filled with fluid and a fourth modification is characterized by radial symmetry found in sea stars etc.

What do crabs, sea urchins, worms, corals all have in common? they have NO backbone and are all invertebrates. Over 95% of all known animals are invertebrates. Their forms range from the microscopic amoeba to giant squids 59 ft. long, inhabit all regions of the world and all have a marine representative.

SPONGES

Phylum Porifera..(pore-bearing). 5000 species of 790 genera...worldwide distribution, fresh and marine. (120 species in Keys!) Size microscopic to 2m

Sponges..animals with many pores, without definite form of symmetry, and do not contain organs or true tissues. They are all sessile. The humble bath sponge, used

for centuries particularly in the Mediterranean region were originally thought of as plants but are now considered animals (only in 1765)(even its own subkingdom ..Parazoa) They probably originated from flagellated protozoans or primitive metazoans. They are the simplest of multicellular marine animals. They are so poorly organized that they are not even included in the direct line of animal evolution.

Their colors though are beautiful, Orange, yellow, green, purple, violet or scarlet or rich brown and have survived millions of years without even moving. Size range from micros. to 2m, form thin incrustation on hard surfaces to which they attach, others are massive tubular, branching, urn- or cup- or fan- shaped (amorphous).. Colors range from drab to brightly colored.

The sponges single purpose in life is to pass water through itself, the water yielding food and oxygen, minerals, and carrying away waste products. The sponges are unchanged since they evolved and were ancient 300 million years ago and appear to be natures orphans. Rachel Carson wrote that "nature seems to have gone back and made a fresh start with other materials" with no evidence of any relationship between them and coelenterates, leaving sponges in an evolutionary blind alley.

Structure.. most are similar in structure, simple body wall containing cells and connective tissues and cell types like amoebocytes which wander through the inner tissue secreting and enlarging the skeletal spicules and laying down spongin threads. Most have a skeleton of spongin, elastic, but resistant fibers of protein which may be the only means of support but can be found together with spicules. The internal skeleton can be made of hard rod or star shaped calcareous or siliceous spicules, the shapes genetically determined for each sponge, and/or the meshwork of protein fibers called spongin (bath sponge) which is similar to silk and the horns of many animals.

Sponges are filter feeders straining off bacteria and fine detritus from the water. O2 and dissolved organic matter are also absorbed and waste materials are carried away. Water is pumped inward through small pore cells into the inner chambers lined by flagellate cells called collar cells. They ingest the food particles and water is expelled through the sponges surface through the osculum.

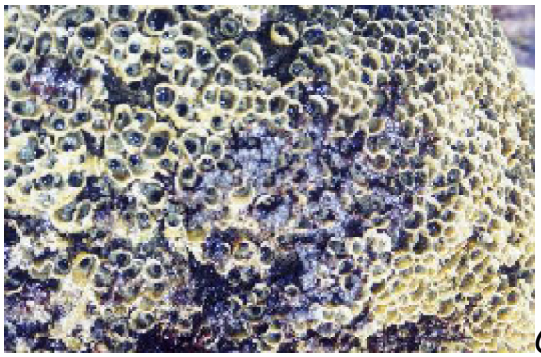
Reproduction can occur asexually by budding off new materials, by fragmentation in which parts grow into new sponges, and in sexual reproduction, eggs from

amoebocytes and sperm from collar cells (or amoebocytes) usually at different times within the individual.

Sperm is shed into the water but eggs stay in the sponge and is fertilized there. This is called spawning. A larva (amphiblastula) may be produced, swim for a few days and settle changing into colonies. Some Antarctic sponges (mature) have not grown in over 10 years.

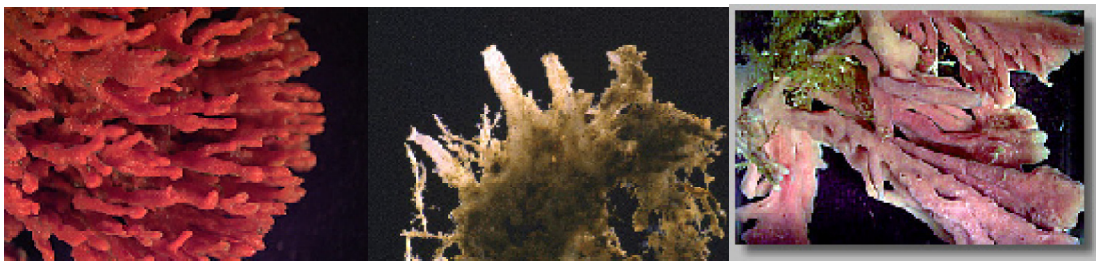
Classification...because they adapt to their environment their shape is of no help to identify them so they are classified by their skeletons, "lime sponges, glass sponges, and fibrous or horny skeletons

Ecology. Sponges live on a firm substratum, vertical range from intertidal to 27,000 ft (one fresh) and the intertidal are seldom exposed to air for any time. They are eaten by sea slugs (nudibranches) , chitins, sea stars, turtles, some tropical fish. Usually more than half the exposed species are toxic to fish. The toxins not only prevent predation but keep the surface of the sponge clean of animal larva and plant spores from settling on them and may prevent neighboring invertebrates from overgrowing and smothering them. Sponges contain antibiotic substances, pigments, chemicals like steroids, toxins, anti-inflammatory, and anti-arthritis compounds. Boring sponges (*Cliona*) weakens oyster shells, and damage and weaken tropical stony corals excavating chambers by chemical and mechanical methods. On reefs some weaken, while some bind skeletons together, some protect undersurface of coral from attacks by boring organisms and are most successful under low light. Other..sulfur sponge is able to dissolve seashells into calcium and accounts for conversion of shells to sand on the ocean floor.


Crumb of Bread Sponge *(Hymeniacedon perlevis)* Kidds Beach S.A.

Loggerhead sponge, shaped like barrels, host up to 12,000 pistol shrimps and other

creatures. The sea orange wraps itself around a hermit crab shell, obtaining transport in exchange for the camouflage and Neptunes Cup grows out of the sea floor in the shape of a goblet.



Microciona (Red Beard Sponge) ...Leucosolinia (Organ Pipe Sponge).. Haliclona (Finger Sponge)

Demospongiae ----------
Calcispongiae.....Demospongiae

Chapter Questions

Questions with Sponge Reading

1. How is water moved through the sponge?

2. What adaptations (special structures or behavior) allow the sponge to lead a sessile existence?

3. From the outside in, what structures comprise the body wall of the sponge?

4. Name the 4 types of spicules and how they would be useful to biologists?

Readings
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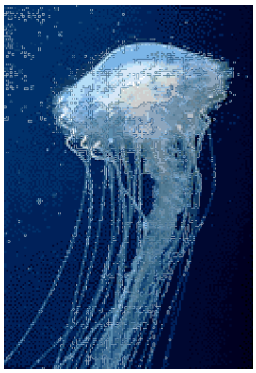
Cnidaria and Ctenophores

Lecture notes

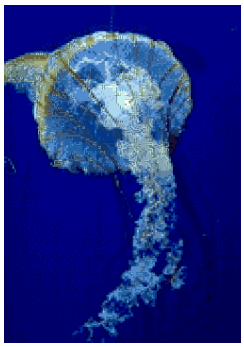
Phylum Cnidaria .
9400 species...3 classes..



East Coast sea nettle (*Chrysaora quinquecirrha*)----->

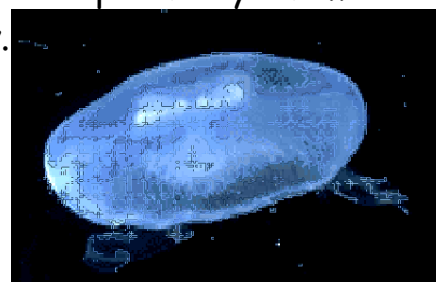
- mainly marine
- free swimming and bottom dwelling
- microscopic to several meters
- radially symmetrical with
- cells arranged into tissues
- posses tentacles and stinging cells
- 2 layer body wall with non-living jelly-like wall containing elastic
- fibers to allow movements in between with digestive cavity
- no anus,
- 2 distinct life history phases, free swimming Medusa and sedimentary polyp.

West Coast sea nettle (*Chrysaora fuscescens*)-------->



Class Hydrozoa..most primitive Many consist of feathery or bushy colonies of tiny polyps. They are attached to pilings, seaweed, shells and other surfaces. The Siphonophores are hydrozoans in drifting colonies. Some polyps form floats, others form long tentacles to capture prey. Portuguese man-of-war is an example (*Physalia*).

Class Scyphozoa...jelly fish has digestive system is a set of radiating canals linking the central portion to a peripheral ring. Some mesogleas can expel heavy chemical ions and replace them with lighter ones to adjust buoyancy.



<--------Moon jelly (*Aurelia aurita*)----------->

Stomolophus meleagris Cannonball jelly fish (7/4/08 Cocoa Beach)

Class Anthozoa Corals and sea anemones only exist as polyps. The sea anemones always bear more than eight tentacles . Some burrow in mud but most dwell on a hard substratum, cemented there by secretions from a well differentiated disk.

Subclass Zoantharia are hard corals whose polyps are encased in a rigid calcium carbonate skeleton. Most hard corals live in colonies which are composed of vast

numbers of small polyps (about 5mm) but can be larger in solitary forms. Most are subtropical or tropical in distribution. In colonial forms, the polyps are interconnected laterally forming a living sheet overlying the skeleton. Corals exhibit a great diversity in growth forms, ranging from delicately branching species to those whose massive skeletal deposits form the building blocks of the reef. On type, *Meandrrina,* the polyps are arranged continuously in rows, resulting in production of a skeleton with longitudinal fissures, a feature which accounts for its name, brain coral.

There is an order related to the hard corals without a skeleton that are anemones which can cover rock faces. The black or thorny corals form a slender, plant-like colonies arranged around a horny axial skeleton and possess numerous thorns.

Octocorallian corals have eight featherlike tentacles and an internal skeleton like structure. These include the horny corals, sea whips and fans and red coral. Most of these have ancestral rod composed of organic material around which is draped the coenenchyme and polyps, the former containing spicules which impart a vivid coloration and form the spines of the red coral which is used in jewelry.

Cubozoans

In the class Cubozoa, which includes box jellies and sea wasps, the medusa is box-shaped and has complex eyes. (video of box jelly swimming)

To trap prey, cnidarians normally employ stinging cells which are discharged (under nervous control?) sometimes exposing barbs and frequently contain a toxin that can enter the body of the prey. Some are extremely potent (sea wasps) (Killer

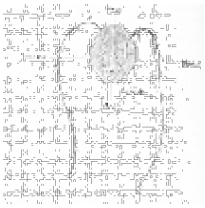
Jellyfish Story) and have killed humans...respiratory paralysis. Sea slugs are known to pirate Nematocysts (stinging cells) and use them for their own protection.

Comb Jellies Phylum: Ctenophora

About 90 species ...worldwide and marine distribution. 4cm to 1m in size..radial symmetry with eight rows of plates..fused cilia (comb) for locomotion.

CTENOPHORA

- 1. These are a group of bi-radial jellyfish called comb jellies because of the presence of ciliated comb plates used in locomotion. Their
- continuous beating refract light creating a prism-like multicolor effect. Each row is a series of small paddles and each paddle is
- composed of thousands of tiny cilia. Collectively, the cilia produce a color spectrum in much the same way as a diffraction grating
- or the surface of a compact disk. Entirely marine and mostly pelagic or planktonic...some can creep.
- 2. Only body cavity is the gastrovascular cavity in the form of canals.
- 3. The body wall is composed of an epidermis, layer of collenchyme, and a gastrodermis. Collenchyme contains amoebocytes,
- connective tissue and true muscle cells, so its more advanced than the mesoglea in cnidarians.
- 4. Most ctenophores possess on their tentacles adhesive cells called colloblasts. The tentacles are used for catching prey and
- balancing organs (nematocysts in cnidarians and only one ctenophore).
- 5. Skeletal structures and excretory and respiratory organs are lacking.
- 6. Varied shapes
- 7. Well developed statocyst at pole and a nerve net system in epidermis.
- 8. They have determinate cleavage (cnidarians is indeterminate) and a cydippid larval form with bilateral symmetry.



Both cnidaians and ctenophores arose from the same basic stock with the presence of nematocysts in one group of ctenophores (*Euchlora rubra*) show that ctenophores may have arisen from a Medusa ancestor. The order Cydippida is considered the most primitive and least modified to the ctenophora plan.

The basic structures that have guided the evolutionary development of the ctenophores are the arrangement of comb plates and general bi-radial symmetry. Modifications are found throughout the group.

As a group these ctenophores are very beautiful animals. Their glass-like transparency, delicate and the iridescence by day and luminescence at night have given them a distance beauty rarely found in the animal kingdom.

Fewer than 100 species have been described. They are classified on the basis of their

- tentacles
- bodyform
- oral lobes,
- gastrovascular divisions
- body compressions.

2 classes and 5 orders make up the phylum.

As mentioned, the body wall contains an outer epidermis, and inner endodermal epithelium with collenchyme (mesoglea) between containing true muscle cells. The mouth is at one end and sense organ at the other. On the surface of the body are 8 rows of comb plates arranged meridionally and equally spaced. They start at the sense organ and extend about 4/5ths of the distance to the oval pole. Each plate

consists of a transverse row of fused cilia borne on modified ectodermal cells, the plates are arranged in succession and united as a ciliary's tract to form a complete comb-plate row. The cilia beat from one end to the other causing the animal to move with the mouth in the front though the direction of the wave is reversible. Some highly modified ctenophores like *Cestum*, the swimming action of the plates is supplemented by the sinuous movement of the ribbon like body.

Tentacles...most have 2, highly extensive usually longer than the body. Its made of mesoglea and longitudinal muscle strands and covered with epidermis. Lateral branches are covered with special adhesive cells (colloblasts or lasso cells). Each colloblast is composed of a sticky crescent-shaped body fastened by 2 filaments (derived from a flagellum). Food is captured by sticky colloblasts of the tentacles which are drawn over the mouth where ingestion of food occurs. The tentacles are also used as balancing organs while floating. The colloblast is considered a cell while the nematocyst of the cnidarians is an organelle of a cell.

Ctenophores are hermaphrodites and male and female gonads occur close to each other. Sometimes fertilization can occur internally but usually the sex cells are released into the sea water where fertilization occurs.

The comb jellies are the most remarkable form of swimming animals occupying an interesting evolutionary position between the radial symmetry of the hydroids and the true bilateral body form of the flatworms. Comb jellies are virtually all true plankton (drifters)-dwellers whose almost invisible transparent bodies drift in the oceans trailing tentacles like fishing lines. These are armed with lasso cells that explode and ensnare their microscopic prey.

The body has 3 layers, like the sea anemone and jellyfish, a mesoglea wedged between the thin outer ectodermal and endodermal layers. Most noticeable is the eight rows of plates of cilia (comb rows or comb plates called ctenes)) whose activities serve to propel the animal while it is searching for zooplankton prey (in a mouth forward position).

The most common genus (found in colder waters) Pleurobrachia, is about 4cm in diameter and has two pits which the tentacles are retracted into. The tentacles are used like drift nets, catching passing food. Once caught the prey is held by a sticky substance, secreted by the colloblasts, until transferred to the stomach following

wiping the tentacles across the mouth. Its reported that when feeding on pipe fish smaller than itself, it plays them out the same way an angler tires out a hooked fish. Both jellyfish and ctenophores possess special equilibrium devices (STATOCYSTS) which are responsive to gravity and help them determine up from down. They are also luminescent.

- Phylum Ctenophora
- Class Tentaculata with tentacles
- Order Cydippida Pleurobrachia
- Order Lobata Mnemiopsis
- Order Cestida Velamen
- Order Platyctenea Ctenoplana
- Class Nuda without tentacles
- Order Beroida Beroe

Order **Cydippida** Pleurobrachia retain characteristics of larva until adult stage is attained...most typical and least modified ...globular or egg shaped, 2 tentacles, simple gastrovascular canals with no peripheral canal system...comb rows equal in length *P. Hormiphora* and *Euchlora*

Order **Lobata** *Mnemiopsis* body compressed and is helmet shaped..a large contractile lobe is founding each side causing the comb plates to be longer than the others. Tentacle sheaths of larva disappear during metamorphosis and adult has reduced tentacles.

Order **Cestida** *Velamen* ribbon shaped and get up to 1 m long East Coast, USA

Order **Platyctenea** *Ctenoplana* most highly modified of all have a creeping or sedimentary existence. Body is flattened...comb rows may or may not be present...testes open to the surface by a duct and pore. Posses tentacle sheaths and retractile tentacles as well as a statocyst.

Class Nuda without tentacles

Order **Beroida** *Beroe* Bell or cone shaped with no trace of tentacles or tentacle sheaths at any stage in their development. Wide mouthed from New England.

Jelly Reading with Questions

Killer Down Under

1. How many people have died in the last century from the BOX jelly stings? (A) 30 (B) 60 (C) 65 (D)4

2. How quickly can cube (box) jelly venom kill a human? (A) several hours (B) 4 minutes or less (C) an hour (D) it doesn't kill

3. How does the venom affect the heart? (A) speeds it up (B) only effects nerve cells not heart (C) slows it down and stops it

4. What is the difference between a planulae and a polyp? (A) planula are mobile and polyps are attached (B) planula are attached and polyps are mobile (C) polyps are adults and planula are larva

5. Where were Chironex medusa found in the wild? (A) close to the mainland (B) in estuaries and streams (C) up to 40 miles offshore (D) a and b are correct (E) b and c are correct.

6. How long does it take for a box jelly to undergo metamorphosis? (A) 12 days (B) 24 days (C) 6 years (D) 4 hours

7. What causes the stinging cells to be triggered? (A) stimulated by temperature changes (B) stimulated by touch only (C) stimulated by chemicals (D) b and c are correct

8. Where in Australia do the box jellies occur in the summer? (A) Gold Coast (B) Great Barrier Reef (C) Sunshine Coast (D) Rockhampton (E) All of these

9. What is a pedalium? (A) tentacles (B) mouth part (C) feeding appendage (D) a live shrimp fed to cube jellies

10. What feeds off box jellies? (A) Asian fishermen (B) sea turtles (C) Great White Sharks (D) Sea Snakes

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Marine Worms

Lecture notes

Worms...the deep sea worm snail *Neopelina galatheae* is the oldest living creature with fossils proving they existed exactly in the same form 500 million years ago....Nematode sea worms are the most numerous of all sea or land animals with an estimated population of 40 septillion. The convoluta worm feeds only once in its life feeding off a special algae and is sustained by starches made through photosynthesis by the algae it swallowed.

Phylum Platyhelminthes...flatworms...3 layers, organs, no anus. They are the only worm like creature without an anus, use cilia on the bottom to glide along the surface and have muscle contraction in the body walls. These animals are worm like...tapeworms, planaria flukes and marine flatworms. There is a free-living flat worm that lives in the book lungs of a horseshoe crab, a tapeworm in the digestive system of the whiting fish some live on the beards or threads of mussels and one lives on the sandy beaches in France...bright green!

Christmas tree worm spawning video

Phylum Nemertea...ribbon worms...900 species..most marine. Like flatworm but has one way digestive system and circulatory system .

Usually very highly colored and found burrowing in sand and mud on the shore or in crevices of rocks. Some can swim and most capture their prey. The most distinctive feature is a proboscis, a long fleshy tube to entangle prey . Though common, some are nocturnal and not usually seen, and others are found under rocks at low tide. They are very elastic. They are of little economical or ecological importance.

Phylum Nematoda or round worms usually found in sediments , especially rich organic matter. Many can even live nicely in tissues of other organisms. The actual number is debatable 10-15,000 but maybe more like 1/2 million.

Phylum Annelida segmented worms 13,000 species mainly the Polychaetes

make up the marine annelids. (6,000 species) They have short extensions or parapodia with stiff sharp bristles or setae often with gills on them for respiration. The life cycle includes a trochophore larval feeding stage...like other groups of invertebrates. They include sandworms, bloodworms, fanworms or featherduster worms, palolo worms and a variety of tube dwelling worms. These can make tubes from mucus, protein, mudgrains, bits of seaweed, shell fragments etc.. Feeding methods relate to the locomotion and many are either suspension feeders/deposit feeders or just plain carnivores.

 Sand Worms Worm cases

LOPHOPHORATES

Three phyla of marine animals, Ectoprocta, formally Bryozoa, Brachiopdoa and Phoronida, are characterized by a lophophore, a circular or U-shaped ridge around the mouth bearing either one or two rows of ciliated, hollow tentacles. Because of this unusual feature, they are thought to be related to one another. The coelomic cavity of them lie within the lophophore and its tentacles and the anus is always elsewhere. The lophophore functions in these animals as a food collection organ and as a surface for gas exchange. They are attached to the substratum or move slowly, using the cilia of the lophophore to capture the plankton on which they feed.

Phylum Phoronida resemble common tube worms seen on dock pilings. Look like polychaete worms. They secrete a chitinous tube within which it lives out its life and they also extend tentacles to feed and quickly withdraw them when disturbed but that's where the resemblance to the tube worm ends. There is no straight tube within a tube but a U-shaped gut within a sac. Only 10 species are known ranging in length from a few mm to 30 cm. Some lie buried in sand and others attach to rocks signally or in groups.

Phylum Ectoprocta (Bryozoa) look like tiny short versions of the phoronoids ..small .5mm and colonial and called moss animals. The new name, ectoprocta refers to the location of the anus (proct) which is external to the lophophore. 4000 species include marine and freshwater forms..only non-marine lophophores. Most live in shallow water but some live at 18,000 feet.

Individuals secrete a tiny chitinous or limestone chamber, ZOECIUM, attached to other members of the colony and to rocks. Individuals communicate chemically through pores between chambers.

Bryozoans- Moss animals or sea mats..sedimentary or bottom dwelling. They live attached to the substratum, either on rocks or empty shells, or on tree roots, weeds or where ever they can hold on to. They are almost all marine, found from the shore downwards in all parts of the world, they are colonial, meaning individuals are termed zooids live together in a common mass. Their taxonomy depends on the sizes shape, and organization of the colonies. The arrangement of the zooids on the colonies is also highly variable. Some are important as pests as they can foul up piers, pilings, buoys and ship hulls.

PHYLUM BRACHIOPODA or lampshells

Bottom dwelling clamlike organism that are permanently attached to the substrate and possess a complex lophophore, which consists of two spiral ciliated tentacles resembling arms.

The LOPHOPHORE is a circular or U-shaped ridge around the mouth bearing either one or two rows of ciliated, hollow tentacles.

The lamp shells resemble clams because they have two shells but these shells are hinged so that one shell covers the top and the other its bottom

side (dorsal and ventral whereas the clam its the left and right side. Many species attach to rocks or sand by stalks that protrude from within the shell, a contractile muscle called the PEDUNCLE, while others become cemented by shell secretions to the substratum. These shells feed on particles suspended in the water, the cilia creating water currents sweeping food particles onto the lophophore which lies within the shell (as opposed to others that are outside). There are only 300 species of brachiopods existing today but more than 30,000 species are known as fossils with the genus Lingula having fossil records back to 500 million years.

Reading with Questions

. Tube Worms

1. Where was the giant tube worm found?

2. How do pogonophorans feed?

3. Where do bacteria get their energy?

4. How are shrimp around the vents different than the normal shrimp near the surface?

5. How hot is the water running out the vents? _____What about water about a foot away from the vent?

6. What is the most prevalent chemical dissolved in vent water?

7. How many bacteria are in an ounce of tissue?

8. How do tube worms reproduce?

9. What happens when the vents stop flowing?

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Phylum Mollusca

Lecture notes

110,000 species in 7 classes. **MOLLUSK EVOLUTION** The mollusks contain animals that are mostly crawlers or completely sedentary. Theirs slowness results from having no legs and using a single foot. The only group of mollusks that became active swimmers were the class of Cephalopods which include octopi, squids, and the chambered nautilus. Their evolution illustrates ways which modifications of the body plan can open up new ecological options and close others as well as give rise to new kinds of animals.

The chambered nautilus has come down to us almost unchanged from the Cambium period, 500million years ago. It has its connection to other mollusks by having a large roomy shell but it is distinctive that it consists of a series of chambers with partitions between them, each being vacated one after another as the animal grows but, the chambers are filled with gas (and can be controlled with part of the animals tissue), and this allows the animal to achieve the specific gravity of the surroundings...

These shelled cephalopods dominated the class du n until about 65 million years ago when they were replace cephalopods...squid, cuttlefish, octopi. During thei alopods were the most abundant, successful and varied cr After this period they shared their dominion with fish a n their relative numbers dwindled.

The three major classes of Mollusks became reco e Cambium period, and since then, have been followi evolution.

Gastropod's have deviated little from the original became active predators, that can hunt, grasp and devour their prey. Their muscular and

nervous equipment for motility was deeply committed from the start to carry them about by crawling over a surface that nothing like limbs, fins, paddles, tentacles or jet propulsion ever evolved.

The pelecypods became standardize early on as stationary filter feeders that sift small particles of food through their gills and their nervous and muscle system are committed to opening and closing their shells and digging themselves deeper into the sand.

DARWIN TO DNA, MOLECULES TO HUMANITY....STEBBINS, G.L., W.H. FREEMAN AND CO. SAN FRANCISCO, 1982 PP 248-(1) p 253

The diversity of mollusks encompasses food, dyes, pests, pathogens, parasites, and pearls. Their variety is reflected in the range of body forms and ways of life. Mollusks include the coat-of-mail shells or chitin, marine and freshwater snails, shell-less sea slugs, tusk shells, clams, mussels, octopuses, squids, cuttlefishes, and nautiluses. While some mollusks can swim, most are attached or live creeping along the bottom.

- The body is typically divided into a head (lost in
- bivalves) muscular foot, and visceral hump containing the body organs.
- There are no paired or jointed appendages or legs.
- Two notable features are the mantle and a toothed tongue called the radula (usually made of chitin).
- Mollusks have a gut with mouth and anus, a blood system, nervous system,reproductive system, and an excretory system with kidneys.
- Gills are present in aquatic species which are used to extract oxygen from the water and in some, to strain out organisms and
- detritus from the water or bottom mud. The particles are then conveyed to the mouth by tracts of cilia

.
Lack of an internal skeleton have kept mollusks small with exceptions of the Giant Squid which can reach 60'. Some giant clams can reach 4.5'in shell length. Many measure less than 1cm and one is only 1mm when full grown.
The mantle...a fold of skin, the mantle, forms ;

- forms a pocket housing the gills
- a chemical sensory organ
- mucus secreting gland
- anus
- excretory pore
- sometimes the reproductive opening

The cells of the mantle are thickened at the edge of the mantle skirt, secreting the shell and slime, acids and ink for defense, mucus for protection and for cohesion of food particles is secreted by the gills and mucus glands. Products of the mantle can be defensive, acting to deter predators. The purple gland in the mantle of the sea hare expels a purple secretion when the animal is disturbed.

The Shell
Mollusks usually hatch from the egg complete with a tiny shell that is often retained at the apex of the adult shell. The shell provides protection from damage and predators and on the shore or land, it prevents the loss of body fluids. New growth occurs at the shell lip in Gastropods and along the ventral margin in bivalves. Shell is secreted by glandular cells. Its mostly composed of calcium carbonate and can show great variation in shape size thickness, sculpture, surface texture and shine. Marine examples are often thick and heavy while land specimens are light. The nautilus is the exception because it has a light brittle spiral shell with thin walls which contain gas which can affect buoyancy. Many shells are sculpted into ribs, lines, beading, knobs, or spines which are much admired by shell collectors and used in the identification of species. Some have reduced or no shell at all, while some have internal shells.

Class Polyplacophora (Amphenura) Chitons or coat of mail shells have an oval shell consisting of eight plates bounded by a girdle. The plates of the shell are well articulated, chitins can roll up in a ball when disturbed, and these articulations are also an advantage when moving over uneven rocks. They are usually restricted to rocky shores.

Class Gastropoda (stomach-foot) Gastropods are the largest class of mollusks (90,000 species) and have only one shell. These include most of the sea shells...limpets, cowries, cone shells, top shells, winkles, abalone, oyster drills,

nudibranchs/sea slugs . The mouth of the gastropod is usually protected by a lid or operculum which is secreted by glands on the upper side of the back of the foot and is the last part of the animal to be withdrawn and acts as a trap door. Its present in larva as well though the limpets loose it later.

Class Bivalvia ..bivalves (formerly Pelecypoda). Clams, mussels, scallops, oysters, (bivalves)...from tiny fingernail clams to a 500 lb. *tridacna* of the Pacific Reefs. Pelecypoda means hatchet foot which reflects the laterally compressed body which is modified for filter-feeding, the loss of the head and developed complex sheet of gill derived tissues for screening microorganisms out of water currents. The shell is closed by adductor muscles passing from one valve to another. Where these attach to the shell, scars are formed on the inside of the shell. These scars are important for identifying and classifying bivalves. Most have two scars (muscles) but oysters and scallops have one. Bivalves have a large pair of gills which fill the mantle cavity which fill a dual role of respiration and feeding. Not all bivalves burrow, mussels secrete byssal threads to attach to rocks and oysters cement their left shell to a hard surface. Scallops live unattached and can swim for short distances by ejecting water from the mantle cavity and clapping the valves. Some even bore into coral, rock and wood...shipworm. Sexes are separate although some oysters may alter sex in their life. Fertilization is external either in the sea or mantle cavity.

Class Cephalopoda. Octopuses, squids, cuttlefish, nautiluses... Cephalopods.. differ from the rest of the mollusks in their appearance and their specialization's for life as active carnivores. They include many pelagic forms, swimmers in the open seas and bottom dwelling octopus and cuttlefish. With the exception of nautiluses, these groups, most of which possessed shells are extinct.

- Most have internal skeletons.
- They are good swimmers catching moving fish, and have evolved various buoyancy mechanisms, very
- responsive to stimuli
- All but nautilus have an ink sac opening off the rectum which contains ink for confusing the enemy.
- The body color can change in response to stimuli and change by pigment cells called chromatophores.
- Have a very well developed eye that focuses by moving its position rather than

change shape of the lens.  (left is what nautilus sees)

 Giant Squid...Mote Marine Lab

Class Scaphopoda.....Tusk shells These are a small group of mollusks that are entirely marine and live buried in sand or mud of fairly deep waters. Only their empty shells are to be found on the beach. The tube of the shell is lined by a mantle, no gills, mantle absorbs oxygen which has a few ridges with cells bearing tiny hair-like cilia that help create a current . Sexes are separate and fertilization occurs externally at sea.

Class Monoplacophora Thes  roup of what was thought extinct, primitive Paleozoic (270-600 million y sks, includes a living mollusk, radically different from other mollusks in that ally segmented. This segmentation violates one of the basic criteria in which mollusks are characterized. This living specimens, *Neopilina galatheae*, was dredged up from off Costa Rica from 3.5 km below the surface in 1952. At present, 11 species are known. Most live at great depths and all are marine. Monoplacophorans are small and have a single, caplike shell, giving them a limpet-like appearance. A number of their organs (nephridia, heart, etc.) are repeated serially, making them resemble species such as annelids and arthropods. Whether this resemblance indicates a close relationship between monoplacophorans and these phyla is an open question. It's fossil ancestors are already known and further study should add light to mollusk evolution. It could be a missing link or just an adaptation to survival in deep water.

- It has a single dome-shaped shell
- no evidence of twisting of the internal organs (like the Gastropods)
- 5 pr. of retractor muscles
- 5 pr. of gills
- six pr of nephridia
- a well developed radula.

Mollusca Life History Most sexes are separate but there are some species that are hermaphrodites. Many mollusks have a trochophore larva like the polychaetes (close affinities between them). The larva develop into a veliger larva (with a tiny shell) Cephalopods lack a larva and the young develop in large yolk filled eggs. Female octopus protect their eggs until they hatch...then she dies.

Ecology They colonized land, fresh and salt water, and most all marine habitats, rocky, coral sandy, muddy, boulder, shingle, transition zones, mangrove swamps, estuaries. The veliger larva of most marine mollusks float passively in the upper waters of the sea forming plankton. Mollusks can be eaten by other mollusks, starfish, bottom living fish like rays, , whales eat squid, sea birds probe mud, humans use them for food, fishing bait, currency, dyes, pearls. Some are pests....shipworms, slugs, snails oyster drills.

Check out this site... TheCephalopodPage

Chapter Questions

Mussel Reading with Questions

The Mussel

1. What is a byssus

2. Where, geographically (range) are mussels found?

3. What organisms feed on mussels?

4 What can cause poisoning in mussels?

5. What is the nutrition value of mussels?

6. What is the main drawback of raising mussels in coastal waters?

Readings

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Marine Arthropods..(crustaceans, Insects, arachnids) .

Lecture Notes -

Arthropods make up the largest phylum with over a million species. They are jointed legged found in every habitat. Crustaceans are the dominant class of marine Arthropods such as lobster, shrimp and barnacles. The bodies are divided into a cephalothorax and abdomen. The success of crustaceans in the sea is bought about by the gills, walking legs, swimming legs, and feeding appendages. Water striders and tide pool insects are the representatives of insecta and the arachnids are the sea spider (Class Pycnogonida) and horseshoe crabs (*Limulus*).

The success of Arthropods is due to their segmentation, and jointed external covering, which allows for great mobility and strength. Growth is accompanied by shedding or molting of the exoskeleton because otherwise growth would be impossible and therefore imposes limitations in terms of size and growth.

Now in addition to crabs and lobsters, crustaceans make up a major component of plankton. Crustaceans bear 5 pairs of appendages, two pairs of antennae, mouth parts. One major line of crustaceans have evolved with large walking animals. Extensions of the body wall at the base of the legs are used for gills. The blood contains hemocyanin, a copper based respiratory pigment like hemoglobin. Sexes are separate and they develop through a series of larval stages increasing size and numbers of segments

with their associated limbs. The simplest larva stage is the nauplius larva, with three pairs of appendages.. 1st and 2nd pair of antennae and mandibles and often swims and suspension feeds (different functions of appendages in larva than adult.)..larger larva develop from the nauplius according to the type of crustaceans. Some do bypass the nauplius by developing within the egg.

Small crustaceans are everywhere, plankton, bottom, among sediments, in and on other animals and plants. These are the bugs, flies and mosquitoes of the sea.

Copepods The class Copepoda includes minute sea inhabitants which provide a major source of food for fish, mollusks, crustaceans and other animals as major components of the plankton. Some are parasitic, infesting invertebrates or vertebrates (fish lice) and the free living are small and capable of rapid population turnover. The large first antennae may be used for quick escape but more commonly are act as parachutes against sinking. They can filter feed on phytoplankton but can't survive on this alone all year round because of low phytoplankton levels, and sometimes seize large prey items like other members of the zooplankton. During the rich spring bloom, filtering becomes worthwhile and the Copepods can pass through several generations quickly before returning the normal rate , often using the fat reserves built up in the bloom for the rest of the year (# of generations per year. related to time period of phytoplankton bloom.)

Barnacles (video of barnacles)

Barnacles are sedimentary marine crustaceans permanently attached to the substratum. For protection barnacles have carried calcification of the cuticle to an extreme and have a shell resembling that of a mollusk. The shell is derived from the cuticle of the barnacle head and enclosed the rest of the body. Class Cirripedia, feed with six pairs of thoracic legs (cirri) which can protrude though the shell plates to filter food suspended in the seawater.. They can filter fine material, including phytoplankton and even bacteria. They are hermaphrodites and carry out cross fertilization

between neighbors. There are 6 nauplius stages increasing size which swim and filter phytoplankton over a period of a month or so before giving rise to a non-feeding larva--the cypris larva. This is the sediment stage of the life cycle , able to drift and swim in the plankton before choosing a settlement site in response to environmental factor which the larva detects by an array of sense organs. Barnacles colonize a variety of substrata including living animals such as crabs, whales turtles, sea snakes and with this moving host, the barnacle does not need to use energy in beating its cirri.

Beach fleas and other Amphipods the most familiar being the beach fleas or sand hoppers found on sandy shores. The Amphipods are mostly marine and scavengers of detritus able to creep using the thoracic periopods (legs) and swim with the abdominal ones. They can feed by scraping sand grains or filtering phytoplankton. The head and tail curve downwards and they commonly are found among debris washed ashore. Whale lice belong to this group of 5,000 species.

Isopods are found in many of the same environments as Amphipods and can be recognized by their flattened top to bottom form. Fish lice belong to this group.

The eucarids...Krill and decapods

The planktonic krill and decapods (shrimps lobsters, crabs) are classified in the suborder Eucarida. they have a well developed carapace, fertilized eggs are carried beneath the abdomen.

Krill have primitive features . All are marine, eggs hatch as nauplii, most have luminescent organs, usually on the eyes, at the base of the 7th thoracic limbs and underside of the abdomen. They are probably used for communication in swarming and reproduction. Krill are pelagic and filter

feed when phytoplankton conditions are suitable but otherwise prey on larger planktonic organisms. Phytoplankton rich seawater enters the tips of the legs and is strained as it passes between the leg bases. Whale krill reach 2 in. long and dominate the zooplankton of the Antarctic Ocean and is the chief food of many baleen whales.

In decopod, the first 3 pairs of thoracic appendages are adapted as auxiliary mouthparts leaving 5 pairs of legs (decopods) (and the 1st pair of these can be claws). Decopods have been divided into swimmers (natantains) and crawlers (reptantains) essentially, shrimps and prawns ///and lobsters, crayfish and crabs. Now they are divided morphologically into two sub-orders..shrimplike with many branched gills and planktonic eggs hatching as nauplius larva (Dendrobranchiata) and Pleocyemata which have gills lacking secondary branches and eggs carried on pleopods before hatching as zoeae.

Prawns and shrimp have no exact zoological definition and are interchangeable. The most important shrimp families are the penaeids and sergestids. The first contain commercial shrimp. Most pelagic shrimps are active predators feeding on crustaceans of the zooplankton, such as krill and Copepods. Bottom dwelling species are scavengers but range from carnivores to herbivores. Sexes are distinct although some females pass through an earlier male stage.

Lobsters and freshwater crayfish ...belong to a group known historically as macrurans (large tails) but now make up 3 infra-orders , Astacidea (lobsters, freshwater crays, scampi) the Palinura (spiny and Spanish lobsters and Thalassinidae (mud lobsters and mud shrimps).

Lobsters and freshwater crays walk on the substratum on the four pairs of back legs. The 1st pair is modified as a pincer. They are carnivorous scavengers living in holes on rocky bottoms. The American lobster can reach 2'long (48 lbs) and live for 100 years. Fresh water crays are omnivorous about 4 inch long.

Squat lobsters and hermit crabs are intermediate between lobsters and crabs. The abdomen is variable in structure and hermit crabs probably evolved from ancestors that lived in crevices and eventually specialized into using discarded gastropod shells. Hermit crabs live as carnivorous scavengers on sea bottoms ranging from bottom to sea shore and have a terrestrial existence in the tropics.

True crabs.

These crabs all possess a reduced abdomen held permanently flexed beneath the cephalothorax The reduction of the abdomen has brought the center of gravity of the body directly over the walking legs making locomotion very efficient and rapid. The sideways gait assists this. The crab shape is therefore the ultimate shape in efficient crustacean walking. They live beyond the top of the shore to the deep sea to the hydrothermal vents 1.6 miles deep and on the other hand the ghost and fiddler crabs live at the top of sandy and muddy shores up rivers and into fresh water. Most crabs burrow to escape their predators descending back-first into the sediment . Some can swim using the last pair of legs as paddles, run rapidly (ghost crabs) , pea crabs live in the mantle cavity of bivalves and the female coral gall crabs become imprisoned by surrounding coral growth with a small opening left for plankton and the small male for reproduction. Most crabs are scavengers although terrestrial ones can eat plan material.

Economically the crustaceans are important as a food source for man and as plankton for the organisms of the sea. Crayfish--over a million pounds a year are caught and another 2 million reared artificially.

Horseshoe crabs and Sea Spiders..Chelicerated Arthropods...no jaws, no antennae

CLASS MEROSTOMATA

Chelicerated Arthropods with abdominal gills and a long spikelike telson. The class contains Limulus the horseshoe crab and fossil sea scorpions called eurypterids.

This genus appeared 175 million years ago and not undergone any evolutionary change since. It also occupies a unique place in Arthropods. Like spiders it possesses chelicerae, claws instead of chewing jaws, lacks antennae and has 6 pair of appendages.

Horseshoe crabs or king crabs have a protective hinged carapace which covers the crab with a long caudal spine protruding behind. There are compound eyes on the carapace and median simple eyes. Beneath the carapace lie the chelicerae and 5 pairs of walking legs (comparable in evolution to the chelicerae, pedipalps and 4pr of walking legs in spiders. They live on sandy or muddy bottoms in the sea, plowing their way through the upper surface of the sediment. During burrowing, the spine levers the body down while the 5th pair of walking legs acts as shovels. The carapace form helps move through sand and the spine is used to right itself if it gets turned over. They are scavenging carnivores and have jawlike extensions on the bases of their walking legs used to trap and macerate prey such as clams and worms before it passes to the mouth. The last pair of legs use the bases to crack open bivalves. The appendages at the rear are modified and each is expanded into 150 gill lamella resembling leaves of a book and appendage movement maintains a current over the gills. Small horse shoe crabs can swim upside down using their gills as paddles. Reproduction occurs at night when they congregate in intertidal zones, the female laying 2-300 eggs which get fertilized by the clasping male. Eggs hatch into larva which mature in 3 years.

Class Pycnogonida

500 species about an inch long...except giant sea spider. The abdomen is reduced to a knob. The intestines extend into the legs as well as gonads located in legs. Between palps and 1st pair of legs are an extra set of legs with which the male carries the eggs. It has 4 eyes near the anterior end

of the animal and has no respiratory or excretory system.

Sea Spiders are exclusively marine found in the intertidal zone and deep sea. They are able to grip the substratum with their claws and sway from one individual to another They feed by either sucking up the preys body tissues or cutting of pieces with their chelicerae and eating them. Colors are usually white/transparent but red in the deep sea species. Economic importance seems to be nothing.

Chapter Questions

Amphipod Reading and Questions

Sand-Burrowing Amphipods

1. Where are amphipods found?

2 What is "sand lickng"?

3 How do the pleopods function?

4. Why are amphipod inhabitants of sandy beaches?

5. How is the food supply replinished?

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Starfish

Lecture Notes

Phylum Echinodermata...spiny skin because most members of the group have defensive spines on the outside of their body. They are found only in

the sea and as adults are either attached or can crawl around on the bottom. The 5 different groups include 1 sea lilies (attached)2. starfish, 3. brittle stars, 4. sea urchins, 5. sea cucumbers. For animals relatively high on the evolutionary scale, it is remarkable that a head has never been developed.. Their weird symmetry is called pentamerism, a form of radial symmetry with the body arranged around the mouth. This 5 point symmetry is displayed by most of the modern day echinoderms possibly making a stronger skeletal framework, but their larva have bilateral symmetry.(so did their primitive ancestors).

The skeleton is made up of many crystals of calcite (calcium carbonate). It supports the body wall or test and the reinforced structure may be soft, sea cucumbers or hard, sea urchins but is not a shell because it is covered by living tissue (sand dollar).

The drifting larva also has a skeleton which serve to support their delicate swimming processes and another feature is their water vascular system.

Water Vascular System

The branched tentacles, tube feet are arranged in a double row along the upper side of each arm bounding a food groove and along the branched arms (pinnules). The tube feet can be extended by hydraulic pressure from within the animal and much of the water vascular system is internal. They are supplied with fluid from a radial water canal which runs down the center of each arm just below the food groove and which sends a branch

into each pinnule. The radial water canal of each arm connects with that of its fellows via a circular canal running along the gullet of the animal. Pressure is generated inside the system by the contractions of some of the tube feet and also by special muscles in the canal itself which generate local pressure increases to distend the neighboring tube feet.

The activities of the tube feet relate to gas exchange and food gathering. The feet are equipped with mucus glands and when a small fragment of drifting food collides with one, the fragment sticks to the foot which flicks it to the food groove and passes to the central mouth. The double rows ensure efficient feeding..

Some echinoderms also use the tube feet for locomotion (stars, urchins and cucumbers).

Suckered tube feet occur in all sea urchins and many sea cucumbers. Sea stars inhabiting hard substrates also have these feet and use them for locomotion and catching prey.

The fluid in the water vascular system is essentially sea water mixed with cellular and organic material. Apart from driving the tube feet, the fluid is responsible for transporting food and wastes, transporting CO2 and O2 and contains many cells, amoeboid coelomocytes which play a role in excretion, wound healing, and repair and regeneration. No excretory organs have been identified in echinoderms.

The nervous system is strange, as there is no head or aggregation of nerve organs, the only real sense organs are the rudimentary eyes of starfish, chemosensory receptors of sea urchins, and balance organs (stratocysts) in sea cucumbers, and that's it! There are simple receptor cells widely spread over the surface of the animal responsive to touch and chemicals in solution. There is a nerve cord running down each arm close to the radial canal and control the tube feet and body wall muscles. Echinoderms are sensitive to gravity and respond when turned upside down.

Prey The common European star feeds on mussels and oysters while the

crown of thorn is well known for its selection of certain reef building coral. Some burrowing stars ingest their prey whole while invert their stomachs into the prey and digest it within the bivalve. Explain how it pulls open prey.

Sea urchins browse on algae on the surface and irregular urchins, sand dollars are more specialized and live partially buried in the sand using modified spines and tube feet to collect particles of detritus for food.

Sea cucumbers use their specialized tube feet around the mouth and sweep the surface of the mud for detritus.

Sexes are separate with a few being hermaphrodite, passing through a male stage before becoming functional females.

Phylum Chordata

These are higher animals possessing a single hollow, dorsal nerve cord and body cavity (vertebrates,) However a number of lowly chordates display the phylums characteristics and are aquatic. The two sub-phlya are Urochordata (sea squirts) and Cephalochordata(lancelets).

Sea squirts are bottom dwellers growing attached to rocks or other organisms, and are encased in a thick protective tunic composed of a kind of cellulose or tunic (thus Lamarck's name, tunicate). The tubular heart pulses first in 1 direction and then in an opposite direction, changing every few minutes. . At the top is the inhalant siphon and on the side the exhalant siphon. There is no head. Water is pumped through the body, the gill collecting respiratory material and acts like a filter for food particles. Wastes are liberated from the anus near the external siphon. They may be solitary or colonial. Larva have an important role in selecting a settlement point and distributes the species. It is also the larva which displays the chordate notocord characteristic. Economically they are important as fouling organisms as well as evolutionary and zoological interest. They are the 1st animals in which alternation of generations was

discovered. Another interesting, but unproven theory, (no fossils), is that vertebrates arose from tunicate tadpoles swimming up rivers where they could exploit the rich organic detritus coming down the river after the freshwater and land plants had become established. In such an environment the development of a backbone to aid in swimming would confer a great advantage. A mutation which produced NEOTENY (attaining sexual maturity in the larval stage) would eliminate the sessile adult.

Three classes occur...Ascidiacea are sessile, living singly or in complex colonial aggregations attached to submerged rocks, wharfs, ships etc. Some resemble black, velvety bananas, others are rounded and pink called sea peaches, others look like scarlet thumbs while others have the appearance of gnarled potatoes. One species, Botryllus, grows as a glistening black or purple mat studded with rosettes of yellow and pink openings like the petals of a flower.

The second class is Thaliacea comprising pelagic, usually glass clear animals, more or less barrel shaped. The third class the Larvacea are minute animals with long tails.

Lancelets have an elongated fish like blade form and the notocord extended into the head. There is no well developed brain, eyes or other sense organs. The adults live in shallow water inshore and are commonly burrowers.

Lecture Questions

Echinoderm Reading and Questions

7. Echinoderm reading

1 How do sea cucumbers get their name?

2 Which organs may have poison glands on the sea urchin?

3. What is Aristotles Lantern and how is it used?

4 Why do sea urchins hold up bits of seaweed ?

5. What part of the sea urchin is eaten?

6 What is he difference between the habitat of sand dollars and heart urchins?

7. How many classes of Echinoderms are known and how many are around today?

8. In what type of habitats are echinoderms found?

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MARINE VERTEBRATES Fish

Lecture Notes -

These share 3 fundamental characteristics, backbone, which enclose the

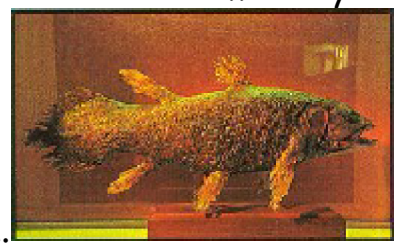
nerve cord, and bilaterally symmetry and a presence of an endoskeleton.

THE FISH

There are over 22,000 species of fish which make up more than half of all vertebrate species and most (58%) are marine.

Jawless fish, Agnatha, first appeared about 550 million years ago. They occupied the worlds rivers and seas and lived unchanged for about 100 million years until 2 revolutionary developments occurred, namely biting jaws which developed from the front gill arches and fins became paired. These enabled fish to be able to eat a variety of foods and swim better. The jawless fish population declined after this. Chondrichthyes evolved before bony fish. These cartilaginous fish had a ventral mouth and a skeleton made of cartilage. The bony fish had a true bone skeleton, specialized mouth, and a swim bladder.

In 1938, off the coast of South Africa, near the Chalumna River, a fisherman brought up a strange fish. It weighed a hundred pounds and was 4 feet long. The body was covered with circular scales and when it was identified by Prof. JBL Smith, it was found to be a living member of an ancient class of fish that was thought to have gone extinct 70 million years ago. It was the Coelacanth, the oldest true fish.



The body forms of the fish are adaptations to the environment or special behavior patterns. The streamlined or fusiform shaped fish allow rapid movement through the water ad are found in predatory fish. Fish compressed from side to side can easily move through plants and in narrow spaces. Flattened dorso-ventrally, depressed, are usually bottom dwellers. Attenuated...elongated eels live in sand, mud or under rocks.

Fins aid in locomotion. The dorsal and anal fin are used as rudders to prevent rolling, paired pectoral and pelvic fins are used in turning,

balancing, and braking. The caudal or tail fin is used mostly for pushing against the water.

In sharks, and other cartilaginous fish, the fins play a role to stop the fish from sinking because of the lack of an air bladder. (dissection)

Three types of fins are found on the tail, heterocercal, the top is taller than the bottom of the fin, homocercal, both top and bottom of tail are the same...symmetrical, and diphycercal, the tail ends in a point.

The mouth of a fish and its teeth are adapted for the type of feeding the fish carries out. There are 5 types of feeding methods:

1. predators, specialized teeth for grasping and chewing,

2. nibblers, take small bites,

3. food strainers, use of gill rakers to strain the food floating in the currents,

4. food suckers, bottom feeders who draw food through the mouth like a vacuum cleaner and

5. parasites, attach to another fish and live off its juices. (Candiru or Vampire Fish)

Fish have a one way digestive system. Food enters the mouth and passed to the pharynx where it is funneled to the esophagus. In parrot fish, sucker fish, etc. the pharynx is equipped with teeth that grind, grasp and tear the food before it enters the esophagus. Often the esophagus can expand to accommodate almost anything a fish can get in its mouth. The walls of the digestive tube are coated with mucus to help food move easily through the gut. The food then enters the stomach where chemical digestion begins. An elongated stomach is characteristic of meat eaters. A sac-shaped stomach is that of fish that consume both plant and animal materials, some stomachs function as grinding organs and some can expand

to accommodate large pieces of food. Puffers, globefish, porcupine fish can pump water into their stomachs to inflate themselves. Parrot fish, pipefish, and seahorses don't have stomachs and digestion and absorption take place in the intestine.

Food passes from the stomach to the intestine where chemical digestion continues and the end products are absorbed. The intestine is folded, coiled and spiraled to increase surface area. Meat eaters have shorter intestines than plant eaters. Nutrients absorbed enter the blood and are transported to various parts of the fish by the circulatory system.

Circulation

Blood is pumped from the heart to gills where gas exchange takes place. Blood carries oxygen via red blood cells to all parts of the body, transports CO2, digested food, wastes etc. and returns to the two chambered heart. The heart has one atria and one ventricle. White blood cells are also present and produce antibodies, aid in blood clotting and destroy germs and microorganisms that enter the blood.

Respiration

Most fish obtain oxygen directly from seawater using a gill. Water is taken in through the mouth and pumped over the gills. The gill is located behind the mouth in the gill chamber and consists of several gill arches. Each gill arch supports many gill rakers and gill filaments. Dissolved O2 diffuses across the thin membranes of the gill and enters the blood. The gill rakers are positioned to stop particles suspended in water from damaging the filaments. Water pumped past the gill leaves the gill chamber through the gill slit. The gill slits in bony fish are covered with an operculum. Jawless and cartilaginous fish have open gill slits. Sharks and rays have a modified gill slit, the spiracle which works with the mouth to bring water into the gill chambers. It is found on the dorsal surface of rays.

Gas Exchange

Thin membranes of gill filaments make gas exchange easy. Diffusion occurs and O2 is picked up by the blood. Diffusion is increased by two features,

1.-surface of gill filaments increased by branching increasing area of membranes which come in contact with water and

2.-water flowing over gills move in opposite direction of blood movement in the gills. This counter current system enables blood to pick up a maximum amount of O2 from the surrounding water. Adaptations include: carp gulping air which can diffuse into the gill filaments, lungfish with air sacs, enlargements of the gill chamber etc.

Buoyancy

Fish with well-developed swim bladders can remain poised at a desired level with minimum effort by increasing or decreasing the amount of gas in the bladder. The bladder can be filled by gulping air or release of gas from the blood through gas glands. When the fish goes deeper, the increased pressure squeezes gas in the bladder, decreasing gas volume of the bladder. The fish becomes heavier/denser. The fish restores gas volume by secreting gas from the blood. As the fish moves up, there is less pressure on the bladder, and the gas expands. The fish becomes lighter and more buoyant so in order to prevent the bladder from overfilling, the fish must reabsorb the gas. Fish with an air-tube connecting the bladder to the digestive tract can let gas escape through the mouth, (open swim bladder) but a closed swim bladder system, reabsorption is necessary. If a fish was pulled up from deep water quickly, its swim bladder could explode! Vertical movement is limited by the swim bladder...predators like sharks, don't have to worry about that because have no swim bladder.

Temperature

Temperature has a profound effect on metabolism of fish because most cold-blooded (ectothermic). Generally a rise in temperature speeds up the metabolism and a drop slows down metabolism and reduces swimming

speed etc. Most fish generate heat but lose it rapidly to the surroundings because they lack insulation. Predatory fish have evolved a countercurrent system for conserving heat and muscles can stay warm with energy producing reactions.

Excretion.....Disposal of wastes produced during metabolism

Bony fish have salt secreting cells in the gills called chloride cells that remove excess salt.

Sight

Like the human eye in some ways but the density difference between the water and cornea of the eye is not so great so the lens of the fish is hard, dense and round to maximize refraction. Light is focused by moving away or toward the retina. The eyes bulge out with the lens protruding through the pupil. Iris is not adjustable. Color vision is developed in fish mainly in shallow clear water helping locate food, breeding partners and avoiding predators. The eyes are on either side of the head increasing the visual field which helps for animals with no neck!

Hearing and Balance

Ears, lateral line organs and swim bladders aid in detecting underwater sounds, maintaining balance and enabling some fish to produce sounds. The inner ear, labyrinth, functions for hearing and balance. Fluid filled canals and receptor cells, neuromast sense cells are sensitive to movement in fish. It bends and pushes ciliary hairs of the neuromast sense cells and the impulse is sent to the auditory nerve to the brain. Ear stones, otoliths, move in the tubes in conjunction with fish movements, shifting positions,and this helps with the balance and hearing. The neuromast cells are also found in the lateral line organ, detecting low frequency vibrations. The swim bladder vibrates as sounds in water pass through the fish. These vibrations are passed to the inner ear. The toad fish generates sounds in this way.

Smell...chemoreception

Detection of dissolved substances in water is how the fish can smell its food. Taste buds in the mouth taste the food, barbels, whisker-like appendages, contain taste buds which enable the fish to probe muddy waters.

Electroperception

The ability of fish to detect weak electrical currents in water/or generate them. This is used for communication and examining the environment. Some can discharge several hundred volts, stunning its prey and easily capturing them to eat. Cartilaginous fish have sense organs in the head called the ampullae of Lorenzini that can detect weak electrical fields. It is used to help locate their prey, assist in navigation and maybe even detect currents.

Outer Covering

The entire skin of the fish is alive, even the scales are covered by a thin layer of living cells, the epidermis the only protective material covering the epidermis is slime secreted by mucus glands scattered over the body. The mucus reduces friction and protects against bacteria etc. Fish odor or body odor is found in the slimy covering. This allows fish to recognize their species.

Scales form a protective outer covering. There are 4 types of fish scales. Sharks and their cartilaginous relatives possess tooth-like Placoid scales. The placoid scale is composed of a core of pulp and covering of dentine. Shark teeth, spines of sting rays, tooth-like projections of saw fish are modified placoid scales.

3 types of non-placoid scales are common to bony fish. Platelike Ganoid scales made of bone are found on primitive fish like the gar pike and sturgeon. Cycloid and Ctenoid scales form an overlapping covering like roof shingles on a house. The scales are thin and flexible allowing great mobility. Cycloid scales are mainly found on soft-ray fish and ctenoid scales are mostly found on spiny ray fish.

Coloration

This serves in functions like camouflage, looking for a mate, advertising the fact its poisonous or showing willingness to remove parasites. Two types of cells control color namely Chromatophores and Iridocytes. Chromatophores are starshaped pigment cells located under transparent scales or in the thin cell layer overlying the scales. The nervous system and endocrine system seem to control the redistribution of pigments within the chromatophore. Iridocytes are pigment cells containing reflecting granules (work like mirrors). The silvery stripes and iridescence of some fish result from light being reflected by iridocytes. There is warning coloration, cryptic coloration (blend), disruptive coloration, and countershading.

Defense and Migration

Fish that don't swim well have evolved protective devices. Some include the sharp spines of the surgeon fish and trigger fish or the protective armor of the trunk fish, seahorse and pipefish. Seahorses have a prehensile tail which they use to hold on to underwater branches and remain motionless. Globefish and puffers expand their bodies by pumping water into their stomachs. Coloration...countershading is where the dorsal side is darker than the ventral side making the fish difficult to see. The clownfish has contrasting colors to deceive the predator (disruptive contrast).

Secretions...unicorn fish expels a cloud of ink, and stonefish and scorpion fish possess poison glands.

Schooling fish apparently have a decided advantage over non-schooling fish.

Migration

There are two reasons for seasonal migration. 1. food and 2.breeding. Migratory fish travel thousands of miles to return to the same place each year. If they breed in fresh water they are <u>anadromous</u> and if they breed

in salt water they are catadromous. A third type remain in the ocean and move on definite pathways between feeding and breeding areas. The ocean wanderings of migratory fish correspond to ocean currents.

Reproduction and life history

Many ways have evolved for marine fish to reproduce.The sexes are usually separate and both sexes have paired gonads located in the body cavity. In most marine fish, the gonads produce gametes only during certain periods of time. This is crucial because both sexes need to be ready at the same time...especially in those that migrate to breed. The timing is controlled by sex hormones which are released into the blood to stimulate the production of gametes. They are released by being triggered by environmental factors like temperature, light, and food availability.

Some fish are hermaphrodites and though able to fertilize themselves they usually breed with other individuals to ensure fertilization between species. This is also common in deep water fish as an adaptation to the dark depths and the chance of NOT finding another fish of the opposite sex.

Sex reversal also occurs in some fish. Individuals begin life as males but eventually change into female or vice versa.

Fertilization in fish is usually external but in some cases, internal fertilization happens. Different types of development of the egg occurs. Usually external fertilization involves the production of many, I mean many, eggs. They end up floating in the plankton and most don't survive. This is OVIPAROUS, or the egg develops outside the body and feeds off the yolk.

Some fish, mainly cartilaginous ones, have eggs that develop inside the body and the young are born alive. This is OVOVIVIPAROUS. Some rock fish have this method of reproduction.

In some sharks and rays, the embryos actually feed off nutrients of the

mother. This is like mammals and is known as VIVIPAROUS.

Other Fish

Lampreys..cooler waters a larval stage during which they little resemble the adult in structure or lifestyle. Adult eel-like and has one or two dorsal fins a caudal fin and no paired fins. The mouth, jawless, is a disk adapted for sucking, with a complex arrangement of teeth, their arrangement specific to the species and therefore used in classification (Agnatha-2 classes, 1 order each, Lampreys have 3 families with a total of 72 species (12/17 genera/2/4 families). They have 7 external gill openings, water goes through the mouth to the chambers. They are covered in mucus, its toxic. They spawn upstream though some are freshwater and some salt. They may migrate for a few months to longer. They migrate back after spawning and here the difference between non and parasitic lampreys comes into play. The non, don't feed and just breed and die. The parasitic feed on blood and fluids of fish for up to 2 years. They detect their prey by sight and attach on the lower surface. They move in with the sucker closed to reduce water resistance but open it before the attack. The teeth come into play now. The only way fish free themselves is by coming to the surface and turning so the lampreys head is in the air.. 4lbs of fish blood can feed a lamprey from metamorphosis to spawning. Moved into great lakes with the opening of the Welland canal.decimating the trout fisheries.

Hag fish or slime eels are eel like have a fleshy fin, and flattened caudal region. They have 4 to 6 tentacles around the mouth. No jaws or stomach but are parasites of larger fish and defend themselves by releasing slime. They can tie their bodies into knots and posses several sets of hearts. They may reach 28" and live in cold oceanic waters preying on dying fish using the tongue to burrow a hole in the side of the fish, loops its body around the fish and thrusts its head into the body of the fish. They feed quickly and may soon be completely inside the fish eating the flesh, worms etc. There are about 20 species and their skin is used in the making of leather goods.

Sturgeons are the largest and longest lived freshwater fish and provide food! Caviar! The sturgeon and paddle fish are the only survivors of an ancient group of fish. They migrate to and from the sea.Sizes are impressive...1800lbs,

Bowfin and Garfish...bowfin can survive out of water using their air bladder as a lung. Garfish, long bodied predators long jaws and many teeth and armor like scales.

Tarpons, Eels, Notacanths...weird that these unalike fish are grouped together but all have larva unlike the adult.

Bristlemouths...luminous organs, bristle like teeth eyes on stalks

Lizard fish and Lantern fish...sit on pelvic fin and lower tail lobe

Spiny finned fish latest flowering of bony fish evolution.

Billfish

The term billfish encompasses two closely related families, the Istiophoridae: sailfish, spearfish, and marlins and the Xiphiidae, the swordfish. The term billfish is usually reserved for the istiophorids and call the only member of the family Xiphiidae, a swordfish. Both families of fish have members whose upper jaw is extremely elongated and narrow. These are all fast-swimming, aggressive fish in the open ocean with a tall dorsal fin and lunate (quarter moon shaped) tail. They have a unique circulatory system that keeps the warmth generated by their active swimming retained in the muscles. This makes their muscles slightly warmer than the surrounding water and gives them an advantage over the slower-moving, completely cold-blooded fishes. Most are tropical and subtropical in distribution but are often caught in temperate waters, especially in summer months.

They are among the oceans fastest swimmers. Sailfish have been clocked

at a minimum of 70 MPH for short bursts and probably cruise at 20 to 30 MPH. The long bill is thought to be a cutwater which aids these fish in very fast swimming. It is also used to decimate schools of fish by thrashing it back and forth horizontally through the water and is thought to be used in "battles" with other bill fish. The lunate tail and narrow, keeled peduncle (area just before the tail) are also adaptations for fast swimming. Even the dorsal and pelvic fins of the sailfish fit into neat grooves on the body to prevent any unwanted drag. Although marlin may be somewhat slower than sailfish, and swordfish slower yet, "slower" in this case is still close to 40-50 MPH.

There are eleven species of billfishes and swordfish, five of which are found in the Gulf of Mexico. The term includes two fish families, which inhabit tropical and sub-tropical oceans worldwide. The family Istiophoridae contains ten members: the marlins (genus Makaira), the spear fishes and white marlins (genus Tetrapturus), and the sailfishes (genus Istiophorus). The swordfish, Xiphias gladius, is the only member of the family Xiphiidae.

Swordfish can easily be distinguished from the istiophorids. The sword or bill of the swordfish is a broad flat blade making up about one-third of the body length. In addition, the fish lacks pelvic fins, and in the adult, teeth and scales.

Although all billfish are large, (at least 5 feet), the two edible species outdo themselves. Both marlins and swordfish are taken at lengths of 6 to 15 feet and 300 lbs to 1000 lbs.

They undergo long distance migrations and range far afield for their food. One fish, tagged off the Virgin Islands, was caught four months later 4,500 miles away off the coast of West Africa.

Young fish less than an inch in length, may take refuge from predators under floating Sargassum or sea grass. Here they prey on smaller, less active fish who are also seeking safe harbor.

Adult billfish eat a wide variety of fish: flying fish, scad, mullet, round

herring, ballyhoo, mackerel, tuna, and jacks. They also eat squids and other billfish. Only humans and mackerel sharks, killer whales and bigger billfish eat billfish.

The bill can be used in aggressive encounters with other billfish as evidence of billfish caught with pieces of bill embedded in their bodies. Whales have also been attacked by billfish.

Catch them on hook and line, baited with live mullet, mackerel or squid though the numbers are dropping rapidly.

Large marlin are always females. Whether males change sex as they attain greater size and become females or just stop growing as fast as the females is presently being studied. Small specimens of males and females are found its just only females are the record catches!

Sharks.

Over 350 million yrs ago, something new happened in the primeval seas...an entirely new class of vertebrates evolved which were quite different from anything before. They had tiny tooth-like body armor called placoid scales, exposed strap-like gill openings, unique paired copulatory organs and flexible skeletons of cartilage. These groups settled on a lifestyle that has persisted to the present. They are slow growing, late maturing, produce small numbers of well formed young of whom a mother invests a lot of resources during development but virtually nothing after the young are born.

Most people think sharks are large, fast swimming elegant savage predators. This is true of some species but only a minority. The group should be of general interest because of the intriguing aspects of biology found in sharks, the exceptional sense of smell, electropreception, and giving birth to live young.

One notable feature is its teeth. In the highly predaceous sharks, these are large and razor sharp used for cutting and shredding their prey into bite size pieces. Some however are bottom feeding species and eat mollusks and crustaceans and their teeth are flattened for crushing the shells of their prey. The fish eaters have long thin teeth to help catch and hold their prey.. A shark may have up to 3000 teeth arranged in 6 to 20 rows according to the species. In most sharks only the first row or two are actively used for feeding. The remaining rows are used for holding prey. They are in various stages of formation with the newest at the back. As a tooth in the functioning row breaks or is worn down, it falls out and a replacement tooth moves forward in a sort of conveyor belt system. They can be replaced every few days. This keeps the functional row sharp. The shark may use over 20,000 teeth in a lifetime and the strength of the jaws can exert a biting strength of 3000kg per sq. cm. (44000 lb/sq. in. on the teeth. (humans are 150lbs).

Sharks find their prey through a number of sensory systems. Many have poor eyesight but some are real good. Some have barbels around their mouth to taste the sea bed for prey. All sharks have a very keen sense of smell. Their nostrils are used only for smelling, not for breathing. The part of the sharks brain that deals with smelling is twice as large as the rest of the brain. Sharks can detect 1 part of blood per million parts of seawater (1 drop in 25 gal). They have a lateral line system which is a series of canals on the entire body and head which are filled with a jelly-like substance, which are sensory receptors which pick up pressure waves caused by movements of other animals or even by the shark itself. On the snout are ampullae of Lorenzini, a series of electro-receptive pits which are the most sensitive electro-perceptive devices found in any animal. They are capable of picking up one-millionth of a volt, which is less than the electric charge produced by nerves in an animals body. The sharks can find their prey from the prey's natural electric output.

Sharks..The six and seven gilled sharks have extra sets of gills preferring cold water some being filmed at 1800m.

The orectoloboids are five closely related families of sharks ranging from 3'long to the whale shark 50' long. All but the whale shark are bottom dwellers and spend most of their time just sitting on the ocean floor and actually skeletons modified so they can actually use their fins for walking on the ocean floor. They have sensory barbels around their mouth. The whale shark has gill arches specially modified to act like a sieve to filter out the planktonic organisms upon which it feeds. Because it of its bulk it needs constant fuel and feeds as it swims.

The thresher, mackerel are among the largest group of sharks in the world. They have a long upper lobe on their caudal fin and use it by swimming through a school of small fish, thrashing the tail and killing or stunning the fish which are then eaten.

The family of mackerel sharks include the great white, mako and basking sharks. Their caudal fins have lobes being nearly equal in length. Most if not all are homothermic which means they can keep their body temperature above that of their surroundings. The Mako is probably the fastest, measured at 60mph and is known to have outswum and eaten swordfish. The great white/white death/white pointer etc. mainly feeds on marine mammals, the only shark to do so, and has broad serrated teeth designed for biting large chunk of flesh from whales and seals. It is viviparous, meaning the embryos develop in the uterus. The basking shark is another filter feeder and the second largest in size...45'.

The requiem sharks, are the typical sharks, the bull shark, which can enter freshwater and has been found more than a thousand miles from the mouth of large rivers. The largest is the Tiger shark..18' and the most dangerous. It swallows almost anything, including roles of tar paper, shoes, gas cans, license plates, cans of paint and human parts The young tiger has dark bands on a silvery background fading with age. (see article)

Hammerhead sharks, also in this group, have large lateral expansions of their head on which the eyes are set. They grow to 15' and the expanse of the head gives a better field of vision, and a more expansive electro-

detecting system.

Shark Reproduction

Success is due to the reproductive adaptations. Males have claspers which release sperm into the cloaca. Young are born as miniatures of the adults and few in number. Their large size reduces predators and allow for more nutrients for the young. Eggs are produced with large yolks.

3 types of egg laying:

1. ovipariy- egg laying...bull head, some nurse sharks

2. ovovivipary- thin shelled eggs hatching in the uterus before full development. No placental development, use yolk. Tiger, dogfish.

3. Vivipary-no shells-some yolk but mostly nourished by mother through the placenta. Bull, lemon, hammerhead, great white.

Comparison of cartilaginous and bony fish

CHONDRICHTHYES OSTEICHTHYES

skeleton cartilage bone

skull no sutures sutures

teeth not fused to jaws fused

nostrils single..each side double

swim bladder absent present

intestine spiral valve none

fert. internal mostly external

scales placoid ganoid, cycloid ctenoid

jaws not protrusible protrusible

gills no operculum operculum

Skates Rays and Chimaeras.

Examples are the eagle rays, electric rays, guitar fish, mantas, sawfish, skates, stingrays, and the chimaeras. There are about 300 species of rays and skates which have flattened bodies and love usually on the bottom (Demersal). There are some rays that look like sharks and some sharks with flattened bodies so the way to tell is that the skates and rays all have heir gill slits on the ventral surface. The enlarged pectoral fins are fused to the head and the eyes are on top of the head. The stingrays have a whiplike tail usually equipped with spines for defense. Poison glands produce venom. Skates are like rays but lack a whiplike tail and stinging spines. Some can have electric organs .

Rat Fish ..about 25 species of this deep water chimaera, is separated because the gill slits are covered by a flap of skin. The long tail gives it the name "ratfish".

	Shark-Myth or Menace Story
Shark Dissection Pictures	Vicious Fishes

Chapter Questions

Fish Reading and Questions

1. **How often do some reef fish reverse gender?**

2. **What are sex-changing fish known as?**

3. **What is the most common type of sex reversal?**

4 Name 3 species of reef fish that change sex several times?

5. **Do fish change appearance when they go back to the one sex each time?**

6. **How is this sex reversing a benefit?**

Readings

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Here is some extra information collected from web sites on

The Rays and Manta Ray

Thanks to all for this educational resource!

Manta Ray: The Good Devil

For centuries it was thought that the manta ray, or "devilfish," was an evil ocean beast capable of destroying fishing boats and devouring people. In fact, the manta ray is one of the gentlest creatures in the sea whose only wish, it seems, is to float peacefully in the water sucking in mouthfuls of water in search of its favorite food -- plankton.

It's understandable why people have been frightened by this tremendous fish. The manta ray is the largest member of the and can measure up to 19 feet long and weigh as much as 2,300 pounds. Some manta rays have been caught that measure an unbelievable 23 feet across. This giant sea creature takes its name from the Spanish word "manta" meaning blanket. With its enormous black fins extended, the manta ray really does look like a huge floating blanket.

Manta rays live mainly in tropical waters and feed on zooplankton, small fish and crustaceans. Like other rays, the Manta has a skeleton made out of cartilage instead of bone, and its nostrils, mouth and gill slits are ventral, or located on its underside. Manta rays can be found browsing through sandflats in search of food or, sometimes, leaping clear out of the water. Manta rays give birth to live young. When their babies are born they are wrapped up in their little wing flaps like pigs in a blanket. Baby manta rays are called "pups."

Manta rays usually swim in pairs, and although they seem frightening, manta rays are so gentle that many will even let humans pet them. Some experienced divers have actually taken rides on the backs of these beautiful, harmless fish.

Despite their size, manta rays are usually graceful and tend to be tolerant with divers.

Manta rays were once called devil fish by sailors who saw large "horns" extending forward from their heads. These horns turned out to be ingenuous scoopers which, when unfurled, guide plankton into the manta's mouth. Manta wingspans can reach up to 20 feet, and they glide though the water like birds. Both gentle and graceful, they have become a favorite attraction for divers. Their range is circumtropical, with sightings in the Atlantic from as far north as New England and south to Brazil. Mantas prefer plankton-rich waters and are regular visitors to a few select locations. In the winter, mantas visit San Benedicto Island, south of Cabo San Lucas, Mexico. Here, they glide past a pinnacle called The Boiler hoping to take advantage of the resident cleaner fish. Mantas also hang

out in Yap, Micronesia at Manta Ridge, another cleaning station. From March through July, mantas visit the island of Tobago, feeding in the rich waters fed by the Orinoco estuary in South America. On Hawaii's Kona Coast, mantas are drawn each evening to the lights of a large hotel. Night divers watch as the mantas feed on the plankton that is attracted by the lights. [from: http://www.letsfindout.com/subjects/undersea/rfimanta.html]

devil ray

also called **MANTA RAY**, any of several genera of marine **rays** comprising the family Mobulidae (class Selachii). Flattened, and wider than they are long, devil **rays** have fleshy, enlarged pectoral fins that look like wings; extensions of these fins, looking like devils' horns, project as the cephalic fins from the front of the head. Devil **rays** have long, whiplike tails provided, in some species, with one or more stinging spines.

Devil **rays**, related to sharks and skates, are found in warm waters along continents and islands. They swim at or near the surface, propelling themselves by flapping their pectoral fins and, at times, leaping or somersaulting out of the water. They feed on plankton and small fishes that they sweep into their mouths with their cephalic fins.

Atlantic manta (*Manta birostris*)

The smallest of the devil **rays**, species *Mobula diabolis* of Australia, grows to no more than 60 cm (2 feet) across, but the , or giant devil **ray** (***Manta*** *birostris; see*), largest of the family, may grow to more than 7 m (23 feet) wide. The Atlantic **manta** is a well-known species, brown or black in colour and very powerful, but inoffensive. It does not, old tales to the contrary, envelop pearl divers and devour them

[from "devil ray" *Encyclopædia Britannica Online* http://www.eb.com:180/bol/topic?eu=30645&sctn=1 [Accessed April 19, 1999].]

Habitat: Manta rays typically are found in the open ocean, but will occasionally pass over reefs.

Average adult size: Adults can grow to be more than 20 feet across, from wing-tip to wing-tip.

Natural history: Manta rays swim near the surface of the open sea. Their bad reputation as a "devilfish" is undeserved. Hardly man-eaters, they cruise slowly through the water, feeding on microscopic plankton. The manta uses the fins on either side of its head to herd plankton into its mouth. It will sometimes swim somersaults in the water to take advantage of a particularly rich area of plankton. Mantas are known to jump out of the water or "breach." They will have one or two babies per "litter."

Range: Found in Brazil north to Bermuda.

Pictures of Mantas

http://www.big.or.jp/~ishigaki/manta/E_manta.html
http://emoo.imaginary.com:4243/objbrowse/~manta

Rays

any of the cartilaginous fishes of the order Batoidei, related to and placed with them in the class Chondrichthyes (or Selachii). The order includes 300 to 350 species.

Rays are distinguished from sharks by a flattened, disklike body, with the five gill openings and the mouth generally located on the underside. **Rays** are further distinguished from sharks by their greatly enlarged, winglike pectoral fins, which extend forward along the sides of the head above the gill openings. Many **rays** swim and breathe differently from sharks, propelling themselves with their pectoral fins and taking in water for respiration through large openings (spiracles) on the upper surface of the head, rather than through the mouth. The **ray**'s tail is generally long

and slender and in many species bears one or more sharp, saw-edged, venomous spines that can be used to inflict painful wounds.

Rays are predominantly marine and are found in all oceans. Many are slow-moving bottom dwellers. feed on plankton and small animals; others take various fishes and invertebrates, sometimes damaging commercially valuable shellfish beds. Other than skates, most or possibly all **rays** bear living young. Fertilization is internal, the male introducing sperm into the female by means of special copulatory organs (claspers) that are the modified edges of the pelvic fins.

Rays can be classified into the following groups: electric **rays**, sawfishes, skates, and various families of **rays** that have slender, whiplike tails equipped with spines and that are all-inclusively called , or whip-tailed **rays**.

The (suborder Torpedinoidei) are distinguished by large paired electric organs between the pectoral fins and the head, with which they can give powerful shocks either for defensive purposes or to kill prey. The electric **rays** have a smooth and naked skin; the head and trunk with the pectoral fins form a circular disk, and the tail is short and stout. About 20 species are known to inhabit warm seas, with some reaching a weight of 200 pounds (90 kg).

All other types of **rays**, which lack electric organs, generally have a rough skin, often bearing strong spines. The (family Pristidae) have a snout that is modified into a long blade possessing a series of strong teeth on each side. About six species are known from warm seas, frequenting sandy shores and estuaries.

In the (suborder Rajoidei), the large pectoral fins extend to the snout and backward, stopping abruptly at the base of a slender tail. In contrast to other **rays**, skates produce eggs; these are large and oblong in shape with dark, leathery shells having a tendril at each corner by which they become

fastened to seaweed or other objects. Skates lack the long, slender barbed spine that distinguishes stingrays. The most widespread skates belong to the genus *Raja* of the family Rajidae.

The remaining **rays** comprise the suborder Myliobatoidei and consist of whip-tailed **rays** (family Dasyatidae), butterfly **rays** (Gymnuridae), stingrays (Urolophidae), eagle **rays** (Myliobatidae), devil **rays** (or **mantas**; Mobulidae), and cow-nosed **rays** (Rhinopteridae). Common to the **rays** of all these families is a long, slender, whiplike tail that usually has a barbed spine connected with a poison gland; this spine is capable of inflicting serious wounds and is a dangerous weapon when the tail is lashed. Almost all of these **rays** are inhabitants of warm seas, except for a few species of stingray that live in the rivers of South America. (*See* .)

The are a group of fishes that are closely related to the **rays** and are either classified as a separate order (Rhinobatiformes) or as a suborder (Rhinobatoidei) of the **ray** order (Batoidei).

The majority of batoid fishes (members of the order Batoidei; *i.e.,* and allies) are bottom dwellers, preying on other animals on or near the sea floor. (Rhynchobatidae and Rhinobatidae), butterfly **rays** (Gymnuridae), eagle **rays** (Mylobatidae), and cow-nosed **rays** (Rhinopteridae) feed on invertebrates, principally mollusks and crustaceans. Whip-tailed **rays** (Dasyatidae) use their broad pectoral fins to dig shellfish from sand or mud. Skates lie on the bottom, often partially buried, and rise in pursuit of such active prey as herring, trapping the victims by swimming over and then settling upon them, a practice facilitated by the skates' habit of hunting at night.

(Torpedinidae) are characteristically bottom fishes of sluggish habits. They feed on invertebrates and fish, which may be stunned by shocks produced from the formidable electric organs. With their electricity and widely extensible jaws, these **rays** are capable of taking very active fishes, such as flounder, eel, salmon, and dogfish. Shallow-water electric **rays** have been observed to trap fishes by suddenly raising the front of the body disk, while keeping the margins down, thereby forming a cavity

into which the prey is drawn by the powerful inrush of water.

Most of the (seven recognized families of the suborder Myliobatoidea, which includes all of the typical **rays**) swim gracefully, with undulations of the broad, winglike pectoral fins. Some species, especially the eagle **rays**, frequently swim near the surface and even jump clear of the water, skimming a short distance through the air.

(From Seaworld info sheets)

The wingspan, or disc-size, of a southern stingray (Dasyatis americana) such as the one shown here can reach up to 1.5 m (5 ft.).

All rays belong to the superorder Batoidea, which includes stingrays, electric rays, skates, guitarfish, and sawfish. Like sharks—their close relatives—batoids have skeletons made of tough connective tissue called cartilage. About 480 species of batoids are distributed worldwide, particularly in warm and temperate climates, and are found in oceans, estuaries, freshwater streams, lagoons, lakes, shallow offshore waters, and coastlines.

Rays primarily feed on molluscs, crustaceans, worms, and occasionally smaller fishes. Some rays crush their prey between their blunt teeth, sometimes referred to as bony plates. Often completely burying themselves in the sand or soft sediment, rays are camouflaged by a grayish-brown, often mottled coloration.

Reminiscent of birds in flight, some rays gently flap their enlarged pectoral fins, or "wings," to "fly" through and sometimes even leap out of the water. A ray's wingspan, or disc-size, can range from about 30 cm (12 in.) in yellow stingrays to over 6.1 m (20 ft.) in manta rays.Among the best know rays are stingrays, which have long, slim, whiplike tails armed with serrated, venomous spines. A stingray lashes its tail only as a defensive measure when it is caught, stepped on, or otherwise disturbed. When wading in shallow waters, people should shuffle their feet to avoid stepping on a buried stingray. In many parts of the world, some rays are commercially important food sources, yet currently, rays are not

considered threatened or endangered. Due to humankind's impact on the marine environment, however, concern is mounting for the future of rays throughout their range.

Food habits

All sharks are carnivorous and, with a few exceptions, have broad feeding preferences, governed largely by the size and availability of the prey. The recorded food of the (*Galeocerdo cuvieri*), for example, includes a wide variety of fishes (including other sharks, skates, and stingrays), sea turtles, birds, sea lions, crustaceans, squid, and even carrion such as dead dogs and garbage thrown from ships. Sleeper sharks (*Somniosus*), which occur mainly in polar and subpolar regions, are known to feed on fishes, small whales, squid, crabs, seals, and carrion from whaling stations. Many bottom-dwelling sharks, such as the smooth dogfishes (*Triakis* and *Mustelus*), take crabs, lobsters, and other crustaceans, as well as small fishes.

The two giant sharks, the whale shark (*Rhincodon typus*) and basking shark (*Cetorhinus maximus*), resemble the baleen whales in feeding mode as well as in size. They feed exclusively or chiefly on minute passively drifting organisms (plankton). To remove these from the water and concentrate them, each of these species is equipped with a special straining apparatus analogous to baleen in whales. The basking shark has modified gill rakers, the whale shark elaborate spongy tissue supported by the gill arches. The whale shark also eats small, schooling fishes.

The (Pristiophoridae) and (Pristidae) share a specialized mode of feeding that depends on the use of the long, bladelike snout, or "saw." Equipped with sharp teeth on its sides, the saw is slashed from side to side, impaling, stunning, or cutting the prey fish. Saw sharks live in midwaters; sawfishes, like most other **rays**, are bottom inhabitants.

(*Alopias*) feed on open-water schooling fishes, such as mackerel, herring, and bonito, and on squid. The long upper lobe of the tail, which may be half

the total length of the shark, is used to frighten the fish (sometimes by flailing the water surface) into a concentrated mass convenient for slaughter.

Most sharks and probably most **rays** segregate according to size, a habit that protects smaller individuals from predation by larger ones. Even among sharks of a size category, dominance between species is apparent in feeding competition, suggesting a definite nipping order. Other sharks keep clear of (*Sphyrna*), whose manoeuvrability, enhanced by the rudder effect of the head, gives them an advantage. When potential prey is discovered, sharks circle it, appearing seemingly out of nowhere and frequently approaching from below. Feeding behaviour is stimulated by numbers and rapid swimming, when three or more sharks appear in the presence of food. Activity soon progresses from tight circling to rapid crisscross passes. Biting habits vary with feeding methods and dentition. Sharks with teeth adapted for shearing and sawing are aided in biting by body motions that include rotation of the whole body, twisting movements of the head, and rapid vibrations of the head. As the shark comes into position, the jaws are protruded, erecting and locking the teeth into position. The bite is extremely powerful; a (*Isurus*), when attacking a swordfish too large to be swallowed whole, may remove the prey's tail with one bite. Under strong feeding stimuli, the sharks' excitement may intensify into what is termed a feeding frenzy, in which not only the prey but also injured members of the feeding pack are devoured, regardless of size.

In most cases the initial attraction to the food is by smell. Laboratory studies have shown that sharks do not experience hunger in the normal sense of the word, and they are much more prone to be stimulated to feeding by the olfactory or visual cues announcing the appearance of prey.

Manta, or devil, **rays** swim mostly at or near the surface, progressing by flapping motions of the pectoral fins. Even the largest often leap clear of the water. In feeding, a **manta** moves through masses of macroplankton or schools of small fish, turning slowly from side to side and using the

prominent cephalic fins, which project forward on each side of the mouth, to fan the prey into the broad mouth.

Chimaeras and ghost sharks dwell near the bottom in coastal and deep waters, to depths of at least 2,500 metres (about 8,000 feet). They are active at night, feeding almost exclusively on small invertebrates and fishe

Reproductive behavior

Mature individuals of some species of sharks segregate by sex, coming together only during the mating season, when the males, at least those of the larger, more aggressive species, stop feeding. Segregation is a behavioral adaptation to protect the females, one principal courting activity used by the male to induce cooperation of the female in mating being that of slashing her with teeth especially developed for that purpose. After mating, the sexes again separate. The pregnant females also tend to keep apart from the other females of like size. As the time of parturition approaches, the pregnant females move to particular areas, which presumably have properties of environment especially suitable as nursery grounds. When giving birth to their young, they stop feeding, and, soon after parturition is completed, they depart.

Nursery areas vary with species. Some sharks--*e.g.,* the bull and sandbar sharks--use shallow waters of bays and estuaries; the silky shark uses the bottom far out on oceanic banks such as the Serrana Bank in the western Caribbean. The Atlantic (*Squalus acanthias*) bears its young mostly during the winter far out on the continental shelf of northeastern America almost two years after mating.

A few skates that have been observed mating may be characteristic of other **rays**. The male seizes the female by biting the pectoral fin and presses his ventral surface against hers while inserting one, or in some species, both claspers into her cloaca. Male skates have one to five rows of clawlike spines on the dorsal side of each pectoral fin. These are

retractile in grooves of the skin and are used to hold the female during mating.

The eggs of skates in aquaria have been observed to be extruded in series, usually of two but sometimes one, with rests of one to five days between extrusions. A female of a European skate, *Raja brachyura*, laid 25 eggs over a 49-day period in the aquarium located at Plymouth, England.

Although the mating of chimaeroids has not been observed, it is generally presumed that the mode of copulation is similar to that of sharks and that the male's frontal spine and anterior appendage of the pelvic fins are probably used in securing the female. Two eggs are laid simultaneously, one from each oviduct. They are often carried for a relatively long period before being laid, several hours or even days, each protruding for the greater part of its length.

All species of sharks, **rays**, and chimaeras produce large, yolk-rich . These are fertilized internally, for which the males are equipped with two copulatory organs called claspers along the inner edges of the pelvic fins. Each clasper has a groove for guidance of sperm. The few published descriptions of mating sharks and **rays** are probably characteristic of the entire group. The male grasps one of the female's pectoral fins with his teeth to hold her in position as he inserts a clasper through a cavity (cloaca) and into a tube (oviduct). Males of most species probably use only one clasper at a time. The sperm travel to the anterior end of the oviduct, where they fertilize the eggs. The eggs then move down the oviduct past the shell gland, where they are covered by a shell or capsule.

In oviparous (egg-laying) species, which include some of the sharks, probably all the skates, possibly some of the guitarfishes, and all of the chimaeras, the eggs are enveloped in a horny shell, usually equipped with tendrils for coiling around solid objects or with spikelike projections for anchoring in mud or sand. The egg cases of most species are more or less pillow-shaped; those of the (Heterodontidae) are screw-shaped with a spiral flange. The eggs of chimaeras are elliptic, spindle-shaped, or tadpole-shaped and open to the exterior through pores and slits that

permit entrance of water during incubation. An egg of the found in the Gulf of Mexico measured 30 centimetres (12 inches) long by about 14 centimetres ($5^1/_2$ inches) wide and was eight centimetres (three inches) thick. Protected by the shell and nourished by the abundant yolk, the embryo of an oviparous species develops for $4^1/_2$ to $14^3/_4$ months before hatching.

The majority of sharks and most, possibly all, **rays** other than the skates are ovoviviparous (*i.e.,* the egg hatches within the mother). In this case, the egg is first coated in the shell gland with a temporary membranous capsule that lasts only during early development. After emerging from its capsule, the embryo remains in the oviduct of the mother, nourished by the yolk sac to which it remains attached. Embryos of some ovoviviparous sharks, notably the porbeagle (*Lamna nasus*), mako (*Isurus oxyrinchus*), and (*Odontaspis taurus*), ingest yolks of other eggs and even other embryos within the oviduct of the mother after the contents of their own yolk sacs are exhausted. In the majority of ovoviviparous sharks and **rays**, organically rich uterine secretions provide supplemental nourishment, which is absorbed by the yolk sac and in many cases by appendages borne on its stalk. In some genera of **rays**, vascular filaments producing these secretions extend through the spiracles and into the digestive tract of the embryos.

Several shark species are viviparous--*i.e.,* the yolk sac develops folds and projections that interdigitate with corresponding folds of the uterine wall, thus forming a yolk placenta through which nutrient material is passed from the mother.

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Marine Reptiles

Lecture Notes

These primitive vertebrates successfully adapted to life in the sea. 4 groups of Marine Reptiles are SEA TURTLES, SEA SNAKES, SALTWATER CROCODILE, AND MARINE LIZARDS. They live in primarily shallow coastal waters of tropical or subtropical oceans, but some turtles move into cooler waters to search for food. The reptiles are usually restricted to warmer waters because they are cold blooded and depend on the external temperature of the water to control their metabolic rates. Their biochemical reactions slow down in cooler water.

Marine reptiles are equipped with SALT GLANDS which remove excess salts (unlike their land and freshwater relatives). In lizards and turtles, these glands are above the eyes and can secrete a concentrated salt solution which end up bathing the eyes. This removes excess body salts, the tears cleanse the eyes. The ability to pump out the excess salts varies and determines which environment the organism can live.

Marine Lizards

Only one marine lizard exists and is the Marine iguana (*Amblyrhynchus subcristatus*) which lives in large colonies on the Galapagos. They have become secondarily adapted to marine life. They spend most of their time basking in the sun on warm rocks along the shore, warming up after swimming in the cold water to eat seaweed.

Flattened tail for swimming (like snakes)/ webbing on all four feet /

powerful claws to anchor in heavy seas / salt glands to get rid of salt taken in while eating macrophytic marine algae (seaweed) / can regulate buoyancy by expelling air and / develops BRADYCARDIA, a marked decrease of heartbeats per minute in response to diving (from normal 43/min to 7-9/min).

The marine iguana derives nourishment exclusively from sea flora and subjects itself to considerable exertion during its feeding dives, and though they can stay under for a considerable amount of time, they usually spend most of the day on the lava boulders along the shore. This probably has to do with the animal being cold blooded and loosing its heat to the surrounding water quickly. It props itself up on the rocks to absorb heat. (temp. tolerance from 21°C (70°F) to 49°C(120°F).

The marine iguana populations appear to be flourishing unlike the land iguanas which are under considerable stress from introduced animals. Where these lizards came from is still a question and whether they migrated from the coast or are leftover from a sinking land mass is still a mystery.

Bioscience Aug 1978 p 512-515

Saltwater Crocodile (*Crocodylus porosus*) inhabits mangrove areas and estuaries in the eastern Indian Ocean, Australia and some western Pacific Islands, and while most live on the coast, they are known to venture into the open sea. The largest is 30' but usually are 20'. They are very aggressive, eat people etc.

SEA SNAKES

There are about fifty kinds of sea snakes with most occurring and probably evolved in warm south Asian and Australian coastal waters. A few species are found as far away as Japan and the Persian Gulf. One, the yellow-bellied Pelamis, has crossed to the tropical Americas west coast and lives by the millions in the bay of Panama.

While sea snakes differ in form and behavior, there are a few features in common. They have flattened, rudder like tails, nostrils set on the top of the snout instead of on each side and equipped with flaps to keep them closed underwater, and smaller size of the broad belly plates that land snakes use in crawling. They have a gland in the mouth that helps get rid of salt from the seawater they drink. They have only one lung like most snakes but it is very long, lined with blood vessels to aid in O2 absorption and at the end is a simple sac to store air. Controlled heartbeats, BRADYCARDIA, reduces pulse rates by 50% when under water. Diving time varies with species, activities and water temp. The more active the less time under and the warmer water decreases diving times.

Reproduction: Sperm is implanted into oviducts of the female and she can store these for weeks or years until the eggs are ripe, fertilization is in the oviduct and many species have the embryo develop there and are born alive. Most are ovoviviparous and have no need to come ashore but a few do to lay eggs.

Olive sea snake...unmarked mustard yellow skin *Aipysurus laevis* up to 6', large mouth and blunt cobra head and dark cobra eyes. Its a fish eater and with cannot catch fish unless it corners them in a crevice...would die in a fish tank with free swimming fish.

Yellow bellied -*Palamis platurus* -gulf of California to Ecuador is equipped with fangs in the front of their upper jaws which to inject their potent venom.. They float on the surface attracting small fish to it like a piece of wood drifting in the water.

Sea snakes are related to the cobras, and are the most venomous of all

snakes though they are not very aggressive. A large number of humans ..Asian fisherman mainly, have died from sea snake bites..some of which possess venom many times more powerful than any land snake. They do have short fangs and small heads and some won't bite even when provoked, but bites and fatalities do occur. The bite is painless but after several hours the legs of the victim become paralyzed, his eyes close and jaws lock. He may live for several days before convolutions and respiratory failure bring death.

Apart from Asians who eat sea snakes, sea eagles are known to feed regularly on the reptiles, seizing them when they come up for air, grab them and drop them on the rocks.

Pacific fish eating fish don't normally eat sea snakes. This does not apply to Atlantic fish but then again there are no sea snakes in the Atlantic...yet. Basically in the Pacific, the fish know that if you eat a sea snake, you die. Sharks, swallowing sea snakes with other food have often spit it out. There is thought that the snakes bite the captor as it is swallowed thereby killing the captor being regurgitated alive before the captor dies-suggesting biting inside is a method of survival. Any exceptions to the rule that did feed on the snakes, died out and not too many fish are bred to enjoy these snakes.

Sea snakes are becoming victims of over exploitation and are hunted now for their skins. Some species are becoming rare.

SEA TURTLES

Class: Reptilia Order: Chelonia Family: Cheloniidae

Sea turtles have been hunted for meat, eggs, shells, leather, and decorative objects and are now becoming victims of pollution. While they are relics of the past, they aren't obsolete nor predestined for extinction. They are beautifully adapted for life at sea and are found in most ocean habitats. They are strong swimmers and protected from predators by size and shell. They can stay under for a long time and some can live in salt water without ever having to drink fresh water. These

adaptations make them slow and vulnerable when they leave the sea to lay eggs on land, the only time they have to leave the sea.

Characteristics: Non-retractable heads and limbs. They have powerful paddle-shaped front flippers to swim and hind fins are used for stabilizing and steering, shells are streamlined and flattened top to bottom to decrease water resistance, fatty deposits and very light spongy bones increase buoyancy enabling them to float easily. (green fat in green turtle.) There is little or no competition between the species.

Feeding: Most turtles feed in shallow coastal waters (food extremely abundant) . The green turtle feeds on meadows of turtle grass (thalassia) throughout the tropics.. the carnivorous turtles, loggerheads, feed on crabs, shellfish, sponges, fish, and horseshoe crabs. The hawksbill can pry mussels off rocks and also eats clams, jellyfish and algae. The Pacific Ridley feeds on sea urchins and other inverts. living in eel grass beds. The leatherback feeds on jellyfish far from shore and is equipped with a mouth lined with sharp spines to hold its prey and a digestive system adapted to withstand the stings. Its also the largest of the sea turtles and are the only turtle whose shell is covered by a leathery skin and whose backbone is NOT fused to the carapace.

- Atlantic Leatherback: Dermochelys coriecea
- Distribution: Tropical, Temporal and Sub-arctic Oceans
- Color & Description: Black or brown (no shell) leathery skin, no plates on shell and no scales on its head or body. The top shell has seven ridges which run lengthwise.
- Adult Weight: 700-1,600 lbs.
- Diet: Mainly Jellyfish, also sea urchins, octopus, tunicates, crustaceans, fish, algae.
- Habitat: Open ocean, bays, estuaries
- Other: Only turtle known to be warm blooded and capable of maintaining body temperatures near 82"F. (even in 45' water)

- Status: Endangered
- See UNat. article the Leatherback

- Atlantic Loggerhead: Caretta caretta
- Distribution: Subtropical, Nova Scotia to Argentina, Caribbean, Gulf of Mexico.
- Color: Red or Brown
- Weight: 250-400/1000 to 1200 lbs the largest of the hardshell turtles.
- Diet: Mollusks, sponges, jellyfish, squid, barnacles , crabs, fish, seaweed.
- Habitat: Open ocean, estuaries, bays, mouths of rivers...brackish waters.
- Reproduction: 1. Nests above high water mark on open beaches
- 2. April to October
- 3. Avg. clutch 120 eggs.
- 4. Incubation- 55-70 days
- Status: Threatened

- Green Turtle: Chelonia mydas
- Distribution: Tropical Oceans except east Pacific.
- Color: Light and dark brown, olive green, bluish black
- Weight: up to 850 lbs.
- Diet: Algae, turtle grass Thalassia (young feed on jellyfish, mollusks and crustaceans)
- Habitat: Open oceans, estuaries, and in summer, sounds and rivers.
- Reproduction: 1. May nest several times in a season.
- 2. Avg. clutch 70-140 eggs.
- 3. Very sensitive when emerging to nest.
- 4. Nest during night
- Other: Undergo long ocean migrations and have been observed sunning themselves in the tropics.
- Status: Endangered (see Shrimpers.)

- Hawksbill Turtle: Eretmochelys imbricata
- Distribution: Tropical oceans near coral and rocky reefs.
- Color: Amber streaked with red, yellow, brown and black
- Weight: 80 - 280 lbs.
- Diet: Young eat plants, adults eat jellyfish, coral, sponges, mollusks, sea urchins, fish (omnivorous).
- Habitat: Oceanic and coral reefs, some lagoons and estuaries
- Status: Endangered

- Ridleys: Lepidochelys kempi
- Distribution: Tropical oceans
- Color: gray to olive green
- Weight: 100 lbs
- Diet: Crabs, jellyfish, snails, clams, fish.
- Habitat: Shallow waters, mangrove habitats.
- Statue: Endangered

Migration: Without any landmarks to guide them, some sea turtles swim a thousand miles or more across open oceans to lay their eggs on tiny island beaches they have not been to since they were hatched 10-50 years before. Their powers of navigation bring them back to their ancestral nesting areas every 2-4 years. Migratory routes have been studied by tagging adults at nesting site. When they approach their nesting sites, usually small desolate beaches with few terrestrial predators, they remain offshore and mate. Its possible that the developed eggs in the female have already been fertilized and that this mating is for future eggs. The sperm can be stored from 2-4 years.

Nesting

While the males wait offshore, the females swim through the surf and

crawl up on the beach and begin to dig their nests with their front and hind flippers, often flinging sand into their eyes. This is washed out by their salty tears. Using the hind flippers, a cylindrical egg chamber is scooped out and about 100 eggs are deposited. They are covered with sand to protect them 1. from land crabs gulls and rats and 2. from drying out.and 3. keeps them at the right temperature. Females may repeat this up to five times during the summer breeding season (500 eggs total) before returning to the feeding grounds.

Hatchlings

After 60 days the baby turtles (2oz) scamper towards the sea equipped with about a weeks supply of yolk. They head toward the faint glow of the rising sun to locate the ocean, hatching at night. Instincts drive these hatchlings towards the lighter horizon so if they emerge during the day, all types of problems follow ,not to mention the frigate birds and buzzards feeding on them.

For years the most popular explanation has been that turtles smell their way back to their natal beaches. It is believed that hatchlings can imprint on distinct chemical characteristics of the beach and years later, when they reach breeding age, remember and retrace trails of these chemicals carried by ocean currents.

The population of green turtles was studied in this effect. They migrate between their feeding grounds off the coast of Brazil and nesting grounds on Ascension Island, midway between south America and Africa...a 2800 mile round trip.

Many years of tagging show that adults of some species go back to the same beach and sometimes almost the same spot on that beach to lay eggs. Establishing that those adults (or any adults) were hatched there, will require tagging of a hatching and seeing that the same turtle comes back when it is sexually mature...10-50 years later.

Why adult turtles would return to their natal beach is another story. They presumably make long-distance journeys to get to habitats they need during only part of their life cycle. Herbivorous green turtles, for example, feed in calm, shallow coastal waters but need steep, sandy beaches to get above the high tide line when it is time to lay their eggs. Because these habitats are often nowhere near one another, migration during the breeding season makes sense. HOWEVER, some green turtle populations appear to swim by and ignore perfect nesting beaches while making their long migration. Its possible that geological and biological factors we can't see are important. Example, a wide current moving away from Ascension Island probably carries the vulnerable, planktonic (drifting) hatchlings quickly away from the coastal predators. This little extra in terms of survival and reproductive success could be worth the extra thousand(s) miles of migration. ALTERNATIVELY, some migratory routes may be vestiges of ancient behavior no longer adaptive. Perhaps small distant islands were once larger or closer together than they are today and with the spreading sea floor, turtles nesting on islands once only a few miles from shore...attractive because of the lack of egg-eating predators...were gradually forced to swim farther and farther out to sea.

Research has shown in the case of the green turtles, that the current going past Ascension Island, sweeps right into the faces of those turtles grazing in the feeding grounds off Brazil. Also its been established that turtles have a well developed nasal epithelium and excellent olfactory acuity. Even if this olfactory imprinting does turn out to be what governs the sea turtle migration, the mechanism is an imperfect one because turtles often colonize new nesting habitats, which would be essential for the species to survive because beaches only last for 100, 1000, or 10,000 years but the turtles have been around for 100million years!

Problems

In 1947, more than 40,000 Kemps Ridley sea turtles came ashore in a single day to lay their eggs on the species main nesting beach in Mexico. Thirty years later, the wholesale collection of eggs and slaughter of nesting females has so decimated the species that no more than 250 animals have nested in a single day since 1978 and is down now to less than 117 during their largest nesting.

Conservation efforts have reduced the egg poachers and the hunting of females but still a new threat which could wipe out the remaining turtles that are the only hope for their future. Every year thousands of endangered and threatened turtles drown in the nets of shrimp fisherman who deploy their nets off our coast in the same waters used by sea turtles. When the turtle finds itself in the way of a net, it usually swims faster but soon it tires and is caught in the net and drowns. 96,000 since 1981 (reported).

Turtle Excluder Device force large fish/turtles out the side through trap doors allowing them to go free but the shrimp go in the net. However, it is only voluntary to use it and less than one percent of the US shrimp boats are using them!

Artificial Imprinting

David Owens and Mark Grassman of Texas A&M U. measured responses of turtles to sand, seawater mixtures containing chemicals that were presumably imprinted as hatchlings. This carried over to try to artificially imprint hatchlings of the endangered Kemps ridley turtle (*Lepidochelys kempi*) to a new nesting beach.

Because todays only nesting beach is near Rancho Nuevo, Mexico on a 15 mile stretch of beach, they are trying to reestablish a second nesting beach at Padre Island TX which was at one time used for nesting. Each

year, researchers collect between 2000 and 3000 eggs (caught before they touch the sand) from Rancho Nuevo, place them in styrofoam boxes filled with Padre Island sand, and send them by air to Texas. After hatching, the baby turtles are allowed to run down the beach at Padre Island in case imprinting occurs at this time and then are collected again and raised in tanks for about a year before they are released. The olfactory imprinting has not been proven yet and this is still an experiment but with the turtles so close to extinction it is worth the gamble. Because the Kemp ridley takes about 10 yrs to mature sexually, the success of this project won't be known for a few more years. Some turtles have returned according to reports in the last two years. If a large population of these turtles start to show up on Padre Island, it will be good evidence to support olfactory imprinting.

Tiny magnetic particles, called magnetite, have been found in sea turtles as will as other migratory animals indicating a possible magnetic compass sense. Navigation by stars however, is considered unlikely because most marine turtles can barely see above water..in fact a blind olive ridley, nested normally with its species on a beach in Costa Rica.

Laura Tangley, June 1984 BioScience Vol 34 No. 6 353-356.

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MARINE BIRDS

Lecture Notes -

Marine birds living at the seashore or far out to sea have become secondarily adapted to the ocean. They possess webbed feet and salt glands that empty into their nose, excrete nitrogenous wastes as insoluble uric acid to conserve water, feed on fish, squid garbage carrion etc. and must return to shore to nest. They are plentiful where food is abundant (upwellings, salt marshes etc.) Competition is reduced between species because of specific adaptations enabling them to

- 1.feed on different foods
- 2. nest in different places and
- 3.remain active at different times of the day.

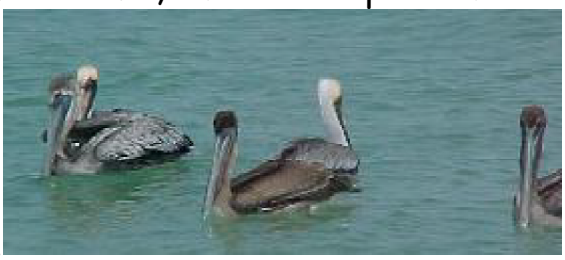
1. Stilt-legged birds Long legs help bird search shallows for food. Herons and egrets wade salt marsh waters, where sand pipers are found along the beaches. The length of the neck, beak, and legs determines where and what types of food are available. examples: heron and egret ...strike at small fish and insects, grasping it into their beaks and swallow their catch head first (won't lodge in throat. Others/probe in sand or mud to search for worms/insects ...flamingos lower their heads upside down scooping a mouthful of food and water into their hooked beaks and use their tongue as a plunger, pushing the water out straining the food.

2. Terns and skimmers (*Sterna hirundo* and *Rynchops nigra*) Long-pointed wings and a forked tail enabling them to hover over the water using keen eyes with polarizing filters to see small fish swimming in the water. The black skimmer flies close to the waters surface and places its oversize lower bill 2 inches into the water and when their bills touch a small fish, (their eyes are positioned so they can't see the water...touch is needed) their tails and wings drop to slow them down...the impact is enough to cause the skimmers head to bend backward and at this point the fish is swallowed whole. Their eyes are the only gulls that possess a vertical pupil (like a cat) which enable them to fly at twilight and dark when other birds can't. The elongated mandible of the beak makes it impossible for adult skimmers to feed while standing near the shore (young skimmers possess a more traditional beak while developing).

3. Gulls (*Larus* sp.)There are 43 species of gulls and their survival depends on their lack of specialization...they feed on anything along the shore, serving as useful scavengers. They are currently endangering tern populations by competing with them by building their nests in sandy dune area formerly occupied by the terns. They forage for their food in water and land, and often pick up clams fly up about 40' and drop them onto the street breaking them open and then rushing to eat it.

4. Cormorants (Phalacrocorax) Usually seen swimming low over the water searching for schools of fish...when located, they settle into the water and make repeated surface dives, using their webbed feet to swim underwater. Its long neck and pointed beak help it probe among blades of sea grass and rock crevasses as it chases small fish. It consumes hundreds of small fish per day because of its high metabolic rate and are used by Asians to catch fish...a ring is placed around the long neck to prevent the bird from swallowing the fish and are trained to dive from fishing boats into a school of fish. They are fed fish small enough to fit past the neck ring and become dependent on their captors. They are often tethered on lines used to pull them back into the boats. the fish are then expelled from the esophagus and crop by gentle prodding. (crop stores

food the birds gulp down rapidly) 

5. Brown Pelicans (*Pelecanus occidentalis*) A big bird with a large pouch below its bill which it uses to catch fish. They live in large colonies and when fish are located, they plunge into the water with their bills open, bob to the surface with the pouch filled with a gallon of sea water and fish. By pushing their heads against their necks, the bird expels the seawater through grooves on their bills. 

6. Frigate Birds (*Fregatta*) Found throughout the tropics and capable of flying far out to sea, and beautiful soaring flight that can out maneuver almost any bird but it cannot settle on the water. they never swim, float or enter the water and must return to shore at the end of the day to rest. They dive toward the water plucking flying fish out of the air, and grabbing small fish and squid from the surface while only wetting the tips of their beaks. They also harass other birds into vomiting their catch and feed on this.

7. Pelagic Birds Many seabirds spend almost their entire life beyond sight of the shore and these are pelagic birds. (return only to breed). Included

are Puffins and albatrosses, sooty shearwaters (migrate 20,000 miles) and storm petrels and gannets.

8. Penguins  

Adaptations

- 1. Buoyancy Birds contain fatty deposits and thin light bones, possess oil glands near their tails (water proofs feathers) (preen) and presence of many air sacs in the thorax, abdomen and long bones of their legs and wings
- 2. Heat Loss Body temp. between 106°F-103°F using air trapped under the feathers to insulate their bodies. Penguins also have blubber under their skin keeping them warm in -80°F .
- 3. Diving By exhaling air from their air sacs and lungs, squeezing air from under their feathers, they can reduce their ability to float to dive under the surface. Their heart rate slows when they dive.
- 4. Migration seasonal migration between feeding and nesting grounds occurs with breeding usually occurring near the poles and feeding in the mid-latitudes. Young birds inherit detailed genetic instructions that allow them to migrate thousands of miles across the water. The longest, the arctic tern (Sterna paradisaea) nests in the arctic in the summer and flies south for the winter to within sight of the Antarctic ice (20,000 miles).
- 5. Senses Sight...excellent binocular vision to perceive fish swimming in deep water. A nictitating membrane, third eyelid protects eyes when diving. Hearing and smell don't appear to be vital in marine birds, although birds hear higher frequency than humans. Taste is the least underdeveloped sense, and birds have no teeth and few taste buds, swallowing food quickly without chewing or tasting it.

Ecological importance

Vital components of marine food web, feeding on and adding to the water droppings to fertilize surface water to stimulate growth of marine plants. Birds are attracted to certain areas and leave guano. Industry.

NAME FOOT&/OR GROUP FEEDING UNUSUAL CHARACTERISTIC

- Heron Stilt-legged Swallow fish head first yellow legs/black bill
- Egret Stilt-legged Swallow fish head first black legs/yellow bill
- Flamingo Stilt-legged Strain water for fish pink/long legs
- Ibis Stilt-legged swallow fish head first long downward curved diving or wading bill
- Roseate Stilt-legged diving or wading small, pink flying bird spoonbill flat bill
- Pelican Webbed-feet scoops up water & fish poor diver/large bill pouch, nests in mangroves
- Cormorant Webbed-feet Dives, swims underwater hooked bill, trained to fish by man
- Anhinga Webbed-feet Swims underwater spears straight bill, no preen fish gland, must dry feathers often called snakebird
- Frigate Flying stealing catch never enter water, redthroat/outmaneuver anyother marine birds- Y shaped tail.
- Gulls Flying land or water scavengers most common marine bird shore and coastal animals nest in dunes
- Penguins Pelagic fish, krill, squid are Antarctica, no flight swallowed underwater
- Puffin Pelagic fish, krill, squid are seldom on land/wide,
- Osprey Vulture Family dives, carries fish back builds huge nest near to nest to shred & devour water, top carnivore
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MAN and the OCEAN ENVIRONMENT

Lecture Notes - (word)

1. Marine Pollution

2. Low O2, high temp., dredging, wastes

3. Removal of marsh lands and wet lands

4. Benefits of the sea

5. Uses of ocean to man

Throughout history the ocean has played a vital role in the development and growth of civilization, and humans have considered the ocean to be an unlimited source of food and a bottomless garbage dump. With a population of 5.5 billion most fisheries are fully exploited and ocean dumping is causing measurable contamination of the food supply.

Some negative influences of man...

1. The use of pesticides and other agricultural chemicals to help crop yield on land has harmed food production in the ocean.

2. A process called BIO-MAGNIFICATION, concentrates toxins such as DDT, PCB'S and mercury in tissues of consumer organisms...many of which are used for human consumption.

3. Alternates to ocean dumping must be sought to prevent further contamination of the food supply.

4. Economic and ethical issues of commercial whaling works these animals toward extinction.

5. Destruction of marshlands by draining and dredging and attempts to control beach erosion in spite of a world wide rise in sealevel.

POLLUTION

For the past 100 years, contaminants like oil, PCB, DDT, heavy metals, radioactive wastes, sewage sludge and garbage is introduced into the sea .

OIL due to tanker accidents, oil rig blowouts, daily oil washed off roadways into sewers and into water, ships pumping waste oil from bildges/ballast, seepage from garbage dumps and natural seepage from the ocean bottom. (the largest discovered off trinidad at 100m /100m thick and contains 1 megaton of oil)

Oil harms the environment by

1. covering or poisining

2. birds die of starvation because they can't fly and no insulation

3. injest oil from feathers while trying to clean

4. damage the liver and vital organs

Crude oil released into the sea usually floats although some sinks .

Oil in intertidal zones...tides bring a new blanket of oil to cover oysters, clams, mussels etc interfering with feeding and breathing. The devastation usually occurs initially but recovery usually occurs with time. More serious than the oil itself has been the various chemicals used such as detergents used to break it up or disperse the oil into the water.. The Torry Canyon disaster in 1967 the chemicals were shown to cause more mortality to marine organisms than the oil itself.

Pelagic...eggs and larva drift in oil slicks, they can't swim and there is less photosynthesis.

Pelagic tar...some components evaporate or dissolve but lots sink to the bottom to be trapped in sediments.

Right whales injest floating tar and sperm whales feed off bottom sediments (complete with tar!)

Sewage and Garbage

The discharge of human sewage and garbage into the coastal waters is practiced throughout the world. The sewage may or may not have had some treatment before discharge. It adds a large volume of small particles to the water and also large amounts of nutrients. In small volumes and with adequate diffusing pipes, it is difficult to detect long-term effect on the communities of the open coast. In large volumes and in semienclosed embayments, the effect can be devastating.

Two examples...

Southern California..LA area discharges 330 million of sewage per day at the Whites Point outfall off the Palos Verdes Penn. Studies around the outfall and others in the area revealed that sewage has caused significant degradation in benthic invertebrate communities in areas near the outfall, kelp beds disappeared near the outfall, more urchins, diseased fish more prevalentand about 4.6% of the Southern Cal. mainland shelf has been changed or degraded as a result of sewage discharge from 4 major outfalls.

Hawaii-Kaneohe Bay on Oahus east side was subjected to a 10-fold increase in population and the bay was subjected to massive domestic sewage discharges, siiltation from runoff during storms and resulted in the total destruction of the once beautiful coral reefs of this shallow bay. Once the discharges were eliminated from the bay, a renmarkable recovery of corals and water clarity was reported!

In addition to sewage, large amounts of garbage are dumped into the ocean every year.

And then there is New York. The city dumps dredge spoils, sewage, chemicals,

garbage, construction materials, which are dumped in such large numbers its visbale from satellites. Sewage alone the 127 municipal discharges contribute 2.6×10^9 or 2,600,000,000 billion gallons per day. The dumping has dropped O2 levels near zero over extensive bottom areas off New Jersey, led to massive fish and shellfish mortalities, and even though most are dumped many miles offshore, some returns to contaminate bathing beaches (needles).

CHEMICALS

Worse than oil or sewage, which are at least visible, are various toxic chemicals produced by the industrialized nations which find their way into the oceans ecosystems.These chemicals are often transfered through the food chains in the sea and exert their effects in animals and places removed in time and space from its source. Certain marine organisms also enhance the toxic effects of many chemicals because of their ability to accumulate the substances in their bodies far above that found in the surrounding water. Another factor that tends to increase the effects of chemicals on living systems is biomagnification in which the chemical increases in concentration in the bodies of organsisms with succeeding trophic level....this can lead to very high concentrations in the top predator...sometimes man!

Example..in the late 1930's, the Chisso Corp. of Japan established a factory on the shores of Minimata Bay to produce vinyl chloride and formaldehyde. By-products from the plant contained mercury and were discharged into the bay. Through biomagnification, the marine fishes and shellfish accumulated high concentrations of the toxic compound methyl-mercury chloride. The fishes and shell fish were in turn consumed by the inhabitants of the area. About 15 years after the dumping of the mercury into the bay began, a strange permanently disabling neurological disorder began to appear among the inhabitants, especially the children. It was called Minimata Disease. The cause was diagnosed as mercury poisoning in 1959 but it took until the early 60's to discover the source from the factories. and until the 1970's before Japan to stop dumping mercury into the sea.

DDT and Pelicans etc Radioactive wastes

Channel Dredging

Channels are dredged deeper and wider so boats won't run into each other or run

aground and until the day comes when (1) no more boats are built, (2) they don't increase in length, beam and draft or (3) moving water stop dumping silt into channels, they will continue to be dredged.

Dredging can damage by tearing up marine habitat by releasing silt which smothers shellfish and cuts down sunlight penetration into the water, changes water current patterns,, creates deep holes in an otherwise shallow and even bottom and the holes can collect detritus and form low oxygen conditions and the worse is the dredged material is usually dumped on the protective marshlands. Deeper channels can also allow denser salt water to travel further up the estuary increasing the salinitys and bringing predators to an otherwise low salinity environment which can then feed of the oysters etc.

Mariculture...farming the sea can add to world food production. (growing aquatic is aquaculture).

History...The japanese/chinese raised fish and japan raised fish and the Japanese grew seaweed on ropes but the main problem with mariculture is

1. lack of suitable domestic organisms

2. gaps in knowledge of nutritional requirements and life cycles (larva stages)

3. need to duplicate the natural environment

4. lack of knowledge in relation to diseases of marine organisms.

Instead of trying to find all these, a way around it is to work out some, which can be done by interupting the natural stages and leave the rest to nature.

There are 2 broad types of mariculture.

1. Duplicate environment artificially

2. Grow more effectively in the natural environment

1. Artificial settings are used in growing lobsters, shrimp, fish.

2. Ranching--rear young from artificially fertilized eggs and release 3 year old fish to ocean.

(most mortality occurs during 1st year of life)

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5. Uses of ocean to man

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Throughout history the ocean has played a vital role in the development and growth of civilization, and humans have considered the ocean to be an unlimited source of food and a bottomless garbage dump. With a population of 6.5 billion most fisheries are fully exploited and ocean dumping is causing measurable contamination of the food supply.

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Some negative influences of man...

1. The use of pesticides and other agricultural chemicals to help crop yield on land has harmed food production in the ocean.

2. A process called BIO-MAGNIFICATION, concentrates toxins such as DDT, PCB'S and mercury in tissues of consumer organisms...many of which are used for human consumption.

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3. Alternates to ocean dumping must be sought to prevent further contamination of the food supply.

4. Economic and ethical issues of commercial whaling works these animals toward extinction.

5. Destruction of marshlands by draining and dredging and attempts to control beach erosion in spite of a world wide rise in sea level.

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The London Convention discourages dumping at sea
The London Convention is a nickname for a United Nations administered agreement on preventing pollution produced by dumping wastes and other harmful substances at sea. This treaty classifies materials according to potential harm to marine life and humans. It bans dumping some substances and regulates dumping others §.

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Currently the U.S. dumps only dredged materials, although other countries still dump sewage sludge and non-toxic industrial waste §. The U.S. and other parties to the London Convention are observing a moratorium on dumping low-level radioactive waste

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POLLUTION

For the past 100 years, contaminants like oil, PCB, DDT, heavy metals, radioactive wastes, sewage sludge and garbage is introduced into the sea .

OIL due to tanker accidents, oil rig blowouts, daily oil washed off roadways into sewers and into water, ships pumping waste oil from bilges/ballast, seepage from garbage dumps and

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natural seepage from the ocean bottom. (the largest discovered off Trinidad at 100m /100m thick and contains 1 megaton of oil)

Oil harms the environment by

1. covering or poisoning

2. birds die of starvation because they can't fly and no insulation

3. ingest oil from feathers while trying to clean

4. damage the liver and vital organs

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Crude oil released into the sea usually floats although some sinks .

Oil in intertidal zones...tides bring a new blanket of oil to cover oysters, clams, mussels etc interfering with feeding and breathing. The devastation usually occurs initially but recovery

usually occurs with time. More serious than the oil itself has been the various chemicals used such as detergents used to break it up or disperse the oil into

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the water.. The Tory Canyon disaster in 1967 the chemicals were shown to cause more mortality to marine organisms than the oil itself.

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- **"We have to drill offshore. we have to do this. Oil executives say in a couple years we could be seeing results from it. So why not do it? We need to do it."<u>John McCain on Offshore Drilling</u>**

- **WASHINGTON —June 19, 2008**

- **President Bush urged Congress on Wednesday to end a federal ban on offshore oil drilling and open a portion of the**

Arctic National Wildlife Refuge for oil exploration…"scientists have developed innovative techniques to reach Anwar's oil with virtually no impact on the land or local wildlife,",

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- **As BP PLC defended its handling of the oil spill in the Gulf of Mexico, documents show it argued against new, stricter safety rules proposed last year by the U.S. agency that oversees offshore drilling.**

- **The British oil giant was one of several companies that wrote to the U.S. Minerals Management Service this past September saying additional regulation of the oil industry was unnecessary. In a letter, BP said the current voluntary system of safety procedures was adequate.**

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When it comes to mixing oil and water, oceans suffer from far more than an occasional devastating spill. Disasters make headlines, but hundreds of millions of gallons of oil quietly end up in the seas every year, mostly from non-accidental sources §

The graph below shows how many millions of gallons of oil each source puts into the oceans worldwide each year

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- **Wednesday 31 March 2010 19.04 BST**

- **Barack Obama took the Republican slogan "drill, baby, drill" as his own today, opening up over 500,000 square miles of US coastal waters to oil and gas exploitation for the first time in over 20 years.**

- **The move, a reversal of Obama's early campaign promise to retain a ban on offshore exploration, appeared aimed at winning support from Republicans in Congress for new laws to tackle global warming. Sarah Palin's "Drill, baby, drill" slogan was a prominent battle cry in the 2008 elections.**

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Down the Drain: 363 Million Gallons

> **Used engine oil can end up in waterways. An average oil change uses five quarts; one change can contaminate a million gallons of fresh water. Much oil in runoff from land and municipal and industrial wastes ends up in the oceans.**
> **363 million gallons §**
> **Road runoff adds up**
> **Every year oily road runoff from a city of 5 million could contain as much oil as one large tanker spill §.**

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Routine Maintenance: 137 Million Gallons

Every year, bilge cleaning and other ship operations release millions of gallons of oil into navigable waters, in thousands of discharges of just a few gallons each. 137 million gallons §

Up in Smoke: 92 Million Gallons

Air pollution, mainly from cars and industry, places hundreds of tons of hydrocarbons into the oceans each year. Particles settle, and rain washes hydrocarbons from the air into the oceans §.

Natural Seeps: 62 Million Gallons

Some ocean oil "pollution" is natural. Seepage from the ocean bottom and eroding sedimentary rocks releases oil.

Big Spills: 37 Million Gallons

Only about 5 percent of oil pollution in oceans is due to major tanker accidents, but one big spill can disrupt sea and shore life for miles §. 37 million gallons §

Crude oil from a tanker that ran aground
Kill Van Kull Channel, between Staten Island and New Jersey, 1991

Offshore Drilling: 15 Million Gallons

Offshore oil production can cause ocean oil pollution, from spills and operational discharges.

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Pelagic...eggs and larva drift in oil slicks, they can't swim and there is less photosynthesis.

Pelagic tar...some components evaporate or dissolve but lots sink to the bottom to be trapped in sediments.

Right whales ingest floating tar and sperm whales feed off bottom sediments (complete with tar!)

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Sewage and Garbage

The discharge of human sewage and garbage into the coastal waters is practiced throughout the world. The sewage may or may not have had some treatment before discharge. It adds a large volume of small particles to the water and also large amounts of nutrients.

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In small volumes and with adequate diffusing pipes, it is difficult to detect long-term effect on the communities of the open coast. In large volumes and in semi enclosed embayments, the effect can be devastating.

Two examples...

Southern California..LA area discharges 330 million of sewage per day at the Whites Point outfall off the Palos Verdes Penn.

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Studies around the outfall and others in the area revealed that sewage has caused significant degradation in benthic invertebrate communities in areas near the outfall, kelp beds disappeared near the outfall, more urchins, diseased fish more prevalent and about 4.6% of the Southern Cal. mainland shelf has been changed or degraded as a result of sewage discharge from 4 major outfalls.

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Hawaii-Kaneohe Bay on Oahu's east side was subjected to a 10-fold increase in population and the bay was subjected to massive domestic sewage discharges, siltation from runoff during storms and resulted in the total destruction of the once beautiful coral reefs of this shallow bay. Once the discharges were eliminated from the bay, a remarkable recovery of corals and water clarity was reported!

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In addition to sewage, large amounts of garbage are dumped into the ocean every year.

And then there is New York. The city dumps dredge spoils, sewage, chemicals, garbage, construction materials, which are dumped in such large numbers its visible from satellites. Sewage alone the 127 municipal discharges contribute 2.6×10^9 or 2,600,000,000 billion gallons per day.

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The dumping has dropped O2 levels near zero over extensive bottom areas off New Jersey, led to massive fish and shellfish mortalities, and even though most are dumped many miles offshore, some returns to contaminate bathing beaches (needles).

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CHEMICALS

Worse than oil or sewage, which are at least visible, are various toxic chemicals produced by the industrialized nations which find their way into the oceans ecosystems.These chemicals are often transferred through the food chains in the sea and exert their effects in animals and places removed in time and space from its source.

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Certain marine organisms also enhance the toxic effects of many chemicals because of their ability to accumulate the substances in their bodies far above that found in the surrounding water. Another factor that tends to increase the effects of chemicals on living systems is biomagnification in which the chemical increases in concentration in the bodies of organisms with succeeding tropic level

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....this can lead to very high concentrations in the top predator. ..sometimes man!

Example..in the late 1930's, the Chisso Corp. of Japan established a factory on the shores of Minimata Bay to produce vinyl chloride and formaldehyde. By-products from the plant contained mercury and were discharged into the bay. Through biomagnification, the marine fishes and shellfish accumulated high concentrations of the toxic compound methyl-mercury chloride.

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The fishes and shell fish were in turn consumed by the inhabitants of the area. About 15 years after the dumping of the mercury into the bay began, a strange permanently disabling neurological disorder began to appear among the inhabitants, especially the children. It was called Minimata Disease. The cause was diagnosed as mercury poisoning in 1959 but it took until the early 60's to discover the source from the factories.

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and until the 1970's before Japan to stop dumping mercury into the sea.

DDT and Pelicans etc Radioactive wastes

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Biomagnification: how DDT becomes concentrated as it passes through a food chain

The figure shows how DDT becomes concentrated in the tissues of organisms representing four successive trophic levels in a food chain.

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The concentration effect occurs because DDT is metabolized and excreted much more slowly than the nutrients that are passed from one trophic level to the next. So DDT accumulates in the bodies (especially in fat). Thus most of the DDT ingested as part of gross production is still present in the net production that remains at that trophic level.

This is why the hazard of DDT to nontarget animals is particularly acute for those species living at the top of food chains.

For example,

- **spraying a marsh to control mosquitoes will cause trace amounts of DDT to accumulate in the cells of microscopic aquatic organisms, the plankton, in the marsh.**

- **In feeding on the plankton, filter-feeders, like clams and some fish, harvest DDT as well as food. (Concentrations of DDT 10 times greater than those in the plankton have been measured in clams.)**

- **The process of concentration goes right on up the food chain from one trophic level to the next. Gulls, which feed on clams, may accumulate DDT to 40 or more times the concentration in their prey.**

- **This represents a 400-fold increase in concentration along the length of this short food chain.**

There is abundant evidence that some carnivores at the ends of longer food chains (e.g. ospreys, pelicans, falcons, and eagles) suffered serious declines in fecundity and hence in population size because of this phenomenon in the years before use of DDT was banned (1972) in the United States.

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Channel Dredging

Channels are dredged deeper and wider so boats won't run into each other or run aground and until the day comes when

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(1) no more boats are built, (2) they don't increase in length, beam and draft or (3) moving water stop dumping silt into channels, they will continue to be dredged.

Dredging can damage by tearing up marine habitat by releasing silt which smothers shellfish and cuts down sunlight penetration

into the water, changes water current patterns,,

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creates deep holes in an otherwise shallow and even bottom and the holes can collect detritus and form low oxygen conditions and the worse is the dredged material is usually dumped on the protective marshlands. Deeper channels can also allow denser salt water to travel further up the estuary increasing the salinities and bringing predators to an otherwise low salinity environment which can then feed of the oysters etc.

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Sand, Gravel, and Coral

Island nations, with limited inland sources of building materials, turn to coastal sand and

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Collecting coral to process for lime, Solomon Islands, 1988 Mining coral removes habitat of local marine species, and weakens coastal storm defenses. Rebuilding coral takes time because colonies of tiny coral animals grow slowly. Mined or dredged areas take a very long time to recover

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Mining sand for landfill, Belize Sand and gravel are in demand as fill, and as an ingredient of concrete. Mining near shores may lead directly to beach erosion. Removing sand from river beds

may also cause beach loss, because floods would have eventually brought that sand to beaches

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Mariculture...farming the sea can add to world food production. (growing aquatic is aquaculture).

History...The Japanese/Chinese raised fish and Japan raised fish and the Japanese grew seaweed on ropes but the main problem with mariculture is

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1. lack of suitable domestic organisms

2. gaps in knowledge of nutritional requirements and life cycles (larva stages)

3. need to duplicate the natural environment

4. lack of knowledge in relation to diseases of marine organisms.

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Instead of trying to find all these, a way around it is to work out some, which can be done by interrupting the natural stages and leave the rest to nature.

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There are 2 broad types of mariculture.

1. Duplicate environment artificially

2. Grow more effectively in the natural environment

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1. Artificial settings are used in growing lobsters, shrimp, fish.

2. Ranching--rear young from artificially fertilized eggs and release 3 year old fish to ocean.

(most mortality occurs during 1st year of life)

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Manganese and Other Metals Deep ocean basins are strewn with metallic nodules §. Composed mostly of manganese, they also contain nickel, copper, and cobalt. Pipelines running to ships or platforms could "vacuum" up these nodules, but no country or consortium is yet mining them, in part because of high costs compared to land-based mining §.

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Mysterious manganese "marbles" lie strewn on the abyssal mud of the ocean's deepest basins. Most are larger than golf balls §.

Each appears to have grown, pearl-like, around some nucleus--perhaps a shark's tooth.

Maximum sustainable yield

In fisheries science, maximum sustainable yield or MSY is the largest long-term average yield/catch that can be taken from a stock of fish without depressing the species' ability to reproduce.

A typical MSY is about 80% of the total population biomass of the mature fish capable of reproduction. The maximum sustainable yield is usually higher than the optimum sustainable yield.

- **Practical Considerations:**

- **Obtaining realistic values for fishing effort and catch per unit effort is not as straight forward as one would like. Catch is made up of:**

- **that retained for its value and eventually marketed**

- **that discarded at sea or dockside (typically 30-40%).**

- **portions of commercial species having little value (heads and guts)**

- **species with no commercial value**

- **undersized individuals**

- **restricted take individuals**

- **Catch is often lumped by fishers or processors into broad market categories including several species.**

- **Effort includes both gear and time.**

- **Effort may be simple: feet of gill netting or number of hooks on a long line per day or hour**

- but it may also be complex, needing to account for:
- varying mesh size
- otter board size
- horsepower of boat
- use of electric "ticklers" to cause bottom fish to swim up into a trawl
- whether the boat uses a sonar fish locator and how up-to-date it is
- how experienced the captain is

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- Even time can be complicated. Fisheries which involve pelagic schooling fish have both a search component and a fishing component. Employment of spotter planes will shorten the search time but not the fishing time.
- Obviously commercial records by themselves are

inadequate, the fisheries manager must conduct additional surveys, sampling, and perhaps even covert observation to accurately determine both catch and effort.

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- Data from the commercial catch should always be supplemented from fishery-independent data. Complicated statistical analysis is essential.

- Fatal Flaws:

- For years we have been managing commercial fisheries based largely on CPUE data. New reports of failed fisheries surface almost daily. Obviously fisheries management has been less than a sterling success. There are three main categories of reasons.

- Technical

  Fisherpersons continually upgrade their gear, adding the latest gimmicks if they think they will help them turn a profit. Nets have become stronger and lighter; boat motors more powerful; refrigeration better so the fleets can remain out longer; fish-locators and navigational aids and record keeping vastly more accurate and afordable. We have been basing catch per unit effort on an effort component which has become subtly but vastly more efficient.

Political

Every management decision has a political component.

Whenever a fishing restriction creates a real or imagined hardship for people, they protest, sometimes violently. Considering the tenuous data available, the efficacy of almost any management recommendation can be questioned. Politicians and bureaucrats tend to err on the side of people rather than fish (fish rarely complain).

High seas fisheries are governed by international treaties. Often the effect on the fish population is secondary to some other bargining point.

- **Biological**

- **CPUE and Sustainable Yield are based on the assumption that an unexploited population will behave in a predictable fashion. An unexploited population is a fallacy. The process of evolution produced something to exploit any available resource.**

- **Much of our historic success at harvesting huge quantities from the sea resulted from the co-harvest of the other species that naturally exploited the species we were harvesting. We virtually eliminated most marine mammals and the largest species of fish very early on. That, of course, left their food supply for us to exploit and as we reduced them, we began to harvest *their* food supply. The history of our exploitation of the sea has been one of migration down the food chain.**

- **Predator species can't recover, even if we would let them, because we are taking all their food. Imagine trying to balance a MSY for anchovetta and tuna at the same time.**

- **Ecosystem destruction has resulted from many technological innovations including fish harvest techniques.**

- **Dams and diversions have disrupted life cycles of anadromous species,**

- **Dredging and filling to create residential, commercial, and agricultural properties has eliminated or damaged nursery grounds for many coastal species.**

- **Bottom trawls crisscrossing the most productive parts of the ocean floor have destroyed the substratum on which fish and their foods depended.**

- **Untold quantities of myriad industrial, agricultural, and medical chemicals have entered the ocean and potentially concentrated in biological systems where their effects include reproductive dysfunction.**

MARK-RECAPTURE

MODELS

'MARK' 'RECAPTURE' RELEASE

- **Longitudinal studies of marked individuals basic tool in wildlife ecology providing information on:**

  - **Basic life history and reproductive biology: growth, maturation, mating patterns, social organization**

  - **Population size**

  - **Rates of gain (immigration + births) and loss (emigration plus deaths)**

Types of marks

- **Natural external - scars, coloration patterns**

  - **photo-id**

- **Natural internal: DNA fingerprints**

- **Anthropogenic but not scientist induced: scars (propeller wounds manatees)**

- **Exterior tags, bands, brands, color marks etc**

- **Internal tags: Discovery tags, PIT tags**

Mechanics of tagging

- ***Tags should:***

  - **Attach with minimal trauma**
  - **Not impede movement**
  - **Not alter susceptibility to predation, disease, or other mortality agents**
  - **Be difficult to dislodge (False -)**
  - **Last for lifetime of animal (or study) (false -)**
  - **Unambiguously identify individuals (false +)**

  - **equal probability of sighting - distribution and behavior**
  - **equal probability of photographing natural marks**

- **Equal probability of survival - age specific rates but cannot age wild individuals**

Concerns re use of natural marks for estimating population size

- **Populations studied must be geographically closed**
- **Samples must be representative of the population**
- **Sample sizes must be sufficiently large**

Concerns re use of natural marks for estimating survival

- **Adult survivorship most influential life history parameter in demography of most marine wildlife species**
- **MRR studies often best method of measurement**
- **Study must be sufficiently long - for long-lived species such as whales - 10 years.**
- **Probability of recapture must be high $\geq$0.2**
- **Probability of individual identification should be homogeneous**

Case study 1: southern right whales off South Africa

Case study 1: southern right whales off South Africa

- 1979-1987 aerial surveys photographs of females with calves
- Females calve 2-4 years - probabilities of recapture unequal between years
- Population increasing
- Purpose built model for closed populations built to handle unequal capture probabilities
- Best estimate 286 adult females (95% CI 265-301)

Case study 2: Antarctic minke whales

Case study 2: Antarctic minke whales

- Individuals can be identified
- Extensive effort required to obtain photographs
- Assume model assumptions satisfied
- Assuming:
  - population size of 100,000
  - accuracy of 0.25 - (95% CI 75,000 - 125,000)
- 415 ship days yr 1, 296 yr 2
- Sighting cruise likely to be more efficient

Case study 3: Florida manatees at 3 winter aggregations sites

Case study 3: Florida manatees at 3 winter aggregations sites

- **Population size ? But 677 marked individuals**
- **Closed populations: No - not assumed**
- **Marking method: Photo ID propeller scars**
- **Homogeneous capture probability - unlikely**
- **Duration of study: 13 yrs (2 locations) 6 yrs (1)**
- **Precise population estimate - not attempted because of heterogeneous capture probability across whole population - some animals unmarked or unavailable**

Case study 3: Florida manatees at 3 winter aggregations sites

- **Adult and juvenile survival -assumed homogeneous capture probability of *marked* population only**
- **Capture probability high >0.5 (2 sites >0.7)**
- **Assumption of equal survival between sampling intervals- individuals sampled early in period < survival to next**

- interval than those sampled late

  - grouped into 2 age groups: juveniles and adults

  - confined sampling period each year 1 November - 31 March

  - multiple sampling within sampling period

- Assumption- identifying one individual in sample does not affect probability of sampling others - okay as no defined social groups

- excellent precise estimates of survival e.g., adult Crystal River 0.962 s.e. 0.009 95% CI 0.943-0.981

- Population size ~1000
- Closed population ? but unlikely - dugongs move
- Marking method - rodeo capture and PTT tag/DNA fingerprint
- Risk of capture mortality ~ 1%
- Homogeneous capture probability - unlikely
- Precise population estimate - capture probability 0.3-0.5

- **Survivorship - capture probability 0.5 and 10 year study**

Take-Home Message

- **Photo-ID studies are more than mucking about in boats with marine mammals!!!!!**
- **Need mathematical evaluation before you start to consider likely effort required to achieve meaningful results**
- **Need to test assumptions of MRR model**
- **Need access to long-term funding**
- **Need to address ethical issues if actual capture involved**

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HYRACOIDEA & SIRENIA:
Remnants of the Subungulate Radiation

Characteristics of Endangered Species :

- Adapted to stable, undisturbed communities
- Low natality and low natural mortality
- Specialized, narrow habitat or environmental requirements
- Historically restricted in distribution, on periphery of range or low in density

Natural History of Manatees

- 2-3 meters long, 350-450 kg, no hind limbs

- **Former range reduced to Florida & Puerto Rico**

- **Habitat: Shallow, warm fresh to marine waters with abundant aquatic vegetation**

- **Feed 4-6 hrs/day, consuming 25-35 kg/day**

- **<u>Reproduction</u>: Polygynous,**

  - **1st breed at 4-6 yrs, every 3-4 years thereafter**

  - **single calf, 390 day gestation, nurse ~1 year**

- **Is this characteristic of an endangered species?.**
  HISTORICAL EXTINCTION EVENTS

Some survivors from the Pleistocene have been driven to extinction during historical times by over-exploitation:

Sea Cow

This was heavy, slow-swimming marine mammal related to the manatee and dugong (Sirenians), but much larger (25-30 feet long). It was discovered in 1741 in the ocean around the Pribilof Islands in Bering Sea (far north Pacific Ocean).

It was used as food by visiting sea-otter hunters, and was extinct by 1768, 27 years after its discovery.

Surviving relatives

A smaller (12 feet long) relative of the sea cow that is endangered by human activities is the Manatee (West Indian or Florida Manatee), a slow-swimming, friendly marine mammal that feeds on sea grass and lives in the coastal waterways of Florida

and in other coastal areas around the Caribbean. There are about 2,000 animals in the population, but at least 200 die each year, mainly from collisions with speedboats. Florida's response to this problem has been to post "go-slow" signs on the waterways, and to rely mainly on voluntary compliance. They have also established some very small sanctuaries. These efforts are not working very well. The death rate has not declined; in fact collisions with boats killed a record number of 95 manatees in 2002. Save the Manatee Club is now filing lawsuits to try to get the government agencies to better enforce the laws protecting manatees.

. Despite the manatee's precarious situation, a consortium of Florida business interests is lobbying to get the mammal removed from the federal Endangered Species list.

The other surviving relative of the sea cow, the dugong, is also in serious trouble. Dugongs are found in a huge area from the Red Sea to the Pacific Coast of Australia and the Solomon Islands. They are so dispersed that accurate population counts have not been possible. The population at the southern end of the Great Barrier Reef was estimated at ~50,000 in the 1960's, but the number has fallen to about 4,000 since then, due to habitat loss, entanglement in fishing nets and nets used to protect swimming areas from sharks . The Great Barrier Reef Marine Park Authority has established a chain of dugong sanctuaries to try to protect the remaining animals.

Dugongs, or sea cows as they are sometimes called, are marine animals which can grow to about three metres in length and weigh as much as 400 kilograms. They are the only marine mammals in Australia that live mainly on plants. The name sea cow refers to the fact that they graze on the seagrasses, which form meadows in sheltered coastal waters. As dugongs feed, whole plants are

uprooted and a telltale-feeding trail is left.

Relatives

Dugongs are more closely related to elephants than to marine mammals such as whales and dolphins, but their closest living aquatic relatives are the manatees. Manatees are aquatic mammals that live in freshwater rivers and coastal waters of West Africa, the Caribbean, South America and the southern United States (Florida). Another close relative was Steller's sea cow, previously found in the northern Pacific. It was hunted to extinction in the 1700s by sealers for its meat. It grew almost three times as long as the dugong and fed on large algae (kelp).

Distribution

Dugongs inhabit shallow, tropical waters throughout the Indo-Pacific region. Most of the world's population of dugongs is now found in northern Australian waters between Shark Bay inWestern Australia and Moreton Bay in Queensland.

Life in the sea

Dugongs swim using their whale-like fluked tail and they use their front flippers for balance and turning. Their movements are often slow and graceful. Early explorers and sailors believed that they were mermaids because of their streamlined bodies and the large teats at the base of their flippers.. They have a rounded head with small eyes and a large snout. The nostrils are at the top of the snout and, like mammals, dugongs must surface to breathe. However, unlike other aquatic mammals such as some whales, dolphins and porpoises, dugongs cannot hold their breath under water for very long. It is generally for only a few minutes, especially if they are swimming fast.

Dugongs have poor eyesight but acute hearing. They find and grasp seagrass with the aid of coarse, sensitive bristles, which cover the upper lip of their large and fleshy snout. Small tusks can be seen in adult males and some old females. During the mating season, male dugongs use their tusks to fight each other.

Life history Dugong list history is made of finely balanced population parameters.

The slow breeding rate and long life span mean that dugongs are particularly susceptible to factors that threaten their survival. Throughout their worldwide range they are threatened by human impacts, particularly on their habitat.

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. Declining numbers

Dugong numbers have declined dramatically in the past 40 years in the southern part of the Great Barrier Reef World Heritage Area south of Cooktown. Surveys indicate that numbers now appear to be fluctuating around a level that is far less than in the early 1960's, and probably before. Whether the southern Great Barrier Reef population is continuing to decline or is stable, or increasing, and at what rate, will not be known for many years but the species undoubtedly faces the threat of disappearing from the southern Great Barrier Reef. The Great Barrier Reef Ministerial Council, comprising the Commonwealth and Queensland Ministers for the Environment and for Tourism, is concerned about the decline and has instigated a number of actions to reverse the trend. Government departments, community groups and industry organisations are working to minimise the number of

dugong deaths from human-related causes

Experts consider that the decline in dugong numbers is due to unsustainable mortality from human-related causes such as habitat loss or degradation, commercial mesh nets (fish nets), shark nets set for bather protection, indigenous hunting, boat strikes, defence activities and illegal take.

- **1999 surveys showed that numbers in the southern Area were back at 1986-87 levels (3993 ± 644),**

. Sea Otters

When the Russian traders had exhausted the terrestrial fur-bearing animals they turned their attention to the sea otters that were discovered in 1741 in the north Pacific, on the Russian and Alaskan coasts. At that time, there were between 150,000 and 300,000 otters living along the north American coast from Alaska to Baja California.

. From 1750 to 1790 most of the animals were killed by hunters, then they were too scarce to be worth hunting (they had reached "commercial extinction") and the trade collapsed. By 1911, when the otters received some protection through the International Fur Seal Treaty, there were only 1-2,000 animals left throughout their range. The population recovered well and the Alaskan (Aleutian Island) population reached a peak in the mid-1970s of about 50,000-100,000 animals. But from 1992 to 2000 it declined by 95% and now as few as 6,000 otters may remain in the entire Aleutian chain. This is just one part of a catastrophic ecosystem collapse that is occurring in the area.

Another population of about 2,400 sea otters survives along the

California coast between Point Conception and Monterey Bay.

They are coming into increasing conflict with inshore fisheries for sea urchins.

. SEAL HUNTING

Fur seals. The loss of furs from other sources was a major incentive leading to massive hunts for various types of seal. The animals were usually clubbed to death when they came ashore to breed. The pattern was familiar - the discovery of large populations of target species, the development of intensive hunting leading to extermination or depletion, the move to a new area. The first phase (1780-1820) was directed at the southern fur seal in many areas of the southern hemisphere and was carried out by sealers from Europe, Russia, Canada and the U.S. Each of the following areas was the site of a fur seal hunt until the population was either commercially extinct (depleted to the level where it was not profitable to hunt) or really extinct: Off the west coast of Namibia in Africa, 40- 50,000 cape fur seal are taken each year. This is about 10% of the world's sealing activity, and much of the profit comes from the sale of penises for the aphrodisiac trade in Asia. Most of the seals are being killed by clubbing to death, which is claimed to be a humane method.

. In the North Pacific, the northern fur seal was hunted on the Pribilof Islands in the Bering Sea, first by the Russians using Inuit labor after they had wiped out the sea otters. The slaughter went from 127,000 in 1791 down to 7,000 a year in

the 1820's after 2.5 million had been killed. The population recovered after the Russian hunters moved to other areas, but after Alaska was sold to the U.S. in 1867 the hunting level went back up to 250,000 per year. This reduced the population again so that in the 1890's the number killed was down to 17,000 a year. It is now illegal to hunt fur seals, except for an exemption allowing Indians, Aleuts, and Eskimos to continue to hunt at a subsistence level (about 2000 a year).

Harp seal. A massive seal hunt also developed in the North Atlantic taking advantage of the huge harp seal population that breeds on the pack ice in winter around Labrador and Newfoundland. The sealers, from Newfoundland, focused on the newborn seals with pure white fur, although adults were also taken for their oil as well as fur. The Newfoundland sealing industry began in the early 19th century and peaked at about 600,000 animals per year in the 1850's. This ultimately led to reduction in the size of the herd to about one fifth of its original size, and the industry went into decline in the early 20th century. A 1998 study shows that the current level of hunting (350,000 animals killed in one season) is not sustainable, and 12 members of Congress have written to Secretary of State Madeleine Albright declaring their opposition to this hunt. Again in 1999 Canada is being criticized for allowing 275,000 of these animals to be killed in spite of public opinion against it. The adult harp seals are also hunted on a subsistence level further north by Inuit hunters, who use the meat for food but also sell the skins in order to pay for the snowmobiles, rifles, gasoline and ammunition that are used in their hunting activities.

Another herd of harp seals, at Jan Mayen Island in the Arctic ocean, was wiped out by a rapid boom and bust between 1840 and 1860.

Elephant Seals were hunted in the Pacific in the 1800s by whalers who wanted to supplement their catch. They were hunted for their oil rather than their fur or skin. Hundreds of thousands of these animals were killed in the southern ocean and along the coast of California. The southern population (a distinct subspecies) was

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. saved when the Kerguelen and Macquarie Islands were turned into nature reserves, but in 1884 it appeared that the northern subspecies had been lost. However, a small colony of about 50-100 had survived on Guadalupe Island off the coast of Baja California. The species was given protection by the Mexican and U.S. governments in the 1920s and the stock is now doing quite well. Today, there are approximately 160,000 northern elephant seals! A large breeding population (~2000) now congregates on the beach at Ano Nuevo, fifty-five miles south of San Francisco, every winter. Seals and sea lions may have had many more breeding colonies on the mainland before they were eliminated by prehistoric hunting.

Walruses were killed for three centuries for their oil, skin, and ivory

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