MARINE BIOLOGY
BIOLOGY 121

COURSE GUIDE

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Oceans
- 71% earth's surface
- ave depth = 3.7 km;
- deepest = 11 km
- all connected but 4 major divisions: Atlantic, Pacific, Indian, Arctic

Seas
- partially isolated by land masses and/or current gyres
- may have different chemical/physical characteristics
- often populated with endemic species due to isolation/physical differences from adjoining oceans
- examples of seas w/isolating mechanisms, features
  * Mediterranean: straits of Gibraltar, endemics and pollution due to little exchange with Atlantic
  * Sea of Okhtosk: embayment formed by Amchitka Peninsula
  * Caribbean: formed by Lesser Antilles and currents, endemics related to Atlantic species
  * Baltic: strait connecting to North Sea, salinity half of oceans due to freshwater runoff, endemics due to both physical isolation and salinity
  * Sargasso: isolated solely by current gyre, endemics, dated 40 yr old plastics

Ocean Floor
- Continental shelf
  * on margins of land masses, shallow, shore to 200m, width varies from 6 km to 1300 km
  * slope of approx 1 degree
  * continuous across Bering Sea, very narrow off S. America
  * formed by erosion of coastline, accumulation of terrogenous sediments (rivers,etc), sediments held against continent by barrier of reef building organisms
  * 80% of landing of world's fisheries
  * major portion of ocean oil & gas exploration
  * strong influence on economy of area
    - Alaska fishing grounds
    - Georges Bank in N. Atlantic
- Continental slope
  * past shelf to depth of 4-6 km; steeper
  * slope varies from 6 to 60 (S.America trenches) degrees; 13 degrees off So. Calif.
  * slides of sediments down slope common
- Abyssal plain
  * approx. 4 - 6 km depth; flat and long
  * constant conditions, no latitudinal variation
- water temp constant at approx. -1.2C
- little current flow, dark
- detritus from above ("detrital rain")

- Submarine ridges
  * shallower, rising out of abyssal plain
  * may reach surface to form oceanic islands, Azores, Ascension
  * formed by sea floor spreading as new material thrust to surface
  * world-wide system involved in plate tectonics
  * rift areas between produce hot water (hydrothermal) vents sites of unique
    marine communities not dependent on photosynthesis for primary
    production
  * branch of the (East Pacific Rise) in Gulf of Calif. forms San Andreas fault
    on land

- Sea mounts
  * rise individually from plain - volcanic
  * Hawaiian archipelago: pass over "hot spot"
  * biologically significant as colonized sequentially, as archipelagos form, and
    with very high incidence of endemism

- Trenches
  * deep narrow troughs in area bordering islands and continents in the Pacific
    Ocean
  * 7 - 11 km (Challenger Deep 11,022m - Mariana Trench)
  * volcanic and seismic activity near trenches: "Rim of Fire"
  * mountains on continental margins or islands formed by deformation of crust
    - Mariana/Tonga Islands next to trench
    - Andes in S. America
    - Kuril-Japanese trench/island system
PROPERTIES OF SEA WATER (PHYS11.LEC UPDATE: February 5, 2013)

Physical milieu of organisms which determines, in part, distributions and abundances

Physical properties
- heat capacity
  * temperature changes slowly
  * damps fluctuations of air (sink)
- density: density inc. w/ decrease max. @ -1.2 deg. C
  * bottom waters of oceans little changed by latitude

Chemical properties:
- solvent
  * polar: dissolution of ionic compounds (salts, etc.)
  * H-bonding: non-polar O-H, N-H, =O compounds (fats, etc.)
- pH acidity/alkalinity

Major constituents: salinity (total dissolved ions)
- polar compounds which dissolve in water
- 86% is NaCl
- Cations: (% of total salt)
  Na (30.62) electrolyte Mg (3.68) enzyme function
  Ca (1.18) prec./shell K (1.10) electrolyte
- Anions: (% of total salt)
  Cl (55.07) electrolyte SO₄ (7.72) anaerobic bacteria
  HCO₃ (0.4) prec./shell Br (0.19) antiherbiv./ neurotoxin

Sulfate reducing microorganisms: sediments/hydrothermal vents
- SO₄ - 2O₂ + S²⁻
- S²⁻ + H⁺ - H₂S (smell)
- H₂S + O₂ - 2H⁺ + SO₄²⁻ (surface)

Salinity variation
- normal: 36ppt
- total amount of dissolved salts; ratio remains the same
- brackish, hyposaline: Baltic 10 ppt <36ppt
- hypersaline; Persian Gulf 70 ppt >36ppt
- factors influencing variations
  * evaporation: lagoons, tidepools
  * freshwater: run-off, rivers

Dissolved gases: saturation
- amount of gas dissolved in water function of salinity and temperature

<table>
<thead>
<tr>
<th>Solubility</th>
<th>N₂</th>
<th>O₂</th>
<th>Ar</th>
<th>CO₂</th>
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<tbody>
<tr>
<td>air (%)</td>
<td>78</td>
<td>21</td>
<td>1</td>
<td>0.04</td>
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<tr>
<td>sea water (ppm)</td>
<td>12</td>
<td>7</td>
<td>90.0</td>
<td></td>
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</tbody>
</table>
- solubility decreases with increase in temp and salinity
- TS curve

- concentration also affected by physical and biological factors

Mixing of waters
- mixed for few hundred meters depth
- mechanisms: diffusion and advection
- deep currents move very slowly: hundreds to thousands of years

Gas distribution in water column
- interplay between biological & physical effects
- temp and salinity effects
- biological effects

\[
\begin{align*}
6\text{CO}_2 + 12\text{H}_2\text{O} & \longrightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} + 6\text{O}_2 \\
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 & \longrightarrow 6\text{CO}_2 + 12\text{H}_2\text{O} + \text{ATP}
\end{align*}
\]

* surface: photosynthesis - CO\(_2\) down, O\(_2\) up
* below photic zone: - CO\(_2\) up, O\(_2\) down
* deep waters affected by temp, not organisms

Carbon Cycle - buffer for atmospheric CO\(_2\)
- CO\(_2\) reservoir in atmosphere and ocean
- water and atmosphere in dynamic equilibrium
- C fixed by plants and cycled through organisms
- different pathways take different amounts of time: geologic vs. rapid cycling

Cycle
Mixing in the Water Column

Depth

Zone of mixing
Greenhouse effect

- effect of different gasses in atmosphere which absorb re-radiated heat and prevent it from leaving earth system
- warms earth 30 C (55 F): absorbs re-radiated IR light
- mostly water vapor
- one-half of effect from carbon dioxide: 0.04% atmospheric gasses
- other gasses effects: methane 20%; CFCs 15-20%, NO 6%
- increase in concentration since Industrial Revolution

- measurements NOAA Mount Mauna Loa Observatory 1958-
  * carbon dioxide 25%; 0.2%/yr (10% since 1958): combustion, deforestation
  * methane 1%/yr fastest (doubled over 300 yrs) cattle, sheep, termites, rice cult.
  * CFCs 4%/yr: insulation, circuit board cleaner, refrigerant
  * NO 0.25%/yr: fertilizer, slash-and-burn, combustion
  * fluorocarbons and ozone destruction

- actual greenhouse effect difficult to measure due to signal to noise ratio
  * cyclic trends: 1940-72 cooled, since 1972 warming
  * 4 - 8X of CO₂ increase by 2200 = mean annual temp up 6°C
  * last century 0.7 C (1.3 F) US team; 0.5 C (0.9 F) UK team
  * 2 - 5°C over next century; Boston - Wash. D.C. 3.3 C
  * last ice age 5-10 °C cooler (18,000 ya)
  * ice caps melt; major cities inundated
  * could affect acidity of waters

Effect on water chemistry
- CO₂ + H₂O <-> H₂O₃ <-> H⁺ + HCO₃⁻ <-> 2H⁺ + CO₃⁻ (lower pH)
- pH ocean approx 7.8 ave; deep = 7.4, shallow warm = 8.4
- affects deposition of sediments
  Gulf of Calif. coquina reef system

Nutrients: more biological interaction
- defined: anything besides CO₂ and H₂O needed by plants for synthesis of organic or skeletal material
- nitrogen and phosphorus in usable forms
- NO₂, NO₃, PO₄ (N=16X P conc.)
- cycled though biological system
- proportional to CO₂, inv. prop. to O₂ (why?)
  surface depleted; returned in animal resp. layers by respiration

Nitrogen cycle
- reservoir is elemental nitrogen in air N₂
- enters system "fixed" as nitrate by bacteria and algae volcanic action
- eaten by herbivores, or decay to release organic N
- excreted by animals as NH₃ (plankton, birds [guano], fish)
- returned to atmosphere by denitrifying bacteria
- returned from shallow marine sediments
- trapped in ocean sediments

**Phosphorus cycle**
- source is erosion of terrigenous deposits releasing $\text{PO}_4$
- dissolved in water and taken up by plants
- plants contribute to animals (herbivores), bacteria, and release back to phosphate pool
- animals excrete and contributed to shallow (exploitable) sediments
- dissolved phosphate incorporated into deep sediments
- enrichment is form of pollution resulting in unsustainable productivity: detergents, fish canneries

**Trace elements**
- Gold - $1,000,000$ in 1 km$^{-3}$
- trade metals in low concentrations
- held tightly by organisms and may be concentrated in the food chain
- some materials which are injurious to marine life are pollutants
Nitrogen Cycle

- atmosphere
  - Cyanobacteria
  - Nitrogen fixation

- nitrate
  - plants
  - ammonia
  - decomposers

- shallow sediments
  - Rapid cycling

- deep sediments
  - Slow cycling
  - animals
Phosphorous Cycle

- terrogenous phosphate (land)
  - Dissolves land sediments
- phosphate
  - Rapid cycling
  - Slow cycling
- decomposers
- plants
- shallow sediments
- animals
- deep sediments
- excretion
Hydrosphere: water on earth
- 98% in ocean
- remaining in polar ice caps

Hydrologic cycle: the transfer of water
- evaporation followed by condensation and return on continent or over ocean
  * determines distribution of water as well as climate
- heat engine
  * heat is transported in water vapor
  * unequal heating of earth drives atmospheric heat engine
  * water vapor content of air doubles with 10 deg C
  * large amounts of heat transported to create winds
  * drag of wind, spinning earth determine wind patterns
  * wind patterns and land masses determine currents
  * currents affect local climatic conditions: Gulf Stream

Major Wind Patterns
- Easterlies: trade winds and polar winds
  * prevailing wind from East to West
  * approximately 30N - 30S latitude
  * begins southward movement, deflected to west (from east)
- Westerlies
  * prevailing winds from 30 - 60N; 30 - 60S
- Doldrums
  * regions of light winds
  * 30 N &S

OCEAN CURRENTS AND DISTURBANCES (Currnt1.lec Update: February 5, 2013)

Currents
- surface
  * wind driven: drag on water
  * surface currents "pushed" by prevailing winds
  * Easterlies: trade winds and polar winds
    - Trade Winds approximately 30N - 30S latitude prevailing wind from EN to SW
    - polar 60+N,S from SE to NW (?)
  * Westerlies: West wind drift - Antarctic
    - 30-60N; 30-60S
    - prevailing winds from SW to NE (?)
  * Doldrums: regions of light winds
    - equator, 30N,S & 60N,S regions of light winds
  * winds on Calif. coast N->S, current deflected W by "Coriolus force"
* from 30N,S- water stacks up on eastern coasts
* Westerlies return water from higher latitudes
* current gyres, circular currents, formed
* gyres run in same direction at boundaries
* N. hemis. right-handed, S. hemis. left-handed
* major currents in Pacific Ocean
  - N. Pacific Gyre
    * Pacific North equatorial (joins Kuroshio)
    * Kuroshio (joins N.P. & Alaska)
    * North Pacific (joins California)
    * California (joins equatorial)
  - Gulf of Alaska (?)
    * Alaska gyre
  - S. Pacific Gyre
    * Pacific South equatorial
    * Peru
  - Antarctic
    * Antarctic Circumpolar "West Wind Drift"
* major currents in Atlantic Ocean
  - North Atlantic
  - West Greenland
  - E. Greenland
  - Labrador
  - Norway
  - Gulf Stream
  - North Equatorial
  - South Equatorial
  - Brazil
  - Benguela
  - Falkland
  - Equatorial Counter Current

- Counter currents
  * submerged currents running in different direction than surface currents; generally the opposite direction
  * 15 cm difference in height from E to W Pacific
  * equatorial counter-current runs downslope @ 100m depth below surface currents
  * one of the largest transporters is Cromwell Counter Current: 100m below surface Pacific
  * other counter-currents include the North Equatorial Counter Current and the South Equatorial Counter Current

- Upwelling
  * areas where deeper nutrient-rich waters are brought to surface
  * high biological productivity, fisheries
- anchoveta off Peru
- sardine/anchovy off California
* three mechanisms
  - winds push water away from land and replaced by deeper nutrient-rich water: W coasts of continents (N. Africa - water from 300m)
  - deep currents strike headlands and are deflected upwards: Pt. Dume, Pt. Fermin
  - diverging currents "bounce" off each other and create vacuum drawing up deeper waters: equator

TEMPERATURE ZONES

Areas broadly defined by annual mean temperature
- tropics: 30 deg N to 30 deg. S
- warm temperate: 30 deg to approx 45, varies
- cold temperate: approx. 45 deg to 60
- polar: latitude above 60 N,S

THERMOCLINE AND PRODUCTIVITY

Thermocline: defined as the depth range in water column over which temperature changes.
  - depth usually 50 to 300M
  - under the thermocline the temp. changes slowly, nearly isothermal
  - varies with area
  * constant in tropics
  * summer in temperate areas: spring and fall turnover
  * does not exist in polar regions
SEASONAL AND LATITUDINAL VARIATION IN THE THERMOCLINE

**TEMPERATE ZONE**

**SUMMER**
1) strat.
2) temp.
3) light
4) nutrients
5) productivity

**EARLY FALL**
1) strat.
2) temp.
3) light
4) nutrients
5) prod.

**LATE FALL**
1) strat.
2) temp.
3) light
4) nutrients
5) productivity

**WINTER**
1) strat.
2) temp.
3) light
4) nutrients
5) prod.

**TROPICS**

**SPRING**
1) strat.
2) temp.
3) light
4) nutrients
5) productivity

**WINTER**
1) strat.
2) temp.
3) light
4) nutrients
5) prod.

**POLAR**

**WINTER**
1) strat.
2) temp.
3) light
4) nutrients
5) productivity

**SUMMER**
1) strat.
2) temp.
3) light
4) nutrients
5) prod.
OCEANIC ENVIRONMENTAL ZONES

The bottom of the ocean, or benthic environment, as well as the waters of the oceans, or the pelagic environment, are classified into zones. Classification allows for ease of reference and defining areas according to physical characteristics that influence the distribution of life in the oceans.

The classification schemes for the benthic and oceanic environments are summarized below along with their major features highlighted.

BENTHIC ZONES

The benthic zones are classified according to the depth of the bottom. The depth range for each of the zones is indicated below.

*Spray Zone (American) or Supralittoral (European).* Area of the shore only wetted by spray.

*Intertidal Zone (American) or Littoral (European).* Area of the shore between the highest high tide and lowest low tide. Very large height differences exist in exposed open coastal areas and at the end of long narrow impounds such as the Gulf of California and the Bay of Fundy.

*Subtidal Zone (American) or Sublittoral (European).* From the lower end of the intertidal zone to the continental shelf, or to approximately 200m. The water above this defines the nearshore or the neritic zone. Areas of high productivity with bottom moderately accessible to the waters above.

*Bathyalbenthic Zone.* From the lower end of the subtidal zone (approx. 200m) to 4000m, area of continental slope.

*Abyssalbenthic Zone.* From the end of the bathyl zone to the abyssal plain, approx. 4000m to 6000m. Cold, dark constant environment of slow currents and fine sediments. Organic input primarily in the form of detritus which rains down from the water above.

*Hadalbenthic Zone.* Below the abyssal plain in the oceanic trenches, approximately 6000Mm to 11,000m.

PELAGIC ZONES

The pelagic zones are divisions of the water column, that is the water from the surface to the bottom. The pelagic zones are defined by more criteria than simply depth. Several factors important to life, that is conditions which potentially influence life change over depth. These physical factors are used in defining the different pelagic zones.

*Epipelagic:* 100m to 150m. The surface to the lowest depth of light penetration. The depth to which light penetrates will vary by latitude as well as by season. Light penetration is most influenced by the amount of minute plankton, especially the plant or phytoplankton, in the water. In the tropics
there is little free-floating phytoplankton and as a result the light penetrates deep. In waters of high phytoplankton concentration, such as the temperate and polar regions, the epipelagic zone is shallower. The depth of light penetration also varies by season with the least penetration during the fast growth periods of spring and fall and the greatest penetration in the summer.

The epipelagic zone is extremely important to the overall productivity of waters since this is the zone in which the plants exist. The epipelagic zone is also known as the Photic Zone, or the zone with light.

Mesopelagic: The mesopelagic zone extends from the bottom of the Epipelagic Zone (approximately 100-150m) to the depth at which the water temperature is 10 degrees Centigrade (approximately 700-1000m), of the 10°C isotherm. The mesopelagic also defines the uppermost part of the Aphotic Zone, or the waters lacking light.

Bathypelagic: The bathypelagic zone extends from the bottom of the Mesopelagic Zone (approximately 700-1000m) to the 4 degree Centigrade isotherm (approximately 2000-4000m). This zone represents the waters over much of the continental slope.

Abyssalpelagic: The abyssalpelagic zone waters are those over the Abyssal Plain (approximately 4000-6000m).

Hadalpelagic: The hadalpelagic zone waters are those in the oceanic trenches, that is at depths below the abyssal plain (6000m and deeper).

Neritic or Nearshore Zone. The neritic or nearshore zone is the water over the subtidal and continental shelf. These are the most productive of ocean waters and are located along the margins of the continents. Bottom structures influence life in this zone and it is here that reefs, kelp forests, and other physical structures provide habitats for many varieties of life.

Oceanic Zone. The oceanic waters cover most of the ocean bottom, from the continental slope and deeper. The bottom is far below and accessible only to a relative few species in these waters. Organisms of the oceanic zone are largely deprived of shelter from physical structures such as rock and coral reefs, and algae. Fishes in these waters are mostly streamlined fast swimmers.
CLASSIFICATION OF HABITAT
(HABIT1L.LEC UPDATE: February 5, 2013)

Plankton
- floating or weak swimming; moves at mercy of currents
- may move vertically; buoyancy important
- buoyancy provided by
  * oils and fats
  * gelatinous body
  * hairs, spines, other processes
  * chain formation
- may move long distances in currents and use buoyancy for vertical movement
- neuston: plankton on the top, or surface layer, of water
- phytoplankton (plants)
  * diatoms, dinoflaggelates
- zooplankton (animals)
  * larvae, eggs, larger jellyfish and fish (Mola mola)

Nekton
- swimming or motile in water column
- may move long or short distances
  * migrations - tuna, marine mammals
  * territorial - fish

Benthos
- on or within the bottom sediments
  * terminology applied to relationship to of organisms with the substratum (sediments)
    - on top: epibenthos, epibiota, epifauna
    - within: infauna
- attachment/mobility (ability to move) and examples
  * sessile: attached and unable to move (both plants and animals)
    - epibenthos
      * plants: either attached with holdfasts or with an encrusting (prostrate) thallus
        - almost exclusively on hard bottoms: very rare on soft bottoms with poor attachment surface; vulnerable to predators
      * animals: several modes of attachment on hard bottoms
        - encrusting (bryozoans)
        - cement shell or tube (barnacles, scallops, worms, tube snails)
        - much less on soft bottoms due to poor attachment surface
    - infauna (animals only): bore or burrow into the substrate
      * hard bottom
        - piddocks: clams that bore into hard bottom/rocks; includes boring bivalve known as "shipworms"
          * boring sponges: dissolve shell material to bore
      * soft bottoms
- anemones, worms forming tubes
- ghost shrimps, clams, mantis shrimps, sea cucumbers, worms, burrowing into bottom

* motile: ability to move (may be very slowly)
  - hard bottoms
    * creeping (foot of molluscs)
    * articulated appendages (arthropods, echinoderm spines)
    * tube feet (echinoderms)
    * sedentary (very slow movement): sea anemones (pedal disc), mussels (byssus)
  - soft bottoms
    * articulated appendages (arthropods, echinoderm spines)
    * creeping: snails with large foot (conchs)
    * plowing: push along just below surface (moon snails, urchins, heart urchins, olive snails)

Demersal
- living close to bottom, often closely associated with benthic forms
  * motile, may undertake diurnal migrations
  * demersal zooplankton
  * demersal fishes and invertebrates

**FEEDING MODES**

- How an organism feeds (not what it feeds on).
  * dictated by habit and genetic constraints
  * includes symmetry of taxon
  * relationship between habit of prey/food and symmetry of feeding organism

Symmetry
- radial, pentamous
  * detect environment from all directions
  * adaptive if have no control over approach of prey
    - planktonic, sessile
- bilateral
  * concentrate sensory apparatus in one area
  * streamlining possible, chasing
- asymmetric

Types of feeding
- predation: kill and consume prey
  * plant or animal prey
  * prey: sessile/sedentary
    - predator
      * habit: motile
      * symmetry: variable - radial/ bilateral
- sea stars, octopus, fishes, snails

* note that chemoreception play large role in detection by invertebrates predators

* prey: motile
  - predator
    * habit: motile (chase - raptorial)
    * symmetry: bilateral symmetry
      - fishes, mammals, crustaceans, molluscs
    * note role of vision

* prey: suspended particles, organisms (suspension feeding: special case - overlaps with predation)
  - active suspension feeding: create current
    * habit: variable - sessile, planktonic, motile
    * symmetry: variable according to habit - bilateral, radial, asymmetric
      - bilateral: smelts, baleen whales, clams, barnacles, polychaetes, basking shark
      - asymmetric: sponges, some tunicates
      - radial: rare (symmetry mostly found in passive feeding)
  - passive suspension feeding: do not create current
    * symmetry: radial, radial superimposed on bilateral symmetry
    * habit: radial/pentamerous
      - jellyfish, corals, anemones, tube snails

- grazing (similar to predation on sessile prey)
  * prey: sessile
    - grazer
      * habit: motile
      * symmetry: variable - radial/ bilateral
        - urchins, snails, fishes

- deposit feeding: ingest sediments
  * same as grazing - equivalents of grazers on hard bottoms
    - holothurians, urchins, brittle stars, some clams

**Summary of the relationships between feeding mode, habit of feeding organism, symmetry and prey/food habit.**

**Definitions of feeding modes and examples.**

**Predator/raptorial** (chase prey down): tuna family, pelagic sharks, squid, marine mammals

**Predator/ambush** (lay-in-wait): glycerid (fanged) worms, halibut, mantis shrimps, caprellid amphipods, clinind fish (kelpfish).

**Grazer** (consume tissues which are then regenerated by prey - plants, colonial species):
  - snails (abalone, turbans, limpets), fish (opaleye), urchins.

**Suspension/active** (create current to bring suspended prey/food to the organism): sponges, baleen whales,
anchovies, salps, mussels, polychaete worms in 2-opening tubes.

Suspension/passive (current carries prey/food to the organism): anemones, "jellyfish", polychaete worms in single-opening tubes, tube snails, corals.

Deposit feeding (ingest sediments and digest organic material): holothurians, urchins, brittle stars, some clams, ghost shrimps, some polychaete worms.

<table>
<thead>
<tr>
<th>FEEDING MODE</th>
<th>HABIT</th>
<th>SYMMETRY</th>
<th>PREY HABIT</th>
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<tbody>
<tr>
<td>Predator</td>
<td>motile</td>
<td>bilateral</td>
<td>motile</td>
</tr>
<tr>
<td>Raptorial</td>
<td></td>
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<td>variable</td>
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<tr>
<td>Predator</td>
<td>motile/variable</td>
<td>bilateral, variable</td>
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<tr>
<td>Non-raptorial</td>
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<td>Grazer</td>
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<td>variable</td>
<td>sessile</td>
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<tr>
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<tr>
<td>Active</td>
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<td>Passive</td>
<td>sessile, sedentary planktonic</td>
<td>radial or radial feeding structure</td>
<td>planktonic</td>
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<tr>
<td>Deposit</td>
<td>motile</td>
<td>variable</td>
<td>add/mix sediments</td>
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**PHYLOGENY & CLASSIFICATION**

(Class1L.LEC UPDATE: February 5, 2013)

Nature of classification
- need for classification
- information conveyed by scheme
- classification schemes based on theory
  - relationships reflected in a scheme
  - life: evolution by natural selection
  - phylogeny or evolutionary histories
- information content to schemes
  - highest information in hierarchical system
    - each level is contained and is partly determined by all levels above it
    - use morphological, physiological, embryological, fossil data

Phylogeny
- evolution implies many unlike species have common ancestor and all forms of life probably stem from the same remote beginnings
- many types of evidenced used, with speculation, to produce theory of evolutionary history,
or phylogeny
- sources of data to formulate phylogenies
  * morphology = external, internal, histology, chromosomes
  * fossil record
  * embryology
  * life histories (stages through which pass in life cycle)
  * behavior
  * ecology
- careful interpretation necessary to weigh evidence
- interpreting data
  * inferring primitive and advanced characteristics
  * problem of convergence
  * homologous (inherited from common ancestor) vs. analogous (similar function only)
    - wings of birds and butterflies
  * phylogenetic tree

Classification of life
- taxa: classification units or groupings (e.g. phylum, family, species)
- variability: 2,3,4,6 kingdoms
- 3 kingdoms for this course
  * Monera, Plantae, Animalia

<table>
<thead>
<tr>
<th>Kingdom</th>
<th>Animalia</th>
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<tbody>
<tr>
<td>Phylum or Division</td>
<td>Chordata</td>
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<tr>
<td>Subphylum</td>
<td>Vertebrata</td>
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<tr>
<td>Class</td>
<td>Mammalia</td>
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<tr>
<td>Order</td>
<td>Primates</td>
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<td>Family</td>
<td>Hominidae</td>
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<td>Genus</td>
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<td>Homo sapiens</td>
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<tr>
<td>Subspecies</td>
<td>Homo sapiens sapiens</td>
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Nomenclature
- binomial nomenclature
  * each species name of two words: genus and specific name
  * Latinized and approved by nomenclature congresses
- Carolus Linnaeus (1720-1778)
- taxonomy: the science of naming organisms, indicates phylogenetic relatedness
- systematics: study of the relationships among species
SYSTEMATIC SUMMARY OF MARINE LIFE

KINGDOM: MONERA
Division: Cyanophyta* (blue-green algae)
Schizomycetes (bacteria*)

KINGDOM: PLANTAE
Subkingdom: Thallophyta (non-vascular plants)
Division: Chlorophycophyta* (green algae)
Rhodophycophyta* (red algae)
Phaeophycophyta* (brown algae)
Chrysophycophyta* (diatoms)
Pyrrophycophyta* (dinoflagellates)
Subkingdom: Embryophyta (vascular plants)
Division: Tracheophyta/Anthophyta

KINGDOM: ANIMALIA
Phylum: Protista/Protozoa (protozoans)
Class: Flagellata (flagellates)
Sarcodina*
Order: Foraminifera* (foraminifers)
Radiolaria* (radiolarians)
Class: Ciliata (ciliates)
Sporozoa
Phylum: Porifera* (sponges)
Class: Calcarea
Hexactinellida
Desmospongiae
Phylum: Cnidaria*/Coelenterata*
Class: Hydrozoa* (hydroids, colonial jellyfish)
Scyphozoa* (jellyfish)
Anthozoa* (anemones, corals)
Phylum: Ctenophora (comb jellies)
Phylum: Platyhelminthes
Class: Turbellaria (flatworms)
Trematoda (flukes)
Cestoda (tapeworms)
Phylum: Nemertea (ribbon worms)
Phylum: Phoronida* (phoronids)
Phylum: Brachiopoda* (lantern shells)
Phylum: Mollusca*
Class: Monoplacophora
Amphineura*/Polyplacophora (chitons)
Scaphopoda (tooth shells)
Gastropoda* (snails, slugs)
Cephalopoda* (octopus, squid, nautilus)
Bivalvia*/Pelecypoda* (clams)
Phylum: Annelida*
Class: Oligochaeta (earth worms)
Polychaeta* ("legged" worms)
Hirudinea (leeches)
Phylum: Sipunculida (peanut worms)
Phylum: Echiura (disgusting worms)
Phylum: Arthropoda*
Subphylum: Chelicerata*
Class: Merostoma* (horseshoe crabs)
Subphylum: Mandibulata
Class: Crustacea*
Subclass: Copepoda* (copepods)
Cirripedia* (barnacles)
Malacostraca
Order: Mysidacea* (mysids)
Isopoda* (louses, pill-bugs)
Amphipoda* (amphipods)
Euphausidacea* (euphausids, krill)
Decapoda
Suborder: Natantia* (shrimps)
Reptantia (crabs)
Section: Macrura* (lobster, crayfish)
Brachyura* ("true" crabs)
Anomura* (sand crabs)
Phylum: Echinodermata*
Class: Asteroidea* (sea stars)
Echinoidea* (sea urchins, sand dollars)
Holothuroidea* (sea cucumbers)
Ophiuroidea* (brittle stars)
Crinoidea (sea lilies)
Phylum: Chordata*
Subphylum: Urochordata* (sea squirts)
Cephalochordata* (amphioxus)
Vertebrata*
Class: Agnatha* (lampreys, hagfish)
Class: Elasmobranchiomorpha*/
Chondrichthyes* (sharks, rays)
Osteichthyes*/Teleostomi* (bony fishes)
Mammalia*
Superorder: Cetacea*
Order: Mysticeti* (baleen whales)
Family: Balaenidae (right whales*)
Balaenopteridae (rorquals*)
Eschrichtiidae (gr. whale*)
Order: Odontoceti* (toothed whales)
Family: Physeteridae (Sperm whale*)
Monodontidae (narwhal, Beluga)
Delphinidae* (dolphins)
Phocoenidae* (porpoises)
Order: Carnivora*
Family: Mustelidae (sea otter)
Order: Pinnipedia* (sea lions, seals)
Family: Otariidae (sea lions)
SURVEY OF MARINE ORGANISMS (PROK1L.LEC UPDATE: February 5, 2013)

Survey of Marine Phyla
- purpose to become acquainted with the major groups of marine organisms
- introduce major features of organisms, important trends
- cover structure, physiology, reproduction, feeding, adaptations, and ecology
- this information will be used later to understand the role of the organisms in the different communities to be studied

KINGDOM MONERA

Prokaryotes
- small, prokaryotes (no organelles, no distinct nucleus)
- reproduce by binary fission
- reproduce rapidly to exploit available resources

BACTERIA/SCHIZOMYCETES
- saprophytic (dead organic matter) or parasitic
- some photosynthetic, some chemotrophs
- important ecologically to breakdown organic matter and release inorganic nutrients
- primary producers in some communities: vents, cold seeps
- conversion and cycling of nutrients

CYANOBACTERIA/CYANOPHYTA (BLUE-GREEN ALGAE)
- can live in extreme conditions: high temperatures (85 deg. C, 185 deg F), dry intertidal heights
- fix nitrogen, need only N₂, CO₂, H₂O, light, minerals

Eukaryote cells
- all plants and animals are composed of this type of cell
- complex cells with organelles
- cells specialize to form complex multicellular organisms with specialized organs

KINGDOM PLANTAE (PLNTS1L.LEC UPDATE: February 5, 2013)

Plants
- photosynthetic autotrophs (self-nourishing) organisms which are at the base of all known food webs except for the deep sea hydrothermal vent community.
- "fix" carbon into biological molecules
- separate into two groups: Thallophyta and Embryophyta
  * Embryophyta - vascular plants
    - possess vascular systems which allow translocation of nutrients, water, synthates (sugars, etc.)
    - allows specialization of organs (leaves, roots, etc.)
  * Thallophyta - Nonvascular plants (Algae)
    - lack vascular system: cannot translocate
- each cell must be capable of carrying out all metabolic activities (gas exchange, nutrient acquisition, photosynthesis, etc.)
- the size and form of this group is limited due to the necessity of: (1) exchanging materials/gasses by diffusion, which is effective only over short distances and (2) access to light for photosynthesis
- thallus ("body") is necessarily thin
- no true specialized organs

Role of photosynthesis
- photosynthetic pigments
  * role to absorb light (radiant energy) and convert into chemical bond energy in photosynthesis

\[
eq 6\text{CO}_2 + 12\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}
\]

* different color pigments absorb color light
  - chlorophyll (green) absorbs red and blue
  - fucoxanthin (brown) absorbs green/blue
  - phycoerythrin (red) absorbs blue
  - accessory pigments serve as alternate light receptors and/or "sunscreens"

- light penetration in water
  * electromagnetic spectrum includes waves varying in length from short, high energy "x" and alpha waves to long, low energy radio waves
  * wavelengths: visible light = 400-700nm; x-ray, gamma ray less; IR=1mm; radar=1m, radio=1km
  * the depth of penetration of (absorption) of wavelengths differs by color:
    - blue penetrates deep; 10% penetrates to 100m in tropics
    - red has shallow penetration; 100% absorbed by 10m in tropics

Reproduction
- reproductive cycle of green and brown algae
  * alternation of generations: gametophyte (1N) and sporophyte (2N)
  * isomorphic or heteromorphic

- red algae (Rhodophycophyta) involve an additional tetrasporophyte generation
- some browns (Phaeophycophyta - fucoids) have eliminated gametophyte generation similar to land plants

**DIVISION: CHLOROPHYCOPHYTA (GREEN ALGAE)**
- macrophytes: green in color, chlorophyll a and b
- represented by attached benthic forms generally thin and small
- shallow habitat, intertidal, floating - need red light
- life-history characteristics
  * rapid growth  * fast reproduction
  * excellent dispersal ability  * palatable to grazers
  * poor competitor with other slower-growing species of algae
  * found in disturbed habitats
  * follows fugitive or "weed" life-history strategy
- local genera
  * Ulva, Codium, Enteromorpha (intertidal)

**DIVISION: CHRYSOPHYCOPHYTA (GOLDEN-BROWN, DIATOMS)**
- microphytes: photosynthetic, planktonic or benthic film on algae, shells
- silica impregnated test (SiO2) epitheca, hypotheca (valves)
- pigments: B-carotene (yellow), fucoxanthin, diatoxanthin, diadunoxanthin, other carotenoids
- most abundant component of marine plankton (2 mil/gal)
- rapidly exploit resources (nutrients) = "blooms"
- reproduce by binary fission
  * size increase after division by extrusion of protoplast to form spore which can germinate into larger individual
  * auxospores: zygotes formed infrequently (3-5 mo.) by union of sperm with protoplasm of ovum
- principal photosynthetic producers of ocean
- shells sink to form diatomaceous deposits

**DIVISION: PYRROPHYCOPHYTA (DINOFLAGELLATES)**
- microphytes: small and planktonic, flagellated
- photosynthetic or heterotrophic
- second to diatoms as producers of organic matter
- may have other colored pigments
- responsible for bioluminescence at night in ocean
- specialized group: zooxanthellae - live within tissues of corals, etc.
- undergo "blooms" = red tide
- many poisonous = paralytic shellfish poisoning: Saxadoma =saxitoxin (50X curare)
  * *Gonyaulax, Peridinium, Ceratium*
- tropical disease ciguatera caused by concentration of toxins in food web
DIVISION: PHAEOPHYCOPHYTA (BROWN ALGAE)
- macrophytes: size ranges from small filamentous to large Giant Kelp
- pigments
  * chlorophyll a and c
  * fucoxanthin (carotenoid pigment = brown color)
  * functions as both sunscreen and accessory light receptor
- highest growth rate of plants: Macrocystis pyrifera 2ft/day
- latitudinal distribution: very abundant and conspicuous species in temperate water
- depth distribution: intertidal and subtidal on rocky coasts to 90 ft.
- alginic acid (alggin) extracted for commercial use
- life history
  * alternation of generations 2N/1N
  * dominant macroscopic sporophyte, microscopic gametophyte
- anatomy/thallus structure (modified for kelps)
  * blade
  * pneumatocyst
  * stipe
  * holdfast
  * haptera
  * growing tip

DIVISION: RHODOPHYCOPHYTA (RED ALGAE)
- mostly marine and live to greater depths
- source of agar: Gelidium (culture bacteria, ice cream)
- pigments
  * chlorophyll a and d
  * accessory pigments: phycocyanins and phycoerythrins allow growth at depth and under shaded conditions
  * may be found under dense kelp canopies and deep waters
- fleshy and coralline (crustose and articulated)
  - fleshy: soft tissues
    * "weed" strategists: Porphyra (nori)
    * grazer resistant with bromine: Laurencia
  - coralline: CaCO3 in cell wall, grazer and surge resistant, poor competitors for space but survive overgrowth
    * encrusting: prostrate
      - Lithothamnion cements corals together to form coral reefs
      * articulated: crustose holdfast and jointed erect branches
      * complex life cycles

SURVEY OF MARINE PHYLA: (PROT1L.LEC UPDATE: February 5, 2013)

KINGDOM ANIMALIA
Heterotrophic nutrition, eukaryotic,
- consumers of ecosystem

PHYLUM PROTISTA OR PROTOZOA (confused taxonomy): single-celled (acellular)
- very important in converting smaller microscopic organisms into larger masses available to larger consumers
- consume bacteria, small phyto- and zooplankton
CLASS SARCODINA
- amoeboid protozoans
- some shelled: important marine species
- pseudopodia: extruded "jelly-like" appendages used to capture and engulf prey of bacteria, algae, diatoms, protozoans

ORDER FORAMINIFERA (FORAMS)
- calcareous tests (CaCO$_3$) with minute pores through which pseudopodia extend
- modified branching pseudopodia: reticulopodia (branched)
- many benthic, some planktonic & abundant: Globigerina
- form calcareous sediments in shallow warm seas: limestone
- no deposition below 15,000 ft (5,000m) due to low pH of water
- fossil deposits for the White Cliffs of Dover

ORDER RADIOLARIA (RADS)
- ornate spherical tests (capsule) of silicate (SiO$_2$) with minute pores
- stiff axial pseudopodia: sticky for prey capture (engulf)
- planktonic and exclusively marine
- stratification of species by depth to 4600m
- fossil deposits form chert

METAZOA: MULTICELLULAR ANIMALS (PORIF1L.LEC UPDATE:February 5, 2013)

PHYLUM PORIFERA: SPONGES
Structure and feeding
- loose multicellular structure, 3 layers or "tissues" (not true tissues)
- perforated body with large cavity in middle (primitive) or number of channels lined with flagellated cells
- body plan classified as asconoid, syconoid or leuconoid depending upon amount of folding of body wall
- "tissue" layers
  * flattened cells of epidermis with ostia
  * middle layer of gelatinous cells (mesenchyme) and supportive spines (spicules) of CaCO$_3$, siliceous, and different shapes and spongin fibers (classified by spicule composition, shape)
  * inner layer of flagellated cells: choanocytes (collar cells) which trap particles on collars and consume them by the process of phagocytosis
- body cavity: anastomosing series of channels lined with choanocytes called the spongocoel
- feed by creating current with flagellae of choanocytes drawing water in through ostia, filter water passing through by trapping particles on collars of choanocytes, engulf particles by phagocytosis, and expel water through the excurrent opening or osculum
- reproduce by budding and resistant gemmules "eggs"
Ecology
- distribution
  * found in dark on bottoms of rocks, caves, depths
  * tropical reefs; fish grazing to limit algal growth
  * poor competitors with algae which mostly restricts distribution to areas where algae cannot grow
- feeding: active suspension feeding on small particles: bacteria, phytoplankton, detritus
- predators: fish, urchins, nudibranch snails, sea turtles

**PHYLUM COELENTERATA/CNIDARIA**
(CNID1L.LEC UPDATE: February 5, 2013)

General characteristics of the phylum
- radial symmetry: no front/back (anterior/posterior) orientation thus oral and aboral sides
- three tissue layers
  * epidermis: flatten cells
  * mesoglea: gelatinous cells with musculature
  * gastrodermis: secrete digestive enzymes into the gut
- gastrovascular cavity: gut with external digestion
- two morphs or body forms possible
  * medusa: swimming bell with tentacles
  * polyp: benthic column with tentacles surrounding mouth (pedal disc, column, tentacles)
- tentacles surround mouth: prey capture and defense
  * nematocysts for stinging (penetrant) and holding (glutinant, volvent)
  * sting to immobilize prey - weak musculature of cnidarian
- simple nerve network causes all parts of the organism to respond to localized stimulus
- nutrition
  * symbiotic zooxanthellae algae (Pyrrophycophyta) in stony corals and some anemones
  * corals/anemones consume demersal zooplankton - passive suspension feeding
  * larger anemones consume larger suspended/tumbled prey: mussels, etc.
  * medusae may capture fish and other planktonic invertebrates by passive suspension feeding
- solitary and colonial forms
  * polyps or medusae and polyps together
- reproduction
  * sexual (form gametes) and asexual (budding) reproduction involving polyps medusae
  * metagenesis: two different body forms/morphs with no difference in ploidy
  * complete potential life history
    - bud planktonic medusae from strobila
    - medusae release gametes (sperm and egg)
    - gametes fuse to form zygote
    - forms planktonic weak-swimming ciliated planula larva
    - larva settles and metamorphoses into new polyp
  * not all stages are present in all groups, some pass internally
- dispersal
  * planula larva and medusae disperse in plankton
  * budding for rapid exploitation of resource (space) but very limited dispersal

**CLASS HYDROZOA**: hydroids
- small and soft bodied
- stalked colonies of polypoid phase dominant: from feather-like structures w/small medusae
- some groups with calcareous skeleton: hydrocorals - common on coral reefs
- passive suspension feeding: small prey
- metagenesis (use both polyp and medusa morphs)
- siphonophores: medusae and polyps together as colony: Physalia (Portuguese Man-of-War)

**CLASS SCYPHOZOA**: true jelly fish
- medusae dominant life phase
- larger than hydromedusae
- may have long feeding tentacles for prey capture
- Aurelia, Pelagia
- reproduction: gonads produce gametes -> planula larva -> scyphistoma larva (polyp) ->
  medusae (ephyra) -> medusae (mature)

**CLASS ANTHOZOA**
- sea anemones, hard and soft corals, sea pens, sea pansys
- polypoid generation dominant
- benthic-sedentary to sessile
- possess sac-like branched gastrovascular cavity
- thicker muscular mesoglea, nematocysts present
- corals have CaCO3 skeleton
- solitary and colonial forms
  * some anemones and corals
  * colonial forms - branching structures and prostrate "heads", hard and soft corals
    - clones compete for space and sting each other to prevent overgrowth:
      anemones and coral heads
    - competition between branching and prostrate species of corals based on ability of the
      branching species to shadow the prostrate species
- reproduce sexually by pedal budding; sexual sperm and eggs in pharynx - ciliated spherical ciliated
  larva
  * clones formed when budding occurs
- predators: parrot fishes, Acanthaster
- forms
  * anemones: solitary and colonial Anthopleura
  * colonial soft corals: Lophogorgia, black coral
  * sea pansy: colony in soft matrix
  * hard corals: Acropora, heads
PHYLUM CTENOPHORA (comb jellies)
- coelenterate-like
- no nematocysts
- 8 rows of cilia
- planktonic near shore or midwater

PHYLUM MOLLUSCA (MOLL1.L.EC: UPDATE February 5, 2013)
- second largest phylum in the animal kingdom
- separate the body into three component parts
  * foot: used for locomotion/attachment, can be extended from shell if present
  * visceral mass: contains the organs, located above(dorsal to) the foot
  * mantle: membrane surrounding the visceral mass to form the mantle cavity, possesses glands with which to secrete the shell
- circulatory system
  * combination of heart, some vessels and circulatory sinus
  * not efficient enough for rapid movement except as modified in the cephalopods
- gills
  * gaseous exchange between circ. system and environment
  * thin stacked thin leaf-like structures filled with capillaries
- reproduction
  * sexual with separate sexes or hermaphrodites
- dispersed by free swimming veliger larvae
- six classes: Ampineura, Monoplacophora, Scaphopoda, Pelecypoda, Gastropoda, Cephalopoda

CLASS AMPHINEURA (chitons)
- shell of 8 articulating plates held in place by a fleshy girdle - no distinct head or localization of sensory organs
- radula (ribbon-like file protruded from the mouth) for rasping (common to other classes as well)
- crawl with muscular foot
- many intertidal species "home" to a "scar" with limited activity periods: dicuss homing

CLASS MONOPLACOPHORA
- thought extinct for 100 my
- found deep in trenches
- shares developmental characteristics with worms which suggests relatedness

CLASS GASTROPODA (snails, slugs)
- distinct head and well developed sensory organs
- may have gills or "lungs" (pulmonates)
- gills are generally within the mantle cavity or may be exposed (nudibranchs)
- all have shell but may be reduced and internal
- all have radula used for either grazing algae or boring into shells of prey
- some limpets exhibit "homing" behavior similar to amphiineurans
- example groups:
  * archaeogastropods: (limpets and abalone) simple shell lacks spiral
  * neogastropods: spiral shells, many predators (welks)
* sea slugs and nudibranchs: shell internal or lacking, gills in mantle fold or on dorsal surface, distasteful and often with warning coloration, some incorporate nematocysts from ingested cnidarians

**CLASS SCAPHOPODA** (tooth or tusk shells)
- live buried in sand/mud
- tusk-like shell

**CLASS PELECYPODA/BIVALVIA** (clams, oysters, etc.)
- shell composed of two hinged valves: ribbing and shape related to habit
- fleshy mantle lines inside of the shell and openings are the siphons through which water is drawn into the mantle cavity
- filter feed by straining particles from water
  * current created by ciliated gills
  * live attached to substrata or in sand/mud
- example groups:
  * clams: burrow into substratum - mud to rock
  * oysters/scallops: one valve attached to substratum - large adductor muscles to hold valves closed
  * mussels: byssus to attach - ribbed with inflated shell to live on surface
  * pholids: bore into hard substratum with acidic secretions and shell

**CLASS CEPHALOPODA**
- highly motile: voracious predators
- head in foot
- hydrostatic skeleton; shell present or reduced to a pen, cuttlebone, or lacking
- propulsion by "jetting": water expelled from mantle cavity
- mouth surrounded by tentacles with suction discs
- may have radula and beak with powerful neurotoxin
- ink gland
- chromatophores allowing rapid color change for camouflage as well as displays
- foraging behavior
  * squid may be cannibalistic
  * octopus may pry or drill shelled molluscan prey
- capable of learning
  * accomplish tasks for rewards
- example groups:
  * octopus: use beak and/or drilling for prey capture
  * squid: swim with finlets and jetting (N. Atlantic giant squid 55 ft, 2 tons)
  * nautaloids: chambered shell used for buoyancy control

**PHYLUM ARTHROPODA** (ART1L.LEC UPDATE: February 5, 2013)
- largest phylum: includes insects, crustaceans
- 800,000 species
- jointed chitinous exoskeleton and jointed legs
- paired appendages adapted for different uses
- must shed external skeleton to grow (molt)
- skeleton of protein (and calcium carbonate - crustacea)
- gills attached to thoracic appendages may be under protective carapace
- all life styles

**SUBPHYLUM: CHELICERATA** - first pair of appendages are pincers or chelicerae
- 4 classes
  * Pycnogonida (sea spiders)
  * Euryptida (extinct)
  * Merostomata (horseshoe crabs)
  * Arachnida (spiders, ticks, scorpions, etc.)
- only two groups marine
- horseshoe crabs: relic species - 1 of 3 extant species on Atlantic coast

**SUBPHYLUM: MANDIBULATA** - first pair of appendages are mandibles
**CLASS CRUSTACEA** 26,000 species (only class primarily aquatic) lobsters, shrimps, crabs, barnacles, sowbugs
- general body plan
  * segmented with articulating plates
  * head: possess 1 pair antennules, 1 pair antennae, 1 pair mandibles, 2 pair maxillae for feeding
  * thorax sometimes covered with sheet-like carapace
  * abdomen no. of segments varies: eggs brooded
  * appendages on each segment adapted for different functions
  * gills associated with thoracic appendages
- reproduction:
  * sexual with internal or commonly external fertilization
  * eggs brooded on abdomen: free swimming planktonic larvae
  * larval forms: nauplius, cypris, zoea, megalops

**SUBCLASS COPEPODA**
- small (1/4 inch)
- long antennae
- planktonic
- grazers on phytoplankton
- very abundant: lowest consumer on food chain
- some parasitic

**SUBCLASS CIRRIPEDIA** (barnacles)
- lands on head and cements to substratum
- secretes CaCO₃ plates
- sessile filter feeders
- sexual reproduction
SUBCLASS MALACOSTRACA (largest group)
- body plan of 8 thoracic and 6 abdominal segments
- last or 6th abdominal plates flattened to form telson

ORDER MYSIDACEA (mysids)
- shrimp-like
- large carapace (cephalothorax) not fused to thorax
- many in mesopelagic
- nektonic to demersal

ORDER ISOPODA (isopods, pillbugs)
- dorso-ventrally flattened
- "pillbug"-like
- benthic motile (some burrow) - scavengers, parasites

ORDER AMPHIPODA
- shrimp-like, small = 1/4 inch
- laterally compressed with no carapace
- very abundant and important in food chain
- demersal zooplankton
  * live on surfaces of plants, etc.
  * gammarid and caprellid

ORDER EUPHAUSIDACEA
- shrimp-like with carapace not covering gills
- planktonic to nektonic
- krill which whales feed on

ORDER DECOPODA: shrimps, crabs, lobsters
- largest order of crustaceans
- 1st 3 pairs thoracic appendages maxillipeds, last 5 pairs chelate legs
- brood legs on ventral surface of abdomen

SUBORDER NATANTIA (shrimps)
- laterally compressed
- rostrum protruding anterior from carapace
- demersal
- pleopods abdominal appendages used for slow swimming
- telson for flip and escape

SUBORDER REPTANTIA
- 1st pair of legs powerful chelipeds

SECTION MARCURA (large tail: lobster, crayfish)
- carapace longer than broad
- use chelipeds and/or mandibles
- spiny and Maine lobster

**SECTION BRACYURA** (true crabs)
- abdomen much reduced and flexed beneath thorax
- carapace broader than long
- may have last pair of legs for swimming (blue crabs)
- rock crabs, snow crabs, spider crabs

**SECTION ANOMURA**
- abdomen flexed sometimes but not reduced in size
- includes hermit crabs, sand crabs, ghost shrimps, tuna crabs

**PHYLUM ANNELIDA**  
(ANNEL1.LEC UPDATE: February 5, 2013)
- segmented worms
- all body structures are repeated in each segment
- 3 classes: Polychaeta (appendages), Hirudinea (leeches), Oligochaeta (no appendages)
- complete digestive tract

**CLASS POLYCHAETA**
- important marine group, extremely abundant with high diversity
- parapodia (leg-like/fan-like structures) may repeat on each segment
- setae (chaetae) or bristles borne on each parapodium
- gills may be present on each parapodium or may only be present on parapodia localized in one area of the body
- may be motile (errant) or tube-dwelling (tubiculous)
  * errant worms have parapodia adapted for either crawling/walking of swimming
  * tubiculous worms in tubes with a single opening may have only setae (parapodia absent) and a head region with either tentacles and bushy gills, or a radially symmetrical radiole which resembles a feather
  * tubiculous worms living in a 2-opening ("U" shaped) burrow have fan-shaped parapodia used to create feeding current through the tube
  * tubes may be epibenthic and constructed of sand, mud or calcium carbonate or may be mucous-lined burrows in soft sediments
- dispersal by planktonic trochophore larvae

**PHYLUM ECHINODERMATA**  
(ECHINO1.LEC UPDATE: February 5, 2013)

General characteristics of the phylum
- echinodermata = spiny skin
- all members of the phylum are marine
- common at all depths: benthic sedentary and sessile habits
- pentameric radial symmetry with oral/aboral orientation to body
- internal calcareous skeleton: plates imbedded in body wall
  may project through to surface as bumps, spines, may be fused to form a test, or may be microscopic in leathery dermis
- water-vascular system
  * series of internally connected tubes
  * water enters via the madreporite, through stone canal to the ring canal, then to radial canals, ampullae and ultimately to the tube feet.
  * contraction of muscles around the ampullae "moves" water in system
  * tube feet common to phylum
    ampullae, tube feet, longitudinal muscles
- larval dispersal: pluteus larva

CLASS ASTEROIDEA (seastars)
- central disc and arms or rays in multiples of 5
- groove with tube feet located on the ventral surface of each ray
- tube feet adapted for specific habitats (hard, soft)
- short spines and dermal gills ("skin gills") cover the body surface
- jawlike nearly microscopic pedicellariae prevent larvae from settling on the body surface
- cardiac stomach protrudes out of mouth for feed, pyloric stomach is internal
- amazing regenerative abilities
- use specialized tube feet at ends of rays to "smell" (chemoreception) slow moving and sessile prey (limpets, barnacles)

CLASS OPHIURIODEA (brittle stars)
- central disc; arms thin, longer, lack grooves, and easily break off
- no ampullae: movement by "snaking" of arms
- can autotomize arms to escape predators
- negatively phototactic behavior
- arms with fines spines typical of suspension feeders; smooth arms typical of deposit feeding

CLASS ECHINOIDEA (sea urchins, heart urchins, sand dollars)
- test of fused plates is body spherical, flattened or oval
- spines articulate and may be large
- move by tube feet or by spines
- well developed chemosensory ability
- specialized Aristotle's lantern jaw structure
- respiration by dermal gills

CLASS HOLOTHUROIDEA (sea cucumbers)
- reduced skeleton and leathery body
- lie on side
- contract muscles to change shape
- many toxic in tropics
- mouth surrounded by tentacles
- gas exchange by respiratory tree connected to cloaca
- can eviscerate digestive system in defense
- complete digestive tract (Parasticopus)
CLASS CRINOIDEA (sea lilies)
- oldest primitive class of echinoderms
- stalked and sessile
- have arms around upward directed mouth

ECHINODERM BLIGHT

I. Infection attacks echinoderms in shallow waters
   - caused by bacterium Vibrio patirae
   - isolated from the sea star Asterina miniata
   - shown to be pathogen on seastars, urchins, sea cucumbers:
     1. A. miniata, Lytechinus spp., Henricia leviuscula
        - suspected to be pathogen in other affected species
        1. Dermasterias imbricata, Astrometris sertulifera, Pisaster giganteus,
           Parasticopus parvimensis, Astropecten armatus, Strongylocentrotus spp., Diadema antillarum,
           Heliaster kubinijii, Linckia colombiae
        - effect is lesions and death within a few days

II. Chronology and geographic extent
   - First detected in southern California at Catalina Island and mainland in 1978
     1. attacked seastars in shallow water
     2. affected sea urchins in early 1980s
   B. Gulf of California
     1. 1977-78 Heliaster kubinijii eliminated from intertidal of N. Gulf
     2. still no signs of recovery
     3. not affected in mid-riff areas of upwelling
   C. central California and western Mediterranean
     1. 1978-79 several species of urchins attacked
   D. Nova Scotia
     1. 1980,1982 Strongylocentrotus drobachiensis
   E. Caribbean
     1. 1983 Diadema antillarum devastated
     2. most prevalent in warm water
     3. attacked sea stars
LOWER CHORDATES AND BONY FISHES  (FISH1L.LEC) UPDATE: February 5, 2013

PHYLUM CHORDATA:
- embryonic notochord: flexible supportive rod running longitudinally and dorsally through the animal
  ventral to the nerve cord (becomes center of backbone in vertebrates)
- all have pharyngeal gill slits at some stage in development
- all have hollow dorsal nerve cord

SUBPHYLUM UROCHORDATA (tunicates)
- solitary and colonial
- pharyngeal gill slits for feeding and respiration
- sessile filter feeders

SUBPHYLUM CEPHALOCHORDATA (lancets)
- Branchiostoma (amphioxus), small marine, fish-like, 2 inches long, translucent
- bury tail first in mud and filter feed through pharyngeal gill slits
- notochord retained and muscles segmented
SUBPHYLUM VERTEBRATA
- endoskeleton characterized by a backbone composed of series of vertebrae
- vertebrae develop around notochord

ICHTHYOLOGY - CLASSES: AGNATHA, CHONDRICHTHYES (ELASMOBRANCHIOMORPHA), OSTEICHTHYES (TELEOSTOMI)

derivation of name: ichthys = fish; logos = a discourse
- the most conspicuous and interesting component of aquatic systems
- not all have embraced with passion

Plato -
"These (the fishes) were made out of the most entirely ignorant and senseless beings, whom the transformers did not think worthy of pure respiration, because they possessed a soul which was made impure by all sorts of transgression; and instead of allowing them to respire the subtle and pure element of air, they thrust them into water, and gave them a deep and muddy medium of respiration; and hence rose the race of fishes and oysters, and other aquatic animals, which have received the most remote habitations as a punishment for their extreme ignorance."

Aristotle: 118 species recognized all from Aegean Sea (322 B.C.)
- also made distinction between fish and invertebrates
- classified marine mammals as fish

Pliny the Elder: 176 species, believed complete list -
"In the sea and the ocean, vast as it is, there exists, by Hercules! nothing that is unknown to us, and a truly marvelous feat it is that we are best acquainted with those things which Nature has concealed in the deep."

For next 18 centuries scholars discovered little new, but were content to copy from his works and merely add fabulous myths and stories. Sixteenth and 17th centuries discoveries resumed. Now believe may be more than 20,000 species of fish, although only half that many described. Little explored areas of the deep sea and Amazon basin

What is a fish?
- defined by Greenwood
  "A vertebrate specially adapted for a purely aquatic life, propelling and balancing itself by means of fins, and obtaining oxygen from water for breathing purposes by means of gills".

Three classes
I. Class: Agnatha
  . hagfish, lampreys
  . lack jaws, instead have round mouth with rasping teeth
  . invaded Great Lakes via St. Lawrence Seaway
  . parasitic on fishes
  . fishery for "slime-eel" (hagfish) for skin
II. Class: Chondrichthyes (Elasmobranchiomorpha)
   - rays, skates, sharks
   - cartilaginous skeleton

III. Class: Osteichthyes (Teleostomi)
   - all other fishes
   - bony skeleton

IV. BASIC FISH ANATOMY
   . Body forms
     1. fusiform/torpedo-shaped: sustained high-speed swimming
     2. deep bodied/laterally compressed: maneuverability
     3. depressed/dorsoventrally flattened: demersal
     4. anguilliform/eel-like: crevices, slither
     5. flatfish: special case of deep bodied w/2 eyes on same side
   . Body regions: fused together and difficult to distinguish
     1. head - to operculum
     2. thorax - under gill
     3. abdomen - operculum to anus
     4. tail - posterior to anus, incl. caudal peduncle, fin
   . Fin structure and placement
     1. structure: fin spines and rays
        a. spines: hard pointed calcareous stiffening rods
           (1) if present, located on leading edge of fins
        b. fin rays: flexible articulated biramous rods
           (1) follow spines in fin
           (2) allow suppleness of fin, undulation
     2. medial fins: single located on longitudinal midline
        a. dorsal
           (1) 1 - 2, may have anterior and posterior lobe
           (2) stabilizes swimming, contributes to thrust if large posterior lobe
           (3) specializations
              (a) defense with sharp spines
              (b) venom glands in Scorpidae
              (c) sucker in Remoras
        b. anal
           (1) contributes to thrust
     3. lateral fins: paired in either side
        a. pectoral
           (1) size, shape placement reflect habit
              (a) large for maneuvering, braking
              (b) small in high speed fishes
              (c) ventral in demersal species
              (d) large in flying fish
b. pelvic/ventral
   (1) generally small
   (2) adjust horizontal attitude, pitch
   (3) specializations
      (a) sucker in clingfishes
      (b) perch in gobies
      (c) abdominal and large in flying fishes

c. caudal
   (1) produces thrust for swimming: shape determines efficiency, swimming
   (2) semilunate: sustained high-speed
      (a) poor start, sustained swimming
      (b) tunas, jacks, lamnid sharks, *Thunnus* (46 mph)
      (c) aspect ratio 7-10
   (3) lobed: quick start
      (a) tire with sustained swimming
      (b) reef fishes, damsels, gobies
      (c) aspect ratio 1-2
   (4) truncate: in-between
      (a) compromise - maneuverability and speed
         i) basses, perches, croakers
         ii) can modify shape with rays
         iii) aspect ratio 3-6
   (5) calculating aspect ratios - \( h^2/A \)
      (a) semi-lunate \( h=4, A=2 \)
      (b) truncate \( h=4, A=4 \)
      (c) lobed \( h=h, A=16 \)
   (6) specializations
      (a) homocercal vs. heterocercal
      (b) flying fish - large inferior lobe

. Scales: covering body when present
  1. protect against physical damage and infection with mucous
  2. some modified for protection with projections
     a. gars, boxfish, blowfish
  3. absent if skin thick (catfish, Mola, Dover sole)

. Coloration: camouflage or advertisement
  1. counter-shading in all fishes
  2. cryptic fishes concealed: predator and prey
  3. species recognition in reef fishes (Pomacentridae)
     a. contingent on shelter being available
     b. many spp. similar in shape, color
     c. territorial recognition and mating
     d. advertise when receptive: displays
     e. juvenile damsels and electric blue to disguise
  4. color change by chromatophores
     a. behavioral and physiological change

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Jaws and teeth: key to feeding and habit
1. major advance in gape-and-suck perciform mouth
   a. new feeding method of sucking suspended prey
   b. adaptive radiation for fishes
   c. teeth not needed as much for catch, just grasp
   d. crevice feeding, changes in body form concomitant
   e. gills grasp as prey swallowed whole
2. buccal pump respiration (see gills)

Internal anatomy
1. skeleton
   a. vertebral column with dorsally and ventrally projecting rays
   b. head of several bony parts
   c. rays or bones in all fins
   d. not heavy bones, density of water or little more
   e. otoliths for sensing vibrations
2. digestive system complete: length correlated to food habits
   a. herbivores = long
   b. carnivores = short
   c. omnivores = long
3. gills: respiratory organs/excretion
   a. bony gill arch with ctenidia and gill rakers
   b. ctenidia highly vascular with capillaries to exchange gasses
   c. gill rakers
      (1) long and fine in suspension feeders
      (2) stout in piscivores to hold prey
      (3) gular plates in parrot fishes to crush shell material
      (4) ventilation: water flows in through mouth, through pharynx,
           over gills and out operculum
      (5) buccal pump allows fish to suck and pump water through gills

V. Water Balance/Osmoregulation: regulate the concentration of dissolved materials and water content of the blood
1. threshold levels for metabolites, water
2. nitrogenous wastes (metabolic products)
3. terrestrial mammals mostly produce urea and require urination and water loss to eliminate
4. fishes produce ammonia - easily diffused
5. blood of fishes hypo-osmotic to sea water
   1. lose water and gain salt
   2. dehydrate without solution
   3. solution to problem
      1. drink sea water
      2. actively secrete salts via chloride cells in gills
      3. diffuse ammonia across gills
      4. eliminate small amount of water in urine
5. freshwater-seawater migration (anadromous (fw spawn); catadromous (sw spawn))
   a. blood hypertonic to freshwater
   b. gain water, lose salts
   c. produce large amounts of dilute urine
   d. actively uptake salts via gills and pharynx

VI. Swim/gas Bladder
   . maintain neutral buoyancy
     1. fishes tissues denser than water
     2. gas concentrated in bladder compensates
     3. volume changes with pressure-depth
     4. must change volume to compensate
     5. metabolically expensive
   . adaptations: vestigial swim bladder
     1. sustained high-speed fishes
     2. demersal fishes: gobies, sculpins, clingfish

VII. Sensory Organs
   . eyes: metabolically expensive
     1. vision fair to good
     2. size and placement reflect habit of fish
       a. increasing diameter with diminishing light regime
       b. nocturnal, midwater fishes with large eyes
     3. degenerate in fishes 1000m - 3000m
       a. direction
         (1) demersal: upwards
         (2) pelagic: to sides
     . lateral line: sense movement of water past fish
       1. series of pits with neuromast cells
         a. gelatinous cupula with nerve fibers
         b. accentuates effect of water movement
         c. nerves communicate to brain
       2. implicated in coordination of schooling
         a. schooling: confuse predators, more eyes
       3. detection of predators pushing "bow wave"

VIII. Reproduction
   . both internal and external reproduction common
   . three systems
     1. oviparous: eggs spawned
       a. small and numerous eggs
       b. up to 15,000,000
       c. example: Leuristhes tenius - Calif. grunion
         (1) females lay eggs in sand at berm-line on spring tides, sandy beaches, at night

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(2) males deposit milt in sand
(3) eggs harden, protective coat
(4) develop in protected position
(5) uncovered and abraded by next spring tide releasing larvae

2. ovoviparous: eggs brooded internally
   a. larger and less numerous eggs
   b. examples in elasmobranchs

3. viviparous: live birth, nurtured embryo
   a. fewer offspring
   b. example: Embiotocids: Surf perches
      (1) "placental" connection between dorsal fin of young and uterus of mother

4. hermaphrodism: sequential most common
   a. protandrous/protogynous: most common
   b. relate to survivorship curve
   c. skewed sex ratios
   d. Calif. Sheephead
      (1) juvenile small, deep bodied, small mouth
      (2) female larger, small teeth for crushing invertebrates, picking: largest changes sex when male dies
      (3) male large, big crushing teeth for large invertebrates

5. unusual adaptations: deep sea anglerfish
   a. eggs and young at surface
   b. male attaches to female as migrate to depth
   c. vascular system fuses with female, degenerates, small

ELASMOBRANCHIOMORPHA/CHONDRICHTHYES
(FISH.LEC) UPDATE: February 5, 2013

- 250 species of pelagic sharks
- 300 species of demersal skates (Rajidae) and rays (Dasyatidae)

I. Structure
   . Body form
     1. fusiform: pelagic sharks
     2. depressed: rays, skates, demersal sharks
   . Fins
     1. negatively buoyant: lack swim bladder (sink)
     2. heterocercal tail: lift but pitches anterior downwards
     3. pectoral fins: rigid, inserted at a positive angle to provide upward lift for anterior portion of body
     4. cannot brake with pectoral fins, limited turning ability
     5. pelvic fins: small
     6. anal fins equipped with claspers present in males
   . Integument: skin with denticles
1. Tooth-like structures embedded in skin with curved spine projecting out of skin
2. Protection and reduces drag on skin

**Gills**
1. Each in separate branchial chamber, or pouch, between pharynx and exterior
2. Flaps cover each pouch on outside
3. Spiracle: opening derived from gill arch located on the dorsal surface of the head
   a. Large in rays and skates: intake for water to ventilate gills

**Teeth**
1. Form in rows and continuously produced
2. Deciduous: outer row shed
3. Shape related to feeding type
   a. Serrated triangular to scythe-shaped in requiem sharks
      1. Cut through flesh by shaking prey
      2. Predators on fishes, mammals
      3. Tiger, great white, hammerhead sharks
   b. Small pointed and flattened
      1. Feed on molluscs, crustaceans, small fish
      2. Smooth hound, nurse, horn sharks
   c. Fused to form pavement-like crushing surface
      1. Feed on hard-shelled molluscs, crustaceans, urchins
      2. Rays, skates

**II. Water Balance/Osmoregulation**
1. Concentrate urea in blood to be slightly hypertonic to seawater
   1. Can invade freshwater for short periods
   2. In fresh water must have high urine flow

**III. Sense Organs**
1. Eyes: range - 18m
   1. Poor to good eyesight
   2. Limited by visibility in water
2. Ampullae of Lorenzini: range - few centimeters
   1. Small structures in pits in snout, head similar in structure to neuromast cells of teleosts
   2. Sensitive to weak electrical fields (muscular contractions), small temp. and salinity variations
3. Lateral canals: range - 30m
   1. Gelatinous filled canals with imbedded neuromast cells
   2. Same placement as lateral line and may create an electrical field in which prey sensed by disturbance
4. Olfaction: range 100m
   1. Olfactory sacs on snout with numerous gill-like lamellae to detect "scent" in water at low concentrations
Sound: range - 1000m
1. hear well in low frequencies
2. frequencies of sound created by prey thrashing in water

IV. Unusual specializations for prey capture and defense
   . electric organs
      1. modified muscle cells in pectoral fins of electric rays create high voltage discharge
      2. used to stun prey
         a. Torpedo californica - Calif. electric ray
   . venom
      1. stingrays have skin covering over "sting" on tail
      2. erected sting with adherent skin driven into victim
      3. protein venom denatured by head, acid, base