Coral Reefs

Biology 200

Lecture Notes and Study Guide

David A. Krupp

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Using this Lecture Outline and Study Guide

This lecture outline and study guide was developed to assist you in your studies for this class. It was not meant to replace your attendance and active participation in class, including taking your own lecture notes, nor to substitute for reading and understanding text assignments. In addition, the information presented in this outline and guide does not necessarily represent all of the information that you are expected to learn and understand in this course. You should try to integrate the information presented here with that presented in lecture and in other written materials provided. It is highly recommended that you fully understand the vocabulary and study questions presented.

The science of biology is always changing. New information and theories are always being presented, replacing outdated information and theories. In addition, there may be a few errors (content, spelling, and typographical) in this first edition. Thus, this outline and guide may be subject to revision and corrections during the course of the semester. These changes will be announced during class time.

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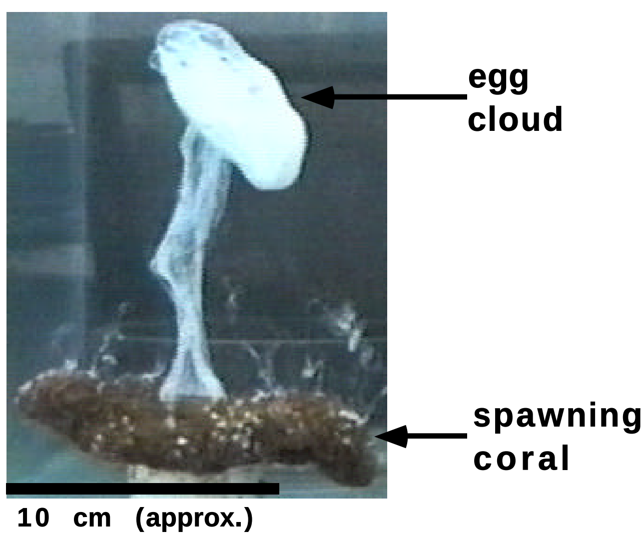
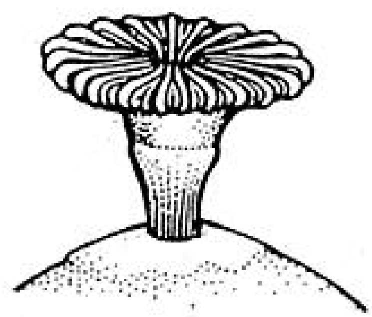


Female Mushroom Coral *Fungia scutaria* Spawning

When space turned around, the earth heated
When space turned over, the sky reversed
When the sun appeared standing in shadows
To cause light to make bright the moon,
When the Pleiades are small eyes in the night,
From the source in the slime was the earth formed
From the source in the dark was darkness formed
From the source in the night was night formed
From the depths of the darkness, darkness so deep
Darkness of day, darkness of night



Of night alone
Did night give birth
Born was Kumulipo in the night, a male
Born was Po'ele in the night, a female
Born the coral polyp
Born of him a coral colony emerged.

[pp. 3-4, Johnson, R.K., 1981. *The Kumulipo: Hawaiian hymm of creation.* Vol. 1. Topgallant Publishing Co., Ltd., Honolulu, HI, 188pp.]

THE NATURE OF NATURAL SCIENCE

I. Science as a Way of Knowing
   A. Some Natural Science Disciplines
      1. biology
      2. chemistry
      3. physics
      4. geology
      5. astronomy
      6. meteorology
   B. What Is Natural Science?
      1. involves attempts to explain observable phenomena in the natural universe
      2. involves a process by which we investigate the natural universe
      3. involves the body of information collected by this process
   C. Unprovable Assumptions Upon Which Science is Based
      1. the universe is real and the human mind is capable of understanding its true nature and there are no mysteries being deliberately cloaked from our view and understanding
      2. all observable phenomena are the effects of previous underlying measurable natural causes
      3. the universe is unified by natural laws that are constant in time and space
   D. Characteristics of Scientific Explanations
      1. derived objectively from independently confirmable observations
      2. rational (that is they must be reasonable and logical)
      3. consistent with known natural laws and well-established, well-documented existing theories
      4 assume natural cause and effect
      5. objectively & empirically testable (i.e., potentially falsifiable)
      6. conclusions must always be regarded as tentative
      7. when an explanation is claimed to be scientific, but does not exhibit the characteristics listed above, then that explanation is said to be pseudoscientific
   E. Operational Rule: the simplest interpretation that is consistent with all of the pertinent data is most likely to be correct (i.e., it must be parsimonious)
   F. Limitations to Natural Science
      1. natural science can only study natural phenomena, phenomena that may be observed (by direct observation or instruments) the same way by any observer
      2. the supernatural, spiritual and mystical cannot be studied by the methods of natural science
      3. natural science can neither confirm nor refute supernatural, spiritual and mystical explanations
      4. thus theological ideologies and beliefs are inherently non-scientific and lie outside of the realm of scientific endeavors
      5. science also does not make moral decision, but may provide objective information that may be used in making moral decisions
      6. natural science explanations should not be regarded as final truth even when supported overwhelmingly by the evidence, rather, as a consequence

of the scientific method (see below), we either become more or less confident in the correctness of these explanations; however, explanations supported overwhelmingly by the evidence may be considered "true beyond a reasonable doubt"

G. Hypotheses, Laws, & Theories
   1. if after repeated testing, the hypothesis has not been disproved, then it may become a theory
      a. like hypotheses, theories yield testable predictions
      b. a theory never becomes absolute truth, but always possesses some amount of uncertainty
      c. however most theories have been so strongly validated that they are often considered to be true beyond all reasonable doubt
      d. a theory usually explains many different kinds observations (e.g., evolution explains the fossil record, anatomical homologies, shared developmental patterns, biochemical similarities, genetic similarities, biogeographical distributions, etc.)
      e. usually, rather than being falsified, most theories are revised as new observations are collected
      f. thus a theory is a very strong statement in science, surviving many attempts to be falsified
      g. theories are widely accepted explanations for the mechanisms behind how phenomena in nature are produced
   2. contrast a theory with a natural law
      a. rather than explaining the mechanism behind a natural phenomenon, a natural law is a description of how nature appears to behave
      b. theories, on the other hand, may provide explanations for the mechanisms behind natural laws
      c. natural laws may be tested through observation and experience
      d. examples of scientific laws
         1) Newton's Law of Gravity
         2) Mendel's Laws of Inheritance
         3) The First & Second Laws of Thermodynamics
      e. Is the concept of evolution a natural law, a theory, or a fact?

II. The Scientific Method
A. General Comments about the Scientific Method
   1. leads to objective, unbiased evaluation of hypotheses
   2. explanations not constrained by an absolute truth
   3. self-correcting - scientific errors usually discovered
   4. leads to a methodical discovery of explanations for phenomena of the natural universe
   5. while the steps of the scientific method (see below) are often presented as though they are rigidly followed by practicing scientists, in fact, they are not
      a. scientists do not maintain a checklist of these steps
      b. steps also ignore the importance of serendipity and intuition in the process of scientific discovery
B. Steps
   1. observation

   a. observe phenomena in nature
   b. these observations must be capable of being observed by more than one objective observer
   c. collecting observations often involves more than merely seeing something happen
   d. may involve systematic collection of data using human senses and/or measurement tools and instruments
2. question
   a. usually best to ask "how", "what" or "when" kinds of questions
   b. best to avoid "why" questions that may suggest "ultimate design" or a supernatural "designer" is involved with the answer
   c. "why" questions often lead to teleological answers
      1) teleology = to explain something in terms of fulfillment of purpose
      2) implies the purpose existed prior to its fulfillment - as though fulfillment was directed by a transcendent being or consciousness or by the evolving organisms themselves striving to achieve some long-range evolutionary goal
      3) note: it is perfectly scientific to discuss the purpose or function of a structure or behavior of an organism; it is not scientific to suggest that such structures or behaviors were intended by some kind of mystical or supernatural intelligence
   d. usually before attempting to answer the question (i.e., form a hypothesis), the investigator will make more observations about phenomena relevant to the question
3. hypothesis
   a. = an educated guess that attempts to answer the question
   b. involves inductive reasoning, whereby one derives general principles from particular facts or instances
   c. must assume the following characteristics of scientific explanations
      1) consistent with natural laws
      2) requires the involvement of natural cause and effect
      3) must be falsifiable, that is must lead to testable predictions
4. prediction
   a. an if-then statement based upon the hypothesis
   b. prediction is a consequence of the hypothesis should the hypothesis be true
   c. involves deductive reasoning, whereby one draws a conclusion from stated premises
5. test the prediction
   a. experiments must have the potential to disprove the hypothesis
   b. experiments must be designed with appropriate controls (a control is a parallel experiment that helps isolate the variable being test against all other possible variables that may influence the results, e.g., a placebo is used as a control to test the medical effectiveness of a drug)
   c. results are collected as data
   d. test results are organized and analyzed
   e. test should be repeated a number of times
6. conclusion

   a. conclude whether or not the hypothesis has been refuted by the test
   b. should also conclude which aspects of the hypothesis and its test need further study
      1) what was inadequate about the study?
      2) should the hypothesis be modified?
      3) what other predictions might be tested?
      4) what new questions may be asked?
7. present test results for critical review
   a. scientific study useless unless others can evaluate it
   b. formal presentation for critical review allows
      1) objective scrutiny of the methods and interpretation of the results
      2) other scientists to replicate the study
   c. formats for presentation
      1) written report in peer-reviewed scientific journals (most important format)
      2) oral presentations at scientific meetings
8. retest the hypothesis or modified hypothesis
   a. test other predictions that may be made from the hypothesis
   b. this retesting may be repeated until hypothesis is well-supported by the evidence and widely accepted by scientists, thus becoming a theory

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VOCABULARY

natural science	teleology	observation	hypothesis
prediction	theory	natural law	cause and effect
natural science	scientific method	control	deduction
induction	variable	data	teleology
pseudoscience	parsimony	natural	supernatural

STUDY QUESTIONS

1. Describe the scope of the Natural Sciences

2. Describe the steps in the Scientific Method. Give a "realistic" example of how it might be used.

3. Explain the three assumptions that scientists make to interpret the natural universe; and discuss the characteristics that make explanations of natural phenomena scientific. Support your essay with examples.

4. Discuss the limitations of science as an system of epistemology. In other words, what kinds of phenomena are studiable by science? What kinds are not? Give some specific examples to support your discussion. Can science ever produce any absolute truths?

5. Contrast hypotheses, theories, and laws. Provide examples to support your discussion.

6. Creationism is the belief that the biblical account of the origin of the universe, the earth, and all living things, as presented in the Book of Genesis, gives an accurate description. Many creationists also hold to the view that creationism is a scientific account. Regardless of the truth or falseness of this account, explain why creationism cannot be regarded as a scientific explanation (be sure to read Genesis I & II in the Old Testament before attempting to answer this question.)

THE CHARACTERISTICS OF LIVING THINGS

I. Great Complexity & Organization

A. Observations Regarding the Complexity of Living Things

1. living things much more highly organized than inanimate objects
2. composed of complex, large, highly improbable molecules

B. Complexity Results from the Hierarchical Organization of Living Systems (Emergent Behavior)

atom
simple inorganic molecule
organic building block molecule
macromolecule
cellular organelle
cell
tissue
organ
organ system
organism
population
community
ecosystem
biosphere

1. atoms
   a. fundamental particles of matter defining the elements
   b. cannot be broken down into smaller particles using conventional chemical procedures
   c. examples of some of the major elements comprising living things
      1) carbon (C)
      2) hydrogen (H)
      3) oxygen (O)
      4) nitrogen (N)
      5) phosphorus (P)
      6) sulfur (S)
2. simple inorganic molecules
   a. molecule = combination of two or more atoms
   b. inorganic molecules not composed of carbon atoms bonded to either other carbon atoms (C-C bonds) nor to hydrogen atoms (C-H bonds)
   c. examples of inorganic molecules important to living things
      1) water (H_2O)
      2) carbon dioxide (CO_2)
      3) molecular oxygen (O_2)
      4) ammonium (NH_3)
3. organic building block molecules
   a. organic (i.e., possesses C-C and/or C-H bonds) molecules used to construct larger molecules or used as sources of chemical energy
   b. some examples

    1) glucose, a simple sugar ($C_6H_{12}O_6$)
    2) glycine, an amino acid ($C_2H_50_2N$)
    3) acetate ($C_2H_4O_2$)
    4) glycerol ($C_3H_8O_3$)
    5) adenine, a nitrogenous base in DNA ($C_5H_5N_4$)

4. macromolecules
    a. very large molecules assembled from repeating series of the organic building block molecules
    b. some examples
        1) starch, assembled from hundreds of glucose units
        2) proteins, assembled from hundreds of different amino acids
        3) nucleic acids (e.g. DNA & RNA), assembled from thousands of nucleotides (each nucleotide = nitrogenous base plus ribose sugar plus phosphate group)
        4) fats, assembled from glycerol and fatty acids; note fatty acids composed of long changes carbon from combining acetate molecules together
5. cellular organelles
    a. structural components of living cells
    b. each structure serves a particular function
    c. some examples
        1) nucleus: encloses the chromosomes which contain the genetic instructions for the cell
        2) mitochondrion: important in the releasing of chemical energy from organic molecules
        3) chloroplast: captures light energy and converts this light energy into chemical energy as simple sugars (found in plant cells)
        4) flagellum: whip-like structure that moves the cell
6. cells (see below)
7. tissues (multicellular organisms only)
    a. groups of similar cells that perform a similar function
    b. some examples
        1) epithelial tissues: forms body coverings
        2) connective tissues: forms skeletons and binds other tissues together
        3) nervous tissue: involved in sensing and responding to stimuli
        4) muscle tissue: involved movement
8. organs
    a. structures composed of several tissues working in concert for a particular function
    b some examples
        1) stomach
        2) liver
        3) intestines
        4) pancreas
        5) gall bladder
9. organ systems
    a. a group of organs functioning together

        b. some examples
            1) digestive system
            2) reproductive system
            3) nervous system
            4) respiratory system
    10. organism = the complete living entity, the individual
    11. population = collection of individuals, all of the same species, living in some defined geographical area
    12. community = a group organisms consisting of populations of different species interacting with each other in some defined geographical area
    13. ecosystem = the biological community plus its surrounding nonliving environment
    14. biosphere = all of the ecosystems of the earth; that part of the earth occupied by living things

II. Cells
    A. The Cell Theory
        1. all living things are composed of cells
        2. cell = fundamental unit of life
    B. Characteristics of All Cells
        1. possess a surrounding membrane that maintains the internal integrity
        2. chemically complex interior where metabolism takes place
        3. genetic instruction set (chromosomes) defining their characteristics
    C. Contrast Cells and Viruses
    D. Two Major Types of Cells
        1. prokaryotic
            a. lacks a nucleus & other membrane-bound organelles
            b. characteristic of bacteria
        2. eukaryotic
            a. possess a nucleus & other membrane-bound organelles
            b. characteristic of all other groups of living things
            c. distinguish animal & plants cells
                1) plant cells possess chloroplasts & cell walls of cellulose
                2) animal cells lack chloroplasts & cell walls

III. Reproduction
    A. Characteristics of Reproduction
        1. living things make exact or nearly exact copies of themselves
        2. requires a mechanism for inheritance
        3. usually involves a process of development
        4. most parents produce more offspring than are required merely to replace the parents when they die
    B. Two Modes of Reproduction
        1. sexual reproduction
            a. involves fusion of gametes (usually haploid) to form zygotes (usually diploid); genetic information from parents combined in offspring
            b. offspring resulting from sexual reproduction are similar yet different from both parents
            c. advantage: offspring unique; provides for diversity within a species; diversity enhances species adaptability and survival when environments

change
- d. disadvantage: process generally complex since chromosomes must be divided during gamete formation (meiosis) ; also need mechanisms for bring sperm & eggs together; process of development from fertilized egg also complex (may involve larval stages)

2. asexual reproduction
   - a. does not involve combination of genetic information from two parents (i.e., no union of gametes)
   - b. offspring usually = clone of parent (genetically identical)
   - c. advantage: simpler than sexual reproduction (no meiosis needed); offspring well-suited for survival in environment where parents occur (good if environment stable)
   - d. disadvantage: leads to low diversity within a species; species may not include individuals capable of dealing with changes in the environment

C. Development and Growth
1. most living things pass through a characteristic life cycle that involves change in form and growth
2. this change in form (e.g. a single-celled egg becoming a multicellular organism) = development
3. most living things exhibit a net accumulation of organic materials: growth

IV. Mechanism for Inheritance (Heredity)

A. Characteristics of Genetic Instruction Set
1. genetic instruction set of all living things contained in nucleic acids (DNA) of chromosomes
2. instruction set defines the structure, functioning, & behavior (to some extent) of all living things
3. instruction set, or portions of it, are passed from parent to offspring

B. Mechanisms for Genetic Change Responsible for Evolution
1. genetic recombination (exchanging of genes yielding new combinations of existing genes; e.g., sexual reproduction)
2. mutation (involves change to the coding sequence of a single gene)
3. chromosomal aberration (alteration of chromosomes affecting many genes at once)
4. when genetic changes are passed on to offspring then the species may evolve

V. Metabolism

A. definition
1. = all of the chemical processes that occur in living cells & organisms
2. involves the acquisition & use of energy & materials

B. Energy
1. = the capacity to do work
2. types of energy significant to living things
   - a. mechanical energy (energy involved in movement)
   - b. radiant energy (e.g., visible light and heat)
   - c. chemical energy (energy stored in the chemical bonds of molecules)
3. some energy-requiring processes of living things
   - a. growth, reproduction & repair
   - b. movement

   c. maintaining homeostasis

C. Examples of Metabolic Processes
   1. photosynthesis
      a. involves the synthesis of complex organic molecules (e.g., glucose $C_6H_{12}O_6$) from simpler inorganic molecules (e.g., carbon dioxide CO_2 and water H_2O)
      b. this is an energy-requiring process: light energy from the sun is ultimately converted into the chemical energy of the organic molecules
         1) light energy initially captured by pigment molecules (e.g., the green chlorophyll pigment of plants)
         2) captured energy may be regarded as being stored by the C-C & C-H bonds of organic molecules
         3) process involves many small chemical steps
      c. overall chemical reaction:

$$\textbf{\textit{light energy}} + 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

   2. respiration
      a. involves the release of energy from organic molecules so that the stored chemical of these organic molecules may be used for energy-requiring processes
      b. overall chemical reaction (note that this is opposite of photosynthesis):

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \textbf{\textit{chemical energy}}$$

V. Interaction with the Environment

A.. Reciprocal Relationship Between Organisms and Their Environments
   1. living things modify their environments
      a. they remove resources
      b. they produce wastes
   2. the environment modifies the behavior and physiology of living things

B. Contributes to Evolutionary Change
   1. environment constantly changing due to
      a. extrinsic factors (e.g., meteorite impacts, solar intensity, etc.)
      b. intrinsic factors (the activities of living things, e.g., oxygen production by plants)
   2. if living things can't adjust to these changes, extinction may result

VI. Adaptability

A. Evolution
   1. evolution = genetic change of a ***population*** over generations
   2. if population changes substantially in its genetic composition, population may become a different species from what it once was
   3. over millions of years the changes can be very dramatic (e.g., dinosaurs evolving into birds)
   4. common ancestry
      a. species sharing features in common likely to have descended from a common ancestor through this process (e.g., human beings, chimpanzees, gorillas, thought to have descended from a common ape-

like ancestor that lived about 5-10 million years ago

b. the history of life as a consequence of evolution may be likened to a huge branching bush
    1) branch points = common ancestors for divided smaller branches
    2) all existing species = the growing branch tips
    3) many branches have died out, their lifeless ends representing extinction

B. Adaptation
1. present day species are the products of thousands of adaptations evolved by their ancestors
2. the adaptations these species have acquired over many generations through evolution enhance their survival
3. process involves the production of heritable variations, natural selection, and chance
    a. production of heritable variations
        1) mutation: changes to genetic instructions of a gene
        2) chromosomal aberration: alterations to whole chromosomes or parts of them
        3) genetic recombination: "mixing and matching" of genes yielding unique combinations of genes
    b. natural selection
        1) in a natural population, individuals exhibit variations in physical characteristics and behavior
        2) some of these variations may result in higher probability of reproductive success than others (let's call these variations "adaptive")
        3) individuals exhibiting these adaptive variations tend to contribute proportionately more offspring to the succeeding generation
        4) if these adaptive variations are heritable, then these offspring will likely exhibit the same adaptive variations as did their parents
        5) with each succeeding generation, proportionately more individuals exhibit the adaptive variations
        6) over long enough periods of time, this process of change could produce new species
    c. chance
        1) not all changes in the genetic composition of a population driven by natural selection
        2) probability exists that any variation may occur more commonly than others in subsequent generations regardless of its influence on reproductive success
        3) such changes are more likely to occur in small populations than large ones

C. Evolution Inevitable
1. changes to the genetic instruction set will definitely occur
2. reproduction ensures genetic changes will be passed on to offspring
3. natural selection means that the more adaptive genetic changes will become more common place in a population while less adaptive ones may eventually disappear

4. over many generations adaptive and neutral genetic changes may accumulate
5. given enough time (several billion years) the changes are enough to account for the species that presently exist on our planet

VOCABULARY

complexity	atom	molecule	inorganic molecule
organic molecule	macromolecule	cellular organelle	cell
tissue	organ	organ system	organism
population	community	ecosystem	biosphere
mutation	metabolism	homeostasis	cell theory
eukaryote	prokaryote	nucleus	asexual reproduction
sexual reproduction	development	inheritance	DNA
respiration	photosynthesis	evolution	adaptation
mutation	natural selection	genetic recombination	

STUDY QUESTIONS

1. List and describe the characteristics associated with living things that distinguish them from inanimate objects.

2. Outline and describe the hierarchical organization of living systems.

3. Define homeostasis and describe several examples of homeostatic mechanisms in living things.

4. Compare the major structural differences between prokaryotic and eukaryotic cells.

5. Define sexual and asexual reproduction. Give the advantages and disadvantages of each.

6. Contrast photosynthesis with respiration. Be sure to present their respective overall chemical reactions in your answer.

7. Briefly describe and explain the mechanisms of evolutionary change.

8. Why does your instructor states that “Evolution is inevitable”?

THE CLASSIFICATION OF LIVING THINGS

I. Dividing the Living World Into Groups
   A. Reasons for Classification (Taxonomy)
      1. common basis for communication about different groups of living things
      2. human attempt to make sense of the tremendous diversity of the living world
      3. imply evolutionary relationships (= phylogeny)
   B. Nature of Groupings
      1. organisms placed within same group exhibit characteristics in common
      2. most groupings arbitrarily defined with evolutionary relationships in mind
      3. problem: nature not organized into neat, discrete packages
      4. hierarchical organization of classification groups
         a. living world generally divided into five major groups, kingdoms, based upon the fundamental characteristics of cells and they way they are organized together
         b. each of these kingdoms are divided into subdivisions called phyla (singular = phylum) or divisions
            1) all phyla within a kingdom consist of organisms that share kingdom characteristics in common
            2) organisms within a phylum (or division) share certain characteristics in common that distinguish them from members of another phylum within the same kingdom
         c. each phylum (or division) divided into subdivisions called classes
         d. each class divided into subdivisions called orders
         e. each order divided into subdivisions called families
         f. each family divided into subdivisions called genera (singular = genus)
         g. each genus divided in subdivisions called species
         h. an example involving the mushroom coral:

Kingdom	Animalia
Phylum	Cnidaria
Class	Anthozoa
Order	Scleractinia
Family	Fungiidae
Genus	*Fungia*
Species	*scutaria*

Figure 1. Example of the hierarchical system of classifying living things using the mushroom coral, *Fungia scutaria*

   C. Five Kingdoms of Life
      1. major characteristics used to classify living things into kingdoms
         a. cell structure
            1) prokaryote (no nucleus) versus eukaryote (has a nucleus)
            2) cell wall present or absent
            3) cell wall chemistry
            4) presence or absence of other organelles
         b. cellularity

        1) unicellular versus multicellular
        2) level of organization of cells into tissues
    c. mode of nutrition
        1) heterotrophy
            a) utilize pre-made organic molecules
            b) types
                1) saprophytic: secretes digestive enzymes to the exterior, then absorbs digested organic molecules (e.g., fungi)
                2) ingestive: digestion occurs internally after ingestion of food (e.g., most animals)
        2) autotrophy
            a) manufactures organic molecules from inorganic starting materials
            b) types
                1) photoautotrophy: use light energy (photosynthesis)
                2) chemoautotrophy: use chemical energy (chemosynthesis)
2. characteristics of the five kingdoms
    a. Kingdom Monera
        1) prokaryotic, single-celled organisms
        2) while not very diverse morphologically, they are very diverse at the biochemical level, including heterotrophic, photoautotrophic, and chemoautotrophic species
        3) some with cell walls, but cell walls composed of peptidoglycan, not cellulose (as in higher plants)
        4) includes eubacteria, cyanobacteria, and archaeobacteria
        5) more recent classification schemes divide Monera into two kingdoms
    b. Kingdom Protista
        1) eukaryotic, generally single-celled, organisms
        2) if multicellular, then cells not well-organized into tissues and organs (more colonies of cells)
        3) a very heterogeneous group include both heterotrophic and photoautotrophic forms
        4) includes protozoa (e.g., *Paramecium*, *Amoeba*, & *Euglena*, etc.) and algae (e.g., diatoms, dinoflagellates, *Volvox*, & most seaweed groups)
        5) more recent classification schemes divide Protista into several kingdoms
    c. Kingdom Fungi
        1) eukaryotic, generally multicellular, organisms (a few species, e.g., yeast are unicellular)
        2) heterotrophic, saprophytic (absorptive) nutrition
        3) most with cell walls (usually composed of chitin) and complex life histories
        4) includes molds, yeast, rusts, and mushrooms
    d. Kingdom Plantae
        1) eukaryotic, multicellular organisms with cells organized into distinct tissues
        2) photoautotrophic nutrition

3) most adapted for a terrestrial existence and possessing vascular tissues
4) cells with chloroplasts and cellulose cell walls
5) includes mosses, ferns, pine trees, cycads, ginkgos, and flowering plants

e. Kingdom Animalia
1) eukaryotic, multicellular organisms with cells organized into distinct tissues
2) heterotrophic, ingestive nutrition
3) most exhibit significant capacity for locomotion
4) cells not surrounded by cell walls
5) includes sponges, sea anemones, snails, insects, sea stars, fish, reptiles, birds, and human beings

II. What is a Species?

A. Typological Species Concept
1. based upon the presence of a common set of physical (morphological and anatomical) characteristics for organisms placed within a certain group
2. useful for classification of fossils and museum specimens in jars
3. problems
a. given the natural diversity within a species, what physical characteristics should be used to define a species?
b. also incorrectly implies species are fixed and unchanging by ignoring the role of evolution in shaping a species

B. Biological Species Concept
1. a collection of similar individual organisms that successfully interbreed among one another, or at least have the potential for successful interbreeding
2. "successful interbreeding" means the production of viable and fertile offspring
3. problems
a. often difficult to demonstrate interbreeding
b. how deal with the "in-betweens" (e.g., mules) - hybrids?
c. what about organisms, such as bacteria, that don't exhibit sexual reproduction?

III. Biological Nomenclature

A. Basic Scheme
1. each species identified by both its genus epithet and its specific epithet
2. example: mushroom coral = *Fungia scutaria*
a. *Fungia* = genus name
b. *scutaria* = species name

B. Rules
1. no two different species with the same combination of genus and specific name
2. no species given more than one combination of genus and specific name
3. genus name always capitalized & italicized or underlined (e.g., *Fungia*)
4. specific name not capitalized but is always italicized or underlined (e.g., *scutaria*)

C. Some Examples

1. bears
   a. *Ursus arctos* = Alaskan Brown Bear
   b. *Ursus maritimus* = Polar Bear
   c. *Ursus americanus* = American Black Bear
2. lobsters
   a. *Homarus americanus* = Atlantic Clawed Lobster
   b. *Panulirus marginatus* = White-Margined Hawaiian Spiny Lobster
   c. *Panulirus penicellatus* = Green Hawaiian Spiny Lobster

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VOCABULARY

phylogeny	biological species	typological species	taxonomy
kingdom	phylum (phyla)	class	order
family	genus	species	binomial
nomenclature	Monera	Protista	Fungi
Plantae	Animalia	unicellular	multicellular
heterotrophy	autotrophy	photoautotrophy	chemoautotrophy
saprophytic	ingestive		

STUDY QUESTIONS

1. What are the reasons that scientists classify living things into groups?

2. Discuss how living things are classified and named.

3. What criteria are used to classify living things into their respective groups? Provide examples to illustrate your discussion.

4. Contrast the typological species concept with the biological species concept. What are the difficulties encountered when using these concepts to identify and classify species.

5. List the five kingdoms of life and the characteristics used to define them. List examples of several types of organisms belonging to each kingdom.

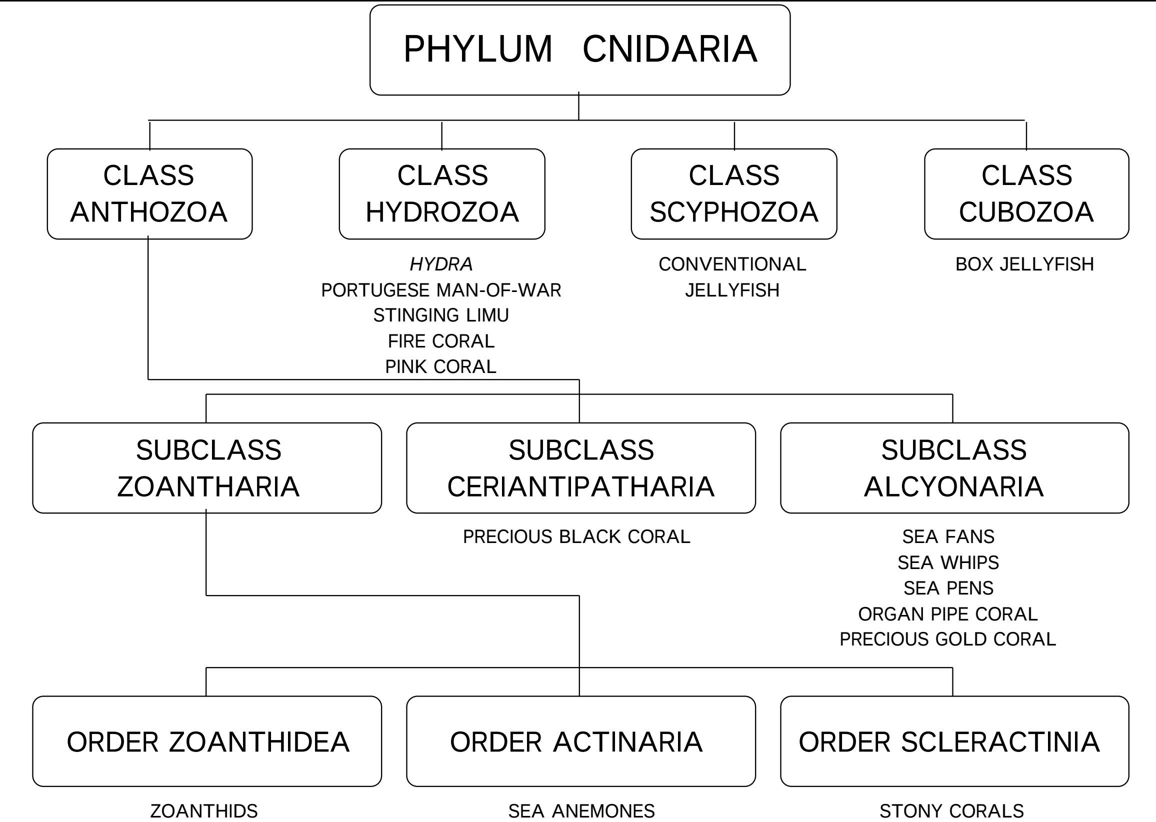
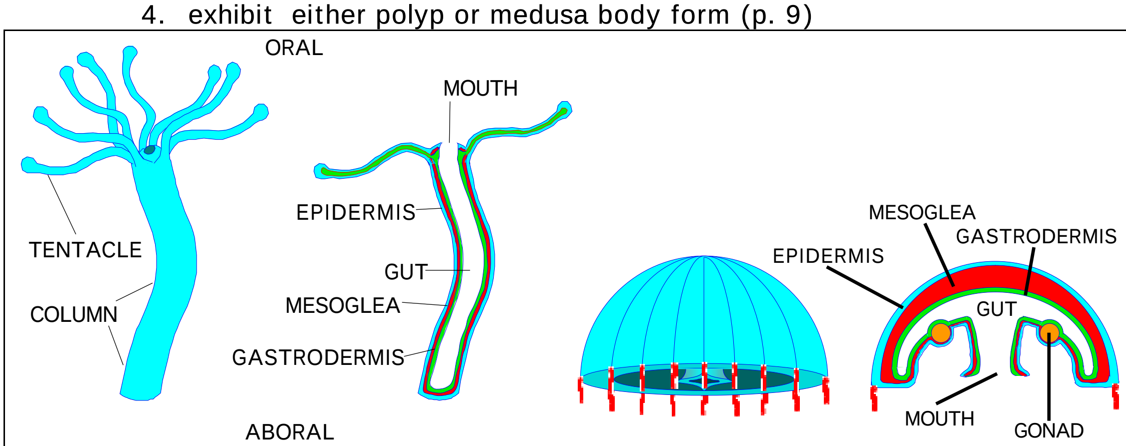


Figure 1. Higher systematics of Phylum Cnidaria illustrating the relationship of stony corals to other members of the phylum.

I. Phylum Cnidaria (Gr. *knide*, nettle; sometimes called Phylum Coelenterata)

A. Phylum Characteristics (pp. 8-15)

1. radial symmetry with oral and oboral ends
2. blind sac gut (= gastrovascular cavity or coelenteron; p. 15)
3. two basic tissue layers (diploblastic) with middle mesoglea (a jelly-like layer, not a true cellular layer between the epidermis and gastrodermis (p. 9)
4. exhibit either polyp or medusa body form (p. 9)



Polyp Body Form   Medusa Body Form

Figure 2. Diagram illustrating the two basic body forms exhibited by cnidarians.

5. possess cells called cnidocytes that produce stinging capsules called nematocysts (pp. 12-14)
6. nervous system consists of a network of nerve cells (nerve net), rather than being centralized into a nerve cord with a brain and peripheral nerves
7. no excretory nor respiratory systems
8. reproduce by asexual budding or sexual reproduction; life cycle typically involves alternation of polyp (asexual) and medusa (sexual) forms

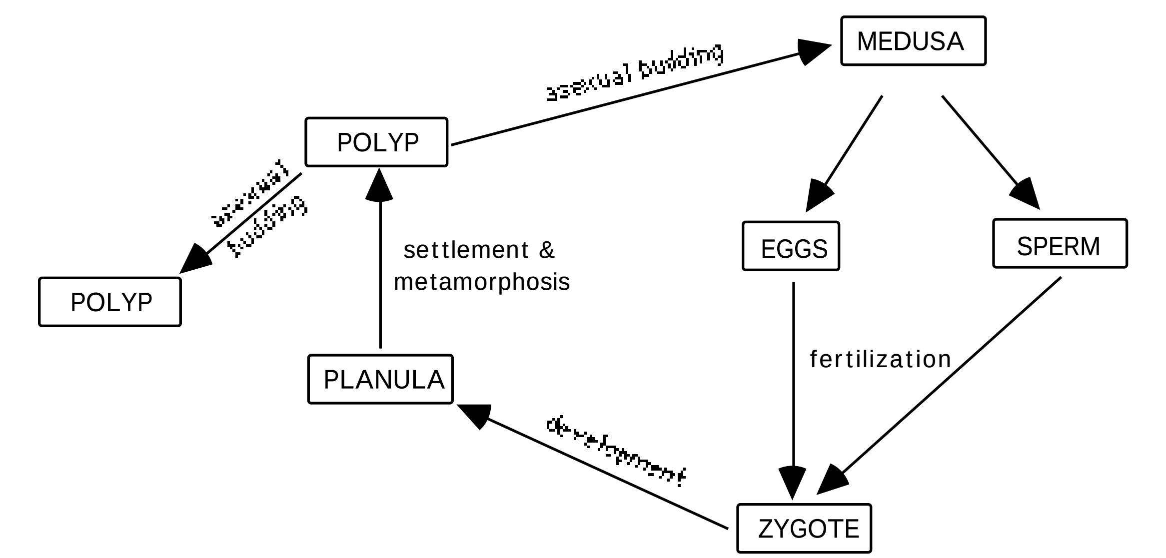


Figure 3. Typical cnidarian life cycle illustrating alternation between the polyp (asexual) and medusa (sexual) generation.

9. many colonial forms exhibiting varying degrees of polymorphism (e.g., Portugese man-of war)
10. most are marine, but a few live in freshwater

B. Cnidarians as Clonal Organisms (pp. 10-11)
1. many cnidarians generate colonies of many individual polyps
2. colony formation typically involves asexual budding of new polyps from pre-existing polyps
3. colony may be regarded as a kind of “superorganism”
4. genet = collection of genetically identical individuals (note: a genet can be just one individual or a whole colony)
5. advantages to clonal living
   a. rapid exploitation of suitable habitat
   b. become large without compromising surface-area-to-volume ratio (theoretically not limited to a maximum size)
   c. individual senescence overcome by potentially immortal genet
   d. partial mortality of colony does not destroy the genet and replacement of dead individuals can occur
   e. asexual dispersal of individuals, or parts of colonies, enhances survival of the genet

II. Cnidarian Classes

A. Class Hydrozoa (Gr. *hydra*, water serpent; pp. 22-26)
1. life cycle with both polyps and medusae, although one or the other form may be suppressed (usually polyp-dominant; p. 22)

2. gut cavity of polyp is simple, lacking a pharynx and not divided by mesenteries (see below)
3. tetramerous (four-part) radial symmetry
4. medusa stage with a velum (= a narrow shelf of tissue that projects inwards from the margin of the umbrella)
5. gonads are ectodermal (found in the epidermis)
6. medusa stage may possess specialized balance organs called statocysts
7. solitary or colonials; some colonial forms highly polymorphic (e.g., Portuguese man-of-war) with polyps specializing for different functions (floats, feeding, reproduction, & defense)
8. some examples
   a. hydroids (p. 22), also called “stinging limu”
   b. fire corals (p. 23)
   c. by-the-wind-sailors (p. 24)
   d. Portuguese man-of-wars (p. 25)

B. Class Scyphozoa (Gr. *skyphos*, cup) – The Sea Jellies (pp. 18-20)
1. life cycle with both polyps and medusae, but medusae dominate with polyp stage reduced or absent (p. 17)
2. polyp stage (scyphistoma) goes through strobilization to produce young medusa (p. 17)
2. bell margin lacks a velum
3. tetramerous (= four-part) radial symmetry
4. gut divided into a complex system of radial canals
5. some with a simple single mouth, but many with thousands of microscopic “mouths” at the ends of oral arms
6. gonads endodermal (found in the gastrodermis)
7. specialized sense organs (rhopalia)
   a. ocelli (= photosensitive eye-like structures)
   b. statocysts (= balance organs)
8. includes some 200 marine species
9. some examples: moon jellies and the upside-down jellyfishes ("true" sea jellies)

C. Class Cubozoa (Gr. *kybos*, a cube) – The Box Jellies (p. 21)
1. medusae with reduced polyp stages that transfer directly into medusae (no strobilization)
2. nearly cube-shaped with a tentacle arising from each of the four corners
3. bell margin turned inwards as a velarium (like a velum)
4. gonads endodermal
5. specialized sense organs (rhopalia)
   a. ocelli (= photosensitive eye-like structures)
   b. statocysts (= balance organs)
6. includes about 15 marine species
7. some examples: box jellies and sea wasps

D. Class Anthozoa (Gr. *anthos*, flower)
1. lack medusa stage entirely (polyp forms only)
2. mouth with a tubular pharynx that projects inward into the gut
3. large gut cavity divided by mesenteries that radiate inwards from the body wall

4. gonads endodermal, borne on the mesenteries
6. hexamerous (6-part) or octamerous (8-part) radial symmetry or biradial (modified radial symmetry that limits the number of planes that can divide the bodyinto equal halves)
7. includes true stony corals
8. non-coral representatives of Class Anthozoa
    a. wire coral (p. 61)
    b. precious black coral (p. 62)
    c. octocorals (pp. 63-65)
    d. zoanthids (p. 66)
    e. sea anemones (pp. 67-70; 72)

III. Systematic Pathway to Stony Corals within Class Anthozoa

A. Subclass Zoantharia
1. usually hexamerous (6-part) symmetry (actually biradial) in arrangement of septa, mesenteries (paired) & tentacles
2. polyps always with more than eight tentacles
3. tentacles are simple, unbranched & non-pinnate
4. some examples: sea anemones and stony corals

B. Order Scleractinia (= Madreporaria; true stony corals)
1. secrete external skeleton (exoskeleton) of calcium carbonate
2. most are colonial, but a few solitary forms exist
3. includes most reef-building corals

TEXT PAGES COVERED

pp. 8-26; 61-70; 72

VOCABULARY

gastrovascular cavity	coelenteron	mesoglea	epidermis
gastrodermis	polyp	medusa	cnidocyte
nematocyst	nerve net	planula	clonal
genet	polymorphism	mesentery	pharynx
tetramerous	octamerous	hexamerous	biradial
velum	strobilization	budding	tentacle
rhopalia	ocelli	statocyst	

STUDY QUESTIONS

1. List the characteristics that define Phylum Cnidaria and each of its four classes.

2. Describe the functioning of nematocysts.

3. What are the advantages of being a clonal organism?

4. Draw a labeled diagram that illustrates the typical cnidarian life cycle. Describe this life cycle.

5. Why is the coelenteron described by the book's author as a "super stomach"?

6. Using diagrams, contrast the following modifications of radial symmetry: biradial, tetramerous, octamerous, and hexamerous. Give examples of representative cnidarians exhibiting these symmetry patterns.

7. LIst the characteristics and examples representatives of the following groups:
   Phylum Cnidaria
   - Class Hydrozoa
   - Class Scyphozoa
   - Class Cubozoa
   - Class Anthozoa
     - Subclass Zoantharia
       - Order Scleractinia

THE ANATOMY AND MORPHOLOGY OF SCLERACTINIAN CORALS

I. Coral Polyp Structure

A. Solitary Polyps

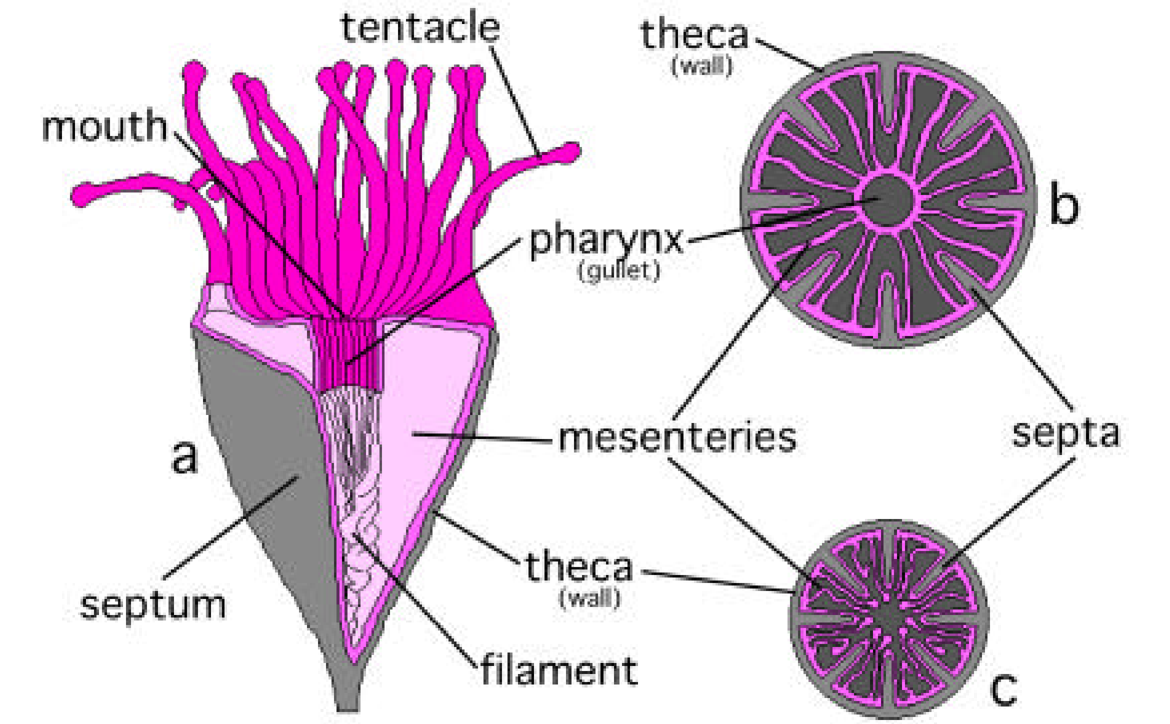


Figure 1. Diagram illustrating a typical solitary coral polyp and the skeletal features of its corallite. a) longitudinal section; b) cross section through the pharynx region; c) cross section below the pharynx region.

B. Colonial Polyps

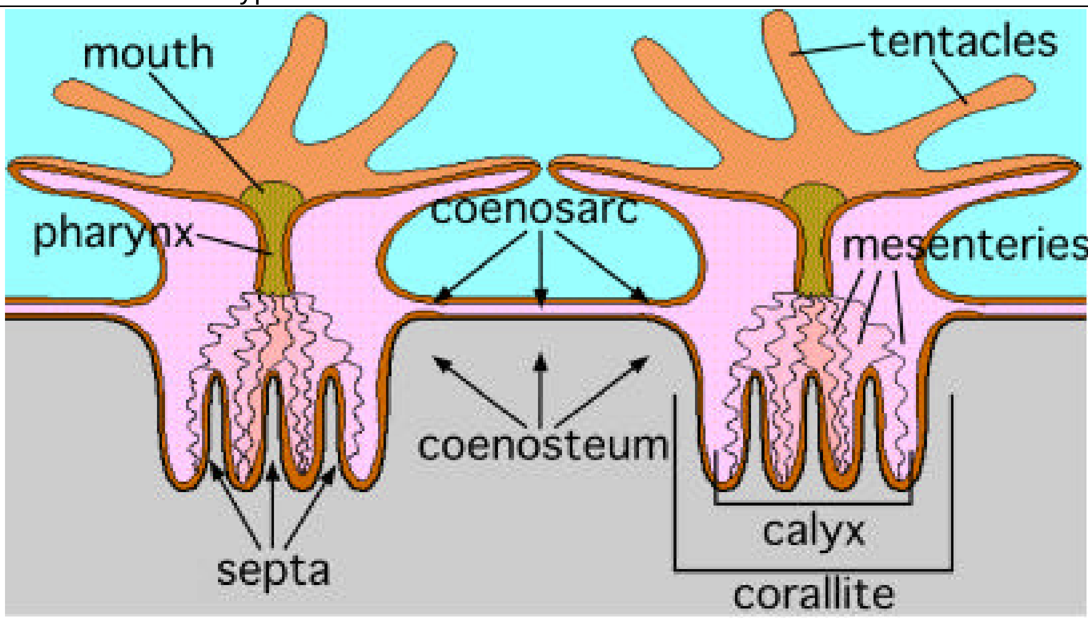


Figure 2. Diagram illustrating longitudunal sections of two adjacent polyps of a coral colony.

C. Principle Skeletal Features (see also p. 41)
   1. corallum (pl. coralla) = the entire coral skeleton
   2. corallite = skeleton produced by a single polyp
   3. calyx (pl. calices) = concave depression that houses the polyp
   4. theca = corallite wall
   5. coenosteum = skeletal material between walls of adjacent corallites
   6. septum (pl. septa) = skeletal plates that radiate into the calyx from the wall (sometimes called scleroseptum)
   7. costa (pl. costae) = extensions of the septa outside the wall of the corallite
   8. columella = central structure of the calyx formed by fusion of the lower elements of the septa

D. Other Skeletal Characteristics
   a. perforate vs. imperforate corals
      1) perforate corals with porous skeleton though which living tissue occurs (e.g., finger coral, *Porites compressa*, p. 142)
      2. imperforate corals characterized as having living tissues restricted to covering the surface of the skeleton (e.g., lace coral, *Pocillopora damicornis*, p. 52)
   b. skeletal protuberances or bumps (p. 41)
      1) tuberculae: larger-than-polyp bumps occuring in the coenosteum (e.g., rice coral, *Montipora capitata*, p. 43)
      2) verrucae: larger-than-polyp bumps formed by several corallites (e.g., cauliflower coral, *Pocillopora meandrina* ,p. 54)
      3) papillae : smaller-than-polyp, nipple-like projections of the skeletal surface (e.g., under surface of the humpback coral, *Cycloseris vaughani*, p. 49)

E. soft tissue features
   1. similar to sea anemone (see Figure 3 below)
   2. tentacles
      a. = outpocketings of gut cavity between mesenteries
      b. usually simple tubes, however occasionally divided into branches
      c. typically, corals have 12 or more in multiples of 6
      d. nematocysts usually found in greatest abundance on tentacles
   3. mesenteries (sometimes called septa – although this causes confusion with skeletal elements bearing the same name)
      a. complete vs. incomplete
         1) complete mesenteries (also called primary mesenteries) connect body wall to pharynx
         2) incomplete mesenteries (e.g., secondary & tertiary mesenteris) do not connect to pharynx
      b. complete & incomplete mesenteries continue below lower edge of pharynx to floor of polyp
      c. free edges of septa exhibit swelling called the filament
         1) many nematocysts on filaments
         2) also cells with digestive enzymes used in the digestion of food
         3) some corals can squeeze filaments out through body wall: used in defense, feeding, and aggressive interactions with neighboring corals

d. muscle bands used in retracting polyp into coral cup found on mesenteries
e. gonads are also found on mesenteries

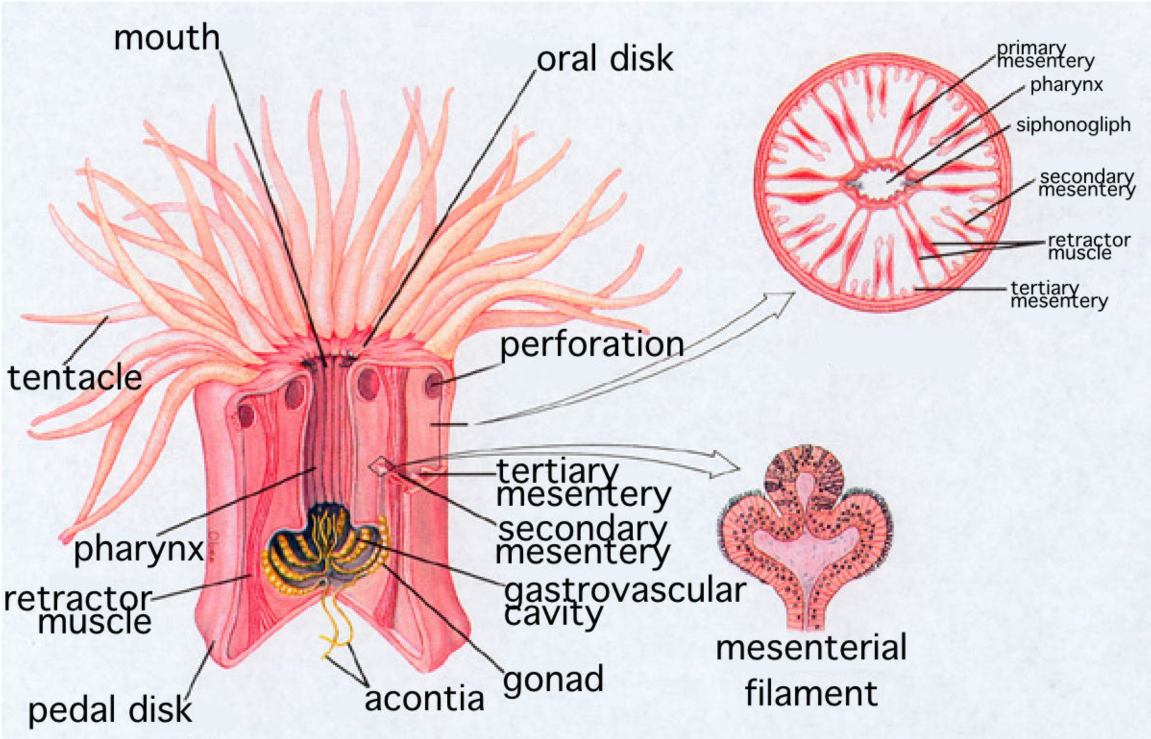


Figure 3. Internal anatomy of a typical sea anemone.

II. Coral Growth Forms

A. Different Arrangements of Corallites Within a Colony (not an all-inclusive list):

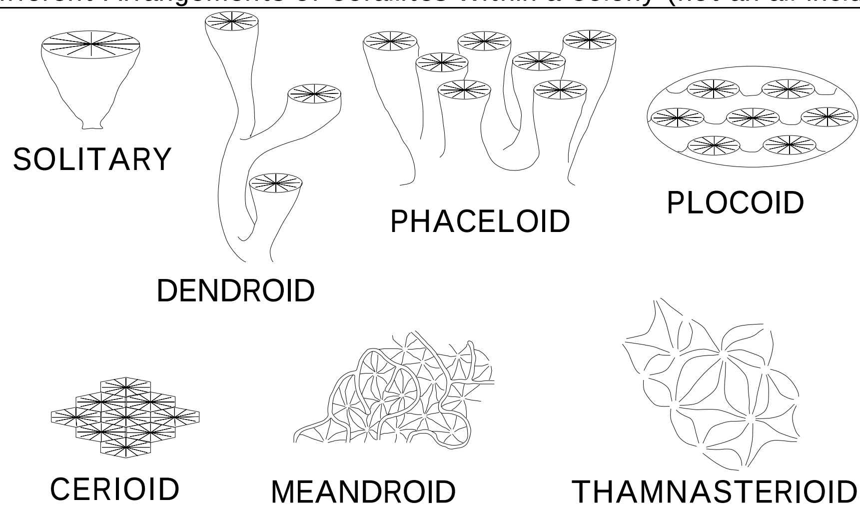


Figure 4. Diagram illustrating different arrangements of corallites within a colony.

1. solitary (e.g., mushroom corals, *Fungia* & *Cycloseris*, pp. 49-51)
2. dendroid = spreading branches of single corallites
3. phaceloid = distinct parallel-arranged corallites arising from a common source
4. plocoid = corallites with distinct walls united to each other by the coenosteum (e.g., *Leptastrea bottae*)

5. cerioid = prismatic corallites closely appressed and sharing common walls (e.g., crust coral, *Leptastrea pupurea*, p. 47, and finger coral, *Porites compressa*, p. 55)
6. meandroid = several corallites forming a series within the same walls giving the appearance
   of meandering valleys (e.g., corrugated coral, *Pavona varians*, p. 46)
7. thamnasterioid = corallites with confluent septa and lacking defined boundaries (e.g., flat lobe coral, *Pavona duerdeni*, p. 45)

B. Intratentacular Versus Extratentacular Budding (p. 79)
   1. intratentacular involves formation of a new polyp from within the ring of tentacles of the original polyp - actually a binary fission process
   2. extratentacular involves formation of a new polyp outside the tentacular ring of other polyps, typically from the coenosteum

C. Different Colony Growth Forms (pp. 39-40)
   1. massive or lobate (e.g., lobe coral *Porites lobata*, p. 56)
   2. columnar (perhaps finger coral, *Porites compressa*, p.55)
   3. ramose or branching (e.g., lace coral, *Pocillopora damicornis*, p. 52)
   4. foliaceous (e.g., rice coral, *Montipora capitata*, p. 43)
   5. laminar or plate-like (e.g., rice coral, *Montipora capitata*, p. 43)
   6. encrusting (e.g., blue rice coral, *Montipora flabellata*, p. 44)

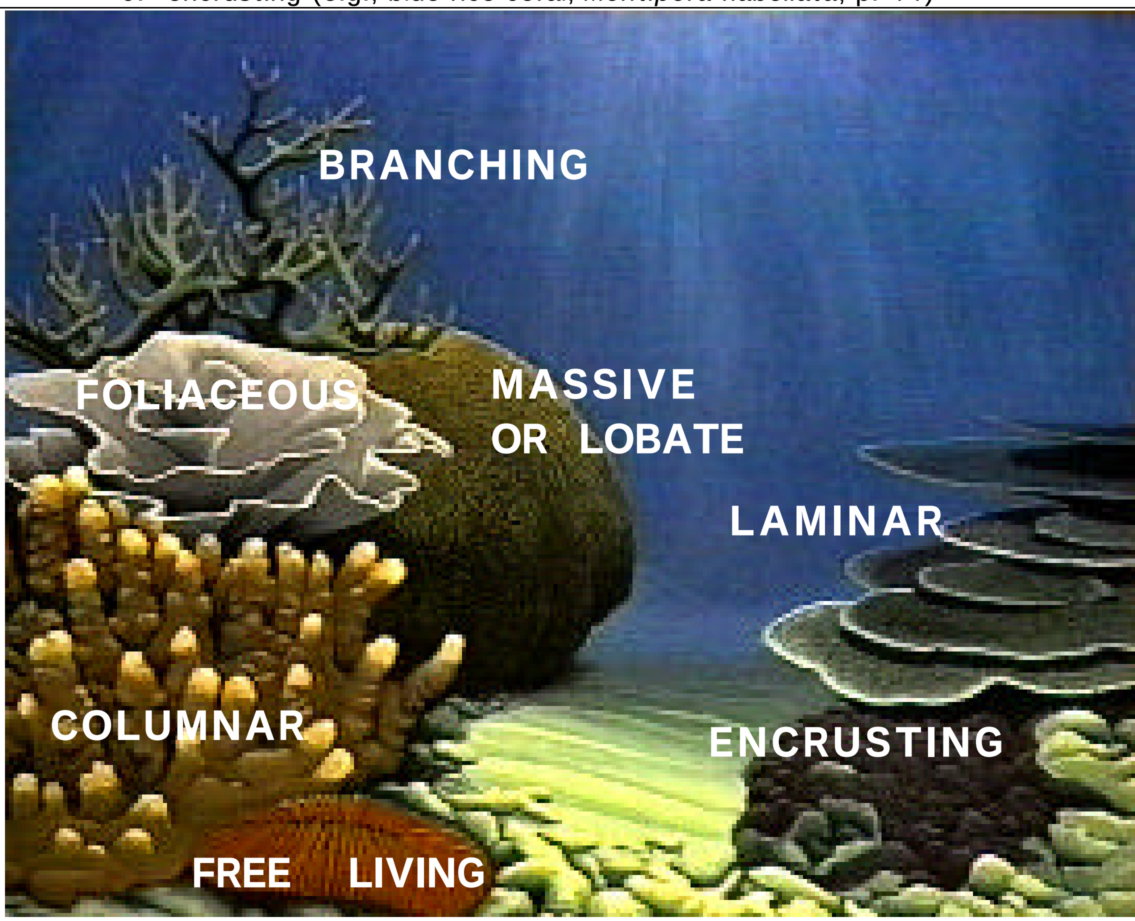


Figure 5. Different colony growth forms of corals.

D. Factors Influencing Colony Growth (pp. 38-40)
   1. water motion
      a. some corals adapted to heavy wave action by forming dense, robust skeletons
      b. sacrifice: depositing dense skeleton means slower growth
      c. some corals (e.g., lace coral, *Pocillopora damicornis*) may alter growth form in different water motion environments
         1) short-branched, robust, but slow growing, form develops in areas of heavy water motion
         2) delicate, fine-branched, fast growing form develops in calm water areas such as protected bays
      d. mushroom corals have a shape that promotes self-righting by water motion (p. 40)
   2. light
      a. most corals need light to support their symbiotic algal partners
      b. shallow water near surface
         1) light scattered by roughness of the water's surface
         2) best light gathering shape = hemispherical branching colony
      c. deep water environments
         1) light rays more straight down
         2) best light gathering shape = flat surface
      d. rice coral, *Montipora capitata* (p. 43)
         1) forms hemispherical branching colonies in shallow water
         2) forms laminar, plate-like colonies in deeper water or shaded conditions
   3. biological factors
      a. genetics
      b. coral symbionts (e.g., gall crabs, p. 113, cause branches of corals to form gall-shaped branches)

E. Coral Skeletal Density Bands
   1. rate and density of skeleton deposition depends upon light and temperature
   2. results in growth bands similar to tree rings

F. Growth Rates
   1. extremely variable (depends upon species and environmental conditions)
   2. massive corals tend to grow slowly (e.g., 0.5 to 1.0 cm per year)
   3. branching corals may grow quickly (e.g., 10 to 20 cm per year)
   4. note: make a distinction between individual coral colony growth and coral reef growth as a whole

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PP. 36-60, 79, 142

VOCABULARY

corallite	calyx (calices)	theca	septum (septa)
columwlla	coenosteum	tuberculae	verrucae

papillae	tentacles	coenosarc	pharynx
mesentery	mesenterial filament	complete mesentery	incomplete mesentery
gonad	intratentacular	extratentacular	massive
lobate	solitary	columnar	ramose
foliaceous	laminar	encrusting	dendroid
phaceloid	plocoid	ceriod	meandroid
thamnasteroid			

STUDY QUESTIONS

1. Be able to recognize the following skeletal features of a scleractinian coral: calyx, corallite, theca, septum, columella, and coenosteum.

2. Understand the anatomy of coral polyps. Especially understand the anatomy and function of the following soft tissue features: tentacles, mouth, pharynx, mesenteries, mesenterial filament, gastrovascular cavity, and gonad.

3. Discuss, with the use of labeled diagrams, the variety of possible arrangements between individual calices in a coral colony.

4. Discuss, with the use of labeled diagrams, the various colony growth patterns exhibited by corals. Also describe how different environmental factors may lead to different growth forms.

CORAL NUTRITION

I. Heterotrophic Feeding (p. 76)
   A. General Modes
      1. predaceous carnivores capturing live prey such as zooplankton
      2. detritus feeding upon particulate organic material & bacteria
      3. absorption of dissolved organic matter from the surrounding water
   B. Active Predation
      1. tentacles important
         a. long tentacles usually found corals that rely predominantly on heterotrophic food sources
         b. tentacles often extended at night, but retracted during the day, suggesting that most feeding activity happens at night when demersal (= bottom-associated) zooplankton rise from the interstices of the reef
         c. large polyp size may also suggest dependency upon heterotrophy
         d. hermatypic corals bearing algae tend to have smaller tentacles & smaller polyps
      2. nematocysts discharge when prey contact made (pp. 12-14)
         a. some penetrate into prey & inject toxin
         b. others coil around the fine hairs of the prey
         c. still others are sticky
         d. stimulus for nematocyst discharge (p. 13)
            1) chemical stimulus lowers the stimulus threshold for discharge
            2) mechanical stimulus
      3. release of chemicals from damaged tissue of prey
         a. stimulates tentacles to bend towards the mouth
         b. stimulates mouth opening response
         c. increasing concentration intensifies response
         d. chemicals cited as stimulating a feeding response
            1) amino acids
            2) reduced glutathione
      4. some corals extrude their mesenterial filaments for feeding
   C. Ciliary-Mucoid Feeding (p. 35)
      1. tentacles may or may not be involved
      2. particulate food becomes trapped in mucus layer over surface of the coral
      3. fine hairs called cilia move particulate food towards mouth
      4. same mechanism is also used to clear sediments from tissue surfaces
      5. direction of ciliary-mucoid feeding/clearing is under chemical control
   D. The Versatile Blind-Sac Gut or Coelenteron of a Coral (p. 15)
      1. gas exchange
      2. hydrostatic skeleton (p. 34)
      3. reproduction
         a. mesenteries bear gonads
         b. gut can serve as a “brood sac” for brooding corals
      4. mesenterial filaments extruded through body wall for defense (p. 91)
      5. infection by zooxanthellae
II. Autotrophy in Corals (pp. 29-33)
   A. Photosynthesis vs. Respiration

1. photosynthesis
   a. involves many steps with the following overall consequences
      1) light energy (electromagnetic radiation) absorbed and converted to chemical energy (= energy stored in chemical bonds between atoms of certain molecules)
      2) captured chemical energy used to synthesize carbohydrates (i.e., glucose)
   b. overall chemical reaction

$$\textbf{\textit{light energy}} + 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

   c. carbohydrates produced may be used in the following ways
      1) sources of stored energy for energy-requiring processes of the plant
      2) building blocks for molecular components of cells & tissues for repair, growth, and reproduction
   d. occurs in plants & certain photosynthetic bacteria
2. aerobic respiration
   a. involves the release of chemical energy stored in organic molecules (e.g., glucose) for energy-requiring metabolic processes
   b. appears to be the opposite of photosynthesis
   c. overall chemical reaction

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \textbf{\textit{chemical energy}}$$

   d. occurs in nearly all cells (including plants) except certain anaerobic bacteria

B. Zooxanthellae
   1. symbiotic algae of corals
   2. scientific name = *Symbiodinium microadriaticum*
   3. live within the endodermal cells of most hermatypic corals
   4. algae actually represent one phase in the life cycle of a type of unicellular plant called a dinoflagellate (p. 29)
   5. “infection” or transmission of zooxanthellae into host tissues
      a. maternal (direct) transmission of zooxanthellae into eggs during gametogenesis
      b. environmental (indirect) transmission into planula larva stage

C. Dominance of Symbiotic Corals Over Asymbiotic Corals in Shallow Tropical Reefs
   1. attributed to the presence of the algae
      a. hermatypic corals = "reef-building" corals - almost always possess zooxanthellae, thus "hermatypic" now often used to imply "possessing zooxanthellae"
      b. ahermatypic corals = corals, usually those lacking zooxanthellae, that do not contribute significantly to reef construction
   2. possible benefits for the coral-zooxanthellae association
      a. higher calcification rates leading to faster coral growth rates (p. 33)
         1) actually this idea has been challenged recently since some

ahermatypic (or azooxanthellate, lacking zooxanthellae) corals calcify as, or more, rapidly than hermatypic corals

2) daytime activation of calcification by zooxanthellae may actually function to enhance photosynthesis
3) possible night-time inhibition of calcification by zooxanthellae
4) prompts major question: "Why are most of the reef-building corals those with symbiotic algae?"

b. zooxanthellae provide coral animal with food for energy and materials for growth, repair and reproduction
   1) zooxanthellae photosynthesis yields production of important organic molecules (e.g., glycerol, amino acids and fatty acids)
   2) transfer of products of zooxanthellae production = translocation
   3) coral animal uses translocated organic materials for to support its nutritional needs
   4) fates of carbon fixed by zooxanthellae photosynthesis
      a) zooxanthellae respiration
      b) zooxanthellae growth
      c) translocated into host tissues
   5) fates of translocated carbon
      a) animal respiration
      b) animal growth, repair and reproduction
      c) lost organic matter
         1) dissolved organic matter
         2) mucus and nematocysts
         3) fat bodies

c. nutrients are recycled between the coral animal host and the algae symbionts
   1) inorganic wastes of coral host metabolism: carbon dioxide, ammonia, and phosphate
   2) zooxanthellae remove and utilize these wastes for production of biological molecules
      a) carbon dioxide for organic molecule synthesis
      b) ammonia for amino acids & other nitrogen-containing biological molecules
      c) phosphate for organic phosphate-containing compounds (e.g., ATP & DNA)
   3) organic products of plant synthetic processes translocated into animal host
   4) recycling conserves nutrients within the association, a possible advantage for survival in the nutrient-poor waters characteristic of coral reefs

d. production and storage of ultraviolet light absorbing compounds
   1) most hermatypic corals live fully exposed in well-lit surface waters
   2) penetration of ultraviolet biologically significant to 30 meters
   3) protective ozone layer thinnest in equatorial-to-tropical latitudes leading to high intensities of ultraviolet radiation at the earth's surface

4) thus, shallow-water reef flat corals exposed to high levels of damaging ultraviolet radiation
5) coral tissues contain high concentrations of these "sunscreen" chemicals which may actually be a product of zooxanthellae biochemistry

e. zooxanthellae, which are single-celled algae, have a protected habitat in the crowded coral reef environment

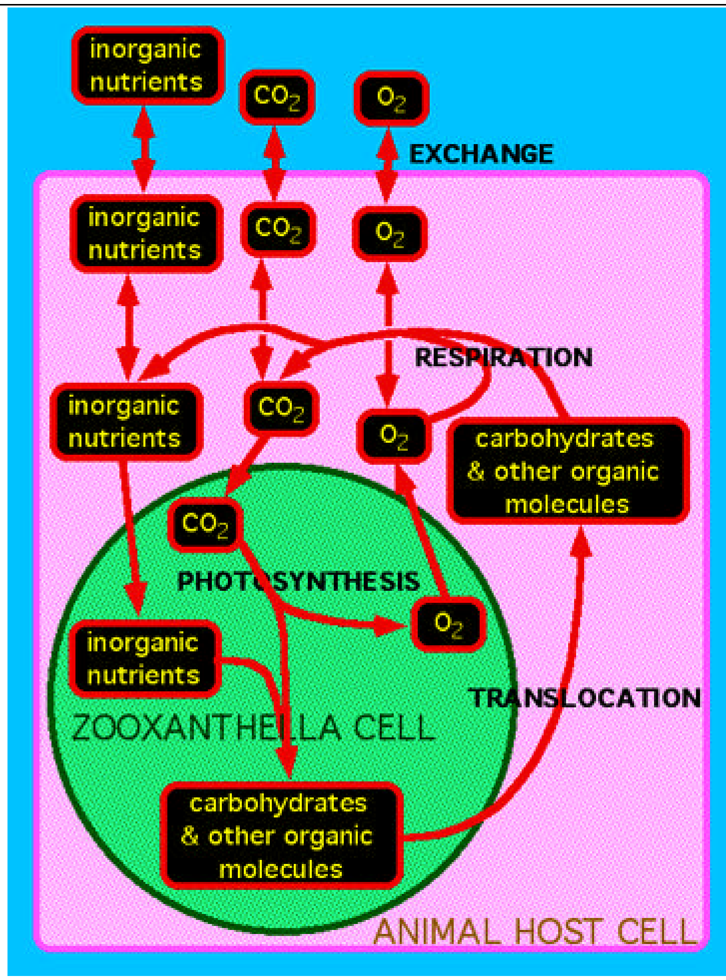

Figure 1. Recycling of nutrients between the coral animal and its endosymbiotic zooxanthellae.

C. Heterotrophy Versus Autotrophy

1. zooxanthellae originally not recognized as symbiotic algae & thought to be "kidneys" for removal of metabolic wastes
2. recognition that zooxanthellae were in fact endosymbiotic algae sparked controversy over their relative contribution to host nutrition
3. night-time polyp expansion, chemical stimulus of feeding behavior, and possession of tentacles, nematocysts, gastrovascular cavity emphasize heterotrophy as prevailing mode of nutrition
4. light-dependency, plant-like colony morphology, and demonstration of algal photosynthesis and translocation emphasize autotrophy as prevailing mode of nutrition
5. controversy rectified by the realization that some corals emphasize

heterotrophy, while others emphasize autotrophy, as their adaptational "strategy"

6. bottom line: dual modes of nutrition contributes to the success of hermatypic corals

TEST PAGES COVERED

pp.12-15, 28-35, 76, 91

VOCABULARY

heterotrophy	autotrophy	ciliary-mucoid	zooxanthellae
hermatypic	ahermatypic	calcification	photosynthesis
translocation	endosymbiosis	inorganic nutrient	cilia
symbiont	host	aerobic respiration	

STUDY QUESTIONS

1. Contrast the features of corals that emphasize their heterotrophic mode of nutrition.

2. Contrast the features of corals that emphasize their autotrophic mode of nutrition.

3. Describe the role of chemical stimuli in the feeding of corals. Be sure to comment on the behavior of nematocysts, tentacles, mouth, and ciliary-mucoid activity.

4. Discuss the advantages of the endosymbiotic relationship between the coral animal and zooxanthellae. Be specific.

5. Discuss the fate of carbon fixed by the photosynthetic activity of the endosymbiotic zooxanthellae of corals.

REPRODUCTION OF SCLERACTINIAN CORALS

I. Introduction
   A. Historical Background
      1. much learned about coral reproduction during the past 20 years
      2. old dogma that most corals brood refuted
      3. despite the avalanche of info collected, unifying generalizations regarding the mode, sexuality, and timing of reproduction in scleractinian life history cycles are still wanting
   B. Basic Concepts to be Covered
      1. asexual reproduction
         a. contrast asexual reproduction with colony growth (colonial vs. solitary)
         b. modes of asexual reproduction
      2. sexual reproduction
         a. sexuality
         b. broadcast spawning vs. brooding
         c. reproductive effort and fecundity
         d. timing and synchrony
         e. gamete buoyancy and dispersal during spawning
         f. fertilization & early development
         g. planula dispersal and settlement
      3. corals as colonies and clonal organisms
II. Asexual Reproduction
   A. Reproduction or Colony Growth?
   B. Types of Polyp Budding (p. 78)
      1. intratentacular budding: when a single polyp splits into two or buds a new polyp from within the ring of tentacles of the parental polyp
      2. extratentacular budding: when a new polyp forms outside the ring of tentacles of the pre-existing polyps (i.e., from the coenosarc)
   C. Modes of Asexual Reproduction
      1. accidental fragmentation (p. 79)
         a. fragmentation of a coral colony resulting from some extrinsic factor such wave breakage of the coral
         b. some examples
            1) turtle damage of *Porites compressa* in Kane‘ohe Bay (p. 73)
            2) *Montipora* fusion/rejection studies
               a) when *Montipora* specimens from two different colonies are placed next to each other they may either fuse together to become one colony or remain distinct
               b) apparently, only clone mates (genetically identical) can fuse together
      2. nonaccidental fragmentation (usually associated with solitary corals)
         a. life cycle has built into a stage of separation into separate individuals
         b. examples
            1) *Cycloseris fragilis* divides into “pie slices” along septal lines to yield new corals
            2) *Fungia scutaria* (p. 83)

            a) disk, or anthocyathus, separates from the stalk, or anthocaulus
            b) anthocaulus (stalk) can regenerate a new disk (anthocyathus)
    3. partial colony mortality
        a. when a large colony is subjected to partial mortality leaving behind patches of living tissues
        b. remaining live patches then continue as separate genetically identical colonies
        c. phenomenon also happens in *Fungia scutaria* (sometimes called parricidal budding) and *Porites compressa* to yield the "Phoenix" phenomenon (p. 142)
    4. asexual planulae or asexual brooding (p. 80)
        a. asexual planula-like structures apparently form within the coelenteron of some corals
        b. hypothesized mechanisms
            1) budding from the pharynx
            2) parthenogenesis (development of eggs without fertilization by sperm)
        c. example: *P. damicornis* in Hawaii & elsewhere
    5. polyp bail-out (p. 81)
        a. under periods of stress polyps may separate from each other and emerge from their calices as floating polyps
        b. polyps resettle under appropriate conditions and begin to deposit new skeleton

II. Sexual Reproduction (pp. 82-85)
    A. Sexuality
        1. appearance of gonads
            a. not true organs, but transitory aggregations of gametes in the mesenteries
            b. gametes arise from primordial germ cells that migrate into the mesoglea of the mesenteries from the gastrodermis
        2. hermaphroditism vs. gonochorism (p. 83)
            a. sexuality usually consistent within coral families
            b. a few exceptions (e.g., Agariciidae, Poritidae, Faviidae, Rhizangidae, Caryophylliidae, Dendrophylliidae)
            c. hermaphroditism
                1) condition whereby both male and female gonads appear in the same individual
                2) majority of scleractinians appear to be hermaphroditic
                3) patterns
                    a) simultaneous hermaphrodites
                        1) develop both male and female gametes at the same time
                        2) gonad arrangements on mesenteries
                            a) eggs & sperm intermingling within the same mesentery
                            b) separate on the same mesentery
                            c) eggs & sperm on different pairs of mesenteries
                            d) separate male & female polyps within the same colony
                    b) sequential hermaphrodites
                        1) change sex through time

            2) not unambiguously documented
      d. gonochorism
         1) gonochoric = separate sexes
         2) sex ratios: usually 1:1 for broadcast spawners
         3) mechanism for sex determination uncertain
      e. mixed patterns (only a few species)
      f. possibility that species may easily shift from one pattern to another although correlation of sperm type with sexuality mode would seem to contradict this (i.e., pointy sperm heads = gonochoric)
      g. adaptive considerations
         1) conventional dogma: hermaphroditism favored when self fertilization possible & probability of finding gametes of opposite sex low
         2) yet observations not consistent with this dogma
         3) stability within families suggest pattern more a consequence of evolutionary history than specific adaptive constraints

B. Brooding vs. Broadcast Spawning
   1. broadcast spawning
      a. release eggs and sperm into the water column
      b. fertilization takes place in the water column
      c. development to the planula stage takes place in the water column
   2. brooding
      a. eggs fertilized inside the coelenteron on the polyp
      b. development to the planula stage occurs within the polyp
      c. release of planula = planulation
   3. patterns
      a. majority of corals are broadcast spawners (compared to a few brooders)
      b. a few reported to do both
      c. no clear cut family-divisible trends discernable (although the Acroporids & Favids tend to be primarily broadcasters; Pocilloporids & Poritidae seem to split)
      d. seasonal trends correlated with these modes: brooders often reproduce throughout the year, while broadcasters seasonal (most often late spring & summer)
   4. adaptive considerations
      a. brooding typically produces planula with the immediate capability to settle out after planulation occurs
      b. broadcasting requires developing embryos and planula to spend substantial time in the plankton before settlement can occur

C. Reproductive Effort and Fecundity
   1. reproductive effort = the energy invested into reproduction
   2. fecundity = the number of eggs a female produces
   3. considerations
      a. many small vs. few large
      b. no. of eggs per polyp vs. no. of eggs per colony (or per cm)
         1) increase eggs with increase polyp size
            a) more egg-bearing mesenteries

b) more eggs/mesentery
2) more polyps/colony, more eggs/colony
c. brooding vs. broadcasting
d. energy invested in sperm vs. that of eggs
e. no. of reproductive events per year or seasonal variation
f. size/age at first reproduction
g. period of reproductive maturity (related to senescence)
h. spatial variation across a colony
1) sterile and post-sterile zones associated with growing regions of the colonies that exhibit localized growth
2) massive colonies: all polyps similarly gravid
i. spatial variation within a population (e.g., variation with depth)
j. environmental stresses yielding lower fecundity (or planula abortions)
1) turbidity & sedimentation
2) high temperature
3) low salinity
4) aerial exposure at low tide
5) low irradiance
6) lack of uv light
7) mechanical damage
8) intrespecific competition
9) oil & fuel oil pollution
10) eutrophication

D. Zooxanthellae Incorporation into Eggs
1. often incorporated into the egg cytoplasm during gametogenesis (direct transmission)
2. some species produce eggs that lack zooxanthellae - pick up zooxanthellae as planulae, possible by ingestion (indirect transmission)

E. Timing and Synchrony
1. despite tropical climates most species exhibit regular periodic reproductive episodes for planula release and synchronized broadcast spawning
2. cycles implicated
a. seasonal (broadcaster vs. brooder differences)
b. lunar/tidal (full moon vs. new moon or several days after these)
c. day/night (most seem to be late night spawners)
3. interface with different stages of gametogenesis and gamete release
a. initiation of gametogenesis
b. rate of gamete maturation
c. final stages of maturation
d. gamete release
4. ultimate causes (advantages to synchronized reproduction)
a. maximizes chances of encounters between sperm & eggs, reduce gamete wastage (although may be negated during multi-species mass spawns)
b. maximize outcrossing in self-fertile hermaphrodites
c. minimize predation by swamping predators and/or being less visible
d. ensure successful recruitment within natal reef (optimal tidal cycle)

   e. ensure dispersal beyond natal reef (optimal tidal cycle)
5. proximate factors associated with cycles
   a. seasonality
      1) seasonal temperature changes
      2) seasonal changes in daylength
      3) seasonal changes in light intensity
      4) seasonal changes in wind & current patterns
      5) seasonal changes rainfall & runoff
      6) latitudinal differences
         a) opposite hemispheres
         b) higher latitudes tend to exhibit shorter breeding season
   b. lunar rhythms
      1) lunar light intensities related to lunar phases
      2) may be correlated spring-neap tide cycles
      3) split spawning vs. repeat lunar spawning by the same individual
   c. daily rhythms
      1) light-dark cycles probably important in final synchronization & release
      2) daily tidal cycles
   d. other factors
      1) water motion or lack of it
      2) chemical cues
   e. interaction of all or most of these
6. gametogenic cycles
   a. most annual broadcasters with single cycle of gametogenesis that lasts for less than 12 months
   b. brooders tend to exhibit multiple non-overlapping cycles
   c. a few corals exhibit overlapping cycles
   d. synchrony of gametogenic cycles
      1) broadcasters = usually synchronized throughout the population
      2) brooders = usually synchronized within colony but among-colony synchrony sloppy
7. chemical cues and spawning synchrony
   a. anecdotal accounts suggest chemical stimulus may tighten spawning synchrony
   b. some evidence for occurrence of estrogen in coral eggs
8. Multiple Species Mass Spawning Events (p. 85)
   a. Great Barrier Reef 134 of 356 species spawn at the same time
   b. Western Australia (similar but later spawning event)
   c. Okinawa
   d. Gulf of Mexico (note: distinguish between multispecies mass spawns & limited species synchronized spawns)
   e. advantages vs. disadvantages
      1) swamp predators = advantage
      2) production of inviable hybrids through congeneric fertlizations = disadvantage (although the extreme diversity of the Acroporids may be result of successful hybridizations)
      3) coincident environmental catastrophy with spawning event

disadvantageous
4) massive amounts of organic matter from mass spawning known to produce a reef kill

F. Egg Buoyancy and Dispersal during Spawning
1. majority of coral eggs appear to be positively buoyant
2. for hermaphroditic spawners egg-sperm bundles that break at the surface advantageous by putting sperm where the eggs are
3. some corals with negatively buoyant eggs (adaptive value ????)

G. Fertilization and Early Development
1. some evidence for sperm chemotaxis
2. but fertilization mainly involves chance sperm-egg encounters
3. self-fertilization by simultaneous hermaphrodites appears to be inhibited
4. cleavage usually leads to a hollow blastula that flattens out into a concave dish before becoming spherical again
5. eventually the embryo becomes a ciliated planula

H. Planula Dispersal and Settlement
1. larval food sources (p 86)
   a. zooxanthellae produce food via photosynthesis
   b. feed upon plankton while in the water column
   c. survive on stored food reserves without feeding
2. most brooded planulae capable of settlement immediately upon release, although some may initially swim up before swimming down
3. broadcasters develop rapidly to competent planulae, but several days may elapse before planula may settle (some may regard this as a mechanism enhancing dispersal to other reefs -- depends upon current patterns)
4. some planulae capable of long distance dispersal via ocean currents (p. 87)
5. settlement may involve responding to specific chemical cues of the environment (pp. 86 & 89)
6. after settlement some coral polyps may detach and assume a planktonic life again under conditions of stress: reversible metamorphosis (p. 90)

I. Rafting of Whole Coral Colonies (p. 88)
1. larvae may settle on floating objects and develop into corals
2. floating object may carry coral long distances

IV. *Fungia scutaria*, a Case History (pp. 50-51, 83)

A. Typical Life Cycle
1. broadcast spawning
2. planula larva settles and grows into an anthocaulus
3. anthocaulus develops an anthocyathus disk at the mouth end
4. eventually anthocyathus breaks free and assumes adult life style
5. remaining stalk (anthocaulus) can regenerate a new disk (anthocyathus)

B. Spawning Behavior
1. gonochoric
2. eggs small and slightly negatively buoyant
3. spawn 1-4 nights following the full moon beginning in the Summer and ending mid-to-late Fall

C. Asexual Proliferation
1. coral can regenerate new anthcauli (anthoblasts?) from residual fragments

of tissue left behind in the skeleton after the parent has died
2. important mechanism for surviving on reefs impacted by episodic freshwater dilution events

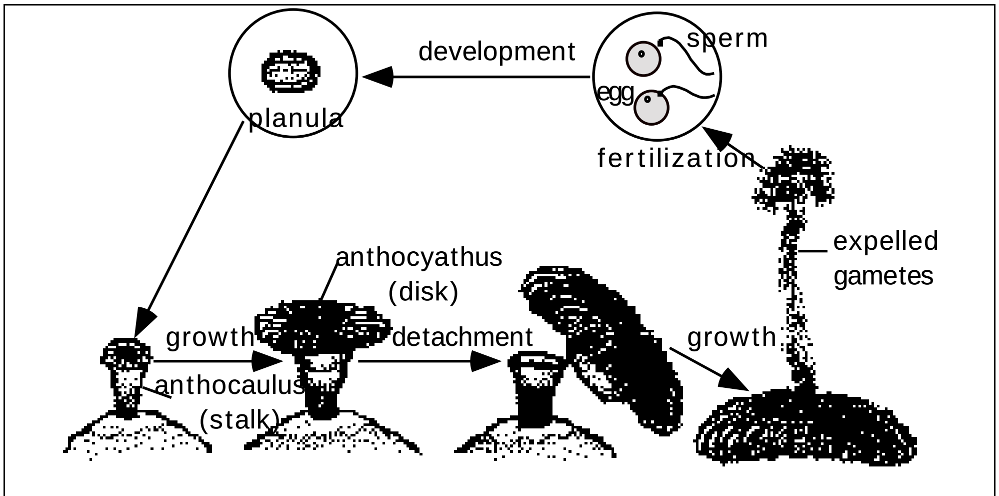

Figure 1. Life Cycle of the mushroom moral, *Fungia scutaria*

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pp. 50-51, 77-90

VOCABULARY

sexual	asexual	broadcast spawning	brooding
reproductive effort	fecundity	hermaphroditism	gonochorism
mass spawning	rafting	fragmentation	planula
parricidal budding	polyp bail-out	anthocyathus	anthocaulus
parthenogenesis	planulation	fecundity	gametogenesis
chemotaxis			
reversible metamorphosis			
extratentacular budding			
intratentacular budding			

STUDY QUESTIONS

1. Describe the patterns of sexuality (hermaphroditism and gonochorism) exhibited by scleractinian corals. What might be the advantages and disadvantages for these patterns?

2. Most corals appear to be broadcast spawners. Offer an hypothesis that may explain this pattern. Support your hypothesis with evidence.

3. Discuss the environmental factors that impact fecundity in corals.

4. Discuss reproductive synchrony in corals. What environmental factors are involved with this synchrony? What are the possible adaptive advantages to synchronizing reproduction?

5. Describe the various modes of asexual reproduction exhibited by corals.

6. What are the advantages and disadvantages of sexual and asexual reproduction?

BASIC ECOLOGICAL PRINCIPLES

I. Introduction
   A. Definition of Ecology (p. 1)
      1. word "ecology" coined from Greek word "oikos", which means "house" or "place to live"
      2. The study of the interaction of organisms with their environments
      3. involves understanding biotic and abiotic factors influencing the distribution and abundance of living things
   B. Scope of Ecology (see also p. 75)
      1. population growth
      2. competition between species
      3. trophic (feeding) relationships
      4. symbiotic relationships
      5. interaction with the physical environment
II. Population Growth
   A. Characteristics of the Population Growth Curve
      1. shape of growth curve dependents upon the intrinsic growth rate (r) of the population and the carrying capacity of the environment (K)
      2. intrinsic growth rate (r) depends upon the innate capacity for reproduction of a species
      3. carrying capacity (K) of the environment depends upon the ability of the environment to support a population

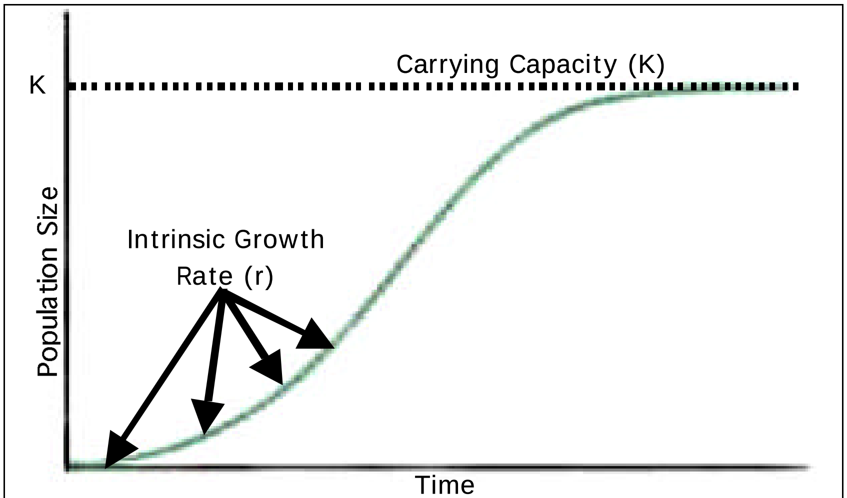

Figure 1. Typical population growth curve.

   B. Density-Dependent Factors Controlling Population Size ("self-regulating" populations")
      1. = factors whose influence on the population size become more important as the population size gets larger or more dense
      2. usually operate with a significant effect when population size is near K, the carrying capacity
      3. density-dependent factors
         a. limiting resources (e.g., food and shelter)

        b. production of toxic wastes
        c. infectious diseases
        d. predation
        e. stress
        f. emigration
    C. Density-Independent Factors
      1. = factors whose influence is not related to population size
      2. may exert an effect upon a population of any size
      3. examples include unpredictable catastrophic events
        a. severe storms and flooding
        b. earthquakes and volcanoes
    D. r & K Selection
      1. certain species (K-selected species) may be more adapted for existing in populations near the carrying capacity (K) of their environments
      2. other species (r-selected species) may be adapted to take advantage of high r-values by proliferating rapidly into disturbed environments
      3. characteristics of K- and r-selected species
        a. K-selected species
          1) tend to be poor colonizers to new environments
          2) tend to mature slowly, but also tend to live for a long time
          3) may invest substantial energy into brooding and extended parental care
          4) but fecundity tends to be lower, banking on producing fewer, but highly successful, offspring
          5) tend to specialize for a particular mode of life (see niche concept below)
          6) tend to be good competitors for that mode of life
        b. r-selected species
          1) tend be exceptionally good at colonizing new or disturbed environments
          2) reach sexual maturity rapidly, but life spans short
          3) don't invest much energy into brooding or parental care
          4) fecundity is high, but individual offspring success is poor
          5) tend to be generalists
          6) tend to be poor competitors for resources in ecosystems that become mature

III. Competition
    A. Ecological Niche Concept
      1. = the "role" a species "plays" in the ecosystem
      2. contrast with the "habitat" which is the physical environment in which the organism lives
      3. the ecological niche of a species therefore includes not just the species habitat, but also the ways in which it interacts with other species and the physical environment
    B. Competitive Exclusion Principle
      1. "no two similar species occupy the same niche at the same time"
      2. possible outcomes of competition
        a. extinction of one species

        b. resource partitioning (splitting the niche)
        c. character displacement: two similar species evolve in such a way as to become different from each other by accentuating their initial minor differences
    3. note that most competitive interactions do not involve direct physical contact, aggressive interaction, between two individuals

IV. Predator-Prey Relationships
  A. Impact Upon Prey and Predator Populations
    1. oscillations in population sizes
    2. coevolution between predator and prey
  B. Impact upon Community Structure
    1. keystone species concept: a keystone species is a species whose presence in the community exerts a significant influence on the structure of that community
    2. examples
        a. California intertidal sea stars
        b. California sea otters and kelp forests
        c. the Pacific Gregory, a territorial damselfish (pp. 157-158)
        d. pin cushion sea stars selectively feeding upon certain corals over others

V. Symbiosis
  A. Definition
    1. different species "living together" in close association
    2. contrast between host and symbiont
        a. host = usually the larger of the partners
        b. symbiont lives in or on the host
    3. facultative versus obligate relationships
  B. Types of Symbioses (p. 105)
    1. mutualism: both host and symbiont benefit
    2. commensalism: symbiont benefits without any major effect on the host
    3. parasitism: symbiont benefits to the detriment of the hosts
  C. Some Examples
    1. coral & zooxanthellae: mutualism
    2. shark & remora: commensalism
    3. human & tapeworm: parasitism

VI. Ecological Succession
  A. Stages (p. 132)
    1. colonizing stage
        a. dominated by r-selected species
        b. characterized by low species diversity
    2. successionist stage
        a. r-selected species replaced by progression of K-selected species as a consequence of competitive exclusion
        b. species composition changes and species diversity increases
    3. climax stage
        a. in the absence of disturbance, competitive interactions lead to the development of a stable climax community
        b. some debate exists about what species diversity may be in such a community

B. Types of Succession
   1. primary succession - results when new uncolonized surface (e.g., fresh lava flow) becomes available for the colonization by living things
   2. secondary succession - results when a severe disturbance (e.g., forest fire or hurricane) wipes out the existing ecosystem; but the substrate is not new, but reflects the composition of the previous community and the consequences of the type of disturbance

VII. Primary Productivity
A. Definition
   1. the rate of production of organic matter by autotrophic organisms (= primary producers)
   2. types of autotrophs
      a. photosynthetic
         1) use light energy in the conversion of inorganic carbon (i.e., carbon dioxide) into organic carbon (i.e., carbohydrates)
         2) examples include terrestrial plants, seaweeds, phytoplankton, and blue-green algae
      b. chemosynthetic
         1) use energy released by the catalysis of certain inorganic chemical reactions to convert inorganic carbon into organic carbon
         2) example: chemosynthetic bacteria from hydrothermal vents on the deep sea floor
   3. primary productivity important because primary producers are the first link in the food chain
   4. relationship between gross primary productivity and net primary productivity
      a. definitions
         1) gross primary productivity (GP) = the rate of production of organic matter from inorganic materials by autotrophs (e.g., rate of photosynthesis by plants)
         2) respiration (R) = the rate of consumption of organic matter (its conversion to inorganic matter) by any organism
         3) net primary productivity (NP) = the net production of organic matter by autotrophs; takes into account autotroph R as well as GP
      b. quantitative relationship (note R is a negative value):

$$NP = GP + R$$

B. Factors Influencing Primary Productivity
   1. light intensity
   2. temperature
   3. availability of inorganic nutrients required for plants
C. Relationship Between Corals & Coral Reef Productivity
   1. cliché: coral reefs = oases of high productivity surrounded by nutrient-poor tropical oceanic waters
   2. coral reef productivity comparable other high productivity systems (mangroves, salt marshes, and agriculture)
   3. coral reefs frequently compared to tropical rainforests (pp.136-137)

4. implication: hermatypic (reef-building) corals bearing endosymbiotic zooxanthellae are responsible for this high productivity
5. note, however, coral reefs are more than just corals (typical coral cover of a reef is about 5-10%)
6. possible explanations for high productivity
    a. nitrogen-fixation by blue-green algae (component of turf algae) contributes organic nitrogen
    b. inorganic nutrients supplied by local upwelling and groundwater sources
    c. efficient nutrient recycling within the system

D. Primary Producers of Coral Reefs
1. zooxanthellae in corals
2. filamentous algal scum (turf algae)
3. coralline (= calcareous) algae
4. non-coralline seaweed
5. filamentous algae growing through the upper layers of the porous reef rock (endolithic algae)
6. interstitial (grows among the sand grains) diatoms
7. phytoplankton

VIII. Energy and Materials Through Ecosystems

A. Trophic Levels
1. 1st trophic level = primary producers
2. 2nd trophic level = herbivores or primary consumers
3. 3rd+ trophic levels = carnivores or secondary (or higher level) consumers
4. highest trophic level = top carnivore
5. decomposers

B. Some Feeding Types in Marine Ecosystem (pp.146-147)
1. algal grazers and browsers
    a. feeding on algae and seaweeds attached to the bottom
    b. examples: herbivorous snails (*opihi*), surgeon fishes (*manini*), green sea turtles
2. suspension feeding
    a. feeding suspended particulate organic matter (including phytoplankton and small zooplankton)
    b. examples: sea fans and mushroom corals
3. filter feeding
    a. a type of suspension feeding involving the creation of a feeding current by the organism
    b. examples: fanworms, clams and baleen whales
4. deposit feeding
    a. feeding involving the ingestion of deposited sediments
    b. examples: sea cucumbers
5. types of carnivores
    a. benthic animal predators
        1) feed on various bottom-dwelling animals (e.g., crabs, worms, etc.)
        2) examples: mantis shrimps and goat fish
    b. plankton pickers

1) select and ingest zooplankton from the water column
2) examples: many damselfish species

c. corallivores
   1) feed on corals
   2) examples: butterflyfishes, flatworms, and nudibranchs

d. piscivores
   1) feed on fishes
   2) examples: barracuda, jacks (*papio*), and sharks

6. omnivores
   a. feed on both plant and animal materials
   b. examples: moorish idols, many triggerfish

7. scavengers
   a. feed on dead organisms
   b. examples: crabs and lobsters

B. Food Chains and Food Pyramids (p. 176)
   1. illustrates feeding relationships (i.e., the flow of energy and materials through the community)
   2. example of a food chain

primary producers → herbivores → 1st carnivores → top carnivores

Figure 2. A typical food chain (decomposers have not been included in this diagram).

C. Food Webs (p. 177)
   1. many animals feed upon different trophic levels
   2. feeding relationships usually much more complex than simple good chain
   3. food webs more complicated in tropical ecosystems than in polar ecosystems
   4. complicated food webs usually more stable than simple ones

E. Energy Flow Through Ecosystems

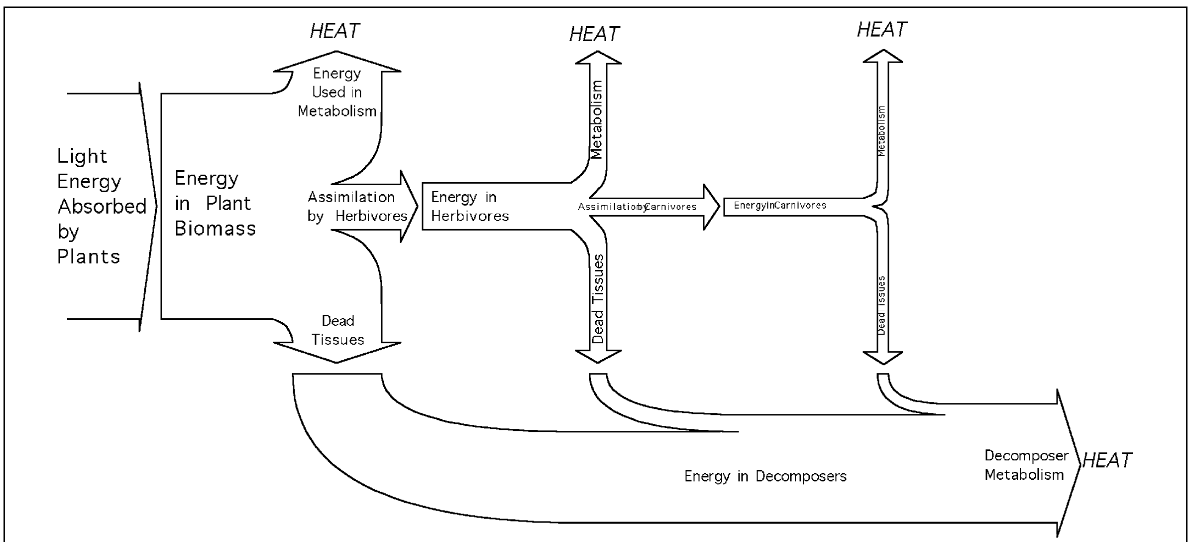

Figure 3. Energy flow through an ecosystem.

1. energy enters ecosystem primarily as light (through plant photosynthesis)
2. most of this energy leaves ecosystem as heat and is thus lost to space
3. energy transfers from one trophic level to the next not very efficient
4. fate of assimilated energy by each trophic level
   a. heat lost due to metabolic activities
   b. death of whole organisms & parts of whole animals (to decomposers)
   c. consumption & assimilation by the next trophic level

F. Biogeochemical Cycles
1. while energy fluxes through ecosystems, materials are recycled
2. these cycles regenerate inorganic nutrients so that plants may use them
3. biogeochemical cycle examples
   a. simplified carbon cycle:

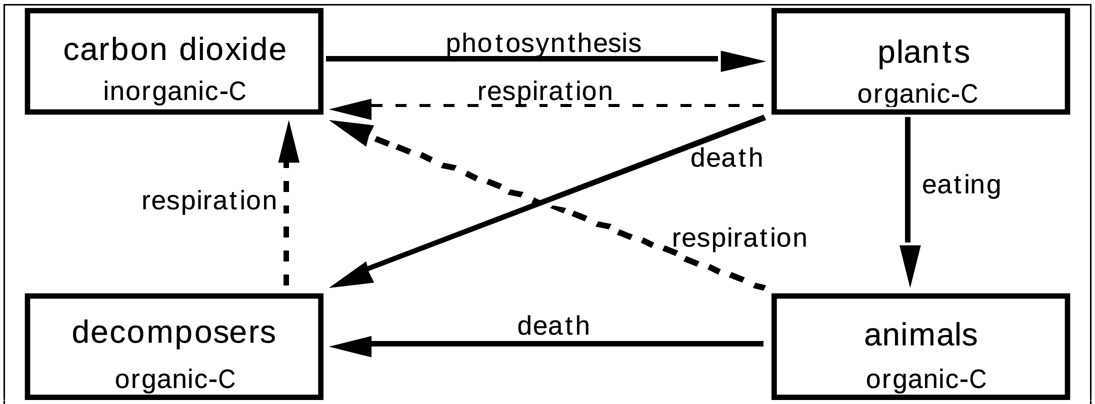

Figure 4. Simplified carbon cycle.

   b. simplified nitrogen cycle:

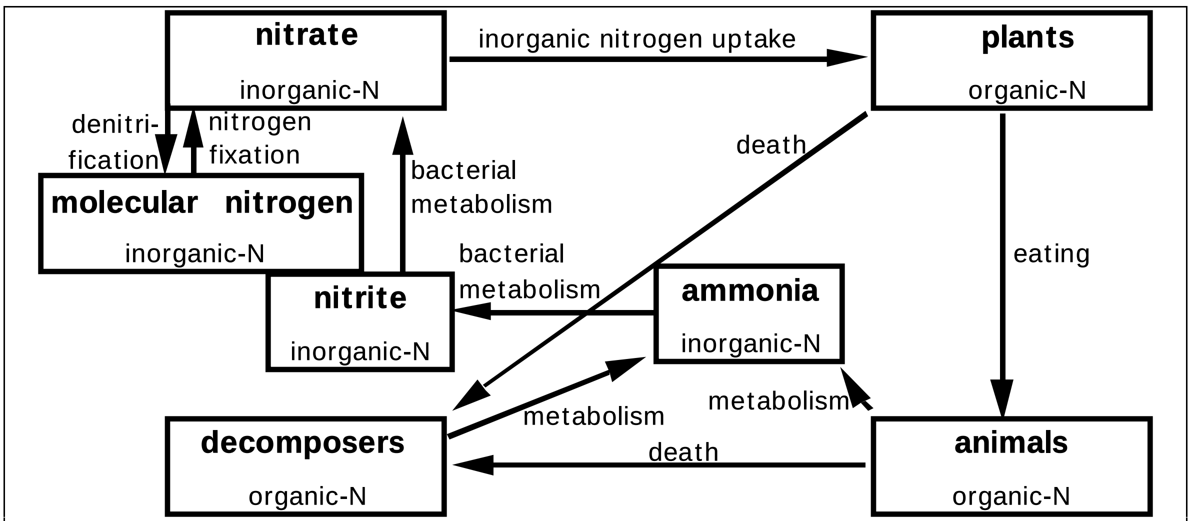

Figure 5. Simplified nitrogen cycle.

c. general picture for biogeochemical cycles in the ocean

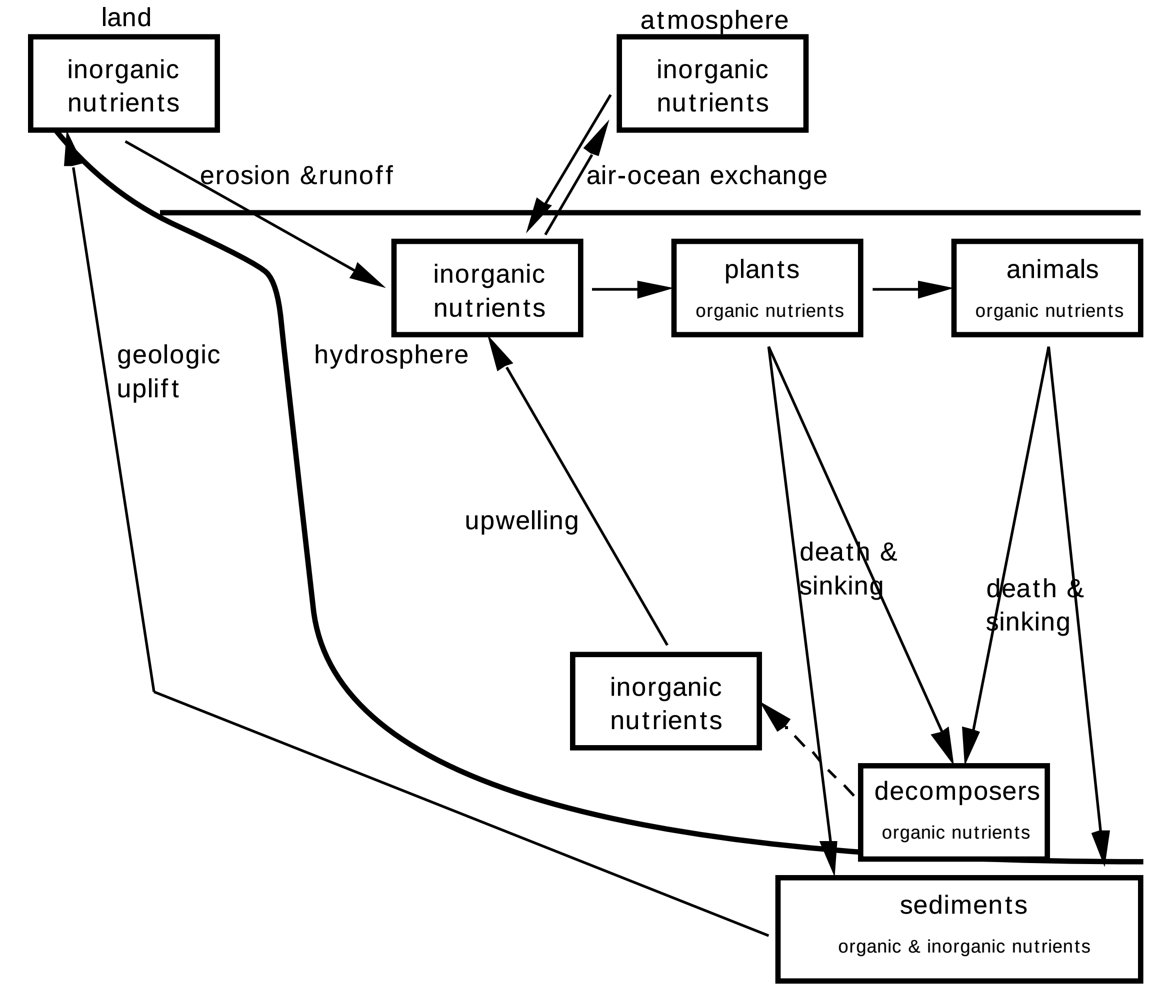

Figure 6. Diagram illustrating generalized pattern of biogeochemical cycles in the ocean.

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pp. 1-2, 75, 105, 132, 136-137, 146-147, 157-158, 176-179, 185

VOCABULARY

ecology	oikos	intrinsic growth rate (r)	carrying capacity (K)
limiting resource	emigration	niche	competitive exclusion
habitat	resource partitioning	character displacement	predator
prey	coevolution	keystone species	symbiosis
mutualism	commensalism	parasitism	primary productivity
autotroph	primary producer	inorganic	organic
biomass	trophic level	herbivore	carnivore
consumer	top carnivore	decomposer	food chain
food web	ecological pyramid	inorganic nutrient	biogeochemical cycle
carbon cycle	nitrogen cycle	corallivore	piscivore

deposit feeder	filter feeder	suspension feeding	omnivore
corallivore	piscivore	plankton picker	phytoplankton
zoopplankton	benthic	algal grazer	scavenger
r-selected species	K-selected species	GP	R
NP	ecological succession	primary succession	secondary succession
colonizing stage	successionist stage	climax stage	species diversity

STUDY QUESTIONS

1. Define the discipline called "ecology". What kinds of things to ecologists study?

2. Draw and label a diagram that illustrates the general pattern of population growth over time (logistic growth curve). Be sure to indicate where the intrinsic growth rate (r) and the carrying capacity (K) dominate the graph respectively.

3. How are population sizes regulated? Be sure to describe both density-dependent and density-independent factors influencing population sizes.

4. Contrast the characteristics of K-selected species with those of r-selected species. Provide several examples of each.

5. What is meant by the Competitive Exclusion Principle? Be sure you define the term "niche" in your answer. How may two similar species evolve to minimize the impact of this principle?

6. Discuss short term and long term consequences of predator-prey relationships. Give real life examples to illustrate your discussion.

7. What is meant by the term "keystone species". Why is the Pacific Gregory (*Stegastes fasciolatus*) considered to be a “keystone species”?

8. Define and contrast the three types of symbiotic relationships. Discuss examples of each type.

9. Contrast food chains with food webs. Draw a labeled diagram that illustrates the characteristics of each.

10. Explain why the relative biomasses of the various trophic levels of an ecosystem may be illustrated in the shape of a pyramid.

11. Contrast how energy and materials move through ecosystems. It would be useful to use labeled diagrams to illustrate your points.

12. Define primary productivity and explain the relationship between grossprimary productivity, net primary productivity, and respiration.

13. Define and contrast the various modes of feeding exhibited by animals. Give examples of each type.

14. Discuss, using written text supported with labeled diagrams, the carbon and nitrogen cycles.

15. Coral reefs are sometimes described as oases in the midst of a watery desert. Why? How can coral reefs thrive under these circumstances? Briefly describe the important biological components of the ecosystem (e.g., who are the important primary producers, consumers, etc.).

16. Discuss the process of ecological succession, explaining what happens during each of the stages. Contrast between primary and secondary succession.

I. Visible Light

A. Characteristics of Light in the Ocean

1. the nature of electromagnetic radiation
    a. electromagnetic radiation includes visible light, UV light, infrared light, radio waves, X rays, and cosmic rays
    b. electromagnetic radiation behaves two ways
        1) as a "beam" of mass-less energy parcels (photons)
        2) as a wave phenomenon
    c. different forms of electromagnetic radiation differ based upon wavelength of the energy

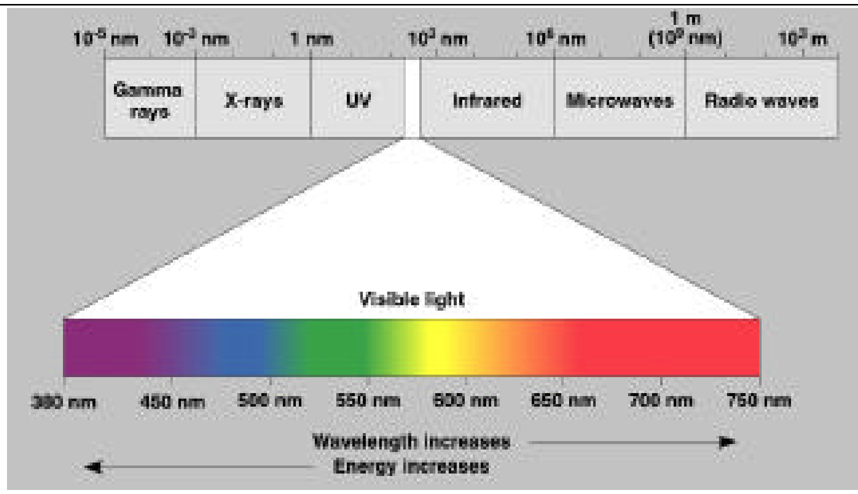

Figure 1. The electromagnetic spectrum with visible light portion expanded.

2. sun emits electromagnetic radiation primarily in the visible and infrared

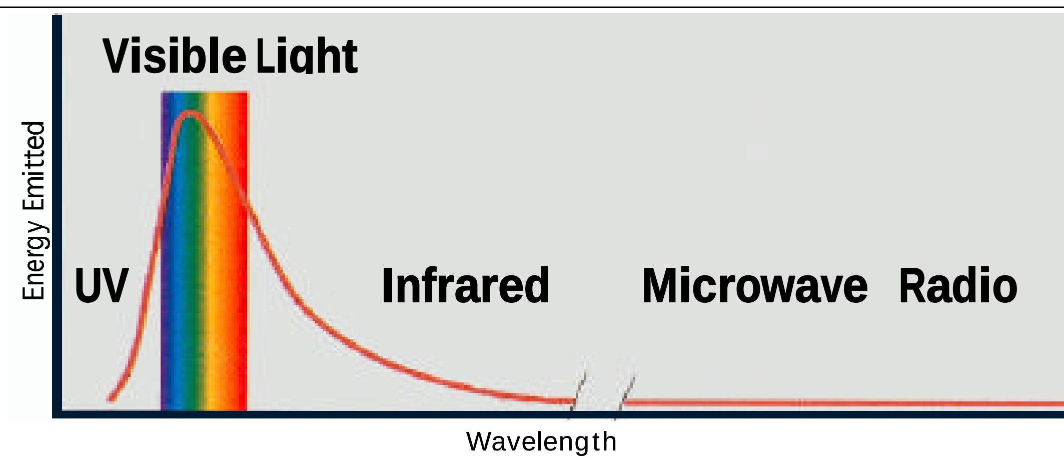

Figure 2. The solar electromagnetic radiation spectrum.

3. light attenuation through water
    a. decreases with depth

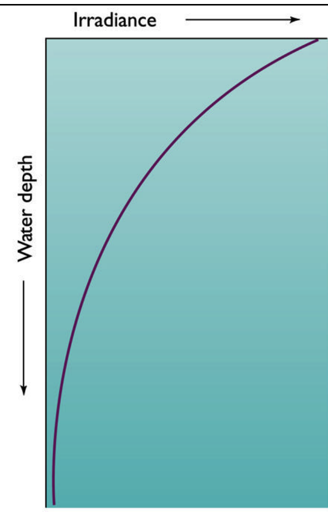

Figure 3. Light intensity decreasing with depth in the ocean.

b. particularly important for marine and aquatic plants which need energy from sunlight to grow
c. in clear waters, enough light penetrates to support plants to depths of 200 meters (thus plant productivity limited to the surface waters of the ocean)
d. 100 meter depth limit of hermatypic corals primarily a result of the overall reduction in light
e. many studies have focused upon how changing light intensities with depth affect the photosynthesis of zooxanthellae of corals
f. animal vision is limited in water (relative to vision in the air)

3. spectral characteristics of visible light and depth in the ocean
   a. red wavelengths absorbed more readily by water than blue wavelengths
   b. thus blue light penetrates deepest in the oceans

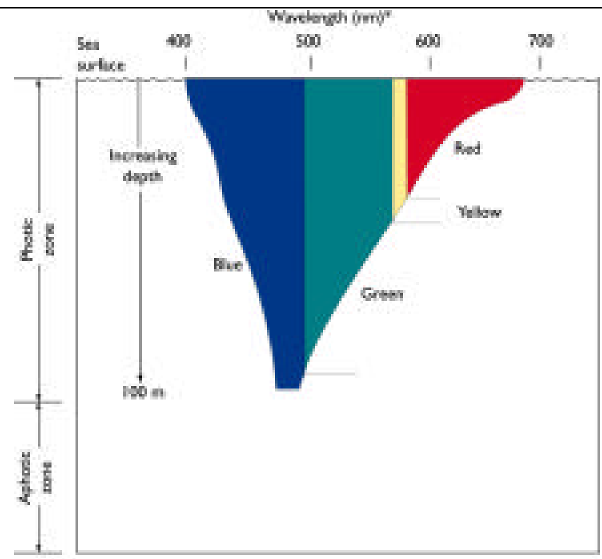

Figure 4. Light penetration with depth in the ocean

c. since different photosynthetic pigments of plants absorb wavelengths of light differently, the change in the spectral characteristics of light with depth likely to influence plant photosynthesis
d. less work has been done to understand the influence of the spectral distribution of light on zooxanthellae photosynthesis in corals
e. animal coloration affected (e.g., a deep-living red fish appears dark brown or black)

B. General Aspects of Measuring Primary Productivity (Photosynthesis) in the Ocean
1. standing crop estimates (assumes primary productivity proportionate to plant biomass)
   a. weigh out total plant biomass
   b. measure concentration of chlorophyll in the water using chemical methods
   c. use satellite (i.e., Coastal Zone Color Scanner, CZCS) to measure chlorophyll content of ocean surface waters by measuring water color
2. measure actual rates of primary productivity directly
   a. oxygen light-dark bottle technique
      1) since molecular oxygen (O_2) is a product of photosynthesis, can measure this to estimate rate of organic matter (i.e., glucose) production
      2) general approach
         a) fill bottle with phytoplankton suspension
         b) measure starting oxygen concentration (O_{2start}) in the bottle
         c) seal bottle and incubate in the light for specific time period
         d) measure ending oxygen concentration (O_{2end}) in the bottle
         e) difference in oxygen concentration (ΔO_2) between starting and ending oxygen concentrations in the bottle:

$$O_{2end} - O_{2start} = \Delta O_2$$

         * *note that if you get net oxygen production in bottle, then ΔO_2 will be a positive value; but if net oxygen consumption (due to respiration) occurs, then ΔO_2 will be a negative value*

      3) problem
         a) plants carry out respiration (consuming oxygen) even while they are photosynthesizing (which produces oxygen)
         b) thus measurements described above measure the net result of both the photosynthetic production of oxygen and the respiratory consumption of oxygen
         c) can't measure photosynthetic production of oxygen directly
         d) above procedure only measures **NET PRODUCTION** of oxygen which is the net results of both **GROSS PRODUCTION** and **RESPIRATION**
      4) partial solution
         a) assume respiration by phytoplankton in the dark is the same as **RESPIRATION** at all light intensities (i.e., assume respiration

is constant and not light-dependent)

b) determine ΔO_2 due to **RESPIRATION**, ΔO_{2R}, by measuring oxygen consumption by the phytoplankton in total darkness (dark bottle); remember ΔO_{2R} should be negative since oxygen has been consumed

c) determine **NET PRODUCTION**, ΔO_{2NP}, in bottle incubated at desired light intensity or depth in the ocean (light bottle); ΔO_{2NP} may be negative or positive depending on the relative rates of photosynthesis & respiration

d. can calculate **GROSS PRODUCTION,** ΔO_{2GP},(= photosynthetic production of oxygen) as follows:

$$\Delta O_{2GP} = \Delta O_{2NP} - \Delta O_{2R} *$$

* *remember ΔO_{2R} is a negative value*

5) **NP** and **GP** as a function of light intensity

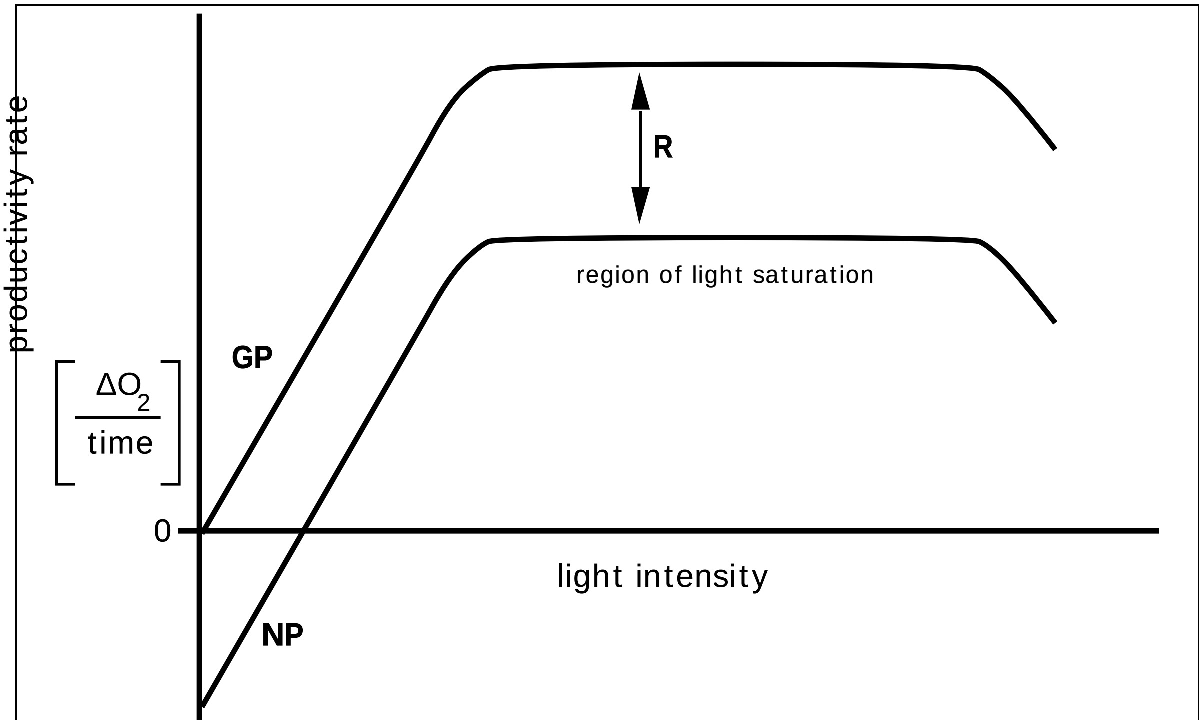

Figure 5. Net and Gross production as a function of light intensity.

b. application to corals
   1) remember that corals are both animal and plant
   2) therefore ΔO_{2R} really represents the combined respiration of both plant and animal

c. may also use the photosynthetic uptake of radioactive C^{14} as a measure of photosynthetic rate

C. Photoadaptation in Corals
   1. "photoadaptation" used to denote changes corals may make in response to

changes in irradiance (on different time scales)

2. generally shade-adapted corals darker in color than high light-adapted corals
    a. difference in color due to greater concentration of photosynthetic pigments (pigment per cm^2 of coral surface)
    b. thus shade-adapted corals partially make up for reduced light of deeper environments by increasing their photosynthetic capabilities
    c. usually involves a change in the amount of pigment per algal cell than a change in the density of algal cells in coral tissues

D. Morphological Responses to Irradiance (Light Intensity)
1. hemispherical branched colony may be the best collector of light in shallow water where considerable light scattering occurs
2. plate-like forms may be better light collectors in deeper water where light tends to be more parallel from the surface

II. Ultraviolet Light

A. Spectrum Considerations
1. UV-C
    a. 200-290 nm
    b. extremely damaging to living systems
    c. most absorbed in the upper atmosphere and negligible amounts reach the earth's surface
2. UV-B
    a. 290-320 nm
    b. also very damaging to living things
    c. most important form of UV impacting the surface of the earth as a result of diminishing ozone
3. UV-A
    a. 320-400 nm
    b. can be damaging given a long enough dose
    c. diminishing ozone not likely to result a much UV-A change at the surface of the earth

B. General Biological Effects of Damaging UV Radiation
1. damage to DNA resulting in mutations
2. damage to other biological molecules
    a. proteins: enzyme inactivation
    b. lipids: disruption of cell membranes and membrane transport systems

C. Corals and UV Radiation
1. effects on corals as evidence by UV screening experiments
    a. decreased growth and increased reproductive output
    b. decreased rates of calcification
2. transplantation experiments (deep corals brought to the surface) demonstrate corals may be UV-sensitive (exhibit bleaching and increased mortality)
3. coral sperm appears to be UV-sensitive (note spawning normally takes place at night)
4. UV absorbing pigments
    a. mycosporine-like amino acids
        1) chemicals apparently produced by zooxanthellae but stored in the

animal tissues
2) concentrations greater in shallow water corals than in deeper ones
3) transplantation experiments demonstrate adaptational changes in pigment concentrations
4) positively buoyant eggs exhibit higher concentrations of pigments than do negatively buoyant eggs

III. Temperature
- A. Effects of Temperature on Living Things and Corals
  1. temperature too low: metabolism gets too slow
  2. increase temperature
     a. metabolism increases
     b. coral growth rates increase
  3. temperature too high
     a. inactivation of enzymes can lead to death
     b. in corals, temperatures above 30º may result in bleaching (= expulsion of zooxanthellae from coral tissues)
     c. note: other stresses (cold shock, UV exposure, may also cause bleaching)
- B. Ecological Limits of Corals Determined by Seawater Temperatures (as evidenced by global distribution of reefs)
  1. 18 - 29°C (low limit correlates with 20° N & S latitude limit of reef corals)
  2. some exceptions exist

IV. Other Factors
- A. Salinity
  1. corals succeed best in normal seawater salinities
  2. perforate corals (those with tissue penetrating into porous skeletons) tend to survive low salinity exposures better than imperforate corals (corals whose tissue only covers the surface of very dense skeleton
  3. corals with high tolerance to low salinity immersions may be prevalent in shallow water environments of semi-estuarine environments (e.g., *Fungia scutaria* and *Porites compressa* in Kaneohe, Bay, Oahu)
  4. episodic freshwater flooding events may result in major reef flat mortality events
  5. high salinity less important because they are less often encountered
- B. Sedimentation
  1. = the deposition of sediments
  2. high sedimentation and low salinity often correlated together because both occur as a result of rain runoff from the terrestrial environment
  3. chronic high rates of sedimentation may exceed coral's ability to clear these sediments using ciliary-mucoid mechanisms
- C. Aerial Exposure at Low Tide
  1. upward coral growth limited by sea level
  2. low tides expose corals to
     a. desiccation
     b. temperature extremes
     c. freshwater from rainfall
  3. extreme prolonged low tide exposure led to a major reef flat kill in Kaneohe

Bay in 1981

D. Water Motion
   1. corals tend thrive in moderate-to-vigorous water motion
   2. vigorous water motion facilitates metabolic exchange: removal of wastes and uptake of nutrients
   3. boundary layer effects
   4. coral morphology in response to water motion
      a. rapidly growing, but fragile skeletal growth forms in calm waters
      b. slowly growing, but robust skeletal growth forms in areas of high water motion

E. Inorganic Nutrient Concentrations
   1. corals tend to thrive in oligotrophic waters of relatively low inorganic nutrient concentrations
   2. effects of high nutrients
      a. high ammonia uncouples the relationship between coral animal and zooxanthellae
      b. increases algal growth on the reef which negatively affects corals
         1) benthic algae may overgrow corals
         2) phytoplankton may enhance survival and growth of sponges and worms that burrow into the coral skeleton, weakening it

F. Currents
   1. important in dispersal of coral species
   2. dispersal mechanisms
      a. planulae
      b. rafted coral colonies

TEXT PAGES COVERED

pp. 128-129, 178-179, 201-202

VOCABULARY

EM radiation	productivity	net production	gross production
respiration	light saturation	photoinhibition	photoadaptation
ultraviolet radiation	ozone	bleaching	perforate
imperforate	boundary layer	oligotrophic	rafting
mycosporine-like amino acids			

STUDY QUESTIONS

1. Discuss how primary productivity is measured using the light-dark bottle technique. What assumptions are made in using this technique?

2. Discuss the characteristics of visible light radiation. How do these characteristics change with depth in the ocean? What are the impacts of theses changes with depth on hermatypic corals? In what ways do corals and their symbiotic algal partners photoadapt to these changes?

3. Describe how ultraviolet radiation affects hermatypic corals, especially shallow water species.

4. Describe how the following environmental factors affect corals and the adaptations corals exhibit in response to these factors: temperature, salinity, sedimentation, aerial exposure, water motion, inorganic nutrients, and ocean currents.

CORAL REEF ECOLOGY

I. The Trophic Structure of Hawaiian Reefs (pp. 2 & 176-177)
   A. Primary Producers (plants)
      1. zooxanthellae in corals (pp. 29-32)
      2. filamentous algal scum (turf algae)
      3. coralline algae (p. 139)
      4. non-coralline seaweed
      5. filamentous algae growing through the upper layers of the porous reef rock (endolithic algae)
      6. benthic and interstitial diatoms
      7. phytoplankton
   B. Herbivores (p. 150)
      1. herbivorous fish
         a. most parrotfish (p. 148)
         b. surgeonfish (p. 148)
         c. Pacific gregory (pp. 157-158)
         c. tidepool blennies
      2. snails (e.g., cowries) and sea hares
      3. sea urchins (p. 148)
      4. herbivorous crabs
      5. green sea turtles (pp. 166-167)
   C. Corallivores (feed on coral tissue; p. 94))
      1. fish
         a. polyp pickers
            1) certain butterflyfish (e.g., *Chaetodon multicintus*; pp. 96-97)
            2) file fishes (e.g., *Pervagor spilosoma*)
            3) blue-eyed damselfish, *Plectroglyphidodon johnstonianus*; p. 98)
         b. coral scrapers
            1) certain butterflyfish (e.g., *Chaetodon unimaculatus*; pp. 96-97)
            2) some triggerfish
            3) a few parrotfish
            4) shortbodied blenny, *Exallias brevis* (p. 95)
            5) stripebelly puffer, *Arothon hispidus* (p. 100)
      2. sea stars
         a. crown-of-thorns, *Acanthaster planci* (p. 101-102)
         b. pin cushion sea star, *Culcita novaeguineae*
      3. others (some may be considered parasites)
         a. long-spined urchin, *Diadema*)
         b. *Epitomium* on mushroom corals (p. 51)
         c. some nudibranchs (e.g., *Phistella* ; pp. 60 & 99)
         d. some flatworms (p. 43)
   D. Coral Mucus Feeders
      1. ornate butterflyfish, *Chaetodon ornatissimus* (p. 97)
      2. coral guard crabs & shrimps (p. 52, 110-112)
      3. bacteria
   E. Non-Corallivore Predators
      1. fish

    a. plankton feeders (e.g., damselfishes and some butterflyfishes)
    b. feeders on benthic invertebrates
        1) goatfishes (p. 148)
        2) wrasses
        3) triggerfishes
    c. piscivores
        1) eels (p. 151)
        2) lizardfishes (p. 151)
        2) baracuda
        3) groupers
        4) jacks (p. 149)
        5) sharks (p. 149)
  2. mollusks
    a. cone shells (some fish eaters, others specialize on specific invertebrates)
    b. triton's trumpet (eat crown-of-thorns)
    c. octopus and cuttlefish (generally eat shelled invertebrates; p. 145)
  3. arthropods
    a. mantis shrimps (stomatopods)
    b. lobsters & some crabs (often omnivores or scavengers; p. 144)
  4. dolphins, seals and sea birds
F. Deposit-Feeding Detritivores (eat dead plant & animal material)
  1. sea cucumbers
  2. brittlestars
  3. spaghetti worms (p. 116)
G. Filter Feeders (phytoplankton, zooplankton, & suspended detritus)
  1. featherduster worms (p. 116)
  2. Christmas tree worms (p. 56)
  3. sponges (pp. 140-141)
  4. tunicates (=sea squirts)
  5. bivalved mollusks

II. Symbiotic Relationships (pp. 105-109)
A. Coral as Hosts
  1. mutualism
    a. zooxanthellae and corals (pp. 29-32)
    b. coral guard crabs and shrimps living among coral branches (pp. 52 & 110-112)
    c. Christmas tree worms (pp. 56 & 117)
  2. commensalism
    a. gall crabs (p. 113)
    b. petroglyph shrimps
    c. damselfishes
    d. microscope copepods, etc.
  3. parasitic relationships
    a. *Epitomium* snails on mushroom corals
    b. parasitic nudibranchs
    c. parasitic flatworms
    d. coral "zits" and trematode worms (pp. 119-120)

      e. bacterial infections (pp. 185-187)
   B. Other Symbiotic Associations
      1. mutualism
         a. cleaner shrimps and fishes (pp. 164-165; 114)
         b. anemones and anemonefishes (p. 69)
         c. anemone hermit crabs (uncertain relationship; pp. 68 & 108)
         d. sea cucumber crab (p. 109)
         e. goby shrimp (p. 108)
         f. pompom crabs (p. 68)
      2. commensalism
         a. shrimpfish and urchins (p. 109)
         b. shrimps and crabs living in anemones (p. 68)
         c. symbiosis and sea jellies (p. 19)

III. Competitive Interactions
   A. Coral Competition (pp. 91-92)
      1. Direct Competition
         a. mesenterial filament extrusion
         b. direct tentacular competition
         c. sweeper tentacles and/or sweeper polyps
         d. mucus secretions
         e. overgrowth (bulldozing)
      2. Indirect Competition
         a. overtopping
         b. water-borne chemicals
   B. Territoriality (pp. 156-158)
      1. contrast territory with home range
      2. territoriality in a damselfish, the Pacific gregory

TEXT PAGES COVERED

2,19, 29-32, 43, 51-52, 56, 60, 68-69, 91-92, 94-120, 135-151, 156-158, 163-165, 176-177, 185-187

VOCABULARY

mutualism	commensalism	parasitism	primary producer
herbivore	carnivore	decomposer	corallivore
piscivore	deposit feeder	filter feeder	sweeper tentacles
sweeper polyps	overgrowth	overtopping	direct competition
indirect competition	territory	home range	

STUDY QUESTIONS

1. Diagram a food web that exhibits the feeding relationships of a coral reef. Be sure to know some of the common components of a Hawaiian coral reef food web.

2. Define and contrast the three types of symbiotic relationships. Discuss several examples of each type. Be sure to know about the relationships mentioned in the outline above.

3. Describe the ways that corals compete with each other on the reef.

4. Describe the symbiotic relationships corals exhibit with other organisms.

CORAL REEF FORMATION AND GEOMORPHOLOGY

I. Types of Reefs

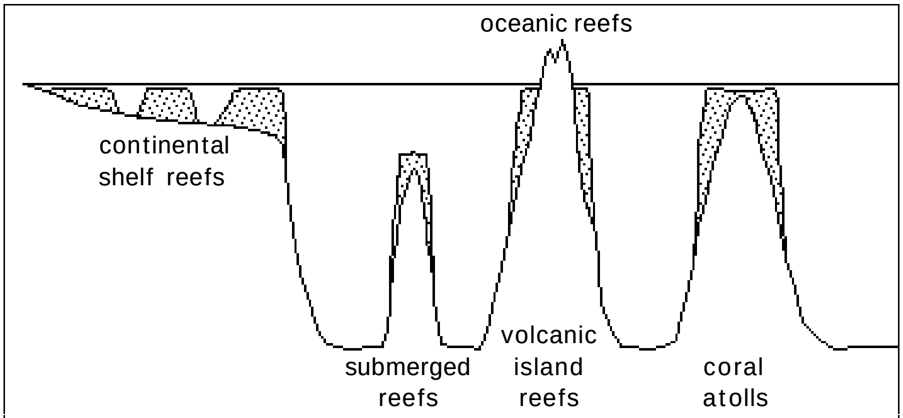

Figure 1. Types of reefs.

A. Oceanic Reefs (pp. 122-127)
   1. reefs that form in the middle of the ocean far from continental land masses
   2. usually form on volcanic islands or seamounts that reach close to the surface
   3. types of oceanic reefs
      a. fringing reefs that form an apron around an oceanic island
      b. barrier reef and lagoon systems
         1) relatively narrow strip of reef that separates a coastal lagoon from the open ocean
         2) lagoon is typically shallow (10 - 20 m) and often greatly influenced by terrestrial processes
         3) lagoon often with patch reefs and coral pinnacles that rise from the lagoon floor to near the surface
      c. coral atolls
         1) roughly circular reef that encloses a central lagoon
         2) vary greatly in diameter from a few kilometers to over 100 km
      d. submerged reefs: reefs that have sunk well below the surface because of subsidence of sea level rise

B. Shelf Reefs
   1. reefs that form on a continental shelf (e.g., Australia's Great Barrier Reef)
   2. types of shelf reefs
      a. fringing reefs that form at the continental margin or around islands that originate on the continental shelf
      b. barrier reefs
         1) form at the edge of the continental shelf (shelf break)
         2) divide neritic waters from oceanic waters
      c. platform (patch) reefs: reef forming on a shallow underwater hillock on the continental shelf
      d. bank reefs: similar to platform reefs, but deeper

C. Global Distribution of Coral Reefs

II. Reef Growth
- A. Net Effect of Two Opposing Processes
  1. reef formation
  2. reef erosion
- B. Reef Formation
  1. basic process
     - a. framework building
     - b. sediment accumulation (fills in open spaces of the framework)
     - c. cementation
  2. components of this process
     - a. principle framework builders
       - 1) branching coral colonies
         - a) coral growth
         - b) coral recruitment
       - 2) branching forms coralline of red algae
       - 3) giant clams
     - b. sand sources
       - 1) coral fragments
       - 2) coralline red & green algal (for greens, *Halimeda*) fragments
       - 3) snail shell fragments
       - 4) broken sea urchins spines
       - 5) foraminiferan shells (paper shells)
       - 6) sponge spicules
     - c. cementers
       - 1) primarily coralline red algae (mainly encrusting species)
       - 2) encrusting corals
- C. Reef Erosion
  1. physical erosion (mechanical and chemical)
     - a. waves - especially storm waves
     - b. gravity
     - c. low tide exposure
       - 1) freshwater kill and dissolution of coral reefs
       - 2) mortality of coral tissues
  2. biological erosion (bioerosion, pp. 161-163))
     - a. direct bioeroders
       - 1) activities directly weaken reef rock and coral skeletons
       - 2) examples
         - a) parrotfishes scrape coralline reef rock
         - b) sponges & worms bore into coralline reef rock
         - c) endolithic algae burrows through coralline reef rock
         - d) rock boring urchins
     - b. indirect bioeroders
       - 1) activities result in coral tissue death
         - a) stops growth
         - b) opens up surfaces for boring organisms
       - 2) examples (predators or parasites on coral tissues)
         - a) crown-of-thorns sea star (pp. 101-102)
         - b) coralivorous nudibranchs (p. 99) and flatworms p. 43)

c) coral feeding blennies and butterflyfish (pp. 95-98)

3. human activities

III. Formation and Evolution of Coral Reefs

A. Atolls

1. Charles Darwin's subsidence theory for atoll formation
   a. mid-oceanic volcanic island forms
   b. fringing reef forms around the edge of the island
   c. as island subsides, reef growth at reef edge keeps up with the rate of subsidence yielding a barrier reef and lagoon around the volcanic island
   d. eventually island sinks below sea level but reef maintains itself at the surface while subsidence continues

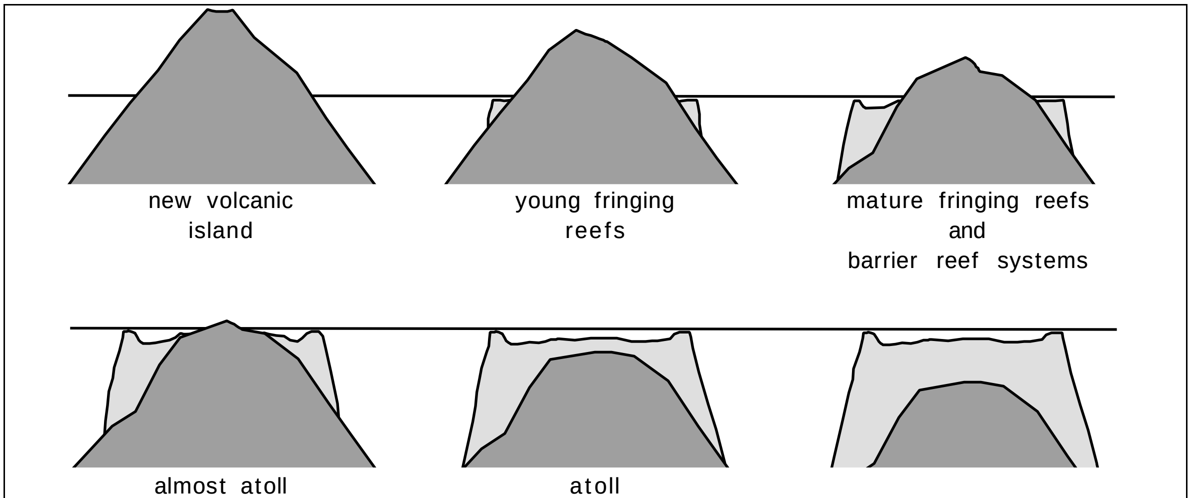

Figure 2. Charles Darwin's theory of coral atoll formation.

2. Hawaiian Islands and Darwin's Point (pp. 130-131)
   a. Hawaiian Island chain formed as Pacific plate moved over "hot spot" in the earth's mantle
   b. islands begin to erode and subside soon after being formed
   c. as islands move northwards reefs develop around them in a sequence similar to that described by Darwin
   d. at Midway, seawater temperatures get too cold and coral reef growth cannot keep up with the rate of subsidence
   e. north of Midway and Kure Atolls Hawaiian island chain becomes a chain of guyots and seamounts

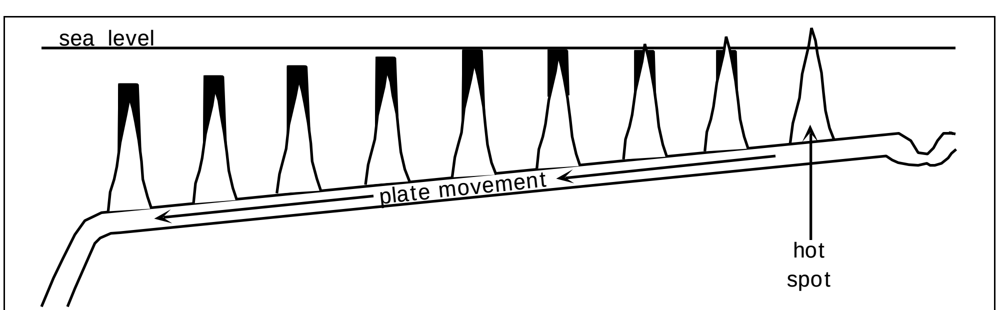

Figure 3. Coral reef evolution and atoll formation in the Hawaiian Islands.

B. Great Barrier Reef
   1. only the uppermost 20 m of limestone of the reef is recent growth (younger than about 10,000 years)
   2. underneath this limestone is much older limestone
   3. reason
      a. sea level was as much as 130 m lower than present about 20,000 years ago (during the last ice age)
      b. sea level began rising abruptly about 18,000 years ago reaching above present levels about 8,000 years ago
      c. thus recent growth has taken place ontop of older reefs whose surfaces were eroded during the last ice age

C. Eustatic Versus Isostatic Sea Level Changes Affecting Reefs

IV. Reef Geomorphology Zones (pp. 38 & 124-126)

A. Environmental Factors Shaping Coral Reefs
   1. water motion
   2. depth (correlated with changes in light and water motion)
   3. sedimentation
   4. proximity to land
   5. relative sea level change (eustatic versus isostatic sea level change)

B. Reef Geomorphological Zones (note: there are about as many different ways to classify reef zones as there are coral reefs; what's described below corresponds best to an oceanic barrier reef).

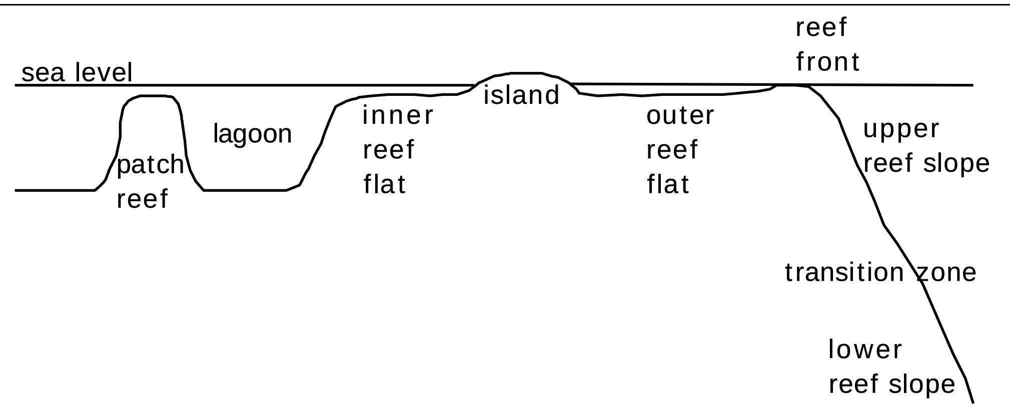

Figure 4. Major geomorphological zones of a typical barrier reef

   1. lower reef slope (150 - 50 m)
      a. steeply sloping seaward margin of the reef
      b. generally below the zone of active coral reef growth
      c. largely composed of broken coral fragments from shallower depths & very fragile species
   2. transition zone (50 - 20 m)
      a. below the impact of most vigorous wave motion
      b. good coral cover, especially more delicate species
   3. upper reef slope (0 - 20 m)
      a. sometimes called buttress zone
      b. composed of spurs (buttresses) and grooves
      c. buttress absorbs wave energy

d. grooves serve as channels for sediment to move to deeper water
e. corals in this zone form dense, robust skeletons
f. also find low-profile encrusting corals here
g. zone of most vigorous coral reef growth

4. reef front
   a. narrow, shallow seaward edge of the reef; exposed at low tide
   b. impacted by heavy wave action
   c. relative intensity of wave correlated with structure
      1) heaviest wave action (e.g., many Pacific reefs) results in the formation of a calcareous algal ridge in this zone
      2) less wave action (e.g., many Caribbean reefs) allows for the growth of robust corals, usually composed massive palm-shaped corals
5. outer reef flat
   a. horizontal reef platform just leeward of the reef front
   b. in high wave energy area usually consists of a very shallow (often exposed at low tide), but low profile bench composed of coralline algae and/or stubby robust corals (may consists of an algal ridge)
6. inner reef flat
   a. shallow, but deeper than reef crest
   b. usually exposed at only the lowest tides
   c. generally 1-2 m depth
   d. coral growth patchy
   e. bottom is primarily covered by pebble dead coral fragments (rubble zone)
   f. size or coralline fragments get smaller as one travels further inward from the breaking waves
   g. much seaweed often on reef flats
   h. occasionally sediments pile high enough to form a coral island or cay - land plants may stabilize the island
   i. back reef flat - see finer and finer sediments as it slopes into the lagoon
   j. occasionally get microatolls
6. lagoons
   a. deeper subtidal areas of the reef
   b. protected from vigorous water motion by the reef
   c. lagoon floors generally composed of fine sediments
   d. oceanic reef lagoons
      1) bodies of water enclosed the barrier reef
      2) generally from 30-100 feet in depth
      3) occasional outcropping of coral as a knoll or patch reef in lagoon
   e. shelf reef lagoons
      1) generally refer to deeper areas of the reef
      2) distinguish from other neritic waters
7. leeward reefs vs. windward reefs of atolls
   a. similar to windward reef
   b. receive less wave energy
   c. corals more fragile
   d. reef less well-developed

V. Ecological Succession on Reefs (pp. 132-135)

A. Ecological Succession
   1. process of how ecosystems change through time = ecological succession
   2. left undisturbed, the biological community will approach a climax stage
   3. impacts upon community structure (e.g., species diversity and trophic relationships)
      a. no disturbance
      b. intermediate disturbance
      c. constant disturbance
B. Lava Flows and Coral Reef Succession (pp. 134-135)
   1. ages of lava flows allow us to establish how long a coral community has existed on that flow
   2. periodic major storms (e.g., hurricanes) complicate the picture

TEXT PAGES COVERED

4-5, 38, 94-103, 122-127, 130-135, 138-141, 161-163, 172-175 & 213

VOCABULARY

oceanic reef	shelf reef	fringing reef	barrier reef
lagoon	atoll	platform reef	patch reef
bank reef	submerged reef	geomorphology	lower reef slope
upper reef slope	transition zone	reef front	buttress zone
spur & groove	reef crest	algal ridge	outer reef flat
inner reef flat	microatoll	framework builder	cementation
bioerosion	Darwin's Point	eustatic	isostatic
guyots	seamounts	ecological succession	species diversity
colonizing stage	successionist stage	climax stage	

STUDY QUESTIONS

1. Distinguish between oceanic reefs and shelf reefs in terms of their respective structures and the impacts of eustatic and isostatic sea level change of their formations.

2. Discuss the factors involved with the balance between reef formation and erosion.

3. Distinguish between direct and indirect bioerosion.

4. Draw and label a diagram that illustrates a profile of a typical oceanic barrier reef and lagoon system. Discuss the physical characteristics of the following reef zones: lower reef slope, upper reef slope, reef front, outer reef flat, inner reef flat back-reef slope, and lagoon.

5. Describe the environmental factors that influence the geomorphology of coral reefs.

6. Describe Darwin's explanation for coral atoll formation. Draw and label a diagram that illustrates your written description.

7. Describe the relationships between plate tectonics and the formation of the Hawaiian Island chain. Include in your explanation a description about how these processes have influenced coral reef development in Hawaii.

8. Discuss the process of ecological succession on a coral reef identifying and describing the major stages. How may the level of disturbance influence the final state?

THE BIOLOGY OF CORAL REEF FISHES

I. General Fish Characteristics
   A. Fish Classification & Evolution
      1. Classification Scheme of the Vertebrates

Phylum Chordata
Subphylum Vertebrate (animals with backbones)
Class Agnatha (jawless vertebrates, lampreys & hagfish)
Class Chondrichthyes (sharks, skates, & rays)
Class Osteichthyes (bony fish)
Class Amphibia (no significant marine representatives)
Class Reptilia (sea turtles, marine iguanas, saltwater crocodiles, sea snakes)
Class Aves (penguins, albatrosses, gulls, pelicans, cormorants, etc.)
Class Mammalia (whales, sea lions, seals, walruses, manatees, dugongs, sea otters, & polar bears)

      2. Fish Evolution
         a. jawless fishes appeared about 400 million years ago
         b. most of these displaced by jawed fishes that evolved shortly thereafter
         c. sharks & their kin appeared early and have not changed much since
         d. bony fish also appeared early and diversified mainly in freshwater
         e. one line of bony fish gave rise to the terrestrial, air-breathing tetrapods (amphibians, reptiles, birds & mammals)
         f. important factors in evolution of fishes & vertebrates in general
            1. jaws (which formed from the first bony gill arch of jawless fish)
            2. swim bladder (which formed first as a lung in freshwater fish inhabiting streams and lakes that occasionally dried up and later was modified as a buoyancy compensator in bony fish - it remained a lung in air-breathing tetrapods)
            3. paired appendages (paired fins in fish; walking legs in tetrapods)
   B. Basic Fish Anatomy
      1. jawless fishes (Class Agnatha)
         a. lack jaws, pair fins and scales
         b. possess medial nostril, medial fins, notochord (rather than vertebral column & other skeletal elements in adults) in adults
      2. cartilaginous fishes (Class Chondrichthyes)
         a. possess jaws with teeth, cartilaginous skeleton (with vertebral column) and paired fins
         b. scales that have the same origin and composition as the teeth
         c. possess 5-7 gill slits, one often modified as a spiracle
         d. intestine with spiral valve
      3. bony fishes (Class Osteichthyes)
         a. possess jaws with teeth, bony skeleton and paired fins
         b. scales, unlike those of sharks, are thin, flat, flexible, & overlaid with skin
         c. four gill arches housed in right & left gill chambers covered by a gill cover (the operculum)
         d. intestine = simple tube with no spiral valve present
   C. Fish Adaptations and Life Styles

1. General Life Style Categories
   a. pelagic cruisers
      1) occurring in water column far away from the bottom (benthic) environment
      2) often referred to as "blue water"
      3) includes tuna, billfish, blue sharks, mackeral sharks (great whites and mako sharks)
   b. demersal
      1) bottom-associated fishes, but not usually sitting on the bottom
      2) rely on the benthic environment as a source of food, place to reproduce, and/or place of refuge, etc.
      3) includes most reef fishes (e.g., butterflyfishes, surgeonfishes, wrasses, parrotfishes, etc.)
   c. benthic
      1) bottom-dwelling fishes that spend the majority of time sitting on the bottom
      2) includes flatfishes, lizardfishes, many scorpionfishes, manyhawkfishes, gobies, etc.
2. Characteristics to Evaluate with Respect to Life Styles
   a. body shape
      1) fusiform
         a) = torpedo-shaped (e.g., tuna)
         b) allows minimal drag while swimming
         c) best shape for a pelagic cruiser

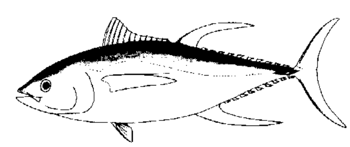

Figure 1. Fusiform body shape in a tuna.

      2) compressed
         a) laterally flattened (e.g., butterflyfishes & surgeonfishes)
         b) allows for maneuverability in surgey environments
         c) useful for demersal fishes that hover above the reef
         d) exception seen in flatfishes that lie on one side of the body as benthic fishes

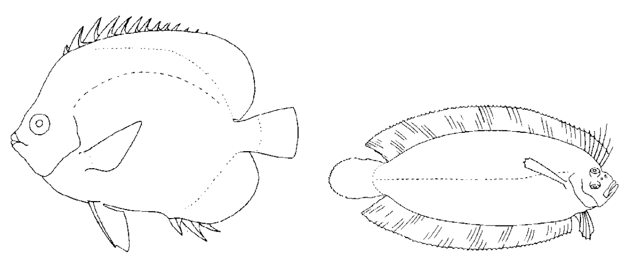

Figure 2. Compressed body shape in two different fish species.

3) elongated or attenuated
    a) long body (e.g., trumpetfish, cornetfish, eels, etc.)
    b) seen in demersal fish that either hover motionless in the water)
    c) seen also in benthic fishes (e.g., eels) that hide in holes in the reef

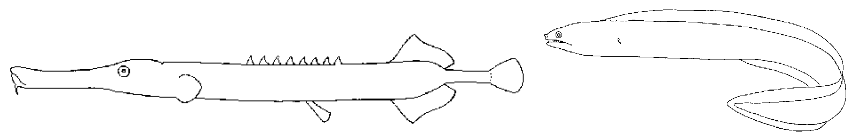

Figure 3. Elongate body shape intwo different fish species.

4) depressed
    a) dorso-ventrally flattened (e.g., frogfishes, scorpionfishes & gobies)
    b) broad ventral surface facilitates resting on the bottom
    c) seen in many benthic fishes

Figure 4. Depressed body shape in several fishes.

b. body coloration
1) source of color
    a) pigment color - chromatophores for yellows, reds, oranges, browns, & blacks
    b) structural color - iridophores (reflection) & light refraction for blues, silvers, & rainbows
2) patterns (pp. 152-153)
    a) countershading
        1) dark blue or black dorsally, white or silvery ventrally
        2) results in blue water "camouflage"
        3) observed most frequently in pelagic cruisers

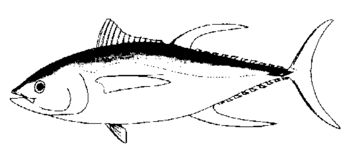

Figure 5. Countershading in a tuna.

    b) camouflage
        1) matching the background coloration
        2) usually involves having irregular dark blotches and spots

3) typically seen in benthic fishes, especially benthic ambush predators (e.g., frogfishes, gobies, & many scorpionfishes)
4) some fishes (e.g., flatfishes) may exhibit rapid color changes in response to different backgrounds

c) disruptive coloration
1) color pattern breaks up the silhouette of the fish
2) may involve dark bars across the eye and tail region
3) seen in many demersal fishes such as butterflyfishes

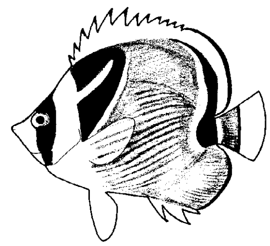

Figure 6. Disruptive coloration in a butterflyfish.

d) bars and stripes
1) bars are vertical (e.g., *manini*)
2) stripes are horizontal (e.g., *ta'ape*)
3) seen frequently in schooling demersal fishes
4) may confuse potential predators by making it difficult to select individual prey from the school

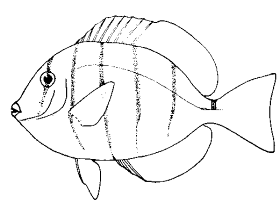

Figure 7. Bars in a *manini*.

e) misdirection
1) false eye spots, etc.
2) observed in many demersal butterflyfishes

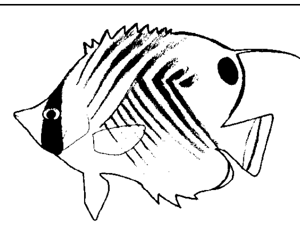

Figure 8. False eye spot on the dorsal fin of a butterflyfish.

d) advertising coloration
   1) bright, obvious color patterns
   2) possible functions
      a) advertising a cleaning station (e.g., cleaner wrasses)
      b) advertising a warning (e.g., *nohu*)
      c) advertising for mates (e.g., male parrotfishes)

e) mimicry
   1) imitating other creatures
   2) seen in a few demersal and benthic fishes
   3) examples
      a) sabertooth blenny mimics cleaner wrasses
      b) shortnose wrasse mimics Potter's angel which sports a defensive spine

f) uniform red coloration
   1) most often observed in deep-dwelling or night active demersal fishes
   2) examples include *opakapaka*, *menpachi*, & squirrelfishes

3) noctural versus diurnal color changes
4) male versus female color differences
5) juvenile versus adult color differences

c. caudal fin types
   1) lunate
      a) stiff, high, narrow fin in the shape of a crescent moon
      b) results in powerful forward thrusts w/ minimal frictional drag
      c) often with caudal peduncle keel which strengths it s articulation with the body for powerful transfer of energy to the tail
      d) associated with pelagic cruisers (e.g., tuna, billfish, mackeral sharks)

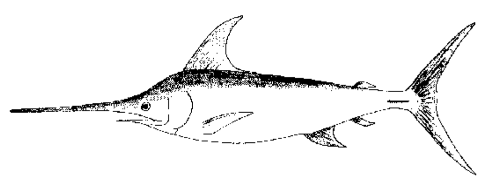

Figure 9. Lunate caudal fin in a billfish.

   2) forked
      a) V-shaped tail fin
      b) deeply forked, narrow fin suggests a strong, near-constant swimmer (e.g., many jacks)
      c) moderately forked suggests a slower-moving fish

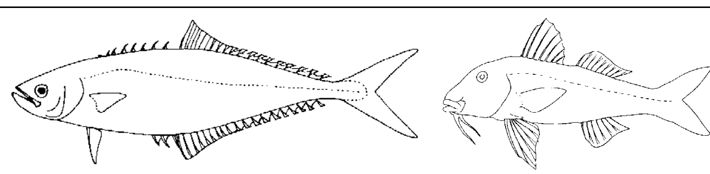

Figure 10. Forked caudal fins in two different fish species

3) truncate
   a) flat edge to caudal fin
   b) characteristic of many demersal fish that use the tail for sudden thrusts, perhaps to escape predators or lunge at prey, but not for constant swimming

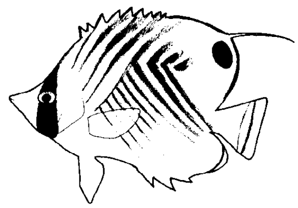

Figure 11. Truncate caudal fins in two different fish species

4) rounded
   a) trailing edge of caudal fin rounded
   b) used only for sudden thrusts, rather than constant swimming
   c) characteristic of most benthic fishes and a few very slow-moving demersal fishes

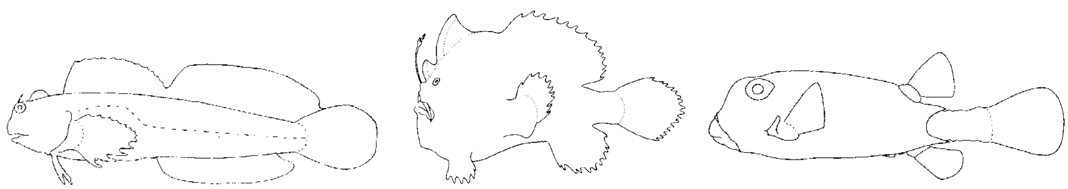

Figure 12. Rounded caudal fins in three different fish species.

5) heterocercal
   a) upper lobe larger than the lower lobe
   b) spinal column extends into upper lobe
   c) generates lift by pushing water down and backwards
   d) observed in sharks and primitive bony fishes

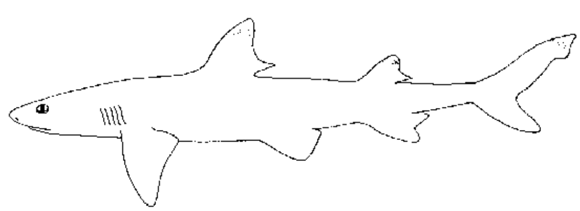

Figure 13. Heterocercal caudal fin in a shark.

d. dorsal fin
   1) fin spines & soft rays
      a) fin spines typically stiff and sharp for supporting fin and provide protection from predators

b) soft rays support fins, but are flexible, allowing fin to undulate

2) maybe used for the following functions
   a) stability (prevent rolling while swimming)
   b) sharp spines for defensive protection from predators
   c) turning (soft dorsal may be used like a rudder)
   d) generation propulsion (undulation of dorsal fin rays in some fish; e.g., triggerfishes and filefishes)
3) relation to life styles
   a) pelagic cruisers
      1) dorsal fin typically small with groove for tucking in fin, reducing frictional drag
      2) used mainly for stability, preventing rolling in the water
      3) may also possess finlets to reduce drag

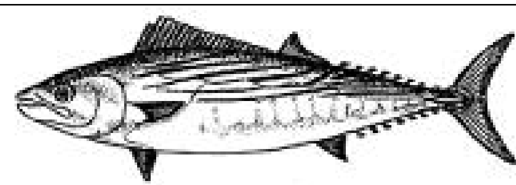

Figure 14. Dorsal and anal fin with finlets in a tuna.

   b) dermeral & benthic fishes
      1) spines generally prominent
      2) special dorsal fin adaptations in some fishes
         a) locking "trigger" spine in trigger fish

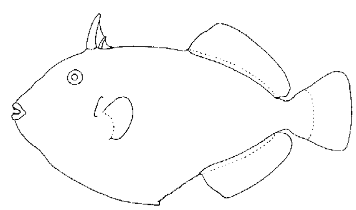

Figure 15. Special dorsal fin "trigger" in a trigger fish.

         b) undulating soft dorsal providing locomotion in triggerfishes and filefishes

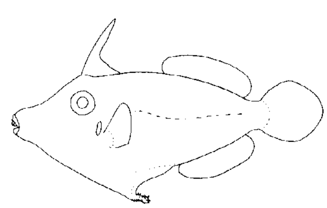

Figure 16. Undulating soft dorsal and anal fin in a filefish

c) lack of dorsal spines and flapping soft dorsal fin in puffers and boxfishes

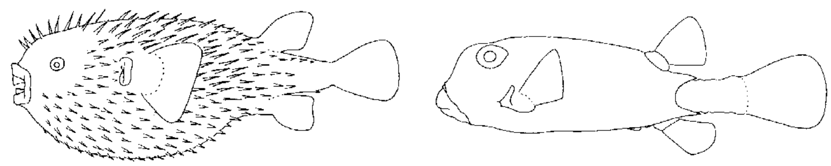

Figure 17. Lack of dorsal fin spines in puffers and boxfishes.

d) toxic spines in scorpionfishes

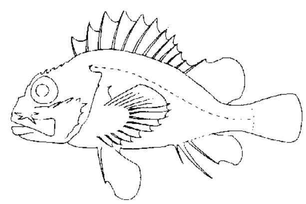

Figure 18.Toxic spines in a scorpionfish

e) modified to attach to larger fish in remoras

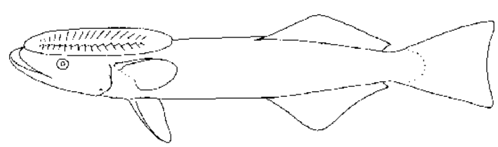

Figure 19. Dorsal fin modified as a "sucker" in a remora.

f) modified as a fishing lure in frogfishes and anglerfishes

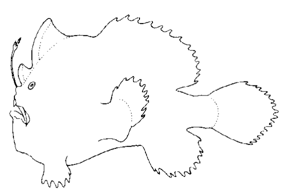

Figure 20. Dorsal fin "fishing lure" in a frogfish.

e. anal fin (similar in structure & functions to dorsal fin)
f. paired fins
   1) pelagic cruisers
      a) wing-like in pelagic fish for generating lift, planing & steering
      b) often there is a shallow slot for tucking this fin in close to the body, reducing frictional drag

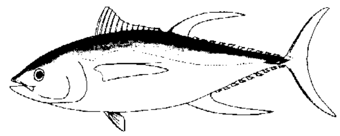

Figure 21. Wing-like lift-generating pectoral fins in a tuna.

c) in sharks, pectoral fins act like wings for generating lift

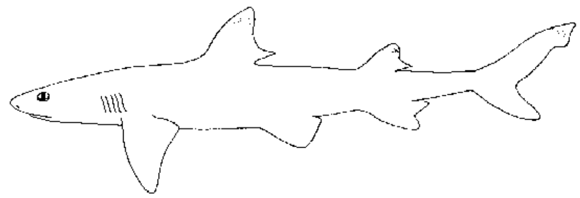

Figure 22. Wind-like lift-generating pectoral fins in a shark.

2) demersal fish
   a) many fishes with flexible, delicate rays for providing highly maneuverable locomotion (helicoptering action; e.g., many butterflyfishes)

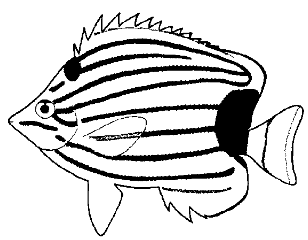

Figure 23. Filamentous pectoral rays in a butterflyfish.

   b) others with wing-like for providing flapping locomotion (e.g., parrotfishes, wrasses, & surgeonfishes)

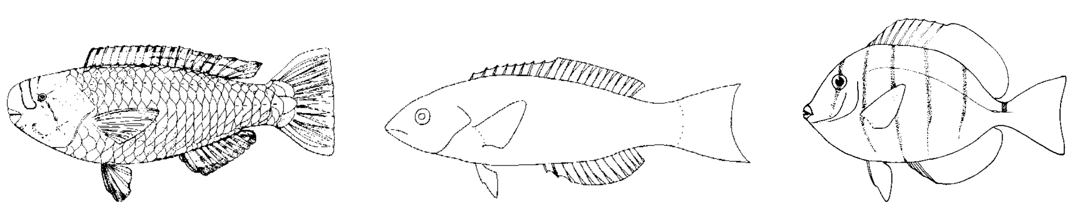

Figure 24. Wing-like "flapping" pectoral fins in various fish species.

3) benthic fish
   a) many with fleshy rays to provide support for sitting on the

bottom (e.g., scorpionfishes, frogfishes, blennies, & gobies)

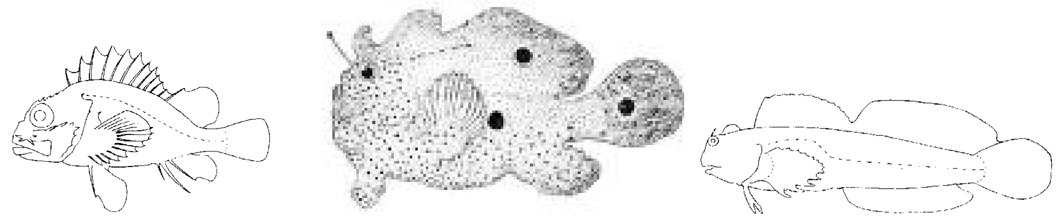

Figure 25. Fleshy supporting rays in pectoral and pelvic fins of benthic fishes.

b) moray eels lack pectoral fins entirely

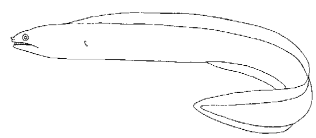

Figure 26. An eel lacking both pectoral and pelvic fins.

2) pelvic fins
   a) pelagic cruisers and demersal fishes
      1) fins triangular and relatively small
      2) used to maintain stability and facilitate steering in the water column
   b) benthic fishes
   c) often reduced in size with fleshy rays for support on the botom
   d) special pelvic fin adaptations
      1) completely absent in puffers and boxfishes

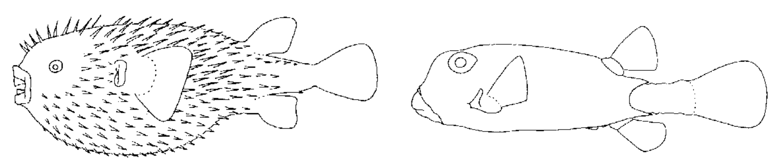

Figure 27. Pelvic fins lacking in puffers and boxfishes.

      2) reduced to a single spine in triggerfishes and filefishes

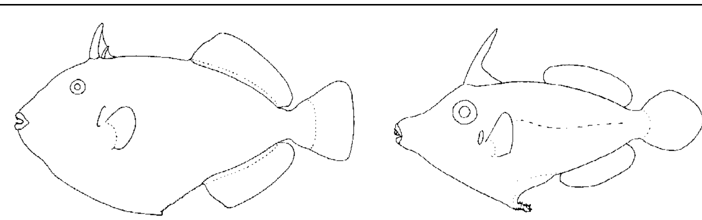

Figure 28. Pelvic girdle reduce to single medial spine in triggerfishes and filefishes.

3) fused into a single "suction cup" in many gobies

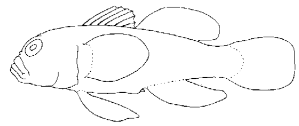

Figure 28. Pelvic fins fused to form a "suction cup" in gobies.

g. other features to note
   1) scales
      a) often microscopic or absent in pelagic and benthic fishes
      b) large and tough in most demersal fishes
   2) size, shape, and position of mouth
      a) large, superior (= upward-pointing) mouth suggests a predator that feeds upon fish in the water column
      b) large, inferior (= downward-pointing) mouth suggests a feeder and large benthic prey
      c) tiny, superior mouth indicates plankton feeding
      d) tiny, terminal or inferior mouth indicates feeding on tiny benthic prey (e.g., small shrimps, coral polyps, etc.)
      e) small, long, slender jaw (e.g., long-nose butterflyfish & bird wrasse) best suited for feeding in small holes, cracks and crevices of the reef
   3) types of teeth
      a) long canines characteristic of piscivores (e.g., lizardfishes & barracuda)
      b) molariform or plate-like teeth suggests feeding on hard-bodied invertebrates (e.g., eagle rays & *mu*)
      c) hard beak-like plates (e.g., parrotfishes) indicates grazing on hard reef substrate (either algae-covered coral or live coral)

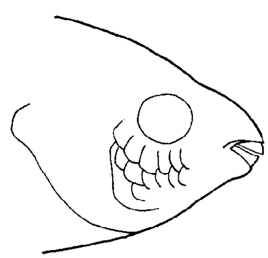

Figure 29. Teeth fused to form a "beak" in parrotfish.

      d) flexible, comb-like teeth useful for grazing on turf algae (as in most surgeonfishes) or living coral tissues (as in the short-bodied blenny)
   4) barbels - tentacle-like sensory extensions from the chin

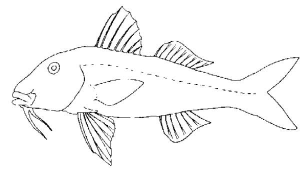

Figure 30.Barbels in a goatfish.

5) eye size
    1) small eye indicates diurnally active
    2) large eye indicates nocturnal or deep-water fish
6) special defenses
    a) toxic spines (e.g., scorpionfishes)

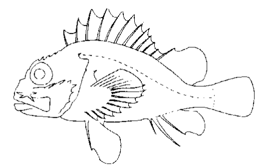

Figure 31. Toxic spines in a scorpionfish

    b) toxic flesh (e.g., puffers and boxfishes)

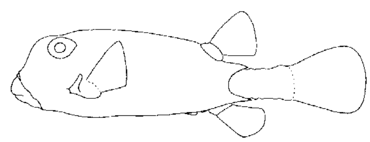

Figure 32. Boxfish with toxic flesh.

    c) body spines (e.g., spiny puffers)

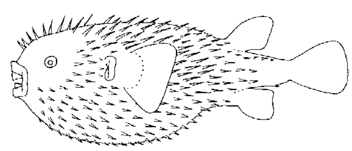

Figure 33. Body spines in a spiny puffer.

    d) fast escapes (e.g., flying fishes)

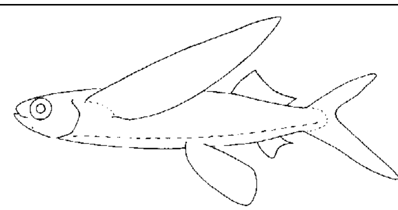

Figure 34. Gliding pectoral fins in a flying fish.

II. Fish Biology
  A. Schooling Behavior (pp. 154-155)
    1. maintaining the school may involve lateral line sense of vibrations in the water
    2. possible advantages of schooling
      a. confuse predators by schooling prey
      b. coordinated predation by schooling predators
      c. increase swimming efficiency by reducing water resistance
      d. increase the probability of finding a mate and fertilization during spawning
      e. more eyes for detecting predators and prey
      f. overwhelm the defenses of a territorial fish
    3. mixed schooling
  B. Territoriality (pp. 156-158)
    1. territory = a defended area containing limited resources
    2. contrast with a home range which is the area over which an individual may roam without vigorous defending that area (note: many home ranging species defend territories within their home ranges)
    3. resources defended (p. 156)
      a. food (e.g., blue-eyed damselfish)
      b. shelter (e.g., domino damsels)
      c. nests (e.g., Hawaiian sargeants)
      d. mates (e.g., some parrotfishes)
    4. example: Pacific gregory (*Stegastes fasciolatus*) algal turf territory
  C. Sex Change in Fishes
    1. protandry
      a. male first, then female
      b. very rare in coral reef fishes
    2. protogeny
      a. female first, then male (terminal phase males)
      b. common in parrotfishes and wrasses
    3. example of the bird wrasse (*Gomphosus varius*, *hinalea 'i'iwi*, p. 160)
  D. Use of Reef Habitat (pp. 168-171)
    1. diurnal fish (p. 169)
    2. nocturnal fish (p. 171)
    3. the crepuscular period (p. 170)

TEXT PAGES COVERED

pp. 148-149, 151-160, 168-171

VOCABULARY

jaws	swim bladder	paired appendages	pelagic
demersal	benthic	fusiform	compressed
elongate	depressed	countershading	camouflage
disruptive coloration	advertising coloration	bars	stripes
misdirection	false eye spot	mimicry	dorsal fin

caudal fin	anal fin	pectoral fin	pelvic fin
medial fin	paired fins	lunate caudal fin	forked caudal fin
truncate caudal fin	rounded caudal fin	heterocercal tail	fin spines
fin rays	finlets	scales	barbels
lateral line system	superior mouth	terminal mouth	inferior mouth
molariform teeth	canine teeth	territoriality	territory
home range	schooling	protandry	protogeny
diurnal	nocturnal	crepuscular	

STUDY QUESTIONS

1. List the three major vertebrate classes characterized by fish-like forms. List the general characteristics that define each group. List common examples of members of each group.

2. Contrast the characteristics identified as adaptations for living pelagic cruising, demersal, and benthic life styles respectively (hint: think about body shape, coloration, fin morphology & function, and major mode of locomotion). Give real life examples of each of these.

3. Describe how the size, shape, and position of the mouth, along with the nature of the teeth, of a fish can indicate the main diet of the fish? Give real life examples of each of these.

4. Describe the various ways and mechanisms different fish possess for the avoidance of being eaten by predators? Give real life examples of each of these.

5. Define schooling behavior in fishes. What are the possible adaptive advantages attributed to schooling behavior?

6. Define territoriality in fishes. What are the possible adaptive advantages attributed to territorial behavior?

7. Describe territoriality by the Pacific gregory?

8. Describe the relationship between sex change and the social biology of the bird wrasse.

9. Explain why it may not be very safe to enter the water during the crepuscular period. In your answer explain what is happening during the diurnal and nocturnal periods as well.

HUMAN IMPACT ON CORAL REEFS

I. Introduction
   A. Factors Correlated With Healthy Reef Growth (pp.128-129)
      1. water temperature range: 18 – 29°C
      2. normal seawater salinity: 32 – 35‰
      3. low inorganic nutrient concentrations (oligotrophic waters)
      4. clear, transparent water
      5. little or no sedimentation
      6. vigorous water motion
   B. Natural Sources of Stress on Coral Reefs (pp. 178-179)
      1. cyclones and hurricanes
         a. storm waves fragment and transport coral colonies
         b. impact depends upon whether the reef is a windward or leeward reef
            1) windward reefs with robust corals that resist uprooting by storm waves
            2) leeward reefs, tending to be dominated by more fragile corals, may be more greatly impacted by storm waves
         b. reef recovery involves regeneration from colony fragments and settlement of transported coral planulae
         c. recovery may take place over the course of decades
      2. ENSO (El Niño/Southern Oscillation) Events
         a. El Niño = "the Christ Child"
         b. involves
            1) a shift in current flow patterns in the Southern Pacific Ocean
            2) has far-reaching global impacts on climate
            3) signaled by an eastward shift in the low-pressure atmospheric cell over Australia to Tahiti
            4) causes a cessation of upwelling along the eastern margins of the Pacific Ocean
            5) unusually warm surface waters may occur in these waters at this time
         c. impacts on corals
            1) correlation between El Niño and the occurrence of severe storms
            2) Eastern Pacific increase in surface water temperatures may cause coral bleaching and eventual mortality
            3) changes in current patterns may influence current mediated dispersal of corals and other organisms
      3. disease (pp. 185-187)
      4. volcanic eruptions and lava flows (pp. 134-135)
         a. completely wipe out the living substrate
         b. reef recovery relies primarily on the settlement of coral planulae
         c. recovery may take centuries
      5. predator population explosions (e.g., crown-of-thorns sea stars)
      6. natural stream and river runoff
         a. freshwater and sediment runoff not conducive to coral growth
         b. don't see coral growth near stream mouths
         c. freshwater flooding events

        1) environments subjected to episodic freshwater flooding usually dominated by species with high tolerance for low salinity
        2) recovery may involve regeneration of tissues in existing skeletons rather than new coral growth (the Phoenix Effect; p. 142)
        3) recovery may take place over the course of months to years
   7. exceptionally low tides
      a. low tides during spring tides leave reef flat corals exposed to air above the water
      b. corals may be impacted by
         1) desiccation
         2) freshwater during rainfalls
C. Contrast Global Versus Local Human Impacts (pp. 180-206)
   1. global factors
      a. global warming
      b. ozone depletion
   2. local factors
      a. thermal effluents
      b. sewage discharges and agricultural runoff
      c. toxic chemical spills (p. 198)
      d. mechanical damage to reefs
      e. sedimentation
      f. destructive resource extraction practices (e.g., fishing)
      g. introduced species
      h. loving a reef to death
      i. non-point source pollution
D. Possible Consequences of Impacts on Corals
   1. outright mortality of coral tissues
   2. breakage of coral colonies
   3. bleaching (p. 182)
   4. diseases (pp. 185-187)
   5. slower growth
   6. reduced reproduction and recruitment
   7. competitive exclusion by other organisms
   8. increased reef erosion

II. Human Utilization of Coral Reefs
A. Traditional Reef Resources for Hawaiians and other Pacific Islanders (pp. 208-209)
   1. food resources (fish, invertebrates, seaweeds)
   2. traditional fish ponds constructed on reef flats of fringing reefs
   3. materials for tools (e.g., sharktooth club, mushroom coral scraper, various kinds of fish and octopus hooks)
   4. religious offerings
   5. body adornment
   6. stones marking locations of ko'a (fishing shrines)
   7. recreation (e.g., coral game pieces and surfing)
B. Modern Uses of Coral Reefs (pp. 210-213)
   1. seafood
   2. food additives (e.g., seaweed processed for thickeners)

3. toiletries (e.g., cosmetics manufacture from seaweed products)
4. health and medicine (e.g., coral as a bone substitute & exotic anti-carcinogenic chemicals from reef organisms)
5. jewelry and art
6. marine aquarium specimens
7. new land
8. cement and other building supplies
9. shoreline protection
10. recreation

C. The Economic Value of Coral Reefs
1. estimated value = $2833 per square meter
2. taking in account the Northwest Hawaiian Islands, Hawaii's reefs valued at $110+ billion
3. annual economic input into Hawaii's economy estimated to be in the 100's of millions of dollars

III. Locality-Specific Impacts

A. Thermal Effluents
1. power generating plants using seawater to cool turbines, etc., return heated seawater to the ocean (e.g., Kahe electric plant on O'ahu)
2. may cause localized bleaching of corals

B. Sewage Discharge into the Ocean
1. sewage discharge results in nutrient enrichment of coastal waters
2. possible consequences of nutrient enrichment (p. 196)
   a. physiological consequences on corals
      1) uncoupling of the controls over zooxanthellae growth in coral leads to abnormal proliferation of algae in coral tissues
      2) reduction of photosynthetic efficiency due to algal self-shading
      3) possibility zooxanthellae become more parasites than mutualistic symbionts
      4) coral colonies exhibit reduce growth or mortality
   b. ecological consequences
      1) increased phytoplankton abundance
         a) reduces light penetration
         b) increased phytoplankton abundance can result in increased abundance of filter-feeding bioeroders, substrate competitors, and corallivorous predators (e.g., crown-of-thorns sea star)
      2) increased competition with benthic seaweed leading to overgrowth by seaweed
3. other sewage-associated pollutants
   1) suspended solids
   2) toxic wastes associated with these solids and sewage effluent

C. Toxic Chemical Spills (e.g., oil spills)

D. Mechanical Damage to Reefs
1. dredging and coastal development (p. 183)
2. mining of reef limestone for building materials (p. 209)
3. anchor damage (p. 181)
4. diver damage (pp. 203-205)
5. net damage (p. 215)

6. atomic testing

E. Sediment Runoff
   1. occurs when soil-holding vegetation is removed leaving bare soil
   2. during heavy rainfall the exposed soil carried down streams into the ocean
   3. sediments then can cloud the water and bury the reef

F. Destructive Resource Extraction Practices
   1. overfishing (pp. 189-191)
   2. use of dynamite to kill and catch reef fish
   3. use of cyanide and bleach to kill and catch reef fish
   4. breakage of coral to extract fanworms
   5. collection of live coral and live rocks

F. Introduced Species (pp. 192-193)
   1. consequences
      a. disruption of normal trophic relationships
      b. alien species displace native species
   2. examples in Hawaiʻi
      a. *taʻape*
      b. seaweeds

G. Loving a Reef to Death
   1. marine tourism (p. 194)
   2. walking on reefs
   3. diver damage (see above)
   4. fish feeding (p. 188)
   5. Hanaumna Bay (p. 195)

H. Non-Point Source Pollution
   1. pollution that cannot be attributed to a single major source
   2. examples
      a. sediments from coastal urban & agricultural development (p. 199)
      b. pesticides (home use, agricultural, golf courses)
      c. nutrients from detergents, fertilizers, leaky septic tanks, and domesticated animals
      d. combusted motor oil, tire rubber and other materials in street runoff
      e. waste water from swimming pools and aquaculture ponds

IV. Global Human Impact Factors

A. Global Warming
   1. solar radiation reaching the earth
      a. solar radiation spectrum
         1) primarily visible light
         2) also ultraviolet and infrared
      b. fate of solar radiation reaching the earth
         1) reflection of light back into space
            a) clouds
            b) snow and ice
            c) the earth's other surfaces
            d) atmospheric dust
         2) absorption of light
            a) atmosphere
            b) oceans

c) land
d) plant photosynthesis
3) radiation back into space as heat
2. the greenhouse effect
a. earth's atmosphere retards the rate of heat radiation back into space
b. earth's natural greenhouse effect maintains a climate suitable for life
c. natural greenhouse gases
1) carbon dioxide
2) water vapor
3) methane
4) ozone

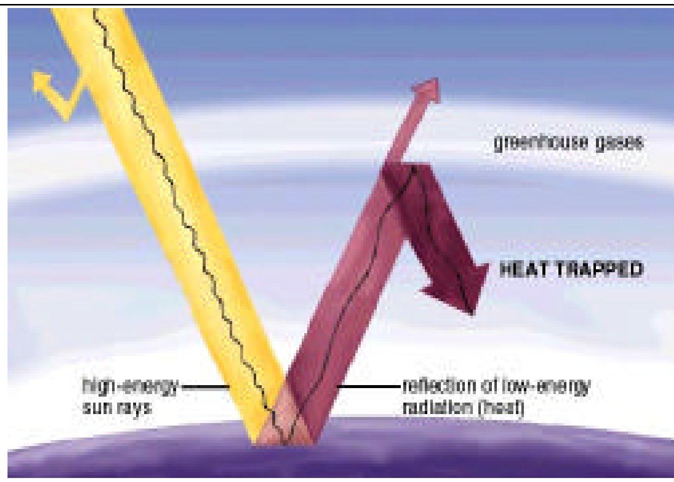

Figure 1. The greenhouse effect.

d. accelerated global warming due to human-introduced greenhouse gases
1) fossil fuel combustion and de-vegetation increases in carbon dioxide
2) agriculturally-generated methane
3) nitrous oxides from automobile exhaust and industrial waste
4) chlorofluorocarbons (CFC's; used as refrigerants and aerosols)

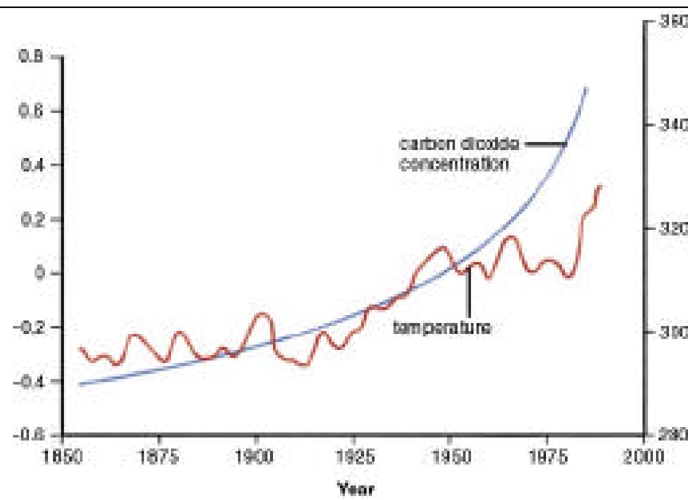

Figure 2. CO_2 increase and global warming.

3. possible impacts on corals and coral reefs
    a. may lead to water temperatures that reach above the lethal limit for hermatypic corals
    b. mechanism of mortality primarily from bleaching (loss of zooxanthellae; p. 182)
    c. bleaching actually result of a synergism between temperature and ultraviolet radiation exposure (see below)
    d. resulting eustatic sea level rise may actually create more shallow water living space for reef corals
    e. increased carbon dioxide levels may increase reef primary productivity and limestone deposition
    f. probable increase in storm frequency may increase the impacts of storms to coral reefs
    g. global climate shifts likely to lead to changes in the following factors that may impact coral reefs
        1) increase or decrease terrestrial runoff into coastal areas
        2) change oceanic circulation patterns which may change coral dispersal and nutrient inputs into reef systems
3. important consideration: What happens atoll islands if sea level rises +1 meter during the next century?

B. Ozone Depletion and Ultraviolet Radiation
    1. ozone = O_3, a molecule composed of three atoms of oxygen
    2. ozone is a very reactive molecule and is damaging to living tissues
    3. 90% of atmospheric ozone found in the stratosphere (a layer 10-40 km above the earth's surface)

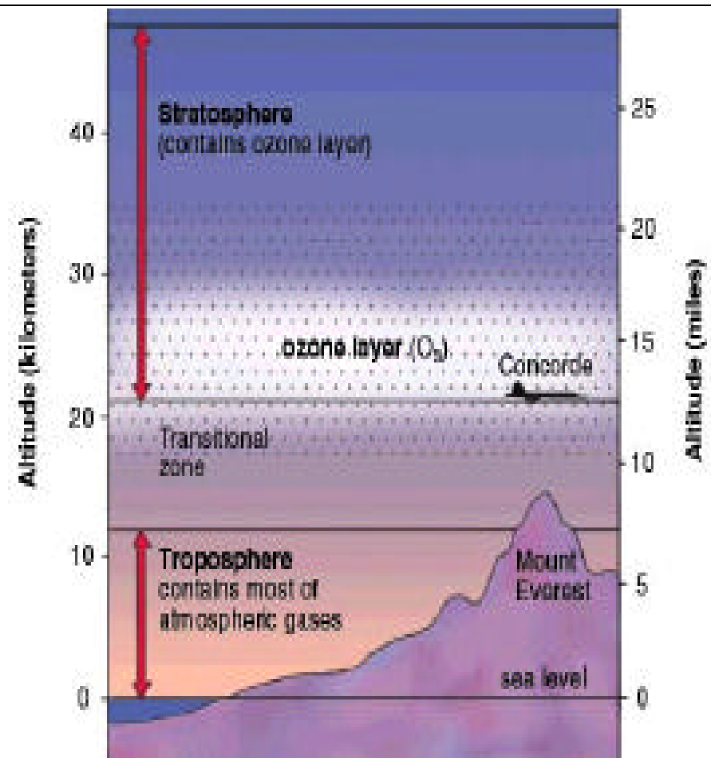

Figure 3. The Ozone layer in the earth's atmosphere.

4. ozone in the troposphere contributes to global warming and smog
5. ozone production and destruction in the upper atmosphere
   a. solar radiation splits molecular oxygen (O_2) into single oxygen atoms
   b. single oxygen atoms highly reactive
   c. reactive oxygen atoms combine with molecular oxygen to form ozone
   d. ozone destroyed by naturally-occurring compounds containing nitrogen, hydrogen, and chlorine
      1) nitrogen from soils and the ocean
      2) hydrogen from atmospheric water vapor
      3) chlorine from the ocean
   e. thus atmospheric ozone concentrations result from a balance between its formation and destruction
6. ozone and ultraviolet radiation absorption in the atmosphere
   a. peak absorbance at approx. 255 nm but sufficient absorption occurs in the region from 290 nm to 320 nm to significantly reduce UV-B radiation intensities reaching the surface of the earth
   b. generally no ultraviolet radiation <300 nm reaches the earth's surface
   c. latitudinal patterns of UV penetration
7. UV-B penetration through water
   a. substantial UV-B penetration may occur to depths of 40 m in clear waters
   b. depth penetration in less clear waters may be distinctly reduced
8. impacts on corals and coral reefs (pp. 201-202)
   a. UV penetration may exert a significant impact on coral physiology and ecology to depths of approx. 30 m
   b. possible physiological impacts of increased UV on corals
      1) bleaching (synergistic with temperature) and possible subsequent mortality
      2) reduced growth
      3) production of UV-absorbing substances (primarily mycosporine-like amino acids)
      4) the significance of these impacts likely to be restricted to shallow water environments, especially reef flats
   c. ecological impacts
      1) community structure likely to change
      2) important point: coral reefs, while likely to survive effects of increased UV exposure, will be different than they are presently

V. Kane'ohe Bay, Oahu, Hawaiian Islands: An Example Human Impact and Remediation
   A. Description of Kaneohe Bay
      1. one of the most extensively studied coral reef systems in the world
      2. barrier reef system
         a. largest embayment in the Hawaiian archipelago
            1) approx.13.5 km maximum length
            2) approx.4.5 km wide from shore to outer barrier reef
            3) approx.30.7 km of shoreline
         b. barrier reef about 1 km wide cut by two natural channels
         c. lagoon averages about 8.4 km (17 m max) deep and filled with fine terrigenous and reefal sediments

    d. fringing reef along shoreline & around *Moku O Loe* (Coconut Island, site of the University of Hawaii's Hawaii Institute of Marine Biology)
    e. patch reefs rise from lagoon floor in the middle of the bay
  3. principally shaped by the following processes
    a. loss of the seaward side of the original volcano forming the Koʻolau Range due to faulting & slippage
    b. coral reef development in what may have been the original caldera
    c. subsidence of the entire island of Oahu
    d. past sea level changes
  4. receives significant freshwater input from Kaneohe watershed
    a. watershed involves an area of about 97 km^2
    b. some nine (most channelized) streams drain this watershed into Kaneohe Bay
    c. annual rainfall averages 140-240 cm/year
    d. total stream discharge rate is approx. 214,000 m^3/day
    e. episodic heavy storms result in acute exposure of reef flat environments to low salinity water
      1) events occur perhaps every 20-30 years
      2) result in significant reef flat mortality (= "reef kills")
      3) may be important in influencing community structure
  5. water circulation
    a. most of the water enters the bay by flowing across the barrier reef
    b. water exits the bay primarily through its two channels
    c. southern end of the bay partially enclosed by Mokapu Peninsula limiting exchange with open ocean water

B. Historical Perspectives and Human Alteration of the Bay (p. 197)
  1. near the turn of the century was known as the "Coral Gardens of the Pacific"
  2. population centers and growth
    a. most of the population restricted to southern and central regions of the bay characterized as primarily residential and urban
    b. northern end of the bay is primarily rural/agricultural
    c. growth
      1) 1920: 2,990
      2) 1940: 5,387
      3) 1960: 29,662
      4) 1990: 66,760
  3. Hawaiians built 28 fishponds along the shorelines of Kaneohe Bay
    a. fishpond = fringing reef flat area enclosed by the construction of rock walls
    b. usually estuarine in character
    c. fishponds actually act as sites of terrigenous sediment trapping
    d. 19 of these have been filled in recent times for housing developments
    e. two were altered for construction of small boat harbors
  4. dredging activities
    a. approx. 14% of total fringing reef area dredged or filled
    b. approx. 5% of patch reef area dredged for seaplane runways and channel widening

c. dredge spoils may have contributed to decreased average depth during the period from 1927 through 1969
5. pesticide and heavy metal contamination
6. sewage pollution in Kaneohe Bay during the 1970's
   a. three sewage outfalls established in South Kaneohe Bay
      1) Kaneohe Marine Corps Air Station in 1940 (primary treatment)
      2) Kaneohe municipal plant in 1963 (secondary treatment)
      3) Ahuimanu plant in 1970 (secondary treatment)
   b. effects sewage discharge
      1) anecdotal accounts in connection with examination of reef cross-sections suggested coral reefs declined during this period
      2) rates of bioerosion accelerated by flourishing of filter-feeding bioeroders (because of increased phytoplankton abundance)
      3) bubble algae, *Dictyosphaeria cavernosa*, overgrew corals
   c. problem compounded by increasing turbidity and sedimentation resulting from urban/residential development in the watershed
7. results of sewage outfall diversion which began in 1979
   a. immediate effect = declines in
      1) turbidity
      2) nutrients
      3) phytoplankton abundance
   b. longer term changes through 1983
      1) decrease in the percent cover of bubble algae
      2) significant recovery of reef corals
      3) decline of fish abundance (based primarily upon anecdotal accounts)
   c. changes subsequent to 1983 (based upon 1990 study)
      1) reef cover plateaued and declined slightly in some places
      2) slowing of recovery was unexpected and explanations were sought
         a) plateau state represents "normal" pre-impact conditions
         b) other impacts related to population growth in the watershed possibly responsible
            1) planned or accidental municipal sewage bypasses into the bay
            2) degeneration of cesspools and septic systems
            3) construction projects leading to increased sedimentation
         c) freshwater kill event in December 1987 may have had a significant influence
            1) low salinity water (approx. 50% seawater) extended to a depth of nearly 2 m in the nearshore environments of Kaneohe Bay for several days
            2) nearshore reef flat environments subject to a "reef kill"
            3) amazingly many of the reef flat corals recovered within several months following the episode

VI. Coral Reefs: Robust of Fragile Systems?
   A. Effects of Natural Disturbance Significant
      1. note natural stresses on coral reefs discussed above
      2. some have argued that natural impacts are more significant than acute

human impacts
3. possible resolution
   a. acute impacts, natural or otherwise, subject to recovery that may involve months to centuries
   b. chronic human impacts retard or suppress recovery or may lead to increasing degeneration of reef environments
4. general consensus: reefs around the world are threatened by human impacts

B. What Can We Do to Protect Coral Reefs
1. support reef-friendly businesses
2. don't pollute and encourage others to do the same
3. learn more about reefs and educate others with your knowledge
4. report dumping, poaching, and other illegal activities
5. never anchor directly on reefs
6. avoid overfishing and other destructive resource extraction methods
7. avoid touching the reef
8. encourage reef-friendly legislation
9. be a responsible aquarium owner
10. support conservation organizations, agencies, and programs
11. support the establishment of marine protected areas
12. promote responsible development
13. promote reef monitoring and basic research aimed at protecting coral reefs and their inhabitants

C. A Geological Perspective
1. corals as possible indicators of the past (p. 213)
   a. chemical compositions and growth rings of fossil corals can be used to make hypotheses regarding past climates
   b. occurrence of elevated fossil reefs indicate past change sin sea level
2. past climate change
   a. in addition to corals, ice varve layers and sedimentary varve layers provide clues regarding past climates
   b. global temperature change
      1) earth surface temperatures subject much variation in the past
      2) Pleistocene ice ages resulted in substantial changes in sea level
         a) about 120,000 years ago sea levels as much as 3 meters higher than present leading to the deposition of reefs that exist now as fossil reefs above sea level
         b) about 20,000 years ago sea levels estimated to be 130 meters lower than present levels
         c) sea level began rising rapidly about 15,000 years ago
         d) general trend during the last 7,000 years has been declining sea levels with superimposed fluctuations
         e) present rise in sea level during the last 100 years miniscule compared to changes that have occurred during the last 20,000 years
3. the long term impact of living things on the earth
   a. responsible for changes to the chemical composition of the air, land and sea

1) present atmosphere largely a consequence of plant photosynthesis
2) large tracts of land originally produced by the deposition of organism skeletons (e.g., the white cliffs of Dover, elevated fossil reefs, & other limestone deposits)
3) accumulation of organic matter responsible for oil and coal deposits (fossil fuels)

b. interaction (e.g., competition, predation, symbiosis, etc.) among species has contributed to the evolution of life on earth
c. bottom-line: living things have been major agents of change on the earth

4. plate tectonics
   a. the shapes of continents and ocean basins are constantly changing
   b. volcanic activity results in chemical changes to the air and sea
   c. volcanic activity creates new living surfaces and destroys others
5. unpredictable catastrophic events
   a. these include major earthquakes, major volcanic eruptions, monster tsunamis, and meteorite/comet/asteroid impacts
   b. the extinction of the dinosaurs possibly due to a meteorite impact
   c. other past extinctions may have resulted from similar events
   d. would we be here now if not for these catastrophic events?
6. thus change is inevitable
7. the principal problem is understanding whether or not environmental change resulting from human impacts to the environment will have negative consequences on the quality of human life

VII. The Real Environmental Problem (p. 184)

A. General Perspectives
   1. we as human beings could do a lot to reduce resource consumption and waste production
   2. however, since all living things consume resources and produce wastes, the more people there are, the more impact humans have on the environment
   3. as long as human populations grow, we run the risk of resource scarcity and pollution
   4. review Ecological Principles lecture on Population Growth

B. The Pattern of Human Population Growth
   1. doublings in the global population
      a. 1850: 1 billion people
      b. 1930: 2 billion people
      c. 1975: 4 billion people
      d. 2017: 8 billion people (predicted)
   2. most of this growth can be attributed to third world countries which have a very high percentage of younger individuals
   3. note that this global population increase cannot go on indefinitely
      a. density-dependent factors will begin to exert their effects on population growth
         1) resources are limited and will eventually become scarce
         2) waste production may reduce births or increase mortality
         3) the quality of human life may decline

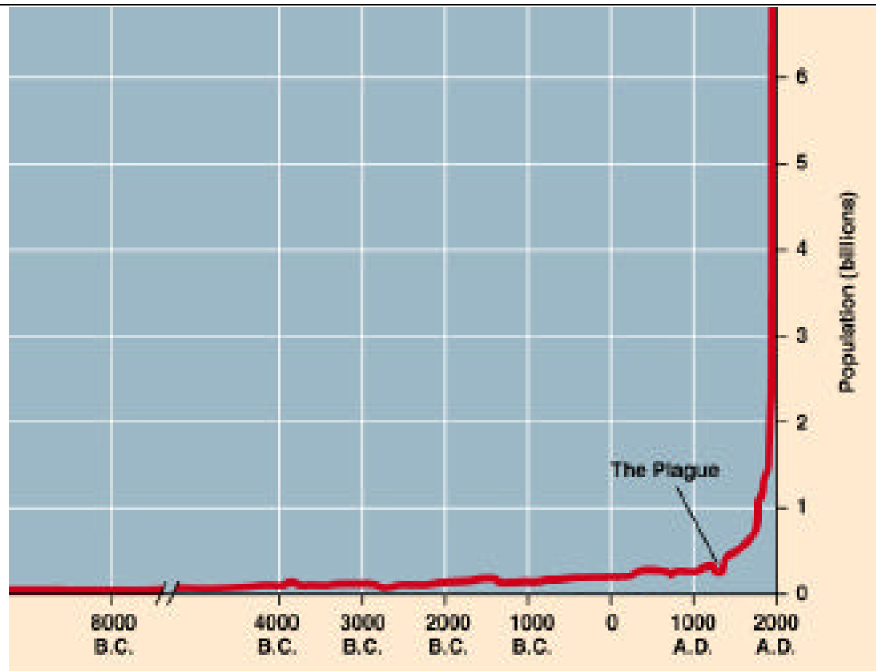

Figure 4. Global human population growth.

TEXT PAGES COVERED

pp. 128-129, 134-135, 142, 178-213, & 215

VOCABULARY

global warming	greenhouse effect	greenhouse gas	coral bleaching
chlorofluorocarbons	ozone	stratosphere	non-point source
watershed	bubble algae	ENSO (El Niño)	upwelling
ice age	oligotrophic	eutrophic	sedimentation
thermal effluent	dredging	alien species	terrigenous sediment
ice varve	ko'a	eustatic sea level rise	ozone depletion
UV-A	UV-B	UV-C	reefal sediments
overfishing	plate tectonics		

STUDY QUESTIONS

1. Discuss how coral reefs have been important to Hawaiians and other Pacific islanders in the past. How are they important to us now?

2. Describe the natural events that often have negative impacts upon coral reefs.

3. Briefly summarize the various impacts of human activities upon coral reefs around the world.

4. Discuss the effects of the following local impacts on coral reef environments: thermal effluent, sewage and agricultural runoff, mechanical damage, destructive

resource extraction practices, excess sediment runoff, introduced species, and excessive recreational use.

5. What is non-point source pollution? Give examples of different kinds of non-point source pollution and briefly describe the effects of each upon the coral reef environment.

6. Discuss the factors that may be contributing to global warming. How might global warming impact reef corals and the reefs they produce?

7. Discuss the factors that may be contributing to increased penetration of ultraviolet radiation to the earth's surface. How are reef corals affected by ultraviolet radiation? What may be the impact of increased ultraviolet radiation upon coral reefs?

8. Discuss the history of pollution in Kaneohe Bay.

9. What can we do about protecting our coral reefs?

10. What should we do about human impacts on coral reefs. Why should we do these things?

11. Are coral reefs robust or fragile ecosystems? Explain and justify your answer.

12. According to your instructor, what is the ***real*** environmental problem facing coral reefs?

APPENDIX I: CHEMICAL PRINCIPLES

I. Elements
   A. Definition
      1. elements are pure substances that resist attempts to decompose them into simpler chemical entities by ordinary chemical reactions
      2. for a material to be composed of a single element, all atoms (see below for definition of atom) comprising that material must be the same
      3. 106 different elements have been identified
      4. of these, at least 92 occur naturally throughout the universe
   B. Some Examples

Table I
Some Examples of Chemical Elements

Element Name	**Chemical Symbol**	**Atomic Number***
hydrogen	H	1
helium	He	2
carbon	C	6
nitrogen	N	7
oxygen	O	8
sodium	Na	11
magnesium	Mg	12
silicon	Si	14
phosphorus	P	15
sulfur	S	16
chlorine	Cl	17
potassium	K	19
calcium	Ca	20
iron	Fe	26

* the atomic number = the number of protons (see below)

II. Atoms
   A. Definition
      1. smallest unit of an element that still has the properties of that element
      2. smallest unit of matter that cannot be subdivided by normal chemical means
   B. Structure of the Atom
      1. three fundamental particles make up the atom
         a. protons
            1) are positively charged (i.e. each proton with a charge = +1)
            2) symbolized as: p^+
            3) the number of protons determine the element that the atom belongs to
            4) the number of protons for an atom = its atomic number (see above)
         b. electrons
            1) are negatively charged (i.e. each electron with a charge = -1)
            2) much small in mass than a proton

3) symbolized as: e^-

c. neutrons

1) are neutral (i.e. neither positively nor negatively charged)
2) symbolized as: n^o
3) the number of neutrons within the atom may vary without changing the element (elements with differing numbers of neutrons = isotopes)

2. in order for an atom to be electrically neutral, the number of electrons and protons must be the same
3. simple structural model for the atom
   a. protons & neutrons found collected together in the center (the nucleus) of the atom
   b. electrons orbit around this nucleus in discrete "shells" found at specific distances from the nucleus
   c. some examples of atoms to illustrate atomic structures

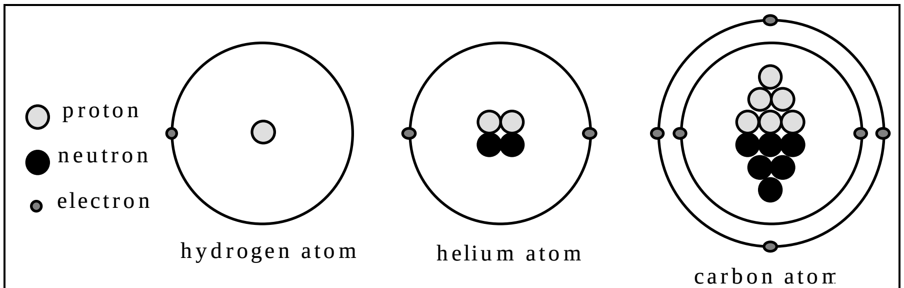

Figure 1. Several examples of atoms representing different elements.

C. Electron Shells

1. electrons viewed as occupying distinct "shells" around the nucleus of the atom
2. uniform pattern in the maximum number of electrons that can occupy these "shells"
   a. most likely configuration is have the shells nearest the nucleus fill before electrons may occupy shells found at greater distances from the nucleus
   b. different shells with different numbers of electrons when maximally filled
      1) first shell with maximum of 2 electrons
      2) second shell with maximum of 8 electrons
      3) third shell with maximum of 8 electrons
3. examples
   a. carbon (C), see above
   b. sodium (Na)
      1) has 11 protons, 12 (usually) neutrons, and 11 electrons
      2) first shell has 2 electrons, second shell has 8 electrons, & third shell has the last remaining electron

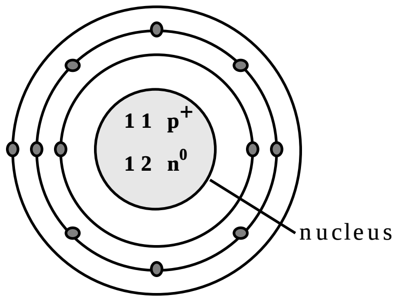

Figure 2. The sodium atom illustrating its electron shell configuration.

b. chlorine (Cl)
   1) has 17 protons, 18 (usually) neutrons, and 17 electrons
   2) first shell has 2 electrons, second shell has 8 electrons, & third shell has seven electrons

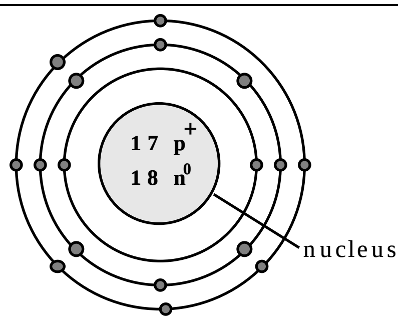

Figure 3. The chlorine atom illustrating its electron shell configuration.

D. Ions
   1. ion = atom that have gained or lost an electron(s) such that it has a net charge
   2. results from the tendency of an atom to be more stable when its outermost shell possesses the maximum number of electrons possible for that shell
      a. some atoms (e.g. sodium, Na) achieves this state when it looses 1 electron, thus possessing a net charge of +1 (the Na^+ ion)

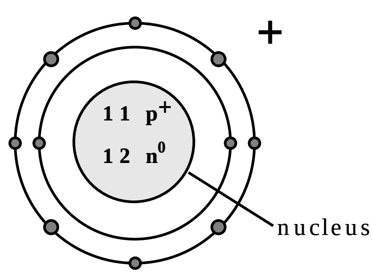

Figure 4. The sodium ion illustrating its electron shell configuration.

      b. other atoms (e.g., chlorine, Cl) achieves this state when it gains 1 electron, thus possessing a net charge of -1 (the Cl^- ion)

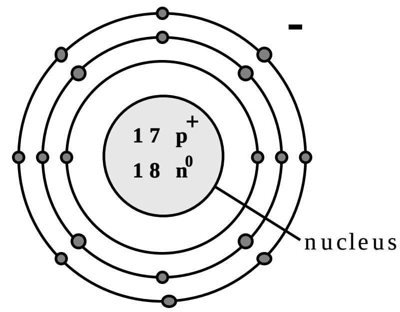

Figure 5. The chloride ion illustrating its electron shell configuration.

3. some examples of other simple ions commonly found in seawater
   a. hydrogen ion (H^+)
   b. potassium ion (K^+)
   c. fluoride (F^-)
   d. calcium (Ca^{+2})
   e. magnesium (Mg^{+2})
4. ionic bonds
   a. form when ions of opposite charge are attracted to one another and stick together because of their opposite charges
   b. example of sodium chloride which results from ionic bonding between sodium and chloride ions (NaCl):

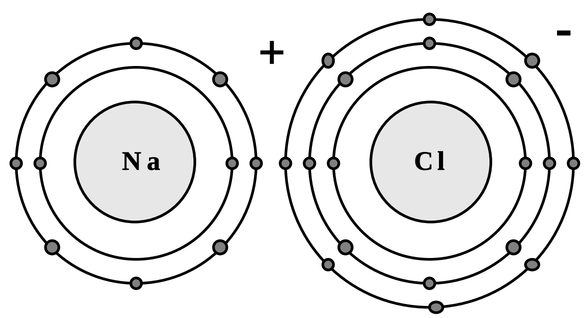

Figure 6. Ionically bonded sodium and chloride (NaCl).

4. complex ions
   a. complex ion = ion composed of two or atoms bound together as a single unit
   b. charge of the complex ion is the net result of the combined charges of all the protons & electrons in all of the atoms bonded together to form the complex ion
   c. examples of complex ions found in seawater
      1) hydroxide (OH^-)
      2) bicarbonate (HCO_3^-)

3) carbonate (CO_3^{-2})
4) nitrate (NO_3^-)
5) phosphate (PO_4^{-3})
6) ammonium (NH_4^+)

III. Molecules and Compounds
- A. Definition
  1. a molecule is a pure substance whose smallest particle is composed of two or more atoms bonded tightly together
  2. these atoms may be held together by ionic bonds or by covalent bonds (involves electron sharing - we won't discuss this type of bonding even though it is very important, especially in biological molecules)
  3. a compound is a molecule composed of at least two *different* elements
- B. Examples of Molecules
  1. molecular oxygen (O_2)
  2. molecular nitrogen (N_2)
  3. ammonia (NH_3), also a compound
  4. carbon dioxide (CO_2), also a compound
  5. water (H_2O), also a compound
  6. methane (CH_4), also a compound
  7. glucose ($C_6H_{12}O_6$), also a compound
- C. Covalent Bonds
  1. while ions may be held together by ionic bonds, many atoms join together through sharing of electrons
  2. chemical bonds formed through the sharing of electrons = covalent bonds
  3. most biological molecules composed of atoms covalently bonded, rather than ionically bonded
  4. the ability of carbon atoms to covalently bond with other carbon atoms, as well as hydrogen, oxygen, nitrogen, and sulfur, is very important in the formation of biological molecules
- D. Inorganic Versus Organic Molecules
  1. organic molecules
     - a. carbon-containing molecules with C-C and/or C-H chemical bonds
     - b. do ***not*** imply that organic molecules are safe for living things - many are safe & useful for living things, but many others are toxic and dangerous
     - c. some examples of organic molecules
       1) methane (CH_4)
       2) ethyl alcohol (C_2H_5OH)
       3) benzene (C_6H_6)
       4) TNT (trinitrotoluene, an explosive material)
       5) nearly all insecticides and herbicides
       6) gasoline
       7) glucose ($C_6H_{12}O_6$, a simple sugar)
       8) biological molecules such as carbohydrates, proteins & fats
  2. inorganic molecules
     - a. molecules lacking C-C & C-H chemical bonds
     - b. examples of inorganic molecules

1) molecular oxygen (O_2)
2) molecular nitrogen (N_2)
3) ammonia (NH_3)
4) carbon dioxide (CO_2)
5) water (H_2O)

E. Hydrogen Bonds
1. weak bonds that occur between polar molecules
2. polarity results from the tendency for some elements to exhibit greater attraction to electrons than others
3. importance
a. most of the special properties of the water molecule that are important to life result because of hydrogen bonding tendencies between water molecules and other molecules
b. structure of proteins & DNA stabilized by hydrogen bonding

IV. Chemical Reactions
A. Typical Format

$X \rightarrow Y$, where X is the reactant and Y is the product

B. Types of Chemical Reactions
1. synthesis; involves the combining of atoms, or simple molecules, into larger, more complex molecules:

$A + B \rightarrow AB$, where product AB is the result A & B binding together

2. decomposition; involves the breaking apart of larger, complex molecules into simpler molecules or individual atoms:

$AB \rightarrow A + B$

3. rearrangement; involves the breaking apart & recombining of atoms to form new molecules:

$AB + CD \rightarrow AC + BD$

V. Acids, Bases and Salts
A. Decomposition of Water Molecules
1. about one water molecule in 10,000,000 decomposes as follows

$H_2O \rightarrow H^+ + OH^-$

2. note ratio of hydrogen to hydroxide is one to one
3. this is a dynamic process

B. Acid
1. a molecule that when dissolved in water gives rise to excess hydrogen ions
2. examples
a. hydrogen chloride (HCl)

        b. acetic acid (CH_3COOH)
    C. Base
        1. a molecule that when dissolved in water gives rise to excess hydrogen ions
        2. examples
            a. sodium hydroxide (NaOH)
            b. potassium hydroxide (KOH)
    D. pH Scale
        1. ranges from 0 to 14
            a. acidic solutions: pH < 7
            b. basic solutions: pH > 7
            c. neutral solution: pH = 7
        2. examples
            a. pure water: pH = 7
            b. blood: pH = 7.4
            c. gastric juice: pH = 0.8
    E. Salt
        1. usually an inorganic compound formed through ionic bonding
        2. may form as a consequence of reacting an acid and a base
VI. Important Biological Molecules
    A. Carbohydrates
        1. characteristics
            a. composed primarily of C, H, & O
            b. ratio of hydrogen to oxygen = two to one
        2. examples
            a. monosaccharides (simple sugars)
                1) C:H:O = 1:2:1
                2) examples
                    a) glucose
                    b) fructose
                    c) ribose
            b. disaccharides (double sugars)
                1) formed by combining two monosaccharides
                2) formation accompanied by the elimination of a water molecule
                3) examples
                    a) maltose, formed from two glucose units
                    b) sucrose (table sugar), formed from one glucose unit and one fructose unit
            c. polysaccharides
                1) very large molecules composed of many monosaccharide units (thus they are polymers)
                2) examples
                    a) plant starch
                    b) glycogen (animal starch)
                    c) cellulose
        3. principle function = energy metabolism (storage as chemical energy)
    B. Proteins
        1. characteristics
            a. composed primarily of C, H, O, & N (although S is present to some

degree as well)

- b. basic unit = amino acid
    - 1) each amino acid possesses an amino group ($-NH_2$) and an acid group (-COOH)
    - 2) there are approximately 20 different kinds of amino acids occurring naturally in the proteins of living things
    - 3) proteins generally composed of linear chains of 100+ amino acids
    - 4) structure & function of proteins ultimately determined by sequence of amino acids
- c. four levels of protein organization

2. principle functions
    - a. structural proteins
    - b. enzymes
3. examples
    - a. keratin, structural protein of hair and nails
    - b. collagen, rigid structural protein of connective tissues
    - c. elastin, elastic structural protein of connective tissues
    - d. sucrase, an enzyme responsible for the breakdown of sucrose
    - e. hemoglobin, blood protein that transports oxygen to the body's tissues
    - f. immunoglobulin, blood protein involved in the body's defense against disease

C. Nucleic Acids

1. characteristics
    - a. composed of C, H, O, N, & P
    - b. basic unit = nucleotide
        - 1) each nucleotide composed of
            - a) ribose sugar
            - b) N-containing (nitrogenous) base
            - c) phosphate group
        - 2. nucleotides linked through sugars & phosphates
2. principle functions
    - a. specifying the genetic code
    - b. translation of code into the amino acid sequence of a protein
    - c. some involved in energy metabolism as temporary energy storage molecules
3. examples
    - a. DNA, deoxyribonucleic acid, contains the genetic code, found in chromosomes
    - b. RNA, ribonucleic acid, invovled in translation of this code
    - c. ATP, adenosine triphosphate, involved in energy metabolism

D. Lipids

1. characteristics
    - a. usually composed of C, H, & O
    - b. ratio of hydrogen to oxygen greatly exceeds two to one
    - c. a very heterogeneous group of molecules
2. principle functions
    - a. energy storage
    - b. membrane structure

   c. steroid hormones
3. examples
   a. triglycerides (neutral fats), composed of three fatty acids & one glycerol
   b. phospholipids, composed of two fatty acids, one phosphate-containing group, and one glycerol
   c. cholesterol, a steroid

VOCABULARY

element	atom	proton	electron
neutron	electron shell	atomic number	nucleus
ion	complex ion	ionic bond	molecule
compound	organic molecule	inorganic molecule	reactant
product	synthesis	decomposition	rearrangment
covalent bond	hydrogen bond	acid	base
salt	pH	carbohydrate	monosaccharide
disaccharide	polysaccharide	polymer	protein
amino acid	enzyme	structural protein	lipid
neutral fat	phospholipid	steroid	

STUDY QUESTIONS

1. Discuss protons, neutrons and electrons with regard to electrical charge and location in the atom.

2. Draw the electron shell diagrams of the following electrically neutral atoms: hydrogen (H), carbon (C), nitrogen (N), oxygen (O), sodium (Na), magnesium (Mg), silicon (Si), chlorine (Cl), and calcium (Ca).

3. For each of the elements listed in question #2 above, predict its most likely ionic form.

4. List, giving both the names & molecular formulae, at least 6 complex ions found in seawater.

5. Contrast between organic and inorganic molecules. Provide at least 4 examples of each type to illustrate for discussion.

6. Discuss and contrast the characteristics of the major groups of biological molecules (i.e. carbohydrates, proteins, lipids, & nucleic acids) in terms of principle elemental composition, basic chemical subunits, and principle functions. Give examples of different kinds of biological molecules.

APPENDIX II: ANIMAL BODY PLANS

I. Symmetry Pattern
   A. Asymmetrical (e.g., many encrusting sponges)
   B. Radial Symmetry
      1. body arranged around a central axis so that splitting them lengthwise through center at any angle always results in two equal symmetrical halves, thus body is like a cylinder, bowl, or saucer
      2. points of body orientation: oral (mouth surface) vs. aboral (surface opposite mouth)
      3. usually associated with a sessile way of life
      4. examples: some sponges, sea anemones & sea stars

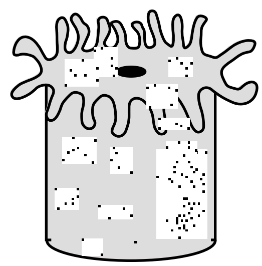

Figure 1. A sea anemone, an example of a radially symmetric animal.

   C. Bilateral Symmetry
      1. body can be cut by only one lengthwise cut through center to give two equal symmetrical halves

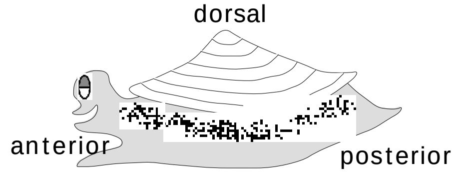

Figure 2. Typical bilateral animal.

      2. points of body orientation
         a. anterior/posterior
         b. ventral/dorsal
      3. usually associated with an active way of life and cephalization (= the development of a head end)
      4. examples: flatworms, slugs, clams, lobsters, sharks, lizards & sea lions

II. Primary Germ Layers
   A. Fundamental Cell Layers of Animals
      1. early in the development of an animal, germ layers form
         a. responsible for specific body structures

b. pattern is consistent across nearly all animal groups
2. types of germ layers in animals
   a. ectoderm: outermost layer responsible for outer body covering and nervous system
   b. endoderm: innermost lining of the digestive tract
   c. mesoderm: middle layer between ectoderm and endoderm responsible for most other body organs

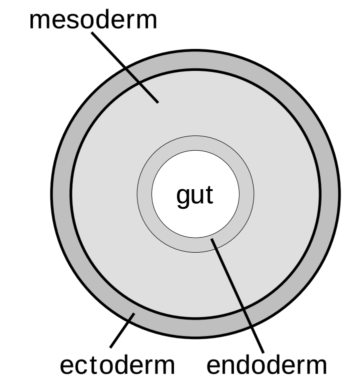

Figure 3. Triploblastic body plan.

B. Germ Layer Arrangements in Animal Phyla
1. none identifiable (e.g., sponges)
2. two present: ectoderm & endoderm (e.g., sea anemones & jellyfish)

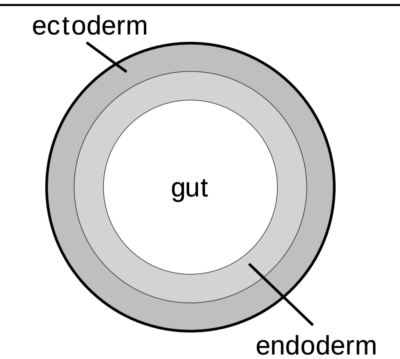

Figure 4. Diploblastic body plan.

3. all three present (e.g., most higher animals)

III. Gut Organization
A. No Gut (e.g., sponges)
B. Blind Sac Gut
   1. with only one opening, the mouth
   2. examples: sea anemones and flatworms
C. Complete Gut
   1. tubular gut with mouth & anus
   2. examples: most bilateral animals, except flatworms

IV. Body Cavity
A. Acoelomate

1. solid body construction lacking a fluid-filled cavity within the mesoderm
2. examples: flatworms and ribbonworms

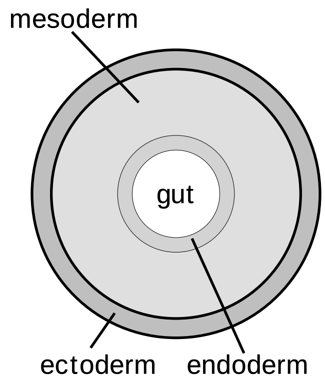

Figure 5. Acoelomate condition.

B. Eucoelomate
   1. possess a fluid-filled cavity completely surrounded by mesoderm
   2. examples: snails, crabs, sea cucumbers & fish

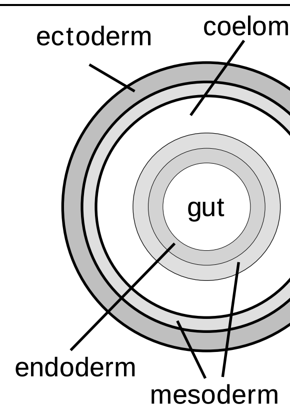

Figure 6. Eucoelomate condition.

C. Pseudocoelomate
   1. possess a fluid-filled cavity, but not completely surrounded by mesoderm
   2. examples: rotifers & roundworms (nematodes)

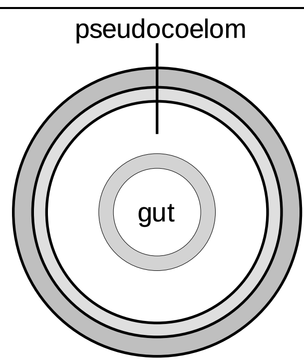

Figure 7. Pseudocoelomate condition.

- D. Advantages of a Fluid-Filled Cavity
  1. hydrostatic skeleton
  2. greater freedom for internal organs
  3. greater body size because of possibility of body fluid circulation

V. Segmentation

- A. Serial Repetition of Body Parts
  1. each segment = metamere or somite
  2. most segmented animals exhibit fusion of segments into specialized body regions, thus obscuring primary segmental pattern

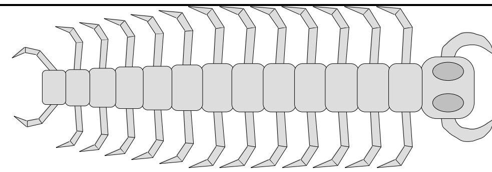

Figure 8. A Segmented animal.

- B. Examples: fire worms, earthworms, fan worms, shrimp & fish

VI. Skeletal Systems

- A. Functions
  1. supports basic body form
  2. protection of internal tissues and organs
  3. serves as non-compressible structure against which muscles can contract for locomotion
- B. Types
  1. hydrostatic skeletons
     - a. = fluid skeleton
     - b. examples
       1. sea anemone body column & tentacles
       2. earthworm coelom
  2. exoskeletons
     - a. = hard skeleton produced by ectodermal tissue
     - b. usually external
     - c. examples
       1. stony coral skeleton
       2. clam shell
       3. crab shell
       4. reptilian scales
  3. endoskeletons
     - a. = hard skeleton produced by mesodermal tissues
     - b. usually internal
     - c. examples
       1. microscopic skeletal elements of sea star skeletons
       2. skeleton and spines of sea urchins
       3. vertebrate bone and cartilage
       4. fish scales

VII. Appendages

- A. Structures that Extend from the Main Trunk of the Body

- B. Generally Functions
  1. locomotion
  2. feeding
  3. protection
- C. Jointed vs. Not Jointed
  1. jointed
     a. endoskeleton type (e.g., vertebrates)
     b. exoskeleton type (e.g., lobsters)
  2. not jointed (e.g., sea anemone tentacles, fire worm appendages, octopus arms)

VIII. Circulatory Systems
- A. Functions
  1. transport essential nutrients from exchange organs (e.g., lungs & digestive tract) to body tissues that need them
  2. transport metabolic wastes from body tissues to exchange organs (e.g., lungs & kidneys) for elimination
  3. maintain water and solute balance for the body
  4. defend body from invading microorganisms (immunity)
- B. Types
  1. none: exchange merely involves diffusion across general body surfaces
  2. body cavity circulation: circulation of body cavity fluids
  3. closed circulatory system: blood flows entirely within blood vessels
  4. open circulatory system: blood flows out of heart and major blood vessels into blood-filled spaces of the body

IX. Nervous Systems
- A. Functions
  1. integration of animal behavior
  2. processes and interprets sensory information
  3. elicits responses (both external and internal)
- B. Types
  1. nerve net (sea anemones and jellyfish)
  2. centralized nervous systems
     a. solid ventral nerve cords (segmented worms and shrimps)
     b. dorsal hollow nerve cord (vertebrates)

X. Coloniality
- A. Colonies
  1. collection of individuals of the same species living in close association and integration
  2. colony may act as a kind of "superorganism" with individuals specializing for specific colony functions (polymorphism)
- B. Examples
  1. corals
  2. Portugese man-of-war
  3. bryozoans
  4. tunicates & their relatives
  5. bees & termites

VOCABULARY

primary germ layer	ectoderm	endoderm	mesoderm
asymmetrical	radial symmetry	bilateral symmetry	oral/aboral
anterior/posterior	dorsal/ventral	cephalization	blind sac gut
complete gut	acoelomate	eucoelomate	pseudocoelomate
segmentation	hydrostatic skeleton	endoskeleton	exoskeleton
appendages	coloniality	nerve net	nerve cord
polymorphism			

STUDY QUESTIONS

1. Understand the basic animal body plan characteristics used to classify animals into phyla: symmetry, gut type, germ layers, body cavity, segmentation, skeleton, appendages, circulatory system, nervous system, & coloniality.

2. Under what circumstances is it advantageous for an animal to exhibit radial symmetry? Bilateral symmetry?

3. Compare the gut of a sea anemone with that of an earthworm.

4. In what ways is it advantageous for animal to possess a fluid-filled body cavity?

5. Compare segmentation in a fire worm to that of a lobster and to that of a fish.

6. How is the skeleton of a vertebrate different from that of a crab?

7. Contrast the workings of the following appendages in animals: sea anemone tentacle, spaghetti worm tentacle, crab leg, human arm.

8. Describe the polymorphism of a Portuguese man-of war (see p. 25).

APPENDIX III: MAJOR ANIMAL PHYLA CHARACTERISTICS

PHYLUM	SYMMETRY	PRIMARY GERM LAYERS	TYPE OF GUT	BODY CAVITY	SEGMENTATION	TYPE OF SKELETON	CIRCULATORY SYSTEM	NERVOUS SYSTEM	SPECIAL FEATURES	EXAMPLES
PORIFERA	no symmetry or radial	N/A	none (channels perforate body)	N/A	no	carbonate or siliceous spicules and/or spongin fibers	none	none	collar cells for creating feeding water currents	sponges
CNIDARIA (=COELENTERATA)	radial	2	blind sac	N/A	no	exoskeleton in many (calcium carbonate or protein)	none	nerve net	tentacles with nemato-cysts; often colonial	sea anemones
PLATYHELMINTHES	bilateral	3	blind sac	acoelomate	no	none	none	ganglia and longitudinal nerve tracts	very flat body	marine free-living flatworms & parasitic flukes
NEMERTEA	bilateral	3	complete	acoelomate	no	none	closed	ganglia and longitudinal nerve tracts	eversible proboscis	ribbon-worms
NEMATODA	bilateral	3	complete	pseudo-coelomate	no	flexible chitinous cuticle (exo-skeleton)	NONE	ganglia and longitudinal nerve tracts	cylindrical body with tapered ends	roundworms
ROTIFERA	bilateral	3	complete	pseudo-coelomate	no	flexible chitinous cuticle (exo-skeleton)	closed	ganglia and longitudinal nerve tracts	ciliated corona, mastax, and foot	wheel bearers
ECTOPROCTA	bilateral	3	complete	eucoelomate	no	chitinous cuticle (exo-skeleton)	none	ganglia and longitudinal nerve tracts	ciliated lophophore for filter feeding; usually colonial	bryozoans or "moss" animals

PHYLUM	SYMMETRY	PRIMARY GERM LAYERS	TYPE OF GUT	BODY CAVITY	SEGMENTATION	TYPE OF SKELETON	CIRCULATORY SYSTEM	NERVOUS SYSTEM	SPECIAL FEATURES	EXAMPLES
BRACHIOPODA	bilateral	3	complete	eucoelomate	no	exoskeleton (bivalved carbonate shell)	open	ganglia and longitudinal nerve tracts	ciliated horseshoe shaped lophophore for filter feeding	lamp shells
MOLLUSCA	bilateral	3	complete	eucoelomate	no	dorsal shell in most (exo-skeleton ; made of carbonate)	open	ganglia and longitudinal nerve tracts	radula present in most	chitons, snails, slugs, clams, oysters, squids, octopods, nautilus
ANNELIDA	bilateral	3	complete	eucoelomate	yes	none	closed	cerebral ganglion and ventral nerve cord	setae & parapodia in polychaetes	sandworms, fanworms, spagetti worms, earthworms leeches
ARTHROPODA	bilateral	3	complete	eucoelomate	yes (often with segment fusion into major body regions)	exoskeleton (chitin)	open	cerebral ganglion and ventral nerve cord	jointed appendages	barnacles, shrimps, crabs, spiders, insects, centipedes
ECHINODERMATA	pentamer-ously radial (modified from bilateral)	3	complete	eucoelomate	no	endoskele-ton (ossicles of calcium salts)	none, coelomic circulation important	circumoral and radial nerves	spatious coelom with tube feet & water vascular system	sea stars, brittle stars, sea lilies, sea urchins, sea cucmbers
CHORDATA	bilateral	3	complete	eucoelomate	yes, but internal as segmental muscles & skeleton	endoskele-ton (cartilage or bone)	closed	brain and dorsal hollow nerve cord	notochord, dorsal hollow nerve cord, tail past anus, pharyngeal gill slits	sea squirts, salps, vertebrates