ESTUARY-NET

A Water Quality Monitoring Project

Produced by:
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Contents

Water Quality Monitoring

Volunteer monitoring programs can include a variety of activities depending on their purpose and funding. For example, if the primary purpose of a monitoring program is public education, volunteers may focus on documenting point sources of pollution in a watershed, an activity that does not require very much equipment. Another group's purpose to collect scientific water quality data may necessitate a different level of funding and commitment.

The kinds of things volunteer monitoring programs can offer include:

1. **Baseline data -** by consistent monitoring of the same sites over time.
2. **Investigative sampling -** to locate sources of pollution by sampling areas found to be suspect and continuing sampling to pinpoint contamination.
3. **Shoreline survey work or watershed surveys** - to document potential and actual, direct and indirect sources of pollution.
4. **Resource inventory -** survey of flora and fauna of the area and surveys of benthic organisms.
5. **Scientific investigations** - testing a hypothesis.

Many different variables can be measured in a water quality monitoring program. A variable is any defined environmental factor or condition that changes over time and space. We will be measuring three different types of water quality variables: physical, chemical, and biological. Physical variables include temperature, tidal height, turbidity, and stream flow which describe the heat energy, movement of water within the estuary, and sediment transport. Chemical variables such as pH (acidity), salinity, and dissolved oxygen represent some of the most important elements and ions present in the waters of the estuaries. Biological variables, such as benthic macroinvertebrates, intertidal organisms, aquatic vegetation, bacteria, and chlorophyll concentrations are indicators of pollution, productivity in the estuaries and habitat quality.

There are complicated relationships between physical, chemical, and biological parameters in estuaries. By monitoring all three types of variables rather than one, we hope to paint a more complete picture of these poorly understood interactions. Understanding these relationships will facilitate management of our estuarine resources and upland watersheds to minimize disturbance that results from human activity. This section briefly describes the water quality variables that you can measure and why they are of interest.

PHYSICAL AND CHEMICAL VARIABLES:

A. Water Temperature

Knowledge of water temperature is important because temperature is a critical factor in determining where marine organisms live and how well they thrive there. For example, each species of phytoplankton has an optimal temperature for survival. Growth rates of estuarine plants and cold-blooded animals generally increase with temperature, up to the thermal optimum. Shifts in temperature cause variations in phytoplankton abundance and species composition.

Temperature also affects the solubility of oxygen in water. Dissolved oxygen is critical for the survival of aquatic organisms which use it in respiration (just as we do). As water temperature increases, the solubility of oxygen decreases.

For example, fresh sterile water at 0°C (32°F) can contain up to 14.6 mg of oxygen per liter of water, but at 20°C (68°F) it can hold a maximum of only 9.2 mg of oxygen per liter. [One milligram (mg) of a substance is equal to one-one thousandth of a gram. There are about 28 grams in an ounce.] Therefore, variations in temperature can drastically affect estuarine organisms.

B. Water Level

Water levels in the estuary vary primarily with the tide, but also with weather conditions, the amount of upland streamflow and runoff entering the rivers. Physical, chemical, and biological conditions within the estuary vary with water level. Changes in water volume in the channels and bays of the estuary change the concentration of dissolved and suspended materials in the water. During periods of high runoff due to storms, the amount of suspended sediment in the water tends to increase because of erosion in the watershed. Depending on the pollutant source, bacterial levels may also increase as runoff increases. Conversely, turbidity levels may increase during periods of low water volume because of the action of wind and waves on muddy bottom sediments at low tide.

C. Salinity

Salinity is generally defined as the total amount of dissolved solids in a volume of water. The salinity of seawater in the open ocean is remarkably constant at about 35 parts per thousand (ppt). Salinity in an estuary, however, varies according to location, tidal fluctuations, and the volume of freshwater runoff. Salinity levels in estuaries are generally highest near the mouth of a river where ocean water enters, and lowest upstream where freshwater flows in. However, actual salinities at specific locations in the estuaries vary through the tidal cycle. Overall salinity levels in the estuaries decline in the spring when snowmelt and rain produce elevated freshwater discharges from streams and groundwater.

Variations in salinity produce changes in species composition, distribution, and abundance in an estuary. Estuarine organisms have different tolerances and responses to salinity changes. For example, benthic (bottom-dwelling) organisms are able to tolerate changing salinities, but salinities outside an acceptable range will affect growth and reproduction.

Salinity is also important because it affects chemical conditions within the estuary, particularly dissolved oxygen levels. The amount of dissolved oxygen (solubility) decreases with increasing salinity. The solubility of oxygen in seawater is about 20 percent less than in freshwater of the same temperature.

D. pH

The pH of a solution is a measure of its acidity. The pH is defined as the negative logarithm of the hydrogen ion concentration in solution, and the pH scale ranges from 0 to 14. Distilled water is neutral and has a pH of 7. Solutions with a pH less than 7 are acidic, and those with pH greater than 7 are basic (alkaline). Because the scale is logarithmic, when the pH increases or decreases by a whole number, the acidity changes by a factor of 10. For example, a solution with a hydrogen ion concentration of 10^4 has a pH of 4 and is ten times more acidic than a solution with a pH of 5. Knowledge of pH is important because most aquatic organisms are adapted to live in pHs between 5.0 and 9.0.

The pH in an estuary will tend to remain fairly constant because the chemical components of seawater resist large changes in pH; dissolved carbonate minerals present in seawater tend to minimize or “buffer” pH changes by reacting with the ions that change pH. Biological activity, however, may significantly alter pH levels in an estuary. The process of photosynthesis removes carbon dioxide (CO^2) from the water. Since CO^2

becomes carbonic acid when dissolved, the removal of CO^2 results in a higher pH (i.e., reduced acidity). Therefore, as algal populations increase during the growing season, pH levels tend to rise. During large increases in the populations of planktonic algae (or “blooms”), pH levels may increase significantly. For example, a pH of 10 was reported during a 1983 algal bloom on the Potomac River estuary.

E. Dissolved Oxygen (DO)

Aerobic aquatic organisms such as zooplankton, invertebrates, and fish require sufficient levels of dissolved oxygen (DO) to survive. The amount of dissolved oxygen in the water is a factor in determining the species and abundance of organisms that can live in an estuary.

Oxygen is supplied to estuarine waters through two natural processes: a) diffusion of atmospheric oxygen into the water and b) photosynthesis by phytoplankton and aquatic macrophytes (seaweeds and seagrasses), which results in production of oxygen. Mixing of surface waters by wind and waves increases the rate of absorption of atmospheric oxygen into the water.

As mentioned earlier, dissolved oxygen levels are influenced by temperature and salinity. The solubility of oxygen, or its ability to dissolve in water, decreases with increasing temperature and salinity. Dissolved oxygen levels in an estuary vary seasonally, with the lowest levels occurring during the late summer months when temperatures climb to their highest levels of the year.

Oxygen is removed from the water by aerobic respiration and bacterial decomposition. Respiration is a process in which animals and plants take up oxygen from the water and produce carbon dioxide. Respiration occurs all the time, while photosynthetic production of oxygen by plants occurs only during daylight hours. As a result, dissolved oxygen levels in an estuary may vary widely because of differences in the amount of oxygen produced by plants.

Bacteria, fungi, and other organisms affect DO levels in an estuary because they consume oxygen while breaking down organic matter produced in the estuary or delivered from the uplands by streamflow and runoff. These decomposers consume oxygen in the process of gaining energy through the breaking of chemical bonds in organic matter.

Oxygen depletion may occur in an estuary when many plants die and decompose, or when runoff or poorly treated wastewater containing large amounts of organic matter enters the estuary. In some estuaries, large nutrient inputs, normally from sewage inputs, stimulate phytoplankton blooms. When these organisms die, their bodies fall to the bottom of the estuary and begin to decompose. The decomposition process depletes the surrounding water of oxygen and, in severe cases, may lead to anoxic (very low oxygen) conditions that kill bottom-dwelling organisms. Shallow, well-mixed estuaries are less susceptible to this phenomenon because wave action and circulation patterns can easily supply the deeper waters with oxygen.

F. Turbidity

Turbidity is a measure of the ability for light to transmit down through the water column. As suspended solids increase in the water, the amount of light travelling through the water column is reduced. This can influence the populations of organisms that are directly dependent upon light (phytoplankton and aquatic plants) and those, in turn that are dependent upon them as a food source. Suspended solids include particles of algae, sediment, detritus or solid waste. High levels of solids in the water can be indicators of problems from shoreline erosion, drainage ditches, or waste facilities. It is beneficial to look at turbidity and suspended solids in connection with other biotic and abiotic factors in order to get a better understanding of its causes and consequences. If total solids were tested for, they should be analyzed for the portion of suspended solids vs. dissolved solids. Since sunlight is the basic energy source for most life forms, the degree of turbidity of the water has an important effect.

Turbidity affects fish and other aquatic life by;

1. limiting photosynthetic processes and increasing respiration, oxygen use and the amount of carbon dioxide produced;
2. clogging of fish gills and feeding apparatus of bottom dwelling animals by suspended particles; and/or
3. obscuring vision of fish as they hunt food and smothering bottom-dwelling animals.

G. Stream Flow

In order to obtain a clear understanding of the functioning of an ecosystem, a picture of the water flow and a water body's pattern of circulation is vital. Many organisms depend upon set flow rates for some portion of their life cycle. The relationship between stream flow and sediment carrying capacity must also be understood as it is the principle force determining the development of gravel beds, mud flats or sand flats.

BIOLOGICAL MONITORING:

Biological monitoring is used for detecting the health of aquatic environments and assessing the relative severity of the pollution impacts. Once a problem is detected, testing is usually necessary to identify the cause, its source, and appropriate mitigation.

Biological monitoring is an effective way to determine water quality problems because:

1. biological communities reflect overall ecological integrity (i.e., chemical, physical, and biological integrity).
2. biological communities change in response to a wide variety of pollutants and to the cumulative impacts of those pollutants.
3. routine monitoring of biological communities can be relatively inexpensive, particularly when compared to the cost of assessing toxic pollutants.
4. the status of biological communities is of direct interest to the public as a measure of a pollution-free environment.
5. where criteria for specific impacts do not exist (e.g., non-point source impacts that degrade habitat), negative changes in the biological communities may be the only practical means of evaluation.

The bioassessment techniques presented in this document focus on the evaluation of water quality, habitat, and benthic macroinvertebrates, intertidal organisms, aquatic vegetation, chlorophyll/plankton, and fecal coliform bacteria.

A. Benthic Macroinvertebrates

Macroinvertebrate communities are good indicators of localized conditions because many benthic macroinvertebrates have limited migration patterns. They are particularly well suited for assessing site-specific impacts (upstream-downstream studies). Macroinvertebrate communities also integrate the effects of short-term environmental variations. Since most species have a complex life cycle of approximately one year or more, sensitive life stages will respond quickly to stress; the overall community will respond more slowly. Degraded conditions can often be detected by an experienced biologist with only a cursory examination of the macroinvertebrate community. Macroinvertebrates are relatively easy to identify by family. Many "intolerant" taxa can be identified to lower taxonomic levels with ease. Sampling is relatively easy, requires few people and inexpensive gear, and has no detrimental effect on the resident biota. Benthic macroinvertebrates are abundant in most streams. Many small streams (1st and 2nd order) which *naturally* support a diverse macroinvertebrate fauna, only support a limited fish fauna.

B. Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) includes all of the underwater plants that live throughout the estuary and near coastal waters. These plants grow only in those areas of the estuary that are shallow enough and clear enough to receive sufficient sunlight for photosynthesis. The salinity and temperature of a particular estuarine location determine, to a large extent, which species can survive. SAV supplies food for several types of waterfowl and small mammals. Like marsh grasses, SAV primarily provides huge quantities of decomposed matter (detritus) and as it dies, many aquatic species use it as a primary food source. SAV uses up excess nutrients that might contribute to eutrophication of an estuary, storing a summer pulse of nutrients for later release in the fall as detritus. SAV also provides habitat for organisms such as barnacles, bryozoans, and eggs of many species. SAV reduces erosion of shoreland zones by dampening the energy of incoming waves.

SAV requires specific physical and chemical conditions to remain vigorous. A healthy stand of SAV indicates a healthy estuary. The decline in the population density of SAV indicates change in ecosystem health.

C. Intertidal Organisms

Intertidal communities are good indicators of localized conditions. Many intertidal organisms have limited migration patterns or a sessile mode of life and are particularly well suited for assessing site-specific impacts. As well, sampling is relatively easy, requires few people and inexpensive gear, and has no detrimental effect on the resident biota. Many species of benthic worms and meiofauna can be used as a temporal indicator of the health of a habitat similarly to tolerant macroinvertebrate communities. As a result, changes in the density and richness of populations in an intertidal area can be used as an indication of ecosystem health.

D. Fecal Coliform Bacteria

Fecal coliform bacteria are a group of bacteria that normally reside in the intestinal tract of warm-blooded animals, including humans. They can enter an estuary in three ways: 1) direct discharge from animals, 2) runoff of waters carrying animal wastes, and 3) sewage discharged into the water.

Fecal coliforms themselves are used as an indicator of sewage pollution. The presence of fecal coliforms indicates the potential presence of pathogenic bacteria (e.g., *Shigella*, *Salmonella*, and *Vibrio*) and viruses such as the one that causes infectious hepatitis. Because the pathogenic organisms are scarce and therefore difficult to detect directly, it is easier to test for fecal coliforms and then assume that the pathogenic varieties are present whenever fecal coliform counts are high.

The acceptable level of fecal coliforms depends on the specified use of a waterbody. They are described in state water quality standards and in limits set by the United States Department of Agriculture through their shellfish sanitation program. In Maine coastal water less than 14 colonies per 100 ml is considered acceptable for harvesting shellfish, while 14 or more colonies per 100 ml is considered contaminated, requiring closure of the bed.

E. Chlorophyll

Aquatic plants can be divided into two categories: macrophytes and phytoplankton. Macrophytes are multicelled plants visible to the eye. This category includes both macroalgae (seaweeds) and flowering plants (eel grass). Phytoplankton (e.g., diatoms) are microscopic one-celled plants that float in abundant numbers in the water column, sometimes grouped in colonies. For example, a liter of seawater might contain one million diatoms. Phytoplankton are extremely important as the basis of the estuarine aquatic food web. They are eaten by zooplankton (microscopic animals) and small fish, which in turn are eaten by larger creatures. Consequently, the abundance of animals in an estuary often depends on the amount of primary productivity (conversion of light energy to plant biomass) taking place. Measuring the amount of chlorophyll (photosynthetic pigments) in the water gives us a useful index of phytoplankton density, and this reflects the amount of primary productivity occurring. Chlorophyll levels can be used to compare primary productivity within a single estuary or between two or more estuaries.

DATA MANAGEMENT:

In order for efforts of volunteers to be valued, the data they collect must be accurate, representative, homogenous and of sufficient duration. Accuracy requires a dataset to have been examined for wrong or missing data. When data is representative, it will reflect the overall conditions of a waterbody, not just an isolated variation. In order for data to be homogenous, it requires that during the entire period of its collection no external conditions changed such as damming, or channel constriction. Duration of a project is also very important to assure that a sufficient number of samples have been collected from which to derive a conclusion.

Quality of data improves with the implementation of a Quality Assurance Project Plan. The water quality monitoring data tables provide a column for identifying whether Quality Assurance/Quality Control measures have been followed when collecting the data.

A. Data Tables

The Estuary-Net curriculum provides activities using three principle types of datasets. A list of all datasets and a summary sheet for submitting and retrieving data are in Appendix XII - Data Management. In Level I, participating schools complete a "Hello" table to gather and analyze personal information about their classes. In later investigative activities, students use existing data tables to identify relationships between water quality monitoring variables.

In Level II, data is compiled regionally for all of the physical, chemical and biological variables. Students can analyze their own data and that of other schools in their region and nationwide.

B. Metadata

Each group participating in Estuary-Net will be required to submit metadata to their local National Estuarine Research Reserve prior to submitting data.

Metadata describes the data presented in a given dataset. It is data about data. Metadata provides information on the refinement of measurements, procedures used, site descriptions, duration of datasets, contacts and quality of the data. Examples of completed student metadata may be found at http://inlet.geol.sc.edu/estsites.html and research metadata may be viewed at http://inlet.geol.sc.edu/stanprod.html. The following descriptors must be included in each school's metadata.

I. Data Set and Research Descriptors

Principal investigators/contact person
Entry verification
Experimental design
Research methods
Site local and description

Date collection period
Associated organizations/researchers/projects

II. Data Table Descriptors

Variable sequence, column format, range of measurements, units
Variable accuracy
Codes for Variables
Data Anomalies
Missing Data
Other Comments

C. Standard Products

In order for the efforts of students and volunteers to be valuable, it is necessary for them to identify an audience for their data. When developing a Quality Assurance Project Plan this is a requirement. However, at any stage of sampling, the project is made more useful when the results are reported to a person or an organization. To best meet the needs of the audience, students should determine the most appropriate format and reporting frequency for their information. This then becomes their standard product. The result is a plan for regularly scheduled analysis of data, which is then usually presented in a graph form for easiest comprehension. For example, a school might decide that a graph of their temperature, salinity and dissolved oxygen saturation over time should be sent quarterly to their watershed coordinator at their regional National Estuarine Research Reserve.

QUALITY ASSURANCE AND QUALITY CONTROL:

Quality assurance (QA), quality control (QC) and standard operating procedures (SOP) are separate components of a monitoring program. They work together to provide data of known quality. Together they minimize and quantify the error that is introduced in sampling and allow the tracking of errors that might occur. QA/QC includes planning, assessment, reporting and making necessary changes to the water monitoring program to ensure quality data. The procedures defined in your Quality Assurance Project Plan (QAPP) will outline what is acceptable for your monitoring objectives. A QAPP may consist of as many as 25 different elements.

I. Project Organization

A. Identify by job titles those individuals using data

B. Identify Project Officers:
1. Project Director - reviews all work
2. WQM Specialist - oversees QA
3. Technicians - field and lab
4. Sampling Specialist - oversees field work
5. Lab Specialist - oversees lab work
6. Data Specialist - oversees data QC
7. Data Reviewer - analyzes data accuracy
8. Regional WQM Coordinator
9. State CZM contact

II. Problem Definition/Background

A. Describe original rational for project
B. Define problem

III. Project Description

A. Data quality objectives
B. Project narrative
C. Special training and certification
D. Documentation and record-keeping

IV. Sampling Process Design

A. Justify monitoring plan design
1. Justify sites
a. Site location - longitude & latitude
b. River mile
c. Data representativeness, comparability
d. Homogeneity of system
2. Access
3. Stream flow & depth
4. Tidal fluctuations
5. Weather variables
B. Schedule of milestones

V. Sampling Process Procedures Table

A. Parameter
B. Procedure
C. Container
D. Preservation
E. Sample number and location

VI. Sample Handling (chain of custody)

VII. Analytical Methods

A. Project objectives in numeric terms
B. Why is the project being done/what is data used for?
   1. Testing ecological hypothesis
   2. Verify permit compliance
   3. Supports permit issuance/revision
   4. Verify WQ standards
C. Detection levels
D. Reporting units
E. Levels of confidence
   1. Standard deviation
   2. % Bias
F. Comparability
   1. Consistent reporting units
   2. Standardized analytical methods
   3. Standard data format
G. Representativeness
   1. Degree data accurately and precisely represents water's characteristics

VIII. QC Requirements for Each Analysis

A. QC procedure
   1. Spike
   2. Split
   3. Replicate
   4. Blank
   5. Calibration check
B. Per cent of samples that are QC
   1. Project beginning 50%
   2. Maintenance of project 5% field samples/10% lab samples
C. Instrument calibration/frequency & maintenance
   1. All field equipment
   2. All lab equipment
   3. Monitoring calibration procedures
      a. Equipment log book

IX. Record Storage/Documentation

A. Procedures to safeguard data
B. Procedures to eliminate data transfer error

X. Evaluation/Assessment of Project

A. Performance - individual & organization
B. System Audit - adequacy people/equipment/procedures
C. Management system
D. Data quality - review by outside expert
E. Inspection - evaluation of performance
F. Corrective Actions
  1. ID problem
  2. Trace problem
  3. Implement change
  4. Document change
  5. Continue until problem solved

XI. Data Review/Validation/Verification

A. Checks for internal consistency
B. Checks for transmittal error
C. Checks for verification of lab work
  1. Interpretation by external resources
    a. Split samples analysis
    b. Duplicate sample analysis
    c. Spiked addition samples
    d. Instrument calibration
    e. Detection limits
    f. Intra-lab comparisons
    g. Tests for normality
    h. Tests for outliers
    i. Database entry checks
  2. Audits by external party
    a. Capable of monitoring
    b. Verify QAPP is done
    c. Identify any problems
  3. Data validity and verification methods
    a. Process
    b. Response to problems

XII. Data Reconciliation

A. Process to assure data meets requirements & objectives
B. Actions to correct invalid data

Adapted from *"Integrating Quality Assurance Into Tribal Water Programs"*, Chris Lehnertz, EPA Region 8

"Guidance for Preparation of Combined Work/Quality Assurance Project Plans for Environmental Monitoring" Office of Water Regulations and Standards, US EPA,
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"Rapid Bioassessement Protocols for Use in Streams and Rivers - *Benthic Macroinvertebrates and Fish*. US Environmental Protection Agency, Office of Water. May, 1989.
Clear Water: A Guide to Water Quality Monitoring. Esperanza Stancioff, University of Maine Cooperative Extension Service. University of Maine, Orono. November, 1992.

WQM GLOSSARY

Accuracy, also known as relative error or bias, is the degree of agreement between sampling results and the true value of the parameter being measured. The equipment and procedures used for measurement are most likely to influence the data accuracy.

Arithmetic Mean or Average should be calculated using at least three values, adding the values and dividing by the number of values.

Biased Sample occurs when all individuals within a population have not had a chance to be randomly chosen or sampled.

Blank Sample consists of a sample container that is filled with distilled or deionized water rather than water taken from the sample site.

Calibration Check is used to check equipment performance with laboratory prepared standard or in accordance with manufacturer's guidelines to ensure equipment is operating properly. A reference sample of known concentration is used to measure accuracy.

Comparability represents how well data from one monitoring program can be compared to those from another. Although not all sampling sites may be directly comparable due to differing climate, circulation, or salinity, similar sampling methods used between sites must be consistent in order to make comparisons, where appropriate, feasible.

Completeness is a measure of the number of samples intended to be taken compared to the number of samples actually taken expressed as a percentage. An 80-90 percent rate of collection is usually acceptable.

Data Quality Objectives (DQO) are the numerical goals that are set for a monitoring project. Based on the objective of the sampling, numbers are defined for the range of data quality that will be acceptable. DQO's reflect the accuracy, precision and completeness for each parameter that is measured.

Median is the value that divides the distribution into two halves (i.e. the middle score). There are an equal number of values on either side of the median.

Metadata are data documentation or "data about data". Metadata provide information about data sets, lineage of data sets, and information on processing, format, contacts, quality and other identified data set parameters.

Normal Distribution is a function where as *n* increases the values of binomial distribution (where *k* successes in *n* binomial trials each has a probability of *p* of success) approaches those of a continuous function which when graphed form a normal curve or bell-shaped curve.

% Bias is set for equipment based on each calibration. A sample of known concentration is measured four times to determine the bias. % bias = (average value - true value)/true value.

Outlier is an element in a set of numbers which is very different from most other elements

Precision assesses the similarity of several measures of the same parameter on the same sample regardless of the accuracy of these data points. Precision is also known as the **reliability** or **replicability** of a measurement.

Quality Assurance (QA) is the process which ensures that a monitoring program is adequately planned and conducted to provide data of the highest possible quality. QA addresses data collecting, sample handling, analysis and data review.

Quality Control (QC) is the set of steps taken during sample collection and analysis to ensure that data quality meets the minimum standards established by a QAPP.

Quality Assurance Project Plan (QAPP) is a written plan that outlines the procedures to be used for ensuring high-quality data when conducting sample collection and analysis for environmental monitoring.

Random Sampling is a way to take samples so that every member of the study population has an equal chance of being chosen.

Replicate Sample is obtained by collecting two or more samples from the same site with the same methods, one immediately after the other. Such samples are considered representative sub-samples of the same environment. Replicate samples are processed normally through the entire measurement system. The degree of difference between the results of the two samples will allow you to assess the variability caused by field sampling methods.

Representativeness is the expression of the degree to which data accurately and precisely represents a characteristic of a population, a parameter variation, a process condition, or an environmental condition. Sample site location or other potential errors such as the type of sample container and lab and data entry mistakes may all play a role in affecting representativeness of data.

Spike Sample is a sample that has a known amount and concentration of a constituent added to it. By introducing a known quantity into a regularly collected sample and determining the percent of material that is recovered in an analysis, an evaluation of measurement efficiency can be made. Samples can be spiked in the field or lab.

Split Sample is the results of taking one sample collected in accordance with SOP and splitting the sample into two bottles. The measurement of agreement between samples will represent the precision. A split sample may be split in either the field or the lab.

Standard Deviation is the square root of the variance, which is the average of the squared differences of each data value from the mean. To calculate the standard deviation, determine the mean of the data. Find the deviation (difference) of each value from the mean. Square each deviation and add the squares. Divide the sum of the squared deviation by n-1. This is the variance. Take the square root of the variance. This is the standard deviation. Standard deviation provides information on the variability in the results. A small standard deviation indicates little variability in the data, a large standard deviation indicates a large variability in the data.

Standard Operating Procedure (SOP) is a step-by-step description of the procedures that should be used for collecting samples and performing the analysis.

Variable is any defined environmental factor or condition that changes over time and space.

Water Quality Monitoring is the collection and analysis of water; organisms living in or adjacent to the water; or physical elements associated with water that seem to characterize the quality of the water.

Estuarine Ecology

WHAT IS ECOLOGY?

A. Introduction

Despite some popular misconceptions, ecologists don't spend their working hours communing with nature, lobbying for environmental causes, or collecting discarded soda bottles from littered landscapes. Ecologists are scientists who test hypotheses about the natural world. They use the scientific method to create carefully designed experiments and then rigorously analyze the data that is produced.

The fundamental goal of ecology is to understand the distribution and abundance of organisms. Toward this end, ecology explores relationships between organisms and **biotic** (living) factors or **abiotic** (non-living) factors in the environment. Ecological interactions range from the impact of predation (a biotic factor) on clam abundance to the effect of salinity (an abiotic factor) on where a species of marsh grass grows.

The sheer number, diversity, and complexity of abiotic and biotic factors makes understanding natural systems extremely challenging. That is, nevertheless, the goal of ecology.

B. What Do Ecologists Study?

Ecologists take many different approaches to their work, but they tend to focus on three levels of organization in the natural world: population, community, and ecosystem. A **population** is a group of individuals of the same species living in a given place. A **community** is comprised of populations of different species that live together. Ecologists studying populations or communities focus on how organisms affect each other, and how the environment affects them.

Ecosystem is a term even more inclusive than community, because it encompasses the community and its abiotic environment. Ecosystems can be extremely large or extremely small and, no matter the size, all ecosystems are connected. In this study we refer to an estuary as an ecosystem. When we speak of the river, marsh, and mudflat we are naming **habitats,** the places where organisms make their homes within the estuarine ecosystem.

A habitat is always considered from the point of view of an individual organism. An ecosystem, in contrast, refers to the flow of energy and nutrients through an ecological system. Both ecosystems and habitats have abiotic and biotic features.

ESTUARINE ECOLOGY:
A. An Introduction To Ecology Through Estuaries

From the largest landscape features to the smallest microscopic organisms, an estuary is a fascinating place. When viewing an estuary from the air, for example, one is awed by striking river bends as freshwater finds its way back to the sea, the vast expanse of marsh grasses or mudflats, extending out into the calm waters, or perhaps the elegant curve of an expansive barrier beach. Wherever there are estuaries, there is a unique beauty, as rivers meet the sea, and both ocean and land contribute to a unique ecosystem of specialized plants and animals.

At high tide, seawater changes estuaries, submerging the plants and flooding creeks, marshes, pannes, mudflats, or mangroves, until what once was land is now water. Throughout the tides, the days, and the years, an estuary is cradled between outreaching headlands and is buttressed on its vulnerable seaward side by fingers of sand or mud.

Estuaries change with the tides, the incoming waters seemingly bringing back to life organisms that have sought shelter from their temporary exposure to the non-aquatic world. As the tides ebb, organisms return to their protective postures, receding into sediments and adjusting to changing temperatures and exposure to differing degrees of sunlight and different kinds of weather.

Flocks of shorebirds stilt through the shallows, lunging long bills at their abundant prey of fish, worms, crabs or clams. Within the sediments, whether mud, silt, sand or rocks, live billions of microscopic bacteria, a lower level of the food web based largely on decaying plants. Estuaries are tidally-influenced ecological systems where rivers meet the sea and fresh water mixes with salt water. Estuaries provide:

HABITAT: Tens of thousands of birds, mammals, fish, and other wildlife depend on estuaries.

NURSERY: Many marine organisms, most commercially valuable fish species included, depend on estuaries at some point during their development.

PRODUCTIVITY: A healthy, untended estuary produces from four to ten times the weight of organic matter produced by a cultivated corn field the same size.

WATER FILTRATION: Water draining off the uplands carries a load of sediments and nutrients. As the water flows through salt marsh peat and the dense mesh of marsh grass blades, much of the sediment and nutrient load is filtered out. This filtration process creates cleaner and clearer water.

FLOOD CONTROL: Porous, resilient salt marsh soils and grasses absorb floodwaters and dissipate storm surges. Salt marsh dominated estuaries provide natural buffers between the land and the ocean. They protect upland organisms as well as billions of dollars of human real estate.

Estuaries are crucial transition zones between land and water that provide an environment for lessons in biology, geology, chemistry, physics, history, and social issues.

B. Geological Formation Of Estuaries

There are four types of estuaries: **coastal plain estuaries,** which formed as rising sea level invaded existing river valleys; **fjords,** which are steep-walled valleys created by glaciers; **tectonic estuaries**, which are formed when geologic faulting or folding resulted in a depression and; **bar-built estuaries,** which are separated from the ocean by barrier beaches lying parallel to the coastline.

FACTORS AND PROCESSES:

The survival of organisms is influenced by living (biotic) and non-living (abiotic) factors. Any of a number of factors can be responsible for the inability of a species to survive in a particular place, unless the species is able to respond through physical or behavioral change.

A. Abiotic Factors

Abiotic factors limit distribution and abundance by affecting an organism's life processes. In an estuarine ecosystem these factors are light, oxygen, water, nutrients, temperature, salinity, and space.

LIGHT: Plants use energy in sunlight to convert water and carbon dioxide into carbohydrates and oxygen. This is accomplished through a series of chemical reactions called **photosynthesis**.

OXYGEN: Oxygen is used in **respiration**. Respiration releases stored chemical energy to power an organism's life processes. An absence of oxygen severely restricts the amount of life that can be supported.

WATER: Without water, no organism can remain biologically active. In fact, all living organisms are comprised of 50 to 99 percent water.

NUTRIENTS: Although sunlight is the fuel for food production, and water and carbon dioxide are the raw materials, plants cannot survive on these alone. Other substances, called nutrients, are necessary for the proper function of a living organism. Major nutrients, including nitrogen and phosphorous, are needed in large amounts. Trace nutrients, such as iron, are required in smaller amounts.

TEMPERATURE: Temperature is one of the best-understood abiotic factors affecting the distribution and abundance of organisms. Temperature has a large impact on plants and animals because it influences their metabolic rates and affects rates of growth and reproduction. Geographic ranges of animals are often defined by temperature, and many species respond to seasonal temperature shifts by acclimatizing to changes or by migrating away from them.

SALINITY: Pure water contains only oxygen and hydrogen, but in the natural world, solid substances such as salt are often dissolved in water. In an estuary, the salt content of water fluctuates continuously over the tidal cycle. It decreases drastically in the upper reaches of estuarine rivers where tidal influence lessens, and varies radically in salt pannes because of evaporation and precipitation. Organisms that spend their entire lives in estuaries need to be capable of responding to large, rapid salinity variations.

SPACE: Space is a precious resource exploited by living things. The need for space is most pronounced for organisms that need a **substrate**, or base, on which to live. Many animals require a certain amount and type of space to meet their needs, other than simple physical attachment. They need space for nesting, gathering food, wintering, and hiding from predators.

B. Biotic Factors

In addition to abiotic factors, a complicated web of biotic factors controls the abundance and distribution of organisms. Biotic factors are interactions among living things that affect the survival of species.

COMPETITION: Competition occurs between organisms using a resource that is in finite supply. Competition can occur between members of different species or the same species. They may compete for food, space, light, nutrients, water, or even pollinators. Competition plays an important role in shaping communities. Species or individuals with a competitive edge have a better chance of surviving long enough to reproduce.

PREDATION: Predation is the killing and/or consumption of one organism by another. **Herbivores** eat plants, seeds, and/or fruits. **Carnivores** eat animals. **Omnivores** eat both plants and animals. Predation is a major selective force in animal evolution. Individuals are more likely to reproduce successfully if they have traits enabling them to avoid being consumed by predators.

PARASITISM: Parasitism is similar to predation in that one species benefits from the relationship and the other is harmed. Parasitism differs from predation, however, because parasitism is generally not fatal to the adversely affected organism.

COMMENSALISM: Commensal relationships occur when one organism benefits and the other is neither helped nor harmed.

MUTUALISM: Mutualism occurs when both organisms gain from the relationship.

INTERACTIONS IN ECOSYSTEMS:

A. Disturbance

Ecologists have recently begun to investigate the natural variability of ecosystems by exploring the impacts of disturbance. Ecological disturbances range in scale from something as small and transient as a footstep to an event as huge and prolonged as a hurricane, volcanic eruption, or glaciation. One outcome of disturbance is **succession**, progressive changes in the composition of a community. Salt marshes provide a good illustration of the role of disturbance in shaping communities. Although disturbance is a natural factor in every ecosystem, humans create additional ones. These are called **anthropogenic** disturbances.

B. Responses And Adaptations

During its lifetime, every organism encounters changes in its environment. These changes can be abiotic (amount of water, salt, light, etc.) or biotic (variations in competition, predation, parasitism, etc.). Ecological **responses** happen during the lifetime of a single organism. An example is the ability of a chickadee to grow about 50% more feathers in winter and molt them in summer. Evolutionary **adaptation** happens over the course of multiple individuals' lifetimes and causes changes to occur in a species' genetic makeup. This process is called **natural selection**. **Speciation**, the creation of a new species through natural selection, occurs when a selective force is intense. It accounts for the diversity of living things on the planet today. Genetic variation within a species can result in adaptation to local conditions.

C. Zonation

Patterns of zonation can be found in many different communities. They are created by combinations of abiotic and biotic factors. A salt marsh is an excellent ecosystem to illustrate how ecologists relate biotic and abiotic factors to the organization of living things. As one walks from upland to water through a salt marsh, **zones**, or distinct bands of vegetation can be seen. High marsh is noted by the dominant grass, usually salt hay, which lies like cowlicks from their periodic tidal baths. At a slightly lower elevation in the marsh, smooth cordgrass is found. Its broad leaves are dappled daily with mud and salt from the tides.

D. Habitat

A habitat is a place where an organism can successfully live. Every species has a set of abiotic and biotic conditions and resources that it needs in order to survive, and there are certain places in the world that meet those requirements. These places are habitats for particular species. Habitat requirements of an organism can be divided into two categories: resources and conditions. **Resources** are items such as the food and water that an organism uses during its lifetime. **Conditions** are characteristics of the environment (such as temperature and salinity) that influence the survival of an organism but are not used by it. Resources and conditions both determine the suitability of a location for the survival of a species.

E. Niche

Different species coexisting in a community can avoid competition through specialized adaptations, so that each species has a unique role in the community. These roles, called **niches**, can be defined in many ways, but all of them involve using limited resources in a unique way. The concept of the niche is most evident in the way that closely related species differ in their use of space, time, and food. For example, great blue herons and snowy egrets are very similar birds who, at first glance, seem to have overlapping ecological requirements. They are both found in similar coastal habitats. Their diets are very similar, but they have evolved different nesting requirements. The great blue heron nests inland in trees and the snowy egret nests on coastal islands in scrubby-growth trees and shrubs.

Niches, important in the organization of communities, can be broken down into broad niches and further into smaller, more specific, niches. For example, spatial niches allow organisms that eat leaves from the tops of trees to coexist with those that eat from lower branches on the same tree. The niche concept is a useful generalization, but in the real world species are constantly invading new places as environmental changes and other factors affect them.

F. Food Chains And Food Webs

Energy is the most crucial resource needed by living things. **Producers** or **autotrophs** (meaning self-feeders), such as plants and some bacteria, are able to obtain energy from the sun and use it to form energy-rich material. **Consumers** or **heterotrophs** (meaning "feeding on others") are organisms, mostly animals, which obtain energy-rich materials by eating autotrophs. This relationship determines how energy flows through a community. The pattern of energy flow, in which an autotroph produces food, a heterotroph eats that autotroph, another heterotroph eats that heterotroph, and so on, is called a **food chain**. In a natural community, however, food chains are not simple, independent units. They are linked together into complex food webs because every species is usually eaten by more than one species of predator, and every predator usually eats more than one type of prey.

G. Watershed

A **watershed** is an area of land that drains into one river, stream, or other body of water. The watershed of an estuary contains the watershed of the river or rivers that flow into it, which may cover tens, hundreds, or thousands of square miles. It is analogous to a bowl. If you drip water onto any spot inside the rim of a bowl, it flows down to the bottom. If you drip the water outside the rim, it does not flow into the bowl. The area contained within the bowl is the watershed. **Runoff**, **groundwater**, or **surface water** feeds watersheds. As water travels through the watershed, it may transport nutrients, sediments, or harmful pollutants.

H. Tides

Within estuaries, the incidence of tides results in highly variable and constantly fluctuating salinity, currents, and water levels. These drastic variations make estuaries extremely harsh and demanding places to live. The position of the moon, sun, and earth, and the configuration of the land all affect **tidal height**, the height above mean sea level to which the tide rises, and **tidal range**, the difference in height between high and low tides. Tidal height and range, in turn, influence the inhabitants of an estuarine ecosystem.

I. Salinity

The number of grams of dissolved salts in 1000 grams of water measures salinity. The most abundant salt in seawater is sodium chloride, which we know best as table salt. The primary classes of salinity are fresh water (0-0.5 parts per thousand - ppt), brackish water (0.5-30 ppt) and salt water (more than 30 ppt).

In all estuaries, salinity varies with proximity to the ocean, and with depth at any given spot along the river. When salt water and fresh water meet, the fresh water, due to its lower density, often floats on top of the salt water.

Salinity also varies with elevation in the marsh. Those areas with higher elevation are flooded less frequently and have less soil salinity than lower areas. Thus plant species with salt intolerance are in areas not subject to frequent tidal flooding, or up-river where they may be exposed to more frequent flooding but the waters are less saline.

ESTUARINE HABITATS AND COMMUNITIES:

The estuarine ecosystem has several different habitats: river, tidal flat, marsh, and salt panne. A river may be the lifeblood of an estuary. As a river approaches the sea, it is influenced by salty tides. During low tide, portions of the river bottom, or benthic zone, are exposed. These mudflats and sandflats support abundant life. The high and low salt marsh are dotted with salt pannes, irregularly shaped and sized pools of water that play an important role in the ecology of the marsh. Each of these estuarine habitats has a unique community associated with it, but all the habitats and communities are interconnected.

A. The River Community

1. Salinity

Scientists classify aquatic systems according to salinity because different biotas, or assemblages of living things, are associated with different levels of salinity. In all estuaries, salinity increases toward the ocean, but it can also vary with depth at any given spot along the river. Salt water, which contains dissolved solids, is more dense than fresh water. Thus, when salt water and fresh water meet, as in an estuary, the freshwater often floats on top of the salt water forming a "salt wedge." Many smaller rivers, however, do not exhibit the wedge effect because their narrowness, shallowness, or sudden turns create turbulence, which mixes the salt and fresh water.

2. Detritus

The riverine food web differs from that of many other ecosystems in that plants are more often eaten dead than alive. Most marsh plants die without being eaten, and their decaying remains become the major component of the organic materials that comprise detritus. As a river floods its banks at high tide, it picks up these small particles of decaying plants and animals, which then remain suspended in the water column to provide the basic nutrients for the estuarine food web.

3. Aquatic Organisms

Aquatic organisms, plants and animals living in water, can be divided into two general groups: nekton and plankton. **Nekton** are all aquatic animals that can swim through the water against currents, such as marine mammals, fish, squid, and some crustaceans. **Plankton**, on the other hand, are all water-borne organisms that cannot swim through the water column, but are transported from place to place by currents.

Plankton is some of the most abundant organisms on earth. Coastal waters receive nutrients from in-flowing rivers and regions of upwelling in the ocean where current patterns cause nutrient-rich water to surface. Plankton can be divided into two groups: **phytoplankton**, which are plants; and **zooplankton**, which are animals.

If we imagine the river to be a field, then phytoplankton are the grass and some types of zooplankton are the sheep. These "sheep" zooplankton are herbivores, while others are carnivores that eat other zooplankton. **Copepods** (a type of crustacean) are one of the most common herbivorous zooplankton. **Cladocera** are carnivores that eat other zooplankton. **Jellyfish** are one of the more familiar types of carnivorous zooplankton.

In the aquatic estuarine food web, **fish** and marine mammals occupy most of the trophic levels above plankton. Larger fish visit the estuary to feed or spawn. Marine mammals, such as seals and otters, often feed upon these fish. Seals use haul-outs, areas where they go to rest, in marshes or on rocks.

4. Birds And Mammals

Diving and wading birds play a large role in the aquatic estuarine food web. Aquatic birds often dive in search of mollusks and other bottom-dwelling animals, while others feed on shallow-bottom vegetation. Estuarine fish are preyed upon by some diving birds. Wading birds have long, stilt-like legs that permit them to venture into tidal inlets to hunt for fish.

B. The Intertidal Zone: Mudflats And Sandflats

In an estuary that has a river draining into it, that river will often have a bottom that shifts and squishes. Walking across it, your feet slide on the sand or sink deeply into the muck. Along the river’s length are patches of silt, sand, mud, or maybe cobbles. These sediments were eroded from the uplands or washed in from the sea. They are constantly reworked into new bars and channels in the river bed.

There’s no mistaking low tide in an estuary. Your nose will alert you as soon as it senses the rotting plant smell of intertidal **mudflats**, **sandflats**, and exposed marsh. At first glance, an exposed mudflat may appear barren and devoid of life. But take a closer look, and you’ll see innumerable holes, trails, and shells, evidence of all the burrowing animals that inhabit the flats.

Mudflats are unusual in that they have two layers in which primary productivity occurs. The first layer is at the surface where diatoms and seaweed receive the light needed to power photosynthetic reactions. The second layer of primary productivity lies beneath the surface where bacteria live in the **anoxic** (without oxygen) sediments. Some of these bacteria are capable of chemosynthesis, a process equivalent to photosynthesis in that it produces organic matter, but different in that it requires certain chemical compounds instead of light.

1. Benthic Lifestyles

Benthic (bottom-dwelling) flora and fauna range in size from the tiniest bacteria to medium-sized worms to the highly visible clams and polychaete worms. Some benthic organisms live in the sediment and are called **infauna**, some are affixed to the surface of the sediment and are referred to as **epibenthos**, and some move around on the surface of the sediments and are called **mobile epibenthos**. Benthic animals display a variety of feeding mechanisms: 1) deposit feeders ingest sediments, digesting the nutritious components; 2) suspension feeders filter food out of the water column; 3) predators feed upon live organisms; and 4) scavengers feed upon dead ones.

Suspension-feeding bivalves, such as clams, and sediment-feeding polychaete worms are examples of infauna. Suspension-feeding mussels and oysters are examples of epibenthos. Scavenger crabs; herbivorous, predatory and deposit-feeding snails; and a wide variety of amphipods and isopods are examples of mobile epibenthos.

2. Birds

Birds have a large impact on the benthic community. Many birds feed on bottom-dwelling creatures, especially the abundant organisms of the mudflat. To minimize competition for this resource, shorebirds have evolved variable feeding strategies, thus filling **niches**, or unique roles, in the community. For instance, they feed in different water depths depending on the lengths of their bills and legs. Birds with long bills and legs, such as herons and egrets, tend to feed in deeper water than those with shorter bills and legs.

C. The Marsh

Marsh Zonation

Salt marshes are a common type of wetland of extreme importance to the balance of certain estuarine ecosystems. Marshes are dominated by important grasses that provide food and shelter to the marine organisms that are permanent and transient residents of the estuary. Marshes are divided into two basic zones: **high marsh** and **low marsh**, which are defined by differences in flooding and soil salinity. Marshes usually have different bands of vegetation, creating high and low zones within the marsh.

Despite its varied and lush vegetation, the marsh is home to relatively few terrestrial animals. Deer, migratory birds, grasshoppers and other animals consume marsh grasses. Small animals, such as shrews and mice provide prey for larger mammals and birds of prey that also live in or around the marsh.

Marsh grasses are thought to be low in nutritive value and to contain toxic compounds; so even with all of these consumers, little of the vegetation is eaten. Rather, most of the plants die and are deposited on the ground to become peat. Some pieces of the plants are then washed into the water to become detritus, decaying particles coated with bacteria, which serve as a nutrient base for the estuarine food web. Detritus is consumed by filter-feeders such as clams, detritivores such as mummichogs, and deposit feeders such as polychaete worms. In general, estuaries are known as hosts for abundant aquatic and avian, rather than terrestrial, animals.

D. Salt Pannes

1. Formation

Salt pannes, pools of water that dot the marsh surface, are an important feature of some estuaries. Pannes range in size from only a foot or two in diameter to many feet across and they are irregularly shaped and sized. Panne creation is believed to begin when something kills an area of grass, either wintertime ice floes, which scour patches of vegetation from the marsh surface, or mats of debris that shield the plants from sunlight. What's left behind is an area of unvegetated peat exposed to the sun, which evaporates water from the soil. This area becomes extremely saline and inhospitable to recolonization by plants. The peat subsides and a water-filled depression, or panne, is formed.

2. Plants And Animals

Glasswort and spike grass are two species of plants that have adapted to the inhospitable conditions of bare patches in the marsh. Glasswort readily tolerates higher soil salinities. Spike grass avoids the salt and dryness by receiving water through underground runners from individual plants living outside the bare patch. When glasswort and spike grass colonize a bare patch, they shade the soil, reducing evaporation and salinity. Other plants - generally cordgrass, *Spartina alterniflora,* or salt hay, *Spartina patens* - can then invade, preventing panne formation.

Pannes are flooded with salt water at varying frequencies, depending on their elevation in the marsh above mean sea level and whether they are connected to the river by creeks. If a panne experiences a long period without receiving rain or seawater, the panne can become extremely saline, warm, and low in dissolved oxygen because of evaporation and heating by the sun. This would seemingly make difficult living conditions, but mummichogs, sticklebacks and eels are well adapted to them. Salt pannes also support large populations of algae. These plants and animals, in turn, provide food for diving and wading birds.

E. Around The Estuary: Open Waters, Coastlines And Uplands

An estuary is a semi-enclosed waterbody appreciably diluted by fresh water flowing into it. An estuary usually ends at the mouth of the river. The ocean is not part of an estuary. Rocky shorelines, barrier beaches, uplands and other surrounding areas all have great influence on the estuarine ecosystem. Uplands, which form the upper end of an estuarine watershed, have a great influence on its health. It is important to understand the ecosystems that surround the estuary, as well as the estuarine ecosystem itself, as they are closely associated with the health and productivity of the estuaries.

1. Open Water

Interactions between open waters and estuaries that line the coast occur during the exchange of tidal waters. This periodic flushing affects salinity, transports nutrients in and out, and varies the water level in the estuary. Biological interactions occur when estuarine species venture out into open waters to feed or spawn. Many open water organisms, conversely, enter estuaries for the same reasons, and the larvae of these species depend on estuaries as nurseries. When estuaries are degraded by human influences such as pollution and development, the survival of numerous open water species, including many commercial fish species, are affected.

2. Barrier Beaches

Barrier beaches play an important role in the creation and survival of some estuaries. By breaking the impact of ocean waves, they protect the estuary and uplands from waves and erosion, facilitating marsh formation and making the estuary a calm haven for animals.

A string of barrier beaches lines much of the Atlantic coast of the United States. These unique features are ribbons of sand that lie a short distance offshore, often separated from land by marsh-filled estuaries. They may be attached to the mainland at one or more points, or they may be islands.

Barrier beaches are constantly moved landward by the rising sea. Powerful waves and currents persistently rework the sands. As sea level rises, barrier islands and river inlets migrate and are continually reshaped. People are often distressed when this happens because it can mean the destruction of expensive oceanfront real estate. They attempt to counteract it by constructing elaborate seawalls and jetties. Their efforts are inevitably futile however, and often create more severe erosion by redirecting wave energy. Erosion and deposition of barrier beaches is a very powerful, fundamental part of the natural system.

The lower section, which is alternately submerged and exposed by the tides, is called the intertidal zone. Organisms of the rocky coast are stratified into zones that reflect species' adaptations to abiotic and biotic factors.

Barriers are unique habitats that support interesting communities of organisms. These communities are found in a pattern of zonation that reflects the decreasing disturbance of habitat occurring with increased distance from the ocean. The **foreshore**, or beach face, is the harshest part of the habitat. The dominant abiotic factors are wave action and a moving substrate, sand. In order to live on the beach, organisms must be able to tolerate these conditions.

Animals surviving in the **swash zone**, the intertidal zone between high and low tide, are adapted to either burrow deep into the sand or quickly re-burrow after being exposed by a wave. Higher on the beach lies the wrack line of seaweed, wood and shells cast ashore by waves. **Isopods** and **amphipods** (small crustaceans) may occupy this region, taking advantage of the food and shade offered by the wrack line. Behind the front line of **pioneer species** plants of high salt tolerance that first colonize an area, usually lies the frontal dune and dune-building species. These plants build dunes by breaking the flow of wind, so that sand is deposited on the ground around them. These species are adapted to sand accumulation.

Beach grass reproduces by sending out horizontal underground runners called rhizomes. Every few inches along the rhizome, a shoot extends up to the surface. Dune vegetation has additional adaptations to reduce the influence of windblown sand, high temperatures, and dry soil. Some plants are coated with small hairs that decrease evaporative water loss by reducing air motion next to the plant's leaves. One kind of beach grass, American beach grass, has rolled leaves which reduce surface area so as to prevent water loss.

Behind the primary dunes, on a barrier beach, are the **back dunes**, which build from the movement of sand transported over the frontal dunes during storms. These more protected areas are inhabited by pioneer plant species and, if left undisturbed, many of the frontal dune plants can thrive there. If the barrier island is wide enough, a maritime forest may lie behind the back dunes. Only the fiercest storms harm these woodlands, stunting the trees when the salt spray kills their buds and leaves and salt water permeates the sand around their roots.

3. Rocky Shore

The difference between a rocky shore and a sandy shore could not be more dramatic. Sand shifts when washed by waves, but rocks undergo limited shifting. Animals can burrow into sand, but rock is impermeable. The most important abiotic factors on a rocky coast are the pounding by waves, availability of space for attachment, and vulnerability of organisms to **desiccation** (drying out), overheating, and freezing.

Like other coastal habitats, rocky shores are influenced by tides, which create zones within the habitat. The wettest section of rock is the **sublittoral zone,** which is always submerged. Above this is the **littoral zone,** which is divided into two parts. The higher part is never submerged but does get splashed and is called the **spray zone**. The lower section, which is alternately submerged and exposed by the tides, is called the **intertidal zone**. Organisms of the rocky coast are stratified into zones that reflect species' adaptations to abiotic and biotic factors.

4. Mangroves

Another kind of shoreline within the Gulf runs along the southern coast of Florida, defined by thick masses of uniquely adapted vegetation. Here, we find mangrove roots creating an intricate tangle of roots, stems and leaves, not quite land, but nevertheless the edge to the sea. Mangrove shorelines are radically different from rocky cliffs and sandy beaches found elsewhere along the coast of the United states. These fascinating plants are well adjusted to life in salt water, with specialized roots, called prop and drop roots, that bring fresh water and oxygen to the plants through roots either submerged in anoxic mud or under saline waters. Mangroves are not a single species, but rather a collective of different plant species, all similarly adapted to the tropical region and its specific challenges.

A mangrove shoreline is a tropical salt marsh of sorts, providing a productive coastal habitat where juvenile fish seek safety before reaching maturity and where a great number of other marine organisms make their homes. Mangroves also serve as valuable shields against the violent storms that frequent the region. The intricate conglomeration of mangrove roots helps to filter out pollutants flowing into coastal waters, and to prevent excessive erosion, through the stabilization of sediments. Amazingly, mangroves actually replenish and build land mass, stabilizing mud and other sediment that would otherwise have been lost into the water through sedimentation.

5. Uplands

Uplands lie above the reaches of the highest tides. The ocean has no direct effect here, except perhaps through flooding or wind-blown salt from occasional severe storms. Firm, relatively dry soils support trees, shrubs, and herbs, which in turn provide shelter and food for animals. Uplands are not part of the estuary, but they do influence it. Groundwater and runoff water flow through and over upland soils before reaching the estuary. Pesticides, fertilizers, and pollutants in the uplands are eventually transported to the estuary. Upland animals often venture out into the estuary to feed, an example of habitat interconnection.

The uplands are physically much more stable than the marsh, and there is more variety in the landscape. Consequently, more species are able to survive there. Upland habitats provide homes for a diversity of organisms.

PEOPLE AND ESTUARIES:

A. Human History Of Our Estuaries

Native Americans were the first human inhabitants of most estuarine habitats across the United States. Use by Native Americans produced few adverse impacts. These bountiful areas provided a valuable source of food, both from the estuarine waters and the surrounding terrestrial areas. The Native American hunting and fishing life style harmonized with the natural world, as they took from and gave to the earth within the boundaries of a sustainable cycle.

With the arrival of Europeans, however, new concepts of private land ownership and widespread clearing for construction and agriculture posed serious threats to estuaries. Estuaries became a focal point for activity. Farms often used salt hay from marshes as fodder for their livestock. Ditches, dams and tide gates became frequently used tools to limit tidal action and develop vast areas of fresh pasture. Controlling mosquito populations that bred in the swampy tidal estuaries led to the widespread drainage of many estuarine areas. By the middle of this century, fifty percent of all Atlantic Coast estuaries had been altered in some way by human activities.

A changing view of estuaries began to emerge in the late 1960s, however. Declines in important fish stocks and a new suspicion of the impacts from pollutants in the environment, created a need to better understand not only estuarine ecosystems, but ecosystems and ecology in general. This new concern marked the beginning of a nationwide environmental movement that continues to this day.

Since the 1960s, a large number of federal, state and private programs have responded to this concern with laws that dictate the more responsible use of estuarine areas. These same groups have assisted in the funding of an increasing number of studies, so that the dynamics of estuaries and their influences on both marine and terrestrial resources may be better understood.

In 1972, the United States Congress passed the Coastal Zone Management Act, which included the establishment of a system of National Estuarine Research Reserves. The many NERRS sites around the United States exemplify the research and educational benefits possible with private, business and government support.

B. Today's Impact

Although positive measures have been taken to reduce human impacts on these coastal areas, limiting development and use within specific areas, estuarine ecosystems continue to be affected by less noticeable, yet highly detrimental problems of pollution. Pollution is a widespread and largely invisible problem in estuaries. Human-made debris, particularly plastics, can adversely affect marine and estuarine environments. Often people become extremely concerned about such litter, without considering other types of pollution even more dangerous to marine and estuarine life. Such marine litter as **coliform bacteria**, excess nutrients from **fertilizers, heavy metals, chlorine, petroleum derivatives, biocides** (pesticides and herbicides), **synthetic compounds, sediments** and **temperature** changes caused by discharge of cooling water from power plants.

Pollutants are introduced into estuaries from either **point sources** or **non-point sources**. Point sources are clearly defined, localized inputs, such as pipes, industrial plants, sewer systems, oil spills from tankers and aquaculture ventures. Federal and state governments regulate them. Non-point sources are indistinct inputs that do not have a clearly defined source, such as runoff of petroleum products from roadways or pesticides from farmland. They are harder to detect and control. Government efforts to deter these polluters are challenged by their sheer number. Pollution can be reduced through individual or collective efforts to avoid or eliminate environmentally insensitive practices.

SUMMARY:

Once we acquire a basic appreciation of our natural world, ecology provides a framework to deepen our understanding of natural systems. That understanding, in turn, reinforces our initial appreciation of nature. Ecological processes are dynamic, shaping the living world around us. We can use the concepts of ecology to make sense of things we see and experience, while we retain the sense of wonder that the natural world provokes in us.

The concepts of ecology are just as important in understanding our backyards as they are in explaining tropical rainforests, New England salt marshes, and mangrove swamps. Ecology is directly relevant to every human life and should be an essential element of our lifelong education.

Ecology is the only science with a fully integrated world view of life on earth. If students are to understand ecology they must draw from diverse fields of knowledge and discover relationships that unify fundamental ideas. For an educator, there could be no better vehicle than ecology for developing a student's understanding of these essential concepts.

Estuaries provide a spectacular setting in which to study ecology. The importance of estuaries in the natural world as habitats, nurseries, water purifiers, flood controls and extraordinarily productive ecosystems, is without question. No matter where we live, we all have personal connections to estuaries and can use our understanding of ecology to help protect them.

Reference Sections

SECTION A:

Abiotic Factors

LIGHT:

Photosynthesis - Plants use the energy in sunlight to convert water and carbon dioxide into carbohydrates and oxygen. This is accomplished through a series of chemical reactions called photosynthesis. In order to photosynthesize, an organism must have a pigment called chlorophyll. The carbohydrate products of photosynthesis provide food (energy) for the plant, as well as for the animals that feed on it. Photosynthesizers, therefore, are essentially food factories powered by sunlight. Without the proper amount of light, they die. Light is consequently an important factor in determining the abundance and distribution of photosynthesizers.

In estuarine waters and other aquatic systems, the most important photosynthesizers are microscopic floating plants called phytoplankton. Since particles of sediment and debris floating in the water, and even the water itself, block the passage of light, the availability of light decreases with depth. As a result, phytoplankton are only found near the surface of the water. The maximum depth at which they can live varies depending on how deep the light can penetrate.

One might expect that the maximum amount of phytoplankton would be found right at the surface, where sunlight is most plentiful, but this is not the case. Sunlight contains damaging ultraviolet (UV) light. Most of the UV light, however, is filtered out by the water very close to the surface, so phytoplankton live most successfully a short distance below, where they still receive plenty of non-UV light.

OXYGEN:

Respiration - Respiration is the opposite reaction of photosynthesis. Rather than creating energy-rich compounds, respiration breaks them down releasing chemical energy to power the organism's life processes. Oxygen must be present for respiration to occur successfully in many organisms. A lack of oxygen restricts the amount of life that can be supported.

In estuarine mudflats, the sediment particles are so fine and compacted that there are no crevices for the oxygen-laden water. This contrasts strongly with dry terrestrial soils, which are relatively permeable to oxygen-rich air. The result is that only the top few inches of the mudflat have enough oxygen to support life. Below that, the mud is black and anoxic (lacking oxygen) and the most abundant organisms living there are bacteria, which are capable of surviving in low oxygen conditions.

Marsh Plant Adaptation to Anoxia - Anoxia is a problem for grasses that live in a salt marsh. The aboveground part of a plant can get the oxygen it needs for respiration from the surrounding air. But root cells also need to respire, and they are trapped in soil, called peat, that is frequently saturated with water by the tides. In the uplands, oxygen reaches plant roots by diffusing through the tiny crevices between soil particles. Since peat crevices are filled with water, airborne oxygen is prevented from reaching the roots. Water does contain some dissolved oxygen, but it is much less oxygen-rich than air. This often leads to anoxia in the peat.

Marsh plants have adapted to survive in these conditions. Smooth cordgrass (*Spartina alterniflora*) and salt hay (*Spartina patens*), for example, respond by developing tiny tubular spaces that run from the roots up through the leaves, where they are open to the air. These spaces allow oxygen to diffuse down to the roots.

Absorption of Oxygen by Animals - Animals need oxygen for respiration and obtain it through a number of different adaptations. The key is to have enough surface area permitting contact between blood vessels and air. Aquatic animals such as fish, starfish, and squids have gills to obtain oxygen from water, while many land animals have lungs to obtain oxygen from air. Gills and lungs perform the same function; both allow oxygen to come in contact with blood flowing through a huge number of tiny blood vessels in thin membranes exposed to the outside medium (water or air). The reason lungs are contained inside the body and gills are not is that the oxygen/blood-vessel interfaces must be moist. If the interfaces were exposed to air, the organism would lose much water through evaporation. Containment of the interfaces within the body limits water-loss. This is not a danger for organisms with gills because they live in a liquid environment.

Some animals do not use gills or lungs to acquire oxygen. Small tubes, called tracheae, permeate the bodies of insects and some other arthropods and allow oxygen to diffuse into the body. Some amphibians have very small lungs and absorb a considerable amount of oxygen across their skin, a moist air/tissue interface.

WATER:

Without water, no living thing can remain biologically active. In fact, all living organisms are comprised of 50 to 99 percent water. The unique properties of water make it an ideal solvent for many crucial biochemical reactions. It participates in other reactions as well.

Water Absorption by Plants - Plants absorb water from the soil through numerous tiny hairs on the roots. The water is then transported to the rest of the plant by the xylem, a system of tiny conducting tubes. The xylem is similar to the human system of blood vessels, except it is not powered by a pump like our heart. In a plant, the water molecules form a continuous chain all the way from the roots to the leaves. The chain is pulled from the bottom of the plant to the top by cohesion between molecules; each time a water molecule in a leaf evaporates (this is called transpiration), the next molecule in the chain takes its place and pulls up the rest of the water-chain.

Terrestrial plants must retain water and not let too much evaporate into the air. This accounts for the watertight epidermal, or outer, layer covering their surfaces. But in order for photosynthesis to occur, cells need to obtain carbon dioxide from the air. Small holes in their tissues, called stomata, are an adaptation that meets both requirements. When photosynthesis is taking place, the stomata open and allow carbon dioxide to diffuse into photosynthesizing cells. A small amount of water loss also occurs because of the air contact. At times when risk of water loss is too great (such as in the midday sun), the stomata remain closed to prevent this drying out (desiccation).

The presence of too much water can pose as many challenges to organisms as a lack of water, because of the threat of soil anoxia. Thus wetness can be an important factor in determining the abundance and distribution of organisms. Certain plants, such as red maple trees, are adapted to live in moist soils. Only a small number of plant species, however, can live in places like marshes where the soil is completely saturated with water, making oxygen essentially absent. The survival of plants in a salt marsh depends in part on their ability to withstand waterlogged soil (See Oxygen, Section A).

NUTRIENTS:

Although sunlight is the fuel for food production, and water and carbon dioxide are the raw materials, plants cannot survive with these alone. Other substances, called nutrients, are necessary for the proper function of a living organism. Major nutrients include nitrogen and phosphorous. Trace nutrients such as iron are required in smaller amounts.

Each nutrient plays a role in the life processes of the organism. Nitrogen is used in the synthesis of proteins, phosphorous assists the energy cycle of cells, and iron facilitates photosynthetic reactions.

Nitrogen and phosphorous often govern the productivity of vegetation. We put nitrogen and phosphorous on our gardens to increase their productivity. Coastal areas, and in particular estuaries, tend to be rich in these nutrients because they receive large inputs from rivers carrying nutrients eroded from upland soils. Ocean waters far from riverine inputs tend to lack nutrients.

The overabundance of nitrogen and phosphorus in a body of water can result in a huge increase in the amount of algae that grows there. This phenomenon, when occurring during the growing season, often causes an algae bloom that creates a green scum on the water surface. Algal blooms often happen when nutrient-rich fertilizers wash into a waterbody from agricultural land, or when untreated or partially treated wastewater is deposited into a waterbody.

TEMPERATURE:

Temperature and Physiology - Temperature is one of the best understood abiotic factors affecting the distribution and abundance of organisms. It is also one of the most important. Temperature has a large impact on plants and animals because it influences their metabolic rates and affects rates of growth and reproduction. Death can occur when temperatures are either too high or too low. Heat death is probably a result of damage to proteins and enzymes. Coldness can slow down life-sustaining chemical reactions and cause body fluids to freeze.

Every species has a particular range of temperatures in which it can survive. For organisms that don’t maintain constant body temperature (plants and cold-blooded animals), rates of metabolism, growth, and reproduction generally increase toward the upper limit of the acceptable range and decrease toward the lower limit. One type of fish found in Antarctica can live at temperatures down to -1.9 C, and it dies if the temperature goes above only +6 C. In contrast, intertidal organisms are able to sustain the wide range of temperatures to which they are exposed, a range that would kill the subtidal creatures living nearby. Barnacles, for instance, are able to endure cold winter conditions even though some of their body tissues freeze.

One of the most important aspects of temperature variation in aquatic systems is the inverse relationship between water temperature and the solubility of gases. Warm water can hold less oxygen than cold water. This has important ramifications for fish, which can be characterized as either warm-water fish (e.g., sunfish and pickerel) or cold-water fish (e.g., salmon and trout). Salmon are only able to live in water colder than 40 F because they have a high oxygen requirement. Water above that temperature is unable to hold enough oxygen for their survival.

Temperature and Geographic Ranges - Geographic ranges of animals are often defined by temperature. Abrupt changes in communities occur at boundaries between places with very different temperatures. Many species respond to seasonal temperature shifts by acclimatizing to them. They adjust their metabolic rate and behavior according to the ambient temperature. This allows them to withstand a wider range of temperatures than if they did not acclimatize. An individual's ability to acclimatize is a result of evolutionary adaptation to tolerate variation in environmental conditions.

SALINITY:

Pure water contains only oxygen and hydrogen, but in the natural world solid substances are often dissolved in water. When they dissolve, the solids dissociate, or break up, into electrically charged ions. The presence of dissolved solids (or ions) in a liquid is called salinity. One of the most familiar and abundant dissolved solids in ocean water is sodium chloride, the compound we know as table salt, but other dissolved substances are also found in smaller concentrations.

Osmosis & Diffusion - Salinity poses challenges for plants and animals because of phenomena known as osmosis and diffusion. Osmosis is the movement of water across a water-permeable membrane. It occurs when the water on one side of the membrane has a lower salinity than the water on the other side. Water molecules passively move across the membrane from the less saline side to the more saline side, until the concentrations on both sides is equal.

Diffusion is the movement of an ion, such as sodium or magnesium, across a membrane that is permeable to that particular ion. Like osmosis, it happens when the ion concentrations of two solutions separated by a membrane are unequal. The ions always move from the concentrated side to the dilute side. In living organisms, diffusion often happens across cell membranes, causing the cell to either gain or lose ions. To counteract this, cells frequently have mechanisms that act as “pumps” to remove unwanted ions and import desirable ions.

Osmosis and diffusion present problems for aquatic organisms because the organisms’ internal ion concentrations are very different from the salinity of the surrounding water. The body fluids of saltwater fish, for example, are typically only 1/3 to 1/4 as saline as seawater. Therefore, if the fish allowed chemistry to simply follow its course, water would leave the fish by osmosis and ions would enter it through diffusion, until the concentration of the body fluids equaled that of the seawater. The result would be a fish that was shriveled, salty, and dead. Luckily, fish and other marine organisms have adaptations that enable them to deal with the saltiness of ocean water by regulating water and ionic exchange. Marine fish drink seawater to get water into their bodies, and they excrete excess salt through glands on their gills. Many seabirds have a similar salt gland in their head near the top of their bill. Crustaceans have impermeable membranes on most of their body and regulate water and ionic balance at their gills and excretory organs.

Smooth cordgrass (*Spartina alterniflora*) can survive even though its roots are bathed in saline water. It maintains a very high salt concentration in its cells (even higher than seawater) so that water will diffuse into the plant, not out of it. They also excrete excess salt onto their foliage, where it gets washed away by rain. If you look closely at smooth cordgrass leaves, you will often find salt crystals on them.

Organisms living in fresh water face different challenges because their internal salinity is higher than the water they live in. If a freshwater fish did nothing to counteract diffusion and osmosis, the fish would bloat up until its internal salinity became so low that it would die. To prevent this, freshwater fish excrete a very dilute urine, have cells that absorb salt, and do not drink any water.

Response to Variable Salinity - The differing physiological requirements of salt and freshwater environments make animals like eels and salmon intriguing because they deal with both conditions during their lives. American eels (Anguilla rostrata) are catadromous, meaning they live most of their lives in fresh or brackish water but spawn in salt water. Adult eels migrate to the Sargasso Sea, an area of the Atlantic Ocean located near Bermuda, to spawn. Their larvae eventually make their way back to marshes and rivers along the American East Coast.

During their lifetimes, the eels encounter both salt and freshwater environments. The same is true for salmon, which are anadromous. They live in salt water as adults but migrate up river into fresh water to spawn. To survive such different salinities, these species have evolved the ability to respond physiologically to the surrounding conditions.

Organisms that spend their entire lives in estuaries need to be capable of responding to large and rapid salinity variations. Salinity fluctuates continuously over the tidal cycle, decreases drastically in the upper reaches of tidal rivers, and varies radically in salt pannes because of evaporation and precipitation. Some large groups of related animals, such as echinoderms (starfish, sea urchins, and others), are entirely absent from areas with low salinities. They have not adapted in such a way as to be able to survive in low-salinity water. Groups like bivalve mollusks (clams, mussels, and others) and polychaete worms (sand worms, blood worms, and others), on the other hand, show only a decrease in the number of species and not a decrease in overall abundance. Those species that can respond to variable salinity are very common in estuaries.

SPACE:

Organisms need space in which to live. Consequently, space is a precious resource that is always exploited by living things. The need for space is most pronounced for organisms that need a substrate, or base, on which to live. Terrestrial plants are a good example of this. They need soil for physical support and as a source of water and nutrients. If no soil is available in a given location, few plants can establish themselves. Plants like trees also have a plant-specific need for sunlight. The fastest growing trees out- compete other trees for space in which to spread a canopy of leaves.

Many animals require a certain amount and type of space to meet their needs, other than simple physical attachment. They need space for nesting, gathering food, resting, wintering, and hiding from predators. Standing dead trees, for example, are an important resource in northeastern forests. Upwards of thirty animal species depend on them, such as the flying squirrels that use them for nesting.

SECTION B:

Biotic Factors

In addition to all the abiotic factors described in Section A, the abundance and distribution of organisms are controlled by a complicated web of biotic factors, meaning factors that arise from other living things. Abiotic factors limit distribution and abundance by affecting an organism's life processes (physiology). Biotic factors, in contrast, are relationships and interactions among living things that affect an organism's survival. It should be emphasized that in this text (with the focus on estuaries) the term organism refers primarily to plants and animals.

COMPETITON:

Competition occurs between any organisms using the same resource. The organisms can either be of the same species (intraspecific competition) or different species (interspecific competition).

Competition can occur for any resource that is required for survival. Plants often compete for light, nutrients, and water, but they might also compete for pollinators or space. Animals frequently compete for water, food, space, and mates.

It is important to note that animals do not have to see or hear each other to be competitors; often they do not have direct contact with one another. To be in competition, they simply must be using the same resource. In a forest, there might be two animals that both feed on insects. If, however, one species feeds on daytime insects and the other on nighttime insects, they are not in competition. They are actually using different resources. Competition plays an important role in shaping communities, since competing species threaten each other's survival or reproductive success. If two species use the same resource and that resource is in short supply, the species cannot coexist (See Niches, Section G). The more successful species excludes the other from a given system. Consequently, competition also influences the evolution of species.

Competition can produce evolutionary changes in body features and behavioral strategies so as to give individuals of one species an advantage over individuals of a competing species. The threatened species then gains a competitive edge and has a better chance of surviving long enough to reproduce.

PREDATION:

Predation is considered another very important biotic factor influencing community structure and dynamics. Predation is the killing and/or consumption of one organism by another. It takes two primary forms:

1) **Herbivores** eat plants, seeds, and/or fruits. The periwinkle (*Littorina littorea*) is an herbivore that eats bottom-dwelling algae.
2) **Carnivores** eat animals. Snowy egrets are carnivores because they eat fish.

Both herbivores and carnivores will kill a competitor for territorial space that supplies mates, food, water, or protection of young.

Some animals, called **omnivores**, eat both plants and animals. The mummichog is an omnivorous estuarine fish that eats a variety of foods, including vegetation and mosquito larvae.

Predation shapes communities by reducing the abundance and distribution of prey species. Kelp sometimes grows in dense, submerged forests, but when sea urchins are abundant these kelp forests are destroyed. Herbivory by urchins is thus an important controlling factor of kelp abundance and distribution. Urchin populations themselves are strongly affected by predation by sea otters (on the West Coast of North America) or lobsters (on the East Coast). Similarly, the blue mussel (*Mytilus edulis*) is abundant in some locations and absent in others. The main factor controlling mussel abundance is the presence of its major predators: crabs, starfish, and eider ducks. (The abundance of crabs and starfish is, in turn, often limited by abiotic factors such as water turbulence and low salinity. Crabs do not have the ability to attach themselves to rocks in turbulent, wavy environments, and starfish generally cannot tolerate the osmotic stresses of low salinity.)

Predation is a major selective force in animal evolution. Individuals are more likely to successfully reproduce if they have traits that help them avoid being consumed by predators. For example, many species have evolved hard shells, quills, speed, size, ferocity, or camouflage.

PARASITISM:

Parasitism is similar to predation in that one species benefits from the relationship and the other is harmed. Parasitism differs from predation, however, because parasitism generally is not fatal to the adversely affected organism. Rather than outright killing its host, a parasite may benefit by simply obtaining shelter or nutrition in its body.

COMMENSALISM:

When one species gains from a relationship and the other is neither positively nor negatively affected, the relationship is called commensal. Lichens often grow on tree trunks because the trunks provide solid support and exposure to sunlight for photosynthesis. The lichen clearly benefits from this relationship, but the tree is neither aided nor harmed.

MUTUALISM:

Lichens themselves are excellent examples of mutualism, where two species involved in a relationship both gains from the interaction. A lichen actually consists of two different organisms: a fungus and an alga. The fungus absorbs nutrients and water and provides support for the alga. In turn, the alga produces food through photosynthesis. It is a give-and-take relationship.

A marine example of mutualism is found in corals, which are actually tiny animals that contain algae within their tissues. Corals provide the alga with support, and the alga supplies the corals with food from photosynthesis.

AMENSALISM:

Finally, amensalism occurs when one species is negatively affected by another species, but the second species is totally unaffected (neither positively nor negatively). This situation is difficult to imagine, but some ecologists believe that amensalism occurs when a plant produces toxic compounds when another species is not present which negatively affect another species. Other ecologists consider this a form of competition.

SECTION C:

Population/Community Habitat/Ecosystem

Ecologists take a number of approaches to their work, but they tend to focus on three levels of organization in the natural world: population, community, and ecosystem. **A population is a group of individuals of the same species living in a given place. A community comprises populations of a number of different species living together.** Populations and communities do not have rigidly defined boundaries. They are abstractions, or levels of ecological organization, rather than actual structures. So, we might have twenty individual egrets making up the egret population in our marsh, and five great blue herons making up the great blue heron population. If these are the only kinds of birds in a marsh, then these two populations comprise the bird community. We can also consider all the animals, plants, etc. living in our marsh and call them the marsh community. This is a way to collectively refer to the populations of every species of living thing in the marsh.

Ecosystem is a term even more inclusive than community, because it encompasses the community and its abiotic environment. Therefore, an ecosystem has components that are living (animals, plants, etc.) and nonliving (soil, water, air, nutrients, etc.). **The concept of an ecosystem refers to the flow of energy and nutrients through ecological systems, whereas ecologists studying from the population or community perspectives focus on how organisms affect each other and how the environment affects them. The word ecosystem is always used by ecologists when they want to refer to the interactions among one or more biotic community(ies) and the associated abiotic features.** In this text, the estuary is referred to as an ecosystem, although in other instances it might be considered simply a part of a larger ecosystem. Likewise, we will refer to the river, mudflats, and marsh as habitats within the estuarine ecosystem; in other situations they might be considered ecosystems in and of themselves.

The habitat concept is explained more fully later in the text, but it is important to note here that, although people often define ecosystem as a combination of community and habitat, this is incorrect. Ecosystems are the sum of a community and its physical and chemical environment, while habitats are considered from the point of view of a single organism. Thus, the habitat of a worm might be the mudflat, but the habitat of a fish that eats the worm might be the river.

HABITAT:
Habitat is the place where an organism lives.

Every species has a set of abiotic and biotic conditions and resources that it needs in order to survive, and there are certain places in the world that meet those requirements. These environments are suitable habitats for that species. A habitat is a place where a plant or animal lives. The habitat characteristics that a species requires can be determined by examining the places where it lives.

It is important to keep in mind that the characteristics of a place that are hostile to one species might be benign to another species. Antarctica, for example, is an extremely cold place, but many species find it a perfectly suitable habitat.

The habitat requirements of an organism can be divided into two categories: resources and conditions. Resources are entities (food, light, water, etc.) that the organism uses or consumes during its lifetime. Conditions, on the other hand, are characteristics of the environment that influence the survival of an organism but are not consumed by it (temperature, salinity, pH). Resources and conditions of a habitat involve the previously discussed biotic and abiotic ecological factors: light, nutrients, oxygen, moisture, temperature, salinity, and space. The factors that organisms use during their lifetime are resources and the factors that simply influence their survival are conditions.

Therefore, if we look at a habitat from the point of view of an individual plant, we should consider the factors the plant needs as resources (light, water, oxygen, nutrients, and space) and the conditions that affect its survival (temperature, salinity, and pH). A plant's habitat can be characterized by considering the overall combination of resources and conditions as they occur where the species lives. For instance, one plant species might live only in a habitat with medium moist soil and with temperature and sunlight levels varying seasonally within a specific range -- a habitat such as a temperate hardwood forest. Another plant species might live only in a nearby habitat where the temperature and sunlight conditions are the same, but the soil is flooded twice daily with saline water -- in other words, a salt marsh.

Habitat characteristics for animals are somewhat different. Like plants, animals need water as a resource, but they do not solely require light for survival. Rather, animals mostly depend on having appropriate food sources, either plants or other animals, in order to obtain energy.

Animals often depend on plants in another way as well -- for diversifying space. It is no accident that rainforests, with their abundance, complexity, and density of foliage, support a large population and diversity of animals. Likewise, it is not coincidence that one finds a greater abundance and diversity of fish in the weedy part of a waterbody than in the areas with little or no submerged vegetation. The more abundant and varied the vegetation, the more space is available to the animals for shelter and protection.

Environmental conditions such as temperature and soil type (for burrowing animals) are very important in determining whether a given location is a suitable habitat for an animal species.

Habitats are also defined by their temporal and spatial characteristics. Are the resources and conditions constant, seasonal, unpredictable, or ephemeral? Are they continuous in space, patchy, or isolated? These qualities can make the difference between success and failure for a species.

In sum, a location's suitability for the survival of a species is determined by its resources and conditions. When all of the species' requirements are met, the location is a suitable habitat and the species has the potential to live there. It should be noted that every species can survive in a range of conditions, some of which cause it to flourish (i.e., maximum reproduction) and some that are marginal (i.e., minimal reproduction).

The concept of a habitat is different from that of an ecosystem, which refers to the flow of energy and nutrients through an ecological system. A habitat, in contrast, is always considered from the point of view of an individual organism. In practice, an ecologist may use either word habitat or ecosystem to refer to the same location, but his/her choice of words reflects the way he/she is thinking about the place. One should say ecosystem when discussing the relationships among all biotic and abiotic components of a place, and habitat when viewing a place from the perspective of an individual of a particular species.

SECTION D:

Food Web & Food Chains

Energy is the most crucial resource needed by living things. Autotrophs (meaning self-feeders), such as plants, are able to obtain energy from the sun (or chemical compounds in the case of some bacteria) and use it, along with certain molecules, to form energy-rich material. They use this material in life processes like growth and reproduction. Heterotrophs (meaning feeding on others) are organisms, mostly animals, which obtain energy-rich materials by eating autotrophs as well as other heterotrophs. This relationship determines how energy flows through a community.

The general pattern of energy flow begins when an autotroph produces food and continues when a heterotroph eats that autotroph, another heterotroph eats that heterotroph, and so on. This pattern is called the food chain. A food chain contains several trophic ("food") levels, and each member of the food chain has a function, depending on its level within the hierarchy. Producers are autotrophs which produce energy-rich organic material from an energy source (i.e., sunlight or certain chemical compounds) and chemical building blocks. Consumers are heterotrophs that eat other organisms to obtain energy-rich organic materials. More specifically, herbivores are consumers, which eat producers (plants), and carnivores are consumers that eat other consumers. A food chain looks like this:

Role	Food chain	Trophic level	Example
Producer	**Green plant**	**1st trophic level**	**Phytoplankton**
Prim. Consumer	**Herbivore**	**2nd trophic level**	**Zooplankton**
Sec. Consumer	**Carnivore**	**3rd trophic level**	**Silverside minnow**
3rd consumer	**Carnivore**	**4th trophic level**	**Bluefish**

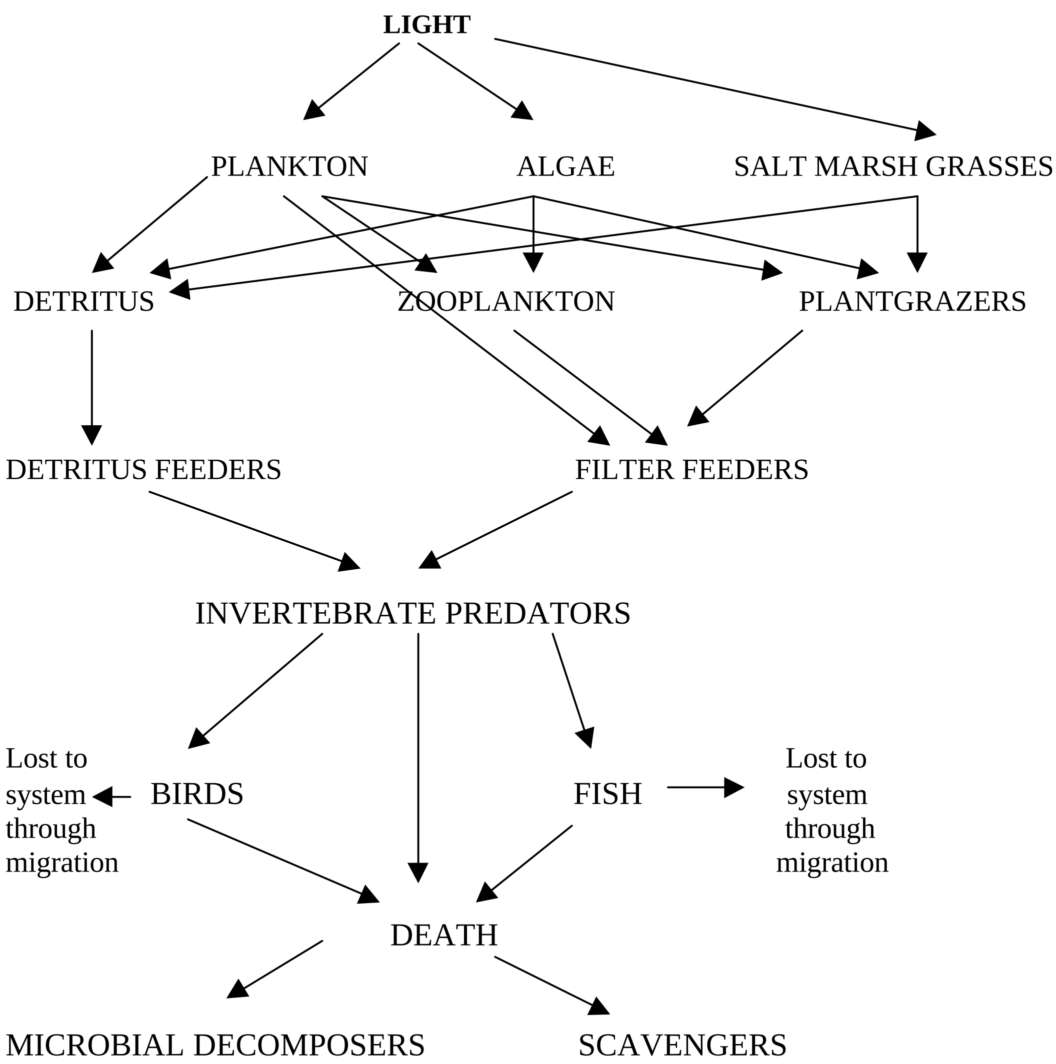
Loss of energy occurs at each stage of a food chain, so the chains rarely have more than four or five trophic levels. In addition, there are generally fewer individuals at the higher levels than the lower levels.

Often one organism will play more than one role in a food chain. The same species of carnivore, for example, might sometimes feed at both the third and fourth trophic levels depending on what prey species it eats and what level the prey was on. The role of an individual organism can even change during its lifetime as it grows from a juvenile to an adult.

Seldom is energy transfer in a community so simple that it can be entirely described by A eats B who eats C who eats plant D. In a natural community, food chains are not simple, independent units. They are linked together into complex food webs because every species is usually eaten by more than one species of predator and every predator usually eats more than one type of prey. A food web is a combination of all the food chains in a system.

Food webs describe the flow of energy and nutrients through a community. By looking at a food web, one quickly notices the interconnectedness of all the organisms in the community. Every species is affected, directly or indirectly, by all the other species. If the population of one species in a community declines through hunting, pollution, deforestation, loss of habitat, etc., there can be far-reaching effects, since all the predators who depend on that organism for food will also be negatively affected. Other organisms hunted by these predators are, in turn, affected by the decrease in predatory pressure. Thus, the human activities of overfishing, air pollution, pesticide and herbicide use, overhunting, and habitat destruction can go far beyond just a single species, sending shock waves throughout an entire community and ecosystem.

AQUATIC FOOD CHAIN



SECTION E:

Disturbance

One reason ecology is so challenging is that the natural world is always changing. Competition theory states that, when two species use the same resource and that resource is limited in supply, the more successful species will exclude the other species. However, ecological communities are nonuniform, continually altering, and subject to random events of change. This makes ecology very different from chemistry and physics. Imagine the havoc if the elements in the Periodic Table had randomly changing atomic weights or if gravity unpredictably fluctuated in intensity.

Ecologists have recently begun to take the variability of natural systems into account by recognizing the importance of disturbance. Although to most people this word connotes something along the lines of an interruption of something pleasant, it has a somewhat different meaning to ecologists. Disturbance is defined as any relatively discrete event in time that removes organisms and/or makes available resources that can be exploited by individuals of the same or different species.

It is important not to place a human scale on disturbance. The impact of a raindrop is insignificant to a human, but it may kill a small organism. Therefore, ecological disturbances range in scale from something as small and transient as a footstep to an event as huge and prolonged as a hurricane, a volcanic eruption, or glaciation. As long as an event removes organisms from the community and/or makes resources available for exploitation, it is a disturbance. Disturbances are often a regular environmental feature, such as the pounding of waves along the coast or the fall of a tree in the forest.

Like other ecological factors, disturbance is a regulator of the abundance and distribution of organisms. In contrast to competition, disturbance limits populations whether or not the organisms were competing for limited resources. This means that disturbance interrupts competition, either preventing displacement of the inferior by the superior, or removing the superior allowing the inferior to thrive. Consequently, the less competitive species are able to survive, meaning the diversity of organisms often increases in a disturbed environment. In the absence of disturbance, the less competitive species would eventually be excluded from the community by the more competitive species.

Examples of increased diversity as a result of disturbance are common. There is frequently a very large number of plankton species in any given place in the ocean or an estuary. Ecologists have puzzled over why this is the case instead of a few species dominating through competitive exclusion. The diversity of plankton is probably a result of the highly variable conditions of the ocean. Aquatic light levels, temperature, and nutrient concentrations change drastically from hour to hour and day to day. This variability prevents any one species from maintaining a competitive advantage, a process that has been observed in many different ecosystems.

One perceptive ecologist has even discovered that the disturbance created by a cow's hoof step in moist field permits microbes to live in the field that would not otherwise be there. And when a tree falls in a forest, it may kill the few individuals unfortunate enough to be crushed under its bulk, but the newly-opened gap quickly becomes invaded by a rich diversity of plants that were unable to live there when the tree was standing.

SUCCESSION:

The invasion by new species of newly opened space is the first step of succession, one outcome of disturbance. Succession is the process by which newly available space is colonized by organisms and then is inhabited by a progressively changing community. The adaptations required to compete successfully change as the community changes over time. When a disturbance (e.g., hurricane, agriculture, etc.) occurs in a forest, it creates an opening that is first colonized by small herbaceous plants. If the system is left undisturbed, these plants are gradually overgrown by shrubs, then small trees, and finally by large trees that out compete the other species. This process does not repeat until another disturbance occurs.

The size of a disturbance determines what kind of impact it has on a community. High level disturbances, meaning ones that are sizable and/or very frequent (such as hurricanes), prevent a forest from ever getting beyond the early successional stage. High levels of disturbance do not promote diversity because very few organisms are able to survive in the face of repeated catastrophic events. Conversely, small, infrequent disturbances, like one person walking through a virgin forest every hundred years, have no significant impact on succession; they do not affect the survival of organisms enough to lead to maximum diversity. An important ecological concept, however, is the intermediate disturbance theory, which says that intermediate levels of disturbance result in greater diversity than either high or low levels of disturbance. Disturbances that are intermediate in frequency or intensity prevent competitive exclusion of early successional species, yet allow continued presence of late successional species. As a result, both early- and late-successional species coexist, producing maximum diversity.

SECTION F:

Adaptation

BIOLOGICAL RESPONSES AND ADAPTATIONS TO ECOLOGICAL FACTORS:

Ecologists are interested in individual organisms because they are the players in the levels that ecologists study: whatever happens to individuals affects populations, communities, and ecosystems. To an ecologist, one of the most important characteristics of an individual is how well it responds to changes in its environment in order to ensure survival. During its lifetime, every organism encounters changes in its environment. These changes can be abiotic (amount of windiness, saltiness, light, etc.) or biotic (variations in competition, predation, parasitism, etc.). If an organism is to survive these changes, it too must be able to change in some way.

ECOLOGICAL RESPONSES:

When thinking about biological change, two different time scales are needed: ecological and evolutionary. Ecological responses happen during the lifetime of a single organism. For example, some birds are able to respond to cold winter temperatures by changing their behavior and physiology. When winter cold arrives, chickadees have about 50% more feathers than they did in the summer. These feathers trap more air, an excellent insulator, next to the bird’s body. And, in winter, chickadees seek well-insulated spots such as snow-covered evergreens where they huddle with other chickadees. These behavioral and physiological responses increase the individual’s chance of survival, and they happen in the course of its lifetime (i.e., on an ecological time scale). However, the range of possible responses by an individual is not infinite; the organism’s genes, which carry all the individual’s behavioral and physiological information, ultimately limit it.

EVOLUTIONARY ADAPTATION & NATURAL SELECTION:

Evolutionary adaptation, on the other hand, happens on a different time scale, over the course of multiple generations of a species, and occurs because of changes in a species’ genetic makeup. Adaptation occurs through a process called natural selection. Every population has some variation in the genes carried by its members. When an environmental change (either biotic or abiotic) occurs, it can act as a selective force for organisms with characteristics favorable to survival in the new conditions. Individuals that carry the genes that encode for these characteristics will survive, and those without the genes will die off before reproducing. The end result is that the genetic makeup of the population changes so that all the organisms are better adapted to (or capable of dealing with) that particular change in the environment. It is important to note that this all happens by chance. It simply depends on whether random genetic variation provides some individuals with traits that permit them to survive and reproduce more successfully than other individuals.

SPECIATION:

Speciation is the creation of new species through natural selection. This occurs when a selective force is intense, as it was in the previous salt marsh grass example, and when genetic changes occur that make it impossible for viable offspring to be produced in matings between individuals of the "old" and "new" species. Speciation accounts for the diversity of living things on the planet today. Sometimes, however, evolutionary adaptations simply produce a population that is well adapted to a particular environment without becoming a new species. For example, seaside plantain (*Plantago maritima*) grows tall (31.5 cm) in the marshes of Sweden, but plants of the same species grow in a dwarf form (20.7 cm) on the exposed cliffs of the Faeroe Islands. A significant height difference occurs even when the plants are grown side by side in an experimental garden, thus subject to the same environmental conditions. The cliff population is evolutionarily adapted to grow shorter than the marsh plants, but it is not a different species. This is an example of genetic variation within a species that results in adaptation to local conditions.

As mentioned previously, an individual’s ability to respond to its environment during its lifetime (change over an ecological time scale) is limited by the genes that it carries. Genetic makeup is in large part a result of natural selection for traits that improve an individual’s reproductive success. In other words, the reason that today’s chickadees grow more feathers in winter and behave to escape the cold is that some ancient chickadee ancestors happened to have genes enabling them to do this. The individuals that didn’t have those genes died during the winter or had low reproductive success subsequently, and the ones that did have those genes were able to reproduce. So today all chickadees, the descendants of those ancient surviving chickadees, are able to grow more feathers and find shelter in the winter. That is why adaptations on the ecological time scale are restricted by the genetic makeup of the individual.

An ecologist is interested in adaptation responses because they are important in determining where a species can live and how successful it is in a given location. This is the basis of ecology: distribution and abundance of organisms.

SECTION G:

Niche

Niche: The role of an organism in a community.

Even if a location provides suitable habitat for a species, it will not necessarily be inhabited by that species. This can be caused by any number of reasons (e.g., individuals have never happened to find that particular spot), but the absence of a species from suitable habitat is frequently a result of competition.

When two organisms use the same resource the more successful organism will usually competitively exclude the other. Species coexisting in a community tend to avoid competition through specialized adaptations, so that each species has a unique role in the community. These roles, called niches, can be defined in many different ways, but each species uses the available resources in a unique way.

It is important to realize that while every organism has both a niche and a habitat, a niche is an abstract concept (the role of an organism within a community) whereas a habitat is a physical place that actually exists and can be seen.

Different species coexisting in a community can avoid competition through specialized adaptations, so that each species has a unique role in the community. These roles, called niches, can be defined in many ways, but all of them involve using limited resources in a unique way. The concept of the niche is most evident in the way that related species differ in their use of space, time, and food. For example, great blue herons and snowy egrets are very similar birds that, at first glance, seem to have overlapping ecological requirements. They are both found in similar coastal habitats. Their diets are very similar, but they have evolved different nesting requirements. The great blue heron nests inland in trees and the snowy egret nests on coastal islands in scrubby growth trees and shrubs.

Niches are important in the organization of communities, which can be broken down into broad niches and, further, into smaller, more specific niches. For example, spatial niches allow organisms that eat leaves from the tops of trees to coexist with those that eat from the lower branches on the same tree. The niche concept is a useful generalization, but in the real world species are constantly invading new places as environmental changes and other factors affecting them.

Niche separation con be extremely narrow and is not limited to differences in food sources. For example, the leaf-eater niche contains other niches, such as spatial niches for animals that eat leaves at the tops of trees as opposed to others that eat only the lower leaves. The coexistence of five closely-related species of warblers in New England boreal forests is an outcome of niche separation. The species feed at different heights, feed in different ways, move in different directions, and nest at slightly different times.

Although niche separation is most interesting to study between closely related species such as warblers, it is important in the coexistence of less similar organisms. For instance, if nuthatches and chickadees living in the same area both use holes in trees as nesting sites, and the population of both are limited by the number of holes, there must be a difference in the kinds of holes that they use. Otherwise, one species would out-compete the other, and the less competitive species would be excluded from the habitat.

The organization of all natural communities can be traced to niches-species differentiation in the use of resources - so that each species plays a unique role in the community and, consequently, tends to avoid competition. It should be noted, however, that natural communities are never in a steady-state equilibrium (See Disturbance, Section E), so the niche concept is simply a useful generalization about community organization. In the real world, species are constantly invading new places, being affected by environmental changes, and so on. Competition occurs as species vie for the available resources. When competition is less important than other limiting factors, successful species occupy unique niches.

SECTION H:

Geologic Formation

GEOLOGICAL FORMATION OF ESTUARIES:

There are four types of estuaries that owe their existence to the sea-level rise that occurred over the 18,000 years since the last ice age.

- **Coastal plain estuaries** were formed as the rising sea invaded existing river valleys. Chesapeake Bay is an example of one such drowned river valley.
- **Fjords** are steep-walled valleys created by glaciers. They are common on Canadian coasts.
- **Tectonic estuaries** are formed when geologic faulting or folding results in a depression, which is then flooded by the ocean. San Francisco Bay is an example.
- **Bar-built estuaries** are separated from the ocean by barrier beaches lying parallel to the coastline.

SECTION I:

Tides

Tides can be the most important natural phenomenon affecting estuarine organisms. Within estuaries, the occurrence of tides results in highly variable and constantly fluctuating salinity, currents, and water levels. These drastic variations make estuaries extremely harsh and demanding places to live.

Different parts of the world can experience different tide patterns as the result of geographic conditions that affect the movement of water. The East Coast of North America has semidiurnal (twice-daily) tides. Approximately 12 hours and 25 minutes pass between successive high tides or successive low tides. In the Gulf of Mexico, tides are diurnal, meaning there is one high tide and one low tide each day. The Pacific Coast of North America is affected by mixing tides, a combination of semidiurnal and diurnal tides; places with mixed tides experience a high tide, a low tide, a higher tide, and a lower tide.

Tidal heights are measured relative to mean sea level, the average height of the ocean. Tidal range is the difference between high and low tide. Many places have small tidal ranges, and some (called amphidromic points) have a tidal range of zero. In narrow channels like an estuarine river, one often notices rapid currents arising from the tidal motion of water. A flood tide occurs when the tide is rising, and an ebb tide happens when the tide is falling. Moments of slack water (no water movement) separate flood and ebb tides.

The earth, the moon, and the sun cause tides. The two major forces driving the tides are the moon's gravitational pull on the earth's oceans and the opposing centrifugal force resulting from the orbit of the moon around the earth. The sun also plays a role, but its gravitational force is smaller than the moon's because the sun is so much further away. The combined influence of these forces causes the water in the oceans to be pulled into two large tidal bulges on opposite sides of the earth. As the earth rotates daily on its axis, high tide occurs when a point on the earth's surface is in one of these bulges, and low tide happens when the point moves out of the bulge.

Centrifugal force is the force you feel when you swing a ball on a string around your head; it is directed outward from the center of rotation. Centrifugal force arising from the motion of the moon around the earth is equal on all sides of the earth.

The strength of the moon's gravitational pull, however, is different in different positions on the earth. It is stronger on the side of the earth facing the moon (because that side is closer to the moon), and weaker on the side facing away from the moon (because that side is farther away from the moon). This variation is important to tides because on he side of the earth facing the moon, gravitational attraction out pulls centrifugal force: a tidal bulge forms. Conversely, on the opposite side centrifugal force is stronger than gravity, and another tidal bulge forms.

Tidal ranges are not constant. They vary depending on the relative positions of the sun and the moon; changes in these positions affect the size of the tidal bulges on Earth. The greatest difference between high and low tides occurs during full or new moons, when the forces of the moon and sun are in line with one another. This alignment of forces happens twice each month and the resulting maximum tides are called spring tides. The smallest difference between high and low tides, called neap tides, happens during the first and third quarters of the moon when the forces of the sun and moon are at right angles. The forces somewhat counteract each other and produce smaller tidal bulges.

The influence of tides makes estuaries extremely dynamic environments, where salinity, water level, and currents are always in flux. This variability makes them ecologically challenging places in which to live.

SECTION J:

Watersheds

Watersheds are what link all of us, no matter where we live, to estuaries. A watershed is an area of land that drains water into one river, stream, or other waterbody. It is analogous to a bowl. If you drip water onto any one spot inside the rim of the bowl, it flows down to the bottom. If you drip water outside the rim, it does not flow into the bowl.

In watershed terminology, the area contained within the bowl is the watershed, and the rim of the bowl is the divide. Every waterbody has an area of land from which it receives water - its watershed, or inside the bowl. Mountains, hill, and other high-relief features form the divides, or bowl rims, between watersheds. Precipitation falls onto the watershed and flows to the body of water as either runoff over the surface of the land, groundwater through the soil and rock, or surface water in streams, brooks and rivers. The watershed of an estuary is the watershed for the river that flows into it, which may cover tens, hundreds, or thousands of square miles.

Watersheds link habitats together, since a drop of rain falling in one place flows through many habitats during its journey to the ocean. The fallen raindrop may pass through the forests, grasslands, swamps cornfields, somebody’s lawn, a parking lot, and a salt marsh before finally reaching the sea. Therefore, rivers, streams, and brooks are similar to the blood vessels in our bodies. A contaminant finding its way into one location in a watershed will eventually be transported to other parts of the watershed, so pollution introduced into one habitat may well be carried to many others and thus have wide-ranging effects. The clearly defined boundaries of watersheds make them ideal units of study for ecologists. All the populations, communities and abiotic components are combined in an ecosystem defined by topography and a network of waterways.

Watersheds can be defined according to different size scales. A tiny brook receives water from a small watershed. The stream that the brook flows into has a watershed that includes the brook’s watershed and the watershed of all the other brooks that flow into the stream. That stream flows into a river, in turn, and the river’s watershed comprises the watersheds of all the streams that flow into it. The watersheds of major rivers can be immense. For example, the watershed of the Mississippi River drains much of the Midwest.

SECTION K:

Barrier Beaches

A string of barrier beaches lines much of the Atlantic coast of the United States. Barrier beaches are ribbons of sand that lie a short way offshore, often separated from land by marsh-filled estuaries. They may be attached to the mainland at one or more points, or they may be islands. Barriers play an important role in the functioning of an estuary. By breaking the impact of ocean waves, they protect the estuary and uplands from waves and erosion, facilitating marsh formation and making the estuary a calm haven for the survival of animals and plants.

The pounding of the ocean constantly batters barrier beaches. Though barrier beaches are taken for granted during summer by hordes of humans, they are unique habitats that support interesting communities of organisms. Like marsh and rocky intertidal habitats, the barrier island community displays a pattern of zonation.

What causes beach zonation? Numerous beach creatures struggle against the pounding waves, the gusting winds, and the salty air, the shifting grains of sand and the poor supply of nutrients. Barrier beach zones reflect species's adaptations to these challenging abiotic conditions.

Ecological disturbances and succession are also important in shaping barrier beach communities (See Disturbance, Section E). A devastating amount of natural disturbance, in the form of waves, wind and water occurs at the beach/ocean interface - so much that succession is permanently prevented from proceeding. Disturbance decreases with distance from the ocean, and successional development of the plant and animal communities becomes evident. The foreshore, or beach face, is the harshest part of the barrier, the dominant abiotic factors there are wave action and the constantly moving substrate, which strongly affect the structure and adaptations of the foreshore community. In order to live on the beach, organisms must be able to tolerate these conditions.

Successful beach organisms include macroinfaunal invertebrates like surf clams, amphipods, isopods, and polychaete worms, meiofaunal organisms are so small that they swim between the sand grains. Bacteria and meiofaunal organisms are important members of the beach community and are often far more abundant than the larger, more visible animals.

The absence of substantial plant growth on the beach means that no large herbivores live in the community. Furthermore, there are few resident carnivores on the foreshore; a carnivore needs to move actively in search of prey, and wave action precludes this life style. (Transient predators like shorebirds do occur). Consequently, most animals living on the open beach are suspension feeders that filter food particles out of the water. These particles may be plankton, meiofauna stirred from the bottom by waves, or detritus suspended in the water. Very little detritus originates on the beach because of the lack of plant growth, but enough detritus is transported from other places so that a reliable food source is provided for beach animals.

Seaward of the foredune beach grass zone, nutrients provided by the wrack line (string of debris stranded by the last high tide) support a few plants called pioneer species, which are hardy enough to withstand extreme conditions. They are adapted to be highly salt tolerant and quickly establish themselves in the shifting substrate. These pioneer plants mark the edge of the foredune zone, where flooding by spring tides and winter storms occurs.

Normally the wrack line left by the highest spring tides is the only one colonized by pioneer plants. Lower wrack lines suffer from substantial natural disturbance; frequent waves wash plants away before they can establish themselves. Wave-induced disturbance is sufficiently reduced in frequency and intensity at the higher wrack lines and therefore plant growth is possible.

Pioneer plants that invade the foredune gain a valuable foothold, which permits exploitation by non-pioneer species. In the Northeast, behind the front lines of pioneer species lie the primary dune and the dune-building species: American beachgrass, beach pea, and dusty miller. Living above the reach of the spring tides and most storms, these species represent the next stage of succession after the pioneer species. They are able to survive because of the protection from disturbance afforded by the pioneer species.

Dune building plants, especially beach grass, cause dunes to from by breaking the flow of wind. The process is initiated when a plant, log or rock creates a wind shadow. Sand grains drop out of the interrupted airstream and are deposited onto the ground. Gradually a mound of sand, known as an embryo dune, accumulates. Over time, it develops into a full-fledged dune.

This might seem disadvantageous for the plants, which become buried. But not surprisingly, dune-building plants are adapted to deal with sand accumulation. Beach grass tolerates burial in up to one meter of sand per year. It reproduces by sending out horizontal underground runners called rhizomes. Every few inches along the rhizome a shoot extends up to the surface. This phenomenon is most evident if you can find an area of the foredune with a sparse population of beach grass. Look for plants-one large and the others smaller- lines up in a row. If you were to dig up the sand, you would find a rhizome and discover that the small plants are clones of the larger one. Through this process, one beach grass plant can quickly become many, hastening dune formation. In fact, burial with sand is beneficial to beach grass, causing it to reproduce more, redirecting rhizomes to grow vertically and to send shoots through the surface.

In the back dune, organisms are subjected to what could be considered interim disturbance, as opposed to the large amount of disturbance on the primary dune and beach (refer to Disturbance, Appendix E). Intermediate disturbance promotes biodiversity as the successional clock is occasionally reset. Competitive plants coexist with species adapted to extreme conditions. Animals unable to live at the sea's edge can thrive in the back dune.

Life behind the primary dune is more sheltered than on the dune itself. This back dune area is less exposed to wind and receives less salt spray. Organisms there are subjected to what could be considered intermediate disturbances, as opposed to the large amount of disturbance on the primary dune and beach (refer to Disturbance, Appendix E). Intermediate disturbance promotes biodiversity as the successional clock is occasionally reset. Competitive plants coexist with species adapted to extreme conditions.

Animals unable to live at the sea's edge can thrive in the backdune. Harriers and owls hunt rabbits, mice, snakes, and voles. Sparrows and grackles forage throughout.

Maritime forests, the final stage of succession on barrier islands, occur in the least disturbed zone. Trees are pruned short, the salt spray kills any high branches. A wide variety of animals utilize these trees eating the fruits they bear and finding shelter in their holes, limbs and rotting structures. Storm waves occasionally overwash the dunes and flood back into the maritime forest, depositing sand and cobbles at the base of trees. This is evidence of the shoreward barrier island migration. It can eventually result in the formation of new inlets as well.

Human activity on dunes is highly detrimental. Trampling footsteps easily erode dunes, kills plants, and disturb animals. Efforts to control access to valuable dune systems is key areas is a step in the right direction.

SECTION L:

River

THE RIVER COMMUNITY:

The river community is a diverse assemblage of organisms. Creatures inhabiting the water column (meaning only the water in aquatic system and not the bottom) including everything from intricately shaped microscopic plants to large marine mammals. Some special terminology is needed to discuss the riverine food web, since aquatic organisms are so different from more familiar organisms. Aquatic organisms can be divided into two general groups: nekton and plankton. Nekton are all the aquatic animals that can swim trough the water against water currents: marine mammals, fish, squid, and some crustaceans. Plankton, on the other hand, refers to all the waterborne organisms that cannot swim against the water column and are transported from place to place by currents.

PLANKTON:

Some people define plankton as tiny microscopic plants and animals. This is a misconception—not all plankton are small, much less microscopic. Jellyfish, for example, are often very large, but they are plankton because they simply drift with the currents. Plankton are subcategorized based on whether they are plants (phytoplankton) or animals (zooplankton), and whether they remain plankton for their entire life (holoplankton) or just part of their life, usually as larvae (meroplankton).

PHYTOPLANKTON:

Plankton are some of the most abundant organisms on earth, yet they are also one of the least familiar life forms to humans. Most plankton are exceedingly small - too small for humans to notice, even though whenever we dive into a lake or the ocean we are swimming in plankton soup.

The abundance of plankton varies greatly, depending on the local conditions, but a gallon of seawater might contain a million or two phytoplankton, several thousand zooplankton, and roughly a billion bacteria plankton. In fact, seawater sometimes appears green because it has chlorophyll-containing phytoplankton. Plankton live within a realm of which most people are totally unfamiliar, but it is a world worth discovering for its wonder-inspiring complexity, beauty and importance.

Phytoplankton are most abundant in places with an adequate supply of nutrients, such as coastal waters receiving nutrients from inflowing rivers and regions of upwelling in the ocean where current patterns cause nutrient-rich water to surface.

Phytoplankton need light for photosynthesis, so they have special adaptations to stay near the surface of the water where light is most abundant. Some plankton have tiny spines or wispy appendages to increase their surface area/body mass ratio and thereby enhance flotation. Others have oil in their bodies to increase buoyancy.

Diatoms are one of the most common groups of phytoplankton. When viewed under a microscope, they are undeniably beautiful. Diatoms are single-celled organisms, although they may form chains. Their exterior fits together like a shoebox, with two elegantly ornamented halves made of silica. Most diatoms are photosynthesizers, but some can also obtain food energy even in darkness by ingesting sugars and amino acids. In fact, some diatoms do not have any chlorophyll at all and are unable to photosynthesize.

Diatoms are notable for their method of reproducing. Their two walls split apart asexually and each half grows a new half. The dilemma is that the new half of each diatom is smaller, to fit inside the older one, so one line of descendants gets smaller with each generation. Once they reach a lower size limit, however, the diatoms reproduce sexually to reestablish a large size. They reproduce very quickly; a population of diatoms can grow sixty-four times larger in just one day.

Dinoflagellates are another common type of phytoplankton that is most abundant in autumn. They are single-celled creatures with two whip-like tails, called flagella, used for propulsion. Despite this animal-like feature, dinoflagellates are classified as plants.

Dinoflagellates are responsible for the only two planktonic phenomena commonly attracting human attention: one for its magic, the other for its potential harm. If you have ever gone night swimming and found that with every stroke the water lit up with a cool, blue-green, mysterious glow, you have shared the water with millions of dinoflagellates - most likely *Noctiluca sp.* Many dinoflagellate species are capable of bioluminescence, the production of light through biochemical processes. Dinoflagellates and other bioluminescent marine animals utilize the same type of chemical process used by fireflies. No one knows exactly why some marine animals bioluminesce, although theories abound. Some suggest, for example, that a flash of light acts like a burglar alarm to protect the bioluminescent creature from predators. Others believe that it is a form of communication.

Dinoflagellates are also responsible for the dreaded “red tides” that occasionally bathe our coasts in reddish-brown water. Red tides are caused by massive population outbreaks of certain types of dinoflagellates. These dinoflagellates contain substances toxic to humans. When they are abundant, the microscopic creatures accumulate in the organs of filter feeders like clams, making the clams dangerous to eat. Shellfish beds are closed during red tide episodes to prevent humans from suffering paralytic shellfish poisoning (PSP). PSP has also killed animals even bigger than humans, such as whales.

Coccolithophores are a third common type of phytoplankton. They are spherical and their surfaces are covered with numerous plates of calcium carbonate (CaCO3), making them resemble soccer balls. Coccoliths, as they are often called for short, are more important offshore but sometimes have population spurts at inshore locations such as estuaries.

ZOOPLANKTON:

If we imagine the river to be a field, then phytoplankton are the grass and some types of zooplankton are the sheep. Just as we commonly think of sheep grazing on grass in a field, scientist often refer to the grazing rate of zooplankton on phytoplankton. It is important to note, however, that although many zooplankton are herbivores (analogous to sheep), many other are actually carnivores that eat other zooplankton (analogous to wolves). Thus, even though plankton are often too small for us to see without a microscope, some zooplankton operate relatively high on the food chain - the third tropic level (See Food Webs, Section D).

Copepods are one of the most common herbivorous zooplankton. Most species eat phytoplankton are their primary food source, filtering them from the water with hairy appendages. Copepods are crustaceans, meaning they are relatives of crabs and lobsters. The family resemblance is apparent, but he glaring difference between copepods and lobsters is that copepods often have clear bodies (although some are colored, sometimes even blue). Under a microscope, one cam sometimes see the copepod’s internal organs. Copepods range in size from less than one millimeter to several millimeters long. Copepods are not shrimp. A different type of zooplanktonic crustacean, the euphausiids (better known as krill, whale food off Antarctica), are a type of shrimp, but they occur mostly offshore.

One of the more familiar types of carnivorous zooplankton are the jellyfish. It should be noted, however, that there are two very different types of creatures that are commonly referred to as jellyfish. True jellyfish belong to a group of animals scientifically called cnidarians, which also includes sea anemones, corals, and hydrozoans. True jellyfish are distinct from the comb jellies, or ctenophores. It is a misnomer to refer to comb jellies as jellyfish. Both have transparent, gelatinous bodies and both eat zooplankton, but jellyfish and comb jellies are different types of organisms.

Many true jellyfish, including the common moon jelly Aurelia, alternate between two main body forms during their life cycle. The more familiar form is the free-swimming medusa stage, characterized by a bell-shaped, parasol-like body that pulsates in order to move. The other body form in the life cycle is the polyp, which remains attached to a hard surface. Medusae typically feed by capturing a variety of small animals, particularly crustaceans and sometimes fish, with their tentacles. Moon jellies, however, have only a fringe of small tentacles. Suspension feeders, they trap plankton on their mucus-covered surfaces. Hair-like flagella then sweep the food into the mouth.

Many people incorrectly call the notorious Portuguese man-o-war (*Physalia sp.*) a jellyfish. In fact, it belongs to another type of cnidarians, the hydrozoans. The Portuguese man-o-war is a member of the siphonophores, an interesting sub-group of hydrozoans. Siphonophores are actually colonies comprised of numerous individuals, each specialized for locomotion, feeding, or reproduction. The man-o-war's long tentacles are made up of many specialized individuals.

Comb jellies, or ctenophores, have a different body structure from the true jellyfish. Many are egg-shaped and have eight rows of pulsating "hairs" running along their sides to provide propulsion. Each row is a series of clusters of cilia, each of which resembles a comb—hence the animals' scientific name (ktenes means combs in Greek). Some ctenophores have adhesive tentacles used to catch prey, especially copepods. Ctenophore populations tend to increase in the summer.

All of the previously mentioned zooplankton, except for the cnidarians, are **holoplankton.** They spend their entire lives as plankton. Many other organisms, however, start out life as planktonic larvae, or **meroplankton**, and then develop into non-planktonic adults. A number of familiar creatures begin life as meroplankton: barnacles, sand dollars, starfish, sea urchins, crabs, eels, spiny lobsters, and many varieties of fish. Magnified, the larvae often look like mysterious alien beings with little or no resemblance to the adult form we are quite used to seeing.

PLANKTON POPULATION DYNAMICS:

Meroplanktonic larvae float in the water until they metamorphose into adults and settle out of the water column (if they are a benthic species).

Having planktonic larvae helps a species such as the barnacle to invade new territory, but mortality of larvae is great, since the probability of randomly settling onto a suitable substrate is low.

Plankton populations fluctuate on a seasonal basis. At temperate latitudes, phytoplankton populations rapidly decline in winter because of decreases light levels, which do not provide much energy for photosynthesis. The dearth of biological activity leads to an accumulation of nutrients in the water column. This permits a huge burst of phytoplankton growth, called a bloom, to occur in spring when light availability increases. The bloom is only temporary, however. The abundant phytoplankton puts a great demand on nutrients, which become scarce. Phytoplankton populations decrease in size as a result.

Nutrient depletion continues to limit phytoplankton populations in the summer. The effect is compounded as the sun warms the surface waters, and the populations become separated from deeper waters by a seasonal thermocline: warm water forms a distinct layer on top of the more dense colder water. When nutrients in the surface waters are depleted by phytoplankton growth, the thermal gradient prevents them from being replenished from below. Consequently, phytoplankton are scarce during summer.

Another phytoplankton bloom occurs in autumn. Cooler surface temperatures cause the thermocline to disappear. Nutrients are then returned to the surface waters, permitting more phytoplankton to grow. The autumn bloom is smaller than that of the spring. Its size and duration are limited by decreasing light levels, as opposed to the spring bloom that is ended primarily by nutrient depletion.

Zooplankton populations increase in response to the spring phytoplankton bloom. The increased food source provided by the bloom permits rapid zooplankton population growth. Grazing by zooplankton serves to reduce phytoplankton abundance and assists in ending the spring phytoplankton bloom. The autumn phytoplankton bloom is too small and too late in the year to stimulate another zooplankton bloom, so zooplankton abundance steadily decreases towa4r the end of summer. Meroplanktonic larvae of benthic invertebrates may be abundant in early summer.

FOOD WEB:

The first level in any food web are the producers. In an estuarine river, as in most aquatic systems, the most abundant producers are phytoplankton. Many species of seaweed, or macroalgae, are also important producers in the estuarine food web. The estuarine food web, however, is based primarily on detritus from decaying marsh plants rather than living plant matter.

Detritivores and herbivores feed upon detritus and producers. In the river, most of the herbivores are zooplankton that eat phytoplankton. A few nektonic species also eat phytoplankton, notably menhaden, a phytoplanktivorous fish.

The next level in the food web is the carnivore. Some types of carnivorous zooplankton feed on other zooplankton, and many fish are carnivores that eat either zooplankton or other fish. Carnivorous marine mammals, like seals, venture into the river to capture fish. The riverine food web, as a whole, is made more complicated by the presence of several omnivores, which may feed at several levels of the food web, such as herbivore, detrivore, and carnivore.

Typical water column food chains might look like these:

phytoplankton (e.g., diatom or dinoflagellate) → zooplankton (e.g., copepod) → fish (e.g., herring, mummichog → fish (e.g., brook trout) → bird (e.g., merganser)

detritus → polychaete worm → fish (e.g., winter flounder) → seal

detritus → amphipod → fish (e.g., rainbow smelt) → bird (e.g., gull, merganser)

Numerous food webs can be created from this information.

SECTION N:

Mudflat & Sandflat

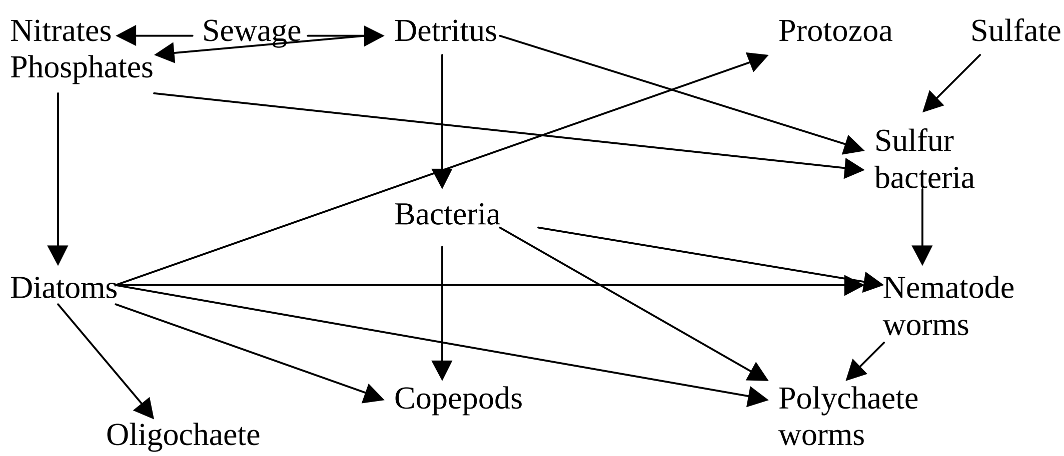
THE INTERTIDAL ZONE: MUDFLATS AND SANDFLATS

The bottom of an estuarine river is shifty and squishy. Walking across it, your feet slide in the sand or sink deeply into the muck. Along the river's length are patches of silt, sand, mud, and cobbles. These sediments have been eroded from the uplands or washed in from the sea. They are constantly reworked into new bars and channels on the riverbed.

Parts of the benthic zone are exposed at low tide. These areas are called mudflats (or sandflats if they are sandy). There is no mistaking low tide in a salt marsh—your nose will alert you as soon as it senses the rotting plant smell of intertidal flats and exposed marsh. Despite the seemingly unpleasant features of the flats (imagine living life submerged up to your head in mud), they are an important habitat for numerous creatures, all adapted to the unique environmental characteristics of the flats.

At first glance, an exposed mudflat may appear barren and devoid of life. But take a closer look and you will see innumerable holes, trails, and shells—evidence of all the burrowing animals that inhabit the flats. You will find scattered seaweeds and, if you are lucky, patches of coloration that hint at a hidden side of the mudflats: microscopic algae carpeting the flats may be important producers in the food web. Many mudflat animals also obtain energy from detritus, bacteria, and plankton.

Generalized food web of a muddy shore.



Bivalves and polycheate worms are common in mudflats. They live between the fine grains of sand and mud. Polycheates are segmented worms, some with and some without appendages. Adaptations that allow these different creatures to burrow and tolerate variable levels of salinity provide them with the opportunity to dominate this challenging habitat. Some polycheate worms are very active, others sedentary.

Despite being virtually unnoticeable because of their small size, meiobenthos and microbenthos are incredibly abundant in most mudflats. Microbenthos include bacteria, flagellates, diatoms and ciliates. The term meiobenthos covers a variety of organisms, but the most common are the tiny, primitive, infaunal roundworms, known as nematodes. In the upper three inches of an acre of soil, there may be as many as five billion nematodes. Estuarine meiofauna and meiobenthos are an important part of the food web. Meiofauna eat bacteria to obtain energy and are themselves eaten by macrofauna and nekton.

EPIBENTHOS AND MOBILE EPIBENTHOS:

Epibenthos requires solid substrates for attachment and are rare in muddy and sandy estuaries. They are more commonly associated with rocky intertidal habitats. Mobile epibenthos are bottom dwelling animals that move on top of the sediment, the most familiar examples being crabs, shrimps, isopods and snails.

Crabs begin their lives as meroplankton. The larvae, which look like microscopic alien monsters, go through several metamorphoses as they drift with the currents. Eventually they develop into adult crabs and settle onto the bottom to live out the rest of their lives as mobile epibenthos. Adult crabs grow by molting. Their exoskeleton (shell) softens and they back out of it, leaving an empty exoskeleton in their image.

Amphipods and isopods, closely related types of crustaceans, are common estuarine epibenthos. They are generally distinguishable by their body shape. Most amphipods have bodies that are compressed from side to side, while their relatives, the isopods, are usually flattened top to bottom. Sand fleas are amphipods that hop along the beach. Other species, however, are associated more closely with the benthic community.

The feeding habits of isopods and amphipods are diverse. Various species, which are difficult to tell apart, are herbivores, carnivores, scavenger detrivores, suspension feeders and, in the case of isopods, parasites. Some amphipods dig u-shaped holes in the bottom, while other isopods and amphipods simply live near the bottom, particularly around seaweed and other plants. Other mobile epibenthos include sand shrimps and assorted gastropods (snails).

BIRDS:

Birds, while themselves not benthic organisms, have a large impact on the benthic community, for many birds feed primarily on bottom-dwelling creatures. Vast numbers of birds frequent estuaries, especially ones with salt marshes, testament to their great productivity. Thousands of migratory birds rely on marshes during their incredibly long journeys between southern wintering grounds and arctic breeding ranges. Much of what they feed upon are the benthic organisms that are so abundant in estuaries. When marshes and dunes are developed or destroyed, the birds' survival is in jeopardy.

At first glance, all shorebirds appear to use the same food resources, but they actually divide the resources spatially so that each species can feed successfully in a different place. Shorebirds feed in different water depths. Birds with long bills and legs tend to feed in deeper water than those with shorter bills and legs. This is an example of niche separation in a community (See Niche, Section G).

SUMMARY OF INTERTIDAL FLATS:

Some benthic organisms (infauna) burrow into the substrate, some are attached immobile to the substrate (epibenthos), and some (mobile epibenthos) move around on the substrate's surface.

Primary productivity occurs in two layers on the intertidal flats, benthic diatoms and seaweeds on the surface and chemosynthetic bacteria in the sediments. Benthic animals display a variety of feeding mechanisms: deposit feeding, suspension feeding, predation, and scavenging. Most noncarnivorous benthic animals feed on plankton, bacteria, or organic detritus in the sediments or water column. Predatory infauna and epibenthos feed on other benthic animals.

The benthic community food web is not isolated from the other estuarine food webs; interactions of energy and nutrient flow occur between them, as when birds or fish feed on benthic invertebrates.

SECTION N:

Salt Marsh

The salient features of the salt marsh habitat are its waterlogged, root-filled, springy soil and its virtually flat, grassy expanses. The salt marsh community is not as diverse as that of the riverine water column, bit it does include a good number of plant species. Salt marsh plants grow in a type of soil called peat, which consists mostly of non-decomposed plant matter.

MARSH ZONATION:

Marshes are divided into two basic zones: high marsh and low marsh. High marsh is only inches higher in elevation than low marsh. The boundary between these zones lies at approximately the elevation of mean sea level. High marsh consists of peat that has accumulated, at the rate of sea level rise, on top of a foundation of ancient low marsh peat. The fringe of low marsh represents newer areas of marsh that have developed (and continue to develop) with slowly rising sealevel, extending the marsh further into the bay or river.

Low marsh is flooded by every high tide, whereas the high marsh is flooded less frequently by the high spring tides that accompany new and full moons (See Tides, Section I). Variations in flooding frequency and concomitant differences in soil salinity have a large effect on the marsh plant community (See Salinity, Section A). Different species are able to tolerate different salinities, and this affects where in the marsh each species lives. The salt marsh plant community displays a distinct pattern of zonation that is related to elevational differences of centimeters.

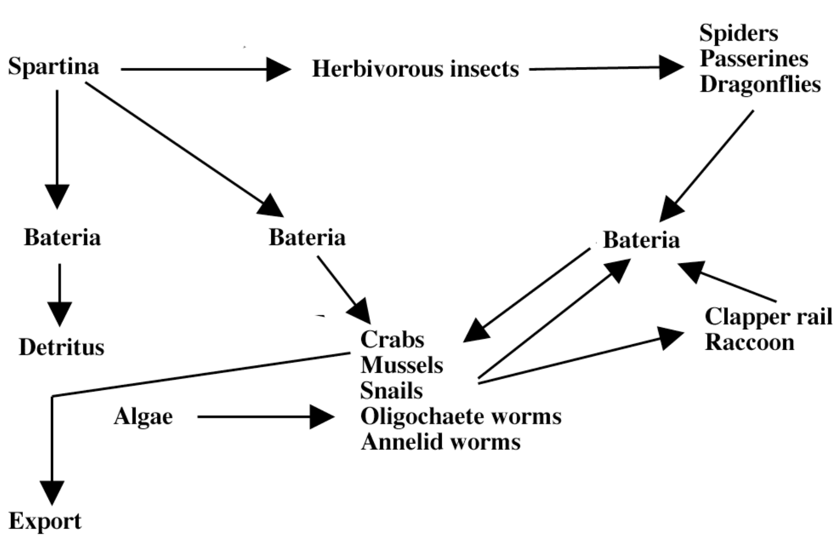
In a New England salt marsh, the highest zone lies at the upland edge of the marsh. It is home to alder, sometimes cattail, a few blueberry plants, and several grasses, all of which are less tolerant to salt and moisture than the plants in zones closer to the river. Upon entering the high marsh, the area lying between the mean water level and the extreme high tide mark, one encounters a region dominated by black rush (*Juncus gerardii*). Black rush grows in dense swaths, and its dark seed heads make it look almost black from a distance. Continuing on toward the river, on then crosses a clear line in the high marsh where salt hay (*Spartina patens*) takes over from black rush. This boundary occurs at the elevation of the highest tides of each month, the ones during the full and new moons (See Tides, Section I). *Spartina patens* is a fine-leaved grass that grows 1-2 feet tall and often lies low on the ground in cowlick swirls. It dominates its zone in the high marsh, but several other plants can also be found there, including spike grass, seaside plantain, orach, glasswort, seaside arrowgrass, seaside goldenrod, sea lavender, and milkwort. Another distinct change in vegetation occurs at the transition between high and low marsh. Smooth cordgrass (*Spartina alterniflora*)--broader-leaved and taller than salt hay and dominates the low marsh right to the river's edge. Marsh zonation is a result of species' adaptations to the environment and their ability to compete with other species.

ANIMALS:

Despite its lush vegetation, the marsh is home to relatively few terrestrial animals. Marsh grasses are thought to be low in nutritive value and to contain toxic compounds, so little of the vegetation is consumed be herbivores. Rather, most of the plats die and are deposited on the ground to become peat. Some are then washed into the water to become detritus, the base of the estuarine food web. Nevertheless, deer occasionally venture into the marsh to consume the grasses, as do grasshoppers. Canada geese graze heavily on marsh vegetation during their fall migration.

Raccoons and small mammals (e.g., shrews and mice) traverse the marsh in search of food. They are preyed upon by Northern harriers and other birds of prey. Microbes are associated with plant roots in soil, and insects are sometimes (excessively) abundant in the air. Greenhead flies and mosquitoes are especially notorious inhabitants. But in general, estuaries are known as hosts of abundant aquatic and avian, rather than terrestrial, animals. Thus, the marsh community and food web are relatively simple, but they form an important part of the overall estuarine ecosystem.

The food web of an Atlantic coast salt marsh.



SALT PANNES:

The salt pannes, or pools of water, that dot the marsh surface are an important feature of some estuaries. Pannes range in size from only a foot or two in diameter to many feet across and are irregularly shaped and sized. Some form almost perfect circles, while others have complex shorelines. They vary in depth from a few inches to a couple of feet and have soft bottoms of sand, mud or silt.

Panne creation is believed to be caused by something killing the grass, either wintertime ice floes, which scour patches of vegetation from the marsh surface, or mats of debris shielding the plants from sunlight or compaction. What's left behind is an area of unvegetated peat exposed to the sun. The sun's heat evaporates water from the soil, making it extremely saline and inhospitable to recolonization by plants. If no plants are able to establish themselves, the peat subsides and a water-filled depression, or panne, is formed.

Often, however, this process is interrupted when bare patches are invaded by glasswort (*Salicornia spp.*) and spike grass (*Distichlis spp.*). As a succulent plant glasswort readily tolerates saline soils. Spike grass avoids the salt and dryness by receiving water through underground runners from individuals living outside the bare patch. When glasswort and spike grass colonize a bare patch, they shade the soil, reducing evaporation and salinity. Other plants, generally smooth cordgrass or salt hay, can then invade, preventing panne formation.

Pannes are flooded with salt water at varying frequencies, depending on their elevation in the marsh above mean sea level and whether they are connected to the river by creeks. If a panne experiences a long period without receiving rain or sea water, evaporation and solar heating can cause the pannes to become extremely saline, warm, and low in dissolved oxygen because of evaporation and heating by the sun. This would seemingly make difficult living conditions, but mummichogs, stickleback, and eels are well adapted to them (See River, Section L). In fact, salt pannes are an important marsh habitat, providing a home for numerous plants and animals. Often pannes teem with schools of fish and support large populations of algae and widgeon grass (*Ruppia maritima*), a submerged aquatic plant. Plants and animals of the pannes, in turn, provide food for diving and wading birds.

SECTION O:

Pollution

Estuaries, like the rest of the world, are still not adequately protected form human disturbance. Salt marshes are no longer so easily and developed, but estuarine ecosystems continue to be affected by the less noticeable yet highly detrimental, problem of pollution.

Most people are aware of trash, the most visible form of pollution. Human-made debris, particularly plastics, can have negative effects on marine and estuarine environments. Ingestion of plastics can kill fish, birds, and mammals, and entanglement in plastics often leads to death or severe injury. Lost lobster traps and fragments of gill nets keep catching animals long after fishermen lose track of them. But often people become extremely concerned about debris (soda bottles, plastic wrappers, etc.) they see littering the beach without considering other types of pollution that may be even more dangerous to marine and estuarine life. Plastic bottles are definitely unsightly, and plastics are a major pollutant in the oceans.

Coliform bacteria in the water indicate the presence of fecal matter from warm-blooded animals, most likely human feces introduced by sewage disposal systems. The bacteria themselves are not harmful to humans, but they can be associated with dangerous pathogens (disease-causing agents).

Nutrients are needed to support life. But, when nutrient concentrations are unnaturally elevated in a waterbody, it can lead to a phenomenon called cultural eutrophication. Phytoplankton and other algae thrive on the additional nutrient and a bloom occurs, sometimes causing a layer of scum to cover the water.

When the phytoplankton die, they fall to the bottom in great numbers and are decomposed by bacteria, which deplete the dissolved oxygen in the water. Bottom-dwelling animals like shellfish then die from lack of oxygen.

TYPES OF POLLUTION:

Heavy metals (e.g., mercury, cadmium, chromium, copper, zinc, and lead) accumulate in estuarine and marine sediments. Eating shellfish and benthic fish contaminated with heavy metals endangers human health.

Chlorine, usually from water and sewage treatment plants, is toxic to estuarine organisms and even tiny amounts can affect fish migrations.

Petroleum derivatives like polynuclear aromatic hydrocarbons (PAHs) cause mutations and cancer.

Biocides (pesticides and herbicides) are widely used to kill undesirable organisms and often unintentionally enter aquatic systems.

Synthetic compounds like paints, household chemicals, and PCBs (polychlorinated biphenyls) can persist and accumulate in marine environments. They act alone and in combination to harm aquatic organisms.

Sediments suspended in water block transmission of light needed for photosynthesis by phytoplankton, seaweeds, and aquatic plants rooted in the bottom. The feeding structures of filter feeders (e.g. clams and mussels) and particulate feeders (e.g. zooplankto) become clogged by sediments, and fish gills can be damaged by the particles.

Temperature pollution occurs when heated water, used to cool power plants is discharged into aquatic systems. It can endanger estuarine organisms.

POINT AND NON-POINT SOURCE POLLUTION:

Pollutants are introduced into estuaries from either point sources or non-point sources. Point sources are clearly defined, localized inputs such as pipes, industrial plants, sewer systems, oil spills from tankers, and aquaculture ventures. The federal and state governments regulate them. Non-point sources are indistinct inputs that do not have a clearly defined source, such as runoff of petroleum products from roadways or pesticides from farmland. Less blatant that big, sludge-spewing pipes, non-point sources might be considered more insidious than point sources because they are harder to detect and control. A majority of pollutants find their way into estuaries from non-point sources.

Pollutants clearly pose a large threat to estuarine organisms. Government efforts to deter pollution are challenged by the sheer number of pollutants and polluters, as well as the difficulty of identifying non-point sources. Reduction of pollution requires substantial individual and collective efforts. This entails changing our lifestyles and decreasing our dependence on the use of potential pollutants.

Glossary

A:
Abiotic factors**:** non-living characteristics of a habitat or ecosystem that affect organisms' life processes (see Section A, Abiotic Factors).
Adaptation**:** a genetically-based body feature or behavior that allows an organism to be better suited to its environment (see Section F, Adaptation).
American eel**:** *Anguilla rostrata* (see Section L, River).
Amphipods**:** small shrimp-like crustaceans.
Anoxic**:** without oxygen, anaerobic (see Section A, Abiotic Factors).
Anthropogenic**:** arising from human activity (see Section O, Pollution).
Aquatic organisms**:** organisms that live in or on the water (see Section L, River).
Atlantic silversides**:** *Menidia menidia* (see Section L, River).
Autotrophs**:** "self-feeders" such as plants and some bacteria (see Section D, Food Webs).

B:
Back dune**:** area immediately behind fore dune; inhabited by mixture of grasses, beach heather and lichen (see Section K, Barrier Beaches).
Bar-built estuaries**:** areas where sandbars form parallel to the shore, partly enclosing the water behind them as the sandbars become islands (see Section H, Geologic Formation).
Barrier beaches**:** spits of sand that form parallel to the shore (see Section K, Barrier Beaches).
Bathymetry**:** the underwater landscape, including submerged mountains and flat areas.
Beach/Ocean interface**:** where waves meet beach (see Section L, Barrier Beaches).
Benthic: (adj.) relating to the ocean bottom.
Benthos: bottom-dwelling flora and fauna; from tiniest microbenthos (bacteria) to medium-sized meiobenthos (nematode worms) to the highly visible macrobenthos (clams, polychaete worms) (see Section M, Mudflat and Sandflat).
Biocides**:** chemical compounds used to kill organisms (See Section O, Pollution).
Biotic factors**:** relationships among organisms that affect their survival (See Section B, Biotic Factors).

C:
Carnivores**:** animals that eat other animals as opposed to herbivores, which eat only plants (see Section D, Food Webs).
Chlorine**:** poisonous, gaseous substance (see Section O, Pollution).
Cladocera**:** order of carnivorous zooplankton, crustaceans.
Coastal plains estuary**:** estuary formed when rising sea level flooded existing river valley (see Section H, Geologic Formation).
Coccolithophore: common type of phytoplankton.
Coliform bacteria**:** bacteria commonly found in colon and used as an indicator of water contamination (see Section O, Pollution).
Commensalism**:** form of relationship in which one species gains from the interaction and the other is neither positively nor negatively affected (see Section B, Biotic Factors).
Community**:** an association of interacting populations (see Section C, Population/Community/Habitat/Ecosystem).
Competition**:** occurs between organisms using a finite resource, whether they are of the same or different species (see Section B, Biotic Factors).
Conditions**:** characteristics of the environment that influence the survival of an organism but are not consumed by it (e.g., temperature, salinity)(see also "Resources").
Consumer: individual that eats other organisms to obtain energy rather than producing its food through photosynthesis or chemosynthesis (see Section D, Food Webs).
Copepods**:** one of most common herbivorous zooplankton.
Cormorant**:** *Phalacrocorax carbo*; common sea bird.
Crustaceans**:** anthropods having hard-shelled bodies and jointed ligaments such as crabs, shrimp and lobsters.

D:
Desiccation**:** loss of water (see Section B, Biotic Factors).
Detritus: newly dead or decaying organic matter coated with bacteria (see Section L, River).
Diatoms**:** one of most common groups of phytoplankton; single-celled organism that reproduces asexually.
Dinoflagellates**:** common type of phytoplankton, most abundant in fall; responsible for “red tides” as well as bioluminescence.
Disturbance: any event that opens up space for colonization, such as the falling of a tree in a forest or removal of marsh grass by storm waves (see Section E, Disturbance).

E:
***Ecosystem*:** the biotic community and its abiotic environment (see Section C, Population/Community/Habitat/Ecosystem).
***Epibenthos*:** organisms that live on the bottom, rather than burrowed into, of an aquatic system (see Section M, Mudflat and Sandflat).
***Estuary*:** A semi-enclosed body of water which has a free connection to the open sea and within which seawater is measurably diluted by fresh water derived from land drainage.

F:
***Fjords*:** a glacial trough valley now flooded with seawater to create a steep-walled inlet (see Section H, Geologic Formation).
Food chain: a representation of the flow of energy between producers, consumers, and decomposers (see Section D, Food Webs).
***Food web*:** a representation of the linkages between food chains in a community (see Section D, Food Webs).
***Foredune zone*:** the area between mean high water and the crest of the frontal dune (see Section K, Barrier Beaches).
***Foreshore*:** the area between mean low water and mean high water (see Section K, Barrier Beaches).
***Frontal dune*:** the dune closest to the water's edge (see Section K, Barrier Beach).

G:
Gastropod: one of a class of mollusks that includes the snails and nudibranchs.
***Groundwater*:** water contained below ground in soil and rock (see Section J, Watershed).
***Gulf of Maine*:** a rectangular embayment of coastal shelf water covering 90,700 square kilometers. Bounded on the north and west by the coastline from Cape Cod, Mass. to Cape Sable, Nova Scotia and on the east and south by Georges Banks.

H:
***Habitat*:** the place where an organism lives (see Section C, Population/Community/Habitat/Ecosystem).
***Haul-out*:** an area on the shore where marine mammals rest.
***Heavy metals*:** metals such as cadmium, chromium, copper, zinc, mercury, lead, that may contaminate a water body and thus endanger organisms (including people) using the water (see Section O, Pollution).

Herbivore: an animal that eats plants (see Section D, Food Webs).
Heterotrophs**:** feed on others; mostly animals; eat autotrophs (see Section D, Food Webs).
High marsh: the area of the marsh flooded infrequently by the high tides associated with new and full moon. In Gulf of Maine, dominated by *Spartina patens* (see Section N, Salt Marsh).

I:
Infauna**:** organisms living between the grains of sand or mud (see Section M, Mudflat & Sandflat).
Isopods**:** aquatic crustaceans with flat, oval body and seven pairs of legs.

J:
Jellyfish**:** carnivorous zooplankton; common in Gulf of Maine and Wells Reserve.

L:
Light: energy source used by plants to form carbohydrates, an important abiotic factor (see Section A, Abiotic Factors).
Low marsh**:** the area of marsh flooded twice daily by tides and dominated by *Spartina alterniflora* in Gulf of Maine region (see Section N, Salt Marsh).

M:
Maritime forest**:** forest dominated by pitch pine and located on the mainland side of a barrier beach or island (see Section K, Barrier Beaches).
Mobile epibenthos**:** bottom-dwelling animals that move on top of sediments: crabs, shrimp, snails, amphipods, isopods (see Section N, Salt Marsh).
Mudflat**:** part of benthic (bottom) zone exposed at low tide and comprised of extremely fine sediments (see Section M, Mudflat and Sandflat).
Mummichogs**:** *Fundulus heteroclitus;* small salt-marsh fish common in the Gulf of Maine region (see Section L, River).
Mutualism**:** form of relationship in which both species involved gain from the interaction (example: lichen) (see Section B, Biotic Factors).

N:
Natural selection**:** the differential survival and/or reproduction of individuals within a population based on hereditary characteristics (see Section F, Adaptation).

Nekton**:** all aquatic animals that can swim through the water against currents: marine mammals, fish, squid and some crustaceans (see Section L, River).
Niche**:** the role of a species within a community (see Section G, Niche).
Non-point source pollution**:** water pollution arising from indistinct sources such as petroleum products from roadways or pesticides from farmland (see Section O, Pollution).
Nursery**:** term used colloquially to refer to estuaries. Many fish species are dependent on estuaries for part of their lives.
Nutrients**:** substances required by organisms in order to grow and survive (see Section A, Abiotic Factors).

O:
Omnivores**:** animals that feed at several levels of food web; diet includes a mix of living and/or dead plants and animals (See Section D, Food Webs).
Oxygen**:** used in respiration, the process in which organisms release stored chemical energy (see Section A, Abiotic Factors).

P:
Panne**:** small pond or pool in the salt marsh (see Section N, Salt Marsh).
Parasitism**:** similar to predation in that one species benefits from the relationship and the other is harmed; differs from predation in that parasitism generally not fatal to adversely affected organism (see Section B, Biotic Factor).
Peat**:** soil in marsh composed of partially decayed moisture-absorbing plant matter (see Section H, Geologic Formation).
Petroleum derivatives**:** toxic pollutants from crude oil products; mixture of hydrocarbons, which are organic solvents (see Section O, Pollution).
Photosynthesis**:** process of using energy in sunlight to convert water and carbon dioxide into carbohydrates and oxygen (see Section A, Abiotic Factor).
Phytoplankton**:** floating aquatic photosynthetic organisms (see Section L, River).
Pioneer species**:** plant species that first invades unvegetated area (see Section K, Barrier Beaches).
Pipefish: elongate fish related to seahorses (see Section L, River).
Plankton**:** free-floating organisms drifting in water, unable to swim against currents (see Section L, River).
Point source pollution**:** pollution from a clearly defined, localized source such as a sewage outfall (see Section O, Pollution).

Pollution: contamination of natural environment (see Section O, Pollution).
Population: all the individuals of a particular species within a defined area (see Section C, Population/Community/Habitat/Ecosystem).
Predation: the killing and/or consumption of living organisms by other living organisms (see Section D, Food Webs).
Primary dune: foredune; dune closest to water's edge.
Producer: autotroph; organism that creates energy-rich compounds from sunlight (through photosynthesis) or certain chemicals (through chemosynthesis); first level in any food web; in estuarine systems, most abundant producers are phytoplankton (see Section D, Food Webs).

R:
Resource: entity (e.g., food, light, water, space) that an organism uses or consumes during its lifetime (see Section G, Niche).
Respiration: process that, using oxygen, releases stored chemical energy to power an organism's life processes; opposite reaction of photosynthesis (see Section A, Abiotic Factors).
Response: ecological responses are behavioral and physical changes that happen during the lifetime of a single organism and increase individual's chance of survival as opposed to evolutionary adaptation, which takes place over multiple generations and is a result of a change in the species genetic makeup (see Section F, Adaptation).
Runoff: precipitation that drains into a water body from the surface of the surrounding land (see Section J, Watersheds).

S:
Salinity: the concentration of salts dissolved in salt water.
Salt marsh: wetland flooded regularly by tidal, brackish water (see Section N, Salt Marsh).
Sand eel: *Ammodytes americanus;* Americ*a*n sand lance (see Section L, River).
Sandflat: area of bottom of aquatic system that is exposed by low tides and composed of sand - particles of sediment larger than those of mud (see Section M, Mudflat and Sandflat).
Scud: *Scud gammarus;* a type of amphipod to one inch that live in masses of seaweed, scuttle under rocks, and swim on their sides in tide pools.
Sediments: particles deposited by wind or water (see Section O, Pollution).
Shags: *Phalacrocorax auritus*; sea bird similar to cormorant.
Silversides: *Menidia spp.*; small schooling fish that spawn in estuaries in April/May, then return to sea; young fish stay in estuary until September.

Space**:** resource needed by all organisms; most pronounced need by organisms that require substrate (see Section A, Abiotic Factors).
Speciation**:** formation of new species through natural selection; occurs when selective force is intense; accounts for diversity of living things on planet today (see Section F, Adaptation).
Sticklebacks**:** *Gasterosteidaa spp.;* small estuarine fish named for spines that line the dorsal fin; three species found at Wells Reserve (see Section L, River).
Sublittoral zone**:** portion of rocky shore always submerged (see Section K, Barrier Beaches).
Substrate**:** the surface on which an organism grows.
Succession: progressive replacement of populations in a habitat (see Section E, Disturbance).
Surface water**:** water in streams, brooks, rivers, ponds and lakes, etc. (see Section J, Watersheds).
Swash zone**:** part of foreshore washed by waves (see Section K, Barrier Beaches).
Synthetic compounds**:** manufactured compounds (see Section O, Pollution).

T:
Tectonic estuaries: land flooded by sea due to subsidence, not sea-level rise (see Section H, Geologic Formation).
Temperature**:** important abiotic factor affecting distribution and abundance of organisms; influences metabolic rate and affects rates of growth and reproduction (see Section A, Abiotic Factors).
Tidal height**:** difference between water level at high tide and mean sea level, the average height of the ocean (see Section I, Tides).
Tidal range**:** difference between high and low tide (see Section I, Tides).
Tides**:** periodic rise and fall of ocean waters due to gravitational pull of sun and moon, and rotation of earth (see Section I, Tides).
Trophic level**:** level in a food chain, e.g., producer, primary consumer, secondary consumer, tertiary consumer (see Section D, Food Webs).

U:
Uplands**:** lands lying above the reaches of the highest high tides.

V:
Vertical stratification**:** laying of fresh water on top of salt water, also known as “salt wedge” effect; occurs when the fresh and salt water is not vigorously mixed together by turbulence.

W:
Water**:** a molecule-composed compound of hydrogen and oxygen, (see Section A, Abiotic Factors).
Watersheds**:** area of land drained by a river or river system (see Section J, Watersheds).
Wrack line: a string of debris stranded by last high tide; cast ashore seaweeds, isolated sources of food and shade support an important community of isopods and amphipods as well as providing food for birds. (see Section K, Barrier Beaches).

Z:
Zonation**:** distribution of plants or animals arranged in zones or bands, caused by gradations of abiotic and/or biotic factors.
Zooplankton**:** animals, often small or microscopic, that drift with the currents, may be either herbivores or carnivores (see Section L, River).