Teacher Guide—Life Science Module
Activity 1: Survival in an Estuary

Featured NERRS Estuary:
Elkhorn Slough National Estuarine Research Reserve, CA
http://nerrs.noaa.gov/Reserve.aspx?ResID=ELK

Activity Summary

In this activity, students investigate the range of conditions that selected animal and plant species need to survive in an estuary. They examine data for abiotic factors that affect life in estuaries—salinity, dissolved oxygen, temperature, and pH. Students use archived data (trend analysis graphs) and real-time conditions at the Elkhorn Slough National Estuarine Research Reserve (NERR) to predict whether a particular animal or plant species could survive in an estuary.

Learning Objectives

Students will be able to:

1. Describe three types of estuarine environments.
2. Describe the particular environmental conditions necessary for organisms to survive in an estuary.
3. List four principal abiotic factors that influence the survival of aquatic life in estuaries.
4. Determine the range of pH, temperature, salinity, and dissolved oxygen tolerated by some common estuarine species.

Grade Levels

9-12

Teaching Time

3 (55 minute) class sessions + homework

Organization of the Activity

This activity consists of 4 parts which help deepen understanding of estuarine systems:

The Estuarine Environment

Surviving Changes: Abiotic Factors that Affect Life

Surviving in an Estuary: Extreme Conditions

Optional: Investigating Other NERRS sites

Background

This activity introduces students to the nature of estuaries, estuarine environmental factors, and four important abiotic factors—pH, temperature, dissolved oxygen, and salinity—and how they vary in estuaries. The study centers on Elkhorn Slough National Estuarine Research

Reserve (NERR) in California. Elkhorn Slough is one of the relatively few coastal wetlands remaining in California. The main channel of the slough, which winds inland nearly seven miles, is flanked by a broad salt marsh second in size in California only to San Francisco Bay.

The reserve lands also include oak woodlands, grasslands and freshwater ponds that provide essential coastal habitats that support a great diversity of native organisms and migratory animals.

Review of Abiotic Factors

What follows is some basic information about four abiotic factors.

pH

pH is a measure of how acidic or basic a solution is. The pH scale ranges from 0 to 14. Solutions with a pH of less than 7 are acidic, and those with a pH greater than 7 are basic (or alkaline).

Knowledge of pH is important because most aquatic organisms are adapted to live in solutions with a pH between 5.0 and 9.0. The pH in an estuary tends to remain relatively constant because the chemical components in seawater resist large changes to pH. Biological activity, however, may significantly alter pH in the freshwater portions of the estuary.

pH is actually a measure of the amount of hydrogen ions in a solution. In fact, some people think of pH as being the “power of hydrogen.” A lower pH indicates that there are more free hydrogen ions in the water, which creates acidic conditions, and a higher pH indicates there are less free hydrogen ions, which creates basic conditions. pH is equal to the negative logarithm of the hydrogen ion activity, meaning that the hydrogen ion concentration changes tenfold for each number change in pH unit. Water on the surface of Earth is usually a little acidic or basic due to both geological and biological influences.

Through a process called photosynthesis, plants remove carbon dioxide (CO_2) from the water and emit oxygen (O_2). Since CO_2 becomes carbonic acid when it dissolves in water, the removal of CO_2 results in a higher pH, and the water becomes more alkaline, or basic.

When algae naturally begin to increase in estuaries as they may do when days lengthen and the water temperature rises in spring, pH levels tend to rise. Respiration, on the other hand, releases CO_2 into the water, thus resulting in a lower pH, so pH levels may drop during the summer nights.

All aquatic organisms have a pH range to which they are adapted. Outside of this range, critical biological processes may be disrupted, leading to stress and death. Most organisms cannot live below a pH of 5 or above a pH of 9. Additionally, pH is used to monitor safe water conditions. Once the background range of pH has been established, a rise or fall in pH may indicate the release of a chemical pollutant, or an increase in acid rain. Additionally, pH affects the solubility, biological availability, and toxicity of many substances. For example, most metals are more soluble, and often more toxic, at lower pH values.

Temperature

Just knowing the temperature of the water in an estuary can give us a pretty good idea of how healthy it is. One important thing we can tell from water temperature is how much oxygen can be dissolved into the water.

Dissolved oxygen is critical for the survival of animals and plants that live in the water. As the water temperature increases, the amount of oxygen that can dissolve in the water decreases. For example, 100 % saturated fresh water at 0°C contains 14.6 mg of oxygen per liter of water, but at 20°C, it can only hold 9.2 mg of oxygen per liter. Because dissolved oxygen is critical for survival, seasonal water temperature (and dissolved oxygen) is an important indicator of habitat quality for many estuarine species.

The temperature of the water also tells us what types of plants and animals are able to live in the estuary. All plants and animals have a range of temperatures in which they thrive and reproduce. For instance, salmon will only breed at temperatures below 18°F. If the water in the estuary is outside the normal seasonal temperature range in which most estuarine organisms can comfortably live, it is probably an indication that something is adversely affecting the health of the estuary.

Differences in water temperature cause the formation of distinct, non-mixing layers in water, otherwise known as stratification, because the density of water changes with temperature. This stratification leads to chemically and biologically different regions in water.

Dissolved Oxygen

To survive, fish, crabs, oysters and other aquatic animals must have sufficient levels of dissolved oxygen (DO) in the water. The amount of dissolved oxygen in an estuary's water is the major factor that determines the type and abundance of organisms that can live there.

Oxygen enters the water through two natural processes: (1) diffusion from the atmosphere and (2) photosynthesis by aquatic plants. The mixing of surface waters by wind and waves increases the rate at which oxygen from the air can be dissolved or absorbed into the water.

DO levels are influenced by temperature and salinity. The solubility of oxygen, or its ability to dissolve in water, decreases as the water's temperature and salinity increase. Therefore, DO levels in an estuary can also vary seasonally, with the lowest levels occurring during the late summer months when temperatures are highest.

Bacteria, fungi, and other decomposer organisms can reduce DO levels in estuaries because they consume oxygen while breaking down organic matter. Oxygen depletion may occur in estuaries when many plants die and decompose, or when wastewater with large amounts of organic material enters the estuary. In some estuaries, large nutrient inputs, typically from wastewater, stimulate algal blooms. When the algae die, they begin to decompose. The process of decomposition depletes the surrounding water of oxygen and, in severe cases, leads to hypoxic (very low oxygen) conditions that can kill aquatic animals. Shallow, well-mixed estuaries are less susceptible to this phenomenon because wave action and circulation patterns supply the waters with plentiful oxygen.

Salinity and Conductivity

Under laboratory conditions, pure water contains only oxygen and hydrogen atoms, but in the real world, many substances, like salt, are dissolved in water. Salinity is the concentration of salt in water, usually measured in parts per thousand (ppt). The salinity of seawater in the open ocean is remarkably constant between 30 and 35 ppt. Salinity in an estuary varies according to one's location in the estuary, daily and storm-driven tides, and the volume of fresh water flowing into the estuary.

Salinity and conductivity are closely related. Both measure the water's ability to conduct electricity, which is a surrogate measure estimating the quantity of salts dissolved in the water. Conductivity is a more sensitive measure (parts per million or less) than salinity (parts per thousand or greater). Pure water is a very poor conductor of electrical current, but salts such as sodium, calcium, magnesium, and chloride, dissolved in the water are in ionic (charged) form and conduct electrical current. Conductivity, which is the opposite of resistance, measures the ability of water to conduct current. A higher conductivity indicates less resistance, and means that electrical current can flow more easily through the solution.

In saltwater estuaries, salinity and conductivity levels are generally highest near the mouth of a river where ocean water enters, and lowest upstream where freshwater flows in. Actual salinities vary throughout the tidal cycle, however, because as the tide rises more ocean water enters the estuary. In saltwater estuaries, salinity and conductivity typically decline in the spring when snowmelt and rain increase the freshwater flow from streams and groundwater. In freshwater estuaries, salinity or conductivity is normally the reverse. The waters of the Great Lakes have a lower salinity that the streams and rivers flowing into them. Lake water intrusion due to storm surges or seiches results in lower salinity near the mouth of the estuary. During storms and the resulting runoff, both salinity and conductivity levels usually decrease, as rainwater and the resulting surface runoff are very low in salts. Although this decrease is measurable in freshwater estuaries, it does not have the same ecological impact that it would in a marine estuary. Salinity and conductivity are frequently higher during the summer when higher temperatures increase levels of evaporation in the estuary.

Conductivity and salinity are dependent on many factors, including geology, precipitation, surface runoff, and evaporation. Conductivity, because it is a much more sensitive measurement, is also very temperature dependent. It increases as water temperature increases because water becomes less viscous and ions can move more easily at higher temperatures. Because of this, most reports of conductivity reference specific conductivity. Specific conductivity adjusts the conductivity reading to what it would be if the water were 25°C. This is important for comparing conductivities from waters with different temperatures.

Environmental factors that increase conductivity and salinity include: increased temperature, fertilizers from agriculture, sewage, road runoff containing automobile fluids and de-icing salts, and a local geology high in soluble minerals, such as carbonates. Conductivity and salinity also increase due to evaporation. The Great Salt Lake in Utah is an extreme example of how evaporation can increase salinity. On warm days, the evaporation of water concentrates the ions that remain behind, resulting in water with higher conductivity and salinity. Often, small diurnal fluctuations in conductivity and salinity are seen as a result of evaporation during the day and condensation and groundwater recharge at night. In saltwater estuaries, the influx of ocean water due to rising tides increases salinity and conductivity within the estuary.

Estuarine organisms have different tolerances and responses to salinity changes. Many bottom-dwelling animals, like oysters and crabs, can tolerate some change in salinity, but salinities outside an acceptable range will negatively affect their growth and reproduction, and ultimately, their survival.

Salinity also affects chemical conditions within the estuary, particularly levels of dissolved oxygen in the water. The amount of oxygen that can dissolve in water, or solubility, decreases as salinity increases. The solubility of oxygen in seawater is about 20 percent less than it is in fresh water at the same temperature.

- Adapted from the NOAA/NOS Estuary Discovery Kit..
URL:http://oceanservice.noaa.gov/education/kits/estuaries/estuaries10_monitoring.html. Accessed: 2008-07-20.
(Archived by WebCite® at http://www.webcitation.org/5ZSbp3lvp)

Materials

Students

- ❑ Need to work in a computer lab or with a computer and projector
- ❑ Copy of the *Student Reading 1 Introduction to South Marsh*
- ❑ Copy of the *Student Reading 2 Survival in an Estuary*
- ❑ *Copy of Student Worksheet Survival in an Estuary*
- ❑ Copy of *Data* Sheet South Marsh at Elkhorn Slough 2004-05

Teachers

- ❑ Download the PowerPoint presentation entitled *Survival in an Estuary. (*To find the presentation go to the Estuaries.noaa.gov website, choose the Curriculum tab, click on the sub-tab titled High-School Curriculum, Life Science and find the presentation under “Supporting Materials”.)
- ❑ Old Woman Creek SWMP tutorial. (To find the tutorial go to the Estuaries.noaa.gov Web site, choose the Curriculum tab, click on Tutorials, and then find the “Monitoring Tutorial”)
- ❑ Bookmark the site: <http://estuaries.noaa.gov/ScienceData/Graphing.aspx>.

Equipment:
- ❑ Computer lab or
- ❑ Computer and Projector

National Science Education Standards

Content Standard A: Science as Inquiry

A3. Use technology and mathematics to improve investigations and communications.

A4. Formulate and revise scientific explanations using logic and evidence.

A6. Communicate and defend a scientific argument.

Content Standard C: Life Science

C4. The interdependence of organisms
C5. Matter, energy, and organization in living systems
C6. The behavior of organisms

Content Standard E: Science and Technology

E2. Apply and adapt a variety of appropriate strategies to solve problems

Preparation

- Download the PowerPoint presentation entitled *Survival in an Estuary*, and prepare to project it in front of the class.
- Review the Old Woman Creek SWMP tutorial (on the Estuaries.noaa.gov Web site. This is a large file, please be patient downloading it). Students will be shown sections of the tutorial to visually explain abiotic parameters to students.
- If possible, arrange for students to have access to online data either by obtaining a computer projector to present the data in front of the whole class or by arranging for student groups to view the data on individual computers. On the computer(s), bookmark the site: <http://estuaries.noaa.gov/ScienceData/Graphing.aspx>. Static data are also provided in this guide if arranging computer access is difficult.
- Make copies of the *Student Reading*, *Student Worksheet*, and *Student Data Sheet*. The graphs on the *Student Data Sheet* can alternatively be projected in front of the class.

Procedure

Part 1 — The Estuarine Environment

1a. Ask the students what resources and conditions they need to survive in their environment. They will probably mention food, water, warm clothes, etc. They may forget things like oxygen to breathe, and the right array of vitamins and minerals, amino acids, and other chemical compounds needed to maintain good health. Choose an estuarine animal or plant and ask students to suggest factors such as temperature that affect conditions in its habitat. List them on the board. Bring up the water quality factors used in this activity if students do not include them:

- temperature
- pH
- salinity
- dissolved oxygen.

For your information, the student worksheet contains a list of specific conditions necessary for survival for selected species.

1b. Show students the Old Woman Creek SWMP tutorial sections that deal with SWMP data and water quality factors.

2. Show the PowerPoint *Survival in an Estuary* and ask students to describe the environment they see. Ask some probing questions as they view the slides:
   - What are the water conditions like—deep or shallow, wide or narrow, salty or fresh?
   - What is the biological community like—rich and abundant, sparse, or in between?
   - Have students read the introductory section of their handout.

3. Have students complete Part 1 of the *Student Worksheet—Survival in an Estuary*.

4. Have students read the *Student Reading—Survival in an Estuary* and *Student Reading—Introduction to South Marsh.*

Part 2 — Survival Changes: Abiotic Factors that Affect Life

5. Go over the graphs on the *Student Data Sheet—South Marsh at Elkhorn Slough 2004-5*, discussing the units on the axes: the y-axis of each graph is different; the x-axis of each graph represents one year of time at South Marsh in the Elkhorn Slough.

6. Have students complete Part 2 of the *Student Worksheet—Survival in an Estuary.*

7. Review and discuss the Part 2 tasks and questions.

Part 3 — Surviving in an Estuary: Extreme Conditions

8. Use the following procedure to have students access or display in front of the class the graphs that show the actual values, measured by buoy, of the four factors: water temperature, pH, salinity, and dissolved oxygen.
   - Go to <http://estuaries.noaa.gov/ScienceData/Graphing.aspx> to find the graphing tool and click on the tutorial to learn how to generate a graph.
   - Choose the type of data: water for water quality parameters and then click on "CA, Elkhorn Slough, South Marsh"

Teacher Notes:

- To find whether a station will have today's data we recommend checking this link first: http://www.estuaries.gov/ScienceData/Data.aspx
- If you cannot access today's gauge data, use data for 10/4/07. You will need to choose, at minimum, one day's worth of data. You may want to increase the amount of data that students analyze and compare by adding several more days, months or years' worth of data.

Timestamp: 10/04/2007 06:15	Salinity: 31.3 ppt
Water Temp: 17.1 C	Dissolved Oxygen: 5.3 mg/l
Percent Saturation: 66.8 %	Depth: 1.72 meters
Turbidity: 5 NTU	pH: 8.2 units the student handouts section.
Specific Conductivity: 47.98	

   - Project the buoy data on the screen and assist students in interpreting the readings.

9. Have students complete Part 3 of the *Student Worksheet—Survival in an Estuary.*

Check for Understanding

1. Direct your students to the Data Graphing Tool on estuaries.noaa.gov: <http://estuaries.noaa.gov/ScienceData/Graphing.aspx>. Help students navigate through the site until they can successfully download trend analysis data for 2005 from one monitoring station at four other NERR sites. Encourage them to choose sites both in your region and in other parts of U.S. coastal areas. OR, download sample data from four sites and hand them out to students.
2. Direct students to fill out an *Extreme Conditions* table for each site.
3. Have students create graphs comparing parameter ranges and time between extremes for new sites with South Marsh data.
4. Discuss with students the patterns they see and ask them to explain why the ranges and rates of change for each factor vary at different estuary sites. Or ask them to write their answers down and collect student work to serve as a summative evaluation for this activity.

Optional Extension Inquiries

- Locate a local water source (pond, river, stream, or lake) close to your school.
- Have students monitor water temperature, pH, salinity, and DO (if possible) daily or weekly over an extended period of time.
- Direct students to graph their summary data and then compare their data to the variation of parameters in the NERR sites featured in this activity.
- Discuss with students the differences in water quality between your local site and that of the NERR sites. Is your local water source habitable for all animal species featured in this activity? What could be done to improve the water quality in your local water source?

Teacher Worksheet with Answers
Activity 1: Survival in an Estuary

1a. Why is it important to monitor abiotic factors in estuarine environments?

Answer: It is important to monitor parameters such as pH, temperature, salinity, and DO because each of these factors must remain within a certain range to ensure the survival of species living in the estuary. Each of these parameters can exceed their normal range when either natural (storms, floods) or human-caused events (runoff from farms, factories, power plants, sewage treatment facilities) occur.

1b. Based on your observations of the images, describe the environment of species living in an estuary. Consider factors such as temperature, water flow, salinity, and weather to name a few.

Answer: Estuaries are complex environments in which diverse species exist or vanish depending on physical and chemical factors. The environment of South Marsh is governed by large swings of temperature and other factors due to seasonal changes. Student answers about their organism will vary.

1c. How is surviving in an estuary different than surviving in a forest, a desert, or in the open ocean?

Answer: Surviving in an estuary is difficult. In an estuary, environmental factors can change rapidly. Conditions in estuaries vary more than in many other types of habitats. Dramatic changes in pH, salinity, and temperature occur frequently and regularly in estuaries. In deserts or the open ocean, conditions are more stable and changes usually take place more slowly.

2. Choose one animal that was highlighted in the images of Part 1. What strategies and adaptations do you think your chosen aquatic species uses to cope with changing abiotic conditions in South Marsh?

Answer: Answers will vary. Hibernation might be mentioned as a strategy to cope with cold, wintry conditions. Some plants such as cordgrass have special filters in their root system that removes salt from the water it absorbs in from the saltmarsh. Bivalves like mussels, clams, and oysters close their shells during low tide and stop feeding and change their method of respiration until they are again covered with seawater. Some aquatic species can migrate to areas with more favorable conditions and move up river or down depending on the salinity at a particular time.

3a. After examining the range of tolerance information for five estuarine species, which of the five organisms do you think would thrive in the abiotic conditions of South Marsh today? Which could survive over the course of a year?

Answer: Answers will vary depending on the current abiotic data.

3b. Review the two-year data set for each abiotic factor in this activity. Choose whether each of the five species on your list is:

i) likely to survive and live in South Marsh

ii) might do fairly well

iii) doubtful to survive given the long-term environmental conditions of South Marsh.

Explain your reasoning for each species.

Answer:

oysters = Salinity of the water is uniformly too high for oysters.

clams = Water temperatures are too cold for clams to spawn.

alewife = DO levels are on the low side.

blue crab = Yes, all factors are within the survival limits of a blue crab.

cohoe salmon = DO somewhat low for salmon, average temperature is too high even though the salinity is good.

Student Reading—1
Activity 1: Introduction to South Marsh

South Marsh is part of the Elkhorn Slough National Estuarine Research Reserve in California. The South Marsh Complex is located on the southeastern side of Elkhorn Slough. The entire complex is approximately 415 acres in size. Mudflat areas with some subtidal creeks, fringing tidal marsh, and created tidal marsh islands dominate the main areas.

Elkhorn Slough is one of the relatively few coastal wetlands remaining in California. The main channel of the slough, which winds inland nearly seven miles, is flanked by a broad salt marsh second in size in California only to San Francisco Bay.

The reserve lands also include oak woodlands, grasslands and freshwater ponds that provide essential coastal habitats that support a great diversity of native organisms and migratory animals.

Figure 1. Satellite view of Elkhorn Slough NERR

More than 400 species of invertebrates, 80 species of fish, and 200 species of birds have been identified in Elkhorn Slough. The channels and tidal creeks of the slough are nurseries for many species of fish.

At least six threatened or endangered species utilize the slough or its surrounding uplands, including peregrine falcons, Santa Cruz long-toed salamanders, California red-legged frogs, brown pelicans, least terns, and sea otters.

Additionally, the slough is on the Pacific Flyway, providing an important feeding and resting ground for many types of migrating waterfowl and shorebirds. The slough and surrounding habitat are renowned for their outstanding birding opportunities.

Many habitat types are located within a short distance from the slough. Upland hills with oak, pine, eucalyptus, grassland and maritime chaparral surround the slough. Several thousand acres of salt marsh, tidal flats and open water comprise the main channel of the slough. Beach and sand dunes separate the estuary from Monterey bay. Riparian habitat is also found on the reserve. Agricultural lands and residential areas border the reserve. The close proximity of these varied habitats supports a remarkable diversity of plant and animal species in a relatively small area.

Figure 2. South Marsh is in the foreground of this image.

Figure 3. The Elkhorn Slough National Estuarine Research Reserve encompasses only 1400 acres of marsh and upland habitat in the top right corner of this image. The rest of Elkhorn Slough and the surrounding lands are owned and managed by a variety of other individuals and entities including the California Department of Fish and Game, The Nature Conservancy, the Elkhorn Slough Foundation, the Moss Landing Harbor District, and the Monterey Bay National Marine Sanctuary

— Adapted from http://nerrs.noaa.gov/ElkhornSlough/welcome.html

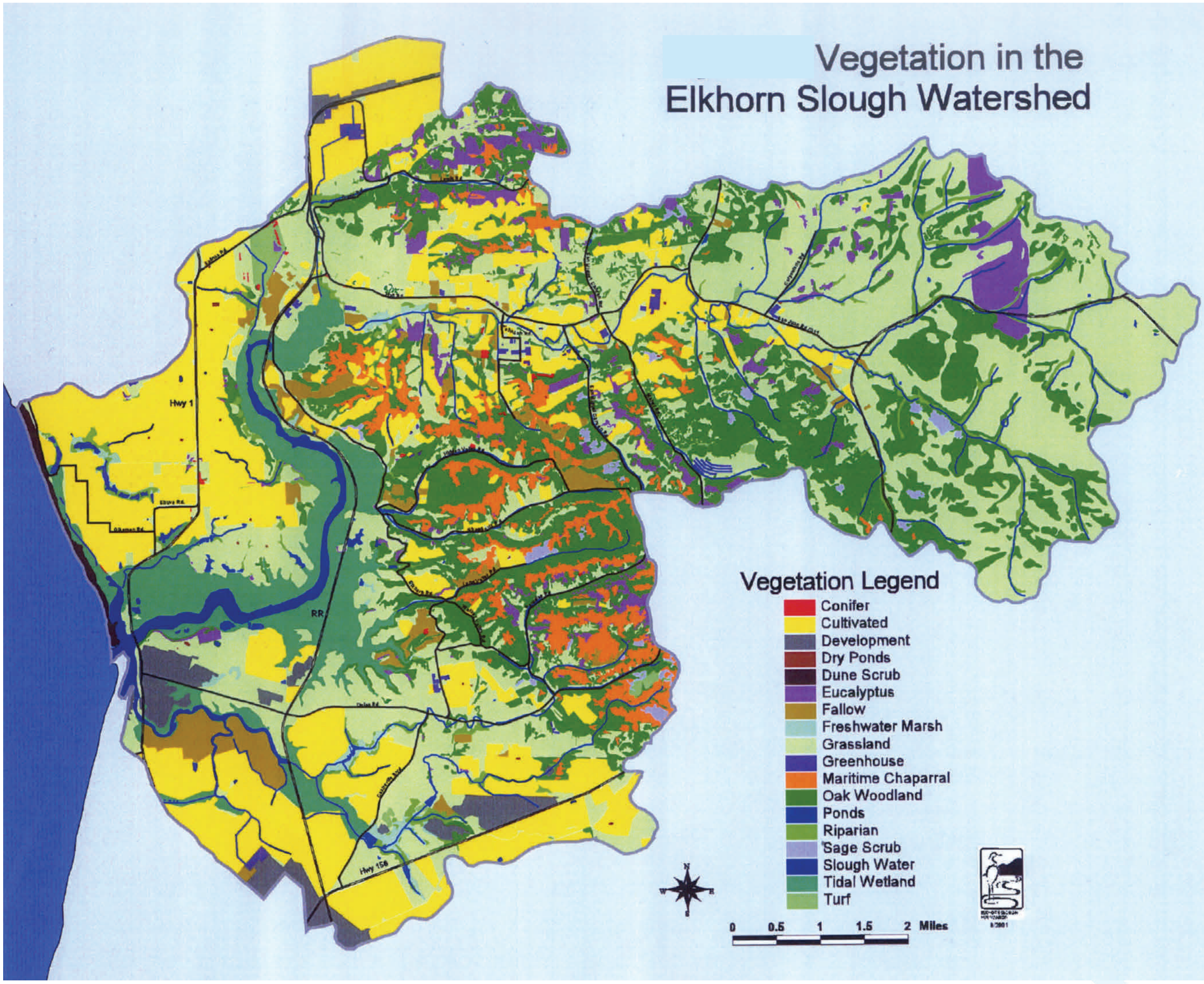


Figure 4. Vegetation map of the Elkhorn Slough watershed courtesy of the Elkhorn Slough Foundation.

Student Reading—2
Activity 1: Survival in an Estuary

An **estuary** is a partially enclosed body of water where two different bodies of water meet and mix such as fresh water from rivers or streams and salt water from the ocean, or fresh water from rivers or streams and chemically distinct water of the Great Lakes. In estuaries, water levels are affected by lunar or storm driven tides. In fresh water, the concentration of salts, or salinity, is nearly zero. The salinity of water in the ocean averages about 35 parts per thousand (ppt). The mixture of sea water and fresh water in estuaries is called **brackish water**.

Estuaries are transitional areas that connect the land and the sea, as well as freshwater and saltwater habitats. The daily tides (the regular rise and fall of the sea's surface) are a major influence on many of these dynamic environments. Most areas of the Earth experience two high and two low tides each day. Some areas, like the Gulf of Mexico, have only one high and one low tide each day. The tidal pattern in an estuary depends on its geographic location, the shape of the coastline and ocean floor, the depth of the water, local winds, and any restrictions to water flow. For example, tides at the end of a long, narrow inlet might be heightened because a large volume of water is being forced into a very small space. However, the tidal change in wetlands composed of broad mud flats might appear to be rather small.

While strongly affected by tides and tidal cycles, many estuaries are protected from the full force of ocean waves, winds, and storms by reefs, **barrier islands**, or fingers of land, mud, or sand that surround them. The characteristics of each estuary depend upon the local climate, freshwater input, tidal patterns, and currents. Truly, no two estuaries are the same.

Survival for any species, regardless of its environment, depends on the ability to adapt to changing conditions. Humans can go inside to get warm on a freezing cold day or put on a heavy coat and gloves. Or if the water main breaks or if the well runs dry, we can hop in our cars and obtain water from another source like a neighbor or local store. For plants and animals that live in an aquatic environment, adaptation is sometimes much more difficult. And for every species that spends most of its time in water, sudden changes in the environment, whether caused by natural agents (storms) or human intervention (pollutants), can spell disaster and lead to the death of many members of the aquatic community.

In estuaries, all plant and animal species live in a transition zone where fresh and salt water meet. Factors that cause change in estuarine environment fall into two categories: **abiotic** and **biotic**. Abiotic factors are those that occur in physical environment such as amount of sunlight, climate, and the geology of the area. Biotic factors are those that deal with the organism and other organisms they share their environment with, including their interaction, wastes, disease and predation.

To measure changes in the physical environment, biologists use factors that relate to natural processes or human actions. These include:

pH

Scientists use pH as an indicator of whether water is acidic or basic. pH is measured on a scale of 1 to 14, where numbers less than 7 are increasingly acidic and numbers greater than 7 are increasingly basic. Distilled water has a pH of 7 and is said to be neutral. Water on the surface of Earth is usually a little acidic or basic due to both geological and biological influences.

pH is actually a measure of the amount of hydrogen ions in solution. In fact, some people think of pH as being the "power

Figure 5. Barrier beach closed

Figure 6. Barrier beach open

of hydrogen." A lower pH indicates that there are more free hydrogen ions in the water, which creates acidic conditions, and a higher pH indicates there are less free hydrogen ions, which creates basic conditions. pH is equal to the negative logarithm of the hydrogen ion activity, meaning that the hydrogen ion concentration changes tenfold for each number change in pH unit. Water on the surface of Earth is usually a little acidic or basic due to both geological and biological influences.

All aquatic organisms have a pH range to which they are adapted. Outside of this range, critical biological processes may be disrupted, leading to stress and death. Most organisms cannot live below a pH of 5 or above a pH of 9. Additionally, pH is used to monitor safe water conditions. Once the background range of pH has been established, a rise or fall in pH may indicate the release of a chemical pollutant or an increase in acid rain. Additionally, pH affects the solubility, biological availability, and toxicity of many substances. For example, most metals are more soluble, and often more toxic, at lower pH values.

Temperature

Temperature is a measure of kinetic energy, or energy of motion. Increasing water temperature indicates increasing energy, or motion of water molecules and substances dissolved in the water. Temperature is a critical factor for survival in any environment. Organisms that live in water are particularly sensitive to sudden changes in temperature.

The Celsius temperature scale is used worldwide to measure temperature. Temperature has a significant impact on water density. Water density is greatest at 4 degrees Celsius, meaning that water at higher or lower temperatures will float on top of water at or near 4° C. This is why ice floats on water, and warm water floats over cooler water. Differences in water temperature cause the formation of distinct, non-mixing layers in water, otherwise known as stratification. This stratification leads to chemically and biologically different regions in water.

Salinity and Conductivity

Salinity and conductivity are measures of the dissolved salts in water. Salinity is usually described using units of parts per thousand or ppt. A salinity of 20 ppt means that there are 20 grams of salt in each 1000 grams of water. Because it is impractical to routinely determine the total amount of salts dissolved in water, a surrogate measure—the ability of the water to conduct electricity—is made for determining both conductivity and salinity. All aquatic life in an estuary must be able to survive changes in salinity. All plants and animals have a range of salinity to which they are adapted. Outside of this range, they will be unable to function and may die.

Salinity and conductivity are closely related. Conductivity and salinity are measures of what is dissolved in the water. Pure water is a very poor conductor of electrical current, but salts dissolved in the water are in ionic (charged form) and conduct electrical current. Conductivity, which is the opposite of resistance, measures the ability of water to conduct current. A higher conductivity indicates less resistance, and means that electrical current can flow more easily through the solution. Because dissolved salts conduct current, conductivity increases as salinity increases. Common salts in water that conduct electrical current include sodium, chloride, calcium, and magnesium.

Salinity affects the ability of water to hold oxygen, and seawater holds approximately 20% less oxygen than freshwater. Many chemical reactions that determine the concentration of nutrients and metals in the water are influenced by salinity. The conductivity and salinity of seawater is very high while these parameters are comparatively low in tributaries and rivers. Freshwater lakes typically have conductivities and salinities even lower than those of inland streams. This is because inland streams pick up salts from rocks, soils, and roads as they flow over the landscape.

Many chemical reactions that determine the concentration of nutrients and metals in the water are influenced by salinity. For instance, salinity and conductivity affect the ability of particles to flocculate, or stick together, which is important in determining turbidity levels and sedimentation rates. Salinity also increases the density of water, with seawater being heavier than freshwater. This density difference inhibits mixing. In fact, conductivity and salinity serve as excellent indicators of mixing between inland water and sea or lake water, and they are particularly useful in indicating pollution events or trends in freshwater. For example, an overdose of fertilizers or the application of road salt will cause spikes in conductivity and salinity.

Conductivity and salinity are dependent on many factors, including geology, precipitation, surface runoff, and evaporation. Since conductivity is a much more sensitive measurement than salinity, it is more impacted by changes in temperature. Conductivity increases as water temperature increases because water becomes less viscous and ions can move more easily at higher temperatures. Because of this, most reports of conductivity reference specific conductivity. Specific conductivity adjusts the conductivity reading to what it would be if the water was 25°C. This is important for comparing conductivities from waters with different temperatures.

Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen gas that is dissolved in a sample of water. DO is usually measured in units of milligrams per liter (mg/L). Just as we need air to breathe, aquatic plants and animals need dissolved oxygen to live. Dissolved oxygen is used for respiration, which is the process by which organisms gain energy by breaking down carbon compounds, such as sugars. Dissolved oxygen is also essential for decomposition, which is a type of respiration in which bacteria break down organic materials for energy. Decomposition is an important process that recycles nutrients and removes organic materials such as dead vegetation from our waterways. Because dissolved oxygen is required for aquatic life, balancing the sources and sinks of dissolved oxygen is essential in maintaining a healthy ecosystem.

The concentration of dissolved oxygen in water is dependent on a number of interrelated factors, including biological factors, such as the rates of photosynthesis and respiration, and physical and chemical factors, such as temperature, salinity, and air pressure.

Dissolved oxygen enters the water by diffusion from the air and as a byproduct of photosynthesis. Diffusion from the air occurs very quickly in turbulent, shallow water or under windy conditions. The amount of oxygen that can dissolve in water is dependent on water temperature, salinity, and air pressure. As temperature and salinity increase, and pressure decreases, the amount of oxygen that can be dissolved in water decreases. Cold water holds more dissolved oxygen than warm water, and water at sea level holds more dissolved oxygen than water at high altitudes. Seawater holds approximately 20% less oxygen than freshwater at the same temperature and altitude.

— Adapted from NOAA's National Ocean Service Estuaries Discovery Kit

Student Worksheet
Activity 1: Survival in an Estuary

Student Name:____

Procedure

Part 1 — The Estuarine Environment

You will be shown a number of images of estuaries. If you were a (specific) animal or plant living in an (specific location) estuary, what factors seen in these images might influence whether you survive or not? Take notes as the images are shown and then answer the following questions.

1a. Why is it important to monitor abiotic factors in estuarine environments?

1b. Based on your observations of the images, describe the environment of species living in an estuary. Consider factors such as temperature, water flow, salinity, and weather to name a few.

1c. How is surviving in an estuary different than surviving in a forest, a desert, or in the open ocean?

Part 2 — Surviving Changes: Abiotic Factors that Affect Life

You will investigate two years' worth of graphical data that describe four abiotic factors affecting the survival of aquatic species at South Marsh in the Elkhorn Slough.

For each graph on the *Student Data Sheet—South Marsh at Elkhorn Slough 2004-5*, determine the lowest and highest value of each abiotic factor. Then determine the approximate time (in days) that elapsed between these two measurements.

Extreme Conditions at South Marsh Table

	2004			2005		
Factor	**High**	**Low**	**Time Between**	**High**	**Low**	**Time Between**
temperature						
pH						
salinity						
dissolved oxygen						

Next, find the range for each factor (high value - low value) for 2004 and 2005.

2. Choose one animal that was highlighted in the images in Part 1. What strategies and adaptations do you think your chosen aquatic species uses to cope with changing abiotic conditions in South Marsh?

Part 3 — Surviving in an Estuary: Extreme Conditions

You will explore the actual values for each abiotic factor on a specific day. Your teacher will project the buoy readings for today's date or supply a hardcopy sheet with data for another day.

Record the date your data was gathered.

date ____

Record the values for temperature, salinity, dissolved oxygen, and pH.

temperature ____

pH ____

salinity ____

dissolved oxygen ____

Consult the list of *Limits of Tolerance to Environmental Factors for Selected Organisms* for the animals, and answer the following questions.

3a. After examining the range of tolerance information for five estuarine species, which of the five organisms do you think would thrive in the abiotic conditions of South Marsh today?

3b. Review the two-year data set for each abiotic factor in this activity. Choose whether each of the five species on your list is:

i) likely to survive and live in South Marsh

ii) might do fairly well

iii) doubtful to survive given the long term environmental conditions of South Marsh.

Explain your reasoning for each species.

Limits of Tolerance to Environmental Factors for Selected Organisms

Oysters
- Grow best in water with a salinity of 12 ppt and above, perish if salinity is below 5 ppt or above 25 ppt
- Spawn only when the water temperature hits 18°C for four hours
- Spawn much more prevalent when salinity is over 20 ppt
- Need a DO level of around 4 mg/l
- Best growth when pH is between 7.5 and 8.5

Clams
- Grow best when the water salinity is above 15 ppt
- Spawn only when the water temperature hits 24°C for four hours
- Clam eggs die when the salinity is below 20 ppt
- Need a DO level of around 4 mg/l
- Optimal growth occurs between 10 and 25°C

Alewife
- Adult and juvenile fish need a DO level of at least 3.6 mg/l
- Alewife eggs and larvae need a DO level of 5 mg/l or more
- Must have a pH higher than 5 but less than 9

Blue Crab
- Needs a DO level of 3 mg/l or more for survival, optimal at 5 mg/l
- Thrives if pH is between 6.8 and 8.2

Coho Salmon
- Like a DO level of 6 mg/l or higher
- Require a salinity of greater than 15 ppt
- Prefer temperatures between 4° and 20°C, do best at 13°C
- Spawn only when temperature is 18°C or higher
- Newly hatched salmon need a DO level of at least 5 mg/l to survive
- pH of 4.0 or lower or higher than 9 is lethal for salmon

Student Data Sheet
Activity 1: South Marsh at Elkhorn Slough 2004

Salinity

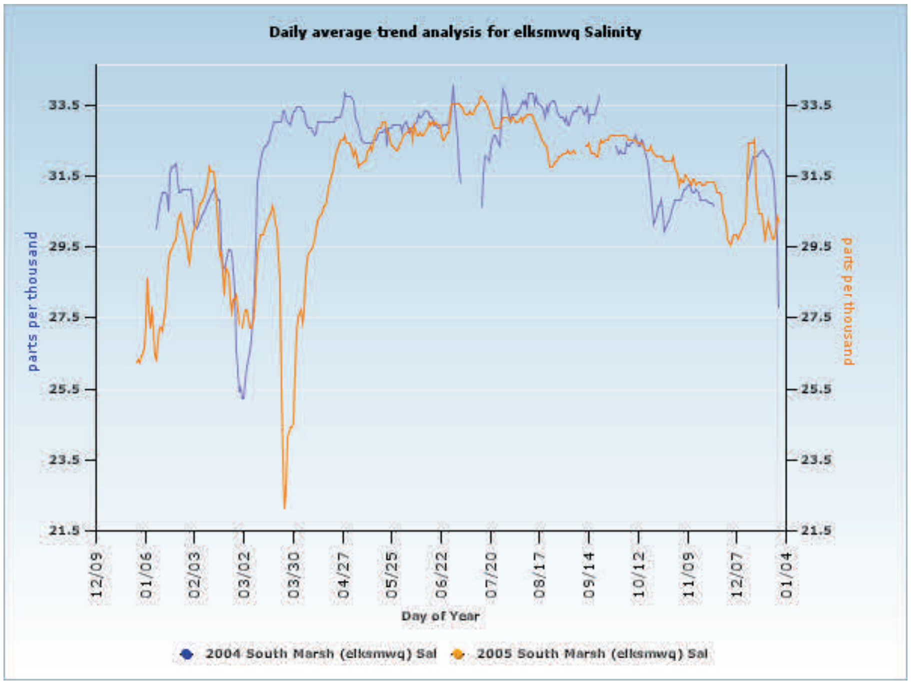


Figure 7.
Salinity: South Marsh

Dissolved Oxygen

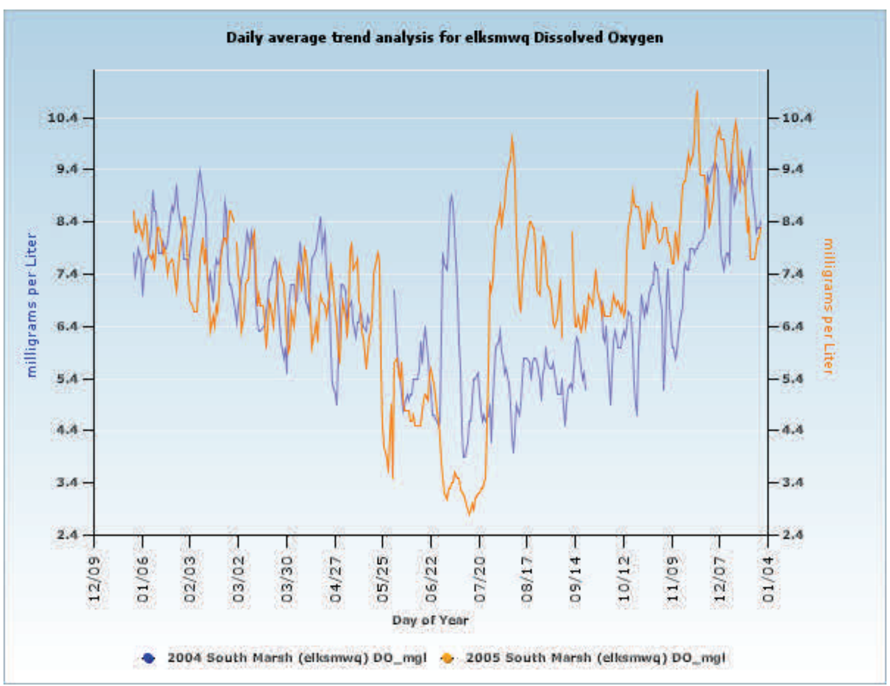


Figure 8.
DO: South Marsh

Water Temperature

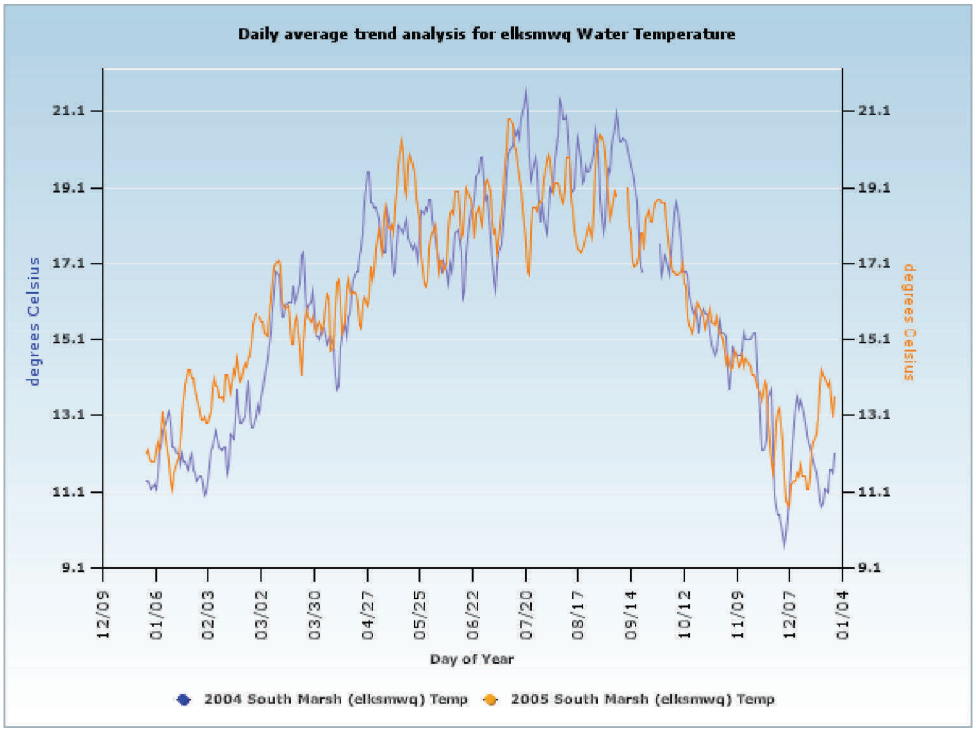


Figure 9.

Water temperature: South Marsh

pH

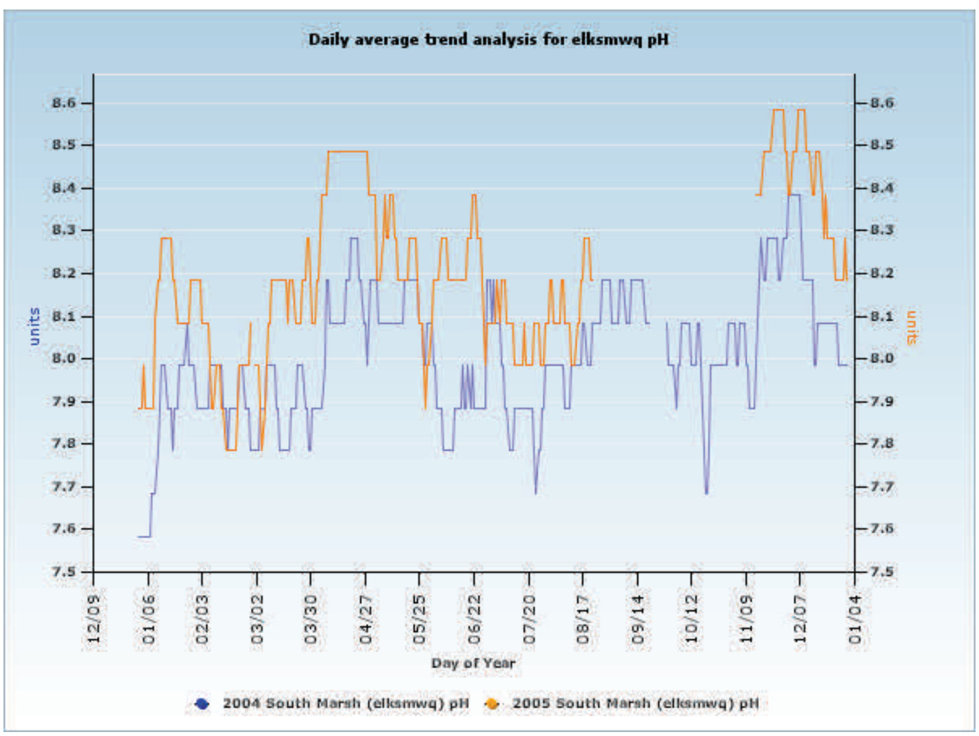


Figure 10.

pH: South Marsh

Teacher Guide—Life Science Module
Activity 2 — Nutrients in an Estuary

Featured NERRS Estuary: Guana Tolomato Matanzas National Estuarine Research Reserve, Florida

http://nerrs.noaa.gov/Reserve.aspx?ResID=GTM

Activity Summary

In this activity, students model estuaries, artificially enriching both fresh and salt water samples with different amounts of nutrients and observing the growth of algae over a several weeks. They relate their results to the phenomenon of algae blooms in estuaries. They then analyze data for different sites at the Guana Tolomato Matanzas National Estuarine Research Reserve (GTMNERR) in Florida to discover the relationships between nitrogen, chlorophyll, and dissolved oxygen. Finally, they study how nutrients cycle through an estuary and suggest recommendations for reducing nutrient inputs to estuary waters.

Learning Objectives

Students will be able to:

1. Understand how water quality and nutrient parameters in an estuary can indicate disruptions to ecological processes in estuaries.
2. 2. Interpret data from an experiment to explain the effects of over-enrichment on water quality and living things; and relate this lab experience to the phenomenon of algae blooms and eutrophication in an estuary.
3. Explain the phenomena of algae blooms and eutrophication in terms of total nitrogen, chlorophyll-a, and dissolved oxygen.
4. Describe the effects of eutrophication on the nitrogen cycle.
5. Explain how nutrients cycle in an estuary and how natural processes and human impacts affect this cycle.
6. Identify sources of nitrogen inputs to estuaries and identify some ways to limit them.

Grade Levels

9-12

Teaching Time

- 1 (55 minute) class session, plus periodic observations every 2-3 days over three weeks (Part 1)
- 3 (55 minute) class sessions (Parts 2 and 3)

Organization of the Activity

This activity consists of 3 parts which help deepen understanding of estuarine systems:

Nutrients in an Estuary

Using Data to Study Eutrophication and Conditions in an Estuary

Eutrophication and the Nitrogen Cycle

Background

Eutrophication and Algal Blooms

An overload of nutrients, called eutrophication (Greek for "good-nutrition"), can be harmful to estuaries. This phenomenon is also referred to as "over-enrichment," or "nutrient pollution." The consumption and recycling of nutrients tend to keep nitrogen levels balanced because bacteria release nitrogen back to the atmosphere at a greater rate than the natural flow of nitrogen into the estuary and the rate of nitrogen fixation.

Over-enrichment often causes "algal blooms" (or sometimes HAB "harmful algal blooms" in cases where the **phytoplankton** are toxic to marine organisms or humans) in estuaries. The influx of high nutrient levels causes excessive growth of algae. Too much phytoplankton in the water column can cause the water to become cloudy, reducing the amount of sunlight available for underwater plants to photosynthesize. Large algal mats floating on the surface can block the light that underwater plants such as seagrasses need. Disturbances to seagrass communities can be harmful to other organism like fish and crabs that depend on the grasses for food, shelter, and nursery areas. On sunny days, the algae's photosynthesis pumps abnormally high levels of oxygen into the water. When algae die, it sinks to the bottom where bacteria in the sediments decompose it. This process removes oxygen from the water. As bacteria decompose algae, more oxygen is consumed. If too much oxygen is removed from deep waters, the small organisms that fish and crabs eat die off. Fish and other predators may die themselves or move to other areas in search of more oxygen.

Algae blooms can disrupt food chains, damage estuarine habitats, and deplete oxygen to the extent that organisms die or move out. The conditions created by these blooms may encourage only species that can tolerate eutrophic conditions (blue-green algae). In addition, the appearance of the cloudy water and decaying algae mats, unpleasant odors, and loss of estuarine species can diminish the recreational value of estuaries.

Algal blooms may result from natural conditions, but they are often linked to excess nutrients that come from human activities. Excess nutrients may come from septic tanks, wastewater treatment plants, point source discharges from sewage and industry, exhaust from cars, emissions from industry, fertilizers from lawns, golf courses, farms, and animal waste (especially from livestock). Sources of nitrogen that do not enter estuaries directly from point sources are transported to estuaries by stream flows, rain, leaching, groundwater, storm water, and as emissions carried through the air.

Algae blooms usually occur seasonally. In the northern hemisphere, they typically occur between May and October. Heavy use of fertilizers in the spring combined with spring rains can introduce excess nutrients to an estuary. Other conditions that favor algal blooms come into play in the months from summer to fall: bright sunlight, still water, and sharp temperature gradients that keep warmer surface water and colder bottom water from mixing.

Algal and phytoplankton blooms can be tracked by measurements of chlorophyll-a. Chlorophyll-a is a pigment in phytoplankton that is involved in photosynthesis. Concentrations of chlorophyll-a are used as proxy measures of phytoplankton abundance. Concentrations are measured in units of μg/L.

Algal Blooms and Nutrient Residence Time

The chance that particular sites within estuaries will experience algal blooms depends on a number of conditions. These include:

- The amount of nutrient input.
- Water quality parameters such as temperature and

salinity.

- Weather and seasonal conditions.
- The residence time of nutrients in the estuary. This is determined by factors such as stream flow, tidal flushing, winds, water depth, and water stratification. These determine whether nutrients will stay in the estuary long enough to alter the nitrogen cycle enough to instigate an algal bloom.

From May 2002 to August 2003, researchers at the Guana Tolomato Matanzas National Estuarine Research Reserve (GTMNERR) in Florida studied how water chemistry and the hydrodynamic factors that govern residence time affect plankton abundance in the lagoons of East Florida. Over a sixteen-month period, they measured nutrient levels and plankton abundance (chlorophyll-a concentrations) at eight sites in the reserve. (A Comparison of Water Quality and Hydrodynamic Characteristics of the Guana Tolomato Matanzas National Estuarine Research Reserve and the Indian River Lagoon in Florida, Phlips, et al., 2004 in Journal of Coastal Research, Special Issue No. 45, 2004.)

Researchers considered all the factors that determine nutrient loading (including nitrogen and phosphorous inputs from all sources) and developed an index (Nutrient Load Index, or NLI), from 1-4, that describes how heavily the site is usually loaded with nutrients (1 represents a low load, 4 represents a high load). They also developed an index that categorizes the sites according to estimated water residence times (RTI) on a scale of 1-4. This was done by summarizing the factors that determine tidal flushing, including tidal excursion, freshwater inflows, wind, water stratification, and depth. The index describes the extent to which nutrients generally remain in the estuary, or are flushed out (1 represents a short residence time, 4 represents a long residence time).

Their findings indicate that regions with short water residence times have lower peak phytoplankton abundance than regions with longer residence times (at least under normal to high rainfall conditions, not accounting for drought). In fact, this held true despite differences in nutrient load index. Sites that had a high residence time index (index of 3 or 4) did not have the highest peak or average chlorophyll-a concentrations even if they had high nutrient load indexes.

Four of the sampling sites were on Florida's northern east coast within the GTMNERR, which is defined by barrier islands. These sites were all relatively close to ocean inlets and as a consequence, all had relatively low residence times (RTI of 1 or 2). The four other sites were sub-basins of the Indian River Lagoon located on the central east coast. The lagoon has a several ecologically distinct basins that differ significantly in their hydrodynamics, water chemistry, and biological features. Their residence times varied, but two of the sites had RTI of 3 and 4.

All eight sites represented different combinations of nutrient load index and residence time index. Graphs illustrating

National Science Education Standards

Content Standard A: Science as Inquiry

A3. Use technology and mathematics to improve investigations and communications.

A4. Formulate and revise scientific explanations using logic and evidence.

A6. Communicate and defend a scientific argument.

Content Standard B: Physical Science

B6. Interactions of energy and matter

Content Standard C: Life Science

C4. The interdependence of organisms

C5. Matter, energy, and organization in living systems

Content Standard F: Science in Personal and Social Perspectives

F3. Natural Resources

F4. Environmental quality

F5. Natural and human-induced hazards

F6. Science and technology in local, national, and global challenges the combined influence of these two factors on phytoplankton abundance are shown below.

The study also analyzed total nitrogen (TN) and dissolved inorganic nitrogen (DIN) concentrations and chlorophyll-a concentrations at all eight sites. The authors of the study acknowledge: "The absence of well-defined relationships between nutrient concentration and phytoplankton biomass (i.e. chlorophyll a) is not unusual for estuarine ecosystems, even those subject to substantial eutrophication (Borum, 1996; Cloern, 2001)." p. 15, Journal of Coastal Research, Special Issue No. 45, 2004.

However, it is still worthwhile for students to analyze this data and see if they can observe patterns. In fact, the authors found significant correlations between chlorophyll-a and TN at all four Indian River lagoon sites. They found no significant correlations between chlorophyll-*a* and TN within the GTMNERR sites.

Google Earth

This activity *requires* the use of Google Earth. If students have computer access, the use of Google Earth (http://earth.google.com/) can help them develop spatial skills.

To find the Tutorial "*Using Google Earth to Explore Estuaries*" go to Estuaries.noaa.gov, click the tab titled Curriculum and then the sub-tab titled Tutorials.

Materials

Students

- ❑ Need to work in a computer lab or with a computer and projector
- ❑ Copy of Student Reading Estuary and Watershed
- ❑ Copy of Student Worksheet Estuary and Watershed, Student Data Sheet 1 — Orienting Yourself to the San Francisco Estuary and Watershed
- ❑ Copy of Student Data Sheet 2 — Water Quality Data

Teachers

- ❑ Water source (preferably from an estuary) with algae
- ❑ Liquid plant fertilizer
- ❑ Sea salt
- ❑ Measuring teaspoons
- ❑ 600 ml beakers
- ❑ Safety eyewear
- ❑ Digital camera

Equipment:
- ❑ Computer lab or
- ❑ Computer and Projector

Preparation

- As possible, plan the scheduling of the parts of this activity. You may want to begin Part 1 of this activity two to three weeks before you begin Parts 2 and 3.
- Assemble materials (See material list).
- Contact the landowner and ask for permission before you collect the water samples you will need for this exercise. Collect pond and/or estuary water samples that include algae. The amount of water you will need depends on how many samples students will treat or control. If estuary water is not available, use pond, stream, puddle, or tap water samples.
- Determine where in your classroom student groups will place their experiment so that all the beakers will get the same amount of sunlight or ambient light. (Note: If you decide to have students design their own experiments, you can allow them to determine if light is a variable they will change.)
- Optional: Set up different sets of beakers yourself and label them prominently. (Note: Ideally students prepare the beakers themselves.)
- If necessary, download Google Earth and install it on your classroom computer(s) or computer lab machines <*http://earth.google.com/*>. Preset the location of the GTMNERR. (Refer to *Using Google Earth to Explore Estuaries* for a brief how-to guide.)
- Bookmark the eutrophication animation below to use during Part 3 of the activity.

http://peconicestuary.org/Nutrients.animation.html

- Make copies of the *Student Reading—Introduction to GTM*, *Student Reading—Nutrients in an Estuary*, *Student Worksheet—Nutrients in an Estuary*, and *Student Data Sheet—GTM 2002-3 Nutrient Data.*

Procedure

Part 1 — Nutrients in an Estuary

NOTE: You may want to begin Part 1 a full two weeks before you begin Parts 2 and 3.

1. Ask students why estuaries are one of the most productive ecosystems in the world. What conditions exist in the estuary that would make it particularly productive? *(Nutrients from land via runoff, surface tributaries, and groundwater, mixing and circulation of nutrients and oxygen by tides, abundance of food sources and protective habitats make the estuary a good place for rearing of many types of juvenile organisms and for diversity of species.)*

2. Ask students what types of nutrients estuaries need to support high productivity. *Plants and animals need nitrogen and phosphorous, as well as many other trace nutrients. Nitrogen is a component of amino acids, enzymes, DNA, and proteins.)* If your students are familiar with the nitrogen cycle, you can suggest they consider how it functions in estuaries.

3. Have teams of students brainstorm ways in which the estuary receives the nutrients it needs. Again, if your students are familiar with the nitrogen cycle, you can suggest they consider how it functions in estuaries. Have them discuss and/or record responses to the following questions:
   - How do estuaries get necessary nutrients?
   - Are these nutrients obtained and simply used up or are they cycled through the estuary?

4. Discuss the teams' brainstormed ideas and answers. Ask if it is possible for an ecosystem to get too many nutrients.

5. Introduce the lab activity as a way of investigating whether estuaries can be affected by "nutrient over-enrichment." Either explain the beakers you have prepared, or using Part 1 of the *Student Worksheet—*

Nutrients in an Estuary, have your students set up the various models.

If you have on both a fresh and salt (or brackish) source of water, have different teams of students do fresh and saltwater models. If you have only one water source, you may increase the number of variables studied. For example, besides the amount of fertilizer in each beaker, different teams could vary the amount of sunlight their six models obtain; the pH of the water samples could be altered slightly by the addition of vinegar to sets of beakers; etc.

6. Have students complete the Predictions portion of the *Student Worksheet—Nutrients in an Estuary* and then discuss student predictions about the beakers.

7. Take a digital picture of each set of beakers every two or three days for two or three weeks. Or have students take their own digital images. Load the images into a data file for later comparison.

8. After students have completed their observations, display the series of images and have students complete Part 1 of the *Student Worksheet—Nutrients in an Estuary*. Discuss the models and results.

Note: Consider having students read the *Student Reading—Introduction to GTMNERR* and *Student Reading—Nutrients in an Estuary* for homework as preparation for Parts 2 and 3.

Part 2 — Using Data to Study Eutrophication and Conditions in an Estuary

9. Have students read the *Student Reading—Introduction to GTMNERR* and *Student Reading—Nutrients in an Estuary*.

10. Project a map of the GTMNERR with Google Earth and show students where the monitoring stations are. Ask students which stations are closest to a source of salt water and which ones are relatively far away from the ocean.

11. Have students complete Part 2 of the *Student Worksheet—Nutrients in an Estuary*.

12. Discuss the readings, tasks, and questions of Part 2.

Part 3 — Eutrophication and the Nitrogen Cycle

13. Project or have students watch the animation illustrating eutrophication and algal blooms found at: http://peconicestuary.org/Nutrients.animation.html

15. Have students complete Part 3 of the *Student Worksheet—Nutrients in an Estuary*.

16. Discuss the questions. Have several students read their letters (question 3f) aloud to the class.

Check for Understanding

Question 3f is the summary assessment for this activity. It directs students to "Write a short letter to the town council of this region outlining your recommendations about steps to take to reduce the amount of nutrient flow into the estuary."

Optional Extension Inquiries

Map and analyze the area around the nearest NERRS site to your region. Have students use Google Earth, as well as other maps and resources, to draw a map that delineates possible sources of nutrients for the estuary: farmland, sewage treatment plants, etc. Then have them download the past years of SWMP data for nutrients from the http://estuaries.noaa.gov/ScienceData/Graphing.aspx site for that estuary. Finally, have them look for patterns or cycles of change in the nutrient data and then propose what point sources or natural sources might be responsible for those patterns or cycles of change.

Teacher Worksheet with Answers
Activity 2: Nutrients in an Estuary

Part 1 — Nutrients in an Estuary

1a. How do you think the amount of fertilizer will affect the amount of algae in each of the samples?

Answer: Student answers will vary.

1b. How do you think the algal growth will differ between the fresh and salt-water samples?

Answer: Student answers will vary.

1c. How is this experiment different from conditions in an actual estuary that receives excess nutrients?

Answer: Student answers will vary.

1d. How did the amount of fertilizer affect the amount of algae in each of the pond/stream samples?

Answer: The amount of algae increases as the concentration of fertilizer increases.

1e. How did the algal growth differ between the fresh and salt water samples?

Answer: The saltier the water, the less abundant the pond algae will be.

1f. Explain using the process of photosynthesis how the level of dissolved oxygen varies with increasing amounts of living algae.

Answer: As algae increase in amount, more oxygen is produced thereby initially increasing DO levels in the water.

1g. Explain using the process of decomposition how the level of dissolved oxygen would vary in the beakers as the algae die and settled to the bottom.

Answer: Bacteria use oxygen during the process of decomposition, effectively lowering DO levels.

Part 2 — Using Data to Study Eutrophication and Conditions in an Estuary

2a. Compare 16-month nitrogen and chlorophyll-a values for each site. During which seasons do peak values seem to occur at most sites? Why do you think so?

Answer: These blooms usually occur seasonally. In the northern hemisphere, they typically occur between late spring and October. Heavier use of fertilizers in the spring combined with spring rains can introduce excess nutrients to an estuary. Other conditions that favor algal blooms come into play in the months from summer to fall: bright sunlight, still water and sharp temperature gradients *that keep warmer surface water and colder bottom water from mixing.*

2b. Do you see a clear pattern that shows a relationship between TN and chlorophyll-a?

Answer: The authors of the study acknowledge: "The absence of well-defined relationships between nutrient concentration and phytoplankton biomass (i.e. chlorophyll a) is not unusual for estuarine ecosystems, even those subject to substantial eutrophication (Borum, 1996; Cloern, 2001)." P. 15 Journal of Coastal Research, Special Issue No. 45, 2004

2c. Which four sites seem to show the strongest correlation between TN and chlorophyll-a?

Answer: The authors found significant correlations between chlorophyll-a and TN at all four Indian River lagoon sites, but no significant correlations between chlorophyll-a and TN within the GTMNERR sites. The sites showing the strongest correlations are Titusvillle, Vero, and Eau Gallie.

2d. What other factors do you think determine whether or not nutrient input will cause algal blooms?

Answer: Tidal flushing, including tidal excursion, freshwater inflows, wind, water stratification, and depth.

2e. If the chlorophyll-a threshold for an algal bloom is 20 ug/L, which sites may have experienced algal blooms during the period of observation?

Answer: Given the threshold of 20 ug/L, Eau Gaille had two algal blooms, while Titusville, and Vero had one each.

2f. Looking at the chart, what conclusion can you make about the influences of nutrient loading and residence time on chlorophyll-a concentrations?

Answer: Regions with short water residence times have lower peak phytoplankton abundance than regions with longer residence times even despite differences in nutrient load index.

Sites within the Guana Tolomato Matanzas NERR all had relatively low residence times, lower average chlorophyll-a concentrations, and generally lower peak chlorophyll-a concentrations. Residence times at Indian River Lagoon sites varied, but two of the sites had RTI of 3 and 4. These sites generally had higher average chlorophyll-a concentrations, and two sites had the highest peak chlorophyll-a concentrations.

Part 3 — Eutrophication and the Nitrogen Cycle

3a. Where does most of the nitrogen that flows into an estuary come from?

Answer: Most of the nitrogen that flows into an estuary comes from runoff from the land into rivers and streams that feed into the estuary.

3b. What is the relationship between microbial activity during algal decomposition and DO levels in an estuary?

Answer: Bacteria break down algae and use oxygen in the process, driving DO levels lower.

3c. What causes the daily cycle of change in dissolved oxygen content in water?

Answer: During nighttime hours, decomposition uses oxygen but plants cannot photosynthesize so DO levels are always lower at night.

3d. Name three possible human-caused sources of excess nutrients in this region.

Answer: Animal wastes, fertilizer from farms, leaking septic systems, and direct discharge of waste from industrial plants or sewage treatment plants.

3e. What do you think the effect of a heavy rainfall event in this region would have on the:

- level of nutrients in the estuary?

  Answer: Heavy rain washes loads of nutrients from the sources mentioned in question 3d.

- level of dissolved oxygen in the estuary?

  Answer: Initially the level of oxygen increases, but as algae and algal mats die, DO can decrease dramatically.

- development of seagrass and other aquatic plants?

  Answer: As seen in a previous image, increased algae cause decreased sunlight for seagrass to photosynthesize so growth is inhibited or stopped completely.

- population of aquatic organisms such as clams, crabs, and snails?

  Answer: Plunging DO levels can cause hypoxic and eventually anoxic conditions that can cause massive extinction events of certain species.

Assessment

3f. Write a short letter to the town council of this region outlining your recommendations about steps to take to reduce the amount of nutrient flow into the estuary.

Students may mention moving industrial plants and limiting outflow of waste products into the estuary, and limiting grazing and farming in proximity of riverbanks.

In general, a brochure written by Florida Sea Grant Extension (available at: http://edis.ifas.ufl.edu/SG061) suggests the following actions:*

1. *Limit urban development, especially along shorelines.*
2. *Preserve wetland buffers or green space and submerged aquatic vegetation associated with coastlines, rivers, and streams.*
3. *Limit the use of fertilizers on residential and commercial lawns and landscaping.*
4. *Manage storm water runoff.*
5. *Use better septic systems.*

* Hauxwell, J.; Jacoby, C.; Frazer, T.; Stevely, J. Accessed: 2008-07-30.http://www.webcitation.org/5ZhWgbRvv

Student Reading—1
Activity 2: Introduction to the Guana Tolomato Matanzas NERR

This activity focuses on the conditions for life in the Guana Tolomato Matanzas National Estuarine Research Reserve (GTM). The GTM Reserve encompasses approximately 55,000 acres of salt marsh and mangrove tidal wetlands, oyster bars, estuarine lagoons, upland habitat and offshore seas in Northeast Florida. It contains the northern-most extent of mangrove habitat on the east coast of the United States.

The GTM reserve is geographically separated into a northern section where the Tolomato and Guana rivers mix with the waters of the Atlantic Ocean, and a southern section along the Matanzas River, extending from Moses Creek south of Pellicer Creek. The unique Matanzas Inlet is one of the last natural, unaltered inlets on Florida's Atlantic coast.

The GTM estuary is rich with scenic beauty and economic value as it produces or supports the vast majority of the commercially and recreationally valuable fish and shellfish found in the region. The submerged lands, marshes, islands and conservation lands provide important habitat for a diversity of plants and animals, including the migrating birds stopping along the Atlantic Coastal Flyway.

The coastal waters of the GTM Reserve are important calving grounds for the endangered Right Whale. Manatees, Wood Storks, Roseate Spoonbills, Bald Eagles and Peregrine Falcons find refuge in the reserve.

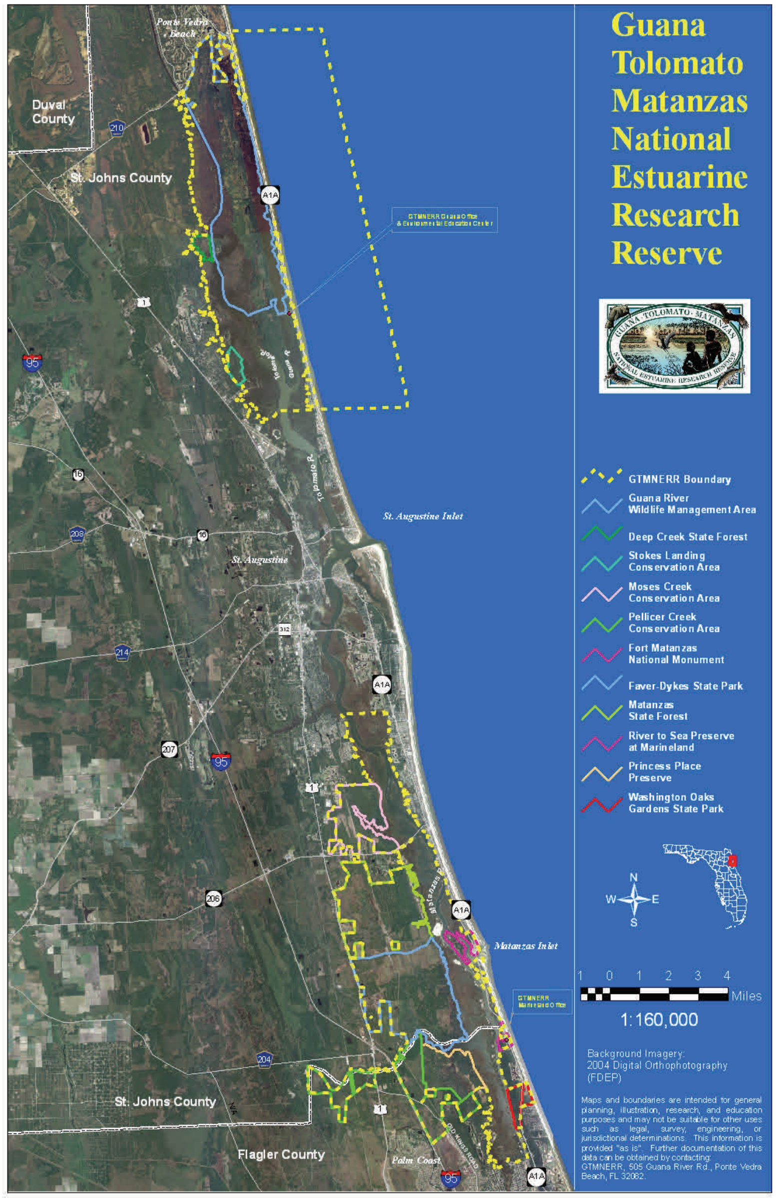


Figure 1. Guana Tolomato Matanzas National Estuarine Research Reserve boundary map.

Student Reading—2
Activity 2: Nutrients in an Estuary

Nutrients in the Estuary

Of all the essential nutrients for life in an estuary, nitrogen and phosphorus are the two that most often limit the growth of primary producers in an estuary. Nitrogen is a key component in 1) chlorophyll, the green pigment in primary producers that absorbs sunlight during photosynthesis, 2) amino acids, the building blocks of proteins, and 3) genetic material, including deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Nitrogen ranks as the fourth most abundant chemical element in living tissue, behind oxygen, carbon, and hydrogen. Phosphorus is also a key component in DNA, and it is found in adenosine triphosphate (ATP), a molecule that is important in energy transfer and storage in living cells.

Natural sources of nitrogen include nutrients from rock weathering and animal waste that enter the estuary from: stream flows; enriched, deep ocean water brought in by tides and upwelling; guano (waste) from birds; dead organisms in the water;, and nitrogen gas in the atmosphere. Air contains nitrogen gas (N_2), but most organisms can't use it in this form. Aquatic life in estuaries needs to obtain nitrogen in forms they can use, or nitrogen that is "fixed." These forms are compounds such as nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), and ammonium (NO_4). Animals get their nitrogen from feeding on plants or on other animals that have fed on plants.

Eutrophication and Algal Blooms

An overload of nutrients is called eutrophication (Greek for "good-nutrition"). Eutrophication, the over-enrichment of nutrients, can be harmful to estuaries. Over-enrichment often causes "algal blooms" in estuaries. The influx nutrients cause excessive growth of algae that results in the water becoming cloudy, thus reducing the amount of sunlight that plants can use to photosynthesize. Large algal mats floating on the surface can block much of the light that underwater plants such as sea grasses need to survive. Disturbances to sea grass communities can in turn be harmful to other organisms like fish and crabs that depend on the grasses for food, shelter, and nursery areas. When algae dies, it sinks to the bottom where bacteria in the sediments decompose it. This process removes oxygen from the water. As bacteria decompose more algae, more oxygen is consumed. If too much oxygen is removed from deep waters, small organisms that fish and crabs eat die endangering all forms of life in the estuary.

Algae blooms can disrupt food chains, damage estuarine habitats, and deplete oxygen to the extent that organisms die or move out. The conditions created by these blooms may encourage only species that can tolerate eutrophic conditions (blue-green algae). In addition, the appearance of the cloudy water and decaying algae mats, unpleasant odors, and loss of estuarine species can diminish the recreational value of estuaries.

Algal blooms may result from natural conditions, but they are also linked to excess nutrients that come from human activities. Excess nutrients may come from septic tanks, wastewater treatment plants, point source discharges from sewage and industry, exhaust from cars, emissions from industry, fertilizers from lawns, golf courses, and farms and animal waste (especially live-stock). Sources of nitrogen that do not enter estuaries directly are transported to estuaries by stream flows, rain, leaching, groundwater, and storm water.

Algal bloom can be detected by measurements of chlorophyll-a. Chlorophyll-a is a pigment in

When water has low levels of oxygen the condition is called **hypoxia**. In estuaries, lakes, and coastal waters, low oxygen usually means a concentration of less than 2 parts per million. **Anoxia** refers to water that has been completely depleted of oxygen. Anoxic conditions may force crabs and other bottom-dwelling organisms to even come up on land to escape oxygen starvation. These events are called "jubilees." Large areas of estuaries where organisms have died off or left for lack of sufficient oxygen are called dead zones. Some estuaries experience dead zones regularly.

Figure 2. The formation of algae mats can lead to conditions harmful for both plants and animals living in the estuary. (Photo Credit: NOAA)

Student Worksheet
Activity 2: Nutrients in an Estuary

Student Name ____

Part 1: Nutrients in an Estuary

In this part of the activity, you will produce models of estuaries that have an increasing amount of nutrient added to them in order to address the following question: What effects does increasing the amount of nutrients in an estuary have on plant growth, on the amount of dissolved oxygen, and on other water quality factors that impact life in an estuary?

Your model will consist of a series of 600 ml beakers containing water samples with algae. You will add nutrients, in the form of commercial fertilizer, to each beaker and then monitor the samples once a week, measuring the water quality parameters and describing the algae growth for several weeks.

Instructions

Put on your goggles! It is very important that you wear them when adding fertilizer to the beakers.

Label one beaker: *No added nutrients*. Also include details about the nature of the water sample (e.g. fresh water or salt water) on the labels.

Label another beaker: *1 teaspoon nutrients*. Add 1 tsp of fertilizer to this beaker and stir until the fertilizer is dissolved.

Repeat for additional beakers with 2, 3, 4, and 4 teaspoons of nutrients in each.

Place the beakers on a counter situated so all the beakers receive about the same amount of sunlight per day.

Record information on the contents of each beaker, using this technique to see inside:

- Stand with your back to a light source so it is shining over your shoulder and through the beaker.
- Place a white piece of paper behind the beaker (on the opposite side of the light source).
- Describe and/or draw any algae you can see in the beaker. (You may not see any algae, especially at the beginning. If that's the case, record, "No algae visible.")

Take digital images of all six beakers and note the time and date you took the pictures.

Making Predictions

1a. How do you think the amount of fertilizer will affect the amount of algae in each of the samples?

1b. How do you think the algal growth will differ between the fresh and salt-water samples?

1c. How is this experiment different from conditions in an actual estuary that receives excess nutrients?

Tracking the Models Over Time

Examine the contents of your beakers, using the technique from the instructions above, and record your observations every two or three days over a period of three weeks. Also take a digital image every two or three days. At the end of three weeks, display all images and observe the changes in your model estuaries.

1d. How did the amount of fertilizer affect the amount of algae in each of the samples?

1e. How did the algal growth differ between the fresh and salt water samples?

1f. Explain using the process of photosynthesis how the level of dissolved oxygen varies with increasing amounts of living algae.

1g. Explain using the process of decomposition how the level of dissolved oxygen would vary in the beakers as the algae die and settled to the bottom.

Part 2 — Using Data to Study Eutrophication and Conditions in an Estuary

In this part of the activity, you will investigate how nutrients affect of algal blooms on water quality at various stations within the GTMNERR site. Using the graphs and chart on the *Student Data Sheet—GTM 2002-3 Nutrient Data*, answer the following questions.

2a. Compare 16-month nitrogen and chlorophyll-a values for each site. During which seasons do peak values seem to occur at most sites? Why do you think so?

2b. Do you see a clear pattern that shows a relationship between TN and chlorophyll-a?

2c. Which three sites seem to show the strongest correlation between TN chlorophyll-a?

2d. What other factors do you think determine whether or not nutrient input will cause algal blooms?

2e. If the chlorophyll-a threshold for an algal bloom is 20 ug/L, which sites may have experienced algal blooms during the period of observation?

2f. Looking at the chart, what conclusion can you make about the influences of nutrient loading and residence time on chlorophyll-a concentrations?

Part 3—Eutrophication and the Nitrogen Cycle

In order for organisms to survive in an estuary, a constant source of nutrients must be present for them to consume. But as you have seen, *too* many nutrients flowing into an estuary can lead to anoxic conditions and even massive die-offs of animal and plant species. In this part of the activity, you will be asked to review your work and examine the effect of nutrients on other abiotic factors that ultimately determine the welfare of species in the estuary.

To summarize your investigations about nutrients in an estuary, view the series of animations at: http://peconicestuary.org/Nutrients.animation.html

3a. Where does most of the nitrogen that flows into an estuary come from?

3b. What is the relationship between microbial activity during algal decomposition and DO levels in an estuary?

This is a simplified diagram of how the nitrogen cycle works in an estuary. Examine the cycle in detail.

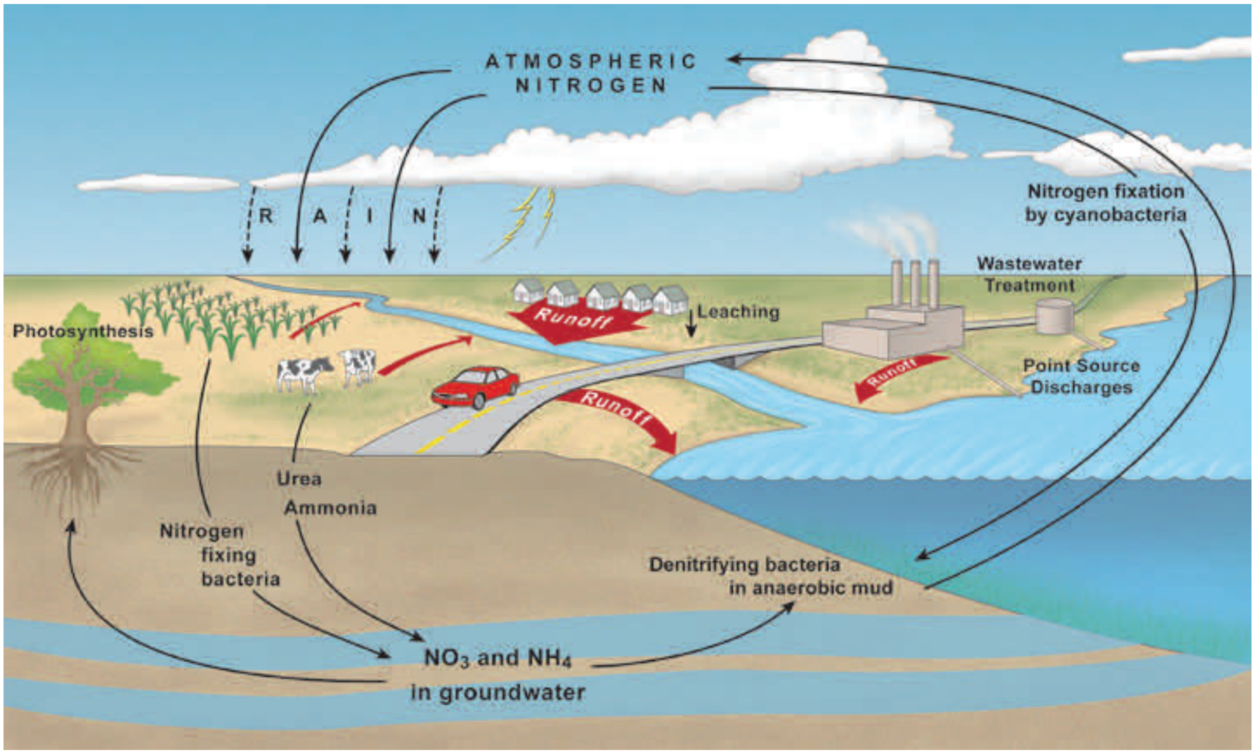


Figure 3. Nutrients and Florida's Coastal Waters: The Links Between People, Increased Nutrients and Changes to Coastal Aquatic Systems. <http://edis.ifas.ufl.edu/SG061>. Published by the Florida Sea Grant College Program with support from the National Oceanic and Atmospheric Administration, Office of Sea Grant, U.S. Department of Commerce. Published for the University of Florida, Institute of Food and Agricultural Sciences (SGEB -55). October 2001. (Archived by WebCite® at http://www.webcitation.org/5ZhWSaa3M)

Imagine that the estuarine system shown in the diagram has a dangerously high level of nutrients.

3d. Name three possible human-caused sources of excess nutrients in this region.

3e. What do you think the effect of a heavy rainfall event in this region would have on the:

- level of nutrients in the estuary?
- level of dissolved oxygen in the estuary?
- development of seagrass and other aquatic plants?
- population of aquatic organisms such as clams, crabs, and snails?

Assessment

3f. As a summary assessment, write a short letter to the town council of this region outlining your recommendations about steps to take to reduce the amount of nutrient flow into the estuary.

Student Data Sheet
Activity 2: GTM NERR 2002-3 Nutrient Data

May 2002 to August 2003, researchers at the Guana Tolomato Matanzas NERR in Florida studied how nutrients, water quality parameters, and physical factors affect algae abundance in the lagoons of East Florida. Over a sixteen-month period, they measured nutrient levels and algae abundance (determined by gauging chlorophyll-a concentrations) at eight sites in the reserve. The study also analyzed total nitrogen (TN) and dissolved inorganic nitrogen (DIN) concentrations and chlorophyll-a concentrations at all eight sites.

The chance that particular sites within estuaries will experience algal blooms depends on a number of conditions. These include:

- The amount of nutrient input.
- Water quality parameters such as temperature and salinity.
- Weather and seasonal conditions.
- The residence time of nutrients in the estuary. This is determined by factors such as stream flow, tidal flushing, winds, water depth, and water stratification.

These factors determine whether nutrients will stay in the estuary long enough to alter the nitrogen cycle enough to instigate an algal bloom.

Figure 4. A satellite image of the GTM estuary with some of the monitoring stations you will be investigating.

(NOTE: Pelser Creek on this Google Map image is actually Pellicer Creek.)

Graphs

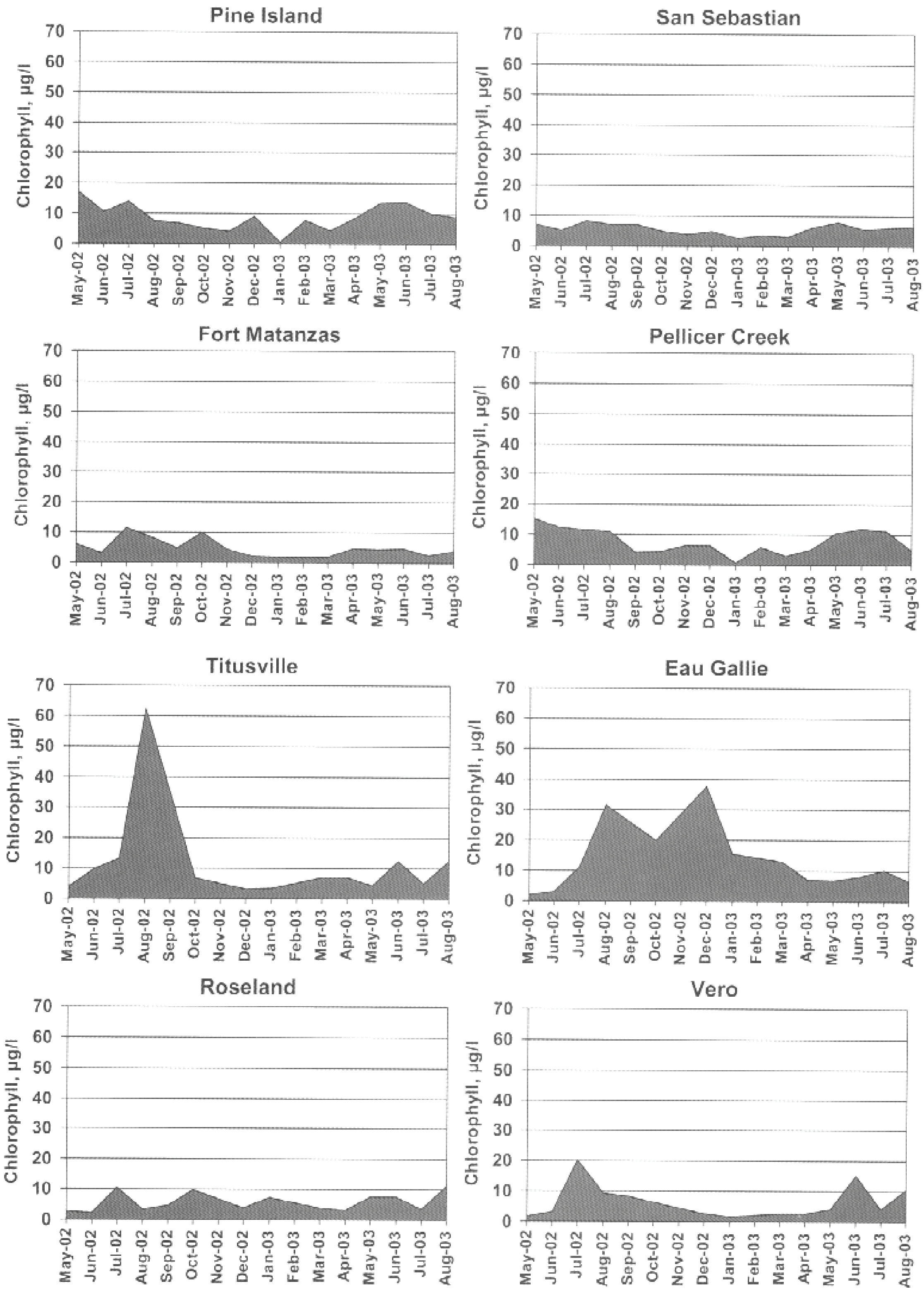


Figure 5. Chlorophyll-a concentration at eight study sites

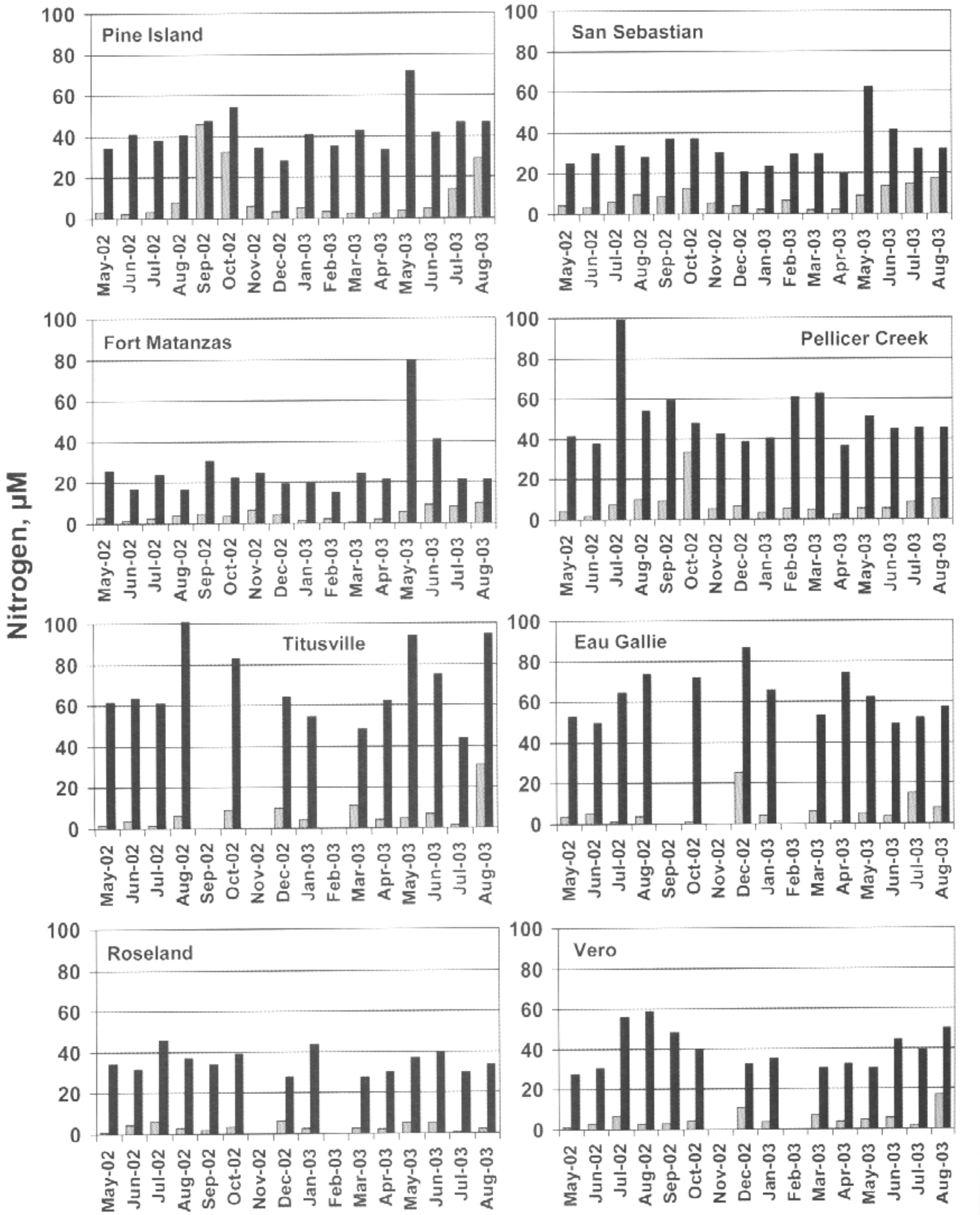


Figure 6. Total nitrogen (solid bar) and dissolved inorganic nitrogen (gray bar) concentrations at eight sampling sites

Chart

Researchers at the reserve considered all the factors that determine nutrient loading (including nitrogen and phosphorous inputs from all sources) and developed an index (Nutrient Load Index, or **NLI**), from 1-4, that describes how heavily the site is usually loaded with nutrients (1 represents a low load, 4 represents a high load).

They also developed an index that categorizes the sites according to estimated water residence times (**RTI**) on a scale of 1-4. This was done by summarizing the factors that determine tidal flushing, including tidal excursion, freshwater inflows, wind, water stratification, and depth. The index describes the extent to which nutrients generally remain in the estuary, or are flushed out (1 represents a short residence time, 4 represents a long residence time).

Site	Nutrient Load Index	Residence Time Index	Peak chlorophyll-*a*	Average chlorophyll-*a*
GTM NERR Sites				
Pine Island	1	2	18	8
San Sebastian	3	1	5	8
Fort Matanzas	1	1	8	11
Pellicer Creek	3	2	10	15
Indian River Lagoon Sites				
Titusville	1	1	4	22
Eau Gallie	2	2	3	20
Roseland	4	4	1	10
Vero	4	4	2	12

Teacher Guide—Life Science Module
Activity 3 — Biodiversity in an Estuary

Featured NERRS Estuary:
Rookery Bay National Estuarine Research Reserve, Florida
http://nerrs.noaa.gov/Reserve.aspx?ResID=RKB

Activity Summary

In this activity, students investigate the incredible biodiversity that exists in estuarine environments. They begin by exploring the Rookery Bay National Estuarine Research Reserve (NERR) using Google Earth. Students then produce an estuary biodiversity concept map and individual organism profile that becomes part of an estuary wildlife exhibit.

Learning Objectives

Students will be able to:

1. Describe the physical and biological components of habitats that exist as part of an estuary.
2. Explain the relationships between primary producers, consumers, and secondary consumers.
3. Describe some adaptations of living organisms to the changing conditions within an estuary.
4. Explain why biodiversity is important and worth preserving in an estuary.

Grade Levels

9-12

Teaching Time

4 (55 minute) class sessions + homework

Organization of the Activity

This activity consists of 3 parts which help deepen understanding of estuarine systems:

Investigating Habitats in an Estuary

Biodiversity in an Estuary

Portrait of Life in an Estuary

Background

This activity introduces students to the amazing biodiversity of an estuarine environment, focusing on the habitats in the Rookery Bay National Estuarine Research Reserve (RBNERR). The reserve is located at the northern end of the Ten

Thousand Islands on the gulf coast of Florida and represents one of the few remaining undisturbed mangrove estuaries in North America. The total estimated surface area of open waters encompassed within proposed boundaries is 70,000 acres, 64 percent of RBNERR. The remaining 40,000 acres are composed primarily of mangroves, fresh to brackish water marshes, and upland habitats.

Rookery Bay has a surface area of 1,034 acres and a mean depth of about 1 m. Salinities range from 18.5 to 39.4 parts per thousand with lower values occurring during the wet season from May through October. Highest values occur during the dry seasons (winter and spring) and can exceed those of the open Gulf of Mexico (35-36 parts per thousand).

Google Earth

This activity *requires* the use of Google Earth. If students have computer access, the use of Google Earth (http://earth.google.com/) can help them develop spatial skills.

To find the Tutorial "Using Google Earth to Explore Estuaries" go to Estuaries.noaa.gov, click the tab titled Curriculum and then the sub-tab titled Tutorials.

Preparation

- Download Google Earth, if you haven't already done so, and install it on your classroom computer (s) or computer lab machines *http://earth.google.com/* (Refer to *Using Google Earth to Explore Estuaries*, for a brief how-to guide.)
- Arrange for students to access the Internet and/or other resources on organisms. For example, the University of Michigan Museum of Zoology's Animal Diversity Web site: *http://animaldiversity.ummz.umich.edu/site/index.html*
- Obtain the poster paper for the concept maps in Part 2 and the poster board for the students' organism profiles in Part 3.
- Make copies of the *Student Reading* and *Student Worksheet.*
- If feasible, assign the *Student Reading—Introduction to Rookery Bay* and *Student Reading—Biodiversity in an Estuary* before beginning the activity, as preparation for Part 1.

Materials

Students

- ❑ Need to work in a computer lab or with a computer and projector
- ❑ Copy of Student Reading Estuary and Watershed
- ❑ Copy of Student Worksheet Estuary and Watershed, Student Data Sheet 1 — Orienting Yourself to the San Francisco Estuary and Watershed
- ❑ Copy of Student Data Sheet 2 — Water Quality Data

Teachers

- large sheets of poster paper (for Part 2)
- large pieces of poster board (for Part 3)

Equipment:
- ❑ Computer lab or
- ❑ Computer and Projector

Procedure

Part 1 — Investigating Habitats in an Estuary

1. Have students read the *Student Reading—Introduction to Rookery Bay* and *Student Reading—Biodiversity in an Estuary*.

2. Show students their starting point (Rookery Bay National Estuarine Research Reserve; 26° 01' 30.55 N, 81° 43' 54.20 W) in Google Earth and have them complete Part 1 of the *Student Worksheet—Biodiversity in an Estuary*.

   If students are using Google Earth for the first time, show them how to use the Search tool, how to zoom in and out to change viewing altitude, and how to use the motion buttons to navigate around the image. (Refer to *Using Google Earth to Explore Estuaries*, available online where you acquired this activity, for a brief how-to guide, or have students go through the "Navigating in Google Earth" tutorial at http://earth.google.com/support/bin/answer.py?answer=176674)

   Discuss why the images seem to change, particularly the color and resolution of some of the images.

3. Review and discuss the Part 1 tasks and questions.

Part 2 — Biodiversity in an Estuary

4. Divide the class into teams, distribute the large paper, and explain that they will produce a large concept map that underscores the biodiversity and the interrelationships of organisms in the dynamic estuarine environment.

5. Have students read the introduction in Part 2 of the *Student Worksheet—Biodiversity in an Estuary*, which describes concept maps. If students are unfamiliar with concept maps, consider drawing a sample concept map on a general topic, such as your school.

6. Have the student teams create their Rookery Bay concept maps, starting with a box that has "Rookery Bay Reserve" and following the instructions in the Concept Map section in Part 2 of the *Student Worksheet—Biodiversity in an Estuary*.

7. When students are done with their concept maps, attach the maps to a board or wall and have a discussion on the similarities and differences between the various maps.

8. Have students answer the question to complete Part 2 of the *Student Worksheet—Biodiversity in an Estuary*.

National Science Education Standards

Content Standard A: Science as Inquiry

A3. Use technology and mathematics to improve investigations and communications.

A4. Formulate and revise scientific explanations using logic and evidence.

A6. Communicate and defend a scientific argument.

Content Standard B: Physical Science

B6. Interactions of energy and matter

Content Standard C: Life Science

C4. The interdependence of organisms

C5. Matter, energy, and organization in living systems

Content Standard F: Science in Personal and Social Perspectives

F3. Natural Resources

F4. Environmental quality

F5. Natural and human-induced hazards

F6. Science and technology in local, national, and global challenges

Part 3 — Portrait of Life in an Estuary: A Wildlife Exhibit

9. Assign or have students select one organism from an estuary to study in detail. You can have students draw the name of an organism out of a bowl (proverbial hat…) or you can have them choose one organism that they would like to focus on.

10. Have students complete Part 3 of the *Student Worksheet—Biodiversity in an Estuary* and produce a poster on their organism.

11. When students finish their posters, create a class exhibit to serve as a viewing area and post students' work.

12. Allow students sufficient time to circulate and read all the class posters.

13. Lead a discussion of the importance of biodiversity, using examples where low biodiversity was problematic, and review the tasks and questions of Part 3.

Check for Understanding

1. Use the concept maps from Part 2 as an assessment of student understanding of the relationships between habitats, characteristics of the habitats, and the species that inhabit the estuary.

   A simple way to do this is to give 1 point for each link on the concept map between two of the three variables. Then, award 2 points for each double link (two lines that reveal a relationship). Add 3 points for complex interrelationships in the concept map (3 or more lines coming from one box). Establish a class scale based on the total points given for each poster.

2. Evaluate the Wildlife Exhibit posters as a summative performance assessment for this activity.

3. Have a discussion with students after the Wildlife Exhibit viewing has ended. Ask students:

- Which animals or plants in Rookery Bay are endangered?
- What conditions in the estuary have caused populations of each of the endangered species to decline?
- Are any actions being taken or projects underway to protect the remaining population and support its recovery?

Optional Extension Inquiries

Ask for permission to take samples of plants native to the estuary region and have student teams compile a pressed sample book. Have students organize their field collection by creating a multi-stage classification and a dichotomous key for the samples they collected.

Teacher Worksheet with Answers
Activity 3: Biodiversity in an Estuary

1a. Describe the estuary features and landforms you saw as you examined the Florida coast.

Answer: Students should mention bays, inlets, wetlands, barrier beaches, and others.

1b. List the types of habitats you identified in the Rookery Bay National Estuarine Research Reserve.

Answer: Upland forests, mangrove forest, salt marsh, and tidal flats habitats are evident.

2. Were there any animal species that were not linked to another with at least one arrow?

Answer: Each species should be have at least one connection to another species and most will have more than one.

3a. Which animals or plants in Rookery Bay are endangered?

Answer: The Florida manatee is endangered. A rare and endangered species list for Rookery Bay can be found at www.dep.state.fl.us/coastal/sites/rookery/species.htm.

3b. Choose one of the endangered animals and find out what conditions have caused its populations to decline. Are any actions being taken or projects underway to protect the remaining population and support its recovery?

Answer: Student answers will vary.

Student Reading—1
Activity 3: Introduction to Rookery Bay NERR

Located at the northern end of the Ten Thousand Islands on the gulf coast of Florida, Rookery Bay National Estuarine Research Reserve (NERR) is a prime example of a nearly pristine subtropical mangrove forested estuary. The Rookery Bay estuarine ecosystem contains bays, interconnected tidal embayments, lagoons and tidal streams. Sources of freshwater drainage include sloughs, strands, a series of tidal creeks and channels, and canals.

A unique upland feature of the Rookery Bay NERR and adjacent region are shell mounds. These are mostly refuse sites used by aboriginal Indians. The mounds form prominent topographical features above the low-lying tidelands of the Reserve.

The region is known for its commercially valuable fishes and shellfish, including mullets, blue crabs and stone crabs. Agriculture, eco-tourism, fishing, and boating are important revenue sources in the region, and the undeveloped areas of the reserve and the Aquatic Preserve are heavily used year-round.

The core of the reserve is currently 12,500 acres of open water, mangrove wetlands, and pine and oak uplands. The state's Rookery Bay Aquatic Preserve and Cape Romano/Ten Thousand Islands Aquatic Preserve are also managed by the reserve, bringing the total of state lands and water managed by the reserve to 112,000 acres.

Figure 1. Rookery Bay seen through an arch of Mangrove trees

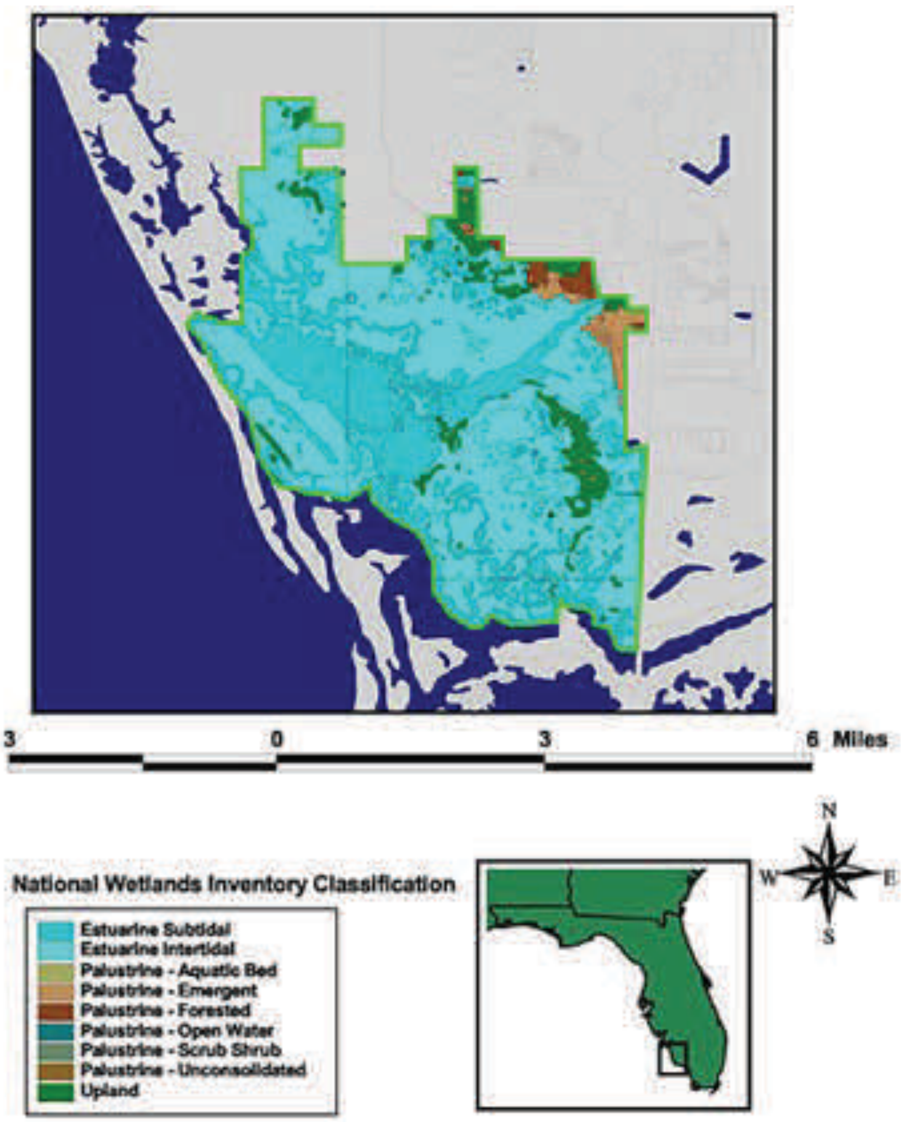


Figure 2. Many diverse habitats occur in the reserve and adjacent lands. Some of these are: 1) Pine/Cabbage Palm/Oak, 2) Pine Flatwoods, 3) Coastal Scrub, 4) Cypress Forest, 5) Freshwater Marsh, 6) Saltwater Marsh, 7) Mangrove Forests, 8) Coastal Strand, and 9) Open Water.

- Adapted from http://nerrs.noaa.gov/RookeryBay/welcome.html and http://www.dep.state.fl.us/coastal/sites/rookery/info.htm

Student Reading—2
Activity 3: Biodiversity in an Estuary

An estuary is a partially enclosed body of water, and its surrounding coastal habitats, where saltwater from the ocean mixes with fresh water from rivers, streams, or groundwater. In fresh water, the concentration of salts, or salinity, is nearly zero. The salinity of water in the ocean averages about 35 parts per thousand (ppt). The mixture of saltwater and freshwater in estuaries is called **brackish** water. An amazing number of plant and animal species have found ways to adapt to the dynamic and ever-changing environmental conditions in the estuary.

A rich array of habitats surrounds estuaries. Habitat type is usually determined by the local geology and climate. Some habitats associated with estuaries include:

- salt marshes
- mudflats
- rocky intertidal shores
- sea grass beds
- mangrove forest
- tidal streams
- barrier beaches

In almost all estuaries, the salinity of the water changes constantly over the tidal cycle. To survive in these conditions, plants and animals living in estuaries must be able to respond quickly to drastic changes in salinity. Plants and animals that can tolerate only slight changes in salinity are called stenohaline. These organisms usually live in either freshwater or saltwater environments. Most stenohaline organisms cannot tolerate the rapid changes in salinity that occurs during each tidal cycle in an estuary.

Plants and animals that can tolerate a wide range of salinities are called euryhaline. These are the plants and animals most often found in the brackish waters of estuaries. There are far fewer euryhaline than stenohaline organisms because it requires a lot of energy and specialized adaptations to tolerate constantly changing salinities. Organisms that can do this are rare and special.

Some organisms have evolved special physical structures to cope with changing salinity. The smooth cordgrass found in salt marshes, for example, has special filters on its roots to remove salts from the water it absorbs. This plant also expels excess salt through its leaves.

Figure 3. Oysters have the ability to adapt to changes in salinity by opening or closing their shells

Oysters and other bivalves, like mussels and clams, can live in the brackish waters of estuaries by adapting their behavior to the changing environment. During low tides when they are exposed to low-salinity water, oysters close up their shells and stop feeding. Isolated in their shells, oysters switch from aerobic respiration (breathing oxygen through their gills) to anaerobic respiration, which does not require oxygen. Hours later, when the high tides return and the salinity levels in the water are considerably higher, the oysters open their shells and return to feeding and breathing oxygen.

Unlike plants, which typically live their whole lives rooted to one spot, many animals that live in estuaries must change their behavior according to the surrounding waters' salinity in order to survive. Blue crabs are good examples of animals that do this.

A Study of One Estuarine Habitat — Mangrove Forest

Mangrove forests grow at tropical and subtropical latitudes near the equator where the sea surface temperatures never fall below 16°C. Mangrove forests line about two-thirds of the coastlines in tropical areas of the world. All mangrove trees are able grow in hypoxic (oxygen poor) soils where slow-moving waters allow fine sediments to accumulate. Mangrove forests can be recognized by their dense tangle of prop roots that make the trees appear to be standing on stilts above the water. This tangle of roots helps to slow the movement of tidal waters, causing even more sediments to settle out of the water and build up the muddy bottom. Mangrove forests stabilize the coastline, reducing erosion from storm surges, currents, waves and tides.

Figure 4. Mangrove forests are common along the southern coast of the United States.

Three dominant species of mangrove tree are found in Florida. The red mangrove colonizes the seaward side of the forest and black mangroves are found further inland. The zone in which black mangrove trees are found is only shallowly flooded during high tides. White mangrove trees face inland and dominate the highest terrain in the estuary. Tidal waters almost never flood the zone where white mangrove trees grow.

—Adapted from
oceanservice.noaa.gov/education/kits/estuaries/media/supp_estuar06b_mangrove.html

Biodiversity in a Mangrove Forest

The mangrove forest is a habitat for many species. It provides nursery grounds for young fish, crustaceans and mollusks. Many fish feed in the mangrove forests, including Snook, Mangrove Snapper, Tarpon, Jack, Sheepshead, Red Drum, Juvenile Blue Angelfish, Lined Seahorse, and Great Barracuda as well as shrimp and clams. An estimated 75% of the game fish and 90% of the commercial fish species in south Florida depend on the mangrove system.

The branches of mangroves serve as roosts and rookeries for coastal and wading birds, such as the Roseate Spoonbill, Double-Crested Cormorant, Great Egret, Great Blue Heron, Osprey, Snowy Egret, Green Heron, and Greater Yellowlegs. Other animals that shelter in the mangroves are the American Coot, American Crocodile, Bald Eagle, Peregrine Falcon, Eastern Diamondback Rattlesnake, and the Atlantic Saltmarsh Snake.

Figure 5. Ospreys are secondary consumers. They feed almost entirely on fish they capture from fresh or saltwater.

Above the water mangroves also shelter and support snails, periwinkles, crabs, spiders, Spanish moss, and Reindeer lichen. Below the water's surface, often encrusted on the mangrove roots, are sponges, anemones, corals, oysters, mussels, starfish, crabs, and Florida Spiny lobster.

As you can see, a unique mix of marine and terrestrial species lives in mangrove forests. The still, sheltered waters among the mangrove roots provide protective breeding, feeding, and nursery areas for a host of animal species important to commercial and recreational fisheries. Protecting this habitat is truly a matter of national importance.

Animal species that inhabit any habitat are classified as either **primary producers**, **primary consumers,** or **secondary consumers**. Green plants, algae, and diatoms are examples of primary producers—organisms that produce their own food through the process of photosynthesis. Primary consumers like minnows and other aquatic species eat the algae to provide their energy needs.

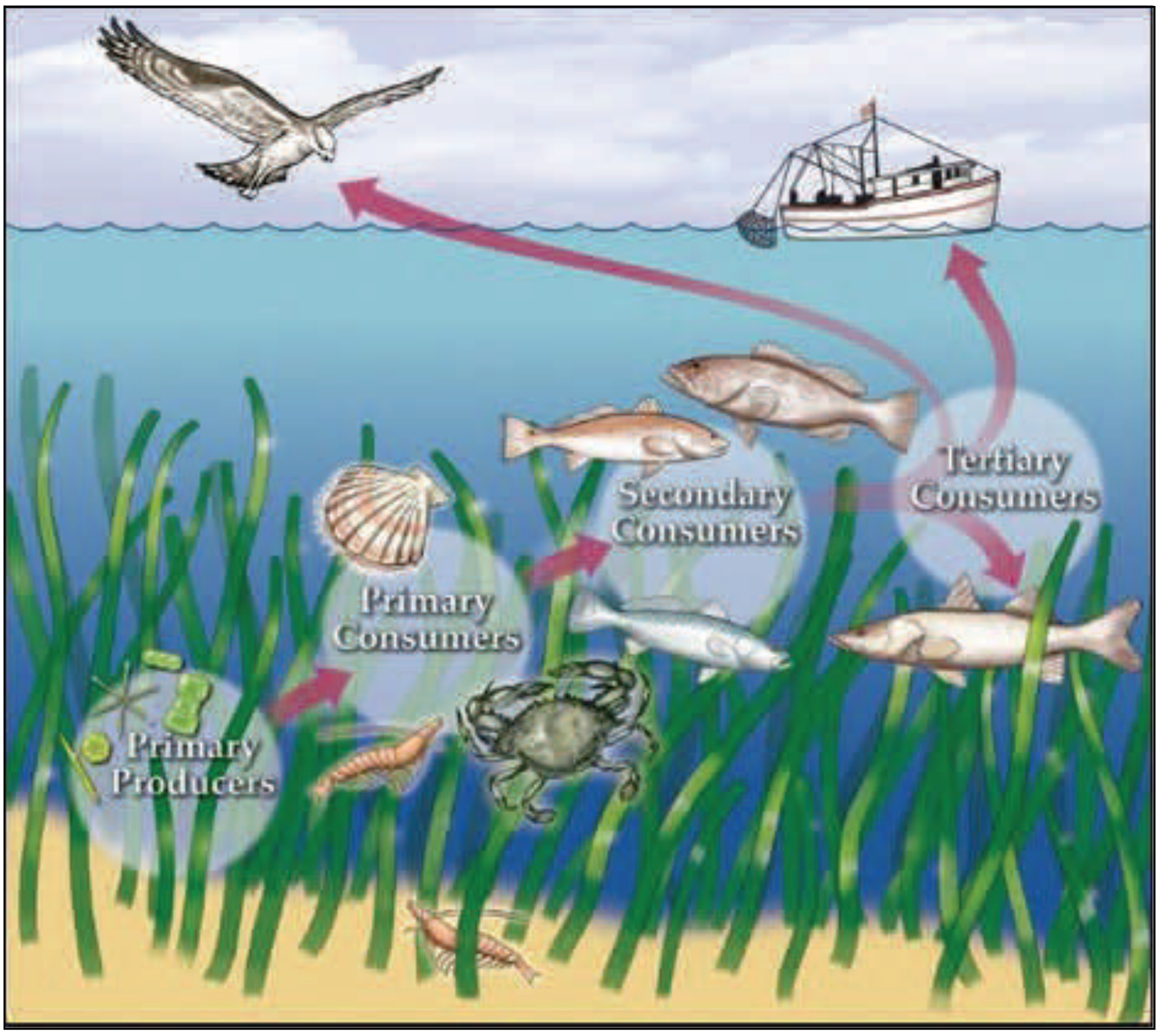


Figure 6. Producers and consumers in an estuarine environment. (Nutrients and Florida's Coastal Waters: The Links Between People, Increased Nutrients and Changes to Coastal Aquatic Systems. http://edis.ifas.ufl.edu/SG061. Published by the Florida Sea Grant College Program with support from the National Oceanic and Atmospheric Administration, Office of Sea Grant, U.S. Department of Commerce. Published for the University of Florida, Institute of Food and Agricultural Sciences [SGEB-55]. October 2001.) Accessed: 2008-07-20.(Archived by WebCite® at http://www.webcitation.org/5ZhWgbRvv)

Organisms such as larger fish that eat primary consumers are called secondary consumers. Birds of prey such as ospreys are secondary or tertiary consumers, as they dive into the water to capture fish in their talons.

Why is Biodiversity Important?

The natural environment is the source of all our resources for life. Environmental processes provide a wealth of services to the living world—air to breathe, water to drink, and food to eat, as well as materials to use in our daily lives and natural beauty to enjoy.

A complex ecosystem like an estuary with a wide variety of plants and animals tends to be more stable. A highly diverse ecosystem is a sign of a healthy system. Since the entire living world relies on the natural environment, especially humans, it is in our best interest and the interest of future generations to conserve biodiversity and our resources.

Some might argue that some species have become extinct with no obvious effect on the environment. But the Earth's systems are so complex that we are still learning about environmental processes and resources and the roles they play. The careless loss of any part of the natural environment means that we may never know what use it was or could have been in terms of future technologies, say, or for medical science, or indeed for the health of the planet itself.

It is important to understand that environments are constantly changing. A healthy, robust environment evolves and adapts to naturally changing conditions. It is fascinating to observe the far-reaching effects that even small changes can make and the importance of genetic diversity for species to adapt, survive and evolve.

Preservation of biodiversity is not necessarily about preserving everything currently in existence. It is more a question of "walking lightly" on the Earth—a balance of respecting the natural changes that occur and of protecting species and environments from wanton extinction and destruction.

Life on Earth would not be the same if our planet's biodiversity were to be radically affected. Estuaries are complex ecosystems that are home for a number of plants and animal species. The loss of a single species has consequences for many others living in the same habitat.

- Adapted from:
URL:http://eco-online.qld.edu.au/novascotia/whatsbio/importance.html. Accessed: 2008-07-30. (Archived by WebCite® at http://www.webcitation.org/5Zhq3RSh2)

Student Worksheet
Activity 3: Biodiversity in an Estuary

Student Name:____

Part 1: Investigating Habitats in an Estuary

In this activity, you will explore the habitats that compose the Rookery Bay Reserve near Naples, Florida.

Open Google Earth and enter the following coordinates in the Search Window: 26° 01' 30.55 N, 81° 43' 54.20 W.

Zoom in to an Eye altitude of 400 m. You should see the main Field Station (buildings in the vicinity of the long dock) of the Rookery Bay Reserve.

Fly south along the coast at a viewing altitude of about 4 km.

1a. Describe the estuary features and landforms you saw as you examined the Florida coast.

Keep going down the coast. You will pass a series of bays: Johnson, East Marco, Goodland, Turtle, and Rookery to name some of the major ones. Stop when you arrive at the region that is bounded by Faka Union Bay and Fakahatchee Bay.

Zoom into this region and examine the type of habitat that surrounds these bays. Can you locate this region on the map of the Rookery Bay Reserve given below?

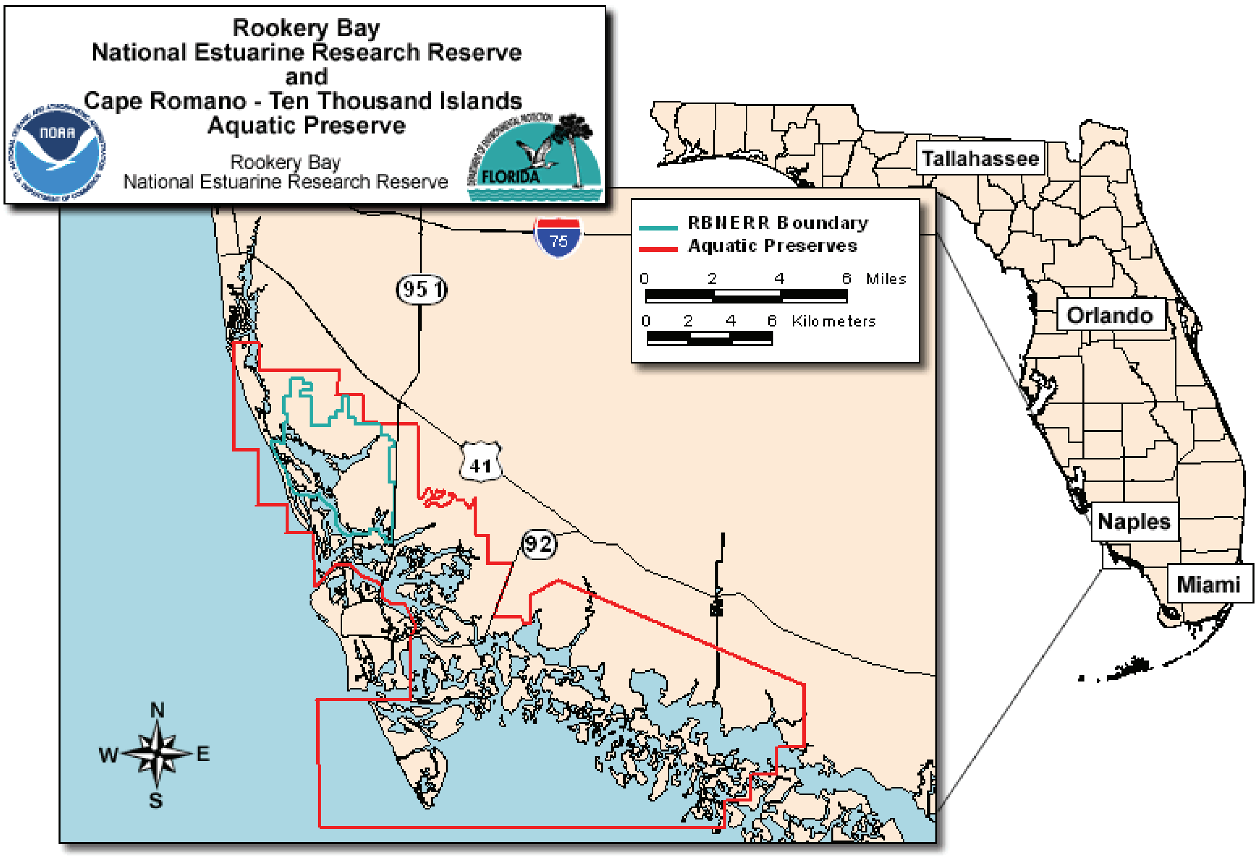


Figure 7. Map of the Rookery Bay NERR

1b. List the types of habitats you identified in the Rookery Bay Reserve. In the first column, list the habitat you identified. In the second column, identify the characteristics of each habitat. In the third column, note whether the habitat is land (terrestrial) or water (aquatic). In the fourth column, note special challenges to living in each habitat to plant and animal species.

Habitat Type

Name of Habitat	Characteristics	Terrestrial or Aquatic	Challenges

Part 2: Biodiversity Concept Map

Every plant and animal that exists in an estuary has a role in the ecosystem. Species depend on each other for food, for shelter, or other life processes. In this part of the activity, you will produce a concept map that shows how the estuarine environment supports the interrelationships of the plants and animals that reside in it.

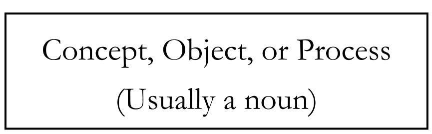
Introduction

Every topic can be broken down into a set of distinct factors. Think about topics such as acid rain, cleaning your room, putting on a dance, the water cycle, or doing homework. You can break each of these down into separate components, which together describe the larger topic. A concept map is a visual way to show how a topic's components or factors are connected or related. In fact, you can think of concept maps as a visual way to outline a topic.

The first step in making a concept map is to identify the individual elements involved in the topic. Just as when you tell a story, you must first identify all the elements before you begin—the characters, the settings, and the plot. A concept map helps people identify which ideas are essential to a topic and which are secondary or only weakly connected. The second step in making a concept map is to show how the parts relate to one another.

The following guidelines will help you make concept maps that are descriptive and complete.

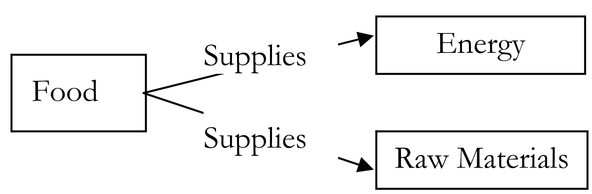
Concepts, objects, places, or processes appear in boxes. Most often, these words are nouns.



Example:

Arrows connect one box to another. The arrow's direction indicates how the reader should progress through the ideas. Words describing the actions and relationships appear on or just above the arrows connecting different boxes. Most often, these labels are verbs.

Example:



When labeling an arrow, using a noun (or a phrase such as "results in") is a clue that you can probably break the down the flow into more components and refine what is in the boxes.

If a box does not connect to the main topic being described in a concept map, then there is no need to draw a connection. When it is complete, you should be able read a concept map as if it were a paragraph or even a story. Select a box, and read along a sequence of arrows. The boxed words and arrow labels should make sense and explain how the ideas interconnect. In the supernova example, you can trace the sequence describing how stars and planets form by starting at any box.

Concept Map

Create a concept map.

- Begin your map with a single box with Rookery Bay Reserve in it.
- Include the major habitats that exist within the estuary (examples: Mangrove forest, tidal flats, etc.).
- Include characteristics of each habitat (see Habitat Table), salinity and other physical and chemical properties of the water (shallow, deep, fresh water, pH, etc.).
- Include the following plant and animal species: algae, Mangrove trees, clams, oysters, shrimp, periwinkles, horseshoe crabs, blue crabs, sea turtles, Snook, Mangrove Snapper, Tarpon, Juvenile Blue Angelfish, Lined Sea-horse, Barracuda, Great Blue Heron, Osprey, Snowy Egret, Green Heron, Greater Yellowlegs, American Coot, American Crocodile, Bald Eagle, Peregrine Falcon, Eastern Diamondback Rattlesnake, and Florida manatee.
- If possible, consult the Rookery Bay field guide for a list of more species to add to your map: http://www.rookerybay.org/Field-Guide.html.
- Indicate which species are primary producers, primary consumers, and secondary consumers.

Question

2. Were there any animal species that were not linked to another species with at least one arrow?

Part 3 — Portrait of Life in an Estuary: A Wildlife Exhibit

In this Part of the activity, you will explore the life of a single animal or plant species and describe how the species adapts to conditions within the estuary. You will either be assigned an organism or allowed to select one that interests you from this estuary system.

Produce a poster about your animal or plant. Include the following:

- A clear title, including the name of your organism;
- The names of the students on your team;
- A series of pictures from the Internet or magazines of your organism;
- Information and, when feasible, pictures on your organism's life cycle, preferred habitat, adaptations to changing conditions in the estuary (such as salinity and temperature), primary and secondary food sources, and whether the species is endangered or not; and
- References for where you got your images and information (e.g. the URLs of the Web sites).

Hang your poster as part of a class exhibit on estuary wildlife.

Walk around the finished class exhibit and read all of the posters.

Teacher Guide—Life Science Module
Final Assessment

- Provide a list of NERR sites to students with their home Internet address. Find the list on page two of this Final Assessment document.
- Break your students into small groups and either assign each group a NERR site or have them select their own to investigate.
- Student groups should select three endangered or threatened species in their chosen estuary to study.
- Students focus on one monitoring station within their estuary.
- Direct students to (http://estuaries.noaa.gov/ScienceData/Graphing.aspx) where they can download their NERR's abiotic parameter data for the most recent complete year available.
- Students produce a PowerPoint, poster, or other presentation outlining the following items:
  a. What research studies focusing on endangered or threatened species in your NERR have been completed or are underway? What are the results of these studies?
  b. Display your data graphs and discuss the water quality in your estuary.
  c. Have hypoxic or anoxic conditions occurred in your estuary during the year? Can you determine the cause of the hypoxia or anoxia (natural cause, human activity cause)?
  d. Are populations of your three chosen species increasing, decreasing or stable?
  e. Name some interventions that you think could increase the number of each of your chosen species in your estuary.
  f. How does a decreasing population of each of your species affect other plant and animal species in your estuary?
- Grade student presentations for clarity, presentation style, and depth of research and analysis.

State	National Estuarine Research Reserve	Website (URL)
Alabama	Weeks Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=WKB
Alaska	Kachemak Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=KBA
California	Elkhorn Slough NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=ELK
California	San Francisco Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=SFB
California	Tijuana River NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=TJR
Delaware	Delaware NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=DEL
Florida	Apalachicola NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=APA
Florida	Guana Tolomato Matanzas NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=GTM
Florida	Rookery Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=RKB
Georgia	Sapelo Island NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=SAP
Maine	Wells NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=WEL
Maryland	Chesapeake Bay MD NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=CBM
Massachusetts	Waquoit Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=WQB
Mississippi	Grand Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=GRD
New Hampshire	Great Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=GRB
New Jersey	Jacques Cousteau NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=JCQ
New York	Hudson River NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=HUD
North Carolina	North Carolina NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=NOC
Ohio	Old Woman Creek NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=OWC
Oregon	South Slough NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=SOS
Puerto Rico	Jobos Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=JOB
Rhode Island	Narragansett Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=NAR
South Carolina	ACE Basin NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=ACE
South Carolina	North Inlet-Winyah Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=NIW
Texas	Mission-Aransas NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=MAR
Virginia	Chesapeake Bay VA NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=CBV
Washington	Padilla Bay NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=PDB
Wisconsin	Lake Superior NERR	http://www.nerrs.noaa.gov/Reserve.aspx?ResID=LKS