Teacher Guide—
Dissolved Oxygen in an Estuary

Featured NERRS activity:
Elkhorn Slough National Estuarine Research Reserve
https://coast.noaa.gov/nerrs/reserves/

Activity Summary

In this activity, students investigate dissolved oxygen (DO) and its effects on aquatic life, with a particular focus on the chemical reactions that occur in an estuary. First, they are introduced to, and analyze data gathered from, water quality sensors in Narragansett Bay National Estuarine Research Reserve (NB-NERR), observing how DO and chlorophyll-a change from the surface to the bottom and consider the relationships between DO and temperature. Then, at the Elkhorn Slough NERR (ESNERR), they analyze DO data and speculate about how hydrodynamics, abiotic factors, and biological processes cause extreme fluctuations in DO in Azevedo Pond.

Learning Objectives

Students will be able to:

1. Explain the relationships between dissolved oxygen and water depth, chlorophyll-a and water depth, and dissolved oxygen and temperature.
2. Apply their knowledge of how these parameters interact during estuarine processes leading to phenomena such as eutrophication, algal blooms, and supersaturation-hypoxia fluctuations.
3. Recognize how processes such as photosynthesis, respiration, and decomposition affect dissolved oxygen.
4. Explain the role of these processes in daily or seasonal dissolved oxygen fluctuations in some estuaries.
5. Apply their knowledge of how hypoxia and anoxia occur, using data as evidence to explain the affect on estuarine animals.

Grade Levels

Middle School 8th Grade

Teaching Time

3 class sessions (55 minutes) + homework

Organization of the Activity

This activity consists of 2 parts which help deepen understanding of the chemistry of estuarine systems:

Dissolved Oxygen in Narragansett Bay

What's Happening in Azevedo Pond?

Featured NERR Estuaries

- Narragansett Bay National Estuarine Research Reserve, Rhode Island

https://coast.noaa.gov/nerrs/reserves/narragansett-bay.html

- Elkhorn Slough National Estuarine Research Reserve, California (Azevedo Pond)

https://coast.noaa.gov/nerrs/reserves/elkhorn-slough.html

Background

In this activity students focus on the relationship between dissolved oxygen, plant growth, chlorophyll-a and temperature using SWMP water quality data from monitoring stations in the Narragansett Bay Estuarine Research Reserve and the Elkhorn Slough Estuarine Research Reserve. If your students have not studied the processes of photosynthesis or respiration, go over the equations as part of your introduction to the activity. What follows is additional background information on the concepts contained in this activity.

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 a major factor that contributes to the type and abundance of organisms that can live there.

Oxygen enters the water through three natural processes: (1) diffusion from the atmosphere and (2) photosynthesis by aquatic plants, and 3) the mixing of surface waters by wind and waves can increase 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. DO levels in an estuary also vary seasonally, with the lowest levels occurring during the late summer months when temperatures are highest.

Bacteria, fungi, and other decomposer organisms 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 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.

Dissolved oxygen is critical for the survival of animals and plants that live in the water. Higher oxygen levels are one indicator of a healthier ecosystem. The more oxygen there is in the water, the healthier the ecosystem is. As the water temperature increases, the amount of oxygen that can dissolve in the water decreases. For example, fresh water at 0°C can contain up to 14.6 mg of oxygen per liter of water, but at 20°C, it can only hold 9.2 mg of oxygen per liter. Thus, seasonal water temperature (and dissolved oxygen) is an important indicator of habitat quality for many estuarine species.

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 during the spring, pH levels tend to rise. An overabundance of algae (called an algal bloom) may cause pH levels in an estuary to rise significantly, and this can be lethal to aquatic animals.

Excessive plant growth and decay can cause significant increases in nutrients such as nitrogen and phosphorous in the water, a condition known as eutrophication. Eutrophication is sometimes a result of pollution sources such as the release of sewage effluent and run-off from lawn fertilizers into streams or rivers leading to the estuary. Eutrophication generally promotes excessive plant growth and decay, favors certain weedy species over others, and is likely to cause severe reductions in water quality due to a decrease in DO. A sever drop in DO from large algae blooms can effect the survival of fish, shellfish and other invertebrates.

When large algae blooms occur the water becomes cloudy, colored a shade of green, yellow, brown, or red.

DO is measured in milligrams per liter of water. DO percent saturation depends on temperature (and also elevation). Percent Saturation is the amount of oxygen dissolved in the water sample compared to the maximum amount that could be present at the same temperature. The graphs in this activity refers to mg/liter.

Azevedo Pond

Preparation

- Make copies of the *Student Readings* and *Student Worksheets*.
- 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.
- Download the PowerPoint—*Azevedo Pond* to a computer that can project in front of the class or onto computers the students can access directly.

Procedure

Part 1 — Dissolved Oxygen in Narragansett Bay

1. Ask the students for their ideas about oxygen and life in estuaries. What conditions are necessary for organisms to survive in an estuary? You can list the responses on the board. How do organisms that live in the water extract oxygen for their use? How does oxygen enter estuary water? Prompt students to apply the concepts they may have already studied, such as solubility of gasses, photosynthesis and respiration, and interactions between the atmosphere, hydrosphere, and biosphere.

Strategy idea: Use "I know"," I learned" as a strategy to collect their thoughts pre- and post-Student reading.

2. Have students read *Student Reading—Introduction to Narragansett Bay* and *Student Reading—Dissolved Oxygen in an Estuary*.

Have students fill in "I learned".

3. Ask students to identify abiotic factors, such as Earth processes in an estuary, or biotic factors that could affect DO.
4. Introduce students to the Web site:http://omp.gso.uri.edu/ompweb/doee/virtual/sensors.htm Give them time to explore the Viewing Windows for each site.
5. Explain that they will observe how dissolved oxygen, temperature, and chlorophyll-a change with depth for two different locations in the bay.
6. As a class or in groups, have students complete the *Student Worksheet—Dissolved Oxygen in Narragansett Bay*, collecting and analyzing data from the two sites: Pomham Rocks, a shore-based site, and South Prudence, situated further out in the Bay.
7. Have the students graph the data they have collected.
8. Discuss results and students responses.

Materials

Students

- ❑ Need to work in a computer lab or with a computer and projector
- ❑ Copy of Student Reading 1: Introduction to Narragansett Bay
- ❑ Copy of Student Reading 2: Dissolved Oxygen in an Estuary
- ❑ Copy of Student Reading 3: Introduction to Azevedo Pond
- ❑ Copy of Student Worksheet: Dissolved Oxygen in Narragansett Bay

Copy of Student Worksheet:
Dissolved Oxygen in Azevedo Pond

Teachers

❑ Bookmark the following sites in all computers:
http://omp.gso.uri.edu/ompweb/doee/virtual/sensors.htm
https://coast.noaa.gov/swmp/#/index
https://coast.noaa.gov/estuaries/science-data/

❑ Download the power point presentation titled "Azevedo Pond" from the estuaries.noaa.gov site.

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

Part 2 — What's Happening in Azevedo Pond?

1. Project the PowerPoint—*Azevedo Pond*, have students create a list of pond characteristics that they think might be a factor effecting the water quality at this site. Ask them to make a prediction about the water quality of this pond .
2. Have students read the *Student Reading—Introduction to Azevedo Pond.*
3. Have students complete the *Student Worksheet—Dissolved Oxygen in Azevedo Pond*. Students may need help interpreting the graphs, particularly if they are not in color.
4. Discuss results and student responses.

Check for Understanding

- Discuss the following:
  - a. In general, what is the pattern of DO levels in a pond over the period of a single day?
  - b. In general, what is the pattern of chlorophyll-a in the same pond over the period of a single day?
  - c. What causes hypoxic conditions in an estuary?
- Have students compare DO levels at various sites within NERRS using the SWMP Data Tool. Download or let students download graphs using the System-wide Monitoring Data (SWMP) data to compare DO stability between an area where eutrophication is common (e.g. Childs River, Waquoit Bay NERR) and a well-flushed area (e.g. Menauhant). How are the DO levels different? Explain why differences occur.
  SWMP Data Tool: https://coast.noaa.gov/

Optional Extension Inquiries

1. Use dissolved oxygen probes, if available, to measure DO and consider how it changes over time under various conditions. For example:
   (1) take measurements of DO from water samples that include algae,
   (2) expose the samples to direct light for about five days, and then measure DO again. (Samples can be collected from an estuary or created using tap water and Elodea.)
   (3) take measurements of DO from a jar of just tap water and another jar with tap water and chopped green vegetables and monitor the DO in the jars over five days.
2. Analyze dissolved oxygen and chlorophyll-a data from sampling sites on Chesapeake Bay to identify conditions that caused fish kills and crab jubilees in the Bay during the summer of 2003.
   https://coast.noaa.gov/estuaries/
3. View an interactive video (click on "Lesson Plans" and find the video) about harmful algal blooms (HAB), and track recent algal blooms in Chesapeake Bay from the Maryland Department of Natural Resources Eyes on the Bay Site: http://mddnr.chesapeakebay.net/

Teacher Worksheet with Answers
Dissolved Oxygen in Narragansett Bay National Estuarine Research Reserve

Part 1 — Dissolved Oxygen in Narragansett Bay

Pomham Rocks

Depth (meters)	DO Saturation (%)	DO Concentration (mg/L)	Water Temperature (degrees C)	Chlorophyll (µg/L)
1				
3				
5				
7				
9				
11				*No reading at this depth*

South Prudence

Depth (meters)	DO Saturation (%)	DO Concentration (mg/L)	Water Temperature (degrees C)	Chlorophyll (µg/L)
1				
3				
6				
9				
12				
15				*No reading at this depth*

1. Why might there be differences in DO concentration at two different locations, at the same depth, within the same estuary?

   Answer: DO concentration can be influenced by factors, such as water temperature, turbulence caused by winds, waves, currents, and mixing, all factors that change from site to site.

2. As depth increases, how does:

   - DO concentration change? DO saturation?

     Answer: As you go deeper, DO concentration and DO saturation both decrease. (Teacher Note: Oxygen dissolves in estuary water partly by diffusion from the atmosphere. This occurs mainly near the surface, DO is higher there. DO is also generated by turbulence in the water caused by currents, winds and waves and by mixing, which is greater near the surface. DO also decreases with depth because of increasing water pressure. DO is also generated by the photosynthesis of plankton and macroalgae (Seaweed), and plants that grow on the bottom. At greater depths, sunlight for photosynthesis decreases.)

   - The temperature of the water change?

     Answer: As you go deeper, the temperature of the water decreases, though not smoothly. (Teacher Note: Students may become confused by the fact that although water gets colder with depth, DO does not increase with these colder temperature. In these cases of changing depth, other factors must also be considered. Water pressure, which increases with depth, and reduced sunlight, which limits photosynthesis, are much stronger influences on DO than colder water.)

   - Chlorophyll amounts change?

     Answer: As you go deeper, chlorophyll concentration decreases. (Teacher Note: Less sunlight can penetrate the water at those depths. Therefore, less sunlight is available for photosynthesis.)

3. Graph your data for Temperature and DO and both sites, with Depth on the X axis.
4. What is the relationship between DO concentration and temperature?

   Answer: Generally, there is an inverse relationship. As temperature increases, dissolved oxygen decreases and as temperature decreases, dissolved oxygen increases. Water at colder temperatures can hold more dissolved oxygen.

Teacher Worksheet with Answers
Dissolved Oxygen in Azevedo Pond

Part 2 — What's Happening in Azevedo Pond?

1. What are the features of Azevedo Pond that could affect dissolved oxygen? List them in the chart below and explain how they could affect dissolved oxygen.

Feature	Affect on Dissolved Oxygen
Shallow	*Most of the water will be close to the surface where oxygen will diffuse into the water, and light can probably penetrate the entire water column allowing for photosynthesis and creation of DO. However, light can probably heat the water column thoroughly, and temperatures that are too high will decrease DO.*
Restricted water flow	*The lack of much water exchange limits DO, because it keeps water from mixing and becoming aerated.*
High productivity of plankton	*Lots of photosynthesis will produce lots of DO, but if there is an overabundance of plankton, it may produce algal mats, especially if there is an excess of nutrients. When the algal mats die, they will decompose and this will consume oxygen.*
Large changes in temperature	*Can cause either a large increase of plant growth that increases DO, or a drop in temperature can cause massive die off of plant matter, subsequent decay and lowering of DO.*
Bordered by strawberry farm	*May receive a high amount of nitrates and phosphates from the fertilizers during rain runoff. These nutrients could cause algae blooms that will produce lots of oxygen, but which will eventually decay, consuming DO.*
Lack of tidal flushing	*Will mean not much mixing. Also means that nutrients and the algae will remain in the pond for longer periods of time, allowing for photosynthesis of algae blooms and creation of DO, but also decomposition of algal mats and eventual hypoxia.* *Poor flushing causes thermal stratification, which further keeps water from mixing. Warmer waters closer to the surface may limit production of DO.*

2. Look at the graph of DO Concentration and PAR (photosynthetically available radiation—a synonym of visible light) for Azevedo Pond from March 13-16, 2016.

   2a. What is the range of DO (green-line) for this period?

   Answer: From a high of about 15mg/L to a low of 0 mg/L.

   2b. Describe the pattern of change in DO observed within a 24-hour period, (each day is starting at 1:00am.)

   Answer: DO rises and fall over the day and night relative to the time of day, higher during the daylight hours and lower at night. Suggesting a possible relationship with sunlight.

2c. How does DO change in relation to PAR from day to day? Why do they exhibit this relationship?

Answer: PAR and DO move up and down in parallel as you move through the day and into the evening.

2d. Why do you think DO and PAR varied like this in Azevedo Pond during March 2016? Explain in terms of photosynthesis, respiration and the features of the pond that affect dissolved oxygen.

Answer: Because the pond is poorly flushed by the tide, plankton and nutrients remain in the pond for long periods of time. The shallow water gets ample sunlight for algae and plants to photosynthesize throughout the water column, generating an abundance of DO. As PAR increases throughout the day, photosynthesis increases. This generates levels of oxygen that cause the water to be supersaturated, but only during the daylight hours. At night, the abundance of algae and the plants continues to respire, but without photosynthesis to balance the respiration. In darkness, the chlorophyll undergo respiration to the point where most of the oxygen is consumed and the water is hypoxic (the percentage of DO saturation is zero).

3. What percent of each year has Azevedo Pond had hypoxic conditions? How does this compare with the other three sites?

   Answer: Each year, about 15-20% of the year or 1.8-2.4 months (54-72 days) have hypoxic conditions. Azevedo Pond is the only one of these sites that has had hypoxic conditions every year between 2006 and 2016.

4. Look back at the map of the Reserve, why might you see this difference in the number of hypoxic events at the other sites?

   Answer: The other sites have greater tidal flow, less restriction of flow than Azevedo Pond

5. How might this information be used by the Reserve Manager to address water quality issues at this site and others around the Elkhorn Slough Reserve.

Answer: Answers may vary, possibly Managers would consider removing tidal flow impediments such as levies and culverts to restore flow to restricted sites, or employ some device fro mixing the water.

Student Reading—1
Introduction to the Narragansett Bay National Estuarine Research Reserve

The Narragansett Bay National Estuarine Research Reserve (NBNERR) is located in the geographic center of Narragansett Bay. The Narragansett Bay watershed drains over 1600 square miles of land and over 60% of the watershed is in Massachusetts. The Bay's watershed is heavily populated and urbanized. Rivers and streams in the watershed feed about 2 billion gallons of fresh water into Narragansett Bay every day. To get a sense of how much water that is think about this; two billion minutes is about 3,800 years!

The Narragansett Bay Research Reserve encompasses roughly 4,400 acres of land and water out to a depth of 18 feet on Prudence, Patience, Hope and Dyer Islands located in the center of Narragansett Bay. Prudence Island is the Reserve's biggest island and is home to the Reserve's headquarters. Approximately 80% of Prudence Island is held in conservation thanks to the Reserve and other local conservation groups. The only way to get out to Prudence Island is by boat, and a ferry runs back and forth to the island each day. Only about 150 people choose to live out on Prudence Island year round. They have to rely on the ferry for everything, even getting groceries and supplies back to their homes in the winter. It is a tough way of life, so not many people spend the whole year on the island. In the summer the island becomes a popular vacation destination and as many as 3000 people might be on Prudence during a weekend in the summer.

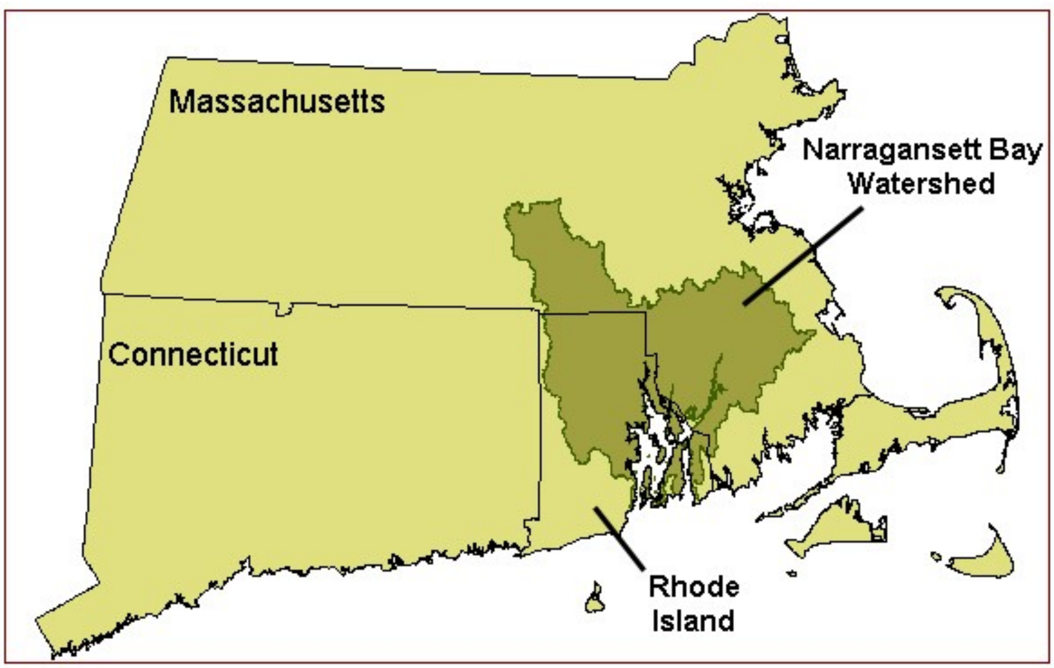

Figure 1 . The ~1600 square mile Narragansett Bay watershed extends up into the State of Massachusetts.

Figure 2 . Prudence, Patience, Hope, and Dyer Islands
make up the Narragansett Bay Research Reserve in the center of Narragansett Bay.

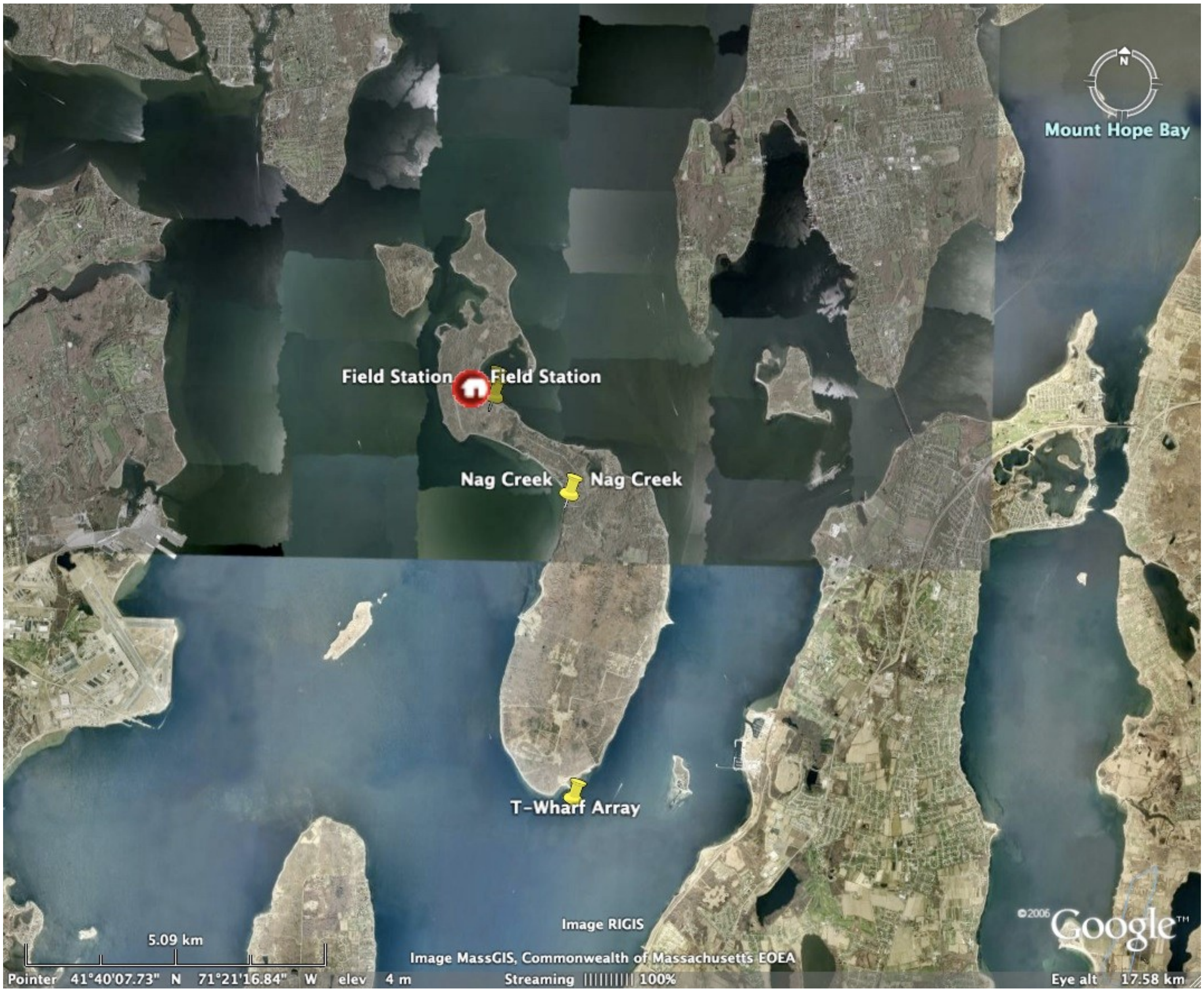

Figure 3 . You will use field and monitoring station data from the sites seen in this satellite view.

Student Reading – 2
Dissolved Oxygen in an Estuary

Dissolved Oxygen in an Estuary

Aquatic organisms such as zooplankton, invertebrates and fish require sufficient levels of dissolved oxygen (DO) to survive. Species diversity and organism abundance in an estuary are determined by the amount of DO in the water. Each species has a DO threshold within which it can survive.

Oxygen is supplied to estuarine waters through three natural processes: (a) diffusion of atmospheric oxygen into the water, (b) aeration of water, and (c) photosynthesis by phytoplankton, aquatic seaweeds and seagrasses.

Diffusion from the surrounding air into the water occurs as oxygen moves from an area of higher concentration to an area of lower. If the air in the atmosphere has a higher concentration of oxygen than the water - the oxygen is "pushed" into the water. The speed of this movement of oxygen is related to the difference in the concentration of oxygen in air to water and the barometric pressure.

Aeration of water can occur during the mixing of surface waters by wind and waves.

Photosynthesis is a chemical reaction that occurs in plants as they "breathe" in carbon dioxide and release oxygen into their environment. In the case of aquatic plants like algae the oxygen is released into the water. There is one problem, photosynthesis requires energy from sunlight, in darkness the process is reversed and the plants consume the oxygen in the water as fuel

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \xrightarrow{\text{sunlight}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

Oxygen is removed from estuarine water in two natural processes: (a) aerobic respiration and (b) bacterial decomposition.

$$\underset{\text{sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} + \underset{\text{ATP and Heat}}{\text{Energy}}$$

Respiration is a process in which animals and plants take up oxygen and produce carbon dioxide. During the process energy from sugars is also released.

Respiration occurs all the time, while photosynthetic production of oxygen by plants occurs only during daylight hours. As a result, dissolved oxygen levels in an estuary may vary widely because of differences in the amount of oxygen produced by plants.

Decomposition by bacteria, fungi, and other organisms affect DO levels in an estuary because they consume oxygen while breaking down organic matter. These decomposers consume oxygen in the process of gaining energy through the breaking of chemical bonds in organic matter.

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

Dissolved Oxygen and Life in an Estuary

All life in an estuary depends on oxygen in sufficient amounts. DO can increase and decrease suddenly, causing a struggle for survival for many animal and plant species.

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

In other words, cold water can hold more dissolved oxygen than warm water, and fresh water can hold more dissolved oxygen than salt water. So, the warmer and saltier the water, the less dissolved oxygen there can be. The maximum amount of dissolved oxygen that the water can hold is called the **saturation value**. Dissolved oxygen measurements are given as a percent of saturation (%) or in units of milligrams per liter (mg/l).

If you consider the equation for **photosynthesis**, you can see why an explosion of plant growth (see algal blooms below) can cause water to become over saturated with oxygen. A huge amount of plant growth releases so much oxygen that the water becomes **supersaturated** (120%).

When the opposite is true, when water has very low levels of oxygen, the condition is called **hypoxia**. DO levels of less than 28% saturation or concentrations between .5 and 2 mg/L are considered lethal to most aquatic life. Hypoxia is often caused by excessive growth of algae, called "algal blooms." Although these blooms may result from natural conditions, they are also linked to excess nutrients that enter estuaries from human sources, such as: point source discharges from sewage and industry and septic tanks; wastewater treatment plants; exhaust from cars; emissions from industry; fertilizers from lawns, golf courses and farms, as well as from animal waste. These nutrients enter estuaries directly from point sources or they are transported to estuaries by stream flows, rain, leaching, groundwater, and storm water.

The influx of high nutrient levels causes excessive growth of algae. When algae dies, it sinks to the bottom, where it is decomposed by bacteria in the sediments. 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, 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.

Anoxia refers to water that has been completely depleted of oxygen. 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. Weak tidal flushing, shallow water depth, and stratification between warmer surface water and colder bottom water may also lower DO concentrations. All of these conditions exist in Azevedo Pond.

Algal blooms can be detected by measurements of chlorophyll-a. Chlorophyll-a is a pigment in phytoplankton that is involved in photosynthesis. Concentrations of chlorophyll-a are measures of phytoplankton abundance. Concentrations measured are measured in units of μ/L. The presence of chlorophyll-a indicates an abundance of algae, which initially increases levels of DO. But eventually the algae decay, driving DO levels down again.

Some estuaries, like Azevedo Pond, have extreme fluctuations in dissolved oxygen from day to night regularly.

These estuaries may go through weeks of daily cycles that are marked by supersaturation in the day and hypoxia at night. Supersaturation can occur during the daytime when algae on the surface photosynthesizes, producing an over-abundance of oxygen. This supersaturation of DO during daylight can be followed by hypoxia during the night. In darkness, phytoplankton and plants no longer have the light they need to photosynthesize, but they do continue the process of respiration, which consumes oxygen.

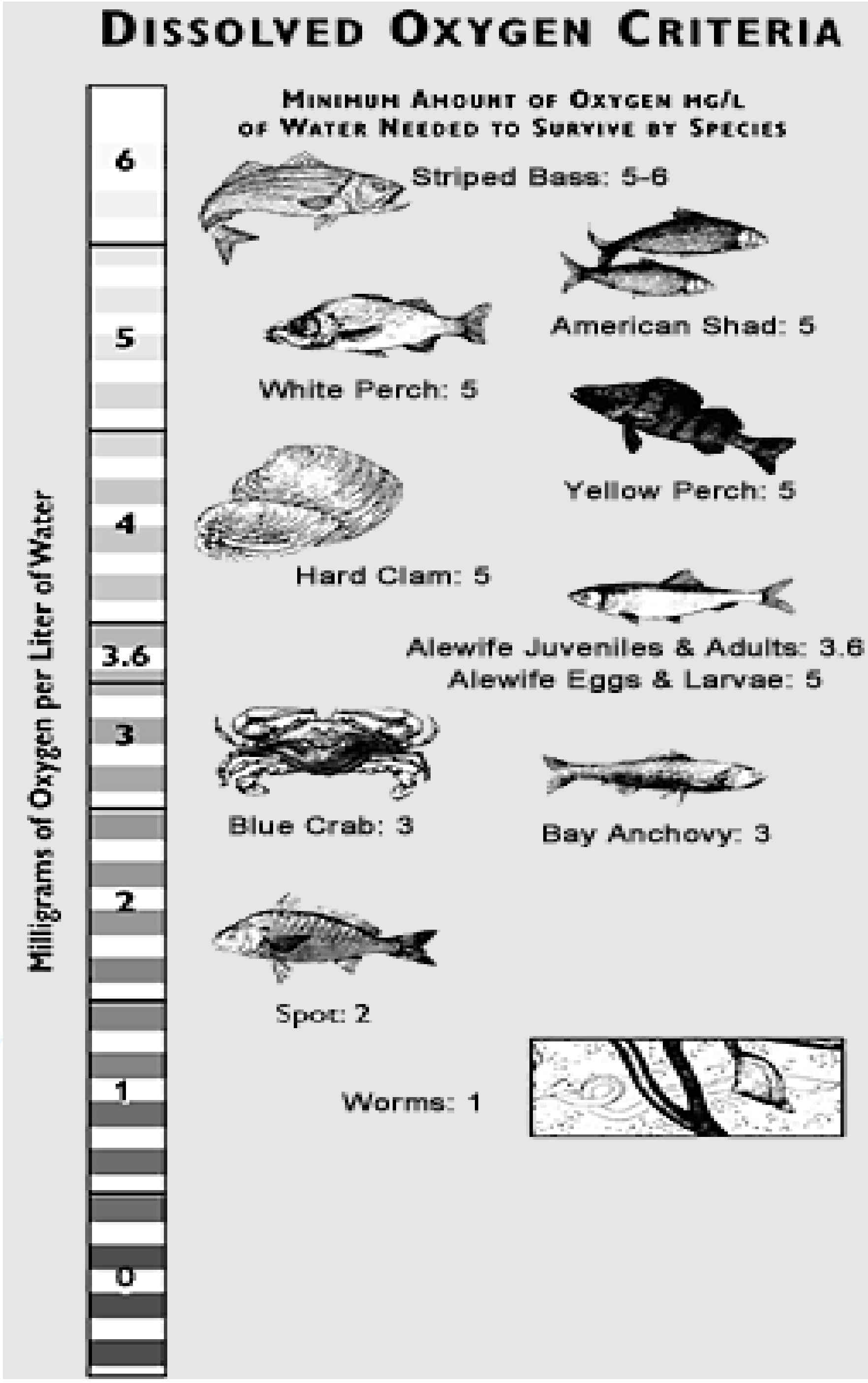

Figure 4. Minimum amount of DO needed for species to survive.

(Credit: Chesapeake Bay Program. URL:http://www.chesapeakebay.net/dissolvedoxygen.aspx?menuitem=14654. Accessed: 2008-08-06.

Student Worksheet
Dissolved Oxygen in Narragansett Bay

Student Name: ____

1. Open the Web site: <http://omp.gso.uri.edu/ompweb/doee/virtual/sensors.htm>.

2. Read the description for Pomham Rocks.

3. Click on the star labeled Pomham Rocks and then click on "Go to Water Reading Sensors."

4. Record DO Saturation, DO Concentration, Water Temperature, and Chlorophyll at each depth for Pomham Rocks.

Depth (meters)	DO Saturation (%)	DO Concentration (mg/L)	Water Temperature (degrees C)	Chlorophyll (µg/L)

5. Repeat these steps for the South Prudence site.

Depth (meters)	DO Saturation (%)	DO Concentration (mg/L)	Water Temperature (degrees C)	Chlorophyll (µg/L)

6. Examine your data for patterns and relationships.

Questions

1a. Why might there be differences in DO concentration at two different locations, at the same depth, within the same estuary?

1b. As depth increases, how does

- DO concentration change?
- DO saturation?
- The temperature of the water?
- Chlorophyll amounts?

1c. What is the relationship between DO concentration and temperature?

2. Graph your data for each of the two sites; Temperature and DO, with Depth on the X axis.
3. What is the relationship between DO concentration and temperature?

Student Reading – 3
Introduction to Azevedo Pond

Azevedo Pond is a small tidal pond located along the shore in the northern part of the Elkhorn Slough National Estuarine Research Reserve in California.

The Elkhorn Slough estuary 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.

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.

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.

The Reserve is surrounded by conventional and organically grown strawberry fields as well as rural housing.

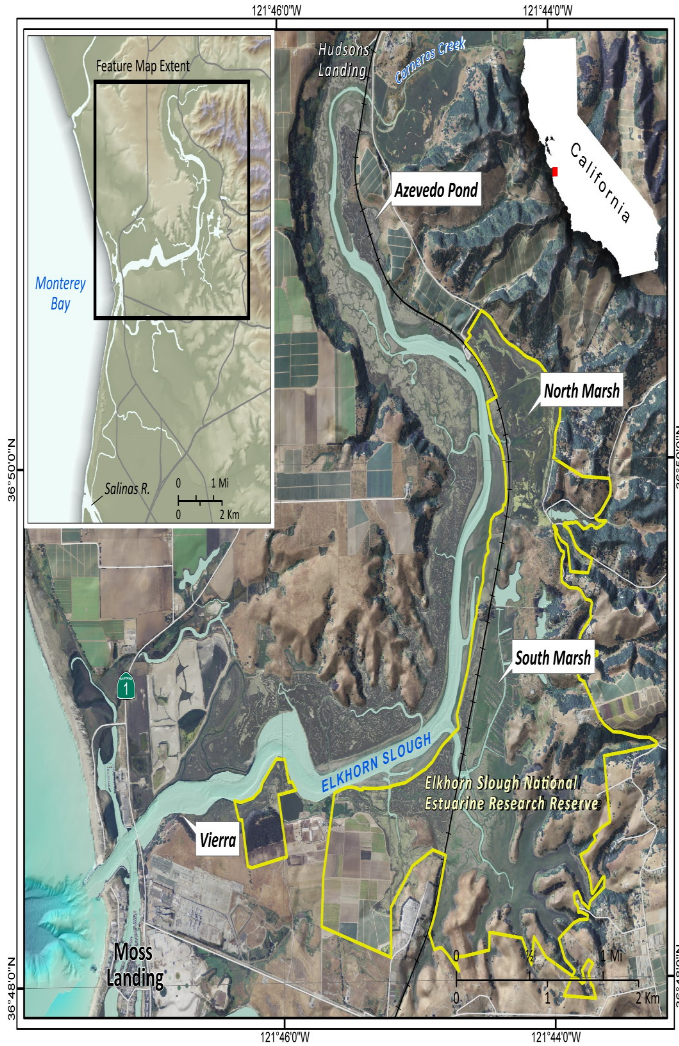

Figure 7. A satellite view of Elkhorn Slough NERR and Azevedo Pond

Azevedo Pond is characterized by:

- Restricted water flow: It has only a partial tidal connection to the estuary, so water in the pond does not get flushed out well and often remains in the pond for a long time.
- Azevedo Pond is only flushed with Upper Elkhorn Slough water when the tide height is greater than 1.2 m. The lack of tidal flushing means that the water can get separated into distinct warmer and cooler layers as it sits for long periods of time.
- The pond is surrounded by a strawberry farm. The only groundwater and surface runoff input the pond receives is from the strawberry farm during rainfall.
- Shallow depth: It is less than 1.5 m deep.
- High productivity by phytoplankton.
- Large daily temperature changes occur periodically.
- The pond produces thick mats of algae during the summer and fall months.

Figure 8. Map of Azevedo Pond and the Surrounding Area

Student Worksheet
Dissolved Oxygen in Azevedo Pond

Student Name: ____

1. What are the features of Azevedo Pond that could affect dissolved oxygen? List them in the chart below and explain how they could affect dissolved oxygen.

Feature	Affect on Dissolved Oxygen

2. Look at the graph of DO Concentration and PAR (photosynthetically available radiation—a synonym of visible light) for Azevedo Pond from March 13-16, 2016.

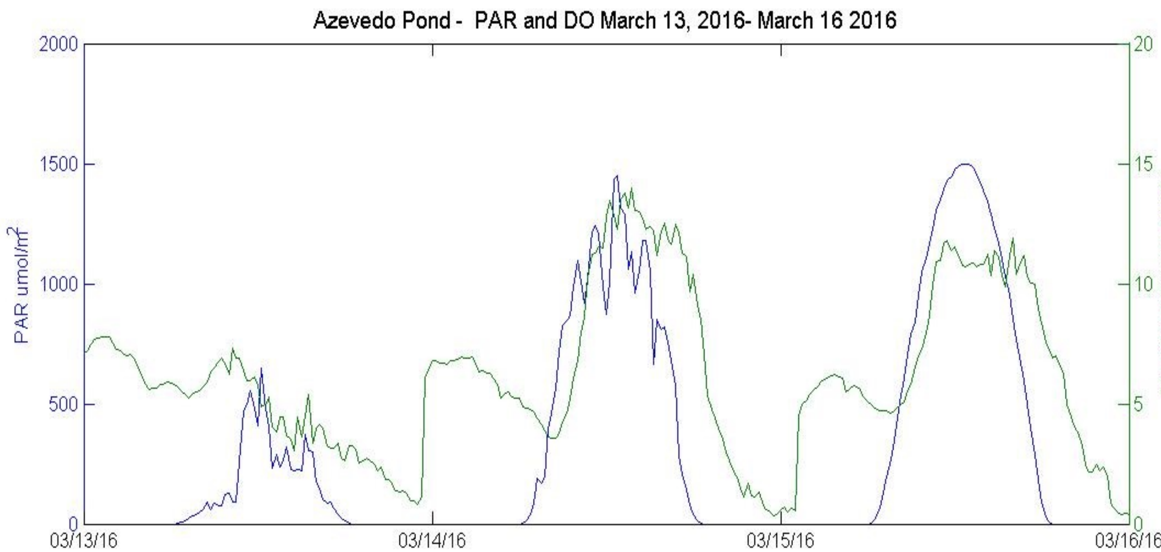

Figure 9. Azevedo Pond Dissolved Oxygen and Photosynthetically Available Radiation, March 13-16, 2016

2a. What is the range of DO (green-line) for this period?

2b. Describe the pattern of change in DO observed within a 24-hour period, (each day is starting at 1:00am.)

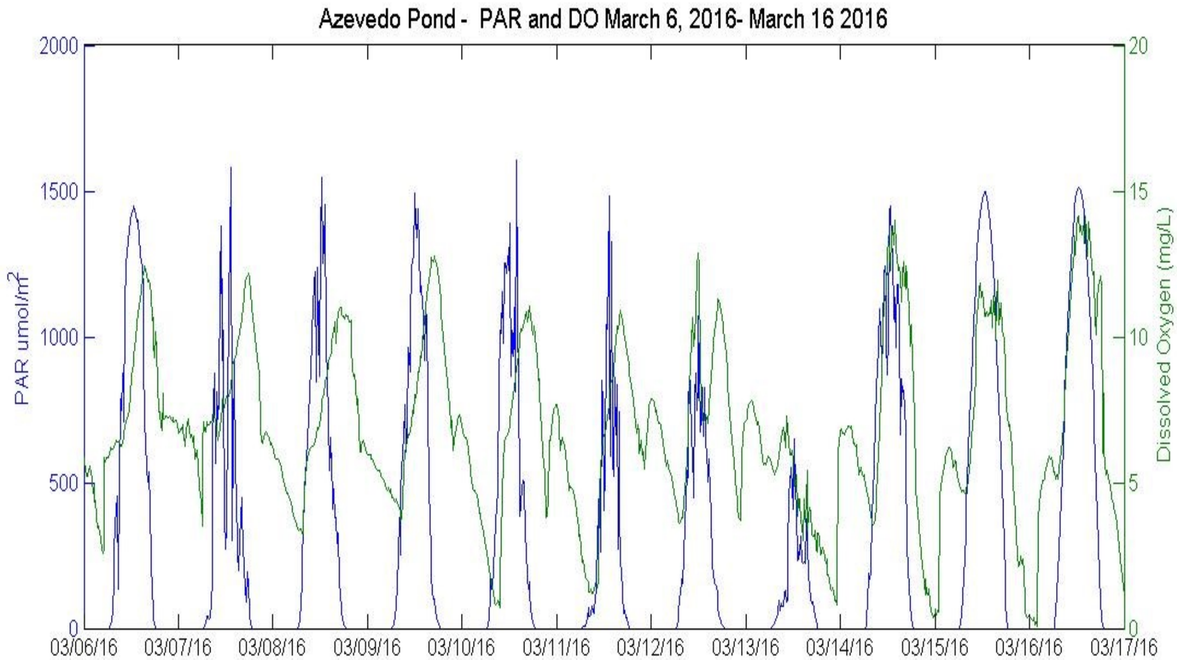

Figure 9. Azevedo Pond Dissolved Oxygen and Photosynthetically Available Radiation, March 6-17, 2016

2c. How does DO (green line) change in relation to PAR (blue line) from day to day? Why do they exhibit this relationship?

2d. Why do you think DO percentage and PAR varied like this in Azevedo Pond during March 2016. Try to explain in terms of photosynthesis, respiration and the features of the pond that affect dissolved oxygen.

Look at the graph below that shows the frequency of hypoxic events (over a twenty year period) in Azevedo Pond and three other sites within the Elkhorn Slough. (Note: Hypoxia is defined as a DO saturation level below 2 mg/L)

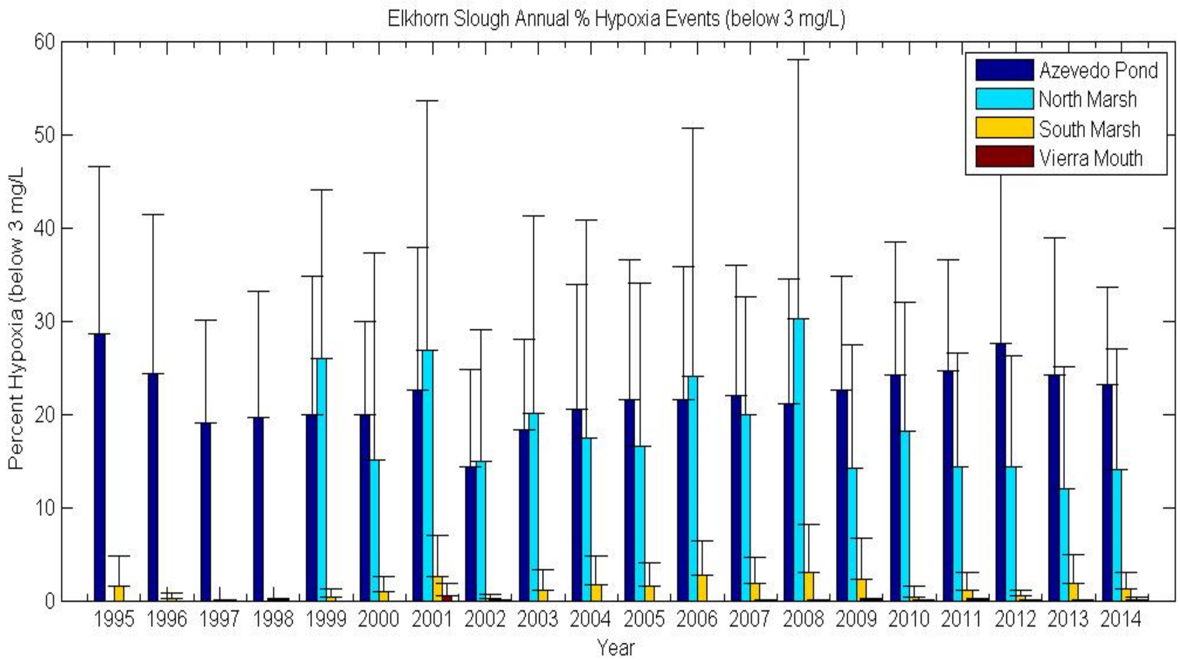

Figure 11— Frequency of hypoxic events in Azevedo Pond (first column in each series) compared to three other sites in Elkhorn Slough

3. What percent of each year has Azevedo Pond had hypoxic conditions? How does this compare with the other three sites?

4. Look back at the map of the Reserve, why might you see this difference in the number of hypoxic events at the other sites?

5. How might this information be used by the Reserve Manager to address water quality issues at this site and others around the Elkhorn Slough Reserve.