OXYGEN OPTODE

Related lesson plan

Hypoxia and the Oxygen Squeeze

What is this sensor?

This sensor is used to detect dissolved oxygen and oxygen saturation levels in a given body of water[i]. Oxygen sensors detect dissolved oxygen, often abbreviated to DO. Although water is made of hydrogen and oxygen, the sensor only measures “free” oxygen, or oxygen that is not bound to another molecule[ii]. The sensor also measures the saturation of oxygen in the water. This is the amount of oxygen the water can hold relative to the atmosphere. Oxygen saturation is usually expressed as a percentage, but it is possible for this number to be over 100% saturation. Oxygen, like other elements and compounds can be mixed into and dissolved in water. A good analogy for dissolved oxygen is when sugar is added to hot tea. Like the sugar, the oxygen present in the water will be invisible, but is an important factor in the end result. The sensor is referred to as an optode, because it uses the properties of light, (opto: “vision”, “light”; -ode: “way”, “path”) rather than another method such as a chemical reaction or electricity to take measurements.

How does an oxygen optode work?

Detecting oxygen in water can be done in a number of ways, including chemical titrations or with the use of electrodes. Optodes, in very general terms, create their measurements by emitting light and measuring the luminescence (similar to a glow) given off by the oxygen in the water[i]. To take a measurement, the optode emits a specific wavelength of light which excites the molecules of the substance being measured. These molecules then emit a slightly different wavelength of light in response to excitation, which the sensor detects. Using various calculations, the sensor then determines how much of the substance (in this case oxygen) is present in the water around the sensor.

How is oxygen measured?

(ml/l), (mg/l) or (ppm)

Oxygen can be measured in milligrams per litre of water (written as mg/l), millilitres per litre (written as ml/l) or as parts per million (written as ppm). For example, if the oxygen sensor gives a reading of 8.3mg/l, this would mean that there are 8.3 milligrams of oxygen in a litre of water. Since this measurement is in grams, it reflects the mass of the oxygen in a volume of water. Using ml/l, this measurement would be 5.7ml/l; this is the approximate volume of the oxygen in the water, rather than the mass. The volume of oxygen is more dependent on the temperature and pressure of the surrounding water, as the volume of a gas can be different depending on the overall temperature and salinity. Ocean Networks Canada observatories measure the volume of oxygen in a litre of water, and thus data is written ml/l, though you may find mg/l in some publications. To convert between mg/l and ml/l, you can use these conversions. These conversions assume certain values for temperature, salinity, and pressure, but are reasonably accurate.

Convert mg/l to ml/l

ml/l = mg/l X 0.7
mg/l= ml/l X 1.39

Occasionally, oxygen may be written as parts per million. In the above example, a reading of 8.3ppm would mean that water contains 8.3 parts of oxygen per million parts of water.

Oxygen water sampling bottles used during a marine expedition.

What is the normal range for these data? What variables influence it?

Quick general reference:

Anoxic	0.35 ml/l
Hypoxic	<1.4 ml/l
Normal/favourable	5–7 ml/l
High	>10 ml/l

Detailed explanation

Dissolved oxygen in salt water is generally lower than in fresh water, and has a relatively small numeric range. For example, water with less than 1.4 ml/l of oxygen is referred to as hypoxic, which means 'low oxygen'[i]. Water with less than 0.35 ml/l is termed as anoxic water, and is an acute or extreme example of hypoxia. Water with 10–11ml/l of oxygen has a relatively high concentration of oxygen, though it can reach near or above 15 ml/l in very favorable conditions. Oxygen levels generally associated with healthy biological process are in the 5–7ml/l range. Bear in mind, dissolved oxygen is only one indicator of health and what is normal for one area may be very unusual for another. Furthermore, it is normal for oxygen levels to fluctuate throughout the year, perhaps due to seasonal changes in currents, biological activity or even human interference (e.g. pollution).

Oxygen may vary or show patterns based on these parameters:

- Temperature: Cold water can hold more oxygen than warm water.
    - $\downarrow$ temperature = $\uparrow$ oxygen
- Salinity: Salty water contains less oxygen than freshwater.
- Depth: Shallow water can exchange gases with the atmosphere, resulting in a greater variability of oxygen.
- Primary production: the process of photosynthesis by phytoplankton can cause an increase in oxygen.
- Decomposition: decay can diminish the amount of oxygen present in water.
- Location of the sensor: location, in terms of both geography and depth, can affect the oxygen reading.
- Biology: animals in an environment will consume the available oxygen through respiration.
- Seasons: Oxygen levels can change seasonally because of the combination of seasonal changes of the factors above, such as a seasonal plankton bloom.
- Pollution: Human activity can introduce additional factors which may alter and often lead to deterioration of oxygen levels.

Applications of principles and variables

Dissolved oxygen concentrations are an important parameter for understanding a body of water and can be used to determine seasonal trends, identify a parcel of water (and where it originated), determine the overall health of a body of water, and can contribute to our general understanding of cycles and processes in the ocean. Variables and trends affecting dissolved oxygen (and their general significance in the ocean), are discussed below. These are in alphabetical order. Bear in mind, many of these factors interact and trends or variations in dissolved oxygen are often attributed to more than a single factor or variable.

Biology

Many organisms within an ecosystem depend on dissolved oxygen, and their presence, absence, or even death can be linked with dissolved oxygen levels. For example, animals which require oxygen are called aerobic and use oxygen from water in the process of respiration. In the oceans, some organisms take in oxygen through pores and moist membranes on their body surface; other organisms, such as fish, obtain their oxygen through membranes in the special structures of the gills. Different animals will require different levels of dissolved oxygen to live comfortably in an environment. If dissolved oxygen concentrations become too low, animals may be forced to move to other locations. This may, in turn, cause a population shift or overabundance of other species in an area. If the animals are unable to move to areas of higher oxygen concentration, this may result in a die-off of particular species. If the water becomes anoxic, it may result in a die-off of all species found in that area.

*These data may be supported with visual data from **cameras**.*

Depth

Oxygen concentrations vary with depth. Dissolved oxygen can enter water through passive exchange with the atmosphere at the surface and also through wind and wave action. Measurements taken at shallow depths are often more variable than those taken at greater depths, because the oxygen in the water may change depending on action at the surface. Equally, oxygen can be affected by tidal action, which is more exaggerated in shallow areas. Although this increased mixing action often results in considerable variability, there is generally a higher concentration of oxygen in the topmost layers of the ocean.

Water at depth is generally lower in oxygen as there are fewer available mechanisms to replace oxygen lost due to respiration or decomposition. For example, water at depth is not able to exchange gases with the surface, nor is it able to gain oxygen through primary production (plants). Furthermore, the processes of decomposition (which uses oxygen) usually occurs on the sea floor and thus, it is not able to regain oxygen that is lost through natural processes. When studying dissolved oxygen at depth, instrument readings are generally lower and more consistent. In addition, differences in dissolved oxygen values at different depths are also due to differences in the composition of the water column. In some areas, such as **Saanich Inlet**, a seasonal "refresh" occurs as large oxygenated water masses enter the inlet at certain times a year. Oxygen can represent a "signature" of where water masses originated.

Decomposition

Decomposition can also greatly affect oxygen concentrations. Bacteria use up oxygen (through respiration) when they decompose organic matter. If there is little or no renewal of oxygenated water, the process of decomposition can lead to rapid and significant oxygen depletion.

In some situations, an excess of nutrients can cause a large bloom of phytoplankton. The phytoplankton can start to die and sink down from the surface when the nutrients are used up. Bacteria decompose this sinking phytoplankton in deep water and at the sea floor causing an overall loss of oxygen to the water (hypoxia). For example, many bodies of water have become contaminated with fertilizers containing nitrates and phosphate from farm and agricultural run-off. This excess of nutrients (called eutrophication) causes plankton to bloom in excessive amounts, which then die in a number of days and then begin to decompose. This causes all the available oxygen to be used by bacteria, rendering the water hypoxic or even anoxic. This can result in large die offs of marine animals (e.g., fish, crabs) or the displacement of species.

In the data, you may notice an upswing in oxygen levels (e.g., produced during a phytoplankton bloom), followed by a steady decline in oxygen levels over time (e.g., due to animals respiring or decomposing). This conclusion can also be supported with data from the ***fluorometer****, which will indicate a large plankton bloom is occurring.*

Location

Location can contribute to dissolved oxygen readings. Although certain dissolved oxygen levels are favourable, all bodies of water will have a 'normal' oxygen range for that area. This means that an area may have a consistently high or low reading, but the animals in this area are adapted to that level of oxygen. When comparing oxygen levels, it is important to have a baseline of 'normal' data for that area, as what may be extreme in one area may be normal in another location.

Primary production

Oxygen is a by-product of photosynthesis. Plants within a body of water generate oxygen that contributes to the overall amount of oxygen found in the water. Often, the largest contributors are microscopic phytoplankton. Phytoplankton usually appear in seasonal blooms that contribute a significant amount of oxygen to the surrounding water.

In the data, you will notice seasonal blooms that generally appear within a 6–8 week window during the spring and fall. The actual time of the bloom will vary from year to year, and can be supported with data from the ***fluorometer****.*

Pollution

Agricultural run-off, sewage, and other human-induced nutrient influxes can create unseasonal or large blooms of phytoplankton. These can cause fluctuations in oxygen levels as the phytoplankton generate oxygen as a by-product of photosynthesis. Alternatively, the death and decomposition of phytoplankton can create depleted oxygen levels.

In the data, you may be able to extrapolate changes from pollution, due to proximity to shore and human and agricultural activities. These data could be supported with data from the ***fluorometer****.*

Salinity

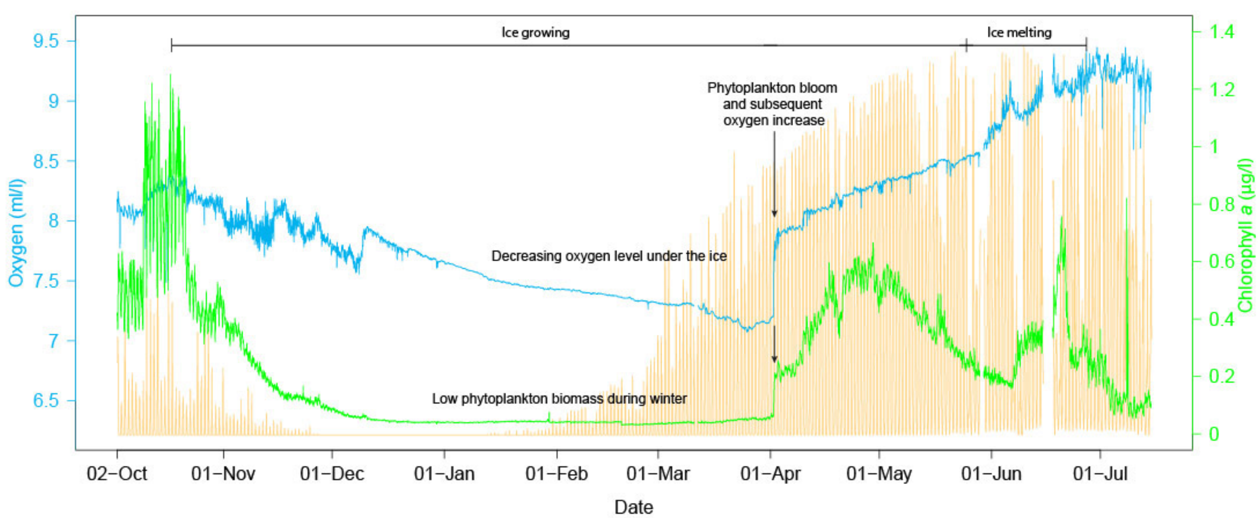
Salty water contains less oxygen than fresh water, and thus the overall salinity will cause water to have different oxygen levels. Near the surface, evaporation can cause salt concentrations to increase, resulting in water that is lower in dissolved oxygen. Equally, water in cold, salty arctic seas may have a lower concentration of oxygen during the winter when much of the fresh water is captured in ice. Surface sensors may detect higher levels of oxygen during spring melt, when the water has a lower level of salinity. Finally, large freshwater influxes from streams and rivers can result in reduced salinity, allowing the water to hold more oxygen.

Within the data, you may notice changes in relation to salinity which may also be related to temperature and seasonal changes.

Seasons

Dissolved oxygen can also vary due to seasonal factors. Season and location are often tied together as a factor in determining changes or patterns in dissolved oxygen. For example, in many areas, the seasonal plankton bloom renews the oxygen that has been removed from the water. Equally, during winter months, there may be little or no primary production, but significant wind mixing. This will result in a seasonal pattern of oxygen cycling that can be observed over the long term. Equally, as temperatures drop the solubility of oxygen increases, but water trapped below seasonal ice also loses oxygen to decomposition. Oxygen concentrations are often impacted by a number of factors that can occur at the same time, depending on the seasons.

Within the data, you may notice trends that follow seasonal plankton blooms and temperature changes.



The amount of light, phytoplankton biomass (expressed as chlorophyll-a concentration) and oxygen concentration during the 2012–2013 winter in Cambridge Bay, Nunavut.

Temperature

Dissolved oxygen levels are highly dependent on water temperature. Cold water can hold considerably more oxygen than warm water because of the compression of the gases at lower temperatures. In the data, it is possible to see higher oxygen levels in the winter months when the water is colder and is able to accommodate a larger volume of dissolved oxygen.

As depth increases, the temperature of the water decreases, but oxygen concentrations at depth may become slightly skewed due to other factors such as respiration and decomposition. Although the water can hold more oxygen because it is colder, there may not be oxygen available for uptake, thus readings remain low.

In the data, you will notice trends related to temperature. These trends can occur on a daily, weekly, monthly, or seasonal basis.

Ideas for classroom explorations

This section is intended to inspire you and your students to explore different ways of accessing, recording, and interpreting data. These suggestions can be used 'as is', or can be freely modified to suit your needs. They can also be used to generate discussion and ideas, or as potential staring points for projects.

- Record the oxygen levels and temperature on a daily basis. Watch for seasonal trends to appear. Inquire, are atmospheric changes reflected in the water data at the same time, or is there a delay?
- Monitor oxygen levels, chlorophyll, and atmospheric conditions. What is their relationship over time? Can your data help you make further predictions?
- Compare oxygen and temperature readings after specific atmospheric events. For example, do the data change during or after a heavy rain?
- Compare local readings to those in other locations. Will one predict or precede the trend of another? What other factors may account for the change in your data?
- Explore the local biology and using the camera, determine which animals are more or less tolerant of low oxygen.
- Determine, if possible, human impacts on the local ecosystems that may account for changes in oxygen.

Ideas for projects

This section contains suggestions for long-term projects you and your students may be interested in investigating using the data. These projects may require support from multiple data sources, experts in the field or additional experimentation.

- Compare the data and inquire about relationships among other seasonal trends. For example, during fish migrations is there a trend in the data? In successful spawning or fishing years, are there differences observed from unsuccessful spawning or fishing years?

- Compare data from several years. Can a seasonal or annual trend be determined? Can this trend be attributed to something using additional data, anecdotal evidence, or both?
- Compare multiple stations using the same variables.
- Explore how oxygen levels change over an hourly basis. Do we see biological responses over short time-scales as well?
- Investigate man-made corrections to human-caused low oxygen. For example, if low oxygen is suspected to be caused by farm run-off, what measures could be put in place or invented to correct or prevent the problem?

Common misconceptions or difficult concept elements

This section is intended to help you anticipate where students may struggle with difficult concept elements or ideas. We've noted content that may require additional support for students to fully understand, or content that may lead to misconceptions.

- Oxygen levels can reach more than 100% saturation. Saturation is not the same as the amount of dissolved oxygen. Saturation is the amount of oxygen the water could hold in relation to the atmosphere. Thus, oxygen may be supersaturated and have more oxygen than the atmosphere, but the dissolved oxygen could still be relatively low or high, depending on the variables affecting the dissolved oxygen level.
- Too much oxygen can be as bad or worse as too little oxygen for some fish and other organisms. More oxygen does not, necessarily, mean better living conditions for the endemic species in that area.
- Oxygen can be measured in volume and mass, and they are not the same thing. As gases are compressible, a given mass of gas will have a greater or smaller volume depending on temperature.
- Conversions between volume and mass generally assume a certain temperature, so some variability in accuracy may result from conversions.
- Although a large bloom of phytoplankton will contribute to an upswing in oxygen in the short term, after they die, this can result in a depletion of oxygen in the long term. An extreme example of this phenomenon is eutrophication, caused by an excess of nutrients from human activity.
- Deeper water is typically cooler than surface water, and cooler water can hold more oxygen. Keep in mind though, as material from the surface (e.g., sinking phytoplankton) sinks through layers of water, oxygen in each of those deeper and deeper layers of water can be lost to decomposition; thus, as material sinks through the water causing depletion, the level of oxygen in the water becomes lower.

Footnotes

[i] **Oxygen Optodes**. (2013, January 1). . Retrieved July 4, 2014.
[ii] Fondriest Environmental, Inc. "**Dissolved Oxygen**." Fundamentals of Environmental Measurements. Fondriest Environmental, 19 Nov. 2013.

[iii] Scott, E. (2007). **Luminescence based measurement of dissolved oxygen in natural waters** [PowerPoint Slides].
[iv] Ecological Society of America. **Hypoxia** [online PDF].