Effects of Water Quality on Metamorphic Organisms

by Mary S. Fabian, 2014 CTI Fellow
Cato Middle College High School

This curriculum unit is recommended for:
AP Environmental Science

Keywords: Metamorphosis, bioindicators, water quality, coral bleaching, ocean acidification, atmosphere, pollution, life cycles, biodiversity

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: This curriculum unit integrates topics related to metamorphosis, biodiversity, and pollution. Often, the generic term "water quality" means little to students who have grown up in developed countries. This unit aims to teach students in a more visceral manner that the quality directly impacts every organism that drinks water or lives in it. The original design of the unit was to repeatedly weave the information about water quality through several units of AP Environmental Science by emphasizing its impact on metamorphic organisms. The unit contains a culminating capstone activity that requires students to synthesize the knowledge from all the different units and evaluate impact of multiple sources of contamination on metamorphic organisms. This curriculum unit includes background knowledge on metamorphosis, maintaining biodiversity, pollution, greenhouse gases and the atmosphere and this role in ocean acidification. This unit also includes strategies for engaging students in hands-on science activities. The intent of this unit is that each module can be used individually or as part of the whole, so that educators of different science courses and grade levels can tailor the content to utilize as much or as little as they need for their own classroom enrichment.

I plan to teach this unit during the coming year in to 35 students in AP Environmental Science.

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Introduction

Cato Middle College High School (CMCHS) is a Cooperative Innovative High School that is under the umbrella of the CMS/NC Career and College Promise. In this program students are provided the opportunity to earn college credit while completing their high school diploma requirements. The school has a cap of 200 students, serves 11th and 12th grade students from Mecklenburg County and is housed on the Cato Campus of Central Piedmont Community College (CPCC). Students take their remaining high school courses required for graduation while taking college transfer classes at Central Piedmont Community College at no cost for coursework or textbooks. The student body consists of students coming from over 20 high schools in Mecklenburg County and reflects the diverse community which it serves: for the 2012-2013 school year there were 45.9% African American, 36.1% White, 7.7% Asian, 6.7% Multi-Racial and 3.6% American Indian. The student body is unequally distributed in terms of sex, with 64.4% female and 35.6% male. Students must apply for admission to CMCHS. To be eligible, students must have an un-weighted GPA of 2.5 or above, a good discipline and attendance record at their home school, and must pass the CPCC Accuplacer Exams. CMCHS had a 100% graduation rate for the years 2011, 2012, 2013 and 2014, and students graduate with an average of 30 college credit hours. The school is set up on a block schedule, semester system that follows the CPCC calendar. There are three, 90-minute CMS classes per day. I am the sole science teacher at CMCHS. My course load includes Honors Chemistry, Honors Physics, AP Physics 1 (as needed) and AP Environmental Science. The ability levels in the classes can vary widely, due to the students coming from so many different high schools and backgrounds. I ensure that activities are differentiated to reach all learners while maintaining rigor appropriate to Honors and AP level classes.

My classes follow different standards depending on whether they are Honors or AP. The Honors level classes follow the NC Standard Course of Study Essential Standards 2009, from the NC Department of Public Instruction. AP level classes follow the Course Descriptions as published by College Board. My classroom is outfitted with a smart lectern, which houses a computer attached to an LCD projector mounted to the ceiling, as well as white boards and individual desks and chairs that can be moved around the room. I try to incorporate lab based activities as much as possible to enhance learning and differentiate instruction. I include lab activities that will challenge students' firmly held scientific misconceptions, as my mainly anecdotal beliefs show that they will hold tightly to their misconceptions, often even in the face of contradictory evidence. Labs and activities are the best way to attempt to overcome this, since simply lecturing to the students will do nothing to dig out these entrenched ideas. My lessons are a mix of lecture, activities and group work nearly every day. Every new unit, I assign my students to new groups of 3-4 students whose desks are attached to each other but separate from the other groups. These groupings can be done randomly, but are most often mixed ability groups that combine high and low academic achieving students to allow for peer tutoring when possible. Several times a week, the groups prepare white boards that demonstrate their work, either solving problems or answering open-ended questions. The groups present their white boards to the class and facilitate whole class discussions on their assignment. Unit tests are given at the end of each unit, with quizzes and checks of white boards allowing me to keep track of student progress throughout each unit.

Rationale

When exobiologists and astronomers search for, or hypothesize about, life on other planets, only planets with water are considered. Water is the one component most scientists agree is essential for life. However, we currently only have this planet, so the water that we do have is precious and valuable to all the organisms that inhabit it. Since water is so vital to life on our planet, it is of the utmost importance that we keep our supplies high quality, pure, and uncontaminated. Quality water sources are extremely important for a variety of reasons such as the health of living organisms and efficiently functioning ecosystem services. Additionally, these quality water sources can serve a range of esoteric functions, such as aesthetic services and recreational purposes.

When water quality degrades, it can have a detrimental effect on the health of the organisms living in that water source, up to and including the elimination of the species at the population level or the loss of the species' local habitats. This degradation can occur for many reasons, such as erosion, pollution, agriculture, human development, and climate change. Water quality ranges from excellent to poor. While these terms can be somewhat subjective, environmental scientists have developed an array of tests with optimal values for various water sources. Water quality testing is best done on site, but it can also be brought into a lab or classroom for testing purposes. The most common water quality tests are for temperature, dissolved oxygen, pH, and nutrient levels.

In addition to these direct methods for assessing water quality, there are many examples in freshwater and marine environments of metamorphic organisms that serve as indicators of water quality. Bioindicator organisms can sometimes be considered more valuable than traditional water testing because organisms integrate over space and time to non-optimal conditions. Therefore, stress in a population can indicate a problem in what might be thought to be good water quality based on periodic point-in-time sampling. Additionally, bioindicators can serve as red flags for pollutants or contaminants that have synergistic effects – perhaps the individual levels are within tolerances, but together they have a detrimental effect on health of the organisms.

The purpose of this unit will be to determine how degraded water sources affect the metamorphosis of different organisms. This unit will include the standard physical and chemical water quality tests, but I plan to reinforce these tests with additional activities that focus on these metamorphic organisms as indicators of water quality. Students will study many examples of metamorphic organisms that live in aquatic environments and learn how different types of environmental factors affect these organisms. Students will also study different types of water biomes, including freshwater and marine ecosystems, as the problems facing each can be slightly different. Due to the importance of maintaining high quality surface waters, I will focus my unit on working with students to evaluate water sources, both on site and in the lab. Students will complete a variety of activities to reinforce the importance of high quality water sources for maintaining environmental health. Another main objective in this unit will be to increase student awareness of the problems facing different aquatic habitats from human impacts. Students will study the effects of degraded water sources and design experiments to test the impacts of varying water quality issues on organisms that undergo metamorphosis. Finally they will evaluate methods for mitigation and remediation of various water quality issues

Objectives

This curriculum unit will differ slightly from the norm, in that it will involve a series of topics as part of an extended "unit" rather than a single short-term topic/unit. Therefore this unit will be comprised 3 main topics, with several sub-topics, from the AP Environmental Science Course Description, as published by the College Board[1]. I plan to weave the foundation knowledge students from these topics that students will need to complete a capstone project near the end of the course. This capstone project will synthesize student learning on water quality, degraded water sources, and the effects of such on organisms that live in the affected waters.

The 3 topics I have chosen cover a large portion of the AP Environmental Science material tested (45-60% by College Board approximations). However, the individual goals could easily be considered modular topics that could be taught as separate units that could be pulled out and modified for any age range that is studying the environmental topic under consideration. I am presenting the units in the order in which they are listed in the College Board's Topic Outline; however one should be free to arrange and use them in a modular fashion wherever appropriate.

Topic 1: Earth's Systems and Resources

This unit comprises 10-15% of the AP Environmental Science content and covers such topics as the atmosphere and global water resources, water cycles, and water use. For my purposes, I plan to begin my study of water quality with the topic of the atmosphere and water cycles. Here is where I will address the atmosphere's role in weather and climate patterns and atmospheric circulation to prepare students for a later understanding of global climate change and the connectivity to water issues. Another important foundational concept to develop here is the importance of atmosphere-ocean interactions. A large part of the degradation of marine ecosystems is due to the role of the ocean as a carbon sink, thus causing ocean acidification which can have a disproportionate effect on marine organisms with lower tolerance levels. Also included in this topic is the study of global water resources and use, which is the main topic that covers water quality studies.

Topic 2: Pollution

Pollution is by far the largest portion of the Environmental Science curriculum; the topics cover 25-30% of the material. This is due to it being a very broad topic, covering not only the types of pollution, but the impacts on the environment and human health, and the economic impacts as well. For the purposes of this curriculum unit, I will be focusing on water (and air, to a smaller extent) pollution caused by human activities such as agriculture, fossil fuel consumption, urbanization and habitat destruction.

Topic 3: Global Change

This final topic in the AP Environmental Science Topic Outline, Global Change comprises 10-15% of the curriculum. This unit covers such concepts as ozone depletion, global climate change, and the loss of biodiversity. I will be developing activities related to global climate change as it impacts water quality and aquatic ecosystems. As this will be near the end of the course, students should begin making connections with ideas from previous units that will allow for richer discussion and more in-depth activities that will prepare them for their capstone project.

Scientific Content: Overview for Teachers

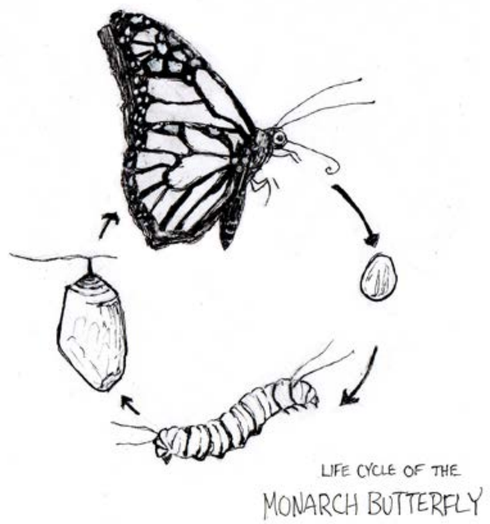
Metamorphosis

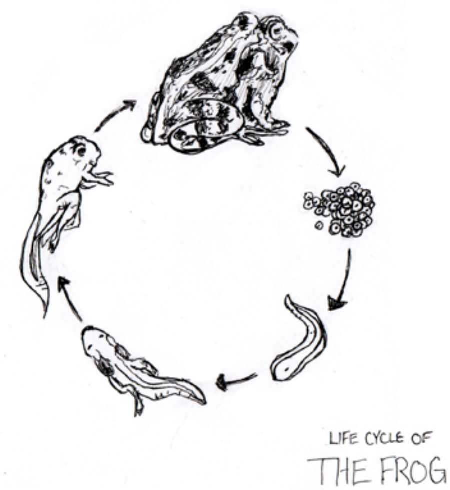
Metamorphosis can be translated from the Greek as simply a 'change in form'. It can be generally described as a larval form that looks very different from the adult form. However, it encompasses a much richer and more complex definition than that simple translation allows. An organism that undergoes complete metamorphoses will exhibit distinctive developmental stages that persist for different periods of time.[2]

The origins of metamorphosis are unclear and buried in the past. Many attempts to explain these almost mythical transformations, from the ancients to devotees of Darwin, have fallen short. In the 1940s, a Harvard biologist named Carroll Williams performed a series of unique experiments on the Cecropia Moth that identified important chemical and hormonal mechanisms behind their metamorphosis process. He was able to identify the two hormones responsible, and how they interacted to trigger metamorphosis.[3] This did not, however, explain how organisms developed the process of metamorphosis. To that end, a relatively recent bold and controversial theory by Donald Williamson attempting to explain the origins of metamorphosis is beginning to be taken seriously. This theory, called larval transfer theory, suggests that evolution happens not only through mutation, but also through hybridization. He calls these “forbidden fertilizations”, meaning the accidental but serendipitous joining of vastly different genomes resulting in occasionally viable offspring. Several experiments resulting in hybrid, viable offspring from very different organisms have shown his theory to be robust. In one successful experiment, eggs from an ascidian, *Ascidia mentula*, were fertilized with sperm from a sea urchin, *Eschina esculentus*. In one of the trials, all of the ascidian eggs developed as sea urchin larvae; approximately 8 percent grew into adult sea urchins, while the other 92 percent reabsorbed their arms and became spherically shaped, with a sucker. This was revealing, because no larval or adult form of sea urchin grows suckers, but the larval form of ascidians have them.[4]

For metamorphic organisms, a larval form is usually the first stage and can be completely anatomically different from the juvenile and adult stages. This reflects the larval form’s adaptation to its own ecological niche, potentially advantageous because the larvae are not competing with the adults for food and other resources. The larva must eat constantly and store as much energy reserves as possible to make it through the next stages. Eventually, the larvae transform to the juvenile stage. The juvenile form is an immature version of the adult form. The process of the larval form transforming into the juvenile is metamorphosis.[5] Metamorphosis probably provides an evolutionary advantage, as the fossil record from 250 million-year-old fossils shows less than 50% of insects underwent metamorphosis in the past, whereas upwards of 88% of all insect genera metamorphose currently.[6]

The representation described above would be an example of a complete metamorphosis, very generally represented for many insects, including the butterflies and moths: egg → larva → pupa → adult. Complete metamorphosis is what most people think of when they hear the word metamorphosis - a caterpillar building a chrysalis (or pupa) and emerging as a beautiful butterfly or a tadpole slowly reabsorbing its tail, growing legs and turning into a frog. Other insects undergo incomplete metamorphosis in which the larval instars are like miniature adults, but are not reproductive. Metamorphosis in this context refers to the transformation from a non-reproductive to a reproductive state. See Figures 1 and 2 for some examples of complete metamorphosis.





Figures 1 and 2: Butterfly and Frog, Examples of Complete Metamorphosis[7]

Incomplete metamorphosis is a process whereby there is no larval form, per se, again very generally represented for insects as egg → nymph → adult.[8] The majority of development and change in an organism that undergoes incomplete metamorphosis happens during the embryological phase. The nymph stage looks similar to the adult, and unlike with complete metamorphosis, the nymphs and adults have similar feeding behavior and environmental needs.[9] Therefore, the juvenile form looks much like the adult with the majority of external change coming from growth. For an insect, this means molting, as their hard exoskeleton does not grow, therefore they must shed it in order to get bigger. Each version between molts is called an instar. The incomplete metamorphosis that occurs internally represents sexual maturation, with the adult form being the reproductive form.[10]

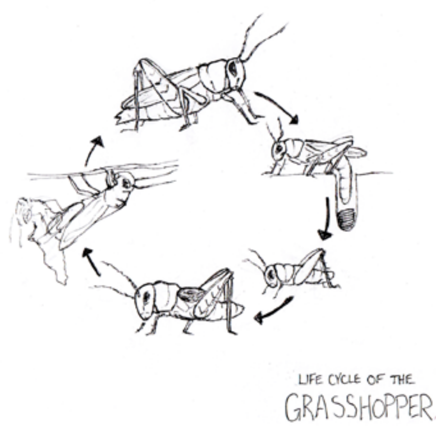


Figure 3: Incomplete Metamorphosis of the Grasshopper[11]

The most diverse larval forms and variety of life history stages are found in aquatic invertebrates, especially marine invertebrates such as jellyfish and sea urchins. Cnidaria, or jellyfish, have alternating generations where the organism passes through two different forms. Jellyfish begin life as small polyps attached to surfaces such as shells and rocks. These polyps can multiply by creating a bud, or cyst, that breaks off and results in a new polyp. Once a polyp is fully developed, it will strobilate, producing larvae that are stacked on top of each other. Each larva will eventually develop into a tiny larval jellyfish that breaks free from the stack and becomes a free swimming form (known as an ephyrae); the ephyrae metamorphose into the adult form, known as a medusa. Upon reaching sexual maturity, the jellyfish release sperm which are swept up by the female. Embryonic development occurs in brood pouches on the females' oral arms. The larvae eventually leave the female and enter the water column where they are free swimming for several days before attaching themselves to a surface and developing into a polyp to start the cycle all over again. An illustration of the life cycle of the jellyfish can be found below in the section labeled Teaching Strategies: Concept Sketches. Sea urchins start life as a free swimming pluteus larva that spend several weeks swimming and feeding in the upper surface waters while their adult structures and form start to differentiate. Adult features begin to appear as larval structures are resorbed and modified. This recently metamorphosed juvenile sinks to the ocean floor where it will spend the rest of its life as a benthic organism. Through abiotic and chemical signals (from with the environment and the adult urchins), synchronous spawning of eggs and sperm will take place, releasing vast amounts of eggs and sperm into the water column. Fertilized eggs rapidly develop into free swimming larvae that start the cycle over again.[12,13]

Earth's Systems and Resources

The AP Environmental Science course is an incredibly rich and diverse subject. Students cover a lot of material in a one semester course, so it is important for the instructor to be well informed in their content knowledge. This section of the course covers such a range of topics as geologic time scales, plate tectonics, seasons, the atmosphere, weather, climate, water resources, the rock cycle, and soil. In the Classroom Activities section below, the activities I am focusing on deal mainly with the effects of ocean acidification on metamorphic marine life.

Earth's atmosphere is a thin, gaseous envelope that covers the planet becoming less dense as it extends upward due to the decreasing influence of gravity and the increasing space in which the particles interact. The predominant gases that make up the atmosphere are oxygen (21%) and nitrogen (78%). These percentages fluctuate by season and planetary location. The remaining 1% of gases is composed of a mixture of argon, carbon dioxide, neon, and helium with trace amounts of water vapor and various pollutants.[14] The carbon dioxide in the atmosphere is responsible for The Greenhouse Effect, which is a phenomenon in which some of the heat that is absorbed by the planet is retained near the surface, creating a homeostasis effect that makes life possible on Earth.

However, excess CO_2 and other so called greenhouse gases such as methane in the atmosphere have been linked to an increase in mean surface temperatures near Earth's surface. The excess CO_2 is attributed to human activities such as power generation and transportation, while ecological issues such as deforestation have led to a loss of CO_2 sinks that previously helped regulate the balance of CO_2 in the atmosphere. This reduction in balancing, or regulating, mechanisms have led to an alarming increase in greenhouse gases in the atmosphere that has been correlated to global climate change.[15]

The atmosphere is usually described as being divided into five layers. The troposphere is the layer that is closest to Earth's surface and extends to a height of approximately 7 km at the poles and 17 km at the equator. It is in this layer that all weather and most clouds occur. Temperature decreases with altitude in this layer. Ozone in this layer is regarded as a green-house gas that is very readily oxidized and damages plants and other biota. The second layer is the stratosphere, which extends upwards from the troposphere to about 50 km. The protective ozone layer is found in the stratosphere, which filters out harmful UV radiation from the sun. Due to the absorption of the UV radiation from the sun, temperature increases with altitude in this layer. Big holes in this protective stratospheric ozone contribute to increased UV radiation exposures and global warming. The third highest layer, the mesosphere, extends from the stratosphere to an altitude of approximately 80-85 km. Temperature again decreases with altitude in this layer due to the decreased density of atmospheric gases. The mesosphere is the coldest of all atmospheric layers. Water vapor found in this layer freezes into ice clouds that can be seen occasionally after sunset. The fourth layer of the atmosphere is the thermosphere, which extends from the mesosphere to approximately 640 km above Earth's surface. Temperature increases with altitude in this layer because the particles of gas present absorb enormous amounts of energy from the sun; however, this layer would "feel" cold because the concentration of particles is so low that there would be insufficient numbers to transfer the thermal energy they contain. The final layer of the atmosphere is the exosphere, which extends from the thermosphere to approximately 10,000 km. It is here where Earth's atmosphere is actually merging into space and where most satellites orbit.[16] A diagram of the layers of the atmosphere is shown below.

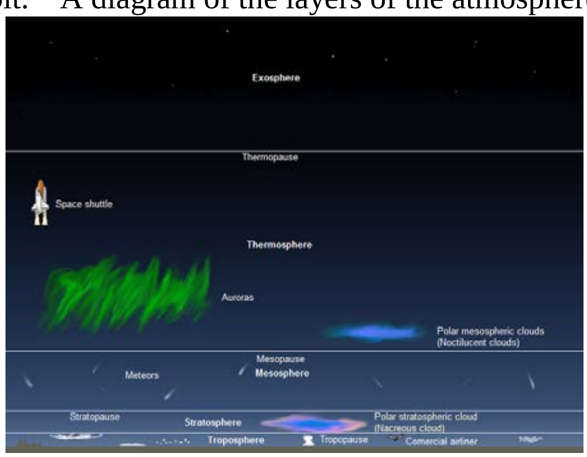
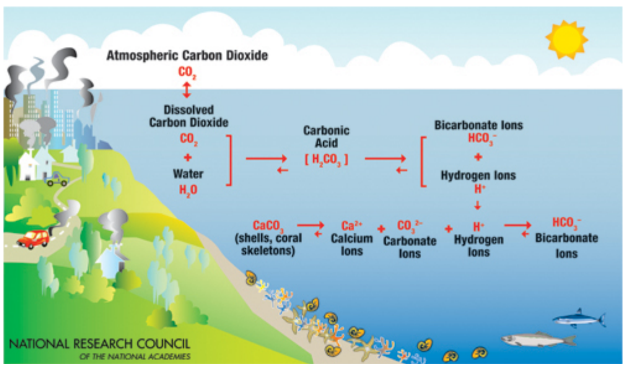
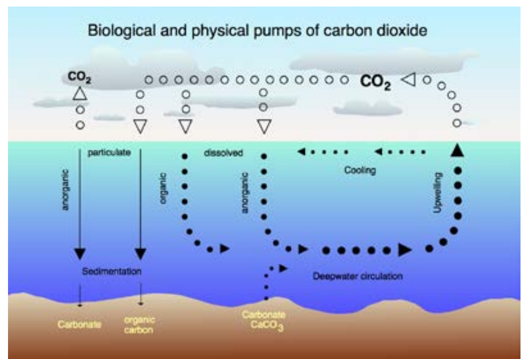


Figure 4: Layers of the Atmosphere[17]

The oceans comprise > 70% of the earth's surface so the atmosphere is constantly interacting with the ocean. Water and gases are exchanged between them via evaporation and precipitation, and diffusion and concentration gradients. The ocean has always acted as a major CO_2 sink for the atmosphere, however, due to the rising levels of this gas, the ocean has been absorbing excessive amounts. This has led to pH changes in the ocean, a process called ocean acidification. Ocean acidification has the effect of removing calcium carbonate from seawater, which is causing significant problems among various forms of marine life. All marine organisms which rely on calcium carbonate to form calcareous skeletons and shells are being affected. Many single-celled algal plankton, which form the basis of the marine food chain, also construct silica and calcareous shells and could be affected. Corals and organisms with skeletons are becoming thinner and more brittle.





Figures 5 and 6: Chemical Reactions of Ocean Acidification[18,19]

Ocean acidification has an extremely detrimental effect on one of the most important marine biomes, the coral reef. Coral reefs are so important because they are one of the most productive and biologically diverse ecosystems in the biosphere. Some sources have calculated that coral reefs have a higher rate of primary production than tropical rain forests and are home to hundreds of species of coral and thousands of species of fish. Coral reefs are increasingly vulnerable to threats from human interactions, including coral harvesting, overfishing[20] and ocean acidification. Ocean acidification harms corals in particular because of their calcium carbonate skeletons; since coral reefs are also responsible for billions of dollars in ecosystem services this is rapidly becoming a major economic as well as ecological problem.[21]

Corals are valuable bioindicators of degraded marine habitat. The first reason, as previously mentioned above is they need calcium carbonate for building reefs. Secondly, corals engage in a symbiotic mutualistic relationship with microalgae called zooxanthellae. This allows both organisms to thrive in a relatively nutrient poor environment. The zooxanthellae benefit from the protection of the coral habitat and obtain nutrients from the coral by-products, namely carbon dioxide and ammonia. The coral gain a source of oxygen, nitrogen, and carbon produced by the zooxanthellae.[22] However, this relationship falls apart if the corals expel their symbiont organisms, causing them to turn white, a process called 'coral bleaching'. At this point, the coral is not dead, but is subject to stress and increased mortality; however they may recover if the zooxanthellae return, or they may die. Global warming and ocean acidification are contributing to conditions that are related to increases in coral bleaching, threatening coral reef ecosystems worldwide.[23]

Pollution

The AP Environmental Science course focuses on all the varied types of pollution, including air pollution, water pollution, noise pollution, solid waste management, and impacts of pollution on human and ecosystem health. Pollution is released from many different sources, and can be a chemical substance (pesticides, heavy metals, etc.), an energy source (such as heat or light), or a naturally occurring substance (nutrients and eutrophication). Pollution sources are manufacturing processes, industrial operations, agriculture, and humans (sewage and landfill). Pollution can be divided into two main categories, point and non-point sources. A point source of pollution comes from one location and can usually be traced back to its source. Common examples of point source pollution would be smokestacks and liquid effluent, or wastewater, which drains into a water source. Non-point sources of pollution come from large areas and cannot be traced back to one specific source. Some common examples of non-point sources of pollution would be runoff from highways or farming operations and exhaust from automotive tailpipes.[24] A major category of runoff pollution is Impervious surfaces, which in addition to highways, includes parking lots, sidewalks, and rooftops that are major conduits of pollutants.[25]

As this curriculum unit is focusing on water quality, the role of sediment contamination must be stressed. Often, overlying water sources can appear relatively clean, but the toxicity levels of the underlying sediments are extremely high. Simply doing traditional water quality testing will not show the problem that exists. Sediment testing is a must for any complete evaluation of water quality. This is another place where bioindicators serve an important function in determining overall ecosystem health. Sediment toxicity can have a disproportionate effect on metamorphic organisms, as quite often their larval forms transform from a planktonic larva to a benthic adult, requiring them to complete metamorphosis in the benthic, sedimentary regions. The processes of bioaccumulation and biomagnifications allow sediment toxicity to make its way up the food chain, exacerbating the problem. Sediment toxicity can also reduce biodiversity, as those organisms unable to tolerate the pollution levels will simply die off or prevent successful metamorphosis of many sensitive species, thereby reducing recruitment and population sustainability.[26]

Global Change

This unit in AP Environmental Science focuses on Earth's systems and how minor changes can cause major perturbations in the system as a whole. Topics range from stratospheric ozone to global climate change to loss of biodiversity. The atmosphere and climate change issues and content were addressed above in the section on Earth's Systems and Resources. Biodiversity refers to the species richness of different biomes. Many factors affect biodiversity such as habitats and their ecological niches, genetic diversity within species and between populations. Tropic areas such as coral reefs are extremely biodiverse, and this biodiversity is considered essential to their sustainability as well as the various services, both ecological as well as economical, that they provide. High biodiversity is regarded as a desirable condition. Many modern conveniences, including medicines have been formulated from resources from the natural world, and places like coral reefs are important recreational and tourists industries. Biodiversity is believed to enrich modern life and uncatalogued species could represent untapped potential for further advances.[27]

Teaching Strategies

It is occasionally difficult to find teaching strategies that work in the science classroom, especially one such as mine in which there is no permanent or designated laboratory facilities. Most of the best known strategies are more suitable for liberal arts style, or discussion based classes. However, there is certainly a wide range of strategies that are not only suitable for the science classroom, but enhance learning to a great degree. The majority of the strategies I outline below come from a book I was given as a new teacher over ten years ago, "Why Didn't I Learn This in College?"[28] I still consult this book when I am looking for new ideas to refresh my teaching. Some of the strategies I have had the most success with, or am the most excited about using, are briefly described below.

Consensus Conclusions

In this strategy, students create individually a list of the five most important facts, equations, concepts, etc that they have learned in a unit of study. For example, students may list the five factors they consider most important for an organism to undergo a successful metamorphosis. The students then move into groups where they share their lists with each other, clarifying their rationales for their choices through discussion. Each group is then required to come to a consensus on their five most important facts as a group. At this point, it can go one of two ways. The students can be placed into new, larger groups which will require more discussion and consensus building. Otherwise, each group then presents their list of five along with the rationale for their selections, leading to whole class discussions. As an additional alternative, the selections can be posted in the room for later examination and discussion.

Board Meetings

I have used this technique successfully for years; it is one of my favorites for formative assessment, group work, and peer tutoring. I purchased several sheets of white board material from the local building supply store and had them cut into roughly 2’x3’ sections. Students in groups are then able to write on these poster sized sections with dry-erase markers at their desks, while working in groups. Students can be given any of a wide variety of tasks from simple calculations to evaluating a problem and writing out their solutions. After a set amount of time, the students stand in a circle while holding up their whiteboards. Each group then presents the information on their whiteboards, with supporting evidence to strengthen their presentation. I ask probing Socratic-style questions to determine the depth of their knowledge and their ability to justify their responses. Over time, the students take over the questioning aspect and begin to challenge their peers for justification. This strategy works equally well when the groups are working on the same questions or when they are working on different problems within the topic.

Line-Ups

This activity serves to force students to take a stand on a subject and defend their position. There are many ways it can be done, from sequencing and ranking tasks, to chronological steps; I plan on using it to make students think about their level of support for varying topics such as balancing human development with maintaining biodiversity or global warming must be stopped at any cost. It would work as follows – a statement would be read to the class, such as “Governments should begin severely regulating carbon emissions, regardless of economic repercussions.” The students are then directed to decide on their support of that position on the scale of 1 means Completely Disagree and 10 means Completely Agree. The students line themselves up in numerical order. Find the middle of the line and fold it on itself, so that students are facing other students, with 10s facing 1s. Have them discuss their rationale for the position they hold.

Walking Tour/Graffiti Mashup

In this activity, posters or charts that represent content material are created, leaving plenty of blank space for writing, and then placed around the classroom. Examples for science could include a process (Nitrogen/Carbon/Water Cycles) or a problem to solve (Ideal Gas Laws). Students are divided into tour groups which are initially assigned to a certain poster or chart as a starting point. Students are given a set amount of time to react to the prompt on the poster and are then required to move on to the next one. At the next poster, the students need to evaluate the previous group’s work, and either correct it, or continue it as appropriate. Continue until every group has rotated through all the charts at least once.

Case Studies

In my experience, at the high school level, students tend to learn better from examples than from derivations or logical reasoning. Case studies can be used very effectively in science when teachers want students to explore how what they have learned applies to real world situations. This has the major advantage of allowing students to transition their learning from theory to application and improves their skills in problem solving, analysis and decision making. Case studies come in a variety of formats, from the simple ("What would you do in this situation?") to more detailed descriptions of a problem with accompanying data to analyze. The most common method for presenting a case study requires students to generate an answer to an open-ended question or develop a solution to a problem with more than one potential solution. Most case studies share certain characteristics, such as a stakeholder who is struggling with a problem that needs solved, a description of the problem, and supporting data, pictures, charts, etc. An example for this unit could have the students analyze "Stream Amphibians as Indicators of Ecosystem Stress: A Case Study from California's Redwoods."[29]

Concept Sketches

Concept sketches are student generated drawings with detailed, content-based annotations.

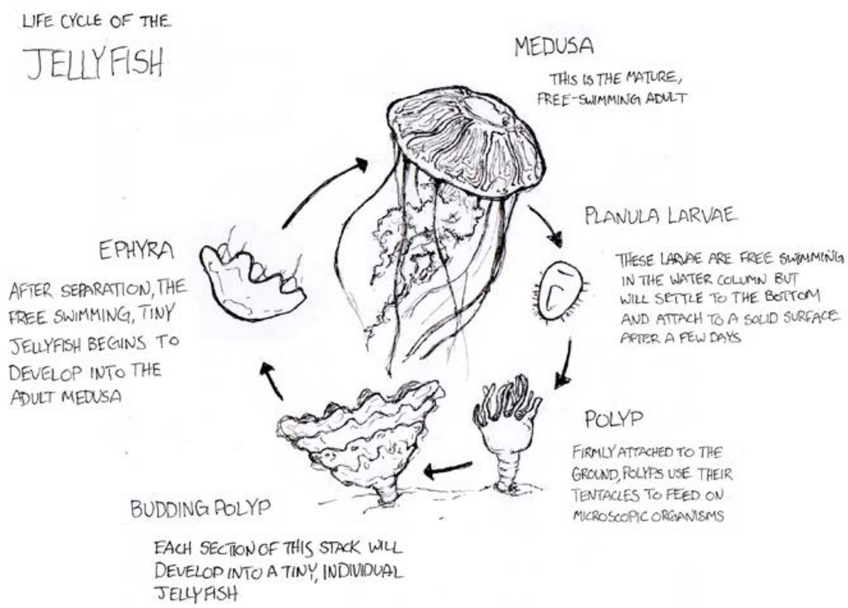


Figure 7: Concept Sketch Showing the Life Cycle of a Jellyfish[30]

Project-based Learning

In the science classroom it is almost more important than any other subject to engage students in *doing* science rather than just talking about it. Hands-on, inquiry based activities are required. Students will be completing a capstone project, outlined below, to synthesize their knowledge of the various aspects of the topic of water quality degradation. They will design and perform their own experiments to test the effects of different forms of water pollution on metamorphic organisms. The activities related to this are described in more detail in the section labeled Classroom Activities, below.

Classroom Activities

My plan is to include the information for this curriculum unit throughout the main units in my AP Environmental Science (APES) class. First, I will introduce the topic of water quality as it pertains to surface water sources during the unit on water. Students will study where water is located on the planet, how difficult different sources are to obtain, and the importance of maintaining high quality water sources. At this time, students will learn the main physical and chemical water tests that determine a water sample's quality. Students will obtain a variety of water samples in order to conduct the standard tests on their samples. At this point, they will evaluate the quality of the samples they have. Second, this topic will then fit in well with the study of ecosystems and biomes. Students will study ecosystem services provided by aquatic ecosystems, as well as learning about symbiotic relationships and keystone and indicator species. This is where students will be introduced to the various metamorphic organisms that serve as indicators of the quality of a water source and can demonstrate any degradation that may be occurring. Students will learn about the life cycles of various aquatic metamorphic organisms to inform their knowledge of how degraded water sources could disrupt different stages of their life cycles.

During the study of these metamorphic organisms, I plan to have students learn in detail about several different types. For pond and lake ecosystems, students will study such organisms as water fleas (*Daphnia)*, dragonflies, damselflies, mayflies, and snails. They will learn how the proliferation of some larvae, such as mosquito, is actually an indicator of poor water quality. In marine ecosystems, students will study such organisms as oysters, which filter water, and cnidaria such as jellyfish and corals. Finally, the students will study these organisms to learn how climate change alters aquatic ecosystems and affect their life history stages. Many of the activities outlined below are hands-on investigations involving live animals. Please obtain proper permission from your school district or governing body to complete these activities.

Activity 1: Butterflies – Models of Metamorphosis

To kick off the students' study of metamorphic organisms and excite their interest, I plan to start the study with an activity on butterfly life cycles. Students will research optimum conditions for butterflies and build their enclosures to mimic these conditions as closely as possible, providing the appropriate food plants, etc. Each group will be given 1-2 butterfly larva of the same species (dancing ladies are often very successful) to care for. Students will observe the larval form (caterpillar) and take daily measurements, such as length and mass. When the caterpillar creates its chrysalis, students will continue to observe the pupa and ensure optimal conditions. Each group will measure the time required for the pupa to undergo its metamorphosis and will be required to predict what changes are occurring inside the chrysalis each day. As a class, the total rate of successful metamorphosis will be determined. This will be used to consider factors that would affect population sustainability and to foster discussions on why some did not proceed successfully through the life cycles stages and metamorphosis.

Activity 2: Earth's System and Resources

Coral Reef Bleaching and Ocean-Atmospheric Interactions

To enhance student learning about global warming and ocean acidification and its effects on coral reefs, the students will develop a lab protocol to test various water quality parameters on coral and/or anemone bleaching. If available, living sea anemones tend to be more common and can be used for investigations as good surrogate species to observe bleaching. Raising the temperature of the water or decreasing the pH will be used to consider how even small changes in temperature or pH could affect the essential coral – zooxanthellae symbiosis and coral reef sustainability.

Experiments will be conducted in which student groups will choose a parameter to change, such as salinity, temperature, and pH. Students would then vary their chosen parameter over a period of days to determine at what point the organisms become overly stressed and expel their zooxanthellae. To complete the activity, students would be required to compare the values at which their organisms bleached with actual, researched current oceanic conditions. Finally, students would research the rate of change of their chosen parameter, i.e. temperature increase, and extrapolate forward to assess the vulnerability of coral reefs around the world.

Activity 3: Pollution

For this unit, students will focus on common pollutants that make their way into fresh surface water sources, such as streams and lakes. Some of the most harmful of these include pesticides from agricultural runoff and hydrocarbons from transportation sources. Students will first learn how to collect larvae from streams using a plankton net, to collect samples to bring back to the lab for testing. If the time of year is not appropriate for insect larval forms, water fleas may be substituted as they are commonly found in ponds most of the year. Students will then choose between a common agricultural pesticide, such as Roundup®, and a transportation related hydrocarbon such as motor oil or gasoline. Students will research standard application rates and typical amounts of runoff into surface waters. Finally, students will learn how to create a dose-response curve to find the LD50, or lethal dose at which 50% of the organisms die within a certain time frame: commonly a 96-hour time point is used. An example is shown below. A complete protocol and lab sheet are included in Appendix Two for this activity.

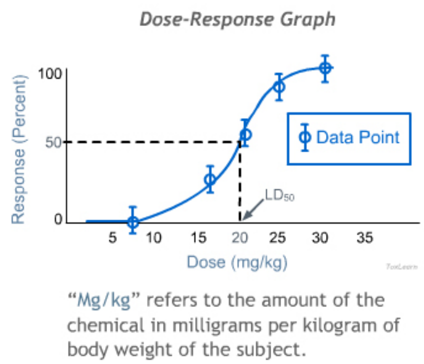


Figure 8: Dose-Response Graph Showing LD_{50} [31]

Activity 4: Global Change

This unit complements the earlier units on global warming and pollution, but focuses on the effects on biodiversity of metamorphic organisms. Students will return to the skill of collecting larval forms from streams and ponds using a plankton net, however, they will also secure water samples from the source to test in the lab at the same time. They will then compare the quality of the water source with the prevalence of different larval forms. Additionally, referring back to the section on pollution in the teacher background, students will also perform toxicity tests on the stream sediment to complete the picture of the quality of the water source. Student groups will be required to sample water sources from all over the county to see if there are differences in different bodies of water, or differences in the same body of water but at different locations. Another related activity will have students collect water samples from parking areas, roadside ditches, agricultural field areas, etc. Students will use dilutions of those runoff water sources to do LD50 tests on larval forms or water fleas, as above.

Capstone Activity

For their final activity relating water quality to metamorphic organisms, students will integrate the concepts they have learned in a capstone experiment. Students will investigate how interactions of different pollutants can affect the process of metamorphosis. Each lab group will be given several tadpoles to test their pollutants' effect on metamorphosis. This will be a long term project, and needs to be started ahead of time, as some varieties of tadpoles can take several weeks to start metamorphosing. Students will measure tadpoles' rate of feeding and growth during this period.

Additionally, students will be looking for signs of problems with the tadpoles' metamorphosis, such as a decreased rate of metamorphosis, the size at metamorphosis, the percent of tadpoles that undergo metamorphosis, and in the case of stunted growth, the point at which the metamorphosis stalled. Students will be guided in the choosing of their pollutants to ensure a wide range across the classes; they will choose two or more pollutants so as to study the effects of the interaction of the pollutants on their tadpole. Typical pollutants could include pesticides, paint, copper (in the form of copper (II) chloride or copper (II) sulfate), phosphates, acids, or thermal pollution. Students will control the amounts of pollutants for their various tadpoles to see if there is a threshold above which metamorphosis does not occur normally. The lab protocol for this will be nearly identical to that in Appendix Two for Activity 3. The main difference will be the application of more than one pollutant to each sample. Although different processes, this is where their experience with the optimized butterfly metamorphosis will be utilized. Ultimately, students will be discovering that it takes very little pollution or stress to interrupt this most important life cycle.

Notes

[1] (The College Board 2013)
[2] (Ruppert, Fox and Barnes 2004)
[3] (Vishniac 1952)
[4] (Ryan 2011)
[5] (Ruppert, Fox and Barnes 2004)
[6] (Pechenik 2005)
[7] (Paxton 2014)
[8] (OpenStax College 2013)
[9] (Cornell University Cooperative Extension 2012)
[10] (Pacific Science Center 2000)
[11] (Paxton 2014)
[12] (Levinton 2009)
[13] (Ruppert, Fox and Barnes 2004)
[14] (Raven, Hassenzahl and Berg 2012)
[15] (Fabian 2006)
[16] (NASA n.d.)
[17] (http://commons.wikimedia.org/wiki/File:Layers_of_the_atmosphere.PNG)
[18] (National Academy of Sciences 2014)
[19] (Grobe 2006)
[20] (Molles 2008)
[21] (Withgott and Brennan 2011)
[22] (Ruppert, Fox and Barnes 2004)
[23] (NOAA 2014)

[24] (Molles 2008)
[25] (Withgott and Brennan 2011)
[26] (EPA 2012)
[27] (Raven, Hassenzahl and Berg 2012)
[28] (Rutherford 2002)
[29] (Welsh and Ollivier 1998)
[30] (Paxton 2014)
[31] (National Institute of Health 2010)

Appendix One

Implementing Common Core Standards & Essential Standards

Mary S. Fabian

CCSS.ELA-Literacy.RST.11-12.3 *Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.*

Students will learn to use plankton nets to capture larval forms of various metamorphic organisms in surface waters. Additionally, students will be required to create a dose-response graph based on the data collected.

CCSS.ELA-Literacy.RST.11-12.7 *Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.*

CCSS.ELA-Literacy.RST.11-12.9 *Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.*

Students will complete a capstone activity in which they will need to integrate material from many different units from the semester. They will evaluate the effects of pollutants on tadpole metamorphosis and then synthesize this information into a recommendation for capping pollutant levels in surface waters.

NC Essential Standard EEn.2.5 *Understand the structure of and processes within our atmosphere.*

Students will be completing a significant number of activities related to this standard, including studying atmospheric composition, weather and climate, and ocean-atmosphere interactions. Students will also be investigating the effects of increased atmospheric disturbances leading to ocean acidification.

NC Essential Standard EEn.2.8 *Evaluate human behaviors in terms of how likely they are to ensure the ability to live sustainably on Earth.*

Students will be studying anthropogenic climate change and its relation to coral reef bleaching.

Appendix Two

Procedure for Activity 3

Part one: Larvae Collection

Materials Needed:
Plankton nets or dip nets
Waders or tall boots
Buckets
Jars for specimen containment

Instructions

Various methods exist for sampling the zooplankton and larvae of a pond or stream. The easiest and most common method is to drag or pull a fine mesh net through the water, either vertically or horizontally, and then collect the animals that have been retained by the net. Place the specimens in the bucket with ample water.

Part Two: Determining LD50

Materials
Petri dishes
Fresh water from source
Pollutant (Roundup, gasoline, etc)
Larvae from Part One
Graduated cylinders
Magnifying glass or dissecting microscopes

Instructions
1. Put 5-10 larvae with the same amount of water in each of 6 petri dishes. (More samples are better, if feasible; and depending on the size of the larvae, you may need to put fewer numbers of larvae in more dishes)
2. Using serial dilution techniques (you will need to describe this because most people won't know what this means, dose each petri dish, except the control with increasing dosages of pollutant.
3. After the established amount of time 24, 48, and/ or 96 hours, count the number of surviving larvae in each petri dish.
4. Using Excel, calculate the mean number of surviving larvae for each treatment, and plot response on the y-axis and concentration on the x-axis.

Teacher and Student Resources and Bibliography

Cornell University Cooperative Extension. *Pests.* 2012. http://psep.cce.cornell.edu/Tutorials/core-tutorial/module12/index.aspx (accessed October 2014).

> Although labeled "pests" this website contains much good information about insects, including their body characteristics and life cycles.

EPA, US. *Water: Contaminated Sediments.* March 6, 2012. http://water.epa.gov/polwaste/sediments/cs/aboutcs.cfm (accessed October 2014).

> This is the EPA website that starts the section on contaminated sediments. It contains information on the most common contaminants as well as where they are most likely to be found.

Fabian, Mary S. *Architecture of Methanotroph Biofilms in Landfill Cover Soil.* Charlotte, 2006.

> A master's thesis on methanotrophic bacteria in landfill soil emphasizing their impact on climate change. It contains extensive background on the history of climate change research and carbon's role in atmospheric change.

Grobe, Hannes. *CO2 Pump.* August 8, 2006. http://commons.wikimedia.org/wiki/File:CO2_pump_hg.png (accessed November 2014).

> An open source image showing how the ocean absorbs CO_2 and the net increase in CO_2 dissolved in the ocean.

Levinton, Jeffrey S. *Marine Biology.* New York: Oxford University Press, Inc., 2009.

> This is an introductory textbook for advanced high school or early college level students. The writing is accessible and clear. This book would be recommended for teachers who wish to supplement their personal content knowledge or advanced students who need enrichment or higher level differentiated content.

McCalman, Iain. *The Reef: A Passionate History.* New York: Scientific American/Farrar, Straus and Giroux, 2013.

> A popular non-fiction book written about the history of The Great Barrier Reef. Interesting, and easy to read this book would be excellent for teachers looking to supplement their content knowledge on coral reefs.

Molles, Manuel C. *Ecology Concepts & Applications.* New York: McGraw-Hill, 2008.

This book is an introductory college level textbook on Ecology. Recommended for anyone who needs to brush up core concepts before teaching this curriculum unit.

NASA. *The Layers of Earth's Atmosphere.* airs.jpl.nasa.gov/maps/satellite_feed/atmosphere_layers/ (accessed November 2013).

This website is suitable for use as an introduction to the layers of the atmosphere and would be appropriate for all age levels. There are also links to quite a few other NASA weather and climate resources.

National Academy of Sciences. *Ocean Acidification Cycle.* 2014. http://dels.nas.edu/Materials/Special-Products/Ocean-Acidification-Image (accessed November 2014).

This image shows the chemical processes that occur during ocean acidification. An excellent visual aid for enhancing understanding.

National Institute of Health. *Introduction to Toxicology and Dose-Response.* November 3, 2010. http://toxlearn.nlm.nih.gov/htmlversion/module1.html (accessed October 2014).

This website gives an excellent overview of the field of toxicology and all the different types of study related to that, such as food toxicology and pharmaceuticals. Also good for learning about dose response curves.

NOAA. *What is Coral Bleaching?* March 5, 2014. http://oceanservice.noaa.gov/facts/coral_bleach.html (accessed October 2014).

This website is the start of the National Oceanic and Atmospheric Administration's exploration of oceans and ocean problems. This particular section examines coral bleaching and would be useful as a starting point for students.

OpenStax College. Concepts of Biology. April 25, 2013. http://cnx.org/content/col11487/latest/ (accessed October 2014).

This textbook is an introductory college level on an open source platform. OpenStax books are very well regarded for being a free online resource and would be a great supplementary text for teachers and students alike.

Pacific Science Center. *Metamorphosis.* 2000. (accessed October 2014). http://exhibits.pacsci.org/insects/metamorphosis.html

This is a very basic website that could be used to introduce metamorphosis to students and young children.

Paxton, Kristin. Savannah College of Art and Design, Savannah.

Artist from whom I commissioned a series of sketches for this curriculum unit.

Pechenik, Jan A. *Biology of the Invertebrates.* 5th. Boston: McGraw-Hill, Higher Education, 2005.

This college textbook is good for higher level learners as well as teachers looking to supplement their content knowledge.

Raven, Peter H., David M. Hassenzahl, and Linda M. Berg. *Environment, 8th Edition.* Jefferson City: Wiley, 2012.

This is an introductory college level textbook Environmental Science classes. The writing is accessible and clear. This book would be recommended for teachers who wish to supplement their personal content knowledge or advanced students who need enrichment or higher level differentiated content.

Ruppert, Edward E., Richard S. Fox, and Robert D. Barnes. *Invertebrate Zoology, 7th Edition.* Belmont, CA: Thomson, 2004.

Another excellent college textbook that would be good for teachers as well as advanced students looking to supplement knowledge or do research.

Rutherford, Paula. *Why Didn't I Learn This in College?* Alexandria, Virginia: Just ASK Publications, 2002.

This book contains a myriad of content-enriching strategies and activities for classroom teachers. There is enough variety that classroom teachers of every age and content area would find something of use in this book.

Ryan, Frank. *The Mystery of Metamorphosis: A Scientific Detective Story.* White River Junction, Vermont: Chelsea Green Publishing, 2011.

A popular non-fiction book that attempts to solve the mystery of metamorphosis. Very readable and enjoyable for a teacher, but might be difficult for secondary students.

The College Board. *AP Environmental Science Course Description.* 2013. http://apcentral.collegeboard.com/apc/public/repository/ap-environmental-science-course-description.pdf (accessed October 2014).

> This document is published by The College Board and contains all the information relevant to the AP Environmental Science course, including topic descriptions, weights of topics, and activity ideas. A must for any teacher of Environmental Science.

Thorp, James H., and Alan P. Covich. *Ecology and Classification of North American Freshwater Invertebrates.* San Diego: Academic Press, 2010.

> This book would be an excellent research book to keep in the classroom for teachers and students alike to consult, especially for help in tasks such as larval identification for samples collect from local freshwater sources.

Vishniac, Roman. "Why Insects Change Form." *Life*, February 11, 1952: 79-88.

> An interesting and thought-provoking article from the middle of the century about a scientist who did all sorts of unusual experiments on larvae in order to determine the causes and requirements for insect metamorphosis.

Welsh, Hartwell H., and Lisa M. Ollivier. "STREAM AMPHIBIANS AS INDICATORS OF ECOSYSTEM STRESS:A CASE STUDY FROM CALIFORNIA'S REDWOODS." *Ecological Applications*, 1998: 1118-1132.

> A good example for a class to use as a case study for starting off a study on water quality's effects on living organisms.

Withgott, Jay, and Scott Brennan. *Environment: The Science Behind the Stories, 4th Edition.* San Francisco: Pearson, 2011.

> This extremely readable textbook would be excellent for advanced high school or introductory college level students. Additionally, it would be a great resource for a teacher new to environmental science. Each chapter has at least one excellent case study to supplement the topic.