Pollution in Marine Environments

Teaching and Learning Module Grades 6–12
Dear Educator,

We are pleased to present you with the third in a series of teaching and learning modules developed by the DEEPEND (Deep-Pelagic Nekton Dynamics) Consortium and their consultants. DEEPEND is a research network focusing primarily on the pelagic zone of the Gulf of Mexico, therefore the majority of the lessons will be based around this topic. Whenever possible, the lessons will focus specifically on events of the Gulf of Mexico or work from the DEEPEND scientists.

All modules in this series aim to engage students in grades 6 through 12 in STEM disciplines, while promoting student learning of the marine environment. We hope these lessons enable teachers to address student misconceptions and apprehensions regarding the unique organisms and properties of marine ecosystems. We intend for these modules to be a guide for teaching. Teachers are welcome to use the lessons in any order, use just portions of lessons, and may modify the lessons as they wish. Furthermore, educators may share these lessons with other school districts and teachers; however, please do not receive monetary gain for lessons in any of the modules. Moreover, please provide credit to photographers and authors whenever possible.

This third module focuses on pollution of marine environments, specifically discussing aspects of how marine waters become polluted and how to prevent/manage pollution. We have provided a variety of activities and extensions within this module such that lessons can easily be adapted for various grade and proficiency levels. Given that education reform strives to incorporate authentic science experiences, many of these lessons encourage exploration and experimentation to encourage students to think and act like a scientist.

Additional teaching modules, and materials such as animations, videos, and blog posts (kids and adults), will also be posted on the DEEPEND website as they become available (http://www.deependconsortium.org/). We hope you and your students dive into these materials and benefit from the adventure.

Sincerely,
K. Denise Kendall, Ph.D., on behalf of the DEEPEND Education and Outreach Team
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Pollution in Marine Environments

Human activities and actions impact the environments around them both directly and indirectly. While marine environments account for greater than 67% of Earth’s surface, many humans do not reside on the shoreline of marine waters. However, their everyday actions and activities still impact marine ecosystems. The effects of pollution depend on the type, degree, and location of the sources of pollutants. In this module we will discuss pollution of marine environments including the entry of pollutants into these systems, common types of pollutants, the effects of pollution in marine environments, and the management of pollution.

What is Pollution?

Pollution can be defined as the introduction of impurities and contaminants that are not normally found within an ecosystem that results in harm to the abiotic and/or biotic components of the ecosystem. Pollutants disrupt the normal functioning of an ecosystem. The effects of pollution have varying degrees of outcomes. Pollution comes in a variety of forms - those seen easily such as an oil spill and others less obvious that have other negative effects on the ecosystem. While we commonly think of pollution as physical (solid) it can also take other forms, such as acoustic, thermal, or light pollution. In this module we will focus on physical and acoustic pollutants as they are more prevalent in the Gulf of Mexico. Physical pollutants commonly found within marine environments include chemicals (such as fertilizers, pesticides, and herbicides), oil, sewage, solid waste (such as plastics), and pharmaceuticals. Concurrently, acoustic pollutants such as sound from ships, sonar devices, oil rigs, and earthquakes muddle the marine environment. Pollution sources are often classified into two categories: point and nonpoint.

Examples of point and nonpoint pollutants. Photo Credit: Stanton Broadway
**Point Pollution**

Point pollution sources are discernible sources that can be identified to a single specific location. Examples of point sources include pipes, wells, containers, smokestacks, tunnels, ditches, and vessels. The most commonly identified point sources are factories and sewage treatment plants. Factory pollution can include pollutants such as oil, chemicals, heavy metals, light, acoustic, and thermal pollution while sewage pollution is oftentimes bacterial or nutrient based. Until the early 1970s there was little regulation of industrial discharge, nuclear contamination, and waste dispersal into marine water. Now, pollution from point sources is closely monitored and controlled by legislation such as the Clean Water Act in the United States.

**Nonpoint Pollution**

Nonpoint sources come from diffuse sources. It is often difficult to pinpoint a single source of the pollution as it typically is a culmination of many sources that cover a wide area. The most common nonpoint sources are precipitation, storm water drainage, hydrologic modification, and fertilizer runoff. In the Gulf of Mexico one of the most detrimental nonpoint pollutants is thought to be runoff. Nonpoint pollution is commonly controlled at the state or local level through management programs as there is limited federal legislation.

**Marine Pollution**

It is estimated that eighty percent of marine pollution stems from land-based activities such as farming, industrial practices, and coastal urbanization. This section will outline some of the common forms of marine pollution.

**Oil Spills**

While oil spills from shipping vessels and oil platforms have traumatic effects on marine environments, they only account for about twelve percent of the oil found in marine environments. The other eighty-eight percent of oil entering marine waters comes from land practices such as from runoff into sewers.

When oil first enters the marine waters it typically forms large slicks on the water's surface. Then, some of the oil evaporates, other portions of the oil sink, and a fraction of the oil is destroyed by solar radiation or through microbial breakdown. Some of the oil will solidify and form tarballs, which float on the surface of the water. This sedimentation and breakdown does not occur quickly; instead it takes months to years depending on the degree of the oil spill.

The presence of oil in marine environments detrimentally impacts the aquatic life that resides in these waters. For example, when marine birds are exposed to oil the water repellant properties of their feathers becomes less effective. As a result, insulating capabilities of the feathers diminish, and the birds are more likely to develop hypothermia. Additionally, as the bird attempts to clean itself, the toxic oil can be ingested. Oil can also adversely affect the
growth and development of aquatic animals. For example, it has been documented that adult fish exposed to oil experience changes in respiration rate and decreases in fertility.

![Oil covering wings of a sea bird. Photo Credit: Stanton Broadway](image)

**Agricultural Pollution**

Runoff from agricultural practices results in the addition of nutrients, herbicides, and pesticides in marine waters. While nutrients such as nitrogen and phosphorus are necessary for crop growth and therefore primary ingredients in fertilizers, excess application of these nutrients in agricultural practices can result in runoff or leaching into nearby bodies of waters. Once these nutrients enter the water system they have impacts on downstream water bodies as these nutrients not only stimulate crop growth, but also other plant and algae growth.

The addition of herbicides and pesticides to agricultural fields can also have implications on water quality. The effects of these contaminants varies by organism given the vast spectrum of herbicides and pesticides available. Some effects on organisms include immune suppression, infertility, or even death.
Industrial Pollution

Industrial wastewater often contains metallic compounds such as zinc, tin, arsenic, and copper. When these heavy metals enter and are stirred up in the water column, they can become toxic. These toxins accumulate in the tissues of small organisms in the water and then are consumed by other organisms, thereby accumulating at higher concentrations within the animals at higher trophic levels.

In addition to wastewater pollution, some industrial practices result in acoustic pollution of nearby water bodies. The majority of this acoustic pollution stems from the machines used within these factories; however, industrial acoustic pollution can also come from transport of industrial products. Acoustic pollution has many implications on marine life including disorientation during migration, increased stress, organ damage, and disruption of metabolic processes.

Solid Waste Pollution

Solid waste and debris such as plastics, glass, and metals enter marine environments. A small percentage (approximately 20%) of solid waste found in marine environments comes from water-based practices, such as fishing, recreational cruises, or cargo ships. The remaining waste and debris found in marine environments originate from sources on land. This waste can harm marine life through ingestion, suffocation, and entanglement. Additionally, solid waste and
debris can not only affect marine life but also humans themselves. For instance, debris such as glass can physically harm beach goers.

Solid waste pollutants including bottles, bags, and tires. Photo Credit: Stanton Broadway

**Pharmaceutical Pollution**

Chemicals from medications, both over the counter and prescription, enter water systems through improper disposal as well as from excretion from the body. Improper disposal of medications can include flushing the medication down the toilet or throwing it away in the trash where it ends up in a landfill. Additionally, when we take medications the human body only metabolizes a portion of the drug. The remaining portion is excreted from the body and enters the sewage system. The majority of sewage treatment facilities do not have the capabilities to remove many of the chemical compounds found in medications. These pharmaceutical chemicals can impact the growth, development, and overall wellbeing of marine organisms.

**Effects of Pollution Concentration**

In addition to the types of pollution, the intensity of pollution must also be taken into consideration. The Gulf of Mexico experiences a seasonal hypoxic zone, also called "dead zone." To date the Gulf of Mexico "dead zone" is the second largest globally preceded only by the dead zone in the Baltic Sea. Excess amounts of nutrients, primarily nitrogen and
phosphorus, flow into the Gulf of Mexico through the Mississippi River Basin. It is thought that the excess nutrients that enter the Gulf of Mexico at this point come primarily from agricultural practices in the Midwest region of the United States. This overabundance of nutrients results in increased algal growth, called algal blooms. When the algae sink and decompose they consume oxygen. This oxygen depletion creates an oxygen low or depleted region in the water column. Regions of water with low dissolved oxygen concentrations (<2–3mg/l) can cause marine life to suffocate and die.

It is a common misconception that chemical pollutants such as toxic chemicals and heavy metals will be diluted in the vast marine waters; however, this is not the case. When many chemicals enter marine systems they actually become more concentrated within the marine food web. This accumulation in the concentration of the chemical pollution is referred to as biomagnification or bioaccumulation. As primary consumers ingest the chemical pollutant the chemical accumulates within the organism. These primary consumers are then eaten by consumers at higher trophic levels in the food web. The concentration of the pollutant builds up in organisms at higher trophic levels in the food web.

**Practices to Prevent Pollution**

While marine pollution comes in many forms and threatens marine environments, there are actions that can be taken to reduce the entry of pollutants into these waters. We will briefly discuss some of the primary actions here, but certainly through research and discussion you and your students can identify other ways to prevent pollution.

There are many campaigns to reduce, reuse, and recycle solid materials. These three actions not only benefit land environments, but also aquatic systems. If humans produce less waste on land and properly reuse or dispose of these materials, then there is an increased chance that these materials will not end up in marine environments. In a similar vein, the use of reusable shopping bags is a means to limit plastic waste which often enters marine environments.

Storm water drains are common in urbanized settings. Rainwater often carries oil or car wash soaps into these drains. Additionally, small solid debris can also be transported. Once in the storm water drains, the material in these systems flows to nearby bodies of water. By consciously managing materials that enter these drains, there is increased chance that these pollutants will not enter marine environments.
Bodies of water are connected via streams and tributaries. By cleaning up and preventing pollutants in upstream bodies of water we can prevent these pollutants from entering downstream water bodies. One way to clean up these bodies of water is to host a community river clean-up and remove solid materials from the water system. Another way to prevent pollutants from entering these systems is to obstruct nutrient runoff by establishing drift fences along stream beds.
UGH! HAVEN'T YOU GUYS EVER HEARD OF RECYCLING?!
What is Pollution?

Pollution is the introduction of impurities that are not normally found within a given ecosystem, which results in harm to the abiotic and/or biotic components of the ecosystem. Pollutants disrupt the normal functioning of an ecosystem. The effects of pollution have varying degrees of impacts in ecosystems. Some pollutants impact the visual appearance of an ecosystem while others harm organisms or processes that occur within an ecosystem.

While we commonly think of pollution as physical (solid waste), it can also take other forms, such as acoustic, thermal, or light pollution. The two most prominent forms of pollution in marine environments are physical and acoustic. Physical pollutants commonly found within marine environments include chemicals (such as fertilizers, pesticides, and herbicides), oil, sewage, solid waste (such as plastics), and pharmaceuticals. Concurrently, acoustic pollutants such as sound from ships, sonar devices, oil rigs, and earthquakes muddle the marine environment.

Figure 1. Semi-submersible oil rig. Photo Credit: Rosanna Milligan.
Pollution Sources

Pollution sources are often classified into two types: point and nonpoint. **Point pollution** sources are discernible sources that can be identified to a single specific location. Examples of point sources include pipes, wells, containers, smokestacks, tunnels, ditches, and vessels. The most commonly identified point sources are factories and sewage treatment plants. Factory pollution can include pollutants such as oil, chemicals, heavy metals, light, acoustic, and thermal pollution while sewage pollution is often bacterial- or nutrient-based.

**Nonpoint sources** come from diffuse sources. It is often difficult to pinpoint a single source of the pollution, as it typically is a culmination of many sources that cover a wide area. The most common nonpoint sources are precipitation, storm water drainage, hydrologic modification, and fertilizer runoff. In the Gulf of Mexico one of the most detrimental nonpoint pollutants is runoff.

Figure 1. Common forms of point and nonpoint pollution. Image Credit: Stanton Broadway.
Marine Pollution

About 80% of marine pollution comes from land-based activities such as farming, industrial practices, and coastal urbanization. Here we will learn about some of the common forms of marine pollution, but keep in mind there are many other pollutants that can effect marine environments.

Oil Spills

When there is a large oil spill from shipping vessels or oil platforms, it is often well-documented in the media. While these types of oil spills have traumatic effects on marine environments, they only account for about twelve percent of the oil found in marine environments. The other eighty-eight percent of oil entering marine waters comes from land practices, such as from runoff into sewers.

The presence of oil in marine environments has negative effects on the aquatic life that live in these waters. For example, when marine birds are exposed to oil, the water repellant properties of their feathers become less effective. As a result of this, insulating capabilities of the feathers diminish and the birds are more likely to develop hypothermia. If the bird tries to clean itself, it then ingests the oil which can poison the bird.

Oil can also adversely affect the growth and development of aquatic animals. For example, it has been documented that adult fish exposed to oil experience changes in respiration rate and decreases in fertility.

Figure 1. Squirt and his friends in the Gulf of Mexico can be effected by oil spills.
Photo Credit: Stanton Broadway.
**Agricultural Pollution**

Runoff from agricultural practices results in the addition of nutrients, herbicides, and pesticides into marine waters. While nutrients such as nitrogen and phosphorus are necessary for crop growth, if these nutrients enter the water system they have negative impacts on downstream water bodies. This is because the addition of nitrogen and phosphorus will cause an overgrowth of algae eventually depleting the water of dissolved oxygen when the algae decompose.

Herbicides and pesticides that runoff into water bodies can have negative impacts on the organisms living in the water. The effects of these contaminants vary by organism given the spectrum of herbicides and pesticides but include immune suppression, infertility, or even death.

![Agricultural field in the Midwest United States. Photo Credit: K. Denise Kendall](image)

**Industrial Pollution**

Industrial wastewater often contains metallic compounds such as zinc, tin, arsenic, and copper. When these heavy metals enter and are stirred up in the water column they can be toxic to organisms. These toxins accumulate in the tissues of the organisms in the food web, especially at higher trophic levels.
In addition to wastewater pollution, some industrial practices result in acoustic pollution of nearby water bodies. The majority of this acoustic pollution stems from the machines used within these factories; however, industrial acoustic pollution can also come from transport of industrial products. Acoustic pollution has many implications on marine life including disorientation during migration, increased stress, organ damage, and disruption of metabolic processes.

**Solid Waste Pollution**

Solid debris such as plastics, glass and metals enter marine environments. A small percentage (approximately 20%) of solid waste found in marine environments originates from water based practices such as fishing, recreational cruises, or cargo ships. The remaining debris found in marine environments originates from sources on land.

This solid waste can harm marine life through ingestion, suffocation, and entanglement. For example, a bird or sea turtle may get caught in plastic used to hold soda bottles together. Additionally, this material not only affects marine life but can also affect humans. For example, debris such as glass that washes onto beaches can physically harm beach goers.

![Figure 3. Squirt does not like his home littered with pollutants. Photo Credit: Stanton Broadway.](image-url)
**Pharmaceutical Pollution**

Chemicals from medications, both over the counter and prescription, enter water systems through improper disposal as well as from excretion from the body. Improper disposal of medications can include flushing the medication down the toilet or throwing it away in the trash where it ends up in a landfill. Additionally, when we take medications the human body only metabolizes a portion of the drug. The remaining portion is excreted from the body and enters the sewage system. The majority of sewage treatment facilities do not have the capabilities to remove the chemical compounds found in medications. The pharmaceutical chemicals can impact the growth, development, and overall well-being of marine organisms.
Acoustic Pollution

Objective
Students will explore how acoustic pollution can affect aquatic animal navigation and communication.

Next Generation Science Standards applicable to activity and extensions
- MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
- MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.
- MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects).
- HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
- HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.

Supplies
- Noise makers (e.g., bell, buzzer, chimes, tambourine, etc.).
- Blindfold(s)

Lesson
As we learned in the Adaptations module (the second module in the DEEPEND series), many marine animals do not rely on sight for navigation and communication. Instead, some animals rely on echolocation, the use of sound waves to determine where objects are located. Other marine animals use other variants of sound waves such as sonar and song to communicate and navigate while migrating or hunting.

This lesson should be conducted in an environment with few obstacles. Ideally, this lesson can be completed in an outdoor fenced in area or a large gymnasium. However, if you must complete this activity in a classroom, it is recommended that you move tables, desks, and chairs to clear a larger area and put padding over any sharp/hard points.

This activity can be conducted multiple ways. First, a single student can be blindfolded while all other students stand in a circle around the blindfolded student. The blindfolded student should be told to head toward a specific sound (e.g., bell). Students standing in a circle should randomly be given noise makers (it is okay if all students do not have a noise maker as they can...
be instructed to clap or stomp). The students with noise makers should be instructed to produce sound while the blindfolded student attempts to locate the assigned sound (e.g., bell). The degree of different sounds can be moderated to mimic little acoustic pollution (e.g., two different noises produced only by a couple of students) to a lot of acoustic pollution (e.g., ten or more different noises produced by many students).

The second manner in which this activity can be conducted is to select a group of students to blindfold (e.g., five). These blindfolded students should each be given an identical noise maker (e.g., harmonica). The blindfolded students should be split up. Their goal is to find each other by playing the noise makers. All other students should be given a different noise maker or instructed to clap/stomp. Once again, you can vary the degree of acoustic pollution by the number of students making noises. This activity mimics the affects of acoustic pollution on communication and navigation while migrating, hunting, or otherwise communicating.

There are a series of worksheets/handouts included for this lesson. The worksheet on the next page (Noise Pollution Investigation) helps students outline the experiment they conduct. Next, (Measuring Sound) is a handout that describes how noise is quantified and presents students with sound levels for commonly encountered sounds. Then, there is a worksheet (Beachings). This worksheet is presented in the form of a case study where students are asked to use online resources to research whale/dolphin beachings and draw conclusions.
Many marine animals do not rely on sight for navigation and communication. Instead, some of these animals rely on echolocation, the use of sound waves to determine where objects are located. Other marine animals use other variants of sound waves, such as sonar and song, to keep in communication and navigate while migrating or hunting. In this experiment you will explore what happens when noise pollutants enter marine environments.

**Materials:**
- Noise makers (e.g., bell, buzzer, chimes, tambourine, etc.).
- Blindfold

**Methods:**
1. One student in the class should be blindfolded.
2. All other students should stand in a circle around the blindfolded student.
3. The blindfolded student should be told to head toward a specific sound (e.g., bell).
4. Students standing in the circle should randomly be given noise makers or clap/stomp.
5. The students with noise makers should produce sound while the blindfolded student attempts to locate the assigned sound (e.g., bell).
   The degree of different sounds can be moderated to mimic little acoustic pollution (e.g., two different noises produced by a couple of students) to a lot of acoustic pollution (e.g., ten or more different noises produced by many students).

**Question:** What are the effects of noise pollution on marine animals?

Write a **hypothesis**:

What are the results of your experiment?

Given your results, explain how noise can affect communication between marine animals.
Measuring Sound

Acoustic pollution occurs in all environment types. Each day you are surrounded by sounds. The level of sounds that surround you can affect your ability to perform tasks, concentrate, and even your hearing. The unit used to describe the loudness of a sound is the decibel (dB). Below is a chart of sounds commonly encountered by humans and associated sound level (in decibels) of each sound. The arrow indicates increase in sound level.

<table>
<thead>
<tr>
<th>Sound</th>
<th>Decibels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing threshold</td>
<td>0</td>
</tr>
<tr>
<td>Leaves rustling</td>
<td>10</td>
</tr>
<tr>
<td>Whisper</td>
<td>30</td>
</tr>
<tr>
<td>Library</td>
<td>40</td>
</tr>
<tr>
<td>Sitting in automobile</td>
<td>50</td>
</tr>
<tr>
<td>Room with television on</td>
<td>60</td>
</tr>
<tr>
<td>Typical conversation</td>
<td>60</td>
</tr>
<tr>
<td>Vacuum cleaner</td>
<td>70</td>
</tr>
<tr>
<td>Classroom</td>
<td>80</td>
</tr>
<tr>
<td>Lawnmower</td>
<td>90</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>95</td>
</tr>
<tr>
<td>Helicopter</td>
<td>105</td>
</tr>
<tr>
<td>Car horn</td>
<td>120</td>
</tr>
<tr>
<td>Firecracker</td>
<td>125</td>
</tr>
<tr>
<td>Jet engine takeoff</td>
<td>140</td>
</tr>
</tbody>
</table>
Beachings

Could acoustic pollution be associated with dolphin and whale beaching? Dolphins and whales use sonar and song to communicate with each other. Sounds produced from land sources (e.g., factories, transportation, etc.) or human run aquatic operations (e.g., cruises, oil rigs, etc.) or even natural disasters (e.g., earthquakes) may interfere with the ability of these marine mammals to communicate efficiently. Additionally, these animals may be attracted to the human produced sounds. Using online resources investigate if acoustic pollution may play a role in dolphin and whale beachings.

Research notes:

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Given your research draw conclusions about the role of acoustic pollution on dolphin and whale beachings. Also outline if you think there are alternative factors contributing to beachings.

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Oil Spill

Objective
Students will explore how oil pollution can affect aquatic organisms and the marine environment.

Next Generation Science Standards applicable to activity and extensions
- MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.
- MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.
- MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
- HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
- HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
- HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
- HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Supplies
- Baking pans or tubs
- Salt water (made either with Instant Ocean or table salt)
  - Food coloring (optional - use to dye water to make it easier to distinguish between oil and water)
- Various types of oil (e.g., motor, olive, canola, sunflower, etc.)
- Aquatic plants
- Objects that mimic animal fur, skin, and feathers (e.g., feathers, fake fur, balloons, etc.)
- Oil spill clean-up options (e.g., cat litter, spoons, cloth, microorganisms such as Alcanivorax borkumensis, etc.)
- Optional additions:
  - Rocks, sand, wood, etc. for students to explore the behavior of the oil in the presence of these physical substrates
Lesson

There are many techniques used to clean up oil from aquatic environments. The most commonly used techniques are: bioremediation, dredging, skimming, dispersion, and burning. In this lesson students will explore the effects of oil on marine environments and organism. While large area oil spills that occur in marine waters, such as those from tanker spills or rig explosions, account for a small fraction of the oil found in marine environments, they are often some of the most publicized causes of oil pollution. One of the more recent oil spills in the Gulf of Mexico was the Deep Horizon Oil Spill of 2010. This oil spill occurred on April 20, 2010 after an explosion on the Deepwater Horizon Macondo oil platform. Millions of barrels of oil gushed into the Gulf of Mexico, creating the largest marine oil spill to date within the boundaries of the United States. A variety of methods were employed to clean-up the oil. However, since the oil spanned great depths of the water column tradition techniques such as skimming only had limited effectiveness. Therefore, scientists turned to the use of bioremediation techniques, primarily the addition of microorganisms in an effort to clean-up oil deeper in the water column before it settled into sediment.

There are a few variations that can be used to set-up this lesson. The simplest variation is to set-up a series of demonstration pans. Fill each pan half way with water. Then, add a different type of oil to each pan. The amount of oil to add will depend on the size of the pans you are using. You will want to add enough oil to easily see how the oil is behaving, but you do not want to cover the entire water surface. Students can observe how each oil type behaves (e.g., does it sink, float, clump, disperse, etc.). After initial observations, students can explore and document the effects of different types of oil on organisms by adding plants to the pans or by dipping animal substitutes (e.g., feathers) into the different pans.

The next variation of this set-up is more inquiry driven. Students can be divided into groups and each group can design an experiment to explore the effects of oil on aquatic organisms and aquatic environments. For this variation it is recommended that students have access to a variety of supplies.

Another, more complex variation, to this lesson integrates the aspect of cleaning up oil from aquatic systems. In this variation students can either be given a tub in which oil pollutes the water or groups of students can set-up their own tubs. The objective in this variation is to not only document how oil behaves in aquatic systems, but also on how effective and safe clean-up techniques are for oil pollution. In order to complete this variation, students will need access to supplies that mimic clean-up machinery/techniques. For example, if students want to explore bioremediation, they will need access to microorganisms such as *Alcanivorax borkumensis*. *Alcanivorax borkumensis* can be ordered from online supply companies. This microorganism works best in environments with some current/shaking so it would be ideal to suggest that a fan be used to circulate the water slowly or to place the pan on a shaker. *Alcanivorax borkumensis* will also need to be given ample time to have an effect on the oil spill, so this experiment may need to be monitored over the course of a couple of days. Simpler techniques would be to dredge, skim, or disperse the oil using techniques such as scoops, cloth, larger tubs, etc. While burning can be used to clean-up oil spills this technique may not be ideal for all
classrooms. If you choose to allow students to explore this method please make sure you have proper safety equipment available (e.g., fire extinguisher, safety glasses, fire blanket, etc.). Additionally, you will want to avoid plastic tubs/pans and limit the amount of oil students begin with.

This lesson can be extended beyond aquatic waters by having the oil spill impact a sandy beach. Students can be tasked with the challenge of ridding the sand of oil without removing the volume of sand from the environment. While students will probably engineer many creative and novel ways to do this, one manner in which to do this is to create a filter system using a soda bottle. By cutting the bottom of a soda bottle off students can fill the bottle with sand. Students can cover the cap/drinking end with cheesecloth, a coffee filter, or a similar material to hold back the sand while allowing liquids to run through. Securing the bottle upside down to a ring stand allows easier manipulation for filtration. Similar to how water if filtered through a variety of rock types before it reaches subterranean aquifers, students can separate the oil from the sand by doing a series of flushes. They may initially need to flush the sand with a dilute soap water (or other solvent) and then continue to flush the sand until all soap residue is removed.

The Oil Spill Investigation, Oil Spill Clean-up, Oil Spill Impacts, and Oil Spill Clean-up Techniques handouts included in this section help students take guided notes, document results from their explorations, and draw conclusions from the investigations. The Oil Spill Investigation handout is ideally used when students design their own experiments, but can also be used when the demonstration pans are set-up prior to class. The Oil Spill Clean-up handout can be used as an extension to the Oil Spill Investigation handout, or it can be used independently. Lastly, the Oil Spill Impacts and Oil Spill Clean-up Techniques handouts are designed primarily to guide note taking and documenting results.
Oil Spill Investigation

While large area oil spills that occur in marine waters, such as those from tanker spills or rig explosions, account for a small fraction of the oil found in marine environments they are often some of the most publicized causes of oil pollution. One of the more recent oil spills in the Gulf of Mexico was the Deep Horizon Spill of 2010. This oil spill occurred on April 20, 2010 after an explosion on the Deepwater Horizon Macondo oil platform. Millions of barrels of oil gushed into the Gulf of Mexico creating the largest marine oil spill to date within the boundaries of the United States. A variety of techniques were used to clean-up the oil. However, since the oil spanned great depths of the water column tradition techniques such as skimming only had limited applications. Therefore, scientists turned to the use of bioremediation techniques, primarily the addition of microorganisms in an effort to clean-up oil deeper in the water column before it settled into sediment. Most of the oil pollution found in aquatic environments come from land sources. For example, from oil leaking from a car or improper disposal of motor oil down storm drains. In this experiment you will explore the effects of different types of oil on marine environments and/or on organisms that live these environments.

Materials:
- Baking pans or tubs
- Salt water
- Various types of oil (e.g., motor, olive, canola, sunflower, etc.)
- Aquatic plants
- Objects that mimic animal fur, skin, and feathers (e.g., feathers, fake fur, balloons, etc.)

Question: What are the effects of oil pollution on marine environments and/or marine organisms?

Write a hypothesis:

Experimental design, explain how you will test your hypothesis:
Data:

Conclusions:
Oil Spill Clean-up

While large area oil spills that occur in marine waters, such as those from tanker spills or rig explosions, account for a small fraction of the oil found in marine environments they are often some of the most publicized causes of oil pollution. One of the more recent oil spills in the Gulf of Mexico was the Deep Horizon Spill of 2010. This oil spill occurred on April 20, 2010 after an explosion on the Deepwater Horizon Macondo oil platform. Millions of barrels of oil gushed into the Gulf of Mexico, creating the largest marine oil spill to date within the boundaries of the United States. A variety of techniques were used to clean-up the oil. However, since the oil spanned great depths of the water column tradition techniques such as skimming only had limited applications. Therefore, scientists turned to the use of bioremediation techniques, primarily the addition of microorganisms in an effort to clean-up oil deeper in the water column before it settled into sediment. Most of the oil pollution found in aquatic environments come from land sources. For example, from oil leaking from a car or improper disposal of motor oil down storm drains. Marine environments and organisms are adversely effected by oil pollution.

There are many techniques used to clean-up oil from aquatic environments. The most commonly used techniques are: bioremediation, dredging, skimming, dispersion, and burning. The purpose of this experiment is to explore the effectiveness and/or feasibility of common clean-up techniques.

Materials:
- Baking pans or tubs
- Salt water (made either with Instant Ocean or table salt)
  - Food coloring (optional - use to dye water to make it easier to distinguish between oil and water)
- Various types of oil (e.g., motor, olive, canola, sunflower, etc.)
- Aquatic plants
- Objects that mimic animal fur, skin, and feathers (e.g., feathers, fake fur, balloons, etc.)
- Oil spill clean-up options (e.g., cat litter, spoons, matches, cloth, microorganisms such as Alcanivorax borkumensis, etc.)
- Additional materials as provided by instructor

Question: How effective and feasible are commonly used oil spill clean-up techniques?

Write a hypothesis:
**Experimental design**, explain how you will test your hypothesis:
Data:

Conclusions:
Oil Spill Impacts

Use the table below to record your oil spill clean-up observations. Summarize the type of oil (e.g., motor, olive, etc.), the degree of the spill (e.g., large scale, a few droplets, etc.), the impact on the marine environment, and the impact on marine organisms.

<table>
<thead>
<tr>
<th>Type of Oil</th>
<th>Degree of Spill</th>
<th>Impact on Marine Environment</th>
<th>Impact on Marine Organisms</th>
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**Oil Spill Clean-up Techniques**

Use the table below to record your oil spill clean-up observations. Summarize the clean-up technique utilized (e.g., skimming, burning, etc.), the water conditions (e.g., calm, choppy, etc.), and the effectiveness of the technique.

For effectiveness use the following rating scale:
- **4** = Removed all of the oil;
- **3** = Removed most of the oil;
- **2** = Removed half of the oil;
- **1** = Removed some of the oil;
- **0** = Did not remove any of the oil.

<table>
<thead>
<tr>
<th>Clean-up Technique</th>
<th>Water Conditions</th>
<th>Effectiveness</th>
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**Nutrient Runoff**

**Objective**
Students will explore how nutrient runoff can affect aquatic organisms and the marine environment.

**Next Generation Science Standards applicable to activity and extensions**
- **MS-LS1-5.** Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.
- **MS-LS2-1.** Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
- **MS-LS2-3.** Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
- **MS-LS2-4.** Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- **MS-LS2-5.** Evaluate competing design solutions for maintaining biodiversity and ecosystem services.
- **MS-ESS3-3.** Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
- **HS-LS2-2.** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
- **HS-LS2-7.** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- **HS-LS4-6.** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
- **HS-ESS3-4.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- **HS-ESS3-6.** Use a computational representation to illustrate the relationship among Earth systems and how those relationships are being modified due to human activity.
- **HS-ETS1-3.** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

**Supplies**
- Small tanks (or containers)
- Salt water (made with Instant Ocean)
- Sand
- Marine plants and algae
- Saltwater crustaceans
- Nutrient supplements (e.g., fertilizer, aquatic supplements)
- Oxygen probe
- Marine aquarium testing kits (specifically nitrogen and phosphates)
Lesson

This lesson allows students to explore the effects of nutrient runoff into aquatic systems. Specifically, students will set up an experiment to observe and measure the effects of nutrient concentrations on marine oxygen levels, plant/algae growth, and crustacean populations.

There is more than one way to conduct this experiment. The first approach is to set-up a demonstration for students. For the most basic demonstration you will need two small tanks. One of these tanks will serve as a control while the other will receive nutrient supplements. Line the bottom of each tank with sand and then put equal amounts of salt water in each tank. Add a variety of marine plants, algae, and crustaceans to both tanks (try to keep similar species and amounts). Take concentration levels for initial oxygen, nitrogen, phosphorus, and other nutrients of interest. Then, add nutrient supplements to the second tank (particularly nitrogen and phosphorus). Let the tanks sit for at least one week. Then, take concentration levels again. Also quantify the health and growth of the plants, algae, and crustaceans. Allow students to see the tanks and analyze the data to determine the effects of nutrient runoff. You can extend this demonstration by setting up a variety to tanks to observe (e.g., one supplemented with only nitrogen, one supplemented with only phosphorus, one supplemented with nitrogen and phosphorus, etc.).

The second approach to conducting this experiment is to allow groups of students to design and set-up their own tank systems to monitor. Students can elect which nutrients to supplement in their tanks, what aquatic plants, algae, and animals to add to the tanks, and other abiotic/biotic factors to manipulate. Conducting the lesson in this manner makes the experiment more student-driven and allows them to focus on exploring aspects of nutrient runoff most intriguing to them.

The first worksheet that supplements this lesson is the Nutrient Runoff Demonstration sheet. This worksheet helps student take guided notes and is ideal for an interactive science notebook. The second handout is the Nutrient Runoff Investigation sheet which provides structure to setting up, running, and analyzing data from a student designed experiment. The Nutrient Runoff Case Study is the third handout in this section which is ideal for a culmination after students have learned about nutrient runoff.
**Nutrient Runoff Demonstration**

Use the chart below to record your observations for the nutrient runoff demonstration. Document the dissolved oxygen, nitrogen, and phosphorus levels in each tank. Then, describe the algae, plant, and crustacean populations in each tank. Specifically, describe the population size and health of the population.

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<thead>
<tr>
<th></th>
<th>Control Tank</th>
<th>Experimental Tank</th>
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<tbody>
<tr>
<td><strong>Dissolved Oxygen</strong></td>
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<tr>
<td><strong>Nitrogen</strong></td>
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<tr>
<td><strong>Phosphorus</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>Algae Population</strong></td>
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<tr>
<td><strong>Algae Health</strong></td>
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<tr>
<td><strong>Plant Population</strong></td>
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<tr>
<td><strong>Plant Health</strong></td>
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<tr>
<td><strong>Crustacean Population</strong></td>
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<td></td>
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<tr>
<td><strong>Crustacean Health</strong></td>
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</tbody>
</table>
Nutrient Runoff Investigation

The Gulf of Mexico experiences seasonal hypoxic zones. Hypoxic zones are regions where dissolved oxygen levels are low and unable to support life. Consequently, these regions are often referred to as "dead zones." The Gulf of Mexico dead zone, located near the Mississippi Basin, is currently thought to be the second largest world-wide given the vast area it spans. An excess amount of nutrients primarily nitrogen and phosphorus, flow into the Gulf of Mexico at the Mississippi Basin. These nutrients stem from many sources but primarily from agricultural fertilizer applications in the Midwestern region of the United States.

An intake of high concentrations of nutrients into aquatic systems can result in increased algal growth. When the algae sink and decompose they consume oxygen. This oxygen depletion creates an oxygen low or depleted region in the water. Regions of water with low dissolved oxygen concentrations (<2–3mg/l) can cause marine life to suffocate and die. In this experiment you will explore the effects of nutrient runoff on abiotic and biotic components of marine environments.

Materials:
- Small tanks (or containers)
- Salt water (made with Instant Ocean)
- Sand
- Marine plants and algae
- Saltwater crustaceans
- Nutrient supplements (e.g., fertilizer, aquatic supplements)
- Oxygen probe
- Marine aquarium testing kits (specifically nitrogen and phosphates)

Question: How does nutrient concentration affect abiotic and biotic components of marine environments?

Write a hypothesis:
Experimental design, explain how you will test your hypothesis:
Data:

Conclusions:
Nutrient Runoff Case Study

Each year a "dead zone" forms in the Gulf of Mexico in the region of the Mississippi Basin. This region experiences algal blooms that eventually decompose and lead to dissolved oxygen levels too low to support life (<2.0mg/l). While this dead zone forms annually, its occurrence has become more frequent and extensive. It is believed that increased inputs of nitrogen and phosphorus from agricultural practices in the Midwestern United States is the cause of this new pattern. Concurrently, the region in which this dead zone forms is considered one of the most productive fishery areas in the United States. The fishermen believe that if Midwestern farmers reduce their fertilizer uses by 50%, this would also decrease the frequency and extent of the dead zone. Therefore, the fishermen propose a bill be passed that requires all farmers to reduce fertilizer usage by half. Given what you know about eutrophication, agricultural pollution, and aquatic systems write an argument supporting this proposed bill. Then, propose alternative practices that would reduce nutrient runoff in lieu of reducing fertilizer usage.

Support for the bill:
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Alternative practices to reduce nutrient runoff:
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Pollution Reduction

Objective
Students will explore what they can do to reduce pollution in marine environments.

Next Generation Science Standards applicable to activity and extensions
- MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
- MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.
- MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
- MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
- HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Supplies
- Products for redesign challenge
- Packaging materials for redesign challenge as requested by students

Lesson
This lesson focuses on teaching students what they can do to prevent and reduce pollution in marine environments. Many students have heard the slogan reduce-reuse-recycle, in this lesson we will reinforce these practices while concurrently building upon them.

The first activity asks students to consider alternatives to placing solid waste into the trash. Students are asked whether an item should be disposed of in the trash, recycled, or composted. There can be more than one justifiable response for some of these items; therefore, this
activity is ideal to get students conversing about ways to reduce pollution. A Trash-Recycle-Compost handout is included to guide student reporting of answer choices.

The second activity outlined for this lesson asks students to research decomposition times for items they commonly dispose of in the trash. The findings of this activity can be shared in small groups as well as with the class. For example, students can discuss the shortest and longest decomposition times they found. The Decomposition Rates worksheet in this section is included to assist students with reporting their findings and conclusions.

The third activity asks students to identify common marine pollutants. Then, students conduct research to identify the most common sources of these pollutants. After which, students outline effects and control/management for each pollutant. While each student can complete this activity individually, it also makes a great group project. After students conduct their research each group of students can decide on one pollutant to present to the class. Thereby, students are learning how to not only find information but also how to effectively communicate it to an audience. The Pollution Source and Management handout presented in this section is designed to assist students with note taking from their research.

The last activity in this lesson is an engineering redesign challenge. Students are challenged to pick an object (or they can be assigned) for which they will redesign the packaging. Students should be encouraged to not only consider the amount of material used in the packaging, but also the type of material. For example, some egg cartons are made from plastic or Styrofoam while others are made from biodegradable cardboard. Included for this activity is a handout entitled Redesign Challenge. The handout asks students to brainstorm the changes they will make to the packaging and the overall environmental benefits of their changes.

Using these activities as a series is ideal as it allows students to first acquire a basic understanding of pollution and ways in which to reduce pollution. Then, as students’ progress through the activities until they are presented with a challenge that asks them to synthesize what they have learned and to apply it. However, each of the activities in this lesson can also act as a standalone lesson or the activities can be completed in an alternative order.
Often solid waste management is simply placing waste in the trash. However, there are other ways in which to dispose of solid waste. In addition to simply placing solid waste into the trash, you can recycle or compost some of the waste. Recycling is the process of reusing waste to make new products while composting is the process of breaking down organic matter into nutrient rich soil and thereby returning and reusing the natural matter. Given the list of solid waste below decide if you should trash, recycle, or compose the waste. There may be more than one correct choice, so provide an explanation for your choice. After you complete the table talk with someone sitting next to you. If you disagree on any of the solid waste disposal options share your explanations.

<table>
<thead>
<tr>
<th>Trash, Recycle, or Compost</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana peel</td>
<td></td>
</tr>
<tr>
<td>Cardboard</td>
<td></td>
</tr>
<tr>
<td>Chip bag</td>
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</tr>
<tr>
<td>Egg shells</td>
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<tr>
<td>Glass bottle</td>
<td></td>
</tr>
<tr>
<td>Napkin</td>
<td></td>
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<tr>
<td>Newspaper</td>
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</tr>
<tr>
<td>Pizza box</td>
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<tr>
<td>Plastic bag</td>
<td></td>
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<tr>
<td>Soda bottle</td>
<td></td>
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<tr>
<td>Tea bag</td>
<td></td>
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</tbody>
</table>
Decomposition Rates

Often solid waste management is simply placing waste in the trash. However, have you ever thought about how long it takes for solid waste to decompose? Write down ten items you commonly throw in the trash. Then, do research to determine how long it would take for each of these items to decompose.

<table>
<thead>
<tr>
<th>Item</th>
<th>Decomposition Time</th>
</tr>
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<tbody>
<tr>
<td>1</td>
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<td>2</td>
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<td>9</td>
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<td>10</td>
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</tbody>
</table>

Which item takes the longest to decompose?

How could you reuse or dispose of the item that takes the longest to decompose instead of putting it in the trash?
Pollution Source and Management

There are many sources of pollution. Some of pollutants can be traced to a single source while others come from many sources and/or locations. Choose five common marine water pollutants. Then, identify the source or sources of this pollutant. Lastly, outline the effects of the pollution as well as commonly used control or management techniques. Share your results with your peers.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Source(s)</th>
<th>Effects</th>
<th>Control or Management Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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Redesign Challenge

Each day we use products that are packaged in a variety of manners. Today, your challenge is to redesign the packaging of a product. It is your goal to use less packaging material, to use a biodegradable material, or to use a recyclable material. Before you get started on your redesign challenge, describe the original packaging material:

Now, describe how you would repack the product:

Lastly, repack your product in your redesigned packaging. Show your classmates the original and the repackaged product for feedback. Did you successfully reduce the packaging material used? Did you use more environmentally friendly packaging materials?
References and resources for teachers and students


Smithsonian National Museum of Natural History. *Gulf Oil Spill*. http://ocean.si.edu/gulf-oil-spill


University of Delaware. *How do you clean up an oil spill?* http://www.ceoe.udel.edu/oilspill/cleanup.html

About the Author:
Dr. K. Denise Kendall is a graduate of the Department of Ecology and Evolutionary Biology at the University of Tennessee-Knoxville (2013). She holds a Florida Professional Teaching Certificate (Biology 6-12) from the University of West Florida. Dr. Kendall is committed to the advancement of science education in K-12 and higher education through the integration of authentic scientific experiences into course curricula.