IMPACTS OF OIL ON MANGROVES

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Extremely productive and beneficial ecosystems, mangrove forests stabilize coastlines by protecting shorelines from storm surges, currents, waves, and tides. They improve coastal water quality and provide shelter to species of fish, crab, shrimp, and mollusks. However, if mangrove forests are compromised by oil spills, they can no longer shield coastlines, provide habitat, or feed organisms living among their roots and branches.

Mangroves are productive coastal ecosystems that dominate the intertidal shores of tropical and subtropical areas. (UF/IFAS/Tyler Jones)

BACKGROUND

Mangroves are a group of mostly woody plants that dominate the **intertidal** shores in **tropical** and **subtropical** areas.[1,2] In the U.S., mangrove communities are widely distributed throughout the Gulf of Mexico and the Caribbean Sea. They are well-developed mainly in the southern part of Florida and in Puerto Rico, but their range, specifically the black mangrove, has expanded to southern Texas and Louisiana (**Figure 1**).[3,4]

These coastal plant communities consist of four dominant types: red mangrove, black mangrove, white mangrove, and buttonwood. Mangroves tend to grow in a specific order from the sea edge. Typically, the red mangrove lives closest to the water and has aerial roots known as prop roots. Black mangroves are

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In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10–year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization, and remediation technologies. GoMRI is led by an independent and academic 20–member research board.

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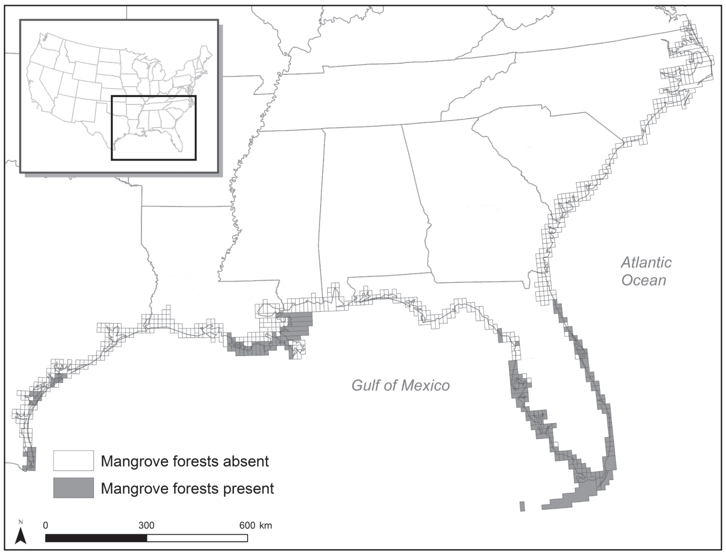


FIGURE 1. *The largest concentrations of mangrove forests in the southeastern United States exist along the Florida coast, based on data from 2006 for Texas and Louisiana and 2004 for Florida. The gray colored cells indicate areas where mangroves were found but does not mean that mangroves covered the entire cell. (Adapted from Osland et al., 2012)*

further inland close to the red mangroves. They have **pneumatophores** that poke out of the **sediment**. Prop roots and pneumatophores have small openings called **lenticels** that provide oxygen for mangroves to breathe (**Figure 2**).[1,2] The white mangrove lives farther inland on more stable higher intertidal **soils**, with the buttonwood farthest away at the landward edge.[2]

Mangroves' tangled, dense root systems provide habitat and food for many species of fish, crabs, and other living creatures.[2,5,6] These roots also help mitigate storm surge and maintain water quality by restricting water flow, trapping sediments, and absorbing excess nutrients from the water.[6] The calm waters provide an ideal environment for breeding and nursery grounds for young fish and shrimp.[7] They also help to stabilize other plants in the surf.[3] Mangroves can adapt to changing environmental conditions, such as fluctuations in **salinity** from flooding or long periods of drought.[5,7] They use the following mechanisms to tolerate high salinities:

- Salt exclusion — mangrove roots have filters that exclude salt while extracting water from the soils.
- Salt accumulation — some mangroves have glands that cause salt to accumulate in older leaves so when they shed their leaves, they also shed salt.
- Salt secretion — special organs or glands remove salts from plant tissues by forming salt crystals on leaf surfaces that can be removed by wind or rain.[8]

OIL IMPACTS

Mangroves are highly sensitive to oil exposure. The extent of damage to and recovery of mangroves depends upon the type of oil spilled and the amount reaching the mangroves and remaining after cleanup efforts. The oil's exposure to waves and currents, the time of year of the spill, and the oil sensitivity of the different mangrove species also factor into impacts.[5,9,10]

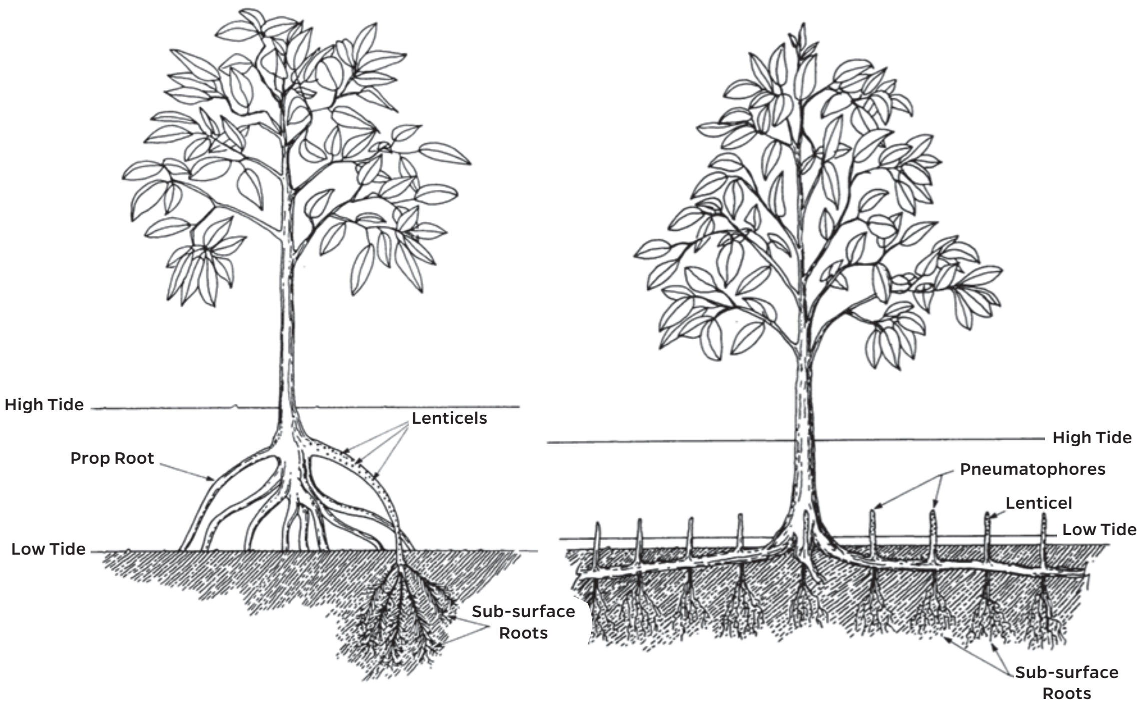
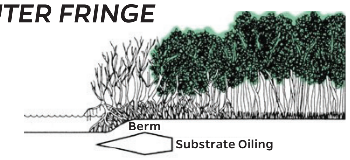
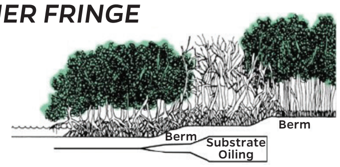
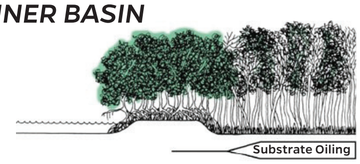
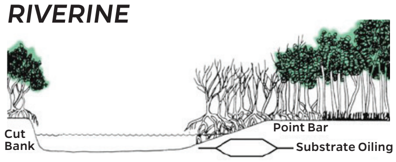


FIGURE 2. *Red (left) and black (right) mangroves have specialized root systems that allow the exchange of air with the atmosphere, providing oxygen to the trees. (Adapted from Teas, 1993)*

TABLE 1. *Mangroves can experience four types of impacts when polluted with oil. (Adapted from Getter et al., 1981)*

IMPACT	*WHAT HAPPENS?*	*WHAT IS AFFECTED?*
OUTER FRINGE 	Oil is trapped on and in front of a high berm at the outer edge of the forest.	Most of the oil collects in and impacts a small area, resulting in defoliation or death of shoreline mangroves and leading to shoreline erosion.
INNER FRINGE 	Oil is pushed into the mangrove forest and deposited on the inner berm.	The vegetation in the area of highest oiling is stressed or dies.
INNER BASIN 	Oil is carried over the coastal berm or through tidal flats into a sheltered mangrove basin.	Oil can be spread over a wide area and damage can be more scattered.
RIVERINE 	Oil accumulates on gently sloping sand bars, with the potential for penetration into the porous soils.	With both oiling of the roots and in the soils, damage can be severe.

Spills at sea are the main cause of oil in mangroves due to their coastal locations. Mangrove forests near ports, refineries, or busy shipping channels are at highest risk.[5] Waves and currents transport oil into the mangrove ecosystems. Once there, oil often collects, coats the vegetation, and penetrates the soil. Water moves slowly through the mangrove forest making natural removal very slow.[9,11] Observations of past spills show that differences in the physical environment, such as wave exposure and land features like **berms**, influence where the oil will go and how long it will persist (**Table 1**).[12]

Past oil spill events around the world demonstrate that mangroves can suffer lethal and **sublethal** effects when exposed to oil. They may show signs of oiling within the first two weeks of a spill event, though evidence of oiling may not appear until weeks, months, or even a year later. When oiling occurs, mangrove leaves can stunt or deform and branches can **defoliate** or die back. Mangrove seedlings can also deform or die. Plants and animals living in the mangrove forest may change in number, location, or die altogether after oiling.[3,5,6]

Oil exposure can lead to defoliation. The loss of leaves allows more light to penetrate the forest floor, which then causes temperatures and salinities to rise. These conditions can cause leaf deformities and seedling deaths or progress to tree death.[3,5,13] Defoliation and death occurred after a spill in Panama in April 1986. Winds pushed oil towards the coast where it penetrated the soils around the mangrove roots. By September of 1986, mangroves in a heavily oiled intertidal zone experienced complete defoliation. Trees rooted in the **subtidal zone** suffered less defoliation.[14]

Oil will impact mangroves regardless of the distance from shore if oil reaches their roots and pneumatophores.[15] Mangrove roots are partially submerged, grow in **anaerobic** sediments, and receive their oxygen from the air through the lenticels on the exposed roots. If the root is damaged or coated with oil, respiratory capabilities of the plant will suffer, which could cause them to suffocate or die.[3,5] The chemicals in the oil can be highly toxic and penetrate the root surfaces, poisoning the plant. Shorter, less mature trees may die within days of oiling. Taller, more mature trees may show no signs of damage for six or more months and then die.[16]

In a recent laboratory study, scientists exposed sections of red mangrove roots to salt water; salt water and crude oil; and salt water, crude oil, and **dispersants** to examine the impacts of oil and oil plus dispersants on water movement through mangrove roots. Results showed the roots exposed to oil or oil and dispersants dried out, suggesting that water was not carried through the roots.

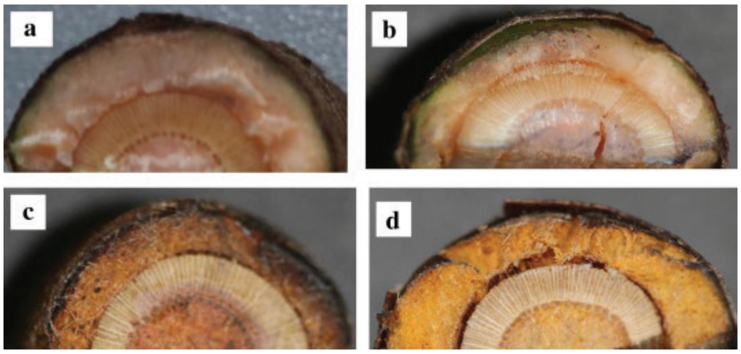


FIGURE 3. *Cross sections of mangrove root segments used in laboratory experiments show the amount of water movement through the root tissues after they are partially submerged in different solutions for seven days: a) cross section of fresh cut root, b) cross section of root exposed to salt water, c) cross section of root exposed to salt water plus crude oil, and d) cross section of root exposed to salt water, crude oil, and dispersants. (Reprinted from Tansel et al., 2015)*

The lack of water movement caused separation between the root layers, weakening the structure of the root (**Figure 3**).[17]

When a June 1991 spill sent one thousand gallons of oil into a restored mangrove area near Port Everglades, Florida, scientists tested three species of oiled mangroves to determine impacts and growth abnormalities over time. The study's results showed that white and black mangrove seedlings were less tolerant to oiling than red mangrove seedlings. Red mangrove seedlings had fewer deaths and increased growth rates after the spill.[18] In an earlier laboratory study, red and black mangrove seedlings exposed to oil and dispersant showed changes in growth, respiration, **transpiration**, and uptake of oil-based chemicals.[12]

Plant roots are further stressed when oil coats the surrounding soil, resulting in compromised soil conditions.[19] Mangroves growing in more porous soils are vulnerable to impacts due to oil penetrating deeper into the ground, as opposed to mangroves growing in fine clay mud.[16] Even muddy mangrove soils can become porous when animals that live there dig burrows for their homes, a process known as **bioturbation**. The digging increases the mixing and turnover of the soil. This process can lead to persistent oiling because of slow rates of oil **weathering** in the absence of oxygen in anaerobic soils.[9] Animals like crabs or worms living in the mangroves can be harmed by oil when it enters their burrows or if they ingest it (**Figure 4**).[7] Burrowing activities help aerate the mangrove soils as tidal waters flow through the network of burrows. This aeration ceases when the animals die, causing stress to the surrounding mangroves.[16]

Under severe conditions, oil spill impacts may continue for years to decades and can result in permanent habitat loss.[5,6] When mangroves are severely oiled, plants can rot and die as a result. This loss of live plant roots, which stabilize the soil, and can increase the rate of land loss.[11,20,21]

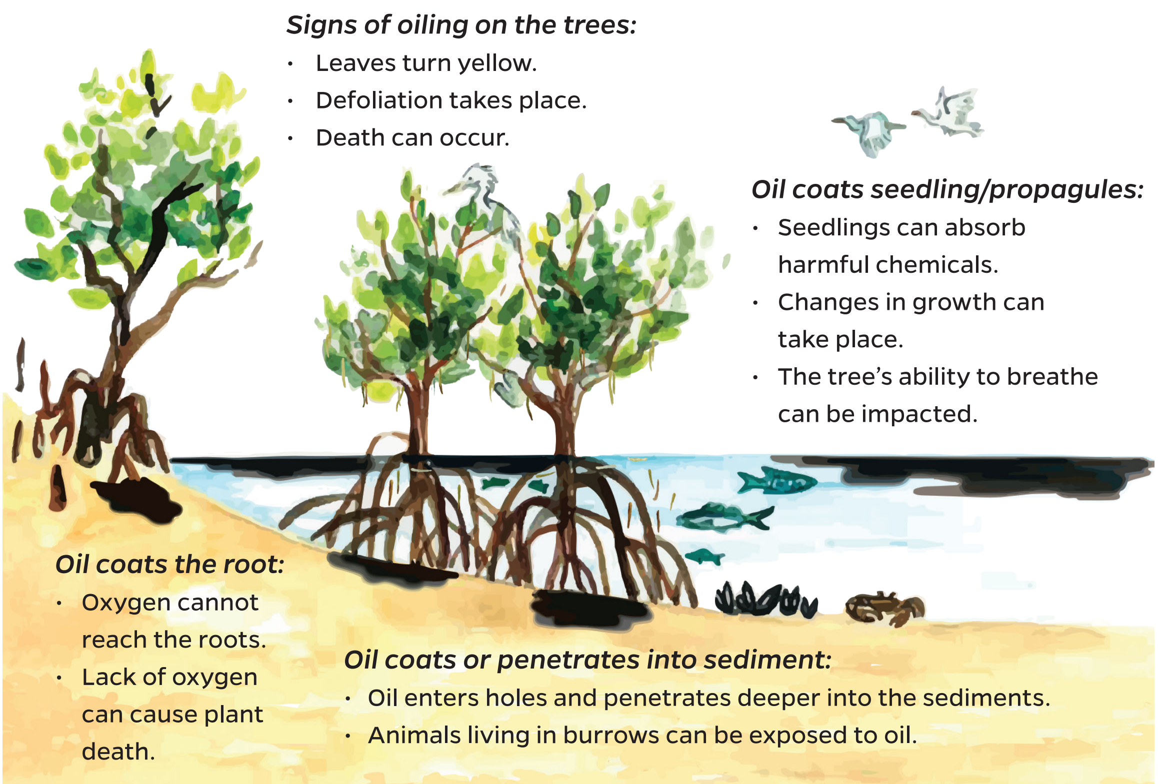


FIGURE 4. *Mangroves are highly vulnerable to oil exposure. Once coated in oil, the extent of damage and recovery will depend on type and amount of oil spilled and the length of time the spilled oil remains. (Anna Hinkeldey)*

PROTECTION, RECOVERY, AND RESTORATION

Protection

The natural regenerative processes of mangrove forests are complex and slow, putting the recovery of oil-damaged habitat at risk. Once oil enters a mangrove forest, the intricate root systems of mangroves can make oil cleanup difficult, so keeping oil off mangrove shorelines is a high priority for oil spill responders.[5,9]

Determining the appropriate response action depends on multiple factors, including oil type, weather, and availability of response equipment.[6] The ideal response would be to keep oil from reaching the shoreline. To do this, responders could mechanically recover the oil offshore, use oil dispersants or **in situ burning** offshore, or protect the mangrove shoreline with **boom**.[6,7]

Keeping oil off as much of the shoreline as possible is essential for the natural repopulation of mangroves. The surviving areas provide uncontaminated seedlings to transplant elsewhere and unoiled soil provides an ideal area for seedlings to grow, making these high priority zones to protect.

If oil happens to enter a mangrove area, considerations need to be made before any cleanup efforts are applied. The benefits of any response efforts should outweigh any damage caused by the cleanup. With such considerations in mind, cleanup options include the following:

- Sediment berms and dams can close off small inlets to protect mangrove habitats.
- Booming and skimming the oil on the water's surface in mangrove creeks can keep it from reaching sensitive areas.
- Responders can remove bulk oil manually or vacuum it from the sediment surface and channels.
- Water can flush free oil from the surface of the sediment and mangroves into collection areas.
- Absorbent materials can collect oil from mangrove surfaces.[6,7]

Some oil response methods can be highly destructive to mangroves. These actions include cutting or burning live trees, high-pressure or hot water flushing, digging trenches, and sediment reworking or removal. Any response techniques that lead to trees being destroyed could have long-term impacts to the mangrove forests, such as increased erosion that could leave the shore unprotected from storm surge.[6]

There are occasions when it may be appropriate to do nothing. Cleanup operations can cause significant damage to roots and seedlings, doing more harm than good. Responders' foot traffic can mix oil into the fine-grained sediments, reducing the oil's breakdown rate.[6,9] With no physical cleanup, the exposed oil will slowly degrade and be removed by natural or storm-generated flushing.[6]

Recovery

Generally, mangroves have the capacity to recover from major natural disturbances such as hurricanes or floods.[6] After a manmade disturbance such as an oil spill, recovery and rehabilitation of the forest can be slowed by the persistence of oil in the soils. When the impacts of oil are damaging but not deadly, mangrove forests can recuperate rapidly, usually in one to five years.[5]

However, sometimes mangroves can be permanently lost due to gradual degradation and weakening. When the trees die, recovery of the area can take 5 to 25 years or longer by natural **recruitment**. To recover, new seedlings need to come from other healthy mangrove forests, and then replacement plants grow to full maturity. When oil spills cause lethal impacts to mangrove forests, it affects the surrounding environment. The changes to sediments, erosion, water circulation, temperature, and salinity make recovery more difficult.[5]

In April 1986, 50,000 barrels of crude oil spilled off Panama's Caribbean coast. Scientists revisited the spill site five years later to conduct a long-term study. Impacts of oiling were still visible. Sediment testing confirmed the oil persisted in the deep muds and continued to leach into the waters. The team also noted a decrease of mangroves in the area. This change reduced the area of living **substrate** on the prop roots on which animals attach and grow.[13]

To understand the long-term impacts of untreated oil and dispersant-treated oil on tropical ecosystems, in December 1984 scientists began a multi-year monitoring project in Panama. Areas were dosed with high concentrations of chemically-dispersed oil to create a 'worst-case' scenario. Over a two-year period, untreated oil had severe effects on the survival rate of mangroves and animals. Dispersant-treated oil had minor or no effects on seagrasses and mangroves. As for animal life, an initial severe decline in the number of mangrove tree snails took place only three days after treatment. However, all treatment sites recovered to pre-spill numbers after one year.[11,22]

Ten years later, scientists revisited the original project sites. Evidence of the continued presence of oil existed with degraded **hydrocarbons** still present in surface and sediment samples in both the chemically-dispersed site and oil-only site. Oil made its way into the sediments by seeping through holes and dead mangrove **propagules.** In the oil-only area, they found many of the original trees had died, as well as healthy seedlings and saplings regenerating in the same area. This regrowth occurred in the same place where oil accumulated during the initial experiment. In contrast, the chemically-dispersed oil site had no measurable effects on adult mangroves and no deaths occurred.[11] To understand chronic long-term oil impacts on mangroves, monitoring forests for years after a spill is essential.

Restoration

Restoration is a technique that can speed up the spill recovery process. Depending on the forest's state after an oil spill, restoration methods may include replanting, removing pollutants from soils, improving the impacted site so that natural regeneration can occur, or restoring an alternate site to provide a similar replacement habitat.[6] Removing stressors and ensuring suitable environmental conditions can help mangroves recover.[23]

When planting seedlings, conditions such as soil type, location, and existing toxic elements in the water must be carefully considered. Residual oil in sediment degrades very slowly. To help stop or even reverse damage from oil, **remediation** may help oil break down faster by adding nutrients or aerating the soil to allow nutrients, air, and water to penetrate more deeply.[5,6] However, both types of remediation have shown only modest effectiveness in field experiments and not after real spills.

Replanting areas where oil killed mangroves has two benefits: 1) speeding the natural **revegetation** process and 2) releasing oxygen into the soils via new root systems, which increases oil degradation through a process called **phytoremediation**. After the 1986 Panama spill, scientists used planted red mangrove propagules and nursery-grown seedlings in holes filled with oil-free soils. Scientists found seedlings planted 9 to 12 months post-spill grew at a faster rate than those planted at six months. Apparently, weathered oil was less toxic over time.[24]

Another long-term study in the mangrove forests of Bahía Las Minas, Panama, showed that replanting may not always be the correct solution to restoring mangrove forests. Oil from the 1986 spill remained in the sediment for more than twenty-four years, making recovery slow.[25] Assessments showed natural recruitment following the spill was plentiful in most areas, and the growth and survival of established plants were not affected by oil in the sediment. Natural recruits began to grow and shade the planted seedlings, causing them to die. Planted sites had lower densities, shorter trees, and smaller **biomass**. Planting may have also altered or damaged some sites, negatively affecting forest recovery. This included responders trampling sediment, which compacted the soil and released residual oil. Holes dug to plant increased erosion and interfered with natural recruitment by damaging existing seedlings and disrupting their establishment.[26]

Scientists continue to study oil spills' impacts on mangroves, some with funding from the Gulf of Mexico Research Initiative (GoMRI). To access other oil spill-related publications, go to GoMRI's website at ***gulfresearchinitiative.org*** or the Sea Grant Oil Spill Science Outreach Program website, ***www.gulfseagrant.org/oilspilloutreach***.

GLOSSARY

Anaerobic — Deprived of or without oxygen.

Berm — An artificial ridge or embankment used as a border or separation barrier.

Biomass — The total weight of organisms in a given area.

Bioturbation — The mixing and turning over of soil by living organisms, which can happen when organisms move, burrow, or ingest and defecate soil grains.

Boom — A temporary floating barrier used to contain an oil spill.

Defoliate — The loss or removal of leaves from a tree, plant, or area of land.

Dispersants — Chemicals that are used during oil spill response efforts to break up oil slicks and limit floating oil from impacting sensitive ecosystems such as coastal habitats.

Hydrocarbon — A compound composed of carbon and hydrogen atoms. Most hydrocarbons naturally occur in crude oil and natural gas and are formed from decomposed organic matter.

In situ burning — A response method used to remove oil from the water's surface through burning.

Intertidal — The area that is above water at low tide and underwater at high tide.

Lenticels — Raised pores in the stem of a woody plant that allow gas exchange between the atmosphere and the plant's internal tissues.

Phytoremediation — A process that uses various type of plants to remove, transfer, stabilize, or destroy pollutants in the soil.

Pneumatophores — Specialized aerial roots that grow out from the sediment's surface to transport oxygen from the atmosphere to the roots.

Propagules — Part of a plant, such as a spore, seed, or cutting, used to reproduce itself.

Recruitment — A process where new plants populate an area through seed germination, seedling survivorship, and seedling growth.

Remediation — The process of reversing or stopping environmental damage.

Revegetation — The process of replanting and rebuilding the soil of land that has been impacted by natural or human-caused disturbances.

Salinity — The average concentration of dissolved salts in water.

Sediment — Naturally occurring material that is broken down by weathering and/or erosion and transported by wind, water, or ice. It can consist of rocks, boulders, sand, and/or the remains of plants and animals.

Soil — Sediments in which plants grow.

Sublethal — Not strong enough to kill but to cause effects that can lead to reduced health or survival.

Substrate — The surface or material where an organism lives, grows, or obtains its nourishment.

Subtidal zone — The area that sits behind the tidal zone below the low tide water line.

Subtropical — Geographic and climate zones located between the tropics and temperate zones.

Tropical — Geographic zone near the equator.

Transpiration — The loss of water through leaves.

Weather (-ing, -s, -ed) — A collection of physical, chemical, and microbial processes that alter and break down oil. It includes processes such as oil spreading, evaporation, dispersing, biodegradation, and photooxidation. These processes are influenced by many factors (e.g., type of oil being weathered, temperature, bacteria present).

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