POLLUTION IN THE OCEAN

Everything Flows Downhill

This Report Is Part Of The Ocean On The Edge Series Produced By The Aquarium Of The Pacific As Products Of Its National Conference—**Ocean On The Edge: Top Ocean Issues, May 2009**

Aquarium of the Pacific

Ocean on the Edge: Top Ocean Issues

Making Ocean Issues Come Alive for the Public

The conference brought together leading marine scientists and engineers, policy-makers, film-makers, exhibit designers, informal science educators, journalists and communicators to develop a portfolio of models for communicating major ocean issues to the public. This report is one of a series of reports from that conference. The reports include: *Coastal Hazards*, *Marine Ecosystems and Fisheries*, *Pollution in the Ocean*, and *Critical Condition: Ocean Health and Human Health*. There is also a series of briefer reports on film-making, kiosk messaging design, and communicating science to the public. All reports are available at www.aquariumofpacific.org

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This report is based very loosely on the report, "Pollution in the Ocean" published by the National Academies in their Ocean Science Series which formed the starting point of discussion at the Aquarium of the Pacific's Conference, "Ocean on the Edge: Top Ocean Issues" held in May 2009, at Long Beach Convention Center. Participants in the pollution workshop session included: Steve Weisberg, Larry Swanson, Jenny Jay, Mike Connor, Dallas Weaver, Karen Setty, James Wood, Elizabeth Keenan, and Dave Bader. The session was facilitated by Steve Weisberg and Larry Swanson. James Wood, Dave Bader and Elizabeth Keenan served as rapporteurs. The document was edited by Karen Setty and Jerry Schubel.

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Introduction

Pollution is the release of undesirable substances into the environment. A pollutant can be any substance whose nature, location, or quantity produces undesired change in the physical, chemical, or biological characteristics of air, water, or land.

Universal Dumping Ground

What if your neighbors dumped their trash into your backyard every day, and no one ever came to pick it up? It would probably get pretty smelly and you might not want to live there anymore. Our global backyard, the ocean serves as a place for all of us to work and play and harvest food. As in this scenario, though, it has been treated for many years as a waste receptacle. As human population has increased, so has our resource consumption and creation of waste products. Since everything flows downhill, much of our waste ends up in the ocean, the ultimate catchment.

At one time, people thought the ocean's vastness could dilute waste well enough to eliminate its impacts. However, we now known that some pollutants remain in the environment for years, decades, or even centuries, and can significantly alter marine ecosystems. The ocean is not able to convert, assimilate, or otherwise rid itself of all the waste we produce. Instead, it may be altered in ways that people never expected, limiting our ability to enjoy and reap the ocean's benefits.

Consequences of Pollution

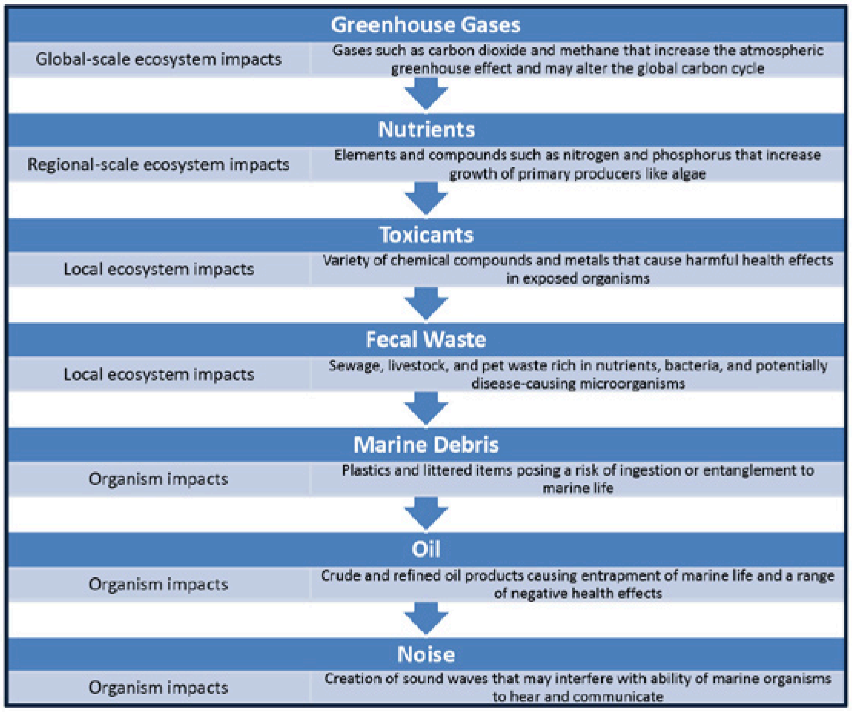
Ocean pollution was ignored for years, but in recent decades the consequences have become more visible. On an individual level, pollutants can cause detrimental effects to the activities, health, and survival of marine organisms and humans. On a larger scale, it threatens biodiversity, climate, and the preservation of some of the most treasured locations on the planet. Notwithstanding, pollution costs us billions in terms of tourism revenue, coastal economic activities, and lost resources.

What can we do?

The good news is that, because much pollution is caused by humans, we also have the ability to reduce or eliminate it. Through regular monitoring, established treatment methods, innovative science and technology, and environmentally aware policies, some pollution effects can be contained and reduced. Many important action steps have already been taken: "scrubbers" have been installed on coal power plants to reduce air pollutant emissions, advanced wastewater treatment plants have been built along the coasts to break down pollutants in sewage, use of some dangerous pollutants have been banned or restricted, and technologies to help prevent and treat oil spills are improving. Despite some successes in reversing the hazardous effects of pollution, much work remains to be done to protect the ocean's health for future generations.

Know your Pollutants?

What do you think of when you hear the word pollution? Many people envision a shorebird covered in black oil, or toxic green ooze being poured into a river. The reality is that many of the pollutants we think



about have a smaller impact on ocean health than others, some of which we cannot even see. Even too much of a seemingly harmless substance can have deleterious effects on the environment. For instance, small quantities of elemental phosphorus and nitrogen are vital to life for people, animals, aquatic plants, and food crops. When these nutrients are released into aquatic ecosystems in high concentrations, though, they can drastically over-fertilize algae. Because high nutrient levels are linked to algal overgrowth, dissolved oxygen reduction, dead zones, and fish kills, they are now recognized as leading pollutants in the world's coastal zones. CO2 is another example of an invisible substance that may have quite harmful systemic impacts on the ocean when present in excess.

Ocean pollutants vary widely, ranging from toxic chemicals to discarded toys to sound waves. They are grouped into different classes based on similar characteristics, sources, and effects. Different pollutant classes can also have different degrees or spatial scales of impact. For example, oil slicks are dangerous to local marine organisms, but usually don't affect life outside the spill area. Greenhouse gases, though, can result in widespread ecosystem changes that cover the globe, even in areas uninhabited by humans.

In addition to the major pollutant types described here, scientists are just beginning to study a new class of pollutants (called contaminants of emerging concern) that have unknown fates and effects in the environment. For example, pharmaceuticals containing hormones may be excreted in urine, bypass wastewater treatment systems, and end up the ocean, with the potential to affect fish reproduction and population dynamics. More research is needed to understand the risks posed by emerging contaminants, and therefore be able to manage their effects.

The sections that follow highlight some of the major known types of pollution, describing their consequences, sources, and some potential solutions. These have been addressed to varying degrees by management measures from region to region and country to country. Across all pollutant classes, though, research and management are ongoing, and awareness and vigilance remain a high priority. In addition, because it is a global problem, much work remains to bring together all of the neighbors who have a hand in creating or preventing ocean pollution.

Marine Debris

Storm drains in coastal regions usually funnel untreated water directly into the ocean. Karen Setty, Southern California Coastal Water Research Project.

Marine debris provides a stark visual reminder of people's impact on the ocean. While some marine debris comes from ocean-based sources such as cargo or fishing boats, a staggering 80% is estimated to come from land-based sources. Much of this trash is plastic and other man-made substances that people have left behind as litter. When it rains, litter is washed into storm drains, and funneled directly into rivers and coastal waters. Water going into storm drains is very rarely directed to a treatment plant or otherwise filtered to get out the trash and pollutants. Thus, much of the litter intentionally or unintentionally discarded into watershed drainage areas travels out to sea or ends up on beaches.

Marine debris can entrap and kill wildlife. NOAA

Consequences

Marine debris is both an aesthetic issue and a direct hazard to marine life. With undesirable changes in beach areas, the economies of coastal communities may be significantly affected by a loss in tourism revenue. People do not want to visit trash-covered beaches; therefore, coastal municipalities often have to spend extra money and resources on beach clean-ups. Debris with sharp edges also poses a hazard to beachgoers, swimmers, divers, and boaters.

In addition to aesthetic problems, ingestion of marine debris and entanglement in debris can harm sea birds, marine mammals, and other sea life. Entrapment and ingestion may lead to death if the animal is not able to move, consume food, and avoid predators. Many marine species are already threatened or endangered, and the effects of debris only make matters worse.

Sources

As the title "everything flows downhill" suggests, large amounts of trash can reach the ocean via drainage from an upland area, whether it was deposited near or miles away from the coast. As an interface between land

Household items and food and beverage containers are common types of marine debris. Shelley Moore, Southern California Coastal Water Research Project

and sea, beaches become a source of marine debris when discarded items are transported into the ocean via runoff and wind; however, beaches also become a receptor when debris released into ocean waters washes ashore.

In 1975, the National Academy of Sciences estimated that 6.4 million tons of debris were discarded into the ocean annually, a figure believed to have increased in subsequent years. The Ocean Conservancy's National Marine Debris Monitoring Project (NMDMP) conducted a 5-year study from 2001-2006 to identify the type and quantity of marine debris on beaches. This study, funded by the US Environmental Protection Agency (EPA), monitored debris in 21 coastal states, islands, and territories, and found that 48.8% of the debris found on coastlines came from land-based sources, followed by 33.4% general source debris, and 17.7% ocean-based debris. Notably, the top three items found overall were plastic straws, plastic beverage bottles, and plastic bags, much of which could have been recycled. Cigarette butts are another very common debris item found on land, in oceans, and on beaches.

Solutions

Marine debris is one form of ocean pollution that can be directly reduced by individual actions. To limit your personal production of trash, you can follow the three Rs: reduce, reuse, and recycle. Easy ways to reduce waste include purchasing products with less packaging, using a refillable water bottle, or bringing cloth grocery bags along when you shop. When you do create trash, be sure to put it in its place (a trash or recycling container) instead of littering. You can also help prevent marine debris by making certain that outdoor waste containers are closed securely, to keep trash from inadvertently blowing away or being targeted by scavenging animals. Another way to reduce ocean debris is to pick up litter when you see it around your home or in public places, and participate in community clean-

Extended Producer Responsibility

In 1991, Germany was experiencing a severe landfill shortage. Because packaging was responsible for 30% of the waste by weight and 50% by volume, the government passed the Ordinance on Avoidance of Packaging Waste. This law made industry responsible for handling packaging waste, in order to help reduce per capita consumption of packaging. This extended producer responsibility (EPR) approach, later coined the "Polluter Pays Principle" (Principle 16 of the Rio Declaration) at the 1992 United Nations Conference on Environment and Development, is gaining popularity in the US and other nations as well. In EPR programs, producers take responsibility for their products from creation through to disposal. This can include policies to reuse, buy-back, recycle, or produce energy from waste materials.

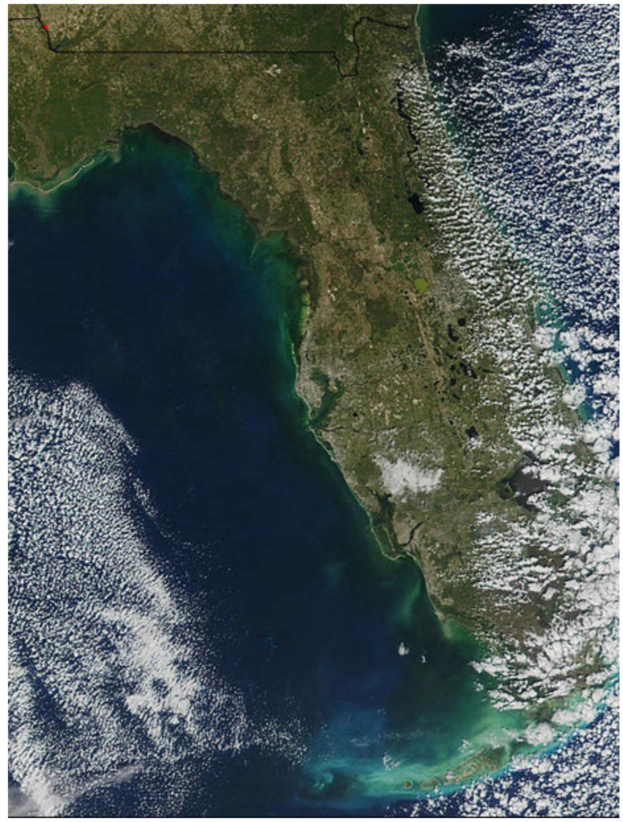
ups. If you see a friend litter, let them know what you have learned about how trash ends up in the ocean.

At a national and international level, there are many laws and programs in place to manage marine debris. In 1987, the US ratified Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL). This law prohibits at-sea disposal of plastic waste and mandates that ships be a certain distance from shore when dumping solid wastes. In 1998 Congress extended dumping regulations to all navigable waterways in the nation with the Marine Plastic Pollution Research and Control Act (MPPRCA).

The US EPA is in charge of monitoring and managing land-based pollution found on beaches and in waterways. In 1990, Congress authorized the EPA to assess the effectiveness of marine debris legislation and other methods to control debris. This led to development of the National Marine Debris Monitoring Program (NMDMP), intended to provide a better understanding of the status and trends in marine debris nationwide. Citizens and community groups in the US also take part in ocean cleanups ranging from a local to international scale. Despite research, monitoring, and removal programs, though, marine debris persists. Better solutions are needed to prevent the release of debris in the first place.

Alternative practices to reduce waste could come in the form of bans or fees for purchase of objects that are commonly thrown away, or provision of reusable alternatives to disposable items. Giving monetary value to items previously seen as waste can motivate litter-reducing behavior. The best example of this in the US is addition of a retail value to recyclable bottles and cans, paid out at the time of purchase and returned when the item is recycled. In many other countries, consumers must either use reusable shopping bags or pay for each plastic bag they take to carry their items. For example, stores in Ireland are required to charge for plastic bags while China has banned them altogether. The Swedish furniture company IKEA voluntarily began a plastic bag reduction program, which reduced plastic bag use at their stores by 95%. The international chain Costco does not issue bags, but instead provides customers with recycled boxes to transport their purchases.

Nutrients



An algal bloom along Florida's Gulf coastline.
Jacques Descloitres, NOAA.

Owing to nutrients released on land, for instance from livestock waste, household detergents, lawn care products, and crop fertilizers, oceans are over-fertilized in many coastal regions around the globe. Nutrients from these and other sources tend to get concentrated in storm runoff, rivers, and water treatment plant effluent. Much of this water flows downhill and eventually releases into lakes or oceans, leading to a localized area at the discharge point where nutrient concentrations are elevated. This imbalance may then instigate a string of negative effects in a process called "eutrophication".

Consequences

Eutrophication is an increase in the production of organic matter through algal blooms or aquatic plants. If too much nitrogen and phosphorus find their way into the ocean, these nutrients fertilize an explosive growth of algae. When the masses of algae die and sink to the bottom, their decomposition consumes most of the oxygen in the water. The resulting lack of oxygen can wipe out marine life across the entire affected area.

In the United States, over 80% of coastal bays and estuaries show signs of excess nutrient enrichment. A prime example is a large area off the coast of Louisiana in the Gulf of Mexico, where oxygen levels drop so low in the spring and summer that most fish and shellfish cannot survive, creating what is known as a "dead zone." Fish, shrimp, and crabs flee the area while less mobile bottom-dwellers such as snails, clams, and starfish may die. This phenomenon occurs yearly and is attributed to excess nutrients, mostly from fertilizer-rich runoff flowing through the Mississippi River basin and emptying into the Gulf.

Other negative effects of algal blooms and eutrophication can include poor aesthetics, odor, toxin-forming harmful algal blooms, fish kills, critical habitat destruction, altered food webs, and a decline in fisheries. Physically, masses of algae can clog water intake pipes and boat motors, resulting in higher maintenance costs. Blooms of algae and odors from decaying plants and animals similarly lessen the appeal of using a water body for recreation, such as swimming, wading, fishing, or kayaking. This may cause losses in tourism revenue and land values, and also create a new cost to clean up or maintain the area.

Algal blooms contribute to loss of endangered seagrass beds and coral reefs by clouding water, cutting off sunlight, and essentially smothering coral. Some algae blooms produce neurotoxins that can sicken and kill marine animals and humans. Researchers are still working to understand precisely how excess nutrient loading may be related to toxin production. Just one outbreak of harmful algae can cost millions of dollars in healthcare needs and lost seafood revenues.

Sources and Mechanisms

The National Research Council report Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution (2000) concluded that the key to addressing coastal nutrient problems is understanding where nutrients come from in our local watersheds. The primary culprit affecting nutrient pollution is runoff of dissolved nitrogen and phosphorus from fertilizers applied to agricultural fields, golf courses, and lawns. Most of the remaining nutrient inputs come from sewage treatment plant discharges, septic system leaks, industrial discharges, and atmospheric deposition. Airborne nutrients come from nitrogen released by the combustion of fossil fuels or from fertilizers or manure vapors. Other sources include animal waste, pet waste, and household wastewater.

Nutrient-rich waters can reach the coastal ocean through several mechanisms. Nutrients washed into small streams and then into larger rivers are not easily dissipated from the system. Thus, nutrient inputs from an area far away from the coast can still contribute to nutrient loading in the ocean, as is the case for the Mississippi River basin, which drains about 40% of the contiguous US. During the last half of the 20th century, the amount of nitrogen collected and discharged by the Mississippi River has tripled.

Fertilizers applied to land can also soak into the ground when it rains or they are irrigated, infiltrating groundwater aquifers.

The tributaries of the Mississippi River carry nutrients from far inland to a concentrated area at the river's mouth in the Gulf of Mexico. US Commission on Ocean Policy. An Ocean Blueprint for the 21st Century. Final Report. Washington, DC, 2004.

Depending on the position of the aquifer, groundwater may then flow into to the coastal ocean. In several regions of the world (California and Oregon for example), natural ocean currents drive upwelling of dense, cool, and nutrient-rich water towards the ocean surface, replacing the warm, nutrient-depleted surface water. Nutrients can also be deposited from the air, either into waterways that flow to the ocean or the ocean surface itself.

Solutions

Nutrient inputs can be drastically reduced by improvements in agricultural practices, reductions in atmospheric sources of nitrogen, and improved treatment of municipal wastewater. A measure as simple as leaving a grass buffer strip around agricultural fields can cut nutrient discharge by a large degree. Many other best management practices (BMPs) have been documented that reduce pollution in runoff from agricultural operations, residential and business complexes, and roads and parking lots. Source reductions at a local level are generally less costly than end-of-pipe treatment mechanisms.

There are many ways that you can help to address nutrient pollution, for example:

- Keep pollutants out of storm drains - You can prevent pollutants commonly found in and around your home from reaching a storm drain and entering the ocean. Always pick up pet waste and wash your car either on your lawn, so that runoff is soaked up by the grass, or at a car wash. Car washes either recycle their water on-site or funnel it to a treatment plant instead of storm drains. Household products should never be disposed of by dumping them in a storm drain.

- Use permeable surfaces rather than pavement - The impermeable surfaces in urban environments block water from naturally seeping into the ground where it would be slowly released to streams or seep into groundwater aquifers. Instead, rainwater picks up pollutants in urban environments and moves very quickly through man-made storm drains flowing directly into the ocean. Permeable surfaces like grass, gravel, or certain types of pavement allow rain water to seep into the ground, filtering out contaminants and replenishing local water supplies.

- Re-direct stormwater to irrigate your plants - Ironically, naturally-purified rain water remains largely unused; it is collected by a system of storm drains and sent offsite. Instead of letting this water run into the ocean, it could be used to irrigate gardens and planters onsite.

Permeable pavement allows water to soak onto the ground onsite, rather than running off into storm drains that go to the ocean. Karen Setty

- Capture gray water to irrigate plants - Gray water (wastewater that does not contain sewage) from sinks and showers is rich in nutrients due to the presence of detergents and food waste. Some homes and businesses capture and reuse gray water onsite, rather than letting it escape down the drain.

- Plant native vegetation - Plants that are adapted to the soil and climate of your area will require very little, if any, fertilizer or watering. This minimizes fertilizer runoff and reduces water runoff.

- Buy low-phosphate detergents - Household laundry and dishwashing detergents are historically a large source of nutrient pollution in the US. Many states have implemented laws to reduce the amount of phosphates used in these products, leading to the availability of more environmentally-friendly alternatives.

According to Clean Coastal Waters, a national strategy with involvement from federal, state, and local agencies, plus academic and research institutions is necessary to effectively combat nutrient pollution. Central to this strategy is creation of long-term monitoring and assessment programs. These would help managers to (1) establish what the “baseline” nutrient levels should be; (2) determine where nutrient over-enrichment is most acute; and (3) measure whether or not actions to reduce nutrient levels have been effective. The report recommends that a national assessment survey be conducted every 10 years to determine the extent of nutrient problems and the effectiveness of efforts to combat them.

CO2

As with nutrients, greenhouse gases such as carbon dioxide (CO2) are being released into the environment at an undesirable rate. Though CO2 is not what we would think of as a traditional pollutant, being necessary to plant life, when present in excess it can disrupt the natural carbon cycle and create large-scale systemic changes that impact many forms of life on earth. Because it affects the entire planet (even untouched wilderness areas), CO2 is a pollutant of increasing global concern. With rising awareness of this issue in recent years, many have learned the story about how greenhouse gases can induce large-scale climate change effects; however, a lesser-known story is playing out in the world's oceans. In a process called "ocean acidification", increased levels of dissolved CO2 in the atmosphere can change the pH of ocean water, disrupting the natural ecosystem balance that sustains marine life.

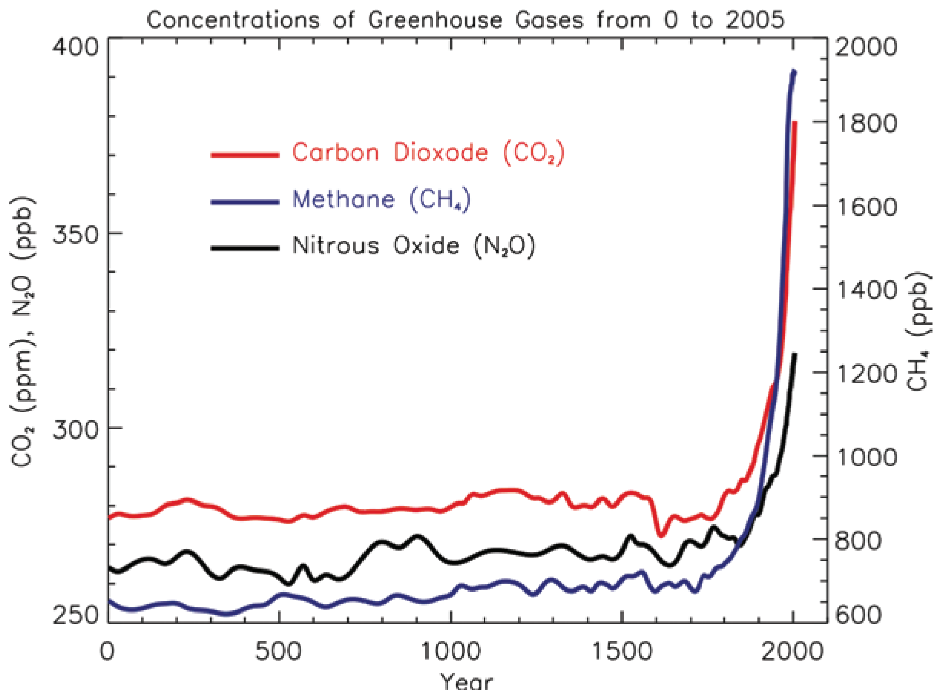
Consequences

As a result of the increase in greenhouse gas emissions, sea ice is melting more rapidly, sea levels are rising, and sea surface temperatures are going up in certain parts of the world. All living organisms require a specific range of environmental conditions to survive, and some delicate species, such as coral, may not be able to adapt to even minute changes in ocean temperature and depth. An increase in sea surface temperatures of just 1-3 degrees Celsius is enough to cause coral to expel the symbiotic algae that allow them to survive. This phenomenon is called coral bleaching, and threatens many reefs around the world.

Sea level rise can be attributed to melting glaciers, mostly from Greenland and the Antarctic, and from the thermal expansion of seawater as its temperature increases. Rising waters threaten to erode low lying coastal marine habitats such as salt marshes and mangrove swamps. These unique marine habitats are home to many endangered species, and are already under pressure from human encroachment and other types of pollution.

Changing weather patterns may also impact the migration cycles and breeding success of some marine fish and seabirds, while melting sea ice fragments critical habitat. The extent and continuity of sea ice is declining at a fast rate at both poles as a result of global warming, causing distress to populations of wildlife like polar bears, walruses, and narwhals. Polar bears depend on thick, extensive ice sheets to hunt, raise their young, and protect themselves from predators.

Every year the ocean absorbs a good deal of the excess CO2 in the atmosphere, which helps to mitigate climate impacts. While this process is helpful in some ways, it is dangerous in others. As CO2 dissolves in ocean water, it forms carbonic acid, which increases the concentration of free hydrogen ions and thus lowers ocean pH. Acidic sea water is



Human activities during the twentieth century drastically influenced the amount of greenhouse gases to the atmosphere. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

known to impair the ability of many marine organisms to build their shells and skeletal structure. Though well understood in a laboratory setting, the systemic effects of ocean acidification are still largely unknown. They pose a threat not only to marine life, but also to the fish and shellfish industries, a major source of human nutrition.

Sources and Mechanisms

Human reliance on fossil fuels is largely to blame for the unnatural increase in greenhouse gases. When we burn oil, gas, and coal to produce electricity and run machinery, we add massive amounts of CO2 to the environment. Some other sources of greenhouse gases include methane release from livestock and rice paddy farming, landfill emissions, and the use of certain chemicals for refrigeration. Deforestation further exacerbates the problem by reducing the ability of landscapes to sequester greenhouse gases.

Solutions

Individual actions to reduce your CO2 footprint include using public transportation, carpooling, walking, or riding your bike instead of taking the car. Another way to reduce your personal contribution to CO2 production is by utilizing alternative energy sources that do not require fossil fuels, such as solar panels. Installing better insulation, programmable thermostats, energy-efficient appliances, and compact fluorescent light bulbs in your home can also cut down on your energy consumption. If many people in your community choose to take these and other small steps, the savings in CO2 emissions will quickly add up.

While individual lifestyle changes help to reduce the problem, change at a larger scale requires the cooperation of businesses and multiple levels of government. The 1992 United Nations Framework Convention on Climate Change kicked off international government efforts to address climate change. The Berlin Mandate in 1995 recognized that emission targets needed to be stricter and called for further negotiations. This led to the 1997 Kyoto Protocol. Unfortunately, the Kyoto Protocol did not gain the required level of participation until 2004, and was not put into effect until 2005. With the implementation of the Protocol, 166 countries have now agreed to take steps to lower their nationwide greenhouse gas emissions. In addition to the Kyoto targets, many countries, regions, and even large corporations are implementing programs like emissions trading, tax incentives, and automobile efficiency standards for reducing their contribution to CO_2 emissions.

Bleached Coral Reefs Closed to Tourists

In 2010, the Country of Malaysia officially closed some of its world-famous coral reefs. Twelve sites that annually attract half a million tourists from around the world were announced off-limits to divers and snorkelers from July to October. The decision was made after almost 90% of the coral started turning white as a result of water temperature increases. From March to July, about 50 different organizations and individuals reported signs of coral bleaching in the Coral Triangle region, the tropical marine waters of Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands and Timor-Leste, home to at least 500 species of reef-building corals. The US National Oceanic and Atmospheric Administration's Coral Reef Watch described this incident as the worst of its kind since 1997-1998, when 16% of the world's coral reefs were decimated. Officials hope that this closure will give the bleached coral time to regenerate.

Toxicants

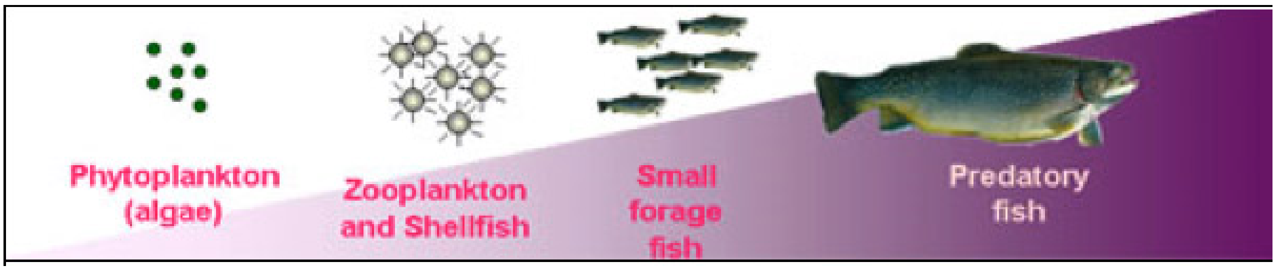
The Clean Water Act, passed in 1972, was extremely successful at reducing toxic pollutant discharges from point sources into US waterways. Prior to the implementation of these regulations, many coastal areas were polluted by toxic chemicals that caused (among other issues) ulcers, fin erosion, tumors and diseases in fish. These problems have widely improved in areas where wastewater treatment has been implemented, but regulation of toxic chemicals still varies among different regions of the world. In addition, other diffuse sources are not as well controlled. Residual toxicants may remain in the environment even after their use and discharge is curtailed. The dangers posed by these "legacy" pollutants can take decades or centuries to truly resolve. Finally, new chemicals and chemical constituents are continuously being developed and put on the market, which may pose a risk to marine life and humans.

Consequences

Toxic chemicals can have either acute or sublethal effects in exposed organisms. Sublethal effects include a range of impairments to growth, development, or reproduction, whereas acute toxicity simply results in death. Certain toxic contaminants will bioaccumulate, posing a different type of health threat. These substances build up in fatty tissue rather than being excreted from the body, and can even be passed to offspring. The decimation of brown pelican populations due to release of DDT in the environment, its bioaccumulation, and the resultant eggshell thinning is a good example of the harmful potential of toxic pollutants.

Toxic substances that are regulated in aquatic environments have generally been well-described by scientists; however, they are only part of the pollution picture. Thousands of other chemicals have been developed for use in industry, agriculture, and household products, some of which are transformed or broken down into other chemical forms in the environment. In general, newly discovered substances lack information about their toxicity in aquatic ecosystems; depending on their intended use, toxicity testing is usually limited to relevant applications like skin or food crops. In addition, the range of their uses, transport pathways, and eventual fates is not usually well-documented. Advanced technology and more sensitive sampling techniques developed during recent years have led scientists to discover the presence of many compounds in the marine waters, like prescription drugs, ingredients from personal care products, and flame retardant chemicals used to coat furniture. The presence, extent, and effects of these "contaminants of emerging concern" are only beginning to be investigated.

One type of emerging contaminant is endocrine disruptors. Endocrine disruptors are substances that act like hormones in the bodies of human and animals, thus interfering with normal activity in the endocrine system. Many detergents, pesticides, plastics, and varnishes, for example, are derived from or contain endocrine disrupting chemicals. Exposure to sufficient quantities of these chemicals could theoretically cause unnatural developmental and reproductive changes. In some controlled experiments, they were shown to alter sex determination and dynamics of fish populations. It is unclear, though, whether commonly found environmental levels of endocrine disruptors are high enough to induce such effects.



Concentrations of bioaccumulative contaminants are generally highest in large predatory fish, and can be over a million-fold hither than levels in the surrounding water. US Environmental Protection Agency.

Sources and Mechanisms

Many toxic chemicals are already well-controlled by legislation and industry practices. Those who discharge chemicals into waterways must adhere to monitoring and quality standards set forth in their National Pollution Discharge Elimination System (NPDES) permits. As pollution from point sources (e.g., discharge pipes) becomes better controlled, though, the impact of other nonpoint or diffuse sources (e.g., stormwater, atmospheric deposition) becomes relatively greater by comparison. For example, rain water often picks up small amounts of toxic chemicals from agricultural fields, lawns, roads, and parking lots and carries them directly to the ocean through storm drains. They may become concentrated at the river mouth or point of stormwater discharge as contaminants are collected from around the watershed. Pharmaceutical, industrial, agricultural, personal care, household cleaning, gardening, and automotive products and wastes still regularly end up in coastal waters.

Contaminants can also reach the ocean through atmospheric deposition. For example, mercury is released into the air when large quantities of coal and other fuels containing trace amounts of the element are burned, as well as from the incineration of mercury-containing medical wastes. It is then washed out of the atmosphere and rains down onto lakes, rivers, and the ocean. Once deposited in ocean sediments, mercury enters a complex cycling pathway. Of greatest concern, inorganic mercury may be converted into methylmercury, the most biologically available and toxic form of the element. Ultimately, mercury ends up in sediments, fish, and other animals, or volatilizes back into the atmosphere.

Toxic contaminants like methylmercury that are more soluble in oils and fatty tissue than in water will tend to build up (bioaccumulate) in the tissues of fish and shellfish and become more concentrated up through the food chain. Predators such as tuna, swordfish, osprey, and pelicans usually contain a higher amount of these chemicals in their bodies than animals lower on the food chain such as zooplankton, mullet, and carp. Whenever humans eat seafood, they may also be consuming bioaccumulated contaminants. Through this pathway, toxic pollution in the ocean can affect even people living far away from the coast. Seafood consumption advisories exist to spread awareness of this problem and limit exposure to contaminants in seafood, especially in sensitive populations like unborn babies and breastfeeding infants.

Depending on a chemical's properties, it may be reduced or transformed naturally over time by physical, chemical, or biological processes such as bacterial metabolism. Other contaminants can remain in the oceans for a very long time. Among the most troubling of these are heavy metals, such as mercury and cadmium, and "persistent organic pollutants," such as PCBs, dioxin, and DDT, which linger in marine sediments for decades. Once the environmental concerns associated with these chemicals were recognized, many of them were banned or their usage restricted. Unfortunately, many times management actions are not taken until the chemical is already widespread in the environment and effects are already being seen.

Solutions

Source reduction, or preventing toxic chemicals from being released into the environment, is by far the best way to control them. Once contaminants are released into the environment, it becomes much more difficult to contain or remove them. Dredging up contaminated sediments in areas where they settle out and concentrate in bays and estuaries and around historic outfalls is one of the few options available. However, the National Research Council report Sediment Dredging at Superfund Megasites: Assessing the Effectiveness (2007) concludes that, based on available evidence, dredging is not always effective at decreasing environmental and health risks.

Technical difficulties with dredging are numerous. Underwater obstacles can prevent dredging equipment from accessing sediments, while dredging can also uncover and re-suspend buried contaminants, adding to the amount of pollution people and animals are exposed to, at least in the short term. Additionally, suspended sediment in the water can block sunlight, and impair filter-feeding organisms. Dredging operations can also be expensive, and brings up the issue of how to safely dispose of the contaminated sediments. Site-specific conditions are usually considered when determining whether to go forward with a dredging project, and monitoring conditions before, during, and after cleanups is recommended to determine their effectiveness. Better pollution control can sometimes be achieved by leaving the system undisturbed and tracking natural attenuation.

Fecal Waste

A warning sign posted at Avalon Beach in southern California. John Griffith, Southern California Coastal Research Project.

It is estimated that America's coastal waters receive nearly 8,000 gallons of treated municipal sewage each day. This wastewater is first treated to remove solid waste and organic material, at a minimum, and outfalls are well-monitored to detect any adverse impacts. In some locations, wastewater discharge is treated to an even higher degree so that it can be reused for groundwater recharge or irrigation. These steps largely address the issue of fecal waste in US marine waters. Still, many communities in both rural areas and large cities have a combined sewer overflow (CSO) system in place to keep the treatment plant from backing up when it rains heavily. This system allows untreated sewage to spill over into storm drains, which discharge water without the benefit of treatment. Accidental sewage spills and leaking pipes or household septic tanks are also fairly common near coastlines. Internationally, disposal of raw sewage into the ocean is common in developing nations, and remains a major pollution issue for both environmental and public health reasons.

Consequences

Raw sewage collected from toilets and other household wastewater contains everything from infectious bacteria and viruses to toxic chemicals and nutrients. Because some of these pollutant types are described elsewhere, this discussion will focus on the fecal pollution impacts related to pathogens. Direct exposure to sewage can cause rashes, earaches, stomachaches, pink eye, diarrhea, vomiting, respiratory infections, hepatitis, encephalitis, and typhoid. In the US alone, approximately 1.8-3.5 million illnesses are caused each year by swimming in sewage-contaminated water; an estimated additional 500,000 illnesses result from drinking contaminated water. Waterborne diseases are a leading cause of death in developing countries, often owing to inadequate sanitation and water treatment infrastructure.

Floating Cities
Holding 3,000 to 7,000 passengers on average, cruise ships are akin to floating cities. Though they advertise fun in the sun and clear waters, there is a darker side to the ships: production of waste, often in sensitive marine habitats. The US Environmental Protection Agency estimated that in one week a 3000-passenger cruise ship generates about 210,000 gallons of sewage, 1,000,000 gallons of gray water (shower, sink, and dishwashing water), 37,000 gallons of oily bilge water, more than 8 tons of solid waste, millions of gallons of ballast water containing potential invasive species, and toxic wastes from dry cleaning and photo-processing laboratories. While cities on land are held to strict standards in terms of wastewater discharge and solid waste management, cruise ships vary widely in their adoption of technology to process wastewater before it is discharged to the ocean. Many discharge raw sewage, containing human pathogens, directly into the marine environment.

Fecal pollution has heavy economic implications as well. The presence of pathogens affects the beneficial uses of a water body, such as its ability to be used for water contact recreation like boating and swimming. High bacteria levels in coastal waters necessitate beach and shellfish bed closures, which in turn harm the local economy. Beaches that are notorious for poor water quality may lose their appeal over time, such that fewer tourist dollars are brought into those communities. Illnesses caused by swimming also result in higher health care costs and lost work days. For example, it is estimated that over 100 million people visit southern California beaches annually, contributing about $9 billion to the local economy. The cost of healthcare for gastrointestinal illness caused by swimming at contaminated beaches is around $20-50 million. Contamination of fish and shellfish is another economic downfall. US medical costs associated with eating sewage-contaminated shellfish range from $2.5-22 million each year.

Sources and Mechanisms

Most raw sewage in the US is sent to be processed in a wastewater treatment plant prior to being discharged into waterways. Areas without centralized treatment services must use alternatives like septic tanks or septic mounds. If improperly maintained, these smaller systems can contaminant groundwater, which may flow downhill into surface or coastal waters. Several small- to large-scale sewage spills and leaks also occur each year at the larger facilities due to aging infrastructure or accidents. While fecal contamination in marine waters often dissipates within a few days, spill sites on beach sand or soil can harbor and sustain bacteria and other pathogens for longer periods of time, providing a more continuous source. Fecal waste left on land by livestock, pets, and wildlife can also contaminate groundwater, streams, lakes, beaches, and the ocean, when they are washed into waterways by rain. Confined animal feeding operations that concentrate animal waste onsite and allow it to spill into local waterways are another large source of fecal waste to US waterways.

Combined sewer systems, which collect municipal sewage and stormwater runoff in the same piping network, serve approximately 40 million people in the US. Overflows built into these systems prevent sewage backup into homes and streets by releasing excessive flows into nearby water bodies. Though no longer used in new construction, many combined sewers were built before end-of-pipe wastewater treatment plants were conceptualized. They are still operated by older cities, especially in the northeast and Great Lakes region, and are a major cause of fecal waste release. With growing urban populations and the high expense of infrastructure renovations, this problem does not have an easy answer.

Solutions

Addressing fecal contamination is of utmost importance to preserving environmental and public health. In some cases, upgrades to old treatment systems can radically reduce overflows and spills. Funding is needed to update and improve infrastructure in many places around the country. Although costly, many cities are working on separating sewers for wastewater and storm runoff. Some cities have created storage facilities for the overflow and then return the overflow water to the system after the excess runoff water has decreased. More frequent monitoring and system maintenance, for example removing blockages and replacing broken pipes, can help as well by preventing accidental releases.

One problem with current beach monitoring programs is the length of time it takes to test water samples, which typically involves culturing bacteria overnight. Faster diagnostic tools for rapidly measuring indicators of fecal pollution, and tracking the sources of sewage contamination, are currently being developed by scientists. These take advantage of faster technology to detect cellular components like genetic material from microorganisms. Faster and more accurate monitoring methods will help to ensure that beaches are closed during the times of greatest risk. They will also allow environmental managers to track, identify, and address sources of fecal contamination.

Individuals can also take action to prevent fecal pollution. Importantly, pet owners should always take responsibility for picking up pet waste, and properly disposing of it in a toilet or trash receptacle according to the laws in your local community. Poorly maintained trash, household waste, or unattended pet food can also attract concentrated areas of fecal waste from wildlife. Maintaining household septic systems and reporting any suspected spills or leaks in sewage lines are other ways to help control fecal pollution sources.

In developing countries, much work remains to be done to install improved sanitation and wastewater treatment infrastructure. In the meantime, a number of international volunteer organizations are working to educate individuals about how to avoid exposure to disease-causing fecal contamination, and how to treat potentially fatal waterborne diseases using the available local resources. Anyone can get involved in supporting these organizations locally through fundraising and advocacy.

Oil

Oil is one of the most visible and commonly discussed types of ocean pollution. Because the effects of oil spills are visually dramatic, they are often widely publicized. This can lead to a distorted public perception of the issue. In reality, oil spills are relatively infrequent, given the extent of control measures put into place over the last few decades. In addition, an even greater amount of oil in the ocean comes from nonpoint land-based runoff and natural seeps.

Consequences

Oil pollution affects ocean ecosystems most significantly by endangering wildlife. Floating on top of the water's surface, oil coats the fur and feathers of marine animals. Oil-soaked plumage makes birds less buoyant, reduces their insulation, and increases their vulnerability to temperature fluctuations. It also impairs flight ability such that they cannot forage for food or escape from predators. When birds attempt to clean off their feathers, they often ingest the oil, causing kidney damage, altered liver function, and digestive tract irritation. This may lead to death through organ failure, impaired digestion, or dehydration. In a similar way, marine mammals like otters and seals are left unable to regulate body temperature when their insulating fur is coated in oil, leading to hypothermia. Most animals covered in oil do not survive without human intervention.

Chronic exposure to small amounts of crude oil or other petroleum products can produce toxic effects in many marine organisms, depending on the persistence and biological availability of specific compounds in the oil. Examples include impairment of feeding, growth, development, and reproduction, as well as increased susceptibility to disease.

In addition, oil floating on top of seawater reduces light penetration, limiting the photosynthetic activities of the marine plants and phytoplankton that form the base of the ecosystem. This in turn affects sources of nutrition for other organisms higher on the food chain. Depending on the location and extent of the oil pollution, these acute effects might be resolved quickly with minimal losses, or have longer-term population and community level impacts. Spilled oil also spreads onto beaches, marring the landscape and inhibiting recreational uses like bathing and kayaking. Substances evaporating from oil can irritate the skin, eyes, and respiratory systems of humans.

Sources and Mechanisms

Oil in the ocean includes crude oil, refined petroleum products (such as gasoline or diesel fuel), and oily refuse. The National Research Council report Oil in the Sea III: Inputs, Fates, and Effects (2003) developed a new methodology for estimating oil inputs to the sea from both natural and human sources. They found that the main natural source of oil in the ocean is seepage, where crude oil oozes into the water from geologic formations beneath the sea floor. These seeps account for about 60% of the total oil in North American waters and 45% worldwide. The remaining oil found in the ocean is attributed to human input.

Oil inputs from human activities primarily originate from: (1) petroleum use, including tanker spills including runoff from highways and discharges from recreational vehicles; (2) petroleum transportation; and (3) petroleum extraction, exploration, and production activities. These sources are further described below:

- Petroleum Use - Surprisingly, oil from individual cars, boats, lawn mowers, jet skis, marine vessels, and airplanes contributes the most oil pollution to the ocean. This category includes oil slicks transported from roadways and parking lots through runoff, oil dumped into storm drains, and jettisoned aircraft fuel.

- Petroleum Transport - Although the amount of oil transported by sea continues to rise, transportation-related spills are becoming rarer. Most recently in 1989, the Exxon Valdez, a single hulled oil tanker, spilled some 34,000 tons of crude oil owing to a navigational error. The event harmed massive numbers of marine animals and birds, and cost over $2.5 billion to clean up.

- Petroleum Extraction, Exploration, and Production - Historically, oil and gas exploration and petroleum production spills have been significant sources of oil in the ocean. Most recently, the Deepwater Horizon oil spill, caused by a drilling rig explosion in April 2010, released tens of thousands of barrels of crude oil per day into the Gulf of Mexico off the coast of Louisiana for just over 100 days, covering an area of at least 2,500 square miles. It is now considered to be the largest marine oil spill in history, though the entire extent of impacts remains to be seen.

Solutions

The best way to reduce the effects of oil in the ocean is to control and reduce the sources. This means addressing the three main types of oil inputs from human activities.

- Petroleum Use - Limiting use of petroleum products can also reduce the amount of oil pollution that ends up in the ocean. The rising prices of petroleum products have led many to begin conserving and seeking alternative fuel sources like solar, electric, wind, hydrogen, or biofuels. Conserving energy and using alternative forms of transportation

A female King Eider covered in oil. Paul Flint, US Fish & Wildlife Service.

and are other ways to minimize society's need for petroleum products and reduce the associated risk of spills and accidents.

When you must use petroleum products, there are steps you can take to control their release to the environment. Oil and other household products should never be dumped in storm drains. When you have the oil changed on your car, it is important to go to a facility that can safely dispose of the oil, or use a drip pan to catch oil if you change it yourself. Stormwater management measures like rain gardens and pervious pavement can help reduce the runoff of oil and other pollutants from your property.

Advances in technology are also helping to reduce release of oil from motor vehicles. For example, some recreational vehicles such as outboard motorboats previously used inefficient "two-stroke engines" that discharged significant amounts of oil into coastal environments. While still being used in many parts of the world today, they have begun to be replaced with more efficient engines in the US since 1990 when the United States Environmental Protection Agency (US EPA) regulated "non-road engines" under the Clean Air Act.

- Transport Accidents - The US Oil Pollution Act was passed in response to the Exxon Valdez disaster, and required new oil tankers to be fitted with a double hull. Most modern tankers have double hull or segregated tank arrangements that dramatically reduce spillage in case of a shipwreck. Transportation spills now account for less than 4% of the total petroleum released in North American waters and less than 13% worldwide.

- Oil Production Accidents - During the past decade improved production technology, more effective regulations, and safety training of personnel have dramatically reduced both blowouts and daily operational spills. Today, accidental spills from oil platforms represent only about 1% of petroleum discharged in North American waters and about 3% worldwide.

Once released, there are no easy ways to address an oil spill. They can take months or even years to clean up. Booms can be used to contain oil spills, and available methods for removing oil from the water include the use of biological agents that help break it down, absorbent materials, and gelling agents that make oil easier to skim from the surface. High-pressure water hoses are used to wash oil-covered beaches. Animals covered in oil must be cleaned off manually.

The National Research Council report Understanding Oil Spill Dispersants: Efficacy and Effects (2005) assesses the use of dispersants, a group of chemicals that act like dish detergent to help disperse and dilute large oil spills by mixing with the surrounding waters. In semi-enclosed coastal areas, the oil may not be diluted sufficiently by dispersants to reduce its toxicity to marine life. In addition, dispersants themselves may have toxic effects. The decision about which oil spill cleanup methods to use is usually very site-specific. In biologically sensitive areas, sometimes observing the situation and waiting for natural attenuation is the best approach.

Noise

A 2005 mass stranding event in North Carolina may have been linked to sonar use. National Marine Fisheries Service Southeast Fisheries Science Center.

For the 119 species of marine mammals, as well as some other aquatic species, sound is a primary sensory means of communicating, navigating, and foraging. The ocean environment has always included an abundance of natural noises, such as the sounds generated by rain, waves, earthquakes, and other animals. However, a growing number of ships, oil exploration activities, and military and civilian sonar use add to the ambient noise in the oceanic environment.

Consequences

The large scale consequences of noise pollution are not well-understood, but evidence points to adverse effects on some marine mammals. Noise can have a detrimental effect on animals by causing stress, interfering with the ability to detect prey and avoid predators, and impairing communication needed for reproduction and navigation. Noise may also force animals into smaller areas of habitat. Exposure to high levels of noise could even lead to permanent hearing loss.

In one well-documented incident in March 2000, fourteen beaked whales and two minke whales suffered traumatic injuries and stranded themselves in the Bahamas after naval sonar was used nearby. Six of the beaked whales died. Autopsies revealed bleeding in the inner ears of three of the beached whales and around the brain of a fourth. The US Navy and the National Marine Fisheries Service (NMFS) reported that the extended use of their mid-range sonar had likely set off a series of events that culminated in internal bleeding. The exact mechanism as to how this happened remains unclear.

Sources and Mechanisms

Human-generated sound in the ocean comes from a variety of sources, including commercial ship traffic, oil exploration and production, construction, acoustic research, and sonar use. Two specific examples where noise is intentionally produced are sound wave use by marine researchers to investigate the properties of seawater, and air gun use to characterize rock underlying the sea floor in search of new hydrocarbon reserves. Noise is also an unintentional by-product of coastal and marine construction, ship propellers, mineral extraction, and aircraft flights. Mine-hunting sonars, fish finders, some oceanographic systems (such as acoustic Doppler current profilers), and high-resolution seafloor mapping devices can create noise at a higher frequency. Researchers estimate that noise pollution is on the rise, though data quantifying noise sources is limited and establishment of large-scale trends is not yet possible.

Although the most recent attention regarding noise pollution focused on the use of naval sonar, the effect of shipping lanes on marine animals poses a greater concern. Low frequency noise emitted from ships can disrupt communication between animals in the ocean. Unfortunately the mechanisms of these effects are not well studied. Limited research suggests that as background noise increases, North American right whales increase the amplitude of their calls in order to be heard, using more energy and potentially alerting predators in the process. Background noise may also limit their communication range, which normally covers thousands of miles, and garble the messages.

Solutions

The National Research Council report Ocean Noise and Marine Mammals (2003) concludes that the impact of human noise on marine mammals is significant enough to warrant concern, yet many fundamental questions remain unanswered. While the whale stranding event presents a tangible and alarming picture of the potential effects of high-energy mid-frequency sonar, observations of the effects of most types of ocean noise on marine mammals and other aquatic organisms are quite limited. Most existing data consist of short-term observations of marine mammal responses to human activity.

The need to establish baseline knowledge and conduct research to improve scientific understanding of noise pollution effects on marine life is emphasized in the National Research Council report Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects (2005). The extent, trends, and potential solutions to noise pollution problems would be clarified by continuous long-term monitoring of changes in both ocean noise and marine mammal behavior. Monitoring over a broad range of frequencies should be initiated in coastal areas, specifically marine mammal migration paths, foraging areas, and breeding grounds.

On an individual level, citizens can advocate for marine mammal protection laws that address the issue of noise. Marine sanctuaries, for example, can be protected from the impacts of noise by limiting exploration in biologically important zones, implementing noise mitigation efforts, and re-routing major shipping channels away from sensitive marine habitat. Keeping boat motors well-tuned and performing regular maintenance like clearing debris from the propeller and repairing bearings and loose plates can also help reduce noise output.

Conclusions

Discussing ocean pollution brings up a diffuse, complex series of issues. Nevertheless, some pollution problems can and have been successfully addressed. Since the network of oceans on this planet is interconnected, the pollution issue will only truly be solved by consistent improvement in areas across the globe. Knowing that the growing human population has intensified the problem of ocean pollution, it is clear that we each need to get involved in contributing to the solution. It will require a high degree of participation and collaboration at the individual, family, community, industry, and government levels.

Efforts at all of these levels become more effective with elevated public awareness about pollution sources and impacts. Just by reading about ocean pollution, you become better equipped to prevent it. Once you are aware of the problem, participation in local volunteer organization is a great way to start taking action. You can help communicate ocean pollution issues to your friends and family, and also encourage legislators to enact regulations that address ocean pollution. Continued public support is vital for research, monitoring, and further development of pollution reduction strategies and technologies.

Appendix A

Suggested Readings:

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