Investigating the Environmental Impacts of Underwater Tunneling

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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1. Introduction

For thousands of years, humans have created bridges. Prehistoric peoples made travel easier by simply laying logs across streams and rivers. Romans built bridges to facilitate military campaigns, while modern civilizations construct bridges to move people and goods. However, it was not until the early 1800's that humans had the idea to tunnel under these waterways. In 1843, engineers completed the Thames tunnel, which was the first tunnel ever constructed under a navigable river (Willis, 2018). Steel reinforced concrete wasn't available at the time to support the massive weight of soil and water, so they had to rely on other methods. Sadly, during the construction in 1827 and 1828, the tunnel partially collapsed, leading to the deaths of six workers (Kuklewicz, 2021). Reinforcing steel bars embedded in concrete emerged during the mid-1800s and revolutionized the construction process (Allan and Iano, 2004). The introduction of rebar allowed for the creation of larger, more complex, and more durable structures. Since the introduction of the first reinforcing bar specifications in 1910, standards for rebar technology have been continuously updated to keep up with its rapid development (Lane and Kleinhans, 2016). The introduction of rebar and the updating of material standards have made it possible for underwater tunnels to bear the weight of water and enable safe passage for people and goods.

As humans begin constructing more underwater tunnels, their environmental impacts become more important. This paper aims to answer the question of whether underwater tunneling has an adverse effect on the environment, namely in areas located within close proximity to the construction site. The paper will begin with a brief explanation of underwater tunneling, followed by the methods and frameworks used to construct the argument. The results section contains an analysis and discussion to elaborate upon the data presented. The paper will end with a conclusion to summarize the ideas discussed throughout.

Brief Overview of Underwater Tunnels

As the name implies, an underwater tunnel is a tunnel that is built under a body a water with the purpose of moving people and goods from one land mass to another. There are three main types of modern, underwater tunnels: immersed, bored, and submerged floating (Gerbis, 2022). Builders construct an immersed tunnel by dredging in the sea floor and then sinking pre-made tunnel sections into the hole. A bored underwater tunnel uses a boring machine to create a hole through the rock and soil under the waterline (Gerbis, 2022). Concrete linings support the weight and prevent the tunnel from collapsing after the boring machine has passed (Gaynor, 2021). The final type, submerged floating, is different from the other two, in that the tunnel is floating under the water and not sitting on the sea floor or buried in the soil. A delicate balancing act using the tunnels' buoyancy, cables, and pontoons keeps the sections in place (Beijing International, 2008).

2. Frameworks and Methods

Two STS frameworks that I will be using to help answer the question of whether underwater tunneling causes environmental damage are case studies and public policy analysis. Case studies are a valuable tool to find information relating to previous underwater tunnel construction projects. Info such as planning, pre-construction stages, construction, and post construction stages can be a valuable asset when determining if underwater tunneling causes environmental damage. Case studies on the cement industry are also essential when determining the environmental impacts of underwater tunneling as these tunnels are made from concrete. These studies were found while researching the process of tunnel construction which is the most energy intensive portion of a tunnel's lifespan.

Public policy analysis is also a valuable tool that can shed light on already existing policies that relate to underwater tunnel construction. Specifically, policy on dredging is an important factor to consider when looking at the environmental impacts of underwater tunneling. The method I used when looking for information on these topics is finding, reading, and synthesizing previous literature in order to come to a conclusion that answers the question. Most of this literature is in the form of scientific studies which investigate topics such as cement production, dredging, and noise pollution.

3. Results: CO2, Dredging, and Noise Pollution

Underwater tunnels are usually constructed using precast sections of concrete placed together during construction (Gerbis, 2022). A principal ingredient for the creation of concrete is cement, a chemical substance used to hold together all the constituent parts of a concrete mix (Mason, 2022). According to the U.S. Geological survey, the U.S. produced 90 million metric tons of cement in the year 2020 alone (USGS, 2021, Pages 42-43). An issue arises when considering the large amount CO2 released during the manufacturing of cement. Every pound of cement manufactured releases about 0.9 pounds of CO2. Since cement is only a small portion of the overall composition of concrete, estimates conclude that manufacturing a single cubic yard of concrete releases 400 lbs. of CO2. This number is equivalent to the amount of CO2 released by driving an average car approximately 400 miles (Portland Cement Association, 2021).

While CO2 emissions have an impact on all life on the planet, the construction of underwater tunnels has a very direct impact on life below the water. One method of tunnel construction involves dredging, a process where a machine removes sediments from the sea floor in order to make a channel where the prefabricated segments will fit (National Park Service, 2019). The dredging process disturbs the sea floor and can have a myriad of adverse impacts on sea life. Corals specifically are easily impacted by dredging activities because of their limited mobility. Unlike other sea life, corals are immobile and often live in colonies susceptible to destruction by the dredging equipment (IADC, 2019). Due to the corals being made of calcium carbonate they are easily damaged when touched and with a growth rate of only between 0.3 and 10 cm a year any loss can be detrimental (Larcom, 2012).

Not only can dredging directly damage sea life through contact, it can also cause damage by stirring up sediments on the sea floor. As previously stated, coral is easily destroyed and broken into small particles. These particles mix with silt and can prevent light from reaching the seafloor (Erftemeijer et al, 2012). Corals have a special symbiotic relationship with photosynthesizing cells called zooxanthellae which rely on the coral for environmental protection and in turn supply the coral with the products of photosynthesis, namely glucose (NOAA). The zooxanthellae and coral will die if sediments obscure the sunlight. A 2012 study conducted to determine the lethal and sublethal impacts of sediment deposition on a coral concluded that after a 12-week exposure to sediment buildup, a layer thickness of 7-12mm formed on the surface of the coral (Flores et. Al, 2012). This layer resulted in all the coral tissues underneath the accumulation dying, exposing a white coral skeleton, often tinged with a green color due to endolithic green algae. Sediment deposition is not the only issue faced by marine life in regards to dredging. The suspended sediment floating through the water can also have detrimental impacts on fish populations. A 2017 study looked at the impacts of suspended sediment on a variety of fish species including fresh water, salt water, eggs, adults, and juveniles. There was a total of 146 combined records on these fish species during the study. The experiments found that 14 studies showed no effect, 12 studies observed behavioral changes, 34 studies recorded physical damage and substantial behavioral changes, 37 studies measured physiological stress and sublethal responses, and 49 studies recorded some level of mortality. It is important to note that different species of fish have remarkably different tolerances to the level of particles in the water with some species able to withstand concentrations up to 28,000 mg/L, while others experience mortality starting at 25 mg/L (Wenger et al., 2017).

Just as humans dislike the sound of construction outside their windows so do animals. More specifically, marine mammals can be negatively impacted by the construction of underwater tunnels due to their reliance on sound to communicate to one another (Popper et al, 2020). A study published in The Journal of the Acoustical Society of America determined that high intensity underwater sounds may cause temporary hearing threshold shifts in harbor porpoises. Harbor porpoises exposed to the sound of piledriving noises for 6 hours had an up to 5dB reduction in hearing sensitivity at a frequency of 8 kHz (Kastelein et al., 2017). This frequency overlaps with the vocalization frequency of many whales and dolphins. In essence, the marine mammals exposed to loud underwater noises may miss important vocalizations and social cues presented by other marine mammals. Additionally, marine mammals may panic if they are too close in proximity to the origin of the noise and swim for the surface (Peng et al., 2015). A rapid ascent to the surface can cause decompression sickness which may result in tissue damage from gas bubble legions or even death. This phenomenon has been observed in mass beaching of whales caused by the ping of underwater sonar systems (Simonis et al., 2020). One can see that underwater tunneling has many adverse effects on the environment, including excess CO_2

release, destruction of coral and fish populations, and noise pollution which can harm marine creatures.

4. Analysis and Discussion

The Impact of Carbon Emissions due to Cement Production

Carbon emissions have become a hot topic in the last several decades, and for good reason. CO_2 is one of Earth's most important greenhouse gases: a gas that absorbs and emits radiant energy. Since the start of the industrial revolution, human activities have increased the level of CO_2 in the atmosphere by approximately 50% (Stein, 2022). An excess of CO_2 can have many detrimental environmental impacts including raising temperatures and ocean acidification (Lindsey, 2022).

Greenhouse gases are responsible for keeping the Earth's temperature at a reasonable level, and any fluctuations can lead to increases or decreases in temperature. As previously discussed, the production process for cement releases large amounts of CO_2 into the atmosphere, which contributes to global warming by increasing global temperatures. Increased global temperatures can have a threefold impact on the environment: higher sea levels, extreme weather events, and changes in ecosystems and wildlife (Lindsey, 2022).

According to NASA, increased temperatures due to global warming raise the sea level by two methods, melting ice and the expansion of seawater as its temperature increases. As temperatures increase, ice sheets, as well as glaciers, begin to melt which contributes to rising sea levels. Seawater is also prone to volume increase due to thermal expansion when the temperature begins to increase. NASA states that approximately half of the measured global sea level rise is due to thermal expansion of the oceans (NASA, 2022). Rising sea levels present a significant threat to coastal communities, especially communities in developing nations who have minimal resources to help mitigate the risks. Frequent and severe flooding is an impact coastal communities will have to deal with as sea levels continue rise (Taylor et al, 2023). Floods have the potential to cause significant damage to both residential and commercial properties, while also obstructing access to critical infrastructure such as schools and hospitals (Kann, 2021). Frequent flooding also has a secondary impact of increasing erosion rates, which can degrade natural flood barriers, such as sand banks and mangroves. With the degradation of these barriers, salt water intrusion is likely to occur which can impact water supplies, agriculture, and coastal ecosystems (Pollard et al, 2019).

The second impact of CO2 emissions from cement production is the acidification of the oceans. CO2 dissolves into the oceans where the water and carbon dioxide react to form carbonic acid. This acid gradually lowers the pH and the water becomes more acidic. In the last 200 years, it has been estimated that the ocean has had an overall acidity increase of 30% (NOAA, 2021). This acidification has a detrimental impact on sea creatures that build shells and skeletons out of carbonates. Coral reefs and oysters are two prime examples of life that are directly impacted by increasing ocean acidification. The acidification increases, resulting in the available carbonates bonding with the excess Hydrogen, causing a sharp decrease in the available calcium carbonate organisms can use to build their shells or skeletons. If the pH gets too low, the shells and skeletons can begin to dissolve (Hoegh-Guldberg et al, 2017). Oysters play a critical role by filtering water, providing a food source for various species, and serving as a barrier against storms to prevent erosion (Horn Point Laboratory, 2023). In the same way, corals also provide protection against erosion and serve as homes for various species in its ecosystem. From this, it is evident that it is critical to reduce carbon emissions from the cement production process in order to protect our oceans.

The Destruction of Coral Populations during Tunnel Construction

Dredging during the construction phase of underwater tunneling causes untold impacts on coral and fish populations. The results section emphasized how dredging destroys corals and deposits toxic sediments that harm marine life. Similar to the acidification of the ocean, a reduction in corals means a reduction in erosion protection for coastal areas. Additionally, many species such as fish, lobsters, clams, sponges, sea turtles, and many others depend on these coral reefs for protection (EPA, 2022). Entire ecosystems exist around corals and a reduction in the number of coral reefs could alter or completely wipe out these delicate ecological communities. Corals are closely tied to seagrass beds and mangrove forests which act as CO_2 sinks, meaning they store more carbon dioxide than they release (UNFCCC, 2021). The destruction of reefs results in the deaths of seagrasses and mangroves which would cause the release of all the CO_2 being stored within these species. The excessive amount of CO_2 in the ocean could cause an increase in acidification and trigger a destructive cycle wherein coral reefs disappear, leading to the death of seagrasses which will release CO_2, thereby exacerbating the problem of acidification.

The Impacts of Noise Pollution on Marine Environments

Marine animals depend on acoustic signals to communicate, locate food, and to sense their surroundings (Erbe et al, 2018). Underwater tunnel construction involves machinery which can create sounds that can travel underwater for miles. Just like humans, marine animals have hearing organs which can be sensitize to certain frequencies and noise intensity. Prolonged exposure to loud noises can damage these hearing organs which can impact the animal's ability to find food or escape predators. Additionally, noise pollution can cause psychological distress in marine animals which can result in changes in behavior and possibly reduce reproductive success. Finally, noise pollution can cause communication disruption in marine animals. Some species utilize acoustic signals to navigate their surrounding which aids in finding food, shelter, and avoiding predators (Southall et al, 2019). Marine mammals such as whales and dolphins are prime examples of sea creatures that rely on acoustics to communicate with one another. Marine mammals also use echolocation to find sources of food (Tejaratchi, 2008). If the construction of underwater tunnels is loud enough, it can disrupt these mammals' ability to find food and mates.

If prolonged construction and the traffic through the tunnel makes enough noise, it seems likely that the only conclusion would be the migration of marine animals away from the area. A loss of marine animals would weaken the already strained ecosystems located in coastal areas and could result in the sharp decline of plant and animal species. One possible situation is that an invasive species, which has adaptations to thrive in this environment, moves in due to the lack of predators and competition (Bax et al, 2003). This invasive species could create a foothold in the area which would prevent native species from ever being able to return to the area. Migration of marine animals could also be detrimental to fishing communities who would now have to travel further to catch fish (Bradford, 2013). Catching the same number of fish for a greater resource expenditure could cause economic downturn in the area.

What can be done?

The Importance of More Research

The first and most important step in determining what steps to take in order to mitigate the environmental impacts of underwater tunneling is to collect more data and conduct more research. Even though the first underwater tunnel opened over 180 years ago, it was not until the mid to late 1900s that these tunnels started to become more widely implemented (Laskow, 2014). Even to this day, there are only approximately 200 underwater tunnels in use with many being located in Asia (MAPFRE Global Risks, 2020). This is in stark contrast to the estimated 600,000 bridges located in the U.S. alone (ASCE, 2021). It is easy to see from these numbers why there is so little information on the environmental impacts of underwater tunneling. It is especially pertinent to conduct research as land becomes more valuable as population centers grow and there becomes a greater incentive to build subsurface and underwater tunnels.

What can be done: Decarbonization

One benefit of having so many bridges is that researchers have been able to look into ways to reduce the carbon footprint of concrete production. Green construction has become more popular than ever as architects, engineers, and construction companies look to design structures which reduce the negative impacts construction can have on the environment (Arnholz, 2021). One method being presented in literature is the decarbonization of the cement production process. Decarbonization is the reduction of carbon dioxide emissions during the manufacturing process by using low carbon power sources. Renewable energy, biofuels, and nuclear power are examples of power sources which can contribute to decarbonizing an industry. A 2021 study discussing decarbonization explains that many processes exist to reduce the emissions of a cement plant including: utilizing heat lost during production, digitizing the plant, using alternative fuels, and carbon capture and storage. The production of cement results in a heat loss of about 35-40% mostly in the form of air which is draws heat away from manufacturing equipment. A proposal is to use this hot air to heat water to create steam which can create electricity and offset the electricity demand of the plant. An additional method to aid in decarbonization is updating existing plants to digital control systems. These digital control systems can result in an estimated 10% operational efficiency gain over analog controls. Using biofuels is also a process that has been implemented in manufacturing facilities in North America. Replacing fossil fuels with waste-derived bio fuels is a way to reduce overall carbon emissions in a cost-effective way. Removing recyclable products from the biomass before burning creates an even more environmentally friendly process. The final solution to reducing the emissions during the cement production process is to use systems which can capture and store the carbon released during the manufacturing process (Fennel et al, 2021).

What can be done: Regulations on Dredging

Dredging is inevitable and necessary to create channels and harbors that are able to support shipping traffic. Regulations exist around dredging and businesses require permits to be able to dredge waterways. The disposal of sediments is also regulated to ensure toxic sediments are less likely to leach into the water. Both the EPA and the US Army Corps of Engineers share joint responsibility for managing and regulating the dredging process and disposal of sediments (EPA, 2022). These regulations however, do not explicitly protect corals, seagrasses, or other marine life from dredging. For example, a 2019 study found that over half a million corals died during the dredging of the Port of Miami from 2013 to 2015 (Cunning et al, 2019). As discussed in previous sections, the reduction of coral can have drastic effects on the levels of CO_2 in the oceans as well as the type of ecosystems that are sustainable. For this reason, it is important to develop regulations that specifically aim to protect coral reefs from destruction during dredging.

What can be done: Noise Pollution

Most regulations about noise pollution involve ships and not machinery. As engine technologies become more efficient and quiet, equipment used to create underwater tunnels should implement this tech. This implementation would help reduce noise as well as vibrations which could harm sensitive ecosystems nearby (Schlote, 2013). In addition to efficient engines, utilizing dampers could also be beneficial to reduce vibrations (Melito, 2020). Unique technologies such as underwater bubble curtains at the construction sites serve as barriers to prevent the propagation of harmful soundwaves (Wursig, Green and Jefferson, 2000). Above all, it is important to spread awareness that these issues exist and to create regulations to ensure noise pollution is unable to harm marine animals.

5. Conclusion

Underwater tunneling will continue to gain prominence as space becomes limited and the need for transportation increases. As more tunnels appear, it is important to consider the environmental impacts these structures can have. Cement used to build tunnels has a high carbon footprint, especially during the production phase. CO2 can have a variety of detrimental impacts on the environment including raising temperatures and contributing to ocean acidification. Rising temperatures can result in higher sea levels, extreme weather events, and changes in ecosystems and wildlife. Ocean acidification can result in the destruction of coral reefs leading to greater erosion and the reduction of ocean ecosystems. Decarbonization techniques can reduce the overall carbon footprint of cement production by reducing the amount of CO_2 emitted.

Dredging is also a danger to marine ecosystems especially coral populations. Similar to ocean acidification, dead corals can have the impact of removing shelter for other ocean species such as fish, lobsters, oysters, turtles, and more. For this reason, it is important to introduce regulations which aim to protect coral populations during the construction of underwater tunnels.

Finally, noise pollution caused by the construction process can disorient marine animals, making it difficult for them to search for food, find mates, and avoid predators. Utilizing more efficient engines as well as dampers and underwater sound barriers are all ways to help reduce the impact of noise pollution on the ocean ecosystem. Overall, it is clear that underwater tunneling has a variety of negative environmental impacts that need consideration. More research can help definitively conclude that underwater tunneling has negative environmental impacts. We need to educate people on this topic and draft regulations to ensure that coastal ecosystems are able to thrive in the future.

Bibliography

Allen, Edward, and Iano, Joseph. Fundamentals of Building Construction: Materials and Methods. 4th ed. Hoboken, N.J.: Wiley, 2004.

American Society of Civil Engineers. (2021). Bridges: 2021 Infrastructure Report Card. ASCE. Retrieved April 2023, from https://infrastructurereportcard.org/wp-content/uploads/2020/12/Bridges-2021.pdf

Arnholz, Jonathan. (2021). What is green construction? Build Your Future (BYF). Retrieved April 2023, from https://byf.org/what-is-green-construction/.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., Warren, G. (2003). Marine invasive species: a threat to global biodiversity. Marine Policy. Volume 27 (Issue 4) Pages 313-323 DOI: 10.1016/s0308-597x(03)00041-1

Beijing International. (2008). *Italian Bridge Cultures*. Beijing official web portal. Retrieved February 13, 2023, from https://web.archive.org/web/20080111050802/http://www.ebeijing.gov.cn/News/BjToday/Communications/t20040325_118331.htm

Bradford, Nick. (2013). Marine Species on the Move: Ocean Distribution Shifts Due to Climate Change. National Environmental Education Foundation . Retrieved September 20, 2021, from https://www.neefusa.org/weather-and-climate/marine-species-move

Cunning, R., Silverstein, R., Barnes, B., Baker, A. (2019). Extensive coral mortality and critical habitat loss following dredging and their association with remotely-sensed sediment plumes. Marine Pollution Bulletin, 145, 185-199. https://doi.org/10.1016/j.marpolbul.2019.05.027

Environmental Protection Agency. (2019). Basic Information about Coral Reefs. Retrieved April 2023, from https://www.epa.gov/coral-reefs/basic-information-about-coral-reefs#:~:text=Coral%20reefs%20provide%20habitat%20for,%2C%20mangrove%2C%20and%20mudflat%20communities.

Environmental Protection Agency. (2022). Dredging and Sediment Management. Retrieved from https://www.epa.gov/cwa-404/dredging-and-sediment-management#:~:text=Managing%20and%20regulating%20the%20disposal,MPRSA%20or%20Ocean%20Dumping%20Act.

Erby, Dunlop, Dolman. (2018). Effects of Noise on Marine Mammals. In *Effects of Anthropogenic Noise on Animals*. Springer Handbook of Auditory Research, vol 66. (pp. 207-239). Springer.

Erftemeijer, P. L., Riegl, B., Hoeksema, B. W., Todd, P. A., & Lirman, D. (2012). Environmental impacts of dredging and other sediment disturbances on corals: A review. Marine Pollution Bulletin, 64(9), 1737-1765. Retrieved April 2023, from https://www.sciencedirect.com/science/article/pii/S0025326X12001981

Fennell, P., Davis, S., Mohammad, A. (2021). Decarbonizing cement production. Joule, 5(6), 1305-1311. https://doi.org/10.1016/j.joule.2021.04.011

Gaynor, A. (2021). How a Tunnel Boring Machine (TBM) Works. EquipmentandContracting.com. Retrieved October 27, 2022, from http://publish-itonline.com/publication/frame.php?i=705526&p=30&pn=&ver=html5

Gerbis, N. (2022, August 24). How do you build an underwater tunnel? HowStuffWorks Science. Retrieved October 27, 2022, from https://science.howstuffworks.com/engineering/structural/build-underwater-tunnel.htm

Hoegh-Guldberg, Poloczanska, Skirving, Dove. (2017).Coral Reef Ecosystems under Climate Change and Ocean Acidification. Frontiers in Marine Science, Vol. 4, Global Change and the Future Ocean Section. Retrieved April 2023, from https://www.frontiersin.org/articles/10.3389/fmars.2017.00158/full

Horn Point Laboratory. (2023). Oyster Importance. Hatchery. University of Maryland Center for Environmental Science. Retrieved April 9, 2023, from https://hatchery.hpl.umces.edu/oyster-importance/

Flores, F., Hoogenboom, M. O., Smith, L. D., Cooper, T. F., Abrego, D., & Negri, A. P. (2012). Chronic exposure of corals to fine sediments: lethal and sub-lethal impacts. *PloS one*, *7*(5), e37795. https://doi.org/10.1371/journal.pone.0037795

IADC. (2019). Dredging around coral reefs. International Association of Dredging Companies. Retrieved March 2023, from https://www.iadc-dredging.com/facts-about/dredging-around-coral-reefs/.

Kann. (2021, October 11). Flood risks threaten infrastructure across the US, climate group warns. CNN. https://www.cnn.com/2021/10/11/weather/infrastructure-flood-risk-climate-first-street/index.html

Kuklewicz, S. (2021). 1828 tunnel flood. The Brunel Museum Thames Tunnel. Retrieved December 14, 2022, from https://thebrunelmuseum.com/1828-tunnel-flood/

Lane, Susan and Kleinhans, Danielle. (2016). Long-Term Bridge Performance Program: Research and Development for Bridge Infrastructure. Federal Highway Administration. Retrieved April 2023, from https://www.fhwa.dot.gov/publications/research/infrastructure/structures/ltbp/16012/index.cfm

Larcom. (2012, August 28). Coral Growth Rates and Sizes. NOAA. Retrieved from https://oceanexplorer.noaa.gov/explorations/12lophelia/background/growth/growth.html

Laskow, Sarah (2014, September 25). The Great Era of Underwater Tunneling. The Atlantic. Retrieved April 2023, from https://www.theatlantic.com/technology/archive/2014/09/tunnel-vision/380706/

Lindsey, (2022). Climate Change: Atmospheric Carbon Dioxide. Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.

Mapfre Global Risks. (2020, February 26). Underwater Tunnels: Applications and Maintenance. Retrieved April 9, 2023, from https://www.mapfreglobalrisks.com/en/risks-insurance-management/article/underwater-tunnels-applications-and-maintenance/#:~:text=%E2%80%9CThe%20first%20infrastructures%20of%20this,200%20underwater%20tunnels%20built%20worldwide.

Mason, T. O. and Lea, . Frederick M. (2022, September 17). cement. Encyclopedia Britannica. Retreived April 2023, from https://www.britannica.com/technology/cement-building-material

Melito, S. (2020). Sound Dampeners for Industrial Noise Control. Elasto Proxy. Retrieved from https://www.elastoproxy.com/sound-dampeners/.

NASA. (n.d.). Sea Level. Climate Change: Vital Signs of the Planet. Retrieved April 7, 2023, from https://climate.nasa.gov/vital-signs/sea-level/#:~:text=Sea%20level%20rise%20is%20caused,1993%2C%20as%20observed%20by%20satellites.

National Park Service. (2019). Dredging. Retrieved April 2023, from https://www.nps.gov/articles/dredging.htm

NOAA. (2021). Ocean acidification. Retrieved from https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

NOAA's National Ocean Service. (n.d.). Zooxanthellae and Coral Bleaching. Retrieved April 07, 2023, from https://oceanservice.noaa.gov/education/tutorial_corals/coral02_zooxanthellae.html

Peng, C., Zhao, X., & Liu, G. (2015). Noise in the Sea and Its Impacts on Marine Organisms. *International journal of environmental research and public health*, *12*(10), 12304–12323. https://doi.org/10.3390/ijerph121012304

Pollard, J., Spencer, T., & Brooks, S. (2019). The interactive relationship between coastal erosion and flood risk. *Progress in Physical Geography: Earth and Environment*, *43*(4), 574–585. https://doi.org/10.1177/0309133318794498

Popper, Hawkins, Thomsen (2020). Taking the Animals' Perspective regarding Anthropogenic Underwater Sound. Trends in Ecology and Evolution, 35(9), 787-794. Retrieved April 2023, from https://www.sciencedirect.com/science/article/pii/S0169534720301324?casa_token=Kb7FP2yhqnMAAAAA:KQJ3RaaY3WkaCMRd122UnpUnO2SIL9To4NARyUidjyBWv8CMsKd06dkQfeHb_NNHn9Ev0oPgMRg

Portland Cement Association. (2018). Sustainable cement & concrete manufacturing toolkit: Carbon footprint. Retrieved from https://www.cement.org/docs/default-source/th-paving-pdfs/sustainability/carbon-foot-print.pdf

Schlote, D. (2013). Improved Ways to Reduce Engine Vibrations. Fraunhofer. Retrieved April 2023, from https://www.fraunhofer.de/en/press/research-news/2013/march/improved-ways-to-reduce-engine-vibrations.html

Simonis, A. E., Brownell, R. L., Thayre, B. J., Trickey, J. S., Oleson, E. M., Huntington, R., & Baumann-Pickering, S. (2020). Co-occurrence of beaked whale strandings and naval sonar in the Mariana Islands, Western Pacific. *Proceedings of the Royal Society B: Biological Sciences*, *287*(1921). https://doi.org/10.1098/rspb.2020.0070

Southall, Finneran, Reichmuth et al, (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals*. 45(2). Pages 125-132.

Stein. (2022, June 3). Carbon dioxide now more than 50% higher than pre-industrial levels. Retrieved April 2023, from https://www.noaa.gov/news-release/carbon-dioxide-now-more-than-50-higher-than-pre-industrial-levels

Taylor, C., Robinson, T.R., Dunning, S. *et al.*(2023) Glacial lake outburst floods threaten millions globally. *Nat Commun* **14**, 487. https://doi.org/10.1038/s41467-023-36033-x

Tejaratchi. (2008). The Dolphin Defender: Dolphins and Sounds. Nature. Retrieved April 2023, from https://www.pbs.org/wnet/nature/the-dolphin-defender-dolphins-and-sounds/807/.

Kastelein, Helder-Hoek, Van de Voorde, von Benda-Beckmann, Lam, Jansen, de Jong, Ainslie, (2017) "Temporary hearing threshold shift in a harbor porpoise (Phocoena phocoena) after exposure to multiple airgun sounds", The Journal of the Acoustical Society of America 142, 2430-2442 https://doi.org/10.1121/1.5007720

Wenger, AS, Harvey, E, Wilson, S, et al. (2017) A critical analysis of the direct effects of dredging on fish. *Fish Fish*. 18: 967– 985. https://doi.org/10.1111/faf.12218

Willis, M. (2018). How the Thames Tunnel Revealed London's Class Divide. JSTOR Daily. Retrieved October 28, 2022, from https://daily.jstor.org/thames-tunnel-revealed-londonsclass-divide/

Würsig, B.; Greene, C.R.; Jefferson, T.A. (February 2000). "Development of an air bubble curtain to reduce underwater noise of percussive piling". *Marine Environmental Research*. **49** (1): 79–93. doi:10.1016/S0141-1136(99)00050-1

UNFCCC. (2021). Coral Reefs. Retrieved April 2023, from https://unfccc.int/blog/coral-reefs#:~:text=While%20reefs%20are%20not%20a,through%20sedimentation%2C%E2%80%9D%20Oburo%20says.

United States Geological Survey. (2021). Mineral commodity summaries 2021. U.S. Department of the Interior. Pages 42-43. https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf