Turning down the dial: Ocean energy development with less sound

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Researchers from Battelle and the University of Maryland developed this apparatus to evaluate fish injuries related to pile driving. Fish are held in the center of this water-filled metal tube while pistons at each end fluctuate to simulate the pressure changes that happen when metal piles are pounded into the ocean floor. Credit: Battelle

The rise of ocean infrastructure development to tap energy sources such as tides, offshore wind and natural gas will require more pile driving, the practice of pounding long, hollow steel pipes called piles into the ocean floor to support energy turbines and other structures. But pile driving creates loud, underwater booms that can harm fish and other marine animals.

Many scientists and regulators have assumed that limiting the combined amount of sound created during the course of a pile driving project can minimize harm to animals. But new research published in *PLoS ONE* indicates that if an individual blow to a pile rises above a particular sound level, fish can be irreparably harmed. The finding has led scientists to recommend the first-ever sound threshold for pile driving that is based on actual fish responses instead of estimates. It's hoped that regulators will use the threshold to help evaluate pile driving project applications.

"Our results can help regulators permit ocean development while also protecting marine life," said bioacoustician Michele Halvorsen, who led the research for Battelle, which manages the Department of Energy's Pacific Northwest National Laboratory. "This is the first research that used controlled laboratory tests to reliably measure the affects of pile driving on fish."

Halvorsen conducts research at PNNL's Marine Sciences Laboratory in Sequim, Wash.

Under pressure

Hitting a steel pile with a large hammer produces sound that causes water pressure changes that impact fish. Sudden changes in water pressure can cause gases such as oxygen to come out of fish blood faster than normal, leading to a decompression sickness much like the bends that divers experience when they rise to the surface too fast. Pressure changes also affect a fish's swim bladder, an internal, air-filled sac that helps the fish maintain weightlessness at different water depths. Alternating pressure changes cause the swim bladder to quickly expand and compress, which punches and bruises neighboring organs and can rupture the swim bladder itself.

When doing pile driving for a project, government criteria require developers to stay below certain sound thresholds. However, those thresholds were established with rough estimates based on extremely limited data. Historically, caged fish have been placed near pile driving activity to assess how they're affected. Government regulators have used these tests to determine how many pile strikes are acceptable and the cumulative sound strengths that those strikes can reach during a project. But ocean floor topography and depths vary widely, meaning the tests aren't uniform and their results can be unreliable.

First laboratory tests for pile driving & fish

To remedy this, Halvorsen worked with colleagues at Battelle in Sequim and the University of Maryland to develop the first laboratory system to evaluate pile driving's effect on fish. Their setup features a hollow, 9.5-inch wide tube made of inflexible, 1.5-inch thick steel that can withstand extreme sounds. At each end of the tube is a speaker with a piston that moves water inside the tube. The pistons recreate the sounds and associated water pressure changes that happen during pile driving.

For their tests, the research team inserted hatchery-raised juvenile Chinook salmon into the water-filled tube. The fish were then allowed to acclimate for 20 minutes so they could reach weightlessness in the water by filling their swim bladders. This step was key to making the test results realistic. That's because fish respond to pressure changes differently based on the volume of air in their swim bladders. Deflated swim bladders tend to protect fish from being harmed by sound waves. If fish with deflated swim bladders are tested before their swim bladders can fill, results are likely to indicate the fish fared better than if they had been exposed to sound waves with a full swim bladder. Halvorsen said most of the caged fish tests don't allow fish to adjust.

Fish inside the tube were exposed to a series of sounds and vibrations representative of those recorded during a 2005 pile-driving project on Washington state's coast. The simulated pile strikes, called impulses, were measured in decibels, which indicate the energy of sound. Fish were exposed to six different intervals of impulses, whose cumulative strength ranged between 204 and 220 decibels relative to 1 square microPascal per second, which is a standard measurement unit for underwater pressure. The impulse ranges used are quieter than underwater explosives. But the total number of impulses varied; fish were either exposed to 960 impulses or 1,920 impulses, both of which are similar to the total number of strikes in typical pile-driving projects. For the fish exposed to fewer impulses, the average intensity of each impulse was greater.

Defining the most harmful

Next, the team looked to see if and how badly the fish had been injured. The researchers divided the injuries they saw into three categories: mild, moderate and mortal. Mild injuries included bruising of the fins or body or a deflated swim bladder that wasn't ruptured. Moving up on the severity scale, moderate injuries involved active bleeding of the fins or capillaries or bruising of the swim bladder, muscles and organs. Finally, mortal injuries were those that either caused the fish to die within an hour of the test or would have soon thereafter due to bleeding or cuts in organs or the swim bladder. Based on their category, each observed injury was given a numerical value. Minor injuries were worth one point, moderates were valued at three and mortal injuries were given five points each.

The research team totaled the numbers for each of the fish tested. They found that if a fish received injuries that were worth a total of more than two points, that fish was at a higher risk for irreparable harm. The team noted that even though a value of just over two doesn't immediately kill a fish, the injuries associated with that score might still cause a fish to prematurely die. For example, more than two minor injuries could collectively give the fish greater difficulty finding food or escaping from a predator. The study showed exceeding the two-point threshold could happen if a test with a total of 1,920 or 960 total strikes respectively included an individual strike of more than 177 or 180 decibels relative 1 square microPascal per second.

Informing field & permit decisions

Halvorsen is sharing these results with regulators in the hopes that her team's laboratory approach to determining pile strike thresholds can help improve the pile driving permitting process. Having such a threshold in mind can also help ocean developers better manage projects as they unfold, Halvorsen said. For example, if developers encounter a hard section of sea bed, they may be able to avoid harming fish by performing more pile strikes with lower intensities.

Beyond ocean energy development, these findings could also be used in pile-driving projects to build piers and bridges over waterways. And oil companies that do seismic explorations of the ocean floor with blasts of pressurized air could also employ this research as the sound characteristics between this work and pile driving are nearly identical.

The research team notes, however, that their results only apply to juvenile Chinook salmon, which are protected by federal laws. Pile strikes may affect other fish with different body structures or salmon of different sizes or ages differently. Additional testing is needed to establish thresholds for other marine organisms.

More information: MB Halvorsen, BM Casper, CM Woodley, TJ Carlson, AN Popper, "Threshold for Onset of Injury in Chinook Salmon From Exposure to Impulsive Pile Driving Sounds," *PLoS ONE*, June 20, 2012, DOI: 10.1371/journal.pone.0038968

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