Impacts to Fish from Pile Driving Generated Sound

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Introduction

Pile driving has been used for thousands of years to create a stable foundation in areas with soils that have poor weight bearing capacity or to support structures over water. Modern pile driving typically involves raising and then dropping a heavy weight (a hammer) onto the top of a vertical pile which can be of various shapes and materials until it can be driven no further (to "refusal") or until it is sufficiently stable to meet the needs of the particular project. While in some respects pile supported structures are preferable from an environmental perspective to solid fill structures that entirely cover aquatic habitat for example there are potential adverse environmental impacts associated with the sound generated from the installation of piles. This paper describes some of those potential adverse impacts to fishery resources and potential means of mitigating for them.

Impacts

High intensity sound such as can be generated through pile driving, considered to be above 187 dB SEL re 1µPa (where dB = decibels, a measure of sound pressure; SEL= sound exposure level, a constant sound level over one second; and µPa = micro Pascals a measure of pressure fluctuation, with 1 µPa as the water pressure reference level)[2] can result in physical injury to fish. These can include change in hearing capability or actual damage to the inner ear, damage or destruction of the swim bladder, other cellular and molecular effects, and possible adverse effects on eggs and larvae.[3] Behavioral effects such as fish leaving or avoiding an area have been observed.[4,5,6] Cumulative stress induced impacts related to sound level and duration causing fish to be more susceptible to things like infection, predation, and slower growth may also result. Recent laboratory studies on juvenile Chinook salmon have found that the number of sound impulses as well as the energy in individual impulses need to be considered when predicting the potential for injury[7], and that one or two "mild" barotrauma injuries including hematoma of the body, fins, swim bladder, liver, intestine and adipose tissue and hemorrhaging of the spleen and intestine from pile driving exposure are unlikely to affect subsequent survival of exposed fish[8]. These "recovery from injury" results may not translate to other salmon life stages, fish in the wild, or to other species.

Mitigation Measures

The primary recommendation that resource managers make to minimize potential adverse impacts from pile driving is a time of year restriction. That is a recommendation that pile driving in an area with a potentially affected resource (e.g., diadromous fish) not be done when that resource can be expected to be within a zone of influence. A time of year restriction can be reduced when necessary if certain measures are taken to limit the sound exposure level, duration of sound, exclude fish from the zone of influence, limit pile driving to lower tide stages when the work area is in the "dry", or to

limit pile driving to times of the day or tide states when species of concern could be expected to not be in the project area.

Means to reduce sound transmitted to surrounding water by pile driving include use of piles that vibrate less when struck such as timber vs. steel, smaller diameter piles, use of a cushion between the hammer and "stiffer" piles such as steel[9], use of a vibratory hammer rather than an impact hammer[10], or the use of a bubble curtain[11]. Limitations on the number of pile driving hammers on a project site, the number of piles driven/day and the duration of pile driving/day can also be beneficial.[12]

Conclusions and Recommendations

Data are limited on behavioral and cumulative exposure impacts. Laboratory studies have been limited to few species and may not be translatable to the wild. Field studies in various environmental settings on a variety of fish species need to be done to validate laboratory findings and gather data on behavioral effects. Use of time of year restrictions and/or other mitigation measures with monitoring remain effective tools for minimizing potential adverse impacts to fishery resources from pile driving generated sound. This agency will continue to review projects that involve pile driving on a case by case basis as they are presented by regulatory agencies as each individual project and project site have their own unique characteristics and resources of concern. These reviews will take the needs and the constraints the permit applicant may be under into consideration which could lead to discussions related to minimizing and mitigating for potential adverse impacts to resources of concern.

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[2] This threshold was established as an interim criteria for injury to fish from pile driving by the Fisheries Hydroacoustic Working Group composed of U.S. West Coast federal and state regulators, June, 2008, and has since been adopted by the U. S. Army Corps of Engineers for use in their Maine General Permit.

[3] Hastings, Mardi C. and Arthur N. Popper. (2005). Effects of Sound on Fish. White Paper for the California Dept. of Transportation. 82pp.

[4] Feist BE, Anderson JJ, Miyamoto R (1992) Potential Impacts of Pile Driving on Juvenile Pink (*Oncorhynchus gorbushcha*) and Chum (*O. keta*) Salmon Behavior and Distribution. Pound Sounds Final Report, University of Washington School of Fisheries and Applied Physics Laboratory http://noaa.academia.edu/BlakeFeist/Papers/439692/Potential_impacts_of_pile_driving...

[5] Slotte, A., Kansen, K., Dalen, J., and Ona, E. (2004). Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. Fish Res. **67,** 143-150.

[6] Mueller-Blenkle C et al. (2012) http://mhk.pnnl.gov/wiki/images/4/4a/Pile_Driving_Noise_on_Marine_Fish

[7] Halverson MB, Casper BM, Woodley CM, Carlson TJ, Popper AN (2012) Threshold for Onset of Injury in Chinook Salmon from Exposure to Impulsive Pile Driving Sounds. PLoS ONE 7(6): e38968. doi:10.1371/journal.pone.0038968

[8] Casper, BM, Popper AN, Mathews F, Carlson TJ, Halverson MB (2012) Recovery of Barotrama Injuries in Chinook Salmon, *Oncorhynchus tshawytscha* from Exposure to Pile Driving Sound. PLoS ONE 7(6): e39593. doi:10.1371/journal.pone.0039593

[9] Use of a cushion of materials other than wood, traditionally used, that don't have variable elastic properties and that are unlikely to catch fire is required by many DOTs. Another consideration is that use of a cushion reduces the pile driving energy imparted which may require a larger hammer or an increase in the number of blows. Personal communication with Azure Dee Sleicher, P.E., Ocean and Coastal Consultants, Trumbull, CT, June 2012

[10] It should be noted that vibratory hammers can be used where there is softer substrate such as sand, slit and clay, but not effectively in areas of hard glacial till, cobble or other obstructions.

[11] Reducing Underwater Sounds with Air Bubble Curtains by J.A. Reyff, Illington and Rodkin, Inc., Petaluma, CA in Transportation News 262 May-June 2009

[12] The U. S. Army Corps of Engineers' Maine General Permit includes provisions that noise levels > 155dB peak re 1 µPa not exceed 12 consecutive hours on any given day and that a 12 hour recovery period with in water noise below this level be provided between work days.