Assessment of the risk of pile driving to juvenile fish

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The problem

In this talk I will report on an effort to reassess the risk of pile driving on juvenile salmonids migrating through Puget Sound. This study was motivated by construction industry concerns that provisions restricting pile driving during the spring migration are resulting in an unbalanced burden to the industry. In simple terms industry wants to know if some construction can be conducted in the spring without harming juvenile fish. Fisheries agencies have agreed to reconsider their regulations in the context of additional studies. Therefore, in this talk I will present some general thoughts on risk assessment and the results of our study to assess the impact of pile driving on Snohomish River juvenile pink and chum salmon migrating through the Navy Homeport construction site at Everett. This research, which is being carried out by the Fisheries Research Institute at the University of Washington, was planned and is supported in a joint effort from: the Washington Department of Fisheries, National Marine Fisheries Service, U.S. Fish and Wildlife Service; General, Manson, and Hurlen construction companies, the Department of Transportation and a number of Puget Sound ports authorities.

I will first briefly discuss the early life history of juvenile salmon the regulations are designed to protect. Second, I will outline the legal criteria required for risk regulation and some specific thoughts on how a reassessment of pile driving risk might be approached. With this basis I will report on our research and how it can be applied to a new risk assessment.

One thing is certain, environmental issues are affecting our lives and business in very real ways, and the Pacific Northwest is a hotbed of conflict involving the efforts to balance environmental and economic needs. The spotted owl issue has changed forever our logging industry. Proposals to declare runs of Columbia River salmon endangered may very well do the same to hydroelectric power in the Northwest. By comparison the effects of pile driving on fish seems small indeed.

Smolts in the spring

To understand the possible impact of pile driving on juvenile pink and chum salmon, we need to briefly discuss their early life history. During the spring runoff these fish begin their migration from their nursery grounds to Puget Sound. One of the critical points in this migration occurs when the fish encounter the saltwater lens near the mouth of their river. The Snohomish River mouth, near the site of the Navy Homeport in Everett Washington, is a typical example (Figure 1). The fish entering the estuary are small, less than 2 inches long, and are not fully adapted to saltwater. Thus, they are confined to the fresh water surface layer since the saltwater stresses their ability to achieve an osmotic balance. Anecdotal evidence suggests that if disturbed by a predator, these fish will move horizontally but seldom do they swim down into the saline water. Being confined to this surface layer, they are exposed to fish predators from below and bird predators from above. Consequently their preferred habitat at this stage is the very shallow nearshore water where predatory fish and birds have a difficult time capturing them. In this environment, juveniles are apparently attracted to floating objects and they do not swim under even the seemingly most inconsequential object. For example, we have observed juvenile pink salmon swim around logs floating at the surface rather than diving a few inches under them. Thus, the young salmon upon first entering the saltwater generally follow the shoreline swimming around most objects in their path. As they adapt to the saltwater environment they begin to move off shore. They eventually reach suitable feeding grounds where they may spend the remainder of the spring feeding. The Everett Homeport site appeared to be a corridor for this early migration. Over the spring fish caught in our collection nets were always between 1 and 2 inches in length. If the site were their juvenile feeding or nursery ground feeding ground we would expect an increase in fish size over the spring.

By comparison the situation was much different at a second study site, the Kingston Ferry Terminal directly across Puget Sound from the Homeport (Figure 2). This area is not strongly influenced by streams so it lacks the freshwater lens found at the Homeport. Consequently the fish found here were adapted to saltwater and would readily dive when disturbed from the surface. We also observed significant changes in their numbers, size, and behavior over the spring. In early May the fish were about 2 inches long and generally were found in distinct schools within a few feet of shore. By the middle of June fish length had increased by 50% and they formed large dispersed aggregations, or shoals, that sometimes extended several hundred feet offshore. In comparison, over the same period the Homeport fish formed dense smaller aggregations and continued to swim within five feet of the shoreline. By mid-June the downstream migration had ended and the schools at both locations were gone. By then fish were big enough to avoid predators more successfully and had moved to the deeper offshore waters of Puget Sound.

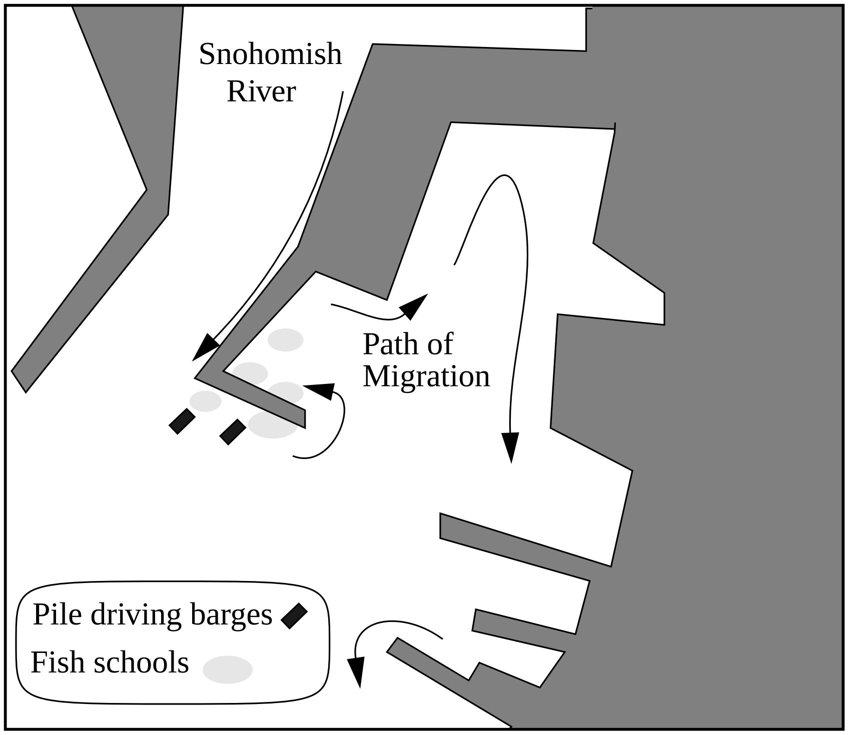

Figure 1. Map of the Everett Homeport with pile driving barges, distribution of fish schools, and presumed migratory path of fish out of the river and along the shoreline.

Thus, the apparent survival strategy of the fish is to remain close to shore until they adapt to full saltwater and are large enough to avoid predators. It follows that the fish are vulnerable to predation during this period and any disturbance that drives them into deeper water before they are ready, could have a significant impact on their survival. This concern is the primary reason prohibiting all but emergency pile driving in the spring. The regulation contains a hint of the bizarre. Since all pile driving activity is prohibited in Puget Sound when juvenile fish are migrating we could infer by reductio ad absurdum[1] that driving a piling in the San Juan Islands has a deleterious effect on smolts leaving the Nisqually river some 100 miles south. The regulations were not designed to be absurd but the approach to risk management used at the time, combined with limited knowledge of the impact of pile driving on the fish, resulted in a very conservative regulation.

1. A technique in logic to disprove a proposition by showing its consequences to be impossible or absurd when carried to a logical conclusion.

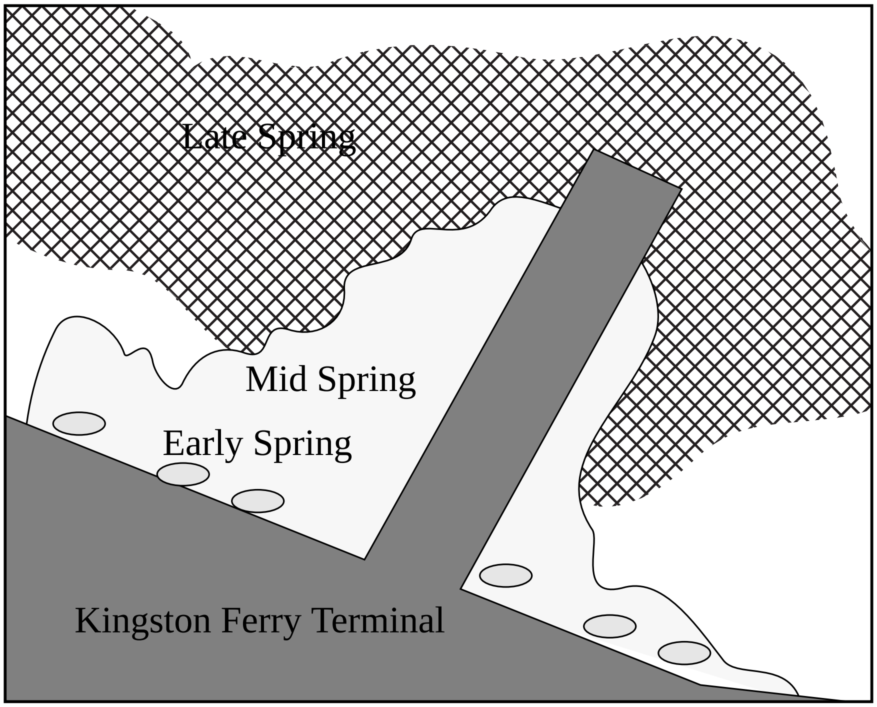

Figure 2. Distributions of juvenile pink and chum salmon at the Kingston Ferry Terminal in early mid and late spring.

Risk regulation

To understand how this situation arose and to develop a way around this problem a brief digression into the legal aspects of risk regulation is helpful[1]. The environmental movement, which essentially began in the sixties, was motivated by high profile cases: Smog was seriously polluting the atmosphere. Bird life was being destroyed by DDT. Chemicals were showing up in our food supply. Environmental groups brought these issues to the courts, which for the most part were composed of individuals trained in the law but woefully ill prepared to deal with the complexities of ecological issues. The law did as the law does and turned to itself for answers of how to balance risk to the population and environment against the hardships of regulation on the economy. To the question, “at what level of risk should regulations be imposed?” the courts gave the answer “regulations should only be imposed when the risk exceeds a *de minimis risk*,” which is a centuries-old common law maximum expressing the idea that the law does not concern itself with trifles. The question of what is a trifling risk is to be determined on a case-by-case basis. Many interpretations exist and I will discuss three that have relevance to our issue.

1. A disclaimer is in order since my credentials as an expert witness on the history of environmental law would never withstand a challenge in a court of law. This discussion is in part drawn from an article by M.B. Spangler, (1984) in *Uncertainty in Risk Assessment. Risk Management, and Decision Making,* edited by Covello, Lave, Moghissi and Uppuluri. Volume 4 in the series “Advances in Risk Analysis,” published by Plenum, New York.

The present pile driving regulations are based one of the most the most restrictive interpretations of *de minimis risk*. This can be denoted as the *minimum perceived risk*, which is the lowest risk level that can be measured or inferred. This interpretation has been commonly applied in dealing with human health. For example, any substance that can be shown to induce cancer at any dosage is considered unacceptable and should be regulated. The *de minimis risk* for salmon can also be evaluated with other criteria. A second approach is to compare risk of pile driving to risk fish experience from other causes, including natural fish and bird predators and perhaps the disturbances to fish that occur from routine boat and shore side activity. Such a *relative risk* can be established by comparing the effects of pile driving on the fish to effects of natural and nonregulated human activities. A third risk criteria accepted by the courts is known as *balanced risk*. In this approach a balance is sought between the cost and benefits of the risk making activity. The balancing formula has been called "Learned Hand's algebra" after Judge Learned Hand, the well-known jurist of the 1920s. Under the algebra, regulation of an activity is assumed valid if the potential severity of injury, factored by its probability, out weighs the burdens of regulation. For salmon this would require balancing the cost of the closure period to the construction industry with the value of the fish potentially harmed.

The current pile driving regulations are in fact based on two criteria. The area-wide spring closure is essentially based on the *minimum perceived risk* criteria. But the provisions also contains elements of the *balanced risk criteria* since variances to the provisions are given for special situations, such as for the emergency repair of a damaged ferry terminal. Here it is assumed that the burden of going without ferry service outweighs the value of fish that might be harmed during the repair of a damaged terminal. In the past few years the balance of burden assumed directly or indirectly in the original provisions has come into question. There is a growing belief that the provisions may not be meeting the *balanced risk criteria*. Neither is it clear that the provisions meet the *minimum perceived risk criteria* since detrimental effects of pile driving have not been determined. There was enough concern in this matter for the various parties involved to agreed to study the issue in the hopes of developing a more balance regulation. At this point the Fisheries Research Institute was brought in to study the problem.

<u>research design</u>

Our task, in the vernacular of risk regulation, is to provide information to quantify the *minimum perceivable risk* and the *balanced risk* criteria of the regulations. In addition, we are seeking information to assess the risk of pile driving relative to other activities. By the nature of ecological research and human decision making the information we have obtained contains uncertainty and is open to different interpretations. Thus, a second task of our study is to identify, as clearly as possible, both the uncertainty of the data and possible differences in its interpretation.

In establishing the original provisions the question was asked, “does pile driving represent a potential risk to fish?” This all or nothing question resulted in closing all of Puget Sound to pile driving in the spring. To achieve a better balance in the provisions we need to approach the problem in terms of a continuum. We realize that, whatever the risk of pile driving to fish, it decreases as the distance between the pile driving activity and the juvenile fish increases. Thus, I believe the relevant question to ask is, “what should be the minimum allowable distance between a pile driving site and a juvenile salmonid habitat?” The answers to this question can be approached graphically (Figure 3). In effect, the complete ban on pile driving mandated in the original provisions implies that risk is significant even at the maximum possible separation distance of fish and pile driving activity. Curve A illustrates this. The risk from pile driving at any place in Puget Sound is assumed significant for all juvenile salmon habitats in the Sound. This is the most conservative risk criteria and is generally embraced by the risk takers,[1] which are the recreational, commercial, and tribal fishing interests. Curve B illustrates a less conservative risk assumption in which pile driving affects fish only at short distances. This curve would be economically favorable to the risk makers, which include construction companies, port authorities and the transportation industry.

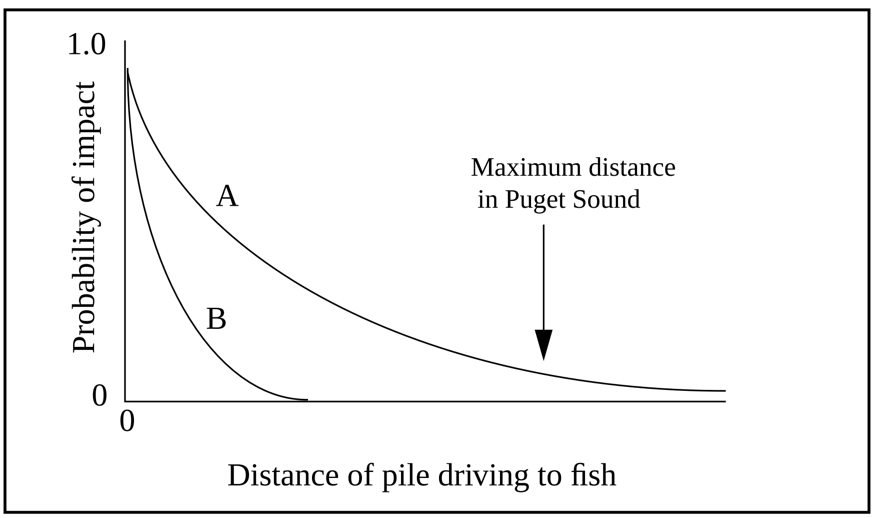

Figure 3. Pile driving risk curve showing the probability pile driving has an impact on fish as a function of the distance from the activity to a fish habitat. Curve A (the risk taker’s curve) embodies the most conservative assumptions on impact. Curve B (the risk maker’s curve) embodies the less conservative assumptions.

The extent of the conflict between the risk makers and the risk takers is graphically illustrated in Figure 3. The conflict lies between these limits and it is in this region of uncertainty that we seek to define new regulations. The task is first to define the initial extent of this uncertainty or

1. The risk taker is the group at risk from the activity of the risk maker group.

disagreement and then through additional studies reduce the level of uncertainty, hopefully moving the risk assessment curves of the risk maker and risk taker closer together. In this scenario a reduction of risk uncertainty is not the final step in establishing new provisions. The level of *de minimis risk* must also be identified. Although conflict can arise in what is an appropriate definition and level of *de minimis risk*, in many situations it is set by a regulatory agency or by the courts and so it can be represented by a single line in the graph.

The intersection of the two risk curves with the *de minimis risk* line defines a *tripartite* decision[1] criteria (Figure 4). In region I both the risk maker and the risk taker curves indicate an unacceptable level of risk. In region III both curves fall below the *de minimis risk* and so no regulation is required. Both sides can agree that pile driving is too risky within a distance D_{min} of a fish habitat and that at distances greater than D_{max} the risk is not significant. In region II the risk maker curve falls below the *de minimis* level and risk taker curve falls above the level so there is disagreement on the need for regulation[2]. This is the current situation with regards to pile driving in Puget Sound. The actions taken here provide a good model for other situations where conflict resolution is required. In our situation the risk makers and risk takers have agreed to allow pile driving provided the effects on fish are monitored. This serves two purposes. First it allows for further collection of data with which to reevaluate the risk assessment curves and second it provides a check to guard against an undue risk to the fish.

1. This approach was developed from workshops on risk assessment held by the Environmental Protection Agency (Morison and Johnson,1989. Collaborative Ecological Risk Assessment. National Ecology Center, U.S. Fish and Wildlife service; Anderson, Emlen, Morison, Swartzman and Park. 1988. Risk regulation through a tripartite decision method relating risk and uncertainty to legal standards. Environmental Research Laboratory, Corvalis Or. USEPA)

2. The graph has also been referred to as the good-bad-ugly (GBU) graph designating the acceptable region as good, the unacceptable region as bad, and the questionable region as ugly. The basic idea of a three-part graph was conceived in a flurry of activity and its reference to a classic western movie was a droll attempt to cut through the pedantic nature that risk assessment seems so readily to assume.

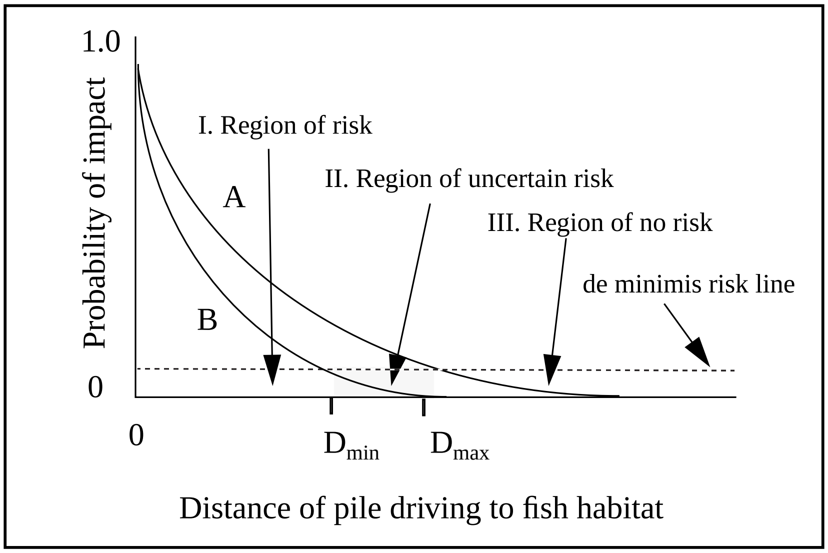

Figure 4. After revaluation of the risk cures new curves are developed that decreases the region of uncertainty and disagreement. A is the new risk takers curve and B is the new risk makers curve. The intersection of the *de minimis ris*k with the two risk curves defines three risk regions. D_{min} is the minimum impact distance with risk taker assumptions, D_{max} is the minimum distance of impact with risk taker assumptions.

Research goals

To apply the above scenario our research is aimed at determining how several different effects of pile driving change with distance. I will discuss three measures. The most conservative measure is based on a sound. A measure of intermediate risk is based on fish swimming behavior and a less conservative measure is based on fish startle behavior evoked by the onset of pile driving.

<u>sound based risk curve</u>

A risk assessment curve based on sound can be established by assuming that maximum risk occurs at sound levels that cause mortality and minimum risk occurs at a fish's threshold of hearing. Since the intensity of sound decreases exponentially with distance from its source[1] and the perception of sound by fish is a function of the log of the intensity of the sound,[2] a risk curve based on sound perception should decrease in a linear manner with distance from the source[3]. If the maximum sound intensity produced in pile driving induces mortality then the risk curve might decrease as a straight line to the distance at which fish can just distinguish the sound of above the

1. $\text{intensity} \sim \text{source} \cdot e^{-\text{distance}}$
2. $\text{perceived intensity} = \log \text{intensity}$: based on Fechner's law (1860) *Elemente der Psychophysik*. Leipzig: Bretikopf und Haertel.
3. $\log(\text{source} \cdot e^{-\text{distance}}) = \log \text{source} - \text{distance} = \text{perceived intensity}$

background level (Figure 5). To assess this scenario we require the distribution of sound at pile driving sites and sound level thresholds for mortality and perception. Sound pressure levels of 5 to 10 db relative 1 Pascal were measured 1000 ft from a concrete piling driven at the Homeport site[1]. There is no direct evidence that juvenile pink and chum salmon are able to detect this level of sound but using information available on adult Atlantic salmon[2] the threshold of detection may be on the order of 2000 ft from a pile driving rig. In fact, juvenile fish may have less developed hearing abilities so the threshold distance could be much less. At the present time there are no data to determine if pile driving sounds can kill fish at close range.

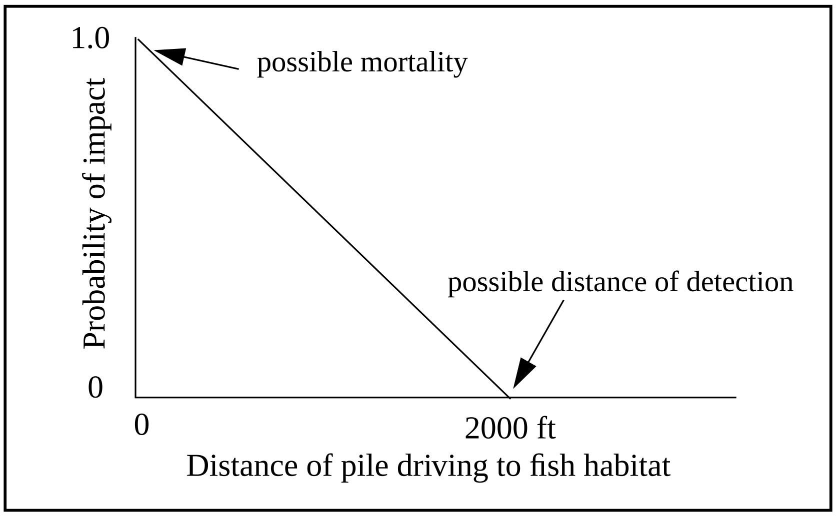

Figure 5. Risk curve based on sound. Assumes 100% risk at the source and zero risk at the level of detection.

<u>behavior based risk curve</u>

A risk curve describing a change in the behavior of fish in the presence of pile driving activity is in effect a *relative risk assessment* since it compares fish behavior with pile driving to fish behavior without pile driving. We can ask if fish behaviors with pile driving are statistically different from their behaviors without pile driving. This comparison can be put in terms of our graphic risk analysis by expressing risk in terms of the confidence interval on the hypothesis: behaviors are different in the two regions (Figure 6).

1. In a familiar terms this is approximately the sound level inside a disco or a teenager's bedroom.
2. Hawkins and Johnstone (1978) The hearing of Atlantic Salmon, *Salmo Salar*, J. of Fish Biology 13: 655-73

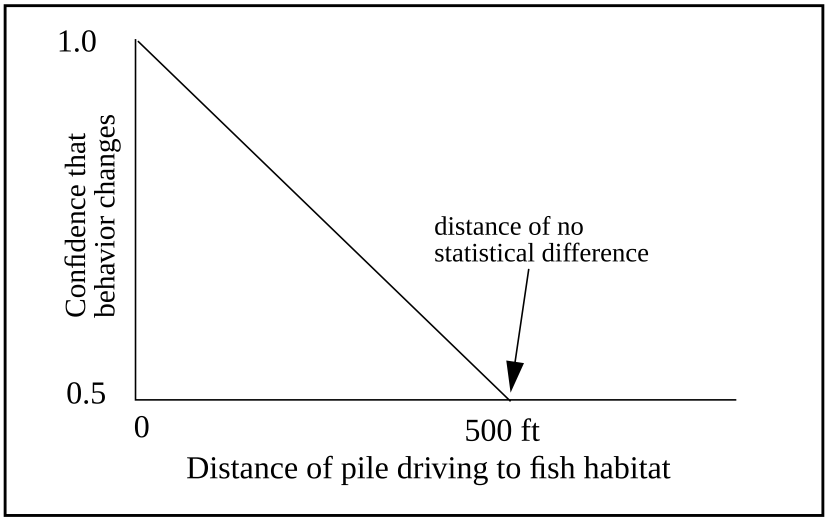

Figure 6. Risk curve based on the confidence level of a change in behavior. Behaviors are indistinguishable at the 0.5 confidence level.

At the Everett Homeport we have observed a number of behaviors that can be used to generate these relative risk curves including: school size, number of schools, their depth, distance from shore, swimming behavior, abundance, and feeding habits. Our observations show statistically significant differences in behavior with and without pile driving. Basically, near the pile driving site schools were larger while the total number of fish was smaller than was observed at sites sway from the site. This result suggests that fish avoided the construction activity to some degree although the effect appeared to be subtle. Pile driving clearly did not drive all fish away from the construction site. In fact, fish often were observed milling around the pile driving rigs during active pile driving.

startle behavior based risk curve

A risk curve based on startle behavior provides a measure of a fish's immediate perception of threat. Startle behavior, in which a fish suddenly darts away from a predator, is easily identified from visual observations. It is generally induced by a sudden stimulus and fish quickly habituate to repeated exposure to the stimulus. We observed fish startling at beginning of a pile driving episode but after a few poundings they would not startle to the sound of the driving. Thus, risk curves based on this measure should tend to characterize only the fish‘s immediate sense of risk. Again our approach would be to determine the number of startle responses as a function of distance from pile driving activity and plot the confidence level of the hypothesis that the startle response frequency with and without pile driving is different. The threshold risk distance could be established as the point where the two situations cannot be statistically distinguished. This is the 0.5 confidence level for the hypothesis. A cursory analysis of data from the Homeport site suggests that startle behavior was only different from non-pile driving environments within tens of yards of a pile driving barge. Qualitative observations suggest that pile driving sounds were no more likely to invoke a startle response than were sudden overhead movements.

Conclusions

There is growing concern that regulations limiting pile driving activity may be overly restrictive and are creating an excessive burden[1] to the economy. At the same time there is an increasing awareness that environmental needs must be given the benefit of the doubt when establishing regulations. Our research on the effect of pile driving on juvenile pink and chum salmon is aimed at seeking consensus in this issue. Since it is notoriously difficult to measure mortality in juvenile fish, (let alone the contribution of a single factor to their mortality), our assessments of pile driving risk, by their nature, are indirect and contain uncertainty. To make this information useful for evaluating regulations we have designed our research so it can be directly incorporated into legal definitions of risk. Our strategy is to evaluate several risk measures representing a spectrum from highly conservative to highly non-conservative points of view. Studies of behavior at several sites in Puget Sound have indicated that pile driving activity does affect juvenile fish. Although the research is not complete it is clear that we will be able to provide differing assessments of risk that should allow for a reassessment of the current pile driving regulations.

Acknowledgments

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1. In the sense of Learned Hand’s algebra.