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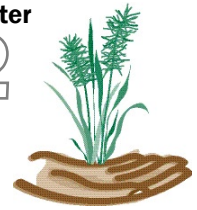
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ASSESSING THE IMPACT OF PILE DRIVING UPON FISH

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Abstract

Pile driving associated with the removal and reconstruction of a jetty was monitored at a busy harbor in the North East of Scotland, adjacent to an important Atlantic salmon river. The main concern was with the impact of noise upon salmon migrating through the lower part of the river estuary. Pile driving was allowed to proceed subject to an agreed program of works to monitor sound levels and ensure least disturbance to salmon.

Both percussive and vibratory pile driving took place. Sound-pressure levels from both were measured. Percussive pile driving involved the repeated striking of the head of a steel pile by a double-acting hydraulic hammer, with a 5 tonne ram weight operated with a mean stroke of about 1 m. Vibratory pile driving was achieved by means of a variable eccentric vibrator attached to the head of the pile.

The majority of piles were initially driven into the substrate by vibration, over a period of several minutes. Each pile was then subsequently driven to its full depth with a sequence of repeated hammer blows. Steel facing piles were inserted adjacent to the quayside and subsequently backfilled to provide a new frontage to the quay. Diagonal-bearing piles were also inserted well behind the quay to strengthen the adjacent roadway.

Sound pressure levels generated by pile driving in water were measured using a calibrated hydrophone suspended 1 m above the bottom. The hydrophone was connected to a low-noise amplifier, which controlled the signal gain and bandwidth. The output was connected to a laptop PC by a digital audio interface. When recording at close range, where sound levels were especially high, a less-sensitive hydrophone transducer was used, connected directly to the audio interface. All sound recordings were made as 16-bit WAV files. For some of the piles, particle-velocity amplitudes were measured by means of an assembly of three orthogonally mounted, calibrated geophones placed on the seabed.

The sound-pressure levels (SPL) of the background noise and vibro-piling noise were measured as a root-mean-square (rms) level expressed in decibels relative to a reference level of one micro Pascal (dB re 1 μ Pa). The shorter-duration impulsive sounds generated by the individual blows of the pile-driver hammer were measured in several different ways: the peak pressure reached during the impulse, the rms pressure measured over the time period that contained 90% of the sound energy (rms impulse), and as the sound-exposure level (SEL) expressed in dB re 1 μ Pa²-s. The latter was defined as the constant sound level of 1s duration that would contain the same acoustic energy as the original sound. Sound levels were converted to source levels (SL), i.e., normalized to an equivalent noise level at a distance of 1 m. In all SL calculations, it was assumed that the spreading loss was represented by the expression 15 log R where R was the distance in meters.

Received sound level in water may be expressed in terms of sound pressure, particle velocity, or intensity, all of which can vary with time over the duration of the sound. In this study, the majority of measurements were expressed in terms of sound pressure. However, it was recognised that it was really necessary to determine the particle velocities as this is the stimulus which is received by the ear of a fish like the salmon. On a few occasions, the particle velocities were measured and the acoustic intensity calculated.

Background-noise levels within the harbor and even within the river itself were high, within the range 118 – 149 dB re 1 μ Pa rms over a bandwidth of 10 Hz-10 kHz. Much of the noise derived from manoeuvring and stationary ships. The sound-pressure levels generated in water by percussive pile driving were very high, but variable depending on the pile type, the substrate being penetrated, the distance from the source, and whether the bubble curtain was in operation. Within the harbor, they ranged from 142-176 dB re 1 μ Pa peak, with sound exposure levels (SELs) of between 133-154 dB re 1 μ Pa²-s, without the bubble curtain in operation. Estimated source levels ranged from 177-202 dB re 1 μ Pa peak. Within the river, more than 220 meters away from the pile driver and separated from it by a spit of land, the sound-pressure levels reaching the fish ranged from 162-168 dB re 1 μ Pa peak, with SELs of between 129-145 dB re 1 μ Pa²-s. Sounds measured at a distance from the source within the harbor consisted of a low-frequency pre-pulse, followed by the main sound pulse. In this case, and in the river itself, the sound was propagated through the substrate, as well as the water, perhaps accompanied by flexural waves at interfaces between strata. Particle velocities within the harbor and in the river reached 110 dB re 1 nms⁻¹, mainly in a vertical direction, and intensities of up to 0.023 Wm⁻² were registered.

The main energy generated by the percussive pile driver extended up to and above 10 kHz close to the source, with most of the energy below 2 kHz. By the time the sound reached the river the higher frequencies had been removed and the predominant frequencies were below 1 kHz, still with considerable energy within the hearing range of salmon (which declines above 250 Hz).

Vibro-piling also generated high sound levels in water, with sound-pressure levels within the harbor ranging from 142-155 dB re $1\mu\text{Pa}$ rms and source levels between 173-185 dB re $1\mu\text{Pa}$ rms. Levels in the river ranged from 140-143 dB re $1\mu\text{Pa}$ rms.

A bubble curtain was successful in reducing the peak amplitude of the sound from the pile driver by up to 5 dB and in reducing the high-frequency content of the sound. The bubbles therefore reduced the likelihood of damage or injury to fish. However, they did not reduce energy at the lower frequencies to which fish are sensitive, especially at a distance from the source.

The principal purpose of monitoring the pile driving was to assess the impact upon salmon. There is some controversy and uncertainty about the actual levels of pile-driving sound which affect fish adversely. It is evident that sound affects different species to a differing degree. Thus, although in some instances a level of 180 dB re $1\mu\text{Pa}$ has been adopted as a standard, above which sounds are likely to kill or cause damage to fish, this is a very uncertain figure which is open to question. It was concluded that the sound pressure levels (SPLs) and sound exposure levels (SELs) generated by percussive pile driving within the harbor were not likely to have killed fish, whether the fish were within the river or the harbor itself. However, the sound levels were high enough close to the pile driver to injure or induce hearing loss in some species of fish. The noise from pile driving in the harbor was certainly high enough to be detected by salmon in the river at considerable distances from the source. The levels of sound from both percussive and vibro-piling were well above the hearing thresholds of the fish. As salmon could not be observed during this exercise, it was not possible to determine whether salmon reacted adversely to the sounds. However, there was a risk that their upstream migration may have been delayed or prevented with consequent effects upon spawning populations. The measurements indicated that any pile driving within the river itself would have the potential to injure or induce hearing loss in salmon and might have adverse effects upon their behavior.

During this exercise, trains of low frequency 'thumping' sounds were recorded within the River Dee, similar to those made by fish. The sounds may be emitted by European eels, which are common at the location.

Biographical Sketch: Tony Hawkins is the managing director of Loughine Limited and an honorary professor at the University of Aberdeen in Scotland. His research interests include underwater acoustics and the sounds made by fish. He is a former director of fisheries research for Scotland and is currently chair of the North Sea Commission Fisheries Partnership, which brings scientists and fishermen together from around the North Sea. Loreetue molor sum zzrit praestrud ent lametum zzrit lore ming ectet ex er sit alisl doloretue consed exeril utat adignisl duisit lummolore modolorem in ut dolortis acilisl elit, con vel dolore min eugiatu sandre mod erit in endigna adip el dolenis odipsum dolenim doluptat.

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