Chapter 50

Multiple-Pulse Sounds and Seals: Results of a Harbor Seal (*Phoca vitulina*) Telemetry Study During Wind Farm Construction

Gordon D. Hastie, Debbie J.F. Russell, Bernie McConnell, Dave Thompson, and Vincent M. Janik

Abstract Offshore construction and survey techniques can produce pulsed sounds with a high sound pressure level. In coastal waters, the areas in which they are produced are often also used by seals, potentially resulting in auditory damage or behavioral avoidance. Here, we describe a study on harbor seals during a wind farm installation off southeast England. The study used GPS/global system for mobile communication tags on 23 harbor seals that provided distribution and activity data; the closest range of individual seals to piling varied from 6.65 to 46.1 km. Furthermore, the maximum predicted received levels (RLs) at individual seals varied between 146.9 and 169.4 dB re 1 μPa peak to peak.

Keywords Pinniped • Propagation • Offshore wind farm • Renewables

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G.D. Hastie (✉) • B. McConnell • D. Thompson • V.M. Janik
Sea Mammal Research Unit (SMRU), Scottish Oceans Institute, University of St. Andrews, St. Andrews Fife KY16 8LB, UK
e-mail: gdh10@st-andrews.ac.uk; bm8@st-andrews.ac.uk; dt2@st-andrews.ac.uk; vj@st-andrews.ac.uk

D.J.F. Russell
Sea Mammal Research Unit (SMRU), Scottish Oceans Institute, University of St. Andrews, St. Andrews Fife KY16 8LB, UK

Centre for Research into Ecological and Environmental Monitoring, University of St. Andrews, St. Andrews Fife KY16 9LZ, UK
e-mail: dr60@st-andrews.ac.uk

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1 Background

1.1 Pulsed Noise in the Marine Environment

Man-made pulsed sounds are now commonplace in the marine environment; these are either produced intentionally (e.g., seismic surveys or sonar) or as a by-product of an activity (e.g., explosives or pile driving). The production of such sounds is likely to increase in the coming years as the petroleum industry expands into new offshore areas and with ambitious renewable energy targets in many countries, offshore wind farm construction will increase. Pulsed sounds from these activities are some of the most powerful produced underwater; for example, peak-to-peak (pp) source noise levels of pile driving monitored by Nedwell et al. (2007) ranged between 243 and 257 dB re 1 μPa_{pp} at 1 m. Similarly, source levels of seismic pulses have been estimated up to ~263 dB re 1 μPa_{pp} at 1 m (Gordon et al. 2004).

The production of these sounds has raised concerns about potential adverse impacts on some marine mammals; many proposed development areas overlap with the at-sea distribution of seals and pulsed sound appears to have the potential to elicit overt behavioral responses (Gordon et al. 2004).

Dedicated studies of the at-sea behavior of seals in response to pulsed sound are extremely limited. However, a small number of observational studies of animals at the surface around industrial activity exist; for example, sightings rates of ringed seals (*Phoca hispida*) from a seismic vessel in shallow Arctic waters showed no difference between periods with the full array, partial array, or no guns firing (Harris et al. 2001). Similarly, observation of ringed seal behavior during impact pipe-driving sounds in Alaska revealed that they exhibited little or no reaction, swimming near to the activities throughout construction and as close as 46 m from the pipe-driving operation (Blackwell et al. 2004).

In one of the few dedicated behavioral studies on individual responses to pulsed sounds, Thompson et al. (1998) carried out controlled exposures using small seismic air guns (source level [SL], 215–224 dB re 1 μPa_{pp} at 1 m) to harbor and gray seals (*Halichoerus grypus*) fitted with telemetry devices. These provided information on the movement, dive behavior, and swim speeds of the seals throughout the exposures. In contrast to the studies described above that showed an apparent lack of a response by animals (Harris et al. 2001; Blackwell et al. 2004), in six of eight trials with harbor seals, the animals exhibited strong avoidance behavior, swimming rapidly away from the source. Stomach temperature tags indicated that they also ceased feeding during this time. Only one seal showed no detectable response to the guns and approached to within 300 m of them. Similar avoidance responses were documented during all the trials with gray seals; they changed from making foraging dives to V-shaped transitting dives and moved away from the source. It was suggested that the responses to more powerful commercial arrays might be expected to be more extreme, longer lasting, and occurring at greater ranges.

Recent research by Götz and Janik (2011) provides insights into the physiological basis of the responses by seals that is highly relevant to multiple-pulsed sound. This work highlighted the role of the mammalian startle reflex, a fast motor response that is elicited if a stimulus has a sudden onset and exceeds a certain intensity threshold (Yeomans et al. 2002) that may facilitate a flight response. The startle reflex can be elicited by stimuli with certain acoustic parameters that pulsed sound often exhibits. For example, in rats, the acoustic startle requires a stimulus to reach an intensity of 80–90 dB above the hearing threshold within about 15 ms of its onset (Flesher 1965). Götz and Janik (2011) presented evidence of spatial avoidance behavior in captive gray seals to a "startle pulse" (a band-limited sound pulse with a peak frequency of 950 Hz spanning ~2 octaves); received levels ranged from 170 to 174 dB re 1 μPa.

Important when considering the multipulsed nature of sounds from seismic surveys or pile driving is that Götz and Janik (2011) presented evidence that repeated elicitation of the acoustic startle reflex leads to a rapid and pronounced sensitization (an increased responsiveness to a stimulus) of sustained spatial avoidance behavior in gray seals. Seals developed rapid flight responses, left the exposure pool, and showed clear signs of fear conditioning. Once sensitized, seals even avoided a known food source that was close to the sound source. In contrast, animals exposed to nonstartling (long rise time) stimuli of the same maximum sound pressure habituated, and flight responses waned or were absent from the beginning. The authors concluded that startle-eliciting noise pulses have the potential to cause severe effects on long-term behavior, individual fitness, and longevity of individuals in wild animal populations (Götz and Janik 2011); this has clear implications for the repeated use of pulsed noise during activities such as seismic surveys or pile driving.

In response to the relative paucity of empirical data on the at-sea behavior of seals in response to pulsed sound, we carried out a study on harbor seal behavior during the construction of the Lincs Offshore Wind Farm in the North Sea.

2 Methods

2.1 Telemetry

To measure the movements and proximity of seals at sea to pile driving, GPS/global system for mobile communication (GSM) tags (McConell et al. 2010) were deployed on 25 harbor seals in the Wash, southeast England, in January 2012 and stayed on the animals for up to 5.5 month. The GPS/GSM tags are data loggers that attempt to record the location of a seal at regular intervals using a hybrid GPS system. Stored location and behavioral data are opportunistically relayed ashore by means of an embedded mobile phone (GSM) modem when the tag comes within mobile phone coverage. These tags provided fine-scale distribution and activity data (seal locations approximately every 15 min), allowing the investigation of movements during pile driving.

Seals were captured while hauled out on intertidal sandbanks. Once captured, the seals were anesthetized with Zoletil or Ketaset. The tags were attached to the fur at the back of the neck using a rapid-setting epoxy resin. A series of morphometric measurements and biological samples were taken.

2.2 Pile Driving

Throughout the period of tag deployment, a total of 31 pile foundations (5-m-diameter piles) were installed using impact pile driving at the Lincs Offshore Wind Farm. The pattern of piling was characterized by intermittent periods of piling (~4–5 h in length) followed by gaps of between a few hours to a few days. Within an individual pile installation, the blow energy was generally characterized by a "ramp up" in blow energy. In general, there is a gradual ramp up to ~700 kJ over the first 60 min before increasing to a full blow energy of ~2,000 kJ for the remaining installation.

To estimate pile-driving SLs, peak-to-peak SLs, estimated by Nedwell et al. (2011) during the installation of piles at the same wind farm, were corrected for changes in blow energy using recordings made with an autonomous moored sound recorder (DSG-Ocean Acoustic Datalogger, Loggerhead Instruments). Received levels (RLs) at each seal were then estimated using data on the timing and associated blow energy for every piling blow using range-dependent acoustic models (Collins 1993) that account for the geoacoustic properties of the subbottom and the discontinuity of these properties at the interface (Jensen et al. 1994); modeling was carried out using the RAMSGeo model in the acoustic toolbox user-interface and postprocessor (AcTUP V2.2 L, Curtin University, Perth, Australia) software. Transmission loss was calculated at 1-km intervals along 5° radii from the piling source location out to a range of 120 km; seal locations were then matched to the predicted RLs at interpolated 1-s intervals along each seal's track. The RLs were validated using a series of boat-based hydrophone recordings during the installation of one of the piles. Recordings were made between 1,000 and 9,500 m from the piling; overall mean error in the predictions at these ranges was 3.3 ± 1.7 (SD) dB re 1 μPa_{pp}.

3 Results

At the end of January 2012, 25 GPS/GSM tags were deployed, of which 22 stayed operational on the animal for over 1 week. All data were cleaned according to Sea Mammal Research Unit (SMRU) protocol (Russell et al. 2011). Throughout the study, the seals regularly moved between haul-out sites on sandbanks around the Wash to areas offshore. During these transits to sea, the seals routinely swam past the wind farm site. The seals were also at sea during pile-driving events; the closest distance of individual seals to active pile-driving locations varied between 6.7 and 46.1 km. All seals therefore also received sound from the pile driving, with maximum predicted RLs at individual seals varying between 146.9 and 169.4 dB re 1 μPa_{pp}.

4 Discussion

Our study illustrates the value of telemetry-based studies to understand the behavior of a wide-ranging species and the potential impacts of anthropogenic sound on movements.

In general, seals made regular movements between haul-out sites on intertidal sandbanks and areas offshore (presumed to be used for foraging). Furthermore, each seal was present in offshore areas during pile driving at some point during the study. Although the seals continued to transit between the haul outs and areas at sea during the study, it should be noted that no seals came closer than 6.7 km to the piling location when pile driving was being carried out. However, without full analyses of behavioral metrics, it is currently unclear whether the patterns of movement and activity are significantly different between periods of piling and nonpiling. Nevertheless, data on the movements by seals around sound fields such as these provide an opportunity for a detailed assessment of levels that may elicit behavioral responses and allow the investigation of the implications of such movements on physiological effects such as auditory damage.

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