moray offshore renewables ltd

Environmental Statement

Technical Appendix 7.3 D - A comparison of behavioural responses by harbour porpoises and bottlenose dolphins to noise: Implications for wind farm risk assessments

Telford, Stevenson, MacColl Wind Farms and associated Transmission Infrastructure Environmental Statement

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APPENDIX 7.3 D

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APPENDIX 7.3 D

1. Background

Moray Offshore Renewables Ltd (MORL) and Beatrice Offshore Wind farm Ltd (BOWL) are currently in the process of assessing the risk posed to marine mammals by construction and operation of the wind farms in the Moray Firth. As part of this, predictions of the behavioural responses to noise created by impact piling have been estimated. However, as there is a high degree of uncertainty associated with species responses to noise, a number of broad assumptions have been made during the assessment process. Specifically, in the absence of empirical data for most species, data on behavioural responses by harbour porpoises (*Phocoena phocoena*) have been used to predict behavioural responses by bottlenose dolphins (*Tursiops truncatus*). The aim of this report is to provide supporting evidence to help contextualise bottlenose dolphins predictions made using harbour porpoise response data by reviewing and comparing data on each species responses to noise.

While the prediction of whether an animal could detect a sound can be made using a combination of empirical studies and acoustic models, predicting the reaction of an individual animal to that sound is extremely challenging and is likely to be highly context specific (Southall et al., 2007; Ellison et al., 2011); the probability of responding will be governed by many factors, including received sound level, hearing sensitivity, as well as age, nutritional state (hungry or satiated), behavioural state (foraging, resting, migrating etc.), reproductive state (pregnant, lactating, juvenile, mature), location and conditioning from previous exposure .

The most complete review of behavioural responses by marine mammals to date is found in Southall et al (2007). Although the step-threshold exposure criteria are now used widely to predict the risk of auditory damage to marine mammals, it was noted by Southall et al (2007) that data on behavioural responses are so limited that

"*insufficient information exists to assess the use of SEL as a relevant metric in the context of marine mammal behavioural disturbance for anything other than a single pulse exposure*" (Southall et al., 2007).

A further issue is that individuals in wild populations are unlikely to respond at consistent received levels (i.e. at a step-threshold), and it is generally more appropriate to consider responses in terms of a dose-response curve that describes the relationship between sound level and the probability of an animal exhibiting a response rather than a simple step-change threshold. To address this, Thompson et al (2011) carried out a modelling exercise using results of a passive acoustic monitoring study (using C-PODS) which reports harbour porpoise responses to pile driving activity at Horns Rev 2 (Brandt et al., 2011). To predict the level of behavioural response, data from Brandt et al. (2011) were used to model changes in the occurrence of porpoises in relation to predicted received sounds levels resulting from a nearby piling event.

Thompson et al (2011) used these data to model the extent of the proportional change with distance by fitting a binomial relationship to the data. Using published data on the size of the pile, together with information on local bathymetry received noise levels were estimated at each of the C-POD sampling sites at Horns Rev 2. A precautionary relationship that was weighted to include the higher response levels was then used to predict the response of porpoises at different received noise levels (dB_{ht} levels).

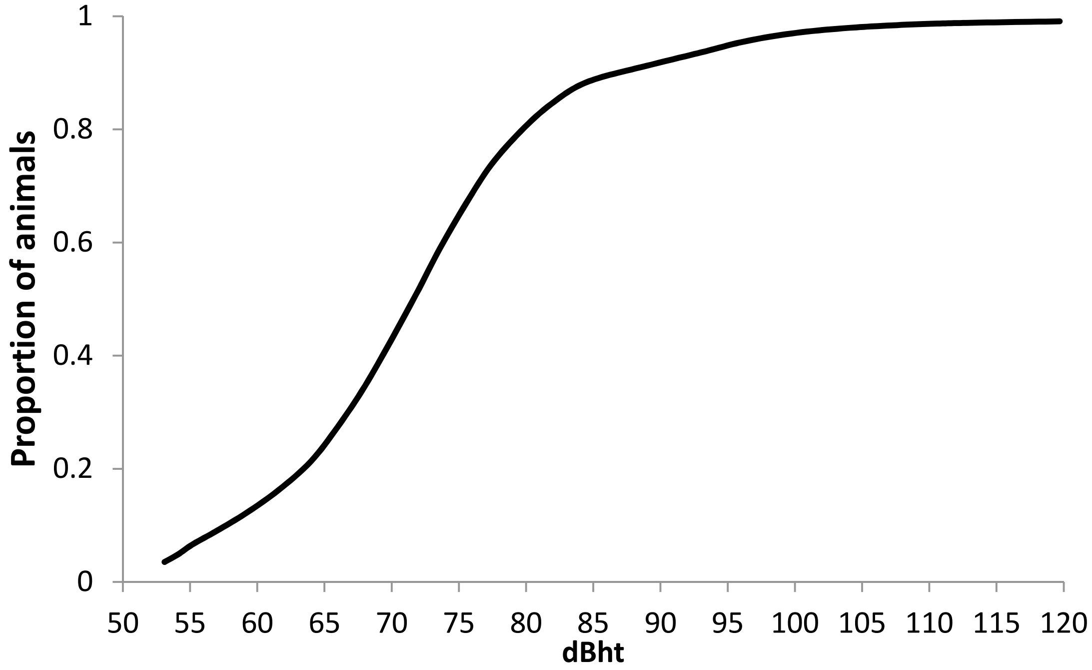

Figure 1: The relationship between sensation level (dB_{ht}) for harbour porpoises and the predicted proportion of animals excluded from the area (taken from Thompson *et al.*, 2011).

In the absence of similar empirical data for bottlenose dolphins, this relationship was also used as a proxy for this species (with the underlying assumption that this relationship holds for similar sensation levels for bottlenose dolphins) during the MORL and BOWL impact assessments. However, when making this cross-species assumption, it is important to review supporting evidence to assess whether this is robust or whether it is likely to lead to conclusions that are more or less precautionary. To assist in this, we summarise the life history of each species and carry out a review of the noise levels that have been reported to elicit behavioural responses by harbour porpoises and bottlenose dolphins to allow us to contextualise the responses predicted during the impact assessment process. Furthermore, we investigate whether data are available to assess noise budgets for each species around the east coast of Scotland.

It is important to highlight that this report does not attempt to support specific numerical criteria for the onset of disturbance but rather points to some general conclusions about how response severity compares between the two species.

2. Life history

The likelihood of an animal responding to a perceived threat by exhibiting directional flight behaviour is likely to be dictated by a number of factors including predation pressure and life history traits. In particular, predation pressure is mediated through the adaptive flexibility of prey behaviour in response to fluctuating risk of predation. Thus, the mere presence of a predation pressure or perceived threat can have a range of effects on a prey animals habitat choice, activity schedule and behaviour. For example, the risk of shark predation influences habitat use by bottlenose dolphins in western Australia (Heithaus and Dill, 2002) and responses to hearing killer whale vocalisations can lead to high-speed directional swimming and rapid movement into shallow water by small cetaceans (Saulitis et al., 2000).

To compare the likelihood that bottlenose dolphins and harbour porpoises will respond to a perceived threat (such as pile driving), a review of the morphological, behavioural and life history traits of each species, as well as the levels of predation under which each species lives was carried out.

2.1 Harbour porpoises

The harbour porpoise (*Phocoena phocoena*) is one of the smallest cetacean species reaching approximately 160 cm in length and 60 kg in weight (Bjorge and Tolley, 2002). They are present in the Moray Firth throughout the year and current population estimate for the North Sea and surrounding waters is 341,366 (Hammond et al., 2002). In terms of life history, because of their annual reproduction, early maturation, relatively short lifespan and high daily energy demands (Kastelein et al., 1997; Hoelzel, 2002), this species sits at a relative extreme when compared to most other cetaceans. Their high reproductive rate means females are pregnant or lactating for much of the year resulting in a high dependency on food resources to maintain energy reserves (Kastelein et al., 1997). Although knowledge on their social structure remains limited (due to inherent difficulties in studying this species) they appear to have a relatively solitary lifestyle, with most sightings consisting of just one or two animals. Larger aggregations occasionally occur, but with the exception of mother-calf pairs, there appears little evidence for strong associations between individuals.

Perceived predation pressure on harbour porpoises in the northeast Atlantic may be relatively high. For example, killer whales are key predators on harbour porpoises elsewhere (Saulitis et al., 2000) and have been observed predating on porpoises in the northeast Atlantic (C. Booth Pers. Comm). Furthermore, historically higher numbers of killer whales may have placed additional predation pressure on these animals (Ford et al., 1998; Bolt et al., 2009; Deecke et al., 2011). Recent evidence of mortality due to interactions with bottlenose dolphins has also been highlighted with an estimated 50% of mortality in stranded animals on the east coast of Scotland being attributed to bottlenose dolphins (Ross and Wilson, 1996; Patterson et al., 1998). In Scotland, recent sighting data from wildlife watching vessels suggest that the probability of sighting harbour porpoises is lower in presence of bottlenose dolphins (Thompson et al., 2004) supporting the theory that harbour porpoises may actively avoid situations perceived as a threat. These factors have potentially led to increased sensitivity to changes or disturbances in their external environment.

2.2 Bottlenose dolphins

In contrast to harbour porpoises, bottlenose dolphins appear to have a relatively dynamic social system, with individuals in some populations forming strong social bonds (Connor, 2000) and others exhibiting a far more fluid system (Wilson, 1995a). On the east coast of Scotland there is a resident population ranging from the Moray Firth to Fife (Cheney et al., 2012). The population size is estimated at approximately 195 individuals with animals reaching up to 4 m in length and 650 kg in weight (Wilson, 1995b; Cheney et al., 2012). Bottlenose dolphins have a relatively long lifespan compared to harbour porpoises, with individuals taking longer to reach sexual maturity and investing heavily in their young (Hoelzel, 2002). As described above, they also form a more fluid social system and are generally encountered in groups of several animals. Group composition can change on a daily or hourly basis with animals having high encounter rates with one another (Connor, 2002). Bottlenose dolphins in the Moray Firth can potentially communicate over relatively large ranges and this, coupled with a patchy distribution of food, has led to loose associations between both males and females (Islas, 2009). Off the east coast of Scotland, they have no significant predation threats and do not appear to face overt competition for food with other marine mammal species (although they are known to frequently attack harbour porpoise which may stem from competition (Ross and Wilson, 1996; Patterson et al., 1998)). When compared to harbour porpoises, these factors have potentially led to a relatively high tolerance to perceived threats or disturbances in their external environment.

3. Review of behavioural responses to noise

A review of behavioural responses by harbour porpoises and bottlenose dolphins to noise in published articles was carried out; we used Southall et al (2007) as a basis for studies prior to 2007 and a carried out a review of the literature since then to identify more recent studies.

Southall et al (2007) utilised an ordinal severity scale based generally on the NRC's (2005) Population Consequences of Acoustic Disturbance (PCAD) Model; Table 1). The severity scale was designed to provide an analytical basis for assessing biological significance, but had to be rooted in the kinds of descriptions provided in the available scientific literature. These analyses were limited to peer-reviewed literature (published or in press) and peer-reviewed technical reports. Southall et al's (2007) goal was to review the relevant scientific literature, tally behavioural effects by the type of acoustic exposure for each category of marine mammal and sound type, and draw any conclusions that were appropriate based on the information available.

For studies published after 2007, the same severity scaling was used to score behavioural responses by individuals/groups (Table 1). However, for analytical purposes, each of the ordinal scores was scaled to between 0 and 1 (where 0=0.0, 1=0.1, 2=0.2, 3=0.3, 4=0.4, 5=0.6, 6=0.7, 7=0.8, 8=0.9, and 9=1.0). In articles where a range of received sound pressure levels (RLs) were reported (e.g. 120-150 dB), the lower value (e.g. 120 dB) was used.

Data for harbour porpoises and bottlenose dolphins (and other coastal dolphins) were collated and presented in terms of measured (or estimated RL and a score of the observed response. These were then analysed in a generalised linear modelling framework; models were created using the software package R version 2.8.1 (R Development Core Team 2011). The predictor variable in modelling procedure was RL (dB re 1µPa) and the response term was the level of behavioural response (0-1). The family specified in the model was *binomial.*

As described above, we do not attempt to support specific numerical criteria for the onset of disturbance but rather we look to provide some general conclusions about how response severity compares between the two species. Furthermore, current understanding of the influences of contextual variables on behavioural responses in free-ranging marine mammals is very limited and the analyses presented here should be considered with these cautions and caveats in mind.

Table 1: Severity scale for ranking observed behavioural responses of free-ranging marine mammals and laboratory subjects to various types of anthropogenic sound (taken from Southall *et al.*, 2007).

Response score[1]	Corresponding behaviors (Free-ranging subjects)[2]	Corresponding behaviors (Laboratory subjects)[2]
0	- No observable response	- No observable response
1	- Brief orientation response (investigation/visual orientation)	- No observable response
2	- Moderate or multiple orientation behaviors - Brief or minor cessation/modification of vocal behavior - Brief or minor change in respiration rates	- No observable negative response; may approach sounds as a novel object
3	- Prolonged orientation behavior - Individual alert behavior - Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Moderate change in respiration rate - Minor cessation or modification of vocal behavior (duration < duration of source operation), including the Lombard Effect	- Minor changes in response to trained behaviors (e.g., delay in stationing, extended inter-trial intervals)
4	- Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Brief, minor shift in group distribution - Moderate cessation or modification of vocal behavior (duration ≈ duration of source operation)	- Moderate changes in response to trained behaviors (e.g., reluctance to return to station, long inter-trial intervals)
5	- Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Moderate shift in group distribution - Change in inter-animal distance and/or group size (aggregation or separation) - Prolonged cessation or modification of vocal behavior (duration > duration of source operation)	- Severe and sustained changes in trained behaviors (e.g., breaking away from station during experimental sessions)
6	- Minor or moderate individual and/or group avoidance of sound source - Brief or minor separation of females and dependent offspring - Aggressive behavior related to noise exposure (e.g., tail/flipper slapping, fluke display, jaw clapping/gnashing teeth, abrupt directed movement, bubble clouds) - Extended cessation or modification of vocal behavior - Visible startle response - Brief cessation of reproductive behavior	- Refusal to initiate trained tasks
7	- Extensive or prolonged aggressive behavior - Moderate separation of females and dependent offspring - Clear anti-predator response - Severe and/or sustained avoidance of sound source - Moderate cessation of reproductive behavior	- Avoidance of experimental situation or retreat to refuge area (≤ duration of experiment) - Threatening or attacking the sound source
8	- Obvious aversion and/or progressive sensitization - Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms - Long-term avoidance of area (> source operation) - Prolonged cessation of reproductive behavior	- Avoidance of or sensitization to experimental situation or retreat to refuge area (> duration of experiment)
9	- Outright panic, flight, stampede, attack of conspecifics, or stranding events - Avoidance behavior related to predator detection	- Total avoidance of sound exposure area and refusal to perform trained behaviors for greater than a day

[1]Ordinal scores of behavioral response severity are not necessarily equivalent for free-ranging vs laboratory conditions.
[2]Any single response results in the corresponding score (i.e., all group members and behavioral responses need not be observed). If multiple responses are observed, the one with the highest score is used for analysis.

3.1 Harbour porpoises

With respect to harbour porpoises there were limited data available on behavioural responses to sound; furthermore, very few of the studies where data were available involved sufficient controls and measurements to make robust conclusions. The review by Southall et al. (2007) concludes that due to uncertainty over the extent to which some of these signals may be perceived by this species and the overarching paucity of data, it was not possible to present any data on behavioural responses of high-frequency cetaceans (which includes harbour porpoises) as a function of received levels of multiple pulses (e.g. pile driving). For non-pulsed noise (e.g. vessel noise), Southall et al. (2007) report that moderate level changes in behaviour (level 4 and above on the ordinal scale; Table 1) by harbour porpoises have been observed at received levels of 80 - 170 dB re 1μPa.

A number of studies published since Southall et al. (2007) have reported behavioural responses by harbour porpoises to noise (Kastelein et al., 2008b; Lucke et al., 2009; Tougaard et al., 2009; Brandt et al., 2011); these report moderate to high level responses at wide range of RLs (100 and 180 dB re 1μPa).

When the response indices are plotted against RL, it is clear that responses by harbour porpoises are highly variable; however, there was a general positive trend with more overt responses with higher received levels (Figure 2). Overall, moderate level responses were observed at levels above 80 dB re 1μPa (Figure 2).

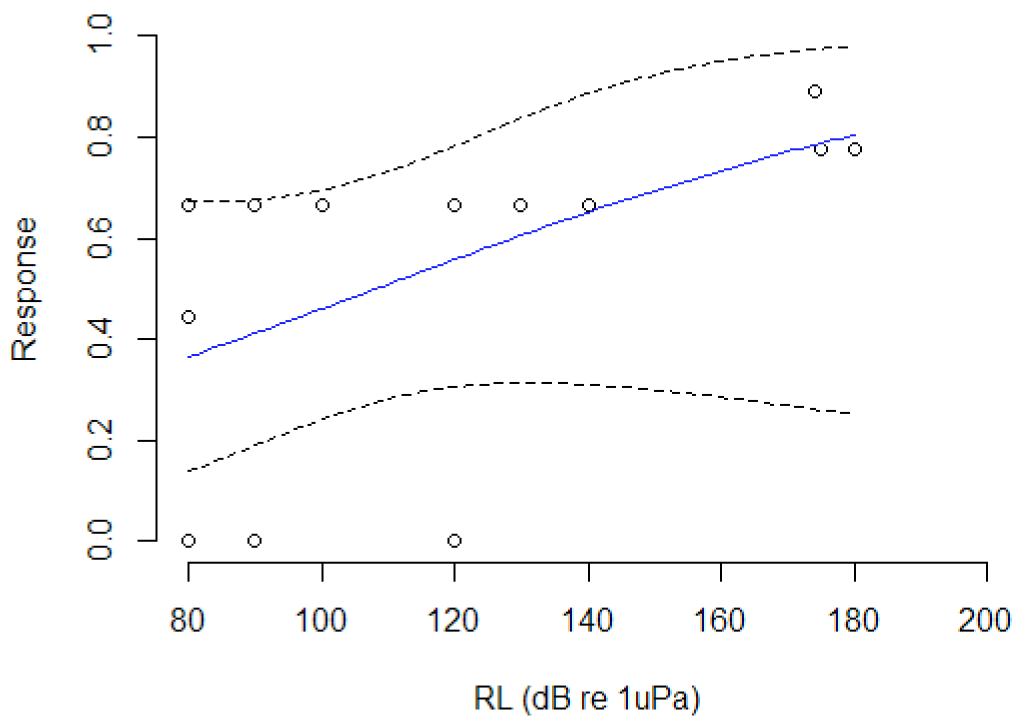

Figure 2: Relationship between received sound level (RL) and the rescaled ordinal response index for harbour porpoises.

3.2 Bottlenose dolphins

As with the harbour porpoises, there were relatively few studies that report behavioural responses alongside measured or predicted received levels (Appendix 1). The review by Southall et al. (2007) did not highlight any data on behavioural responses to pulsed noise; however, other mid-frequency cetaceans exhibited moderate level responses (level 4 and above on the ordinal scale (Table 1)) at received levels of between 120 and 180 dB re 1µPa. For non-pulsed noise, Southall et al. (2007) report moderate level changes in behaviour by bottlenose dolphins (and other dolphins) at received levels of 120 - 180 dB re 1µPa.

Studies published since Southall et al. (2007) on behavioural responses by dolphins to noise are very limited but one has reported moderate level responses to non-pulsed noise by bottlenose dolphins at RLs of 140 dB re 1µPa (Niu et al., 2012); furthermore, a study of Risso's dolphins reported no response at levels of 135 dB re1µPa (Southall et al., 2010).

As with harbour porpoises, when the response indices are plotted against RL, the level of response by dolphins appears highly variable; however, there was a general positive trend with more overt responses with higher received levels. Overall, moderate level responses were observed at levels above 140 dB re 1µPa (Figure 3).

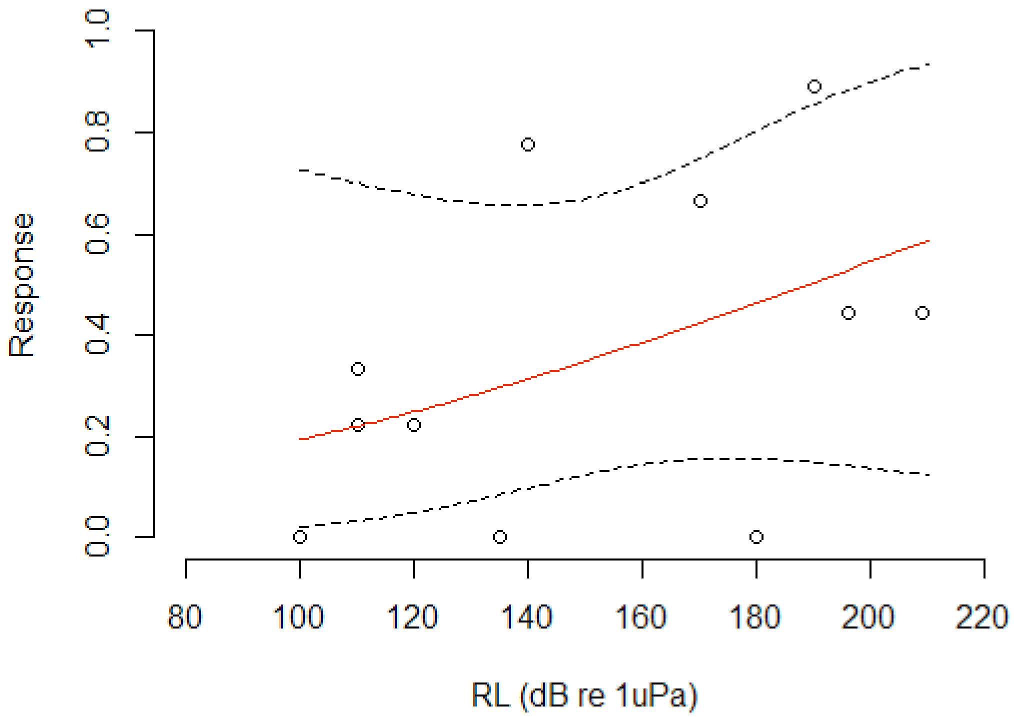

Figure 3: Relationship between received sound level (RL) and the rescaled ordinal response index for coastal dolphins.

3.3 Species comparison

Although the studies that have been reviewed here reported responses to a number of different sound sources with a wide range of different characteristics (sound pressure level, frequency and duration), it is possible to make some broad conclusions from the results. Firstly, it is clear that responses by both species exhibit a high degree of variability, highlighting the fact that step thresholds are generally inappropriate for predicting behavioural responses. Secondly, both species have positive relationships between RL and the level of behavioural response suggesting that both species are likely to exhibit more overt responses to higher sound levels.

As a likely result of small sample size, the differences in response level by each species to received sound level was not significant (GLM: Deviance=0.55, df=1, P=0.46). In other words, the results suggest that bottlenose dolphins do not exhibit significantly higher level responses to noise than harbour porpoises; in fact, comparison of the best-fit relationships are indicative of higher level responses by harbour porpoises than bottlenose dolphins at similar noise levels (Figure 4). For example, moderate level changes in behaviour (level 4 and above on the ordinal scale (Southall et al., 2007) and 0.44 on the scale in this report) were predicted to occur at approximately 50-60 dB re 1 µPa lower in harbour porpoises than in dolphins (Figure 4). Again it is important to highlight that we have not attempted to define or support specific numerical criteria for the onset of disturbance but rather have attempted to compare how response severity may compare between the two species.

In general, it is clear that both harbour porpoises and bottlenose dolphins exhibit behavioural responses to underwater noise. However, it is important to highlight that there are a number of documented cases of apparent tolerance by marine mammals to noise and although some are documented here, there is a clear risk that these are under-represented in the review due to the nature of scientific journals being more likely to publish a positive rather than a negative result. These results should therefore be considered with this in mind.

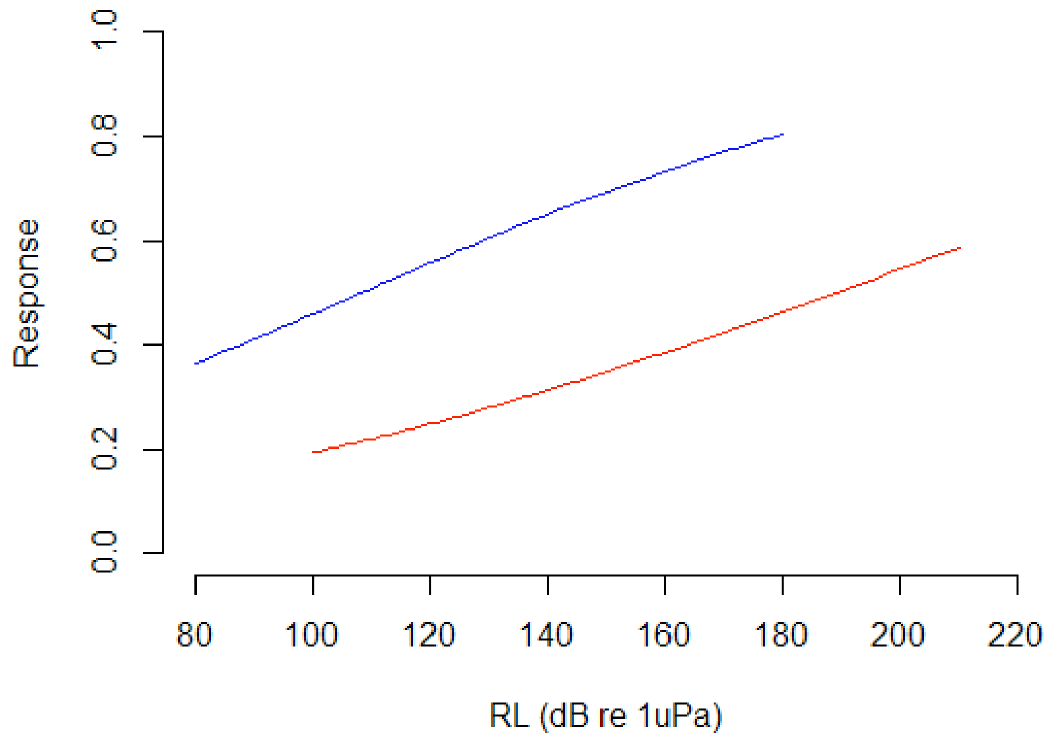

Figure 4: Figure showing the response indices for harbour porpoises (blue) and dolphins (red) illustrating the relative differences in predicted responses with received sound level (RL).

4. Review of noise exposure in Scottish East Coast bottlenose dolphins

As described above, there are a number of documented cases of apparent tolerance by cetaceans to noise. For example, bowhead whales (*Balaena mysticetus*) tolerated an increase in 40 dB in seismic survey noise when feeding in summer than during the fall migration, where broadband received levels of airgun pulses corresponding to avoidance were ≥120 – 130 dB re 1 μPa (RMS over pulse duration)(Richardson et al., 1995). Other examples of apparent tolerance can be found in sperm whales (*Physeter macrocephalus*) with seismic surveys in Norway (Madsen et al., 2002) and detonators (Madsen and Mohl, 2000), and in blue (*Balaenoptera musculus*) and fin whales (*Balaenoptera physalus*) with respect to LFA sonar (Croll et al., 2001).

It is likely that, to a certain degree, behavioural tolerance will be governed by individual experience of previous exposure to noise. In general, the use of coastal habitats by bottlenose dolphins exposes them to higher levels of human activities than many other cetaceans (Nowacek et al., 2001). From this perspective, a review of the likely levels and frequency of noise exposure by both bottlenose dolphins and harbour porpoises was proposed for this report. However, although a number of relatively long-term acoustic recordings have been made in the Moray Firth; calibrated recordings required to measure absolute sound levels are extremely limited (P. Thompson, Pers. Comm.) and would be insufficient to make reliable estimates of sound levels routinely encountered by each species.

Nevertheless, a number of data sources on the spatial and temporal patterns of anthropogenic noise sources (primarily vessels) were available in the literature and may provide a proxy for each species exposure to high levels of noise. For example, investigation of the data used by Hastie et al (2003) showed that in a key hotspot for dolphins in the Inner Moray Firth, approximately 18% of the dolphin schools that were sighted had vessels present within a few hundred metres. Furthermore, recent modelling of vessel distributions in the Moray Firth predict that in certain near-shore areas frequented by dolphins, average daily vessel hours in 1km grid cells can exceed 8 hours. In contrast, offshore areas of the Moray Firth were predicted to have relatively low levels of boat traffic (generally <2 hours per 1km grid cell) (Lusseau et al., 2011).

This study (Lusseau et al., 2011) also examined vessel exposure on an individual dolphin basis and predicted that mean vessel exposure for individual dolphins ranged between 0.698 (SD= 0.40) and 1.11 (SD=0.97) hours per day. Given the predicted low density of vessels further offshore, it is likely that individual harbour porpoises would experience markedly less noise exposure than the dolphins. Furthermore, this vessel associated noise within the inner Moray Firth is markedly less than noise levels that appear to be tolerated by other bottlenose dolphin populations; for example, in Sarasota, Florida, resident bottlenose dolphins share the inshore waters with over 34,000 registered boats, (Nowacek et al., 2001) resulting in individuals being exposed to a vessel passing within 100 m approximately every six minutes during daylight hours.

Although these results should not be interpreted as evidence that repeated exposure to noise does not influence the behaviour bottlenose dolphins, they do lend weight to the hypothesis that bottlenose dolphins as a species appear generally more tolerant of noise than harbour porpoises.

5. Conclusions

The likelihood of an animal responding to a perceived threat by exhibiting directional flight behaviour is dictated by a number of factors including predation pressure and life history traits. Perceived predation pressure on harbour porpoises in the Moray Firth may be relatively high; both from historical predation from killer whales and from current mortality due to bottlenose dolphins. In contrast, bottlenose dolphins in the Moray Firth do not appear to suffer any predation. Therefore, when compared to harbour porpoises, bottlenose dolphins potentially have a relatively high tolerance to perceived threats or disturbances in their external environment.

Through a review of behavioural responses by harbour porpoises and bottlenose dolphins to noise in published articles, it is possible to make some broad conclusions. Firstly, it is clear that responses by both species exhibit a high degree of variability. Secondly, both species appear to have positive relationships between received sound level and the level of behavioural response suggesting that both species are likely to exhibit more overt responses to higher sound levels. Furthermore, comparison of the best-fit relationship for bottlenose dolphins is indicative that they are less sensitive than harbour porpoises to similar noise levels.

From a risk assessment perspective, these results indicate that the use of a harbour porpoise behavioural dose/response is likely to be a precautionary approach to predicting bottlenose dolphins' responses that will potentially over-estimate impacts for this species; the results of the bottlenose dolphin behavioural response predictions should therefore be viewed in this context.

6. References

Barlow, J. & Cameron, G.A., 2003. Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. Marine Mammal Science, 19: 265-283.

Bejder, L., Samuels, A., Whitehead, H. & Gales, N., 2006. Interpreting short term behavioural responses to disturbance within a longitudina perspective. Animal Behaviour, 72: 1149-1158.

Bjorge, A. & Tolley, K.A., 2002. Harbour porpoise - *Phocoena phocoena*, In: Perrin, W.F., Wursig, B., Thewissen, J.G.M. (Eds.), Encyclopedia of Marine Mammals, Academic Press, Tromso, pp. 549-551.

Bolt, H.E., Harvey, P.V., Mandleberg, L., Foote, A.D., 2009. Occurrence of killer whales in Scottish inshore waters : temporal and spatial patterns relative to the distribution of declining harbour seal populations. Aquatic Conservation: Marine and Freshwater Ecosystems, 675: 671-675.

Brandt, M.J., Diederichs, A., Betke, K., Nehls, G., 2011. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series, 421: 205-216.

Buckstaff, K.C., 2004. Effects of watercraft noise on the acoustic behaviour of bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Marine Mammal Science, 20: 709-725.

Carstensen, J., Henriksen, E.O., Teilman, J., 2006. Impacts of offshore wind farm construction on harbor porpoises: acoustic monitoring of echo-location activity using porpoise detectors (T-PODs). Marine Ecology Progress Series, 321: 295-308.

Cheney, B., Thompson, P., Ingram, S., Hammond, P., Stevick, P., Durban, J., Culloch, R., Elwen, S., Mandleberg, L., Janik, V., Quick, N., Islas Villanueva, V., Robinson, K., Costa, M., Eisfeld, S., Walters, A., Phillips, C., Weir, C., Evans, P., Anderwald, B., 2012. Integrating multiple data sources to assess the distribution and abundance of bottlenose dolphins Tursiops truncatus in Scottish waters. Mammal Review, DOI: 10.1111/j.1365-2907.2011.00208.x

Chilvers, B.L., Corkeron, P.J., 2001. Trawling and bottlenose dolphins' social structure. Proceedings of the Royal Society of London Series B-Biological Sciences, 268: 1901-1905.

Connor, R.C., 2002. Ecology of group living and social beahviour, In: Hoelzel, A.R. (Ed.), Marine mammal biology: an evolutionary approach, Blackwell, Oxford, pp. 353-370.

Connor, R.C., Wells, R.S., Mann, J., Read, A.J., 2000. The Bottlenose Dolphin: Social relationships in a fission-fusion society, In: Mann, J., Connor, R.C., Tyack, P.L., Whitehead, H. (Eds.), Cetacean Societies: Field studies of dolphins and whales, The University of Chicago Press, Chicago, pp. 91-126.

Cox, T.M., Read, A.J., Solow, A., Tregenza, N., 2001. Will harbor porpoises (*Phocoena phocoena*) habituaute to pingers? Journal of Cetacean Research and Management, 3: 81-86.

Cox, T.M., Read, A.J., Swanner, D., Urian, K.W., Waples, D., 2003. Behavioral responses of bottlenose dolphins (*Tursiops truncatus*) to gillnets and acoustic alarms. Biological Conservation, 115: 203-212.

Croll, D.A., Clark, C.W., Calamabokidus, J., Ellison, W.T. & Tershy, B.R., 2001. Effect of anthropogenic low-frequency noise on the foraging ecology of *Balaenoptera* whales. Animal Conservation, 4: 13-27.

Culik, B.M., Koschinski, S., Treganza, M., Ellis, G., 2001. Reactions of harbor porpoise (*Phocoena phocoena*) and herring (*Clupea harengus*) to acoustic alarms. Marine Ecology Progress Series, 211: 255-260.

Deecke, V., Nykänen, M., Foote, A., Janik, V., 2011. Vocal behaviour and feeding ecology of killer whales Orcinus orca around Shetland, UK. Aquatic Biology, 13: 79-88.

Ellison, W.E., Southall, B.L., Clark, C.W., Frankel, A.S., 2011. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. Conservation Biology, 26: 21-28.

Finneran, J.J., Schlundt, C.E., 2004. Effects of pure tones on the behavior of trained odontocetes. (SPAWAR Systems Command Technical Report # 1913). San Diego: US Navy.

Finneran, J.J., Schlundt, C.E., Carder, D.A., Clark, J.A., Young, J.A., Gaspin, J.B., Ridgway, S.H., 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. Journal of the Acoustical Society of America, 108: 417-431.

Ford, J.K., Ellis, G.M., Barrett-Lennard, L.G., Morton, A.B., Palm, R.S., Balcomb III, K.C., 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters. Canadian Journal of Zoology, 76: 1456-1471.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide Jorgensen, M.P., Heimlich, S., Hiby, A.R., Leopold, M.S., Oien, N., 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology, 39: 361-376.

Hastie, G., Wilson, B., Tufft, L., Thompson, P., 2003. Bottlenose dolphins increase breathing synchrony in response to boat traffic. Marine Mammal Science, 19: 74-84.

Heithaus, M.R., Dill, L.M., 2002. Food availability and tiger shark predation risk influence bottlenose dolphin habitat use. Ecology, 83: 480-491.

Hoelzel, A.R., 2002. Marine Mammal Biology: An Evolutionary Approach. Blackwell, Oxford.

Islas, V., 2009. Genetic characterisation and social structure of the East Scotland population of bottlenose dolphins (Tursiops truncatus).

Johnston, D.W., 2002. The effect of acoustic harassment devices on harbor porpoises (*Phocoena phocoena*) in the Bay of Fundy. Biological Conservation, 108: 113-118.

Johnston, D.W., Woodley, T.H., 1998. A survey of acoustic harassment device (AHD) use in the Bay of Fundy. Aquatic Mammals, 24: 51-61.

Kastelein, R., Verboom, W.C., Jennings, N., De Haan, D., 2008a. Behavioral avoidance threshold level of a harbor porpoise (*Phocoena phocoena*) for a continuous 50 kHz pure tone. Journal of the Acoustical Society of America, 123: 1858-1861.

Kastelein, R.A., de Haan, D., Vaughan, N., Staal, C., Schooneman, N.M., 2001. The influence of three acoustic alarms on the behaviour of harbour porpoises (Phocoena phocoena) in a floating pen. Marine Environmental Research, 52: 351-371.

Kastelein, R.A., Hardemann, J., Boer, H., 1997. Food consumption and body weight of harbour porpoises (*Phocoena phocoena*), In: Read, A.J., Wiepkema, P.R., Nachtigall, P.E. (Eds.), The biology of the harbour porpoise, De Spil Publishers, Woerden, The Netherlands, pp. 217-234.

Kastelein, R.A., Jennings, N.V., verboom, W.C., De Haan, D., Schooneman, N.M., 2006. Differences in the response of a striped dolphin (*Stenella coeruleoalba*) and a harbor porpoise (*Phocoena phocoena*) to an acoustic alarm. Marine Environmental Research, 61: 19-39.

Kastelein, R.A., Rippe, H.T., Vaughan, N., Schooneman, N.M., Verboom, W.C., De Haan, D., 2000. The effects of acoustic alarms on the behavior of harbor porpoises (*Phocoena phocoena*) in a floating pen. Marine Mammal Science, 16: 46-64.

Kastelein, R.A., Verboom, W.C., Jennings, N., de Haan, D., 2008b. Behavioural avoidance threshold level of a harbour porpoise (*Phocoena phocoena*) for a continuous 50 kHz pure tone. Journal of the Acoustical Society of America, 123: 1858-1861.

Kastelein, R.A., Verboom, W.C., Muijsers, M., Jennings, N.V., van der Heul, S., 2005. The influence of acoustic emissions for underwater data transmission on the behaviour of harbor porpoises (*Phocoena phocoena*) in a floating pen. Marine Environmental Research, 59: 287-307.

Kastelien, R.A., de Haan, D., Goodson, A.D., Staal, C., vaughan, N., 1997. The effects of various sounds on harbor porpoise, In: Read, A.J., Wiepkema, P.R., Nachtigal, P.E. (Eds.), The biology of the harbor porpoise, De Spil Publishers, Woerden, The Netherlands, pp. 367-383.

Kastelien, R.A., Jennings, N.V., verboom, W.C., De Haan, D., Schooneman, N.M., 2006. Differences in the response of a striped dolphin (*Stenella coeruleoalba*) and a harbor porpoise (*Phocoena phocoena*) to an acoustic alarm. Marine Environmental Research, 61: 19-39.

Koshinski, S., Culik, B., 1997. Deterring harbor porpoises (*Phocoena phocoena*) from gillnets: Observed reactions to passive reflectors and pingers. Report of the International Whaling Commission, 47: 659-668.

Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., Williamson, J., 1997. Acoustic alarms reduce porpoises mortality. Nature, 388: 525.

Leeney, R.H., Berrow, S., McGrath, D., O' Brien, J., Cosgrove, R., Godley, B., 2007. Effects of pingers on the behavior of bottlenose dolphins. journal of the Marine Biolocical Association of the United Kingdom, 87: 129-133.

Lucke, K., Siebert, U., Lepper, P.A., Blanchet, M.A., 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. Journal of the Acoustical Society of America, 125: 4060-4070.

Lusseau, D., 2006. Short term behavioural reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand. Marine Mammal Science, 22: 802-818.

Lusseau, D., New, L., Donovan, C., Cheney, B., Thompson, P.M., Hastie, G.D., Harwood, J., 2011. The development of a framework to understand and predict the population consequences of disturbances for the Moray Firth bottlenose dolphin population. Scottish Natural Heritage Commissioned Report.

Madsen, P.T., Mohl, B., 2000. Sperm whales (Physeter catodon L-1758) do not react to sounds from detonators. Journal of the Acoustical Society of America, 107: 668-671.

Madsen, P.T., Mohl, B., Neilsen, B.K., Wahlberg, M., 2002. Male sperm whale behavior during exposure to distant seismic survey pulses. Aquatic Mammals, 28: 231-240.

Morisaka, T., Shinohara, M., Nakahara, F., Akamatsu, T., 2005. Effects of ambient noise on the whistles of Indo-Pacific bottlenose dolphin populations. Journal of Mammalogy, 86: 541-546.

Nachtigall, P.E., Pawloski, J.L., Au, W.W.L., 2003. Temporary threshold shifts and recovery following nose exposure in the Altantic bottlenosed dolphin (*Tursiops truncatus*). Journal of the Acoustical Society of America, 113: 3425-3429.

Niu, F., al., e., 2012. Behavioral responses of two captive bottlenose dolphins (*Tursiops truncatus*) to a continuous 50 kHz tone. Journal of the Acoustical Society of America, 131: 1643-1649.

Nowacek, S.M., Wells, R.S., Solow, A.R., 2001. Short-term effects of boat traffic on bottlenose dolphins, Tursiops truncatus, in Sarasota Bay, Florida. Marine Mammal Science, 17: 673-688.

Olesiuk, P.F., Nichol, L.M., Sowden, M.J., Ford, J.K.B., 2002. Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises, *Phocoena phocoena* in Retreat Passage, British Columbia. Marine Mammal Science, 18: 843-862.

Palka, D.L., Hammond, P.S.H., 2001. Accounting for responsive movement in line transect estimates of abundance. Canadian Journal of Fisheries and Aquatic Science, 58: 777-787.

Patterson, I.A.P., Reid, R.J., Wilson, B., Grellier, K., Ross, H.M., Thompson, P.M., 1998. Evidence for infanticide in bottlenose dolphins: an explanation for violent interactions with harbour porpoises? Proceedings of the Royal Society of London B, 265: 1167-1170.

Richardson, W.J., Greene, C.R.J., Malme, C.I., Thomson, D.H., 1995. Marine Mammals and Noise. Academic Press, Inc., San Diego, CA.

Ross, H., Wilson, B., 1996. Violoent interactions between bottlenose dolphins and harbour porpoises. Proceedings of the Royal Society of London B 263, 283-286.

Saulitis, E., Matkin, C., Barrett-Lennard, L., Heise, K., Ellis, G., 2000. Foraging strategies of sympatric killer whale (Orcinus orca) populations in Prince William Sound, Alaska. Marine Mammal Science, 16: 94-109.

Southall, B., Calambokidis, J., Tyack, P., Moretti, D., Hildebrand, J., Kyburg, C., Carlson, R., Friedlaender, A., Falcone, E., Schorr, G., Douglas, A., DeRuiter, S., Goldbogen, J., Barlow, J., 2010. Biological and Behavioural Response Studies of Marine Mammals in Southern California, 2010 ("SOCAL-10"), pp. 1-29.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.G., Greene, C.H., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., Tyack, P.L., 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals, 33: 411-521.

Teilmann, J., Tougaard, J., Miller, L.A., Kirketerp, T., Hansen, K., Brando, S., 2006. Reactions of captive harbor porpoises (*Phocoena phocoena*) to pinger-like sounds. Marine Mammal Science, 22: 240-260.

Thompson, P., Hastie, G., Nedwell, J.R., Barham, R., Brooker, A., Brookes, K., Cordes, L.S., Bailey, H., McLean, N., 2011. Framework for assessing the impacts of pile-driving noise from offshore windfarm construction on Moray Firth harbour seal populations. Report to Moray Offshore Renewables Ltd and Beatrice Offshore Windfarm Ltd.

Thompson, P.M., Lusseau, D., Barton, T., Simmons, D., Rusin, J., Bailey, H., 2010. Assessing the responses of coastal cetaceans to the construction of offshore wind turbines. Marine Pollution Bulletin, 60: 1200-1208.

Thompson, P.M., White, S., Dickson, E., 2004. Co-variation in the probabilities of sighting harbor porpoises and bottlenose dolphins. Marine Mammal Science, 20: 322-328.

Tougaard, J., Carstensen, J., Teilman, J., Skov, H., Rasmussen, P., 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). Journal of the Acoustical Society of America, 126: 11-14.

Wilson, B., 1995. The Ecology of bottlenose dolphins in the Moray Firth, Scotland: A population at the northern extreme of the species range. PhD Thesis, University of Aberdeen.

7. Appendix 1: Dolphin behavioural responses to noise in literature

Study	Species	Noise source	Type of acoustic measurement	Type of response	Severity scale	Received level (dB re 1μPa)
(Palka and Hammond, 2001)	White-sided and white-beaked dolphins	Vessel noise	RL estimates based on source and environmental characteristics	Visual observations of individual and group movements and behavioural patterns	3	110-120
(Buckstaff, 2004)	Bottlenose dolphins	Vessel noise	Calibrated RL measurements	Passive acoustic monitoring of individual vocal behaviour	2	110-120
(Morisaka et al., 2005)	Indo-Pacific dolphins	Vessel noise	Calibrated RL measurements	Passive acoustic monitoring of individual vocal behaviour	5	120-130
(Nachtigall et al., 2003)	Bottlenose dolphins (captive)	Nonpulse noise (bands)	Calibrated RL measurements	Visual observations of behavioural responses	6	170-180
(Finneran and Schlundt, 2004)	Bottlenose dolphins (captive)	Nonpulse noise (tones)	Calibrated RL measurements	Visual observations of behavioural responses	0 & 8	180-200
(Chilvers and Corkeron, 2001)	Bottlenose dolphins	Vessel noise	No Data	Visual observations of individual foraging behaviour	NA	NA
(Cox et al., 2003)	Bottlenose dolphins	ADDs	No Data	Visual observations of movement and diving behaviour	0 & 6	NA
(Hastie et al., 2003)	Bottlenose dolphins	Vessel noise	No Data	Visual observations of movement and diving behaviour	2	NA
(Kastelien et al., 2006)	Striped dolphin (captive)	Nonpulse noise	Calibrated RL measurements	Visual observations of movement, respiration and behaviour	0	100-120
(Bejder et al., 2006)	Bottlenose dolphins	Vessel noise	No Data	Visual observations of movement behaviour	3	NA
(Lusseau, 2006)	Bottlenose dolphins	Vessel noise	No Data	Visual observations of movement and behaviour patterns	3	NA

(Leeney et al., 2007)	Bottlenose dolphins	Aquatech Pinger	No Data	Visual observations group movements and behavioural patterns	6	NA
(Southall et al., 2010)	Risso's dolphin	Simulated MFA sonar	Calibrated RL measurements	Visual observations for individual and group movements and behavioural patterns, passive acoustic monitoring and dtags	0	135
(Finneran et al., 2000)	Bottlenose dolphins	Recorded explosives	Calibrated RL measurements	Visual observations of movement and behaviour patterns	4	196-209
(Niu and al., 2012)	Bottlenose dolphins (captive)	Nonpulse noise (tones)	Calibrated RL measurements	Visual observations of behavioural responses and click production	7	140-160
(Lucke et al., 2009)	Harbour porpoise (captive)	Seismic airgun playback	Calibrated RL measurements	Visual observations of behaviour	8	174 (p-p)

8. Appendix 2: Harbour porpoise behavioural responses to noise in literature

Study	Species	Noise source	Type of acoustic measurement	Type of response	Severity scale	Received level (dB re 1μPa)
(Culik et al., 2001)	Harbour porpoises (wild)	PICE pinger	RL estimates based on source and environmental characteristics	Visual observations of individual and group movements and behavioural patterns	0 & 6	RLs = 80-120 dB
(Olesiuk et al., 2002)	Harbour porpoises (wild)	Airmar AHD	RL estimates based on source and environmental characteristics	Visual observations of individual and group movements and behavioural patterns	6	RLs = 140-160 dB
(Johnston, 2002)	Harbour porpoises (wild)	Airmar AHD	RL estimates based on source and environmental characteristics	Visual observations of individual and group movements and behavioural patterns	0 & 6	RLs = 120-130 dB
(Kastelien et al., 1997)	Harbour porpoise (captive)	Nonpulse noise	Calibrated RL measurements	Visual observations of movement, respiration and behaviour	0, 4 & 6	RLs = 80-120 dB
(Kastelein et al., 2000)	Harbour porpoise (captive)	Nonpulse noise	Calibrated RL measurements	Visual observations of movement, respiration and behaviour	0 & 6	RLs = 90-120 dB
(Kastelein et al., 2005)	Harbour porpoise (captive)	Nonpulse noise	Calibrated RL measurements	Visual observations of movement, respiration and behaviour	0 & 6	RLs = 90-120 dB
(Kastelein et al., 2006)	Harbour porpoise (captive)	Nonpulse noise	Calibrated RL measurements	Visual observations of movement, respiration and behaviour	6	RLs = 100-120 dB
(Kraus et al., 1997)	Harbour porpoise (wild)	Dukane pingers	No Data	Measurements of by-catch rates	NA	NA

(Johnston and Woodley, 1998)	Harbour porpoise (wild)	AHD	No Data	Visual observations of exclusion zones	NA	NA
(Cox et al., 2001)	Harbour porpoise (wild)	ADD	No Data	Visual observations of exclusion zones	0 & 6	NA
(Kastelein et al., 2001)	Harbour porpoise (captive)	Nonpulse noise	Calibrated RL measurements	Aerial observations of individuals	6	90-120
(Barlow and Cameron, 2003)	Harbour porpoise (wild)	ADD	No Data	Measurements of by-catch rates	NA	NA
(Koshinski and Culik, 1997)	Harbour porpoise (wild)	Wind turbine noise	Calibrated SL measurements	Visual monitoring	NA	NA
(Teilmann et al., 2006)	Harbour porpoise (captive)	Nonpulse sequences	Approximated from SL using transmission & absorption loss	Visual observations of movement behaviour	6	130-150
(Carstensen et al., 2006)	Harbour porpoise	Pile driving	No Data	Passive acoustic monitoring	7	NA
(Kastelein et al., 2008a)	Harbour porpoise (captive)	Pile driving	Calibrated RL measurements	Visual observations of movement behaviour	6	100-120
(Tougaard et al., 2009)	Harbour porpoise	Pile driving	Calibrated RL measurements	Passive acoustic monitoring	7	175-195 (p-p)
(Brandt et al., 2011)	Harbour Porpoise	Pile driving	Calibrated RL measurements	Passive acoustic monitoring	7	180-196 (p-p)
(Thompson et al., 2010)	Harbour porpoise	Pile driving	No Data	Visual & Passive acoustic monitoring	0 & 6	NA