ID: W2802392056

TITLE: Guiding principles for assessing the impact of underwater noise

AUTHOR: ['Rebecca C. Faulkner', 'Adrian Farcas', 'Nathan D. Merchant']

ABSTRACT:

Underwater noise pollution poses a global threat to marine life and is a growing concern for policymakers and environmental managers. Evidence is mounting of noise-induced habitat loss, heightened physiological stress, masking of biologically important sound (e.g. for communication, predator/prey detection), auditory injury, and in extreme cases, direct or indirect mortality (Popper et al., 2014; Southall et al., 2007). Initial studies focused on charismatic megafauna (particularly marine mammals), but in recent years effects have been discovered in other taxa and at lower trophic levels, including various fish species (Popper et al., 2014), functionally important marine crustaceans (Solan et al., 2016) and zooplankton (McCauley et al., 2017). Projected growth in the blue economy is expected to bring an expansion in noise-generating activities, notably the construction of offshore wind turbines and other marine infrastructure, geophysical surveys using seismic airguns or sub-bottom profilers, sonar usage and vessel traffic. With increasing awareness of the potential cumulative impact of these and other activities on marine ecosystems, managers are faced with tough choices over how best to alleviate pressure on the marine environment from multiple stressors and industrial sectors. Unlike other marine pollutants such as microplastics or persistent organic pollutants, underwater noise is ephemeral and quickly disperses in the environment. If effective, interventions to reduce noise pollution could lead to a rapid easing of this pressure on acoustically sensitive organisms. Current measures to manage underwater noise pollution largely involve requiring environmental impact assessments (EIAs) for major inshore and offshore projects, in accordance with legislation for protected species or habitats (e.g. EU Habitats Directive, US Marine Mammal Protection Act). If acoustically sensitive species may be present and potentially harmful noise levels are expected, modelling is carried out to estimate the possible extent of adverse effects. On this basis, regulators may grant or decline consent, or require additional mitigatory action to be taken. However, many EIAs for underwater noise do not apply scientifically credible methods, and regulators often lack the expertise to critically assess consent applications (Farcas, Thompson, & Merchant, 2016). Furthermore, while in some northern European countries noise abatement technologies are being routinely deployed (e.g. for pile driving of offshore wind farms in Germany, Denmark, Norway, Sweden and the Netherlands), in other jurisdictions it is rare for the effect of reducing technologies to be assessed (and consequently recommended or required as a condition of consent), and the consideration of cumulative effects remains inadequate (Willsteed, Gill, Birchenough, & Jude, 2017; Wright & Kyhn, 2015). Our purpose in this article is to set out clear guiding principles for assessing the impact of underwater noise, providing developers, regulators and policymakers with a robust, science-based framework to address this emerging threat. Based on our experience of advising these stakeholders and of conducting assessments, we identify shortcomings in current practice (and suggest remedies), and propose concrete steps to improve the compatibility of individual EIAs with cumulative effects assessments. We also promote an adaptive approach to EIA which enables regulators to consider the benefits of additional noise reduction measures, rather than the assessment being presented as a fait accompli. Our aim is to encourage more rigorous and informative assessments, and to help orient newcomers to this rapidly evolving area. Each stage in the EIA process for underwater noise (Figure 1) involves making choices which critically affect the outcome of the assessment. In summary, acoustically sensitive species (receptors) are first ?scoped in? to the assessment (Figure 1a), and corresponding noise exposure criteria are identified which specify thresholds for different types of effect (Figure 1b). Then, significant noise sources from the project are scoped in (Figure 1c), and used to derive input parameters for a noise propagation model which predicts the extent and magnitude of noise levels at the site (Figure 1d). ?Effect zones? are then derived by combining the noise model predictions with the noise exposure criteria (Figure 1e), yielding predicted areas where the thresholds for different effects are exceeded. Though seldom done in practice, the risk reduction achieved by applying additional noise reduction technologies may then be modelled (Figure 1f), and the developer may be required to lead or participate in a cumulative effects assessment which includes other planned developments (Figure 1g). In the following sections, we discuss the challenges and pitfalls of the EIA process at each stage, and make recommendations for best practice. The first step is to identify receptors that have the potential to be affected by anthropogenic noise (1a). Detailed knowledge is required about the project area, including the spatial and temporal distribution of species and their seasonal sensitivities (e.g. known spawning and nursery grounds or migratory routes). Receptors that are ?scoped in? should include acoustically sensitive species protected under environmental legislation and other relevant species (e.g.

identified as important for conservation, ecological, or economic reasons). Although many EIAs primarily focus on marine mammals and (to a lesser extent) fish and sea turtles, marine crustaceans and elasmobranchs are also sensitive to noise and vibration, and should be scoped in where relevant (Hawkins & Popper, 2017). Information on acoustic sensitivity should be derived from the scientific literature to identify at-risk species. In considering species sensitivity to sound, it is important to note that sound has two components: sound pressure and particle motion. Similarly to other mammals, marine mammals primarily sense sound pressure. Although some fish species are able to detect sound pressure indirectly, fish and aquatic invertebrates primarily sense particle motion (Nedelec, Campbell, Radford, Simpson, & Merchant, 2016). At present, there are no noise exposure criteria for particle motion, and current criteria (even for species which only sense particle motion) are based solely on sound pressure (Popper et al., 2014). Furthermore, the modelling of particle motion is not common practice and warrants further research (Farcas et al., 2016). As such, the scope for including particle motion in routine assessments is currently limited, although instrumentation and techniques for particle motion measurement and analysis are becoming more widely available (Nedelec et al., 2016). The next step is to identify appropriate noise exposure criteria (also termed impact criteria or noise thresholds; 1b). Such criteria define sound levels at which various severities of response are expected, e.g. mortality, Permanent Threshold Shift (PTS; permanent loss of hearing sensitivity) and Temporary Threshold Shift (TTS; e.g. Southall et al., 2007; Lucke, Siebert, Lepper, & Blanchet, 2009; Popper et al., 2014; National Marine Fisheries Service, 2016). Criteria for marine mammals typically require the application of a frequency weighting to account for the frequency sensitivity of hearing for the species or species group (National Marine Fisheries Service, 2016; Southall et al., 2007; Tougaard, Wright, & Madsen, 2015). In selecting noise exposure criteria, assessments should refer to the latest set of widely applied and peer-reviewed criteria available. For example, currently the most relevant marine mammal criteria are those developed by the U.S. National Oceanic and Atmospheric Administration (NOAA) to reflect recent advances in the field (National Marine Fisheries Service, 2016). These provide acoustical thresholds for the onset of TTS and PTS in marine mammals in response to impulsive and continuous (non-impulsive) sound. At present, the most relevant criteria for fish are those published by Popper et al. (2014). These criteria provide quantitative thresholds for TTS, recoverable injury and mortality in fish in response to several impulsive sound sources, and qualitative guidance for continuous sources. There is currently insufficient data to establish noise criteria for marine invertebrates (Popper et al., 2014). However, studies conducted thus far have revealed a range of negative effects from noise (e.g. Solan et al., 2016), and assessments should draw on this literature where relevant. While these noise exposure criteria provide thresholds for auditory impairment, they do not quantitatively address behavioural responses. Behavioural effects are particularly difficult to assess, since they are highly dependent on behavioural context (Ellison, Southall, Clark, & Frankel, 2012; Popper et al., 2014) and responses may not scale with received sound level (Gomez et al., 2016). Consequently, there is considerable uncertainty in assessing the risk of behavioural responses, and the application of simplistic sound level thresholds for behaviour should be avoided. Recent studies have considered more sophisticated approaches to quantify the risk of behavioural responses, for example through dual criteria based on dose-response curves for proximity to the sound source and received sound level (Dunlop et al., 2017). Approaches based directly on the ?distance of effect? reported for insitu behavioural studies (e.g. Merchant, Faulkner, & Martinez, 2017) can also be used as an empirical estimate of the risk of behavioural responses (Gomez et al., 2016), provided that the sound level of the noise source in the cited study is not substantially exceeded in the assessment scenario. One common pitfall in the application of noise exposure criteria is inconsistency between the acoustic metric modelled to predict risk and the acoustic metric defining the exposure threshold (and auditory weighting if applicable). Impulsive noise criteria are generally defined using zero-to-peak sound pressure level (SPL), peak-to-peak SPL or cumulative sound exposure level (SEL), while non-impulsive criteria use cumulative SEL or the root mean square) SPL. Since it is not possible to convert directly between these units, it is critical that predictions of noise levels arising from the activity are made using the same units as the threshold to be applied. To assess the validity of noise exposure predictions made using modelling, regulators need to know that: (i) all relevant noise sources have been scoped in; (ii) appropriate source levels for these noise sources have been estimated using units which are consistent with the threshold criteria; and (iii) sufficient and appropriate data are available to parameterise the noise propagation model. When identifying which noise sources should be scoped in, all potential sources should initially be considered. These include lower intensity noise sources, increased vessel activity, dredging and drilling. If these are subsequently scoped out, clear justification should be provided based on published literature, such as source levels for the activities and acoustic sensitivities of the receptors. Once the source(s) have been identified, the predicted source level(s) should be stated, providing detail of how the source level was derived (i.e. from published literature or using a source model), and any associated uncertainty. As highlighted in section 2.1.2, the source level should be expressed using the same acoustical metric as the noise exposure criteria. In addition to the source level, evidence of appropriate environmental data for the model is required, including the bathymetry, sediment characteristics of the seabed, sea surface and water column properties, and ambient noise levels. Where possible, uncertainty in these parameters should be incorporated into the assessment. Inadequate input data can result in misleading noise exposure predictions; these factors are considered in more detail in Farcas et al. (2016). Many sound propagation loss models are available, ranging from sophisticated numerical models to simplistic models based on spreading laws. No single model is applicable to all environments and acoustic frequencies (see Farcas et al. (2016) for more detailed discussion). The choice of model primarily depends on: (i) water depth; (ii) frequency range of sound to be modelled; and (iii) whether the environment varies considerably with range from the source. To ensure confidence in the modelling, models should be validated with field measurements of sound propagation. Common shortcomings at this stage in the assessment include the application of models which are not appropriate for the environment, insufficient model validation and inadequate description of the model (often the case when contractors use proprietary models). By combining noise model predictions with the noise exposure criteria, ?effect zones? are derived (see Figure 2). These zones show the predicted areas where the thresholds for different effects are exceeded. The risk of impact can then be assessed by overlaying effect zones on species densities and/or known (seasonal) habitat (e.g. fish spawning areas). The effect zones predicted can be strongly influenced by the noise exposure criteria used (Figure 2a), whether animals are assumed to flee from the source at the onset of disturbance (Figure 2b) and whether noise abatement measures are implemented to reduce risk (Figure 2c). Guidelines for selecting appropriate criteria are provided in section 2.1.2, and regulators should be aware that criteria selection can be a major factor in determining the assessment outcome (Figure 2a), since they may differ in their noise exposure thresholds and any frequency weightings applied. Assumptions of fleeing animal behaviour in the estimation of effect zones are controversial, since animals may be motivated to remain in the affected area (e.g. due to prey availability or mating opportunities) despite harmful noise exposure. On the other hand, assuming for the purposes of the assessment that animals remain stationary, including close to the source, for extended periods (some criteria use a 24-hr period for cumulative exposure) may be considered unrealistic. The assumptions underlying such models, particularly probability of fleeing, swim speed and flight path, will strongly influence the size of the effect zones predicted (Figure 2b), and these parameters should be given careful consideration by developers and regulators to ensure that risk is not underestimated. The most direct and comprehensive way to mitigate the risk of acoustic impact on marine species is to reduce the amount of noise pollution emitted at source (noise abatement). For pile driving, alternative piling technologies such as vibratory piling and continuous flight auger (CFA) piling may reduce noise levels emitted (though see Graham et al., 2017). There are also several noise reduction technologies available, such as big bubble curtains and acoustic barriers that are integrated into the piling rig (e.g. IHC Noise Mitigation System), which are now being routinely deployed in German waters. The application of these technologies reduces the effect zones predicted for auditory injury (Figure 2c), and has been demonstrated to reduce the distance at which harbour porpoise are displaced from pile driving activities (Dähne, Tougaard, Carstensen, Rose, & Nabe-Nielsen, 2017). Nevertheless, in many countries it is rare for such technologies to be required by regulators, and the reduction in effect zones that would be achieved through their use is not typically modelled as part of the assessment process. We recommend that modelling the effect of noise abatement technologies is required by regulators of noise-generating activities, so that regulators are informed of the risk reduction options available. This is particularly important for the assessment of cumulative impact from multiple activities (see next section), where regulators need to be informed of the measures available to reduce cumulative risk for specific populations and habitats. Although noise abatement technologies are uncommon in some countries, less direct mitigation measures are often applied. Standard mitigation measures include spatiotemporal restrictions on activities to avoid sensitive habitats and times of year. Such restrictions will often be the most cost-effective mitigation solution for seasonally occurring species, provided accurate and up-to-date species distribution data are available. Additionally, in situ measures may be taken (e.g. JNCC, 2017), such as soft-start procedures (also known as ?ramp up?), whereby the source level is gradually increased (with the intent to displace animals before harmful levels are reached), and the establishment of a surveillance zone in which a marine mammal observer will monitor visually and/or acoustically for marine mammals prior to and during the activity. However, these in situ measures have been criticised as arbitrary and evidence for their efficacy is lacking (Wright & Cosentino, 2015). Some developers have also used acoustic deterrent devices (ADDs) to displace animals prior to the activity, with the intent of reducing the risk of auditory injury. Use of ADDs introduces additional acoustic disturbance, and the extent of marine mammal displacement from ADDs may exceed the range of displacement from the activity itself if noise abatement measures are applied (Dähne et al., 2017). As such, use of ADDs should be considered carefully in the context of the proposed activity. Impacts from individual projects do not occur in isolation, but form part of the cumulative pressure exerted on marine ecosystems by human activity. To assess the cumulative impact of multiple human activities, environmental managers are increasingly requiring (or are themselves carrying out) cumulative effects assessments (CEAs) for underwater noise, often based on data gleaned from individual EIAs. This highlights the need for consistency in the methods and metrics used in individual EIAs. EIA-based CEAs led by developers of individual projects have clear shortcomings when compared to CEAs led by government agencies on a regional and strategic level (Willsteed et al., 2017). Nevertheless, this approach remains the preferred option in many jurisdictions. Developers conducting these EIAs and CEAs should consider it in their interests to promote coherence in EIA methodologies, since this reduces the uncertainty (and therefore the risk of declined consent) in resulting CEAs. Similarly, regulators and government agencies conducting CEAs should specify clear requirements at the EIA stage to ensure that assessments at the project level can feed into a consistent cumulative assessment. In the case of impulsive noise, many regulators now require licensed activities to be reported to national noise registries, which in turn feed into international registries used in region-scale assessments of impulsive noise activity and its associated risks (Merchant et al., 2017). There is great potential for these reporting and assessment mechanisms to be integrated into the regulatory process as forward-looking management tools for cumulative effects assessment and marine spatial planning, and to meet the requirements of legislative frameworks such as the EU Marine Strategy Framework Directive (MSFD). These registries could also serve as vehicles for the much-needed standardisation of data reported to regulators within the EIA process. Scientific understanding of the impacts of underwater noise pollution is advancing rapidly and the potential for widespread effects on marine fauna is increasingly clear. Both developers and regulators have a responsibility to address this risk by ensuring that the potential impacts of noise-generating activities are appropriately assessed and mitigated for. Nevertheless, at present many EIAs for underwater noise do not apply appropriate methods and lack reference to the best available science. The guiding principles set out here provide a basis for the more consistent, evidence-based approach that is required to conduct meaningful EIAs and to inform larger-scale risk assessments. We hope these guidelines will empower regulators, developers and stakeholders to raise the standard of EIA practice, leading to better informed regulatory decisions which support sustainable management of underwater noise pollution. The concepts developed in this article are based on the authors' experience in projects and advisory roles funded by UK government departments (DEFRA, BEIS), regulatory bodies (MMO, NRW) and various commercial clients; we gratefully acknowledge their support, without which this work would not have been possible. R.C.F. and N.D.M. conceived the ideas and led the writing of the manuscript; A.F. carried out the modelling for Figure 2. All authors contributed critically to the drafts and gave final approval for publication. Data have not been archived because this article does not contain data.  Rebecca Faulkner is the primary scientific advisor on underwater noise to regulatory bodies in England and Wales, and has extensive experience of assessing the impacts of noise on aquatic life. Adrian Farcas is a senior scientist responsible for modelling underwater noise for EIAs and in advisory work for UK Government. Nathan Merchant is a principal scientific advisor on underwater noise to the UK Department for Environment, Food & Rural Affairs (Defra), co-convenor of the OSPAR Intersessional Correspondence Group on Noise, and a member of the European Technical Group on Noise, which advises on the implementation of the EU MSFD.

SOURCE: Journal of applied ecology

PDF URL: https://besjournals.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/1365-2664.13161

CITED BY COUNT: 33

PUBLICATION YEAR: 2018

TYPE: article

CONCEPTS: ['Underwater', 'Noise (video)', 'Environmental science', 'Computer science', 'Geology', 'Oceanography', 'Artificial intelligence', 'Image (mathematics)']