Noise Matters, or Does It? How Can We Truly Assess Impacts Without a Common Standard

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Contents

Abstract

Due to increasing concern about the effects of anthropogenic noise in aquatic habitats, there has been an explosion of research papers in recent years documenting possible effects on a large range of freshwater and marine species. While this increase in assessment can be seen as beneficial to our understanding of this possible stressor and potential regulatory implications, it is difficult to properly assess the importance of underwater anthropogenic noise due to the lack of open access to data, and due to ongoing geographic biases. To obtain truly objective measures of the importance of noise as a stressor, it is necessary to calculate some measure of noise effects consistently across studies, or at least provide sufficient data for others to calculate this metric. Here the authors quantify the percentage of papers that allow independent quantification of noise effects and find only 25% of published papers contain enough data for independent assessment of effects. The authors therefore call for increased adherence to

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open data policies and also call for increased geographic representation to better understand whether and how noise might be an important stressor to fish. Before a clear regulatory framework can be developed, it is incumbent on our community to decide how "effects" should be measured and to fully embrace data transparency to allow assessments of the true impacts of noise on aquatic ecosystems.

Keywords

Meta-analysis · Anthropogenic noise · Effect size · Fish

Introduction

There is increasing concern as anthropogenic sound levels continue to rise in both freshwater and marine environments (Duarte et al. 2021), prompting calls for improved regulation on these underwater pollutants (Popper et al. 2014; Nolet 2017). Major anthropogenic sound sources include shipping vessels, construction, seismic surveys, and recreational boating (Hildebrand 2009; Frisk 2009), and their impacts can persist over long temporal and spatial scales (Rako-Gospić and Picciulin 2019). Regulations have been proposed (Popper et al. 2014) to limit the sound levels and durations of these noise inputs to reduce their impacts, but any recommendations must consider the impacted species and trade-offs with human economic activities. While much of the regulatory impacts have been focused on charismatic marine mammals (Southall et al. 2008; Erbe et al. 2019), fish are the most abundant and diverse vertebrate group in both marine and freshwater ecosystems and play essential roles in ecosystem functioning, global fisheries, and food security. Thus, there is a critical need to assess the true impacts of underwater anthropogenic sound on fishes to inform realistic regulations and management.

There is clear experimental evidence that increased sound levels can cause at least temporary physiological and behavioral changes in fishes. Many have used these findings to argue for stronger regulatory control of anthropogenic sound. However, translating experimental results into real-world impacts remains challenging. Differences between laboratory and field conditions, inconsistencies in the metrics employed, and the variable outcomes reported across studies all contribute to this difficulty. Exposure to sonar bursts has been shown to damage hearing in some species in caged experiments (Halvorsen et al. 2012), yet repeated exposures in field settings often yield minimal detectable impacts (Miller and Cripps 2013; Davidsen et al. 2019). Similarly, various types of boat noise can affect fish behavior and physiology (Nedelec et al. 2017; Mickle and Higgs 2018; Amorim et al. 2022), but these effects are highly species-dependent (Pieniazek et al. 2020) and may vary with behavioral context (Woods et al. 2022). While it is perhaps expected that different studies will show different effects, especially given the high species diversity of fishes, it is difficult to synthesize these disparate findings without a standardized framework to assess effects.

The limitations with the individual-study approach currently in vogue are that it is difficult to ascertain and summarize the importance of underwater noise as a stressor to fish, especially given that each study uses different metrics to assess effects. While there have been several excellent reviews of this field in recent years (Mickle and Higgs 2018; Popper and Hawkins 2019; Putland et al. 2019; Pieniazek et al. 2020), all they can tell us are the ways that noise impacts have been assessed, what techniques have been used, and a range of possible effects seen—with little quantification of actual impacts. One solution to this problem is performing a true meta-analysis of effect size but to our knowledge, only one paper (Cox et al. 2018) has done this, and the data used are now 10 years old; an update is urgently needed. A significant problem with the meta-analysis approach, however, is the lack of accessible data for effect size calculations. Of the 452 studies identified by Cox et al. (2018), only 42 contained sufficient information for effect size calculations, at least partially due to limitations in reporting of mean, variability, and sample size. With increased calls for open data access (Salguero-Gómez et al. 2021), it is hoped that limitations on data access would be reduced. A key goal of the current paper is to evaluate data availability in field-based noise-impact studies and to assess whether current reporting practices allow independent calculation of effects sizes. By building on the foundational work of Cox et al. (2018), the authors of the current chapter aim to highlight the need for consistent, quantitative assessment of noise effects on fishes and to encourage a broader adoption of effect size metrics to support more rigorous, evidence-based regulation.

Literature Search

To obtain an updated overview of the feasibility of calculating effect sizes of noise impacts in fishes, a comprehensive literature search was conducted for all studies that investigated the effects of underwater noise in field settings published since 2000. Following the procedures outlined in Pieniazek et al. (2023), a Boolean search was conducted in Web of Science for appropriate papers published between 2000 and 2025 using the search terms: TS = (fish) AND TS = (anthropogenic noise OR noise pollution) AND TS = (field OR wild OR free-swimming), where TS refers to the topic field. Once the initial database was compiled, additional searches were conducted by examining citations within these papers as well as papers that cited them after publication. A final review of this collated list was conducted by reading the titles and abstracts of all papers collected to verify that each paper met the criteria of this analysis.

Percent of Papers with Available Data

The final literature compilation yielded 127 published papers that met our criteria, with the number of studies increasing sharply since 2015 (Fig. 1). While it was encouraging to see such engagement in this field, it was less heartening to see how few studies provided the necessary data to calculate mean effects and associated variance, both critical for determining the magnitude of noise impacts and enabling reliable cross-study comparisons. Ideally, the raw data would be publicly available, but the inclusion of means and measures of variation for experimental and control

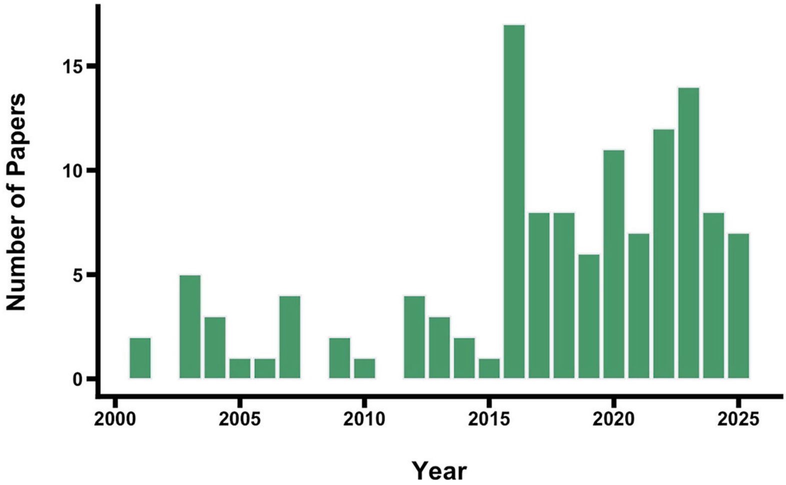

Fig. 1 Distribution of papers by year, since 2000, of all published papers that met the Web of Science search topic search criteria of (fish) AND (anthropogenic noise OR noise pollution) AND (field OR wild OR free-swimming)

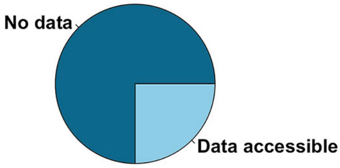

Fig. 2 The percentage of identified papers with data that was freely available, either in the publication itself or through open access databases since 2000

treatments is sufficient to allow effect size calculation (see below). In worst-case scenarios, a clear figure with means and error bars is now enough to calculate these basic data parameters after digital scanning. Despite this rather liberal application of data analytics, only 31 of the 127 studies contained enough data to allow meaningful effect size estimation, a success rate of only 25% (Fig. 2). While one might think that current calls for open data (Salguero-Gómez et al. 2021) might mean this is more a problem of the past rather than current work, there are no difference in data accessibility in older versus newer papers, limiting any serious effort to truly understand the actual impact of underwater noise on fish health.

A More Comprehensive Way to Report Effects

While the emphasis in our field seems to be simply reporting statistical significance, or the probability that any effects are nonzero, this is of limited value in determining the impact noise may have on exposed fish. The effect size tells the reader not just whether or not distributions differ by a somewhat arbitrary value, typically 0.05 in our field, but rather the magnitude of this difference (Sullivan and Feinn 2012). In simple terms, the effect size is the magnitude of the difference between two means (e.g., a control and noise-exposed group of fish) relative to some measure of the variance present. For the purpose of extracting data from published reports, the simplest effect size to calculate is Cohen's *d* (Cohen 1988):

$$d = \frac{M_1 - M_2}{s}$$

where M_1–M_2 represents the magnitude of the difference between two treatment means (e.g., exposed and control), and s represents the standard deviation of one of the treatments.

An alternative formulation of effect size is Hedges *d* (Hedges and Olkin 1985), which adjusts for differences in sample size and unequal variances:

$$d = \frac{M_1 - M_2}{\sqrt{(n_1 - 1)s_1^2}} + \frac{(n_2 - 1)s_2^2}{n_1 - n_2 - 2}$$

where n is the sample size of each treatment. While the Hedges' formulation is preferred on statistical grounds, it can be difficult if not all the requisite parameters are specified in a given study.

The order of M_1 versus M_2 does not matter, as "d" can be thought of as an absolute value, and the treatment used to calculate "s" does not technically matter as long as it is consistent for all metrics. Cox et al. (2018) argue that the designation of each mean should influence the sign of the effect size metric. For example, an increase in growth should result in a positive effect size, whereas an increase in "stress" hormone production should result in a negative effect, but these arbitrary definitions may be difficult to designate in certain circumstances.

Geographic Bias in Field Studies

A substantial limitation in assessing global underwater noise impacts on fish is the geographic bias in study locations. Of the 31 studies that contained sufficient data for effect size estimation in the current synthesis, the majority were conducted in the USA and Canada, followed by Australia and New Zealand. Only a handful originated from Northwestern Europe, China, Brazil, and Mexico (Fig. 3). This same pattern holds for all 127 published studies (Fig. 3)—whether or not they have available data—and represents a real problem for our field. No studies were found in the entire African continent and very limited representation across much of South America, Asia, and the rest of Europe. This geographic bias is not, of course, unique to underwater acoustics research, but without a more equitable geographic distribution, it will be difficult to fully realize a comprehensive view of the true effects of underwater noise.

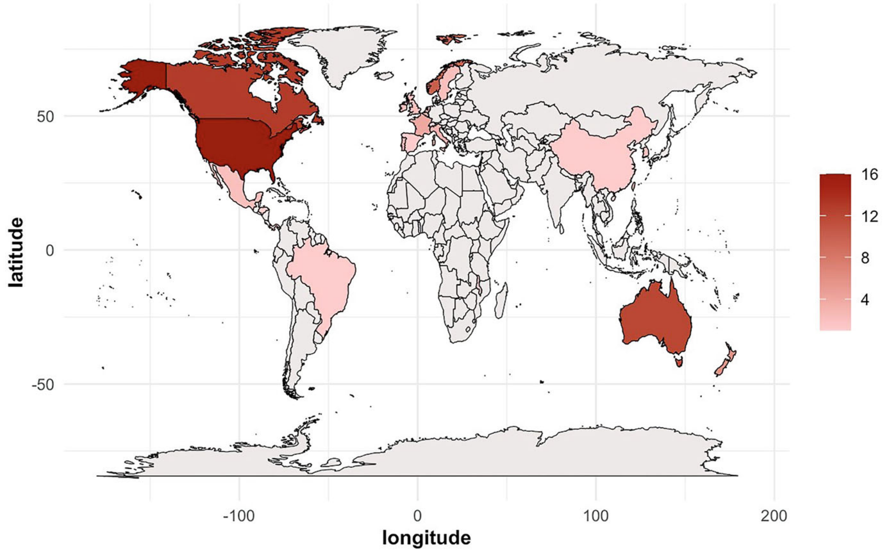

Fig. 3 Geographic distribution of all studies that met our search criteria for examination of the effects of noise on fish in field studies. Numbers next to the color scale represent the number of published studies in each country

A Call for Open Data and Effect Size Reporting

A significant limitation with attempts to fully summarize the effect of underwater noise highlighted here and in Cox et al. (2018) is the poor accessibility of much of the data collected for published papers. Only 9% of studies reviewed by Cox et al. (2018), and only 25% of studies in our expanded dataset, provided enough information to calculate appropriate effect sizes. Very few studies reported effect sizes directly.

There have been repeated calls for greater openness (Hampton et al. 2013; Mills et al. 2015; Durden et al. 2017) and many funding agencies, scientific societies, and journals require open data access, but our field still falls woefully short of these goals. While there are inherent challenges in freely providing access to one's data (Callaway 2019; Salguero-Gómez et al. 2021), it is vital to allow summary and recommendations on the extent of impacts of noise championed by many in our field (Popper and Hawkins 2019; Hawkins et al. 2020; Popper et al. 2020). There are now data repositories for underwater sound recordings (Parsons et al. 2022; Darras et al. 2025), but there seems to be less commitment to meeting the call for fully accessible data. Without this openness, our field will continue to operate in isolated research silos, undermining both regulatory progress and public understanding of underwater noise issues.

The authors therefore recommend that:

1. All studies on the effects of underwater sound provide raw data collected for all publications in accessible databases.
2. All such studies include effect size calculations for all reported experiments.
3. At minimum, authors provide a summary table in publications containing sample sizes, means, and measures of variance for every treatment tested.

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