Background Noise Impacts Harbor Porpoise Detections in Passive Acoustic Monitoring

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Contents

Abstract

Passive acoustic monitoring (PAM) is instrumental to monitor marine mammals, with many applications, including impact of noise. Noise, however, also affects the ability of PAM to detect sounds of interest. The performance of a PAM algorithm was tested by feeding it recordings of ship noise merged with harbor porpoise (*Phocoena phocoena*) clicks. Three groups of porpoise clicks ("click trains") were inserted every 10 sec in files containing ship noise, one at a time (n = 1180 min). The recall (probability of detecting porpoises in 10-sec bins) was modeled using a generalized linear model with a binomial distribution and one explanatory variable: noise in one of four frequency bands (<20 kHz, 20–80 kHz, 80–150 kHz, and the decidecade centered on 16 kHz). The best model had the

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20–80 kHz band as the explanatory variable, but noise in all bands masked detections when exceeding 90 dB re. 1μPa, becoming a cofounding factor. Therefore, decreased detections at these noise levels cannot be attributed unequivocally to effects of noise on the behavior of porpoises but may be due to masking of the PAM instrument. However, PAM can be used, as long as the noise levels above 20 kHz are monitored and accounted for.

Keywords

Sound · Underwater noise · Detections · Ship noise · Monitoring · PAM

Introduction

Monitoring wide-ranging cetaceans is a difficult task, and using traditional visual methods alone is limiting, especially for small-sized animals with cryptic behavior. The development of affordable passive acoustic monitoring (PAM) devices that can be deployed for long periods was a game changer, becoming instrumental to monitoring many cetacean species, such as the harbor porpoise (*Phocoena phocoena*). Harbor porpoises produce only one type of sound: polycyclic, narrow-band clicks. These clicks have peak and centroid frequencies between 100 and 150 kHz, with little or no spectral energy below 100 kHz, duration of about 100 μs, and − 3 dB bandwidths between 12 and 20 kHz (Hansen et al. 2008; Kyhn et al. 2013; Møhl and Andersen 1973; Villadsgaard et al. 2007). Clicks are emitted in trains in a narrow, forward-oriented beam (Au et al. 1999, 2006). A click train is a group of clicks with regular or gradually changing inter-click intervals (Koschinski et al. 2008), and the patterns in click production appears to be context dependent (Clausen et al. 2010; Sørensen et al. 2018; Verfuss et al. 2005). These characteristics make harbor porpoises' sounds well suited for PAM.

PAM systems have several advantages over visual surveys, as they can be used during bad weather conditions (e.g., high waves, fog) as well as at night. Data collection can be accomplished with no supervision, and therefore, the performance is not affected by the experience or levels of alertness of the observer. Moreover, because cetaceans spend most of their lives underwater, animals sometimes are only detected acoustically or are detected acoustically before they are detected visually (e.g., Yack et al. 2013).

Existing PAM devices that can be used specifically to study harbor porpoises can be divided into two main types: devices that only log data about acoustic events and those that record continuously. The most used data logger is the C-POD and its predecessor the T-POD (Chelonia Ltd., Cornwall, UK). T- and C-PODs have been successfully used for many applications, including understanding the impact of underwater noise (Dähne et al. 2013; Gallus et al. 2012; Koschinski et al. 2008; Kyhn et al. 2008; Tougaard et al. 2009). Wideband continuous recorders opened up the possibility of more detailed sound analysis. Not only can the raw data be audited and reanalyzed using different parameters (e.g., detection thresholds), but it is also possible to study the temporal and spectral characteristics of the background noise. In turn, this can be used to better understand how noise impacts the target species.

Harbor porpoises are common in coastal and shelf waters (Bjørge and Øien 1995; Hammond et al. 1995), so they are regularly exposed to vessel traffic (Wisniewska et al. 2018). Ship noise is typically assessed at low frequencies (e.g., the EU descriptors for a healthy marine environment are measured at 63 and 125 Hz, Dekeling et al. 2014). This could suggest that porpoises would not be affected, as their best hearing is at high frequencies (Kastelein et al. 2010). However, recent studies carried out with devices that can record the full broadband signals from ship noise have shown that ship noise extends to much higher frequencies (Hermannsen et al. 2014) and that porpoises respond negatively, responding behaviorally or vocally, when noise exceeds certain levels (Dyndo et al. 2015; Wisniewska et al. 2018). Although high frequencies travel short distances (Urick 1983), porpoises are often close to vessels, and so it is expected that ship noise also contributes to masking porpoises' ability to detect sounds of interest (Erbe 2015).

Masking does not only affect the animals but also the PAM system itself. This phenomenon is well-known yet remains understudied (Clausen et al. 2019; Sarnocinska et al. 2016). If ship noise masks the PAM system, noise becomes a confounding factor, and reduced detections cannot be directly interpreted as reduced vocal behavior or displacement of harbor porpoises. There is, therefore, a need to further disentangle noise impact on detections and impact on the animals.

To address this, the performance of a PAM detector/classifier algorithm was investigated under different noise conditions on files containing ship noise that were merged with real harbor porpoise clicks. By doing this, the same number of porpoise detections was expected throughout the entire recording of a passing vessel. Thus, any decrease in or lack of detections would be a direct result of noise masking.

Ship Noise and Porpoise Clicks

The data used here were obtained from five deployments carried out in Danish inner waters in 2015: four in the Great Belt area (55.3615 N, 10.9655 E) in August ($n = 1$), September ($n = 1$), and November ($n = 2$) and one in the Little Belt area (55.5295 N, 9.7535 E) in August (Fig. 1). The equipment used was one ST 202HF (Ocean Instruments, New Zealand), recording continuously at a sampling rate of 576 kHz. The ST hydrophone had a sensitivity of −172 dB re: 1 V/μPa.

The deployment location in the Great Belt is close to a shipping lane, so ship passages were selected to ensure only one vessel was passing at a time, assessed by the pattern of increasing and decreasing noise levels (Fig. 1). A total of 25 individual ship passages were selected, amounting to 430 min of recordings, covering different time periods in five deployment days.

Three porpoise click trains were merged with ship noise to prevent pseudo-replication. These trains were also extracted from the data and had different

Fig. 1 Map of the study area. The rhomboids indicate the location of the acoustic recorders

durations, signal-to-noise ratios, amplitude variations, repetition rates, and number of clicks. Only one click train was merged at a time and inserted every 10 sec in each file. Periods with porpoise detections in the original files were removed to prevent errors in the interpretation of the results, which left in almost 1180 min of data.

Noise Levels

For each 10-sec bin (n = 7076), the noise levels (dB re: 1μPa^2/Hz) were estimated from the power density spectrum (Welch average, 512-point FFT, Hann window, 50% overlap) for three frequency bands: 0–20 kHz, 20–80 kHz, and 80–150 kHz, as well as the decidecade centered on 16 kHz. The 16 kHz decidecade band was used because Wisniewska et al. (2018) identified it as a useful proxy for predicting porpoise reactions to ship noise, when noise in that band exceeds 96 dB re. 1 μPa^2/Hz.

Porpoise Detections

The data consisted of *.wav* files of 10 or 30 min in duration, which were analyzed using D-PorCCA. D-PorCCA is a new analytical tool specifically developed for analyzing acoustic data of species that emit narrowband high-frequency clicks, like the harbor porpoise. D-PorCCA includes a transient sound detector (adapted from Gillespie et al. 2008 by Parcerisas 2021), a porpoise click classifier (Cosentino et al. 2019), and a click train detector (Cosentino 2020). The click train detector groups clicks into acoustic events, which are then classified as either high- or low-quality porpoise click trains, based on the output of an algorithm that favors gradual changes in centroid frequency, amplitude, and inter-click intervals (Cosentino 2020).

Noise Impact

The recall (probability of porpoise detection in a given 10-sec bin) was modeled using a generalized linear model with a binomial distribution and one explanatory variable: noise level in one of three frequency bands (<20 kHz, 20–80 kHz, or 80–150 kHz) or the decidecade centered on 16 kHz. The Akaike information criterion (AIC) value was used to compare the performance of the models with each other.

Detections

The number of porpoise clicks detected decreased as the noise levels increased with passing vessels. The effect was visible when looking at individual vessel passages (Fig. 2), especially for increasing levels of noise in the 20–80 kHz frequency band. The models predicted reduced detections as a function of noise (Fig. 3) in all bands, and the model with the lowest AIC value (AIC = 3886.69) had noise in the 20–80 kHz frequency band as the only explanatory variable. The next best model was the one with noise in higher frequencies 80–150 kHz (AIC = 3972.76), then the decidecade centered on 16 kHz (AIC = 4070.34), and last the band <20 kHz (AIC = 4075.84).

Disentangling Impacts

Wisniewska et al. (2018) found that the decidecade centered on 16 kHz could be used as a proxy to identify the noise levels at which porpoises respond behaviorally (by moving away from the noise) or becoming silent. The models in this study indicate that noise masks porpoise detections when it reaches about 90 dB (dB re: 1μPa^2/Hz) in all frequency bands, but especially the 20–80 kHz band (Fig. 3). This means that when noise surpasses these thresholds, masking occurs (Fig. 4).

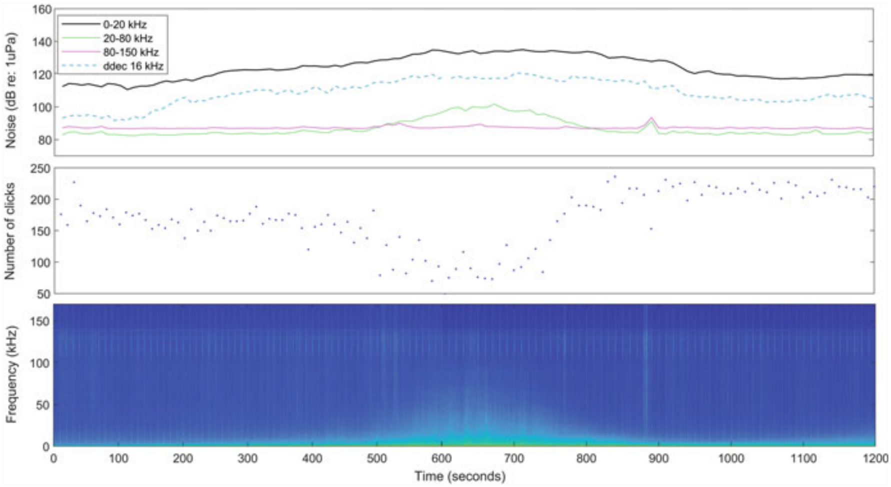

Fig. 2 Ship noise and porpoise detections. Top panel: background noise levels (dB re: 1μPa^2/Hz) in three frequency bands (0–20 kHz, 20–80 kHz, and 80–150 kHz) and the decidecade centered at 16 kHz. Center panel: changes in the number of clicks detected in 10-second bins. Bottom panel: long-term spectral average of the merge files, showing the passing of an individual ship recorded on August 12, 2015, at 3.56 am in the Great Belt area. The vertical lines with energy between 100 and 150 kHz are the inserted porpoise click trains

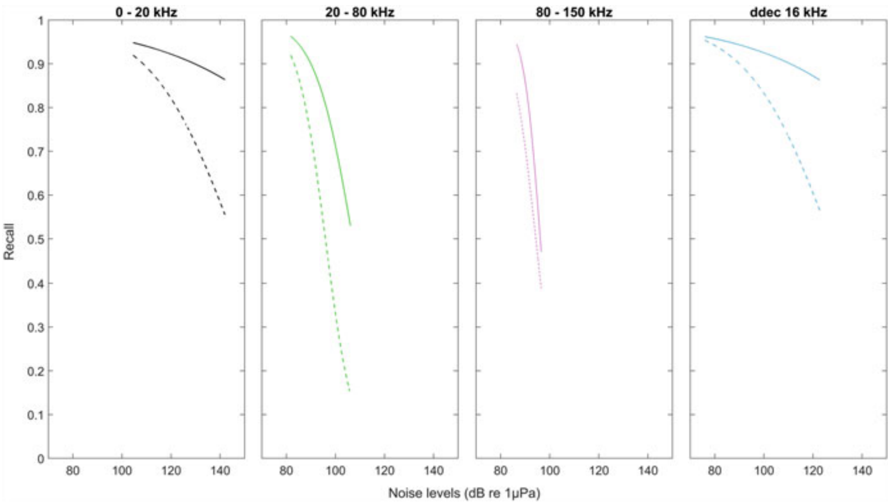

Fig. 3 Recall (probability of detecting porpoises) as a function of ship noise. Modeled recall shows a decrease in detections as noise (dB re: 1μPa^2/Hz) increases in different frequency bands: <20 kHz (AIC = 4075.84), 20–80 kHz (AIC = 3886.69), 80–150 kHz (AIC = 3972.76), and the decidecade centered at 16 kHz (AIC = 4070.34). Solid lines include porpoise click trains of high and low quality. Dashed lines include only porpoise click trains of high quality

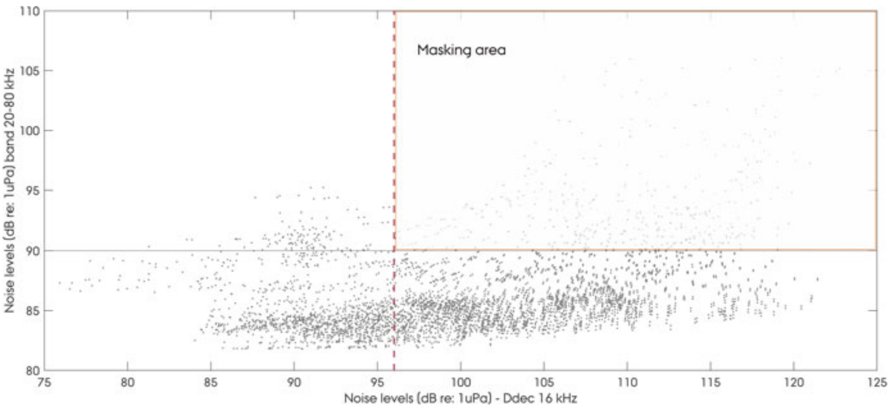

Fig. 4 Masking. Noise levels (dB re: 1μPa^2/Hz) in the ddec centered at 16 kHz vs in the 20–80 kHz frequency band. The shaded area shows where noise masks the acoustic reaction of porpoises

Conclusions

Ship noise extends far beyond the low frequencies at which it is typically monitored, reaching frequencies at which porpoises react both by changing their behavior (e.g., moving away) and also by becoming silent (Dyndo et al. 2015; Wisniewska et al. 2018). However, reduced detections (or no detections at all) during noisy periods cannot be safely explained as an effect of noise in the behavior of porpoises. At high received noise levels, the noise masks the PAM system's detectability, becoming a confounding factor.

As long as frequencies above 20 kHz are monitored and accounted for in the analysis, PAM can be used for monitoring the impact of noise on animals.

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