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Variation in harbour porpoise activity in response to seismic survey noise

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Animals exposed to anthropogenic disturbance make trade-offs between perceived risk and the cost of leaving disturbed areas. Impact assessments tend to focus on overt behavioural responses leading to displacement, but trade-offs may also impact individual energy budgets through reduced foraging performance. Previous studies found no evidence for broad-scale displacement of harbour porpoises exposed to impulse noise from a 10 day two-dimensional seismic survey. Here, we used an array of passive acoustic loggers coupled with calibrated noise measurements to test whether the seismic survey influenced the activity patterns of porpoises remaining in the area. We showed that the probability of recording a buzz declined by 15% in the ensonified area and was positively related to distance from the source vessel. We also estimated received levels at the hydrophones and characterized the noise response curve. Our results demonstrate how environmental impact assessments can be developed to assess more subtle effects of noise disturbance on activity patterns and foraging efficiency.

1. Introduction

Human disturbance may not lead to acute, easily measurable behavioural responses in exposed wildlife [1,2]. Less overt effects can arise from trade-offs that animals make [3], such as deciding to remain in disturbed areas and tolerating higher exposure levels where prey are abundant [4]. However, these trade-offs may also influence activity budgets, potentially affecting fecundity and survival [1,5] or having biologically significant consequences at a population level [6–9].

There is particular concern over the potential impacts of underwater anthropogenic noise on marine mammals [10,11]. Aversive behaviour towards intense noise sources such as pile driving (e.g. [12]) and seismic surveys [13] may not necessarily lead to broad-scale displacement [14]. However, it is not known whether there are more subtle changes in the activity budgets of animals remaining in exposed areas.

Patterns of echolocation clicks can be used to characterize the activity of both bats [15] and odontocetes [16–19]. Here, we use an array of passive acoustic loggers coupled with calibrated noise measurements to assess the effects of a seismic survey on the activity pattern of harbour porpoises (*Phocoena phocoena*).

2. Material and methods

The study was conducted around a commercial two-dimensional seismic survey in northeast Scotland. The survey vessel used a 470 cu inch airgun array with a shot point interval of 5–6 s to survey a 200 km^2 area between 1 and 11 September 2011 (see the electronic supplementary material). Full details are provided in [14].

Patterns of porpoise echolocation clicks were characterized at 22 sites in and around the seismic survey area throughout August and September 2011 (figure 1). Data from V.1 continuous porpoise detectors (CPODs) (www.chelonia.co.uk) had previously been used to characterize the occurrence of porpoises [14]. While the

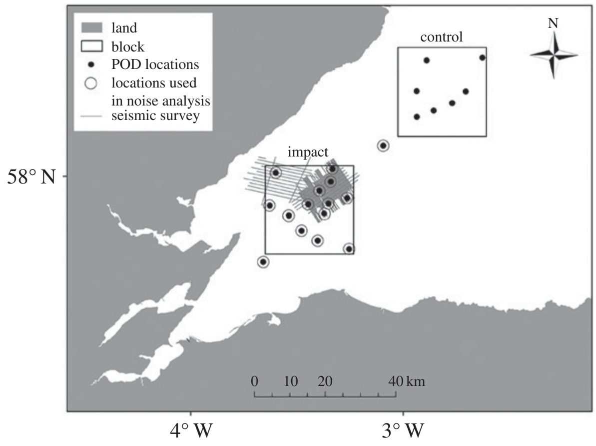

Figure 1. Map of the study area showing the seismic survey lines and the locations of CPOD deployments.

sensitivity of CPODs at different sites could vary between different units or different local conditions, our sampling design and mixed modelling approach were designed to account for this (see the electronic supplementary material).

We calculated the inter-click intervals (ICIs) from the time series of detected clicks. A Gaussian mixture-model was fitted to log-transformed ICIs to identify different patterns of echolocation clicks [16]. Each ICI was classified as either a regular ICI (regular clicking for navigation and prey searching), a buzz ICI (buzzes associated with attempted prey captures or social communication), or an inter-train ICI (pauses between click trains) [20,21] (see the electronic supplementary material).

Following [14], we used data from CPODs in 25 km by 25 km control and impact areas (figure 1; see the electronic supplementary material) to assess the effect of seismic surveys on the occurrence of buzz ICIs when porpoises were present (i.e. in hours in which at least one ICI was detected). The presence of buzz ICIs was modelled as a function of seismic period (before or during) and experimental block (control or impact). Crucially, we also evaluated the interaction between these covariates to test whether seismic surveys influenced buzzing activity. We fitted a binary mixed-effects model in R 13.01 [22], with location included as a random effect. Model selection was based on Akaike's information criterion and the significance of retained covariates evaluated using Wald's tests.

The presence of buzz ICIs for each minute in which at least one ICI was detected was then modelled as a function of distance from the seismic vessel. Following previous studies [12,14] on likely spatial scales of porpoise responses to noise, we used data from within 25 km of the vessel (see the electronic supplementary material). A binary generalized linear model was fitted using generalized estimating equations (GEE-GLM) [23] (see the electronic supplementary material). We used QICu for model selection [24], and Wald's tests to assess significance [25].

Calibrated noise measurements were made at 15 sites between 1.6 and 61.8 km from the seismic vessel [14]. Airgun noise was characterized in terms of broadband sound exposure level for single pulses in dB re 1 $\mu Pa^2 s$ (using the region of the waveform that contained the central 90% of the pulse's energy; hereafter sound exposure level (SEL)). Peak-to-peak source levels were estimated to be 242–253 dB re 1 μPa at 1 m. We tested whether there was a relationship between buzz occurrence and estimated noise levels at the corresponding CPOD location using a bootstrapping procedure (see the electronic supplementary material).

3. Results

There was a significant interaction between experimental block and seismic period (Wald's test: $\chi^2_1 = 7.2$, $p = 0.007$), indicating that the seismic survey had a differential effect in the control and impact block. This resulted in a 15% reduction in the occurrence of buzz ICIs in the impact block during the survey (figure 2). Wide confidence intervals (CIs) highlight high levels of natural variability in detection of buzzes.

The probability of occurrence of buzzes increased significantly with distance from source (Wald's test: $\chi^2_1 = 9.6$, $p = 0.002$), ranging from approximately 0.15 at 0 km (95% CI: 0.11–0.19) to 0.35 at 40 km (95% CI: 0.25–0.48) (figure 2).

Noise measurements allowed us to characterize this relationship in terms of estimated received noise levels (figure 2). This probability increased from 0.07 (95% CI: 0.03–0.17) to 0.31 (95% CI: 0.16–0.52) for SEL that varied from 165 to 130 dB re 1 $\mu Pa^2 s$ (figure 2).

4. Discussion

Short-term responses to this seismic survey did not result in broad-scale displacement, suggesting that impact assessments should focus on sub-lethal effects within affected sites [14]. Our results indicate that porpoises remaining in the impact area reduced their buzzing activity by 15% during the seismic survey. Moreover, the probability of detecting buzz ICIs when porpoises were present increased with distance from the source vessel, suggesting that the likelihood of buzzing was dependent upon received noise intensity. The baseline probability of occurrence of buzzes was around 0.4 in the impact block before the survey, although with high natural variability. This probability declined to 0.1–0.2 at estimated received SEL of 150–165 dB re 1 $\mu Pa^2 s$ (figure 2). Such changes were unlikely to result from the presence of seismic noise, as this was mostly below 400 Hz [14], while most energy in porpoise clicks is within 110–150 kHz [26].

Porpoises may use high-repetition click trains for prey capture or for social communication [27]. Thus, observed changes in buzzing occurrence could reflect disruption of either foraging or social activities. Despite this uncertainty, these data provide a worst-case indication of the extent to which foraging was disrupted by noise exposure. These effects may result from prey reactions to noise [28], leading to reduced porpoise foraging rates. Alternatively, foraging effort may change if porpoises adjust time budgets or diving behaviour to avoid noise. Irrespective of the proximate mechanism(s) through which seismic surveys reduced buzzing rates, this clearly has the potential to affect the energy balance of exposed animals.

High metabolic rates [29] mean that porpoises have limited ability to cope with prolonged starvation [30]. Our results provide an estimate of the noise levels at which porpoise activity patterns are disrupted, and an indication of the scale of potential reductions in foraging activity [6]. Porpoise occurrence and activity is typically characterized by large seasonal and diel variability [19,31,32], as also reflected in our results (figure 2). Further studies are now required to explore the environmental conditions that drive this variation, and develop energetic models to assess whether this scale of disturbance has long-term consequences for individual energy budgets [33].

The commercial seismic surveys studied in this paper were licensed by the Department of Energy and Climate Change (DECC) and followed UK guidelines to reduce potential impacts on marine mammals.

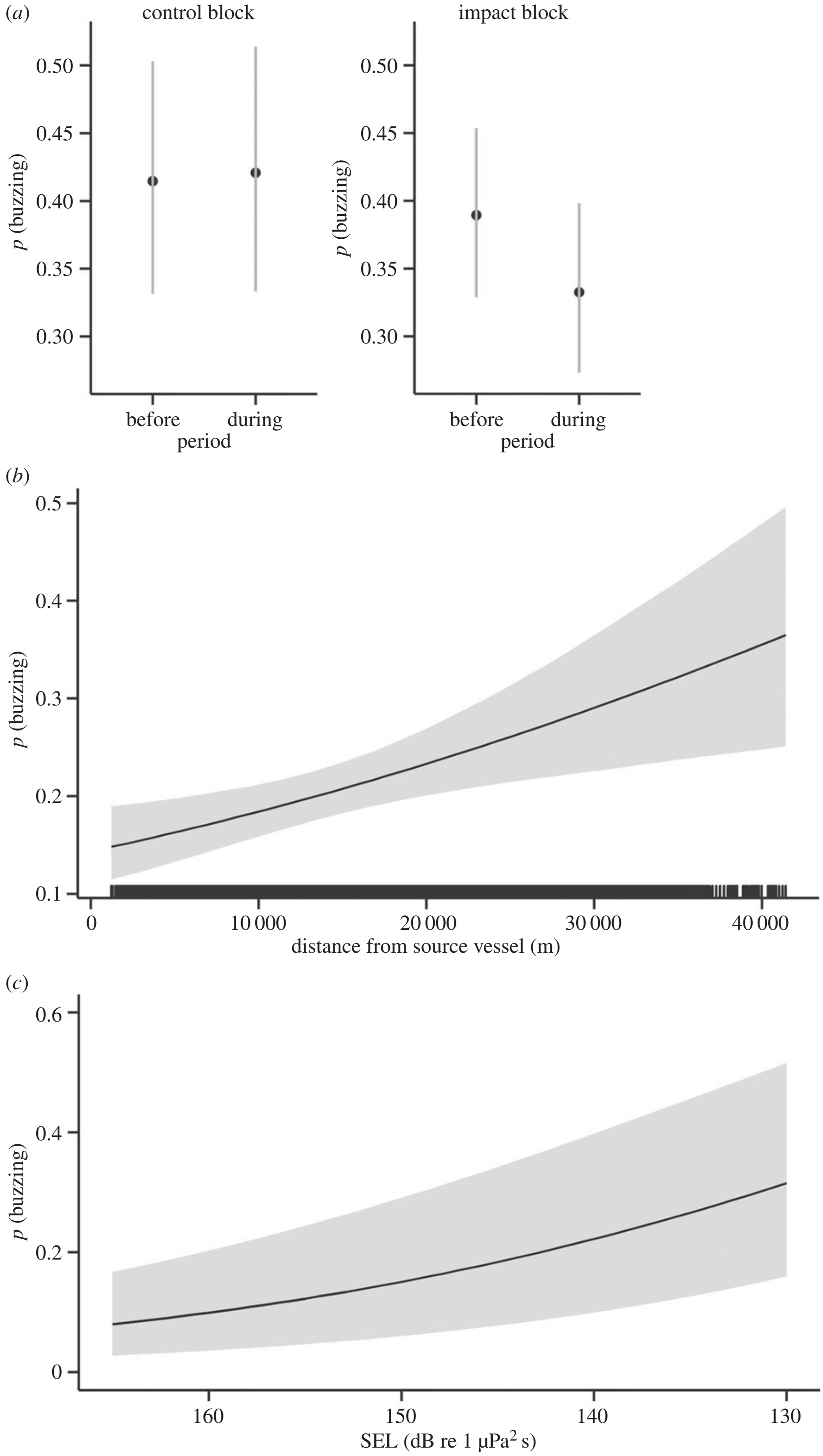

Figure 2. Modelling results. (*a*) Changes in the probability of feeding buzz occurrence in control and impact blocks, before and during the survey. (*b*) Estimated relationship between the probability of buzz occurrence and distance from the source vessel. (*c*) Estimated relationship between the probability of buzz occurrence and unweighted SEL.

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Data accessibility. The dataset used in this paper is available in the Dryad data repository: doi:10.5061/dryad.1847s

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