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Shipping noise in a dynamic sea: a case study of grey seals in the Celtic Sea

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ABSTRACT

Shipping noise is a threat to marine wildlife. Grey seals are benthic foragers, and thus experience acoustic noise throughout the water column, which makes them a good model species for a case study of the potential impacts of shipping noise. We used ship track data from the Celtic Sea, seal track data and a coupled ocean-acoustic modelling system to assess the noise exposure of grey seals along their tracks. It was found that the animals experience step changes in sound levels up to ~20 dB at a frequency of 125 Hz, and ~10 dB on average over 10–1000 Hz when they dive through the thermocline, particularly during summer. Our results showed large seasonal differences in the noise level experienced by the seals. These results reveal the actual noise exposure by the animals and could help in marine spatial planning.

1. Introduction

Anthropogenic noise in the marine environment has increased significantly over the past five decades (McDonald et al., 2006). Growing evidence suggests that this increased noise is negatively impacting a range of species from crabs (Wale et al., 2013) to cetaceans (e.g. Rolland et al., 2012). Most research has concentrated on the acute impacts of loud impulsive sounds, such as pile driving, sonar and seismic air guns on acoustically sensitive species (e.g. Richardson et al., 1995). However, chronic, persistent noise, such as that from shipping, is becoming the focus of more recent research (e.g. Rolland et al., 2012; Simpson et al., 2016). Shipping noise has increased by 2.5–3 dB per decade over the last four decades (30–50 Hz; McDonald et al., 2006). This increase is particularly evident near major ports due to greater shipping density, usually concentrated in shallow shelf waters.

Noise from ships has the potential to mask the communication of acoustically active marine mammals (e.g. Williams et al., 2014) and result in changes in their behaviour such as (i) reducing the communication distance between the animals (e.g. grey seal (*Halichoerus grypus*): Bagocius, 2015), (ii) increasing the amplitude of vocalisations (e.g. right whales (*Eubalaena glacialis*): Parks et al., 2011) and (iii) reducing calling rates (e.g. beluga whales (*Delphinapterus leucas*): Lesage et al., 1999). The mitigation of shipping noise pollution is therefore integral to marine spatial planning in the shelf seas, where anthropogenic activities are rapidly increasing (Ellison et al., 2011). The International Maritime Organisation (IMO) recently released guidelines for the reduction of underwater shipping noise (IMO, 2014 MEPC.1/Circ.833). Anthropogenic underwater noise has also recently been recognised as a form of pollution in European legislation through the Marine Strategy Framework Directive (MSFD descriptor 11: 2010/477/EU). Shipping noise is principally concentrated at low (<300 Hz) frequencies (Richardson et al., 1995). For low frequency noise policy requires monitoring of trends in the ambient noise level within the 1/3 octave bands of 63 and 125 Hz (centre frequency), which will be studied in this paper. With chronic persistent noise, a comprehensive approach is required since both the source (ship) and the receiver (mobile marine species) are moving through space and time, and this provides an additional challenge to assessing sound exposure.

Currently, there is insufficient observational data to support a thorough assessment of either ambient noise levels or their impacts on marine animal populations (UKMS, 2014), and there is an urgent need for detailed sound propagation predictions for complex noises and moving sources to generate and test hypotheses about their impacts on behaviour and energetics. Sound propagation modelling is an essential tool to assess the impact of shipping noise on marine mammals. The area affected by noise and the severity of the impacts depend on the frequency, duration and ability of the sound to propagate (Bailey et al., 2010). Key factors affecting sound propagation are the oceanographic and geomorphological characteristics of the surrounding region. Underwater acoustic signals do not propagate along a straight line, instead sound waves experience multiple reflections from the sea surface and seabed (Katsnelson et al., 2012). Furthermore, meso-scale features (e.g. fronts and eddies) and fine-scale characteristics (e.g. internal waves) can

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result in fluctuations of sound energy by up to ~20 dB (Lynch et al., 2006; Shapiro et al., 2014). Despite of their importance, these features are rarely incorporated into sound transmission models due to the lack of high resolution data on seawater parameters (e.g. temperature and salinity).

The Celtic Sea (see Fig. 1) provided the ideal location in which to investigate the use of oceanographically-referenced sound propagation models for assessing shipping noise exposure to marine animals. Shipping traffic in the Celtic Sea is heavy because it links the Atlantic with the UK coastal waters. The Celtic Sea is shallow with depths rarely exceeding 120 m. The sea is strongly stratified with a sharp thermocline from April to November and is mixed in winter, and a series of bottom fronts exist during the summer (Pingree, 1980). In addition, eddies with a typical diameter of 20–40 km also exist over the shelf-break region in late summer (Pingree, 1980).

Our previous study (Shapiro et al., 2014) showed the strong variability of sound propagation in the Celtic Sea due to strong seasonal variability in water column stratification. The transmission loss (hereafter TL) differs between summer and winter by as large as ~20 dB. In summer, when the source of sound is on the onshore side of the bottom front, sound energy is mostly concentrated in the near-bottom layer, resulting in step changes of TL in the water column up to ~20 dB. In winter sound from the same source is, however, distributed more evenly in the vertical. When the source is on the seaward side of the front, the sound level from a shallow source is nearly uniform in the vertical and the TL is significantly greater (~16 dB at 40 km distance) in summer than in winter. Such large seasonal differences in sound TL are, therefore, likely to result in significant seasonal changes in shipping noise exposure experienced by marine animals.

Assessing the effects of underwater noise on marine animals requires large databases that characterise animals' behaviour, movements and associated noise levels. Grey seals (*Halichoerus grypus*) are a highly tractable species which move over wide areas and feed predominantly at the benthos in shelf seas (McConnell et al., 1999; Thompson, 2012). This makes them a good choice for the reconstruction and assessment of received sound levels of animals. The movements of individuals and underwater behaviour can be tracked in fine detail using GPS-GSM (Russell and McConnell, 2014) or satellite tags that record position and dive profiles, allowing dive by dive sound exposure to be calculated and potential behavioural or energetic consequences to be assessed. Unlike many cetaceans, grey seals do not critically depend on hearing to survive, but they are highly vocally active in air and in water with a substantial repertoire (Asselin et al., 1993). They use sound and vibrations in aggression, mating and in mother-pup bonding (Bishop et al., 2015) and the repertoire extends across a wide range of frequencies though most are typically <3 kHz. They can also use sounds passively in foraging scenarios (Stansbury et al., 2015). Pinnipeds have anatomical adaptations that mean they are well-adapted to hearing in water, and have hearing ranges from very low frequencies ~100 Hz (Kastak and Schusterman, 1998) to high frequencies ~30 kHz (Cunningham and Reichmuth, 2016). It is therefore likely that shipping noise is within the hearing range of grey seals.

The aim of this paper is to assess the shipping noise exposure experienced by grey seals along their tracks, and how this exposure varies seasonally. We used two grey seals and the Celtic Sea for this case study. However, we believe that the general outcomes of this research are applicable to other shelf seas and other animals, where both the source (ship) and receiver (marine animal) move in space and time. To achieve this we used a state-of-the-art ocean and acoustic propagation model (Shapiro et al., 2014) populated with GPS tracks and dive data from grey seals, and real-time AIS shipping data from winter and summer.

2. Materials and methods

2.1. Shipping data

The accurate modelling of shipping noise first requires detailed information on shipping in order to estimate the source levels (SL) of ships. The realistic operational information and ship properties were extracted from an Automatic Identification System (AIS) database through a web-based ship tracking database (*http://www.marinetraffic.com/*),

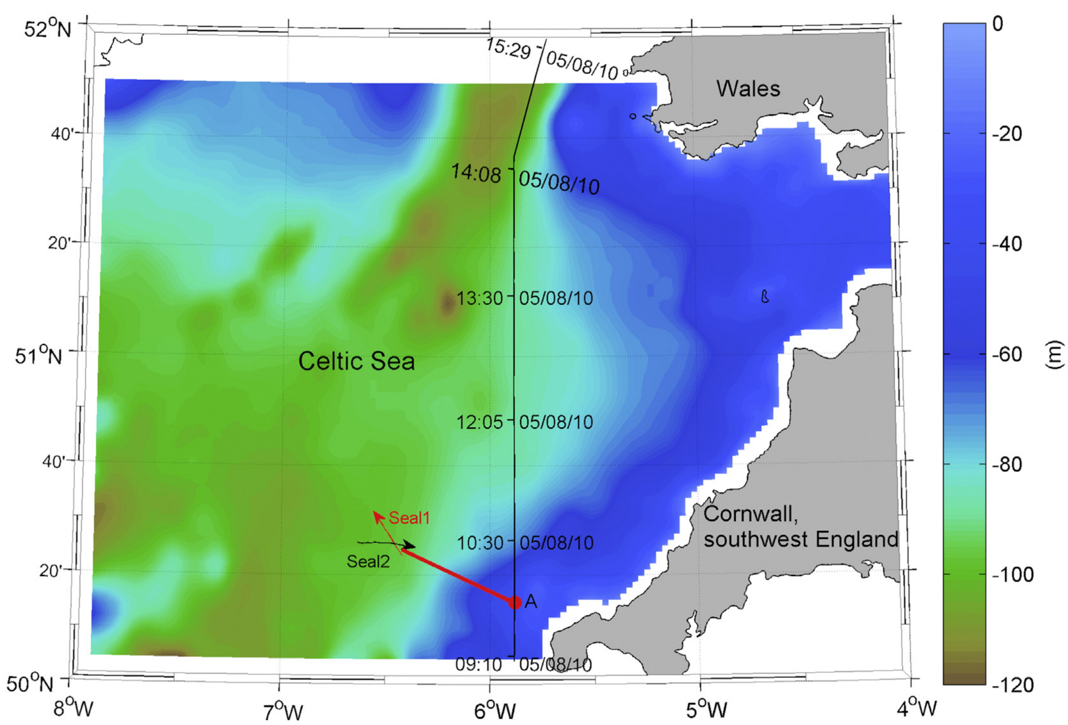

Fig. 1. Study area showing the bathymetry of the model domain. Transect A (thick red solid line) is used to calculate 2D transmission loss. Dot represents the location of the source. Solid line with time stamps express an example of shipping track from a commercial cargo ship (MMSi: 353633000). Arrows represent the horizontal tracks of two seals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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