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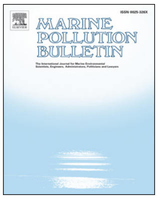

Underwater noise levels of pile-driving in a New Zealand harbour, and the potential impacts on endangered Hector's dolphins

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ABSTRACT

Impact pile-driving generates loud underwater anthropogenic sounds, and is routinely conducted in harbours around the world. Surprisingly few studies of these sounds and their propagation are published in the primary literature. To partially redress this we studied pile-driving sounds in Lyttelton Harbour, New Zealand, during wharf reconstruction after earthquake damage. That Lyttelton harbour is routinely used by Hector's dolphins (*Cephalorhynchus hectori*), an endangered species found only in New Zealand, provided further context for this study. Steel piles of 0.61 or 0.71 m diameter were driven using three different pile-drivers. Maximum calculated source SEL was 192 dB re 1 μPa^{2}s @ 1 m (SPL_{0-p} of 213 dB re 1 μPa @ 1 m). Propagation of piling noise was strongly influenced by harbour bathymetry and a rock breakwater near the piling operation. We calculated range estimates at which Hector's dolphins may suffer temporary hearing threshold shift and behavioural change.

1. Introduction

Impact pile-driving produces impulsive, repetitive sounds that are among the loudest anthropogenic underwater sounds, particularly when steel piles are driven (Richardson et al., 2013). This form of noise pollution has been extensively studied in relation to windfarm construction (e.g. Bailey et al., 2010; De Jong and Ainslie, 2008; Nedwell et al., 2007) but there are very few studies of noise generated due to wharf construction that are published in the primary literature (for exceptions see Paiva et al., 2015; Würsig et al., 2000). Since several dolphin species routinely occur close inshore and in harbours (e.g. Dawson, 2018; Parra and Jefferson, 2018), this lack of literature is a potentially important weakness in the protection of these species.

Pile-driving noise has been established as a serious threat to some marine mammal species (Thompson et al., 2013). Wild harbour porpoise (*Phocoena phocoena*) show strong avoidance reactions to pile-driving (Brandt et al., 2011; Dähne et al., 2013; Tougaard et al., 2009). Temporary hearing loss has been documented in captive animals, following exposure to pile-driving noise (Kastelein et al., 2015). Hector's dolphin (*Cephalorhynchus hectori*), an endangered, nearshore delphinid found only in New Zealand, is routinely present in Lyttelton harbour. The Banks Peninsula Marine Mammal sanctuary (including Lyttelton harbour) was created in 1988 to reduce the impact of incidental catch in gill nets and trawling, the main threats to Hector's dolphins. That Hector's dolphins have very similar acoustic behaviour to harbour porpoises (Dawson, 2018; Dawson and Thorpe, 1990; Villadsgaard et al., 2007), are similarly sized and have broadly similar ecology (Würsig et al., 2018) raises the potential for pile-driving to be an additional impact, and provides the context for this study.

Impact pile-driving radiates noise into the water and sediment surrounding the pile. The majority of the underwater noise arises from radial expansion of the pile as it is struck by the hammer, radiating directly into the water column (Reinhall and Dahl, 2011; Tsouvalas and Metrikine, 2013). Energy is also transferred into the seabed, and can radiate back into the water, or travel as surface waves (Sholte waves) along the water-seabed interface (Tsouvalas and Metrikine, 2016a). For these reasons, pile-driving noise does not behave strictly as a “point” source. The spectrum of a typical pile strike is broadband, with most energy below 1 kHz but with significant energy extending to > 100 kHz, especially at close range (e.g. Nedwell et al., 2007; Tougaard et al., 2009).

Sound propagation is usually described as involving two kinds of losses, spreading losses and absorption. Spreading losses range between cylindrical (shallow water; 10*log(R), where R is range) and spherical (deep water; 20*log(R)). Absorption is frequency dependent, high frequencies are rapidly absorbed, while low frequencies can be detectable above ambient noise at very large ranges (Ainslie and McColm, 1998; Malme and Beranek, 1995). Shallow water, however, imposes a lower limit on the frequencies it can support to propagate based on depth (Forrest et al., 1993; Jensen et al., 2011). In practice, sound

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propagation is complex, especially in shallow water, influenced also by the roughness of the surface, depth, the nature of the bottom, and any layering in the water column (Marsh and Schulkin, 1962; Pine et al., 2014).

Modelling propagation from impact pile-driving presents an especially difficult challenge, due to the influence of bottom layer properties (Lippert and von Estorff, 2014) as well as bottom and surface reflections in shallow water transmission (Marsh and Schulkin, 1962). Currently there is no available software that can adequately model this complex process in a realistic coastal setting, accounting for the various environmental factors, and beyond ranges > 1.5 km (Denes et al., 2016; Duncan et al., 2010; Fricke and Rolfes, 2015; Reinhall and Dahl, 2011). For these reasons a strong empirical approach to measuring propagation was used in the present study.

The 2010 and 2011 Christchurch earthquakes extensively damaged the city's port in Lyttelton harbour. Port development was combined with repair work, under the Canterbury Earthquake Recovery Act (2011), allowing the work to be carried out without the usual resource consent process, and therefore, under less strict environmental management. The construction work involved 15 months of pile-driving.

Our purpose in this contribution is to describe the acoustic characteristics of noise pollution generated by impact pile-driving during the wharf reconstruction in Lyttelton harbour, quantify the propagation of this noise within this harbour, and investigate the potential impact this noise may have had on the local Hector's dolphin.

2. Materials & methods

2.1. Study area

Lyttelton harbour (43°36′47″S, 172°44′24″E), on the east coast of the south island of New Zealand, is a shallow harbour (Fig. 1) with a dredged shipping channel.

Pile-driving was carried out using three different impact hammers (Table 1). In each of these, hydraulic power was used to lift a steel hammer which then dropped via gravity on the top of the pile. The piles were steel, hollow, and closed-ended, with a diameter of 0.61 m or 0.71 m. Each pile was approximately 80 m long and driven an average of 66 m into the seabed (HEB construction, pers. comm. 2015). The contractor's records of pile-driving activity, which specified pile location, pile-driver, and the sequence of lift heights used, were made available by HEB construction and Port Lyttelton. A "soft start" using the hammer on its lowest energy setting for the first 2 min, was standard practice (i.e. required by the pile-driver manufacturers). Pile-driving was scheduled from Monday to Saturday between 7:30 am and 6 pm. Weather conditions restricted the actual operation time.

Table 1
Pile-drivers used in Lyttelton harbour.

Model	Gross weight (t)	Hammer weight (t)	Lift height range (m)	Max energy (kJ)
BSP 1146	35	14	0.5–1.5	206
Bruce SGH 1015	28	10	0.2–1.5	147
Junttan HHK18A	18	9	0.2–1.2	106

2.2. Field techniques and data collection

Sound recordings were made using three autonomous recorders (two DSG Ocean recorders and a SoundTrap HF) and two boat-based recorders (for recording locations see Fig. 1). The SoundTrap HF recorder (sampling frequency, $f_s = 288$ kHz, frequency response 20 Hz - 150 kHz ± 3 dB) was moored in an average water depth of 6.5 m, approximately 370 m from the piling activity ('SoundTrap' in Fig. 1). This location (close to the breakwater at 'Sticking Point') was chosen to reduce the risk of the recorder being damaged by docking vessels while minimising the range to the noise source. A DSG recorder (HTI-96 min hydrophone, $f_s = 80$ kHz, max. frequency response 2–30 kHz), was moored just outside the harbour channel, in about 8 m of water, directly in front of the piling 750 m away ('DSG' in Fig. 1). These two recorders were moored and removed each recording day. A further DSG recorder ('Duty cycle DSG' in Fig. 1) was set up on a duty cycle, recording for 5 min every hour ($f_s = 80$ kHz) and moored in about 9 m of water, continuously from February 27, 2015 to March 25, 2015, near a channel marker about 1.9 km from the piling activity. This recorder was used to record ambient noise. All autonomous recorders were moored about 2 m above the seafloor. Water height varied within 1.5 m due to tide (https://www.linz.govt.nz/). The substrate was generally a very fine clay silt mixture, including a small amount (1%) of sand, with a fluid mud layer on top (5–8 cm thickness, up to 45 cm in the channel), due to the high sedimentation in Lyttelton harbour (OCEL Consultants NZ Limited, 2014).

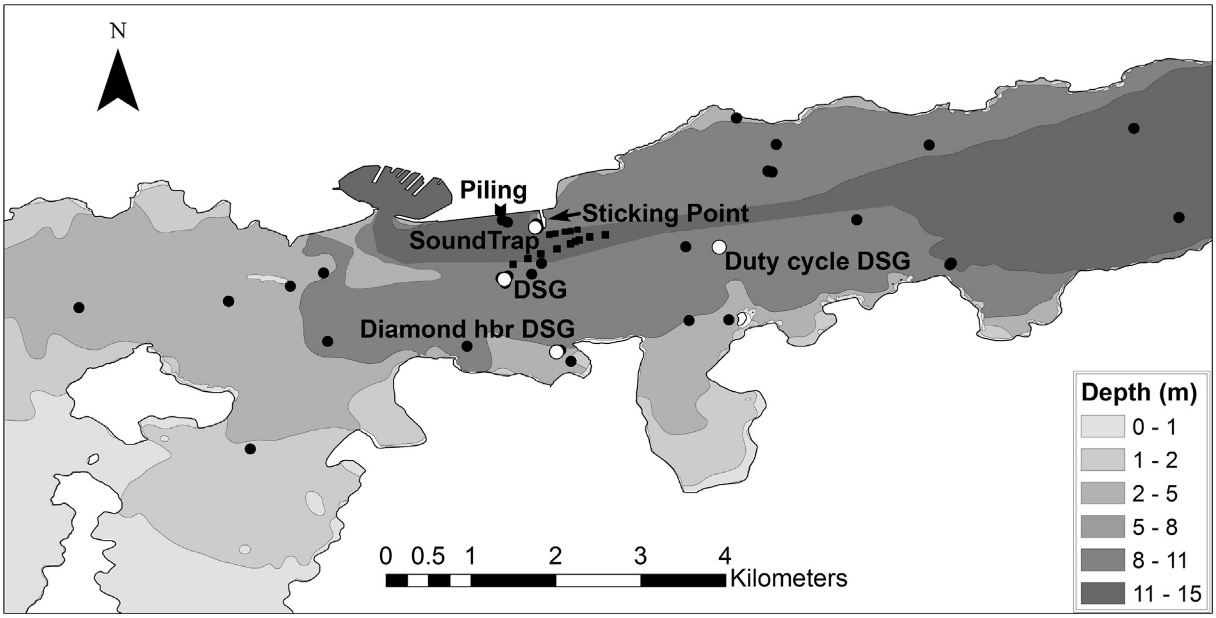

Fig. 1. Location of moored recorders (white dots) and boat based recordings (black dots) in Lyttelton Harbour.