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Seismic surveys and marine turtles: An underestimated global threat?

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ABSTRACT

Seismic surveys are widely used in marine geophysical oil and gas exploration, employing airguns to produce sound-waves capable of penetrating the sea floor. In recent years, concerns have been raised over the biological impacts of this activity, particularly for marine mammals. While exploration occurs in the waters of at least fifty countries where marine turtles are present, the degree of threat posed by seismic surveys is almost entirely unknown. To investigate this issue, a mixed-methods approach involving a systematic review, policy comparison and stakeholder analysis was employed and recommendations for future research were identified. This study found that turtles have been largely neglected both in terms of research and their inclusion in mitigation policies. Few studies have investigated the potential for seismic surveys to cause behavioural changes or physical damage, indicating a crucial knowledge gap. Possible ramifications for turtles include exclusion from critical habitats, damage to hearing and entanglement in seismic survey equipment. Despite this, the policy comparison revealed that only three countries worldwide currently include turtles in their seismic mitigation guidelines and very few of the measures they specify are based on scientific evidence or proven effectiveness. Opinions obtained from stakeholder groups further highlight the urgent need for directed, in-depth empirical research to better inform and develop appropriate mitigation strategies. As seismic surveying is becoming increasingly widespread and frequent, it is important and timely that we evaluate the extent to which marine turtles, a taxon of global conservation concern, may be affected.

1. Introduction

Natural underwater sound in marine habitats consists of a combination of acoustic sources, both abiotic and biotic in origin (Au and Hastings, 2008; Hildebrand, 2009). Travelling approximately five times faster in water than in air and covering much greater distances at higher amplitude levels, sound is an efficient method of propagating energy through the marine environment (Hildebrand, 2009; Jung and Swearer, 2011; Bouton et al., 2010). As a result, it is used by many marine organisms to communicate, navigate and locate food (Castellote et al., 2012; Codarin et al., 2009; Janik and Sayigh, 2013; Leis et al., 2011; Bouton et al., 2010). However, noise-generating activities, such as shipping and oil and gas exploration, are transforming the marine soundscape (Compton et al., 2008; Hatch and Wright, 2007). In particular, there is growing concern over the potential impacts of airgun sound emitted during seismic surveys on marine fauna (Lavender et al., 2014; Weir and Dolman, 2007). This method uses sound waves to search for oil and gas deposits beneath the sea bed using cylinders of compressed air (airguns) which are suspended in the water column. The simultaneous firing of these airguns generates bubbles, the expansion and collapse of which creates sound waves (see Figs. 1; A.1 for Glossary). Individual seismic surveys vary enormously in source size, shot interval, operation duration (both the length of individual lines and total operational activity per day) and spatial scale, depending on the type of survey, geographic area and other parameters. However, a 'typical' 3D seismic survey uses a source consisting of 20 to 40 individual airguns that are fired simultaneously at shotpoint intervals of 18.75 or 25 m as the vessel moves along a predetermined line at a towing speed of approximately 4.2 knots. The time taken to complete individual survey lines may be short (<1 h) or may exceed 24 h, but typically is of several hours duration followed by a cessation of operations for 2 to 3 h as the vessel turns to the subsequent line. Seismic surveys may continue within an area for several months when a prospect is particularly large, and sometimes require more than one source vessel operating concurrently.

To date, much of the research on this topic has focused on marine mammals due to their known reliance on sound (Caldwell, 2004; Gordon et al., 2003; Weilgart, 2007). More recently, fish and invertebrates have begun to receive greater levels of attention (André et al., 2011; DeSoto et al., 2013; Lillis et al., 2013; Popper et al., 2005; Radford et al., 2014; Simpson et al., 2015). One important taxon has, however,

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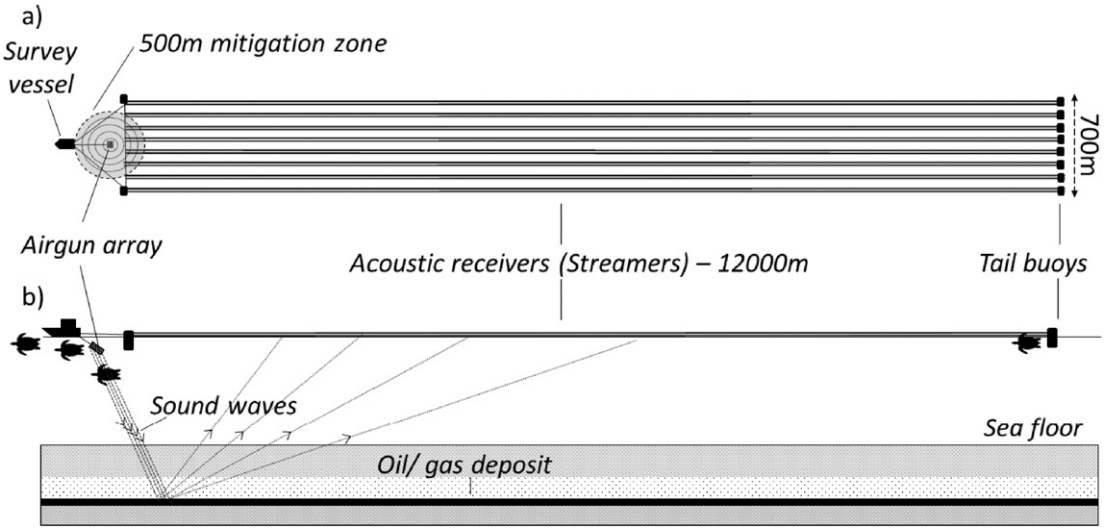

Fig. 1. Schematic showing seismic vessel towing survey equipment and potential impact zones for turtles: a) aerial and b) horizontal views. Not to scale, for illustration purposes only.

so far been over-looked. Seven species of marine turtle are present in nearly all of the world's oceans, occupying a diverse range of habitats throughout their various life-stages (Wallace et al., 2011). Most species are highly migratory, moving periodically between pelagic, neritic and terrestrial environments to forage and breed, often aggregating in key areas (Godley et al., 2010). As a result of the many anthropogenic stressors facing marine turtles, such as fisheries bycatch, habitat loss, climate change, and pollution, they are of global conservation concern.

Acoustic disturbance from seismic survey activities may lead to the interruption of normal behaviours (such as feeding or breeding) and avoidance, leading to displacement from the area and exclusion from critical habitats — an effect that has been documented for a number of cetacean species, particularly mysticetes (baleen whales) and delphinids (Castellote et al., 2012, 2010; Goold, 2009; Richardson et al., 1990; Weller et al., 2002). Additionally, startle responses, such as increased swim speeds and altered dive durations, have been observed in fish and marine mammals (Boeger and Pie, 2006; Robertson et al., 2013) possibly leading to physical damage (and mortality) such as decompression sickness and strandings (Gordon et al., 2003; Jepson et al., 2013; Mann et al., 2010; Wright et al., 2007). A reduction in hearing sensitivity may be observed as a result of damage to auditory organs and structures, such as sensory hair cells (Gordon et al., 2003; McCauley et al., 2003). Noise may also cause stress which in turn can lead to a depressed immune function (Anderson et al., 2011). Bouton et al. (2010) suggested that noise-dependent stress might affect reproductive and growth processes in fish and DeSoto et al. (2013) found that scallop (*Pecten novaezelandiae*) larvae exposed to playbacks of seismic pulses displayed significant developmental delays.

In addition to the noise-induced issues, the firing of airguns during seismic surveys may cause rapid changes in pressure, an occurrence that is known to cause barotrauma in fish, whereby tissues and organs are damaged (Carlson, 2012; Casper et al., 2013; Popper et al., 2014). Another potential risk to turtles is entanglement in seismic equipment, such as tail buoys and their associated attachment materials, towed behind the survey vessel, (Figs. 1 & 2), possibly leading to injuries or mortality (Ketos Ecology, 2009).

Seismic surveys employing airgun arrays have the potential to cause harm to various marine taxa (Gordon et al., 2003; McCauley et al., 2000) yet despite this, there is a lack of knowledge concerning the potential impacts for marine turtles (DeRuiter and Larbi Doukara, 2012; Lavender et al., 2012; Piniak et al., 2012b; Weir, 2007). Given their conservation status, there is a need to assess the degree of threat posed by oil and gas exploration, especially as it is increasing worldwide, both in terms of frequency and distribution (McBarnet, 2014).

The purpose of this study was to: (1) examine the potential effects of seismic surveys on marine turtles, (2) assess the availability and adequacy of current policy (statutory guidelines) and mitigation techniques, and (3) identify areas requiring further research and development. To address these, a mixed-methods approach was employed, involving a systematic review, policy comparison and stakeholder analysis.

2. Materials and methods

2.1. Systematic review

We reviewed all relevant literature with the aim of understanding how seismic surveys may affect marine turtles. Studies carried out on marine mammals and fish were also examined. A broad primary question was formulated: '*What are the potential impacts of seismic surveys on marine turtles*?' This was then broken into a number of components: *behavioural responses to sound*; *physical impacts*; *monitoring* and *the effectiveness of mitigation measures*.

Three separate literature searches were carried out, one for each group of marine animals — *turtles*, *marine mammals* and *fish*. Google Scholar and ISI Web of Science were searched for the terms *seismic*, *airgun*, *noise*, *sound* or *hearing* along with the taxa. The first 100 results were viewed, spurious hits were ignored and all relevant references

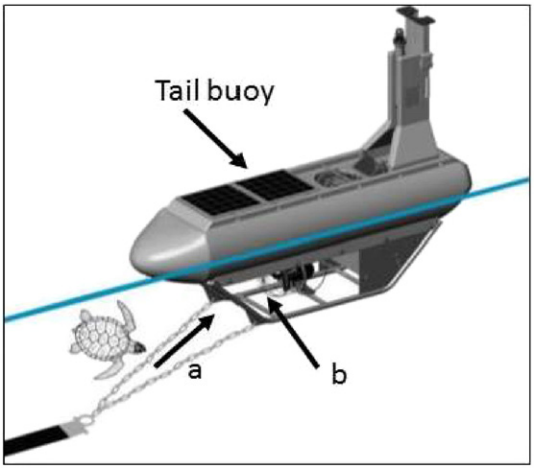

Fig. 2. Schematic of a turtle that has startle-dived in response to an approaching tail buoy. Turtles may become trapped (a) in front of the under-carriage in the area between the buoy and chains or (b) inside the under-carriage structure.