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An integrated approach to assessing marine seismic impacts: Lessons learnt from the Gippsland Marine Environmental Monitoring project

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ABSTRACT

Marine seismic surveys are a fundamental tool for geological research, including the exploration of offshore oil and gas resources, but the sound generated during these surveys represents a source of noise pollution in the marine environment. Recent evidence has shown that seismic surveys may negatively affect some cetaceans, fish and invertebrates, although the magnitude of these impacts remains uncertain. This paper applies a case study on marine seismic impacts (the Gippsland Marine Environmental Monitoring (GMEM) project) to the critical assessment of the advantages and challenges of field-based methods in the context of future research and management priorities. We found that an interdisciplinary approach, using both conventional (e.g. dredging) and innovative (e.g. autonomous imagery) experimental components, make for more robust interpretations and also provide a failsafe in case of limited suitable data (e.g. equipment issues related to image acquisition). Field observational studies provide an unparalleled capability to undertake ecologically realistic research, although their practical challenges must be considered during research planning. We also note the need for appropriate environmental baselines and accessible time-series data to account for spatiotemporal variability of environmental and biological parameters that may mask effects, as well as the need for a standardised technique in sound monitoring and equipment calibration to ensure accuracy and comparability among studies.

1. Introduction

Environmental impacts are changes to an aspect of the environment (physical, biological, chemical) caused by a stressor. In the context of marine management, environmental impacts can be quantified by measuring biological responses (e.g. changes in abundance or diversity) or surrogate physical parameters (e.g. chlorophyll-*a* for phytoplankton). The methods to quantify environmental impacts vary according to bioindicators (Cooper et al., 2009), criteria of impact significance (Liu et al., 2012), and consideration of cumulative effects (Jones, 2016). There has been increasing attention directed towards the potential impacts of ocean noise on marine fauna (Williams et al., 2015), with low-frequency acute sound from activities such as marine seismic surveys being of particular concern (Gordon et al., 2003; Nowacek et al., 2015; Wright and Cosentino, 2015; Hawkins and Popper, 2016; Carroll et al., 2017; McCauley et al., 2017).

Marine seismic surveys are a fundamental tool for research on the structure, composition and dynamics of the Earth's crust. These data help reveal the deep-Earth processes that drive plate tectonics and associated seismic (earthquakes/faulting) and volcanic (eruptions) activity. The same tools are also essential for the exploration of oil and gas resources that occur in offshore sedimentary basins. In such surveys, an array of airguns release compressed air into the water column as a bubble, thereby generating low-frequency sound waves that propagate through the seafloor to the subsurface. Hydrophones and accelerometers towed behind a vessel measure the reflections of the sound, allowing the imaging of geological formations deep below the seafloor. These images can be interpreted by geologists to identify potential oil and gas reservoirs. Seismic surveys are undertaken in two configuration types: 2-D seismic surveys in which a single airgun array and streamer of hydrophones are used to generate 2-dimensional images of the subsea geology, and 3-D seismic surveys in which multiple (usually ≥ 10 or more) parallel hydrophone streamers allow the creation of a 3-dimensional model of the subsea geology. In addition to seismic surveys, vertical seismic profiling (VSP) is used down the borehole in offshore drilling to correlate the stratigraphy with seismic data.

Alternative techniques to acquire comparable marine geophysical data are in their infancy (e.g. Summerfield et al., 2005; Pramik et al., 2015), and the use of airguns remains the most effective way to identify potential offshore oil and gas resources (Gisiner, 2016). The international economic significance of the offshore petroleum industry will

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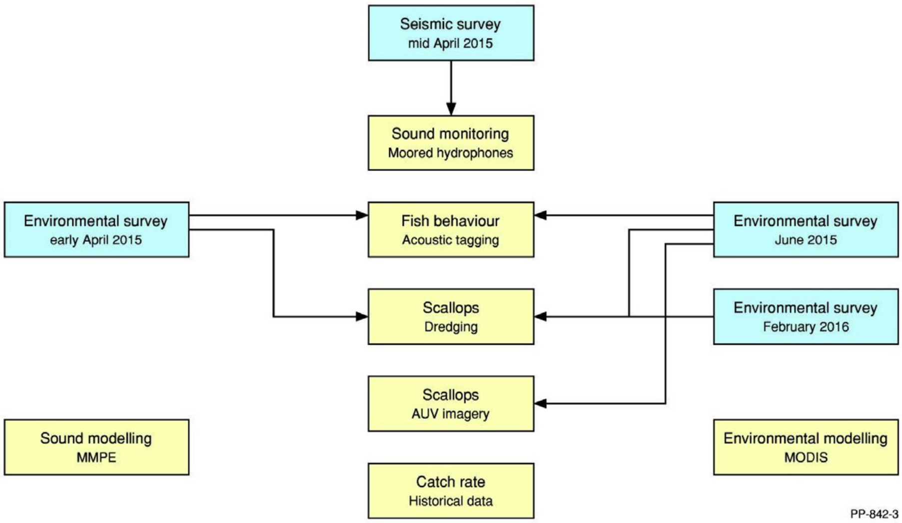

Fig. 1. Components of the Gippsland Marine Environmental Monitoring (GMEM) project, with field surveys (blue) connected to their respective experimental components (yellow). Large text describes the project component, and small text indicates the date (for surveys) or method (for experimental components). AUV = Autonomous Underwater Vehicle, MODIS = Moderate Resolution Imaging Spectroradiometer, MMPE = Monterey Miami Parabolic Equation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

continue in the immediate future with oil demand still projected at over 103 million barrels per day in 2040 (IEA, 2016), until renewable energy sources are able to be adopted at a global scale (Kaivo-oja et al., 2016). Until such time as demand for petroleum resources is substantially diminished, or alternatives to seismic surveys are found, seismic surveys will remain a source of noise in the ocean. Consequently, there is a continued need to understand the environmental and biological impacts of sound sources on regions, habitats, and species. However, achieving this understanding is challenging, due to the technical issues associated with measuring the impacts of sound on organisms (e.g. lack of standards as reviewed in Carroll et al., 2017), as well as limited information on marine habitats and the distribution of species (e.g. National Marine Science Plan, 2015).

Once these impacts have been assessed, the next step is the translation of this assessment into effective policy and regulation, as well as the assurance that mitigation measures are indeed effective. Many countries have adapted legislation or advice incorporating precautionary principles to protect marine mammals from potential impacts of seismic surveys (e.g. *Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment* for Canada, *2013 Code for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations* for New Zealand) and have a regulatory body in place to assess the risk of proposed activities (e.g. Bureau of Ocean Energy Management in United States, National Petroleum Safety and Environmental Management Authority in Australia). However, there are fewer legislative and regulatory directives that address potential impacts on other species. Australia is one exception to this, with proposed seismic surveys requiring an approved environment plan (EP) that includes a risk assessment of impacts and measures to reduce to a level deemed acceptable by the regulator. Importantly, the EP is not confined to marine mammals, but includes all species of stakeholder concern (e.g. commercial invertebrates and fish).

Investment in well-designed impact studies helps inform decisions around the regulation of seismic survey activities and mitigation strategies (e.g. Cato et al., 2013; Dunlop et al., 2016). Mitigation measures may include visual and acoustic observations, shutdown and low-power zones, soft-starts (i.e. ramp-ups), and avoidance of biologically important areas and times. However, many of these measures are only applied to a small group of animals, mirroring the legislative requirements underpinning them. For example, Australia's *Environmental Protection of Biodiversity and Conservation Act 1999* provides guidelines for seismic surveys to minimize impacts only on whales, excluding dolphins and porpoises. While elements of these, such as soft-starts, have been used to mitigate effects on marine vertebrates, there have been limited studies on the effectiveness of these procedures (Dunlop et al., 2016).

This paper applies a case study (the Gippsland Marine Environmental Monitoring (GMEM) project) to critically assess a multi-faceted approach to investigate the potential impacts of marine seismic operations, particularly in the context of future research and management priorities for Australian marine resources. We do not intend to advocate the GMEM project as a global template; rather we use it as a case study to examine issues that should be universally considered in seismic impact studies. We focus on Australia due to the location of the case study, drawing on international examples where suitable. Similarly, this paper centres on the impacts on fish and invertebrates due to the target species of the case study, with some extensions to cetaceans when relevant to policy and management. The paper is divided into two main sections: a section devoted to the case study and its characteristics that can inform future studies, and a section focussing on application of the insights generated by such studies to marine environmental managers and policymakers.

2. Case study

The Gippsland Marine Environmental Monitoring (GMEM) project was developed in response to concerns from the fisheries industry about seismic survey activity in the Gippsland Basin (Bass Strait, Australia), as well as a broader need to acquire baseline data to quantify potential impacts of seismic operations on marine organisms. This project combined field and desktop studies (see yellow boxes in Fig. 1) in experimental (0–1 km from seismic survey lines) and control (≥10 km from seismic lines) zones to examine the potential impacts of a 2-D marine seismic survey in 2015 on fish and scallops, as well as environmental conditions associated with a known 2010 scallop mortality event in this region (Hall, 2010).

Results showed no evidence of consistent adverse effects on scallops, fish, or commercial catch rates due to the 2015 seismic survey. Specifically, commercial (*Pecten fumatus*) and doughboy (*Mimachlamys asperrima)* scallops from dredged samples and *in situ* images were found to have high variability in abundance and size among locations and time periods, but this was not linked to the seismic survey, nor was there observed scallop mortality attributable to the seismic survey (Przeslawski et al., 2018). Three fish species found in abundance (gummy shark *Mustelus antarcticus*, swell shark *Cephaloscylum laticeps*, tiger flathead *Neoplatycephalus richardsoni*) were acoustically tagged and released, with various tagged individuals returned sporadically over the monitoring period, including during the seismic survey operations. Behaviour consistent with a possible response to the seismic survey operations was restricted to flathead which increased their swimming speed during the seismic survey period and changed their