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Review

Good or bad vibrations? Impacts of anthropogenic vibration on the marine epibenthos

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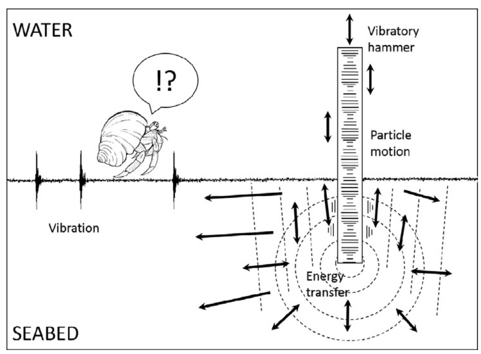
HIGHLIGHTS

- Anthropogenic activities on the seabed produce high amplitude vibrations.
- Sensitivities to vibration are undocumented for many benthic invertebrates.
- Extraneous vibration may elicit behavioral, physical, or physiological changes.
- Here information is summarized regarding anthropogenic vibration and the benthos.
- Noise assessments must consider the role of seabed vibration in tandem with sound.

GRAPHICAL ABSTRACT



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ABSTRACT

Anthropogenic activities directly contacting the seabed, such as drilling and pile-driving, produce a significant vibration likely to impact benthic invertebrates. As with terrestrial organisms, vibration may be used by marine species for the detection of biotic and abiotic cues, yet the significance of this and the sensitivities to vibration are previously undocumented for many marine species. Exposure to additional vibration may elicit behavioral or physiological change, or even physical damage at high amplitudes or particular frequencies, although this is poorly studied in underwater noise research. Here we review studies regarding the sensitivities and responses of marine invertebrates to substrate-borne vibration. This includes information related to vibrations produced by those construction activities directly impacting the seabed, such as pile-driving. This shows the extent to which species are able to detect vibration and respond to anthropogenically-produced vibrations, although the short and long-term implications of this are not known. As such it is especially important that the sensitivities of these species are further understood, given that noise and energy-generating human impacts on the marine environment are only likely to increase and that there are now legal instruments requiring such effects to be monitored and controlled.

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1. Introduction

Recently there has been a growing concern regarding the impact of terrestrial anthropogenic noise, with the implications being far reaching, affecting for example, length and pitch of bird songs (LeFrancois et al., 2009; Slabbekoorn and Peet, 2003), insect prey detection (Wu and Elias, 2014) and calling of other species such as frogs (Kaiser and Hammers, 2009; Parris et al., 2009). Indeed in the case of vibration, it has been said that man produces so much 'bioseismic pollution' that seismic signaling in animals is now difficult to study (O'Connell-Rodwell et al., 2001). With advances of technology enabling further exploration and usage of resources, anthropogenic noise is also having an impact upon the marine environment (Roberts et al., 2015; Roberts et al., 2016). The marine natural soundscape consists of wind, water currents, earthquakes, lightning, rainfall and marine organisms all contributing to the ambient sounds (NRC, 2003; Tasker et al., 2010). However fishing, exploration for gas and oil, construction, shipping, sonar and recreational activities have added to this background level. Marine ambient sound has significantly increased since the 1950s (Andrew et al., 2002; McDonald et al., 2006; NRC, 2003). In addition to introducing a water-borne acoustic stimulus, many sources are likely to cause vibration within the seabed by direct means (e.g. contact with the sediment) or indirectly (propagation via the water column). The levels of seabed vibration, both natural and anthropogenic, in the marine environment are not well documented, yet it is clear that human activities add considerably to this 'vibro-scape' by, for example, dredging, pile-driving and drilling the seabed.

Just as we use underwater acoustics to navigate, communicate and find food, many marine organisms are adapted to do the same (Hatch and Wright, 2007). Indeed sound may be more important to marine species than light (Boyd et al., 2011). For benthic organisms, it is likely that vibration is of similar importance, yet most work to date has focused upon terrestrial species (Hill, 2008, 2009). In the same way that noise has been shown to negatively affect fishes, in terms of physical damage, physiology and behavioral changes (Engås et al., 1996; Hawkins et al., 2014b; McCauley et al., 2003; Picciulin et al., 2010; Smith et al., 2004), here we aim to show that noise/vibration also appears to affect invertebrate species (Christian et al., 2003; Hughes et al., 2014; Morley et al., 2014; Roberts et al., 2015; Roberts et al., 2016; Wale et al., 2013a, 2013b), particularly due to sources directly contacting the sediment. However, many studies regarding invertebrates are not peer reviewed (see Aguilar de Soto, 2016), and until recently there has been a lack of studies regarding sediment vibration and marine species, with only brief mention of this topic in review papers such as Stocker (2002). Whilst acoustic noise has been addressed within recent regulations, e.g. the OSPAR convention and the European Marine Strategy Framework Directive (Borja et al., 2013; Borja et al., 2010; Tasker et al., 2010; Van der Graaf et al., 2012), vibration within the seabed is not mentioned and is only implicit in the term 'marine energy'. This is not surprising, since this area of research is relatively new with very few data regarding the sensitivities of benthic species to natural vibration, let alone anthropogenic sources, which at present are not often measured in terms of particle motion. For example, a recent EU report summarizing the environmental impact of marine renewable energy device emissions concluded that there was a limited understanding of the vibrations produced from such devices or their biological relevance (Thomsen et al., 2015). However, given the prevalence of seabed vibration-producing activities, and the importance of benthic and epibenthic organisms (Gray and Elliott, 2009), it is likely that many species are exposed to a stimulus that may cause damage, a physiological or behavioral change, as seen with acoustic stimuli. Therefore here we review the available information to determine whether this is sufficient to set exposure criteria, as with water-borne stimuli. No attempts have been made to set criteria for management of seabed vibration, perhaps unsurprisingly, as the setting of criteria for acoustic sources and fishes/turtles is still limited by data deficits (Hawkins et al., 2014a; Popper et al., 2014). Indeed such criteria require information regarding the wide range of sensory abilities, source types and propagation conditions in the marine environment, and links to specific responses with particular levels (if present).

As such, here we collate information about the sensitivity and responses of benthic invertebrates to vibration with a focus predominantly on bivalves and crustaceans as examples. The focus on these groups relates to the recent availability of detection abilities of species within these groups (Roberts et al., 2015; Roberts et al., 2016), and is emphasized by their commercial importance. We then place this information within the context of anthropogenic vibration. We take the view that in order to understand any ecological repercussions of a stressor, a good knowledge of the physics of the stressor and the environment is required, hence this is included here.

2. Sediment vibration

In the terrestrial environment, sound may be distinguished from vibration in that it travels through the air, whereas vibration through the ground (Goodall, 1988; Goodall et al., 1990). This distinction is less clear in the marine environment, where sound and water-borne vibration may relate to the same energy and hence create confusion in the literature, with different terms used for particle motion and vibration. For example, the term 'vibration' may be used to describe all types of particle motion, the acoustic field as a whole or just seabed motion. Similarly the term 'sound' may be related solely to compressional waves (pressure), or to also include particle motion, or just to refer to the vibration an organism can perceive. However, more commonly, 'sound' is used to describe pressure changes that may be detected by a specialized organ, which may produce an internal or external response (Hill, 2008). Although the particle motion component of an underwater sound may propagate not only via the water column, but also by the bed (Hazelwood, 2012; Hazelwood and Macey, 2016; Miller et al., 2016), the underwater bioacoustics literature often refer simply to 'particle motion' when describing the water-borne component of a stimulus. Thus the distinction of sediment/solid particle motion is made by linking to 'substrate' or 'sediment' vibration, although, in reality a substrate (such as sand, mud or gravel) may have increased fluidity and