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*Contribution to the Theme Section 'Acoustics in marine ecology'*

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## INTRODUCTION

# Acoustics in marine ecology: innovation in technology expands the use of sound in ocean science

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ABSTRACT: This Theme Section provides an overview of the increasing importance of acoustics in understanding marine ecosystems, and of the scientific and management drivers behind recent development and implementation of acoustic technologies. We focus on 3 issues, which are explored in greater depth by contributions to the Theme Section: (1) passive listening systems to measure and monitor marine ecosystems; (2) active acoustic technologies to explore habitat use and predator–prey behavior; and (3) effects of anthropogenic sound on the marine environment. We call for more explicit consideration and support by international scientific organizations, given the rapid developments in technology and approaches described across the Theme Section, for these essential acoustic research and monitoring efforts, to support basic scientific understanding and adaptive conservation management.

KEY WORDS: Acoustic ecology · Passive and active acoustics · Communication · Remote sensing · Noise impacts · Marine life · Conservation management



Sound is a critical, if not primary, sensory modality for most marine life forms (e.g. Tavolga 1964, Richardson et al. 1995, Tyack 1998, Wartzok & Ketten 1999). Advances in science and technology have also enabled marine scientists to effectively use acoustics to explore the marine environment. At the same time, recent revelations and concerns among scientists, conservationists, regulatory agencies and industries regarding noise impacts on marine life have accelerated our investigations on how marine animals use sound and are affected by it (see NRC 2000, 2003, 2005, ICES 2005, Jasny et al. 2005, MMC 2006, Nowacek et al. 2007, Southall et al. 2007, 2009, Wright & Highfill 2007).

Deliberate or incidental sound-producing human activities in our ocean include important enterprises, such as commercial shipping, military uses, offshore energy exploration and development, and coastal development. There is considerable scientific uncertainty regarding the effects on marine life. While some sounds may actually have beneficial outcomes for marine animals (e.g. by enabling them to avoid dangerous interactions) and many other sounds have little or no effect, there is increasing evidence that negative effects can occur, depending on the sounds and the species exposed (see Southall et al. 2007 and Wright & Highfill 2007 for recent reviews). Marine mammal stranding events that coincided with military tactical sonar training (e.g. ICES 2005, Cox et al. 2006) have dominated public (and to some extent scientific) interest in this subject. However, advances in science and technology are enabling new uses of acoustics to study the oceans; they are also prompting conservation and management considerations with regard to potential effects of less intense but more persistent sounds. Current prac-

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tical issues relating to the effects of noise on marine life beyond military sonar issues, include efforts within the International Maritime Organization to consider quieting technologies for large commercial vessels (see Southall & Scholik-Schlomer 2008, USG 2008, 2009), offshore energy development activities in important biological areas (such as around endangered eastern grey whales near Sakhalin Island, Russia [Reeves et al. 2005]), and the exploration and development of extended continental shelf energy resources by many nations, particularly in Arctic ecosystems. These include contentious, frequently misunderstood and inaccurately portrayed situations, sometimes influenced by conclusions that are inconsistent with our current understanding of the underlying issues. A general scientific paradigm is needed for obtaining, delivering, and applying knowledge.

There have been considerable recent developments in science and technology related to our understanding of the role and utility of acoustics in marine ecology. Howard Browman was responsible for the idea and initiation of a Theme Section on this topic in MEPS, for which we acknowledge and thank him. B. L. Southall and D. P. Nowacek were asked to serve as Guest Editors. This Theme Section includes a combination of original scientific work, review articles, and several new mathematical models or conceptual paradigms for assessing data in terms of decision-making and planning of future research.

The Theme Section includes original studies on the use of passive listening systems to measure and monitor marine ecosystems, such as longitudinal measurements of ambient noise to calculate underwater sound budgets, and changes in the sound regime as a function of natural factors and human activities; passive acoustic monitoring on variable spatial scales to characterize marine life and other features of the acoustic scene; and advancements in logging technologies for collecting acoustic and movement data to measure animal behavior. The second set of contributions considers the use of active acoustic technologies to explore habitat use and predator–prey interactions at different trophic levels within marine ecosystems. The final set of contributions considers various effects of anthropogenic sound on the marine environment, including definitions, clarifications and experimental methodologies related to behavioral responses; highly relevant yet poorly understood auditory phenomena such as estimating realistic spatial scales of communication masking; and ecosystem approaches to managing marine noise that are informed by terrestrial analogues.

These manuscripts address diverse but interrelated marine science and conservation issues, thus demonstrating that our ability to understand and manage marine systems is increasingly informed by the strategic use of sound in the oceans; concurrently we must continue to improve our understanding of the conditions under which sounds may negatively affect marine life. Technology is rapidly advancing and enabling the collection of more comprehensive data—particularly in integrating physical, biological and chemical data—and passive and active acoustic methodologies are a principal component of this technological advance. There is a growing need to simultaneously measure many different dimensions of marine ecosystems to understand dynamic interrelationships, particularly given our increasing appreciation of the importance of cumulative and synergistic effects of sustained or interacting stressors (e.g. ocean acidification and fishing pressure). Marine acoustics are an integral methodology in the evolution of this increasingly sophisticated scientific effort.

Currently we lack key data in many areas pertaining to the impacts of sound on the distribution and behavior of marine life; specifically lacking are data needed to inform conservation management decisions. In addition to the need for more and better conventional measurements of marine animal distribution and direct impacts, we require more comprehensive and integrated ecosystem-level data to assess the potential impacts of sound on and between trophic levels. Much of the current research on the use of sound for exploration, as well as on its effects, are supported by organizations that produce intense underwater sounds (e.g. military and offshore commercial industries) who seek to understand the environmental impacts of these sounds. While this has resulted in a great deal of relevant information, it may result in applied datasets that are useful for only a narrow set of questions, sources, and subject species. There are some concerns regarding the objectivity of data obtained under funding from institutions with an inherent interest in the resulting conclusions. An additional and perhaps more pressing concern is that this funding structure may result in a purpose-driven, applied research agenda that ultimately answers the questions of yesterday, rather than the basic biological issues that remain unresolved and the ecosystem-perspective questions of today and tomorrow.

Open questions regarding noise impacts on marine ecosystems are vexing for sound-producing industries and for regulatory agencies in many nations (see NRC 2000, 2003, 2005, Southall et al. 2007, 2009), and a sustained research effort will be required for decades to address these issues. Current research on narrow applied questions is (perhaps) inevitable and generates useful information, but ecosystem-tuned research is needed. We suggest the development of new funding programs (e.g. by the European Science Foundation, U.S. National Science Foundation) for promoting

the study of acoustics in marine ecology. Such a program should facilitate longitudinal measurements of ambient noise trends and variability in noise budgets, seasonal presence and abundance of marine life using passive and/or active acoustics, and increasingly complex measurements of noise effects on marine life, such as spatial measurements of noise interference and cumulative effects on behavior and/or physiology within and between trophic levels.

Development of scientifically valid regulations on sound in the marine environment is a challenge. The purpose of science is to inform and improve society and to manage responsible interactions with the ecosystems that we affect. This can be accomplished only with a complete picture of the diversity and variability in ecological processes and of the anthropogenic impacts to which they are subjected. Acoustics research is a vital prerequisite for managing sound in the ocean, and we must harness the capabilities of sound generation while minimizing its negative effects.

## LITERATURE CITED


Cox TM, Ragen TJ, Read AJ, Vos E and others (2006) Understanding the impacts of anthropogenic sound on beaked whales. J Cetacean Res Manag 7:177–187

ICES (2005) Report of the Ad-Hoc Group on the Impact of Sonar on Cetaceans. ICES, Copenhagen

Jasny M, Reynolds J, Horowitz C, Wetzler A (2005) Sounding the depths. II. The rising toll of sonar, shipping, and industrial ocean noise on marine life. Natural Resources Defense Council (NRDC), Washington DC

MMC (US Marine Mammal Commission) (2006) Advisory Committee on Acoustic Impacts on Marine Mammals, Report to the Marine Mammal Commission, February 2006. US Marine Mammal Commission, Bethesda, MD

Nowacek DP, Thorne LH, Johnston DW, Tyack PL (2007) Responses of cetaceans to anthropogenic noise. Mammal Rev 37:81–115

NRC (National Research Council) (2000) Marine mammals and low-frequency sound. National Academies Press, Washington DC

NRC (2003) Ocean noise and marine mammals. National Academies Press, Washington DC

NRC (2005) Marine mammal populations and ocean noise: determining when noise causes biologically significant events. National Academies Press, Washington DC

Reeves RR, Brownell RL Jr, Burdin A, Cooke JG and others (2005) Report of the independent scientific review panel on the impacts of Sakhalin II Phase 2 on western North Pacific gray whales and related biodiversity. IUCN, Gland

Richardson WJ, Greene CR, Malme CI, Thomson DH (eds) (1995) Marine mammals and noise. Academic Press, New York

Southall BL, Scholik-Schlomer A (2008) Final report of the NOAA International Conference on Potential Application of Vessel-Quieting Technology on Large Commercial Vessels, 1–2 May, 2007, Silver Spring, MD

Southall BL, Bowles AE, Ellison WT, Finneran JJ and others (2007) Marine mammal noise exposure criteria: initial scientific recommendations. Aquat Mamm 33:411–522

Southall B, Berkson J, Bowen D, Brake R and others (2009) Addressing the effects of human-generated sound on marine life: an integrated research plan for U.S. federal agencies. Interagency Task Force on Anthropogenic Sound and the Marine Environment of the Joint Subcommittee on Ocean Science and Technology, Washington DC

Tavolga WN (ed) (1964) Marine bio-acoustics. Pergamon Press, New York

Tyack PL (1998) Acoustic communication under the sea. In: Hopp SL, Owren MJ, Evans CS (eds) Animal acoustic communication, Springer, Berlin, p 163–220

USG (United States Government) (2008) Minimizing the introduction of incidental noise from commercial shipping operations into the marine environment to reduce potential adverse impacts on marine life. U.S. submission to the 58th session of the Marine Environment Protection Committee, International Maritime Organization [MEPC 58/19]

USG (United States Government) (2009) Noise from commercial shipping operations and its impacts on marine life. U.S. submission to the 59th session of the Marine Environment Protection Committee, International Maritime Organization [MEPC 59/19]

Wartzok D, Ketten DR (1999) Marine mammal sensory systems. In: Reynolds JE II, Rommel SA (eds) Biology of marine mammals. Smithsonian Institute Press, Washington DC, p 117–175

Wright AJ, Highfill L (2007) Considerations of the effects of noise on marine mammals and other animals. Int J Comp Psychol 20:89–316