Ocean & Coastal Management 115 (2015) 17–24

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Impacts of anthropogenic noise on marine life: Publication patterns, new discoveries, and future directions in research and management

R. Williams [a, b, *], A.J. Wright [c, 1], E. Ashe [a, b], L.K. Blight [d], R. Bruintjes [e], R. Canessa [f], C.W. Clark [g], S. Cullis-Suzuki [h], D.T. Dakin [i], C. Erbe [j], P.S. Hammond [a], N.D. Merchant [k], P.D. O'Hara [l], J. Purser [m], A.N. Radford [m], S.D. Simpson [e], L. Thomas [n], M.A. Wale [o]

[a] Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews, Fife, KY16 8LB Scotland, UK
[b] Oceans Initiative, Pearse Island, BC V0N 1A0, Canada
[c] Department of Environmental Science and Policy, George Mason University, 4400 University Drive, Fairfax, VA 22030, USA
[d] Procellaria Research & Consulting, 944 Dunsmuir Road, Victoria, BC V9A 5C3, Canada
[e] Biosciences, College of Life and Environmental Sciences, University of Exeter, Stocker Road, Exeter EX4 4QD, UK
[f] Department of Geography, University of Victoria, Victoria, BC V8W 3R4, Canada
[g] Bioacoustics Research Program, Cornell University, 159 Sapsucker Woods Rd., Ithaca, NY 14850, USA
[h] Environment Department, University of York, UK, Heslington, York YO10 5DD, UK
[i] Ocean Networks Canada, University of Victoria, Victoria, British Columbia V8W 2Y2, Canada
[j] Centre for Marine Science & Technology, Curtin University, Perth, WA 6102, Australia
[k] Centre for Environment, Fisheries and Aquaculture Science (Cefas), Pakefield Road, Lowestoft, Suffolk NR33 0HT, UK
[l] Canadian Wildlife Service, Environment Canada, Institute of Ocean Sciences, 9860 W. Saanich Rd., Sidney, BC V8L 4B2, Canada
[m] School of Biological Sciences, University of Bristol, 24 Tyndall Avenue, Bristol BS8 1TQ, UK
[n] Centre for Research into Ecological and Environmental Modelling and School of Mathematics and Statistics University of St. Andrews, The Observatory, St. Andrews Scotland KY16 9LZ, UK
[o] School of Life, Sport, & Social Sciences, Edinburgh Napier University, Sighthill Court, Edinburgh EH11 4BN, UK

ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form
23 May 2015
Accepted 28 May 2015

Keywords:
Anthropogenic
Conservation
Ecology
Marine
Ocean noise
Policy
Shipping

ABSTRACT

Anthropogenic underwater noise is now recognized as a world-wide problem, and recent studies have shown a broad range of negative effects in a variety of taxa. Underwater noise from shipping is increasingly recognized as a significant and pervasive pollutant with the potential to impact marine ecosystems on a global scale. We reviewed six regional case studies as examples of recent research and management activities relating to ocean noise in a variety of taxonomic groups, locations, and approaches. However, as no six projects could ever cover all taxa, sites and noise sources, a brief bibliometric analysis places these case studies into the broader historical and topical context of the peer-reviewed ocean noise literature as a whole. The case studies highlighted emerging knowledge of impacts, including the ways that non-injurious effects can still accumulate at the population level, and detailed approaches to guide ocean noise management. They build a compelling case that a number of anthropogenic noise types can affect a variety of marine taxa. Meanwhile, the bibliometric analyses revealed an increasing diversity of ocean noise topics covered and journal outlets since the 1940s. This could be seen in terms of both the expansion of the literature from more physical interests to ecological impacts of noise, management and policy, and consideration of a widening range of taxa. However, if our scientific knowledge base is ever to get ahead of the curve of rapid industrialization of the ocean, we are going to have to identify naïve populations and relatively pristine seas, and construct mechanistic models, so that we can predict impacts before they occur, and guide effective mitigation for the most vulnerable populations.

1. Introduction

Anthropogenic underwater noise is now recognized as a world-wide problem, and recent studies have shown a broad range of negative effects in a variety of taxa. Underwater noise from

* Corresponding author. Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, KY16 8LB Scotland, UK.
E-mail address: rmcw@st-andrews.ac.uk (R. Williams).
[1] Current address: Marine Species & Threats, Department of Conservation, PO Box 10420, Wellington 6143, New Zealand.

http://dx.doi.org/10.1016/j.ocecoaman.2015.05.021

shipping is increasingly recognized as a significant and pervasive pollutant with the potential to impact marine ecosystems on a global scale (Clark et al., 2009; Merchant et al., 2015; Williams et al., 2014b). Different noise sources such as seismic surveys have widespread regional effects, but a much greater local impact than shipping (Hildebrand, 2009). Pile driving for offshore construction, military activity, anti-predator devices, and pleasure crafts (with depth-and fish-finders) may also be significant local or regional sources of underwater noise (Tougaard et al., 2009; Wright, 2014). Marine renewable energy devices may produce lower noise levels than many other anthropogenic sources, but have the potential to cause long-term exposure to sessile marine organisms (Gill, 2005).

Regarding manmade ocean noise as a pollutant is a relatively recent development. Underwater noise was first posited as a potential threat to marine fauna fairly recently, in the context of long-range communication among baleen whales (Payne and Webb, 1971). Prior to that, underwater noise research was focused on military applications: hydrophones have been used to listen for sounds produced by submarines since World War I, and radiated noise from ships was identified as a nuisance in signal processing of active sonar in World War II (Lemon, 2004). Only in the last few decades has noise as a source of disturbance to marine life become a field of study (Simmonds et al., 2014).

At the 3rd International Marine Conservation Congress (14–18 August 2014, Glasgow, Scotland), we organized a symposium, originally entitled "Impacts of ship noise on marine life: Research and outreach on the Pacific Northwest coast." The symposium consisted of six talks. During the planning phase, it became evident that there was a need to broaden the scope of the symposium geographically, beyond Pacific waters, and thematically, to include anthropogenic noise sources other than shipping activities. The final symposium was called "Impacts of ship noise on marine life: new discoveries in research." The talks ultimately spanned organisms from crustaceans to the great whales, and described ongoing research and conservation efforts in both the Atlantic and the Pacific. During the symposium debriefing phase, the participants agreed that there was value, given the fast-moving nature of ocean noise research, in using these six projects as case studies to illustrate how various researchers and managers are approaching the study of ocean noise impact and mitigation. There was also recognition that no six projects could ever cover all taxa, sites and noise sources, so the participants agreed to conduct a follow-on bibliometric analysis to place the talks within the broader historical and topical context of the peer-reviewed ocean noise literature as a whole.

The primary objective of the paper is to describe six ongoing projects around the world that illustrate ways that researchers, managers, environmental educators and policy-makers are addressing the issue of ocean noise across various taxonomic groups and jurisdictions. Secondarily, we placed these six case studies in a broader context by conducting a bibliometric analysis of published ocean noise literature. Through this, we aim to explore broad trends in research on ocean noise published in English since 1900. This component of our work highlights the exponential growth of research on ocean noise over the last century, tracks temporal patterns in topics covered by ocean noise researchers, and reveals the changing landscape of journals that publish research on this topic.

2. Methods

2.1. Case studies

Here, we showcase effects of noise in two species-specific case studies, one vertebrate and one invertebrate (i & ii). Next, by using the Strait of Georgia site in British Columbia (BC), Canada as an example, we illustrate recent approaches to establishing baseline noise levels (iii) and creating noise models (iv). Finally we present potential noise management scenarios using empirical data and statistical models of ocean noise and marine mammals (v); and discuss current initiatives led by environmental non-governmental organizations (ENGOs) and various partnerships to bring ocean noise to the public attention (vi).

i. Rapid recovery following noise exposure? The case of the threatened European eel (*Anguilla anguilla*) (presented by RB, on behalf of project collaborators JP, SDS, ANR);
ii. The effect of ship noise on the behaviour and physiology of *Carcinus maenas* (presented by MAW, in collaboration with ANR, SDS);
iii. Noise exposure from shipping in the Strait of Georgia, British Columbia (BC), Canada (presented by NDM in collaboration with DTD, PDO);
iv. Key issues in spatiotemporal data and analysis of vessel movement patterns as an indicator of marine noise (presented by RC, on behalf of PDO, NS);
v. Chronic ocean noise and critical whale habitats: mitigation through marine spatial planning or allowable harm limits to target populations (presented by RW, on behalf of project collaborators: EA, CWC, CE, PSH, LT);
vi. Engaging diverse audiences to advance management solutions for underwater noise (presented by AJW, in collaboration with LKB).

2.2. Bibliometric analysis of ocean noise literature

Literature searches were conducted on 10 October 2014 by querying the ISI Web of Science database using the search terms listed in Table 1. This database was chosen because of its well-defined coverage and advanced search possibilities to facilitate extraction of summary statistics. The search was conducted for papers published in English only, so we consider this broadly illustrative but by no means complete. The terms were entered into the "Topic" field, and the option to omit conference proceedings was selected. This includes Science Citation Index Expanded (SCI-EXPANDED) –1900-present, Social Sciences Citation Index (SSCI) –1975-present, Arts & Humanities Citation Index (A&HCI) –1975-present. Although we searched from the beginning of the ISI database, the first papers using the search terms in Table 1 appeared in the 1940s. Subsequent temporal analyses are plotted beginning in 1940. Occurrences in the title, abstract, and all other fields in each record were returned, for a total of 576 unique papers (with some appearing in two or more searches), which constituted the basis for the analysis. After accounting for papers that returned more than one search term, full record (including abstracts when provided; N = 493) was downloaded and stored in a spreadsheet for analysis (see Supporting/Supplementary Information). This was done by saving search results to "Other file format, Tab-delimited (Win)". Synonymous search terms (e.g., airgun noise and seismic survey noise) were then merged for better comparison of topic coverage.

The bibliographical data were visually assessed in various ways. Firstly, the unique papers with abstracts included were split into two categories: those that included any of the terms "impact," "effect" or "conserv*" and those without. The rates of citation for each group as well as the total pool of records were then calculated and plotted. Citation rate was calculated by dividing the number of citations for a given paper in a given year and then further divided by the total number of papers (among those 493 papers downloaded in this analysis) published up until that year. The mean