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PRACTICAL APPROACHES FOR REDUCING OCEAN NOISE ASSOCIATED WITH SEISMIC EXPLORATION

GLOBAL ALLIANCE FOR MANAGING OCEAN NOISE (GAMeON)

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A REPORT ABOUT QUIETING WORKSHOP TWO

Practical Approaches for Reducing Ocean Noise Associated with Seismic Exploration

Global Alliance for Managing Ocean Noise
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Executive Summary

Workshop Two: 'Practical Approaches for Reducing Ocean Noise Associated with Offshore Seismic Exploration' fostered a productive setting for stakeholders across international governing bodies, industry leaders, non-governmental organizations (NGOs), and academia to debate, break down barriers, and ultimately develop data-informed and technologically advanced solutions. The workshop culminated by identifying and proposing opportunities for actionable next steps. GAMeON recommends the following actions: (1) build robust regulatory standards for noise reduction and attenuation; (2) develop a noise mitigation decision aid; (3) strive to limit high rise time with high frequency noise broad bandwidth signals; (4) foster additional multi-sectoral discussions on integrating regulatory standards and reduce duplication for speculative, pre-lease surveys.

Approach

Multi-sectoral dialogues provide the capacity to address ocean quieting in a way that initiates actionable steps. Through multi-sectoral implementation of principal ocean management tools, we have an opportunity to achieve the United Nations Sustainable Development Goals (SDG). SDG14 is about "Life below water" and is one of the 17 Sustainable Development Goals established by the United Nations in 2015 (Goal 14 | Department of Economic and Social Affairs (un.org)). Multi-sectoral mechanisms are the most effective at reconciling the ecological, governance, and social dimensions of an ocean challenge, in this case ocean quieting (Reimer et. al, 2020). While implemented more broadly for SDG14, constructive dialogue must be implemented for ocean noise.

The blue-acceleration, i.e., the growth in ocean-based economic activity, must be balanced with conservation of marine resources. Use of marine resources can lead to conflicts between sectors, such as industry versus government, at different levels of organization, and at multiple spatial and temporal scales (Klinger et al., 2018). The continued growth of offshore renewable energy, shipping, and geophysical exploration will likely lead to an increase in cross-sector conflicts. In the European Union, a new strategy has been adopted that seeks to achieve both sustainable marine resource use and economic expansion. Multi-sector management of ocean noise is complicated by the spatial and temporal scales of marine mammal life functions (Schupp et al., 2019) and acoustic habitats. While this report predominately focuses on marine mammals, these recommendations apply for more broadly to all marine species. Single sector and multi-sector management frameworks must be used in concert to maintain pace with changing ecological, governance, and social conditions (Schupp et al., 2019).

By providing a setting for multi-sectoral dialogues, participants can overcome obstacles to multi-sectoral management by addressing data gaps and how decisions made in one sector can impact another sector. Multi-sectoral dialogues build connectivity between sectors "in spatial, temporal, provisional, and functional

dimensions" (Schupp et al., 2019) to collaboratively solve ocean noise.

The Global Alliance for Managing Ocean Noise (GAMeON) is an international partnership of proactive and action-minded scientists, managers, policy makers, and industry representatives fostering inclusive dialogues to fuel creative, workable solutions that will transform ocean noise management (GAMeON, 2022). GAMeON is developing responsible, modern, integrated, and informed solutions for managing anthropogenic ocean noise with three key actionable goals:

- Scan horizons to proactively identify emerging concerns and solutions;
- Map existing and emerging knowledge on ocean noise, technology, and policy;
- Create inclusive dialogues and networks to collaboratively solve ocean noise issues globally.

The GAMeON Quieting Workshop Series intends to foster collaborative conversations among key, multi-sectoral attendees. Workshops focus on three key topics around the theme of practical approaches for reducing ocean noise: (1) offshore renewable energy development; (2) seismic exploration; and (3) shipping. The sequential series will culminate with a symposium that will synthesize the current state of science and technology from the three workshops and will develop strategic, actionable next steps.

Primary Research Questions:

1. How can multi-sectoral dialogues be used as a tool to drive noise reduction from anthropogenic sources, including offshore renewable energy, shipping, and seismic exploration?

2. What barriers and opportunities exist to implementing ocean quieting approaches for seismic exploration?

Methods

A group of stakeholders were selected based on a criterion of having equal representation across sectors: government, industry, NGOs, and academia (Table 1) with an expertise in marine seismic surveys. Recruiting experts across these different sectors to be representatives was not even, thus there is an uneven number of participants for the panel across sectors, as shown in Table 1. Having additional representation across different levels of organization (e.g., between and among individuals, groups, nations, etc.) and representing at multiple spatial scales was important to gain a holistic understanding. Thus, participants were recruited from a global expert network of marine bioacoustics and geophysical sciences.

Table 1. Stakeholders were invited to represent their sectors during the workshop's panel discussion. (Source: GAMeON, 2023)

Public / Governmental Organization	Private / Industry	Non-Governmental Organization	Academia / Research
Australian National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA)	EnerGeo Alliance	International Fund for Animal Welfare (IFAW)	School of Biological Sciences, University of Queensland
U.S. Department of the Interior: Bureau of Ocean Energy Management (BOEM)	*Former* ExxonMobile	OceanCare	Duke University Marine Laboratory
National Oceanic and Atmospheric Administration (NOAA), National	Sercel	Natural Resource Defense Council (NRDC)	Southall Environmental Associates

Ocean Service: Office of National Marine Sanctuaries			
Joint Nature Conservation Committee			School of Biology / Scottish Oceans Institute, University of Saint Andrews
National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service: Office of Protected Resources			Geospatial Ecology of Marine Megafauna Laboratory, Oregon State University
			Stanford University
			Dalhousie University

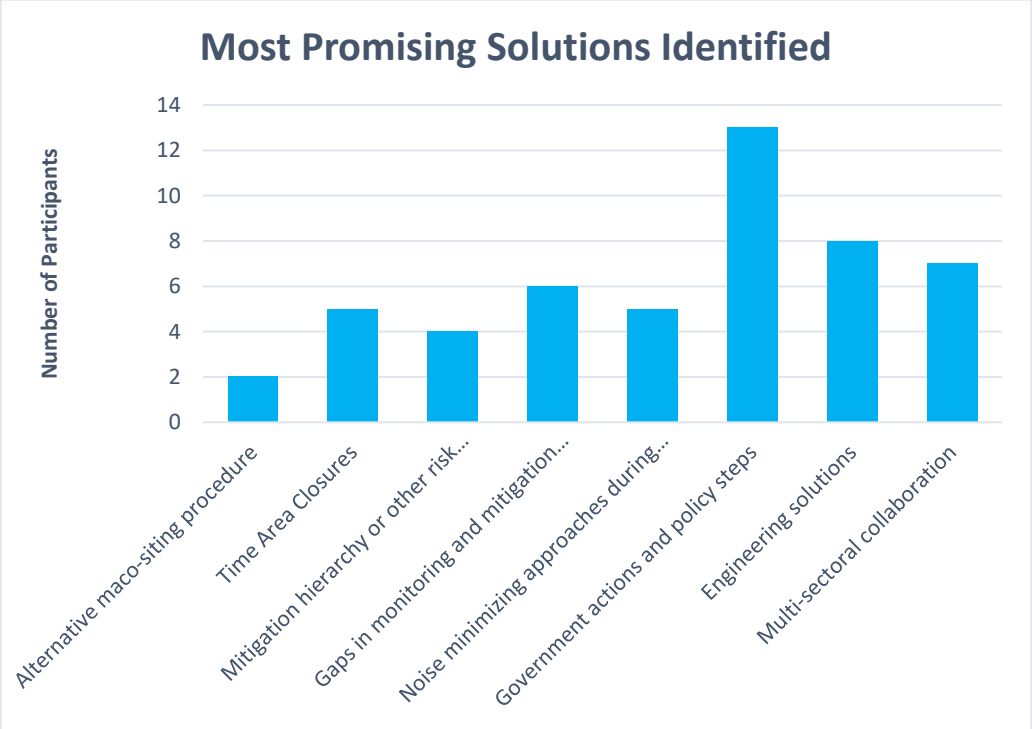

Figure 1. Solutions selected by survey participants (n = 16) as the most promising to overcome the challenge of ocean noise as it relates to seismic exploration. The potential solutions were identified by the GAMeON Steering Committee and participants were provided the option to select any number or all applicable solutions. (Source: GAMeON 2023)

Representatives were invited to participate as either a panelist or a presenter. A preliminary research survey was administered to the workshop participants (n = 16, Figure 1), both presenters, panelists, and to registrants, with the intention of gaining their initial perspective on practical approaches for reducing ocean noise associated with seismic exploration. The survey also provided an opportunity for those who may typically be less likely to voice their perspective in a panel discussion to share their thoughts and ideas. The survey questions addressed both

general quieting solutions and specifically solutions for seismic.

Marine seismic surveys use sound energy to map geological structures under the seabed. Towed devices use compressed air to produce pulses of high-energy, low-frequency sound waves that travel through the water to penetrate the sea floor, as shown in Figure 2. These sound waves bounce back to the ocean surface where hydrophones record the strength and return time of each sound wave. From this data, maps of the geology below the seabed are developed (CAPP, 2016). In addition, there are other applications, including bottom nodes and VSPs.

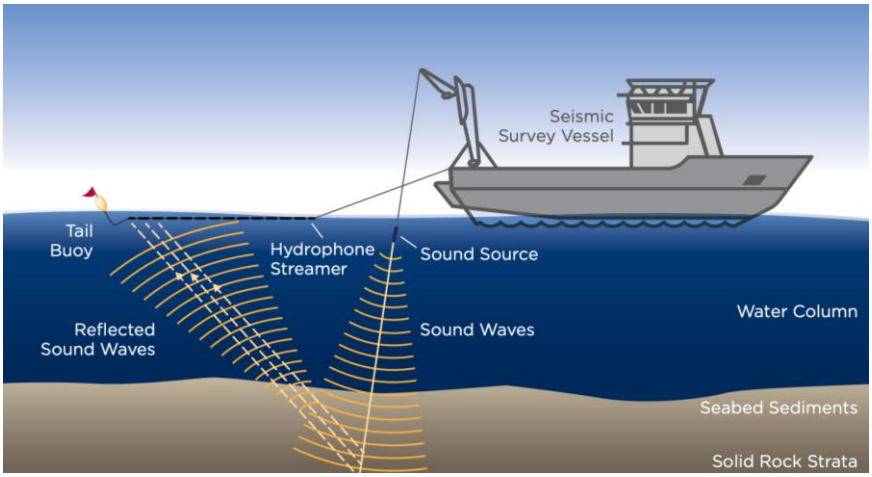

Figure 2. The marine seismic survey process. (Source: Canada's Oil and Natural Gas Producers, 2016)

The workshop agenda was developed to reflect pressing challenges and opportunities:

Presentations (60 minutes)
Theme: Science to Regulation

- Operational and Engineering Solution Options for Seismic Surveys
- Specifical Engineering Solutions
- The Regulatory Perspective

Discussion (60 minutes)
Theme: Synthesis assessment with actionable solutions

- Discuss and evaluate available and near-horizon options for **technological approaches** to minimizing impacts of noise from seismic surveys. These may include but not be limited to airguns redesigned to produce less noise and in more targeted frequency band (i.e., lower source levels, less broadband production, minimizing airgun array size) and marine vibroseis as potential alternatives for airguns.
- Discuss and evaluate available and near-horizon options for **operational approaches** to minimizing impacts of noise from seismic and other geophysical exploration. These may include but not be limited to reducing survey area and/or repeat surveys to the minimum necessary to accomplish commercial goals and smart scheduling. Smart scheduling is defined as temporal and spatial planning to minimize impacts relative to known important biological periods (e.g., key breeding/spawning or migration periods).
- Develop action items.

Results

Survey Results

Survey participants were asked to provide their perspectives on (1) what barriers they think exist

between sectors to implementing ocean quieting approaches for seismic exploration, (2) what action(s) can be taken to best manage ocean noise associated with seismic exploration, and (3) what are the most promising solutions to minimize ocean noise associated with seismic exploration. Question 1 and 2 were structured as long answer questions with a box for a response. Question 3 was structured as a multiple-selection question where participants could select any or all identified solutions. Potential solutions were identified by the GAMeON Steering Committee and included: (a) alternative macro-siting procedures, (b) time area closures, (c) mitigation hierarchy or other risk assessment frameworks, (d) gaps in monitoring and mitigation, (e) noise minimizing approaches during unique phases, (f) government actions and policy steps, (g) engineering solutions, and (h) multi-sectoral collaboration.

Questions (1) and (2) were coded with the meeting minutes and workshop transcript in NVivo to explore opportunities and barriers. Regarding (3), out of all the surveys (n = 16), a majority (n = 13) identified government actions and policy as the most promising area for minimizing ocean noise associated with seismic exploration, as shown in Figure 1. This was followed by engineering solutions (n = 8) and multi-sectoral collaboration (n = 7).

Quieting Workshop Two

Workshop Two: 'Practical Approaches for Reducing Ocean Noise Associated with Seismic Exploration' fostered a productive setting for multi-sectoral dialogues. Stakeholders across sectors debated, broke down barriers, and developed data-informed and technologically advanced solutions. The focal topics of this workshop will include current status and future directions in: (1) technological approaches for reducing noise impacts from seismic exploration (e.g., vibroseis, 'low noise' airguns; and (2) operational approaches for reducing noise impacts from seismic (e.g., minimizing airgun array size, reducing survey area, smart scheduling). This workshop culminated by identifying and proposing opportunities for actionable next steps.

The workshop attracted a large number of registrants (n = 213), a significant number of audience attendees (n = 114), and expert participants (n = 13) on November 28, 2022. A total of 17 questions were asked by audience attendees of the expert participants, and several attendees requested information regarding subsequent GAMeON workshops.

Social Impact Analysis

From the workshop, opportunities and barriers were analyzed using NVivo, a qualitative data analysis software, to code the survey's long-answers, workshop meeting minutes, and workshop transcript. The following barriers and opportunities were identified as nodes: sectoral conflicts, ecological interventions, governance interventions, social interventions, and technology. Sub-nodes were identified within each, as seen in Figure 3. The following social impact analysis of the workshop can be used by the GAMeON Sounding Board to facilitate discussion during subsequent workshops and the synthesis symposium.

The framework used identifies three distinct ocean quieting approaches: (i) ecological interventions, (ii) governance interventions, (iii) social interventions or behavior change. These categories and conservation interventions were adapted from IUCN's CMP Conservation Actions Version 2.0 and Brooke et al. 2020.

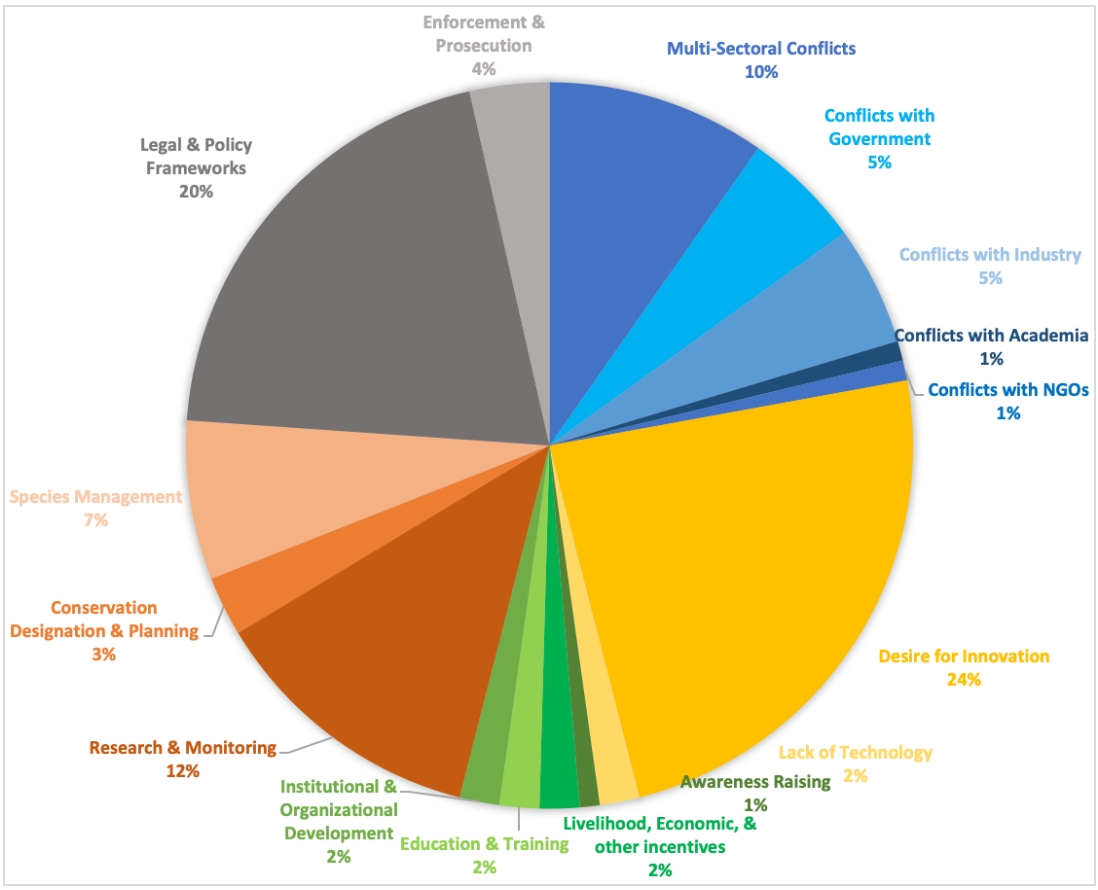

Figure 3. Pie chart of identified barriers and opportunities compared by the percentage of the number of times they were coded. The chart is color coded by identified nodes: sectoral conflicts are blue, technology is yellow, social interventions are green, ecological interventions are orange, and governance interventions are grey. (Source: GAMeON 2023)

Certain barriers and opportunities that arose regarding sectoral conflicts included unilateral conflicts with government, industry, and NGOs, as well as multi-sectoral conflicts. For the sake of this report, government refers to regulatory bodies in different countries. Regarding conflicts with the governments (n = 6 references), a participant pointed to a disjointed and bureaucratic system that lacks communication and awareness raising regarding permitting. Another participant also pointed to a lack of awareness by regulators about the opportunities new technology holds for ocean quieting. This lack of information sharing extends to regulators and NGOs that lack awareness of the industry constraints with regards to applying mitigation measures and alternative survey technologies– another participant identified. A common theme of greater communication amongst all multi-sectoral stakeholders is apparent. Regarding conflicts with industry (n = 6), several participants pointed out that industry members need a greater incentive to collaborate and share seismic data to minimize duplication over areas. Another participant concurred that incentives can also be used to drive the use of new and quieter technologies during planning efforts. Regarding conflicts with academia (n = 1) and conflicts with NGOs (n = 1), a participant suggested that academics and NGOs should be able to provide their data more easily to regulators to inform decisions making and there should be more data-driven decision making.

Multi-sectoral conflicts were the most common (n = 11), where no specific sector was targeted as the culprit of the conflict. One participant stated that if the geophysical industry invested in conventional seismic survey vessels and airgun arrays, a financial implication would be incurred.

With this financial implication, the participant asked for much greater incentives to make this costly technology shift. A second participant agreed that the geophysical industry has little incentive to proceed with research and development of quieting technologies, thus the onus should be on the regulators to require the use of quieter technology. With a lack of broad communication among stakeholders, an industry representative offered to foster an information sharing opportunity between regulators and industry to be "a little bit more proactive" about quieting seismic exploration. Another participant offered that a barrier exists of asymmetric knowledge, which could be overcome by hiring geophysicists within the regulatory bodies.

Barriers and opportunities arose around ecological interventions, including conservation designation and planning, research and monitoring, and species management. Participants suggested opportunities around conservation designations: time-area closures and mitigation hierarchy. Research and monitoring were the most frequently coded area (n = 14). A participant suggested using the mitigation hierarchy in survey planning to provide an opportunity for quieting. The same participant stated that considering seasonality regarding temporal and geographical avoidance of migratory species and fisheries is a practical solution to avoiding species interaction with anthropogenic noise.

The following gaps in research were identified: population, movement, and distribution of marine mammals for temporal avoidance, baseline spatial monitoring, and impact on species from seismic surveys. Regarding the impact on species, a pattern of interest arose in the physiological response of marine mammals to the rise time of a given acoustic signal (i.e., the amount of time required for a signal to go from zero to peak energy). Further research is needed to gain a better understanding of behavior changes and disturbance thresholds for marine mammals with respect to this characteristic. Signals with sharp, or fast rise times may be more disturbing to animals and/or have the potential to impact cortisol levels in marine mammals. Sharp rise times also typically have a greater potential for barotrauma, though this is a concern only for exposures very close to the source. Barotrauma is physical tissue damage caused by a pressure difference between an unvented space inside the body and surrounding gas or fluid. Further research is needed to explore how rise time may impact marine mammals, and other auditory-reliant marine species. There was additional emphasis on the importance of continued research and development around technological interventions, such as noise abatement, mitigation, and other source alternatives.

Risk assessment was identified as an important aspect that must be conducted prior to conducting surveys. Species management was considered (n = 8) in conjunction with risk frameworks and applying the precautionary principle. Associating temporal avoidance, the limitation of times when seismic activities are being conducted, with critical life stages of marine mammals provides an opportunity for species-specific management. Time area closures are only partially effective since the operational impacts can extend beyond the closure area.

From the regulator's perspective, there are mandates that manage noise in the environment, although without a specific target. In the United States, there are numerous statutes including the Marine Mammal Protection Act of 1972, which manages at the population level and is tied closely to acoustic threshold criteria. The onset of PTS is considered to be a "Level A" take. Onset of TTS is considered a "Level B" take. PTS and TTS acoustic thresholds consider peak pressure or weighted SEL, whichever is exceeded first. Onset of behavior disturbance is considered a "Level B" take. In the European Union Marine Strategy Framework Directive, Descriptor 11 states: "Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment." This directive is set through cooperation at union level but considers regional and subregional specificities.

Regarding governance interventions, barriers and opportunities were considered about both enforcement and prosecution (n = 4) and legal and policy frameworks (n = 23). Regarding enforcement, participants suggested enforcing

that only a minimal number of vessels deployed per project and a minimal sound source level be enforced. Informed spatio-temporal restrictions are effective when enforced. A participant also suggested requiring marine mammals observers and enforcing this.

Regarding legal and policy frameworks, a barrier identified in this area is that regulations may be too focused on per-project scales and should be more holistic for longer term success. There are several policy options when considering exposure: (1) limit % of population exposed per time with a set maximum; (2) limit % of population that can decline because of the activity; or (3) limit the number of maximum pulse block days within specified habitat over time. In other jurisdictions, such as in Australia, there are even stricter targets. With the blue whale, the conservation and management plan created a large sanctuary area where both TTS and PTS must be avoided, and nothing can impact foraging.

Other opportunities for legal and policy frameworks, including requiring oversight of maximum power levels; require a detailed plan from seismic operators on how industry will minimize sound levels, how they will calculate minimum required levels, and how they will configure the survey and airguns to produce only minimum levels; minimize horizontal propagation of unwanted sound; and explore project-specific technology options. A participant offered that permitting should consider the differences between seismic sources and methods that will be used prior to a permit being granted. Additionally, aligning with the German government model for quieting pile driving, a participant suggested setting performance targets with the lowest practical source levels. Another participant aligned that if regulatory agencies set actual noise limits, they could drive innovative quieting technologies as Germany did.

Additionally, a participant noted the prevalence of quieting in peer-reviewed literature and reports. A Merchant et al. 2022 paper regarding underwater noise research identified that alternative approaches to defining good environmental status (GES) thresholds will be necessary since population-level consequences of noise exposure modeling is currently data limited. Measures that reduce noise levels, including quieting and noise abatement have been limited. An European Union Commission 2021 report states an explicit need to reduce underwater noise in its waters and speaks to reviewing the European Union Strategy Framework Directive for possible noise cap. Delivering on the EU report will require "further research focused on the development and implementation of quieting measures" because "while quieter alternative to seismic airgun surveys have been developed and tested successfully, none are available at commercial scale due to a lack of regulatory incentive to encourage their use" (Merchant et al. 2022).

For the barriers and opportunities of the social interventions, the following were considered: awareness raising (n = 3), education and training (n = 2), institutional and organizational development (n = 2), and livelihood, economic, and other incentives (n = 2). A participant pointed to the opportunity to raise societal awareness regarding this issue so that constituents could apply appropriate pressure on their federally elected officials. Information sharing was brought up by multiple participants in the context of industry data-sharing to reduce redundancy of surveys and data-sharing of findings of environmental impact assessments. The economic incentive for industry professionals to switch from conventional seismic survey vessels and airgun arrays to the new technologies was discussed as an opportunity. Specifically, marine vibroseis is expensive; if industry professionals were compensated for the switch, the switch would be more likely. Pneumatic alternatives to conventional airguns that limit high rise time and reduce or eliminate high frequency noise emission are available commercially. Their deployment involves capital and operational expenses that is smaller than those of marine vibroseis. However, small as it may be, increased cost is significant and in effect it impedes their deployment as replacements for conventional airguns. Similarly, improved passive monitoring systems have a small but significant cost that impedes their deployment.

A common theme of interest in applying new technologies arose and technology was discussed as both a lack of (n = 2) and a desire for innovation (n = 27). Participants noted that while new technologies may be available, there is a lack of awareness regarding operationally-effective and cost-effective noise abatement technology. Yet, alternative technologies provide a promising solution for reducing ocean noise associated with seismic exploration, thus development of best available technologies will benefit overall ocean quieting. Developing a standard of noise abatement technologies on a project basis has the opportunity to result in the least possible environmental impact. Several operational modifications, engineering modifications, and new technologies were offered by a presenter to reduce the acoustic output from a seismic array, as seen in Table 5. Operational mitigation measures including shutdowns and ramp ups are usually viable; there is risk of prolonging the time frame of the survey and may increase the likelihood of interactions. Engineering modifications and alternative technologies provide the most promising solutions to reducing ocean noise. Very low frequency sources and marine vibroseis technology limit the intensity of audible frequencies for marine species. Many of these technologies are proprietary or still in development, some are ready and available commercially to all seismic operators. However, deployment of any new technology has a cost in time, money, and risk, some solutions may be very expensive to implement, and some may not be suitable for all geophysical objectives. The characteristics of sound output from seismic operations can be significantly reduced or modified by new technologies and methodologies if required by regulators.

Lessons learned from seismic survey monitoring programs

From 2004-2021 the International Union for the Conservation of Nature (IUCN) worked with the Sakhalin Energy Investment Company (SEIC), operator of the huge Sakhalin II project close to the near-shore Sakhalin feeding area used by Western Gray Whales (WGW), to help that company minimize risks to the whales and habitat. In 2006, as part of this initiative, IUCN created a panel of independent scientists – the Western Gray Whale Advisory Panel (WGWAP) – which, from 2017-2021 provided scientific advice and recommendations on the company's operations and mitigation measures. While there are numerous examples of monitoring and mitigation programs associated with seismic surveys, few had the benefit of the time, resources, people, and information as the seismic survey task force, which ultimately became the noise task force (SSC Cetacean Specialist Group, IUCN, 2019) of the WGWAP. The NTF was composed of representatives from SEIC and the WGWAP, and outside specialists were brought in when needed. Among other products, the NTF reviewed and refined noise exposure guidelines, created the most extensive monitoring and mitigation program to date, and conducted numerous quantitative analyses to achieve goals such as minimizing total noise exposure to the whole population. The publications that resulted from this and other monitoring and mitigation programs in the Sakhalin area, notably the ExxonNeftegas efforts, provide significant resources going forward (e.g., Gailey et al 2022, Aerts et al 2022). Much of the NTF work was focused on the SEIC seismic surveys, though it also addressed issues of continuous noise produced by offshore industrial activity (e.g., vessel dynamic positioning), particularly in its development of exposure guidelines. Finally, and importantly, the resources invested in the WGWAP and, in this case the NTF, processes provided the opportunity to develop a tremendous number of resources and importantly, GAMeON was born out of those efforts.

Action Items and Recommendations

Workshop Two: 'Practical Approaches for Reducing Ocean Noise Associated with Seismic Exploration' created a space for constructive dialogue. Through the survey results and social impact analysis many barriers and opportunities surfaced that provide the GAMeON Sounding Board with direction, as shown in Table 4. Additional conversations, specifically relating to seismic exploration, and geophysical exploration is advisable since this second workshop provided only a short period of time to explore this complex challenge. Important to note is that

seismic exploration employs the intentional use of sound to complete an activity, opposed to producing noise solely as a byproduct, as it is in offshore energy development and shipping, though much of the energy emitted is indeed not used and is a byproduct, and in effect, wasted energy. Yet, clear patterns of barriers, such as sectoral conflicts and regulatory transparency, and clear patterns of opportunities, such as knowledge sharing and technology advancements, exemplifies a pattern of solution-driven stakeholders willing to collaborate to resolve these issues.

Constructive dialogue creates ample opportunity to explore sectoral conflicts, ecological, governance, and social interventions, and technology. Through this discussion stakeholders broke down ecological, governance, and social barriers to build upon the many opportunities in the multi-sectoral space. Implementing the action items and recommendations provided below, combined with innovative technology as shown in table 5, creates opportunities for stakeholders across sectors to reduce ocean noise during seismic surveys.

Table 4. Action items and recommendations for reducing ocean noise. (Source: GAMeON, 2023)

Intervention Category	Action Items	Recommendations
Ecological Interventions		
Conservation Designation and Planning	• Time-Area Closures • Alternative macro-siting procedures	• Use of mitigation hierarchy • Use of risk assessment tools • Develop a noise quota system
Research and Monitoring	• Gather in-situ empirical measurements • Increase understanding of marine species behavior changes • Increase understanding of marine species disturbance threshold • Increased scientific understanding of source • Define the rise time needed to lead to a physiological “startle” response from marine mammals • Efficacy of mitigation methods	• Research and development incentives, e.g. interagency prize opportunities
Species Management	• Update risk framework for protected species and habitats • Temporal and spatial avoidance	• Apply the precautionary principle • Use of aerial surveillance
Governance Interventions		
Enforcement and Prosecution	• Enforce spatio-temporal restrictions • Enforce use of minimum and lowest practicable level of source	• Increase enforcement efforts through inter-agency collaboration

Legal and Policy Frameworks	• Seasonal restrictions • Spatio-temporal restrictions on survey efforts • Noise reduction and attenuation standards: site-specific power levels; minimize horizontal propagation, field-based mitigation methods (e.g. shut downs and ramp ups) • Permit considerations for different seismic sources and methodologies using innovative engineering solutions • International agreement or convention on the phasing out of airgun surveys	• Ensure regulations are strict but realistic and practical • Develop policy incentives programs • Develop clear performance targets
Social Interventions		
Awareness Raising	• Industry guidelines • Increase community engagement to increase stakeholder buy in	• Increase awareness of technology innovations • Engage communities • Additional opportunity for multi-sectoral dialogue
Education and Training	• Train marine mammal observers • Increased knowledge base of engineering solutions amongst regulators • Increase knowledge base of industry professionals on environmental concerns	• Educating regulators on the availability of mitigation technologies • Foster additional settings for multi-sectoral dialogue
Institutional / Organizational development	• Repository of information with centralized and transparent data	• Foster information sharing opportunities and collaboration for industry regarding survey data to eliminate redundancy and duplication
Livelihood, Economic, and other incentives	• Geophysical industry investment in new vessels that can facilitate new technology	• Market-based / subsidy incentive programs for industry • Bringing new noise mitigation technologies to market • Innovative funding mechanisms e.g. prizes

Table 5. Noise abatement technology options for reducing ocean noise, with gaps in information where measures have not been explored. (Source: Mike Jenkerson and GAMeON, 2023)

Noise Mitigation Measures	Details	Advantage	Disadvantage
Operational Modifications			
Temporal avoidance		Total reduction in the output during closure times	Operational impacts on interaction between closure periods and optimal operational times
Areal avoidance		Total reduction in the output for the specific area	Operational impact often extends beyond the closure areas due to sound propagation; some development could be severely hampered or stopped as flexibility can be limited
Reduced acoustic output of airgun array	High frequency output is a byproduct of generating sufficient low frequency energy; advances in receiver technologies have enabled the use of smaller sources; very long offset ocean bottom node (OBN) surveys can still require large arrays	Reduction in the output from the airgun array	Minimal operational impact or cost increase
Engineering Modifications			
Modify airgun design to reduce bandwidth	Modify airgun port shape, slowing shuttle velocity and reducing the acceleration distance to limit high frequency content generated during actuation (eSource™; Bluepulse™); all of the peripherals are compatible	The slope of the output signal and the peak amplitude is reduced, as is the spectral output at higher frequencies and the sound exposure level	Teledyne and Sercel have kits to update standard airguns; a capital expense
Cluster elements in the array to modify the spectrum (option A)	Design a hyper cluster of standard airguns to maximize the low frequency energy generated (Shearwater-Harmony™)	Generates more low-frequency and less high-frequency output, reduced peak amplitude; High frequency noise is still at 25 kHz if conventional airgun heads are used	Limited cost increase
Cluster elements in the array to modify the	Impulsive high pressure-high volume ‘cluster’ (ION-Gemini™); source can be used as a stand-alone	Generates more low frequency and less high frequency output;	Some cost for redesigned chamber; a separate

spectrum (option B)	source or across the full seismic band	reduced peak amplitude; High frequency noise is still at 25 kHz if conventional airguns heads are used	chamber size is used for full band seismic imaging
Desynchronize airgun activation (option A)	Small (ms) scatter in activation times; Staggering airgun activation modified outgoing wavefield spectrum; reduced high frequency output without affecting low frequency spectrum	Spectral output at high frequency; peak sound pressure level and sound exposure level should be reduced; High frequency noise is still at 25 kHz if conventional airguns are used.	Minimal operational and capital cost
Desynchronize airgun activation (option B)	Large (sec) scatter in activation times (e-seismic™, popcorn™); staggering airgun activation modified outgoing wavefield spectrum; reducing peak output generates a continuous wavefield	Reduction in the peak amplitude; High frequency noise is still at 25 kHz if conventional airguns are used	Minimal operational and capital cost
New Technologies			
Marine vibroseis (MV)	Frequencies lower than 100Hz are required for effective imaging; MV techniques allow the output from the source to be highly controlled in output level, bandwidth and phase; phase and amplitude control could allow sources to improve the reconstruction of the wavefield between source lines with less shots acquired and faster acquisition	The spectral output is highly controllable with only frequencies needed for imaging being output; the peak amplitude is >24 dB down, and the sound exposure level is reduced. There is no high frequency noise above a few harmonics of controlled signal.	The initial cost of a source array will be large; once system are available geophysical and operational benefits could accrue
Impulsive low pressure-high volume (SERCEL - Tuned Pulse Source (TPS)™)	A very low source used primarily to improve the very low frequency content (~1-5 Hz); the TPS has zero acceleration distance smooth ports and changed shuttle design releasing the energy over a longer period; air filled middle chamber reduces cavitation	Spectral output is concentrated mostly at frequencies <10 Hz. High frequency noise is limited to less than 2 kHz	A separate array is used for fill band seismic imaging
Vibratory low frequency sources (Wolfspar™)	A very low source used primarily to improve the very low frequency content (~1-5 Hz); use large volume displacements to generate lower frequencies	Spectral output is focused in narrow bands at frequencies <10 Hz. There is no high frequency noise above a few harmonics of controlled signal.	For full band seismic imaging a separate array must be used

Call to Action

Moving forward, the Global Alliance for Managing Ocean Noise (GAMeON) recommends the following three concrete and specific deliverables for specific parties, as identified by participants during the workshop:

1. *Build robust regulatory standards* for noise reduction and attenuation which can be used internationally to increase the transparency and consistency of requirements, including quantifiable noise level limits and spatial/temporal closures, especially in areas of vulnerable species.

2. *Develop a noise mitigation decision aid for industry and governing bodies* to understand technological, efficacy, and commercial availability of quieting technologies and methods (e.g., operational and engineering modifications). This decision aid will inform regulatory action, incentivize technological advancements, and streamline implementation.

3. *Strive to limit high rise time* with high frequency noise to lower potential for impacts and still achieve efficacy of exploration data objectives.

4. *Foster additional multi-sectoral discussions* on integrating regulatory standards and reduce duplication for speculative, pre-lease surveys.

Contact Us

Should you have questions or interest in getting involved with GAMeON, reach out to GAMeON Secretariat Juliette Lee at Juliette.Lee@boem.gov.

Citations

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