Practical Approaches for Reducing Ocean Noise:
Opportunities using systemic evidence synthesis, multi-sectoral dialogues, and ‘Smart Shipping’ technology to protect marine mammals from anthropogenically produced sound

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EXECUTIVE SUMMARY

This Master’s Project presents data-informed strategies to minimize anthropogenically produced ocean noise that impacts acoustically sensitive marine mammals. With the blue acceleration—"the demand for resources from the ocean to be used as an engine of human development" (Jouffray et al., 2020)—we can mitigate impacts of ocean noise using multi-sectoral collaboration and technology. Anthropogenic ocean noise can be generated by offshore renewable and non-renewable energy development, shipping, and geophysical exploration, three key components of the blue economy. As we strive to responsibly utilize our ocean resources, we have a unique opportunity to develop multi-sectoral approaches to reduce or mitigate anthropogenically produced ocean noise.

Anthropogenic ocean noise from offshore wind energy development, shipping, and geophysical exploration threatens acoustically sensitive marine mammals throughout their life functions, including communication, feeding, and defense. Since the production and reception of sound is centrally important to these species, noise pollution can have significant consequences.

Congruent with the mission of the Global Alliance for Managing Ocean Noise (GAMeON), an international partnership of proactive and action-minded scientists, managers, policy makers, and industry representatives, I present three different approaches in subsequent chapters that explore ways to proactively identify emerging concerns and solutions, to create inclusive dialogues and networks, and to map existing and emerging technologies to solve the pressing ocean challenge of human produced noise.

I generated an evidence synthesis of quieting measures and technologies, implementation challenges, and solutions for offshore renewable energy development and shipping utilizing Colandr, a machine learning platform. I identified multi-sectoral stakeholders for ocean quieting that can collaborate on developing practical approaches to reduce ocean noise. I then planned and executed a workshop in collaboration with the GAMeON to host a conversation with these stakeholders focused on ‘Practical Approaches for Reducing Ocean Noise associated with Offshore Renewable Energy Development.’ I developed a user-interactive geoprocessing tool that identifies 'smart shipping' paths to reduce noise in marine mammal critical habitat and migratory corridors. These are three of many ways in which the challenge of ocean noise can be approached.
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ABSTRACT

This Master’s Project presents data-informed strategies to minimize anthropogenic ocean noise. With the blue acceleration—the driver of human development through the use of ocean resources—we can mitigate impacts of ocean noise using technology and multi-sectoral collaboration. Anthropogenic ocean noise can be generated by offshore renewable energy development, shipping, and geophysical exploration, three key components of the blue economy. Anthropogenic ocean noise from these point sources threatens marine mammals throughout their life functions, including communication, feeding, and defense. Since the production and reception of sound is centrally important to these species, noise pollution can lead to significant consequences. Congruent with the mission of the Global Alliance for Managing Ocean Noise (GAMeON), three different approaches are presented that explore ways to proactively identify emerging concerns and solutions, to create inclusive multi-sectoral dialogues, and to map existing and emerging technologies to solve the pressing ocean challenge of human produced noise. These three approaches include evidence synthesis, multi-sectoral dialogues, and ‘smart shipping’ geospatial technology.

Keywords: ocean noise; marine mammal; offshore renewable energy; shipping; geophysical exploration; bioacoustics; evidence synthesis

INTRODUCTION

Noise in the Ocean Environment

Jacques-Yves Cousteau, the father of ocean exploration and founder of the first underwater breathing apparatus, deemed the ocean silent in his 1953 book, The Silent World. Yet, the undersea world is anything but silent. Sound is essential to the survival and prosperity of many marine organisms across the entire trophic cascade. Marine mammals are acoustically sensitive and are the focal subjects of this study. Anthropogenic ocean noise impacts marine mammals across all taxonomic groups: cetaceans, pinnipeds, sirenians, and marine fissipeds. Specifically, throughout marine mammals' life functions, the production and reception of sound is centrally important (Southall, 2019). Anthropogenic ocean noise includes shipping, industrial noise, offshore renewable energy development, and seismic air guns for geophysical exploration—all of which are used on a global scale and are increasing with the blue acceleration. The blue acceleration is defined by the Stockholm Resilience Center as "the demand for resources from the ocean to be used as an engine of human development" (Jouffray et al., 2020). With a greater understanding of the frequency of occurrence and severity of how anthropogenic threats
influence behavior and the development of innovative technologies, multi-sectoral stakeholders can collaborate to develop solutions to minimize anthropogenic noise.

**Offshore Renewable Energy**

According to the law, the United States (US) can take particular scientific and regulatory approaches available to the Bureau of Ocean and Energy Management (BOEM) to monitor and mitigate anthropogenically produced impacts on marine mammals during offshore renewable energy development. The Biden Administration intends to deploy 30 gigawatts (GW) of renewable energy in US territorial waters by 2030, which presents a positive transition away from our dependence on fossil fuels to a clean energy market (Foster & Elizinga, *no date*). BOEM must simultaneously take care to minimize the impacts on marine mammals. Offshore renewable energy development threatens marine mammals throughout their entire life, including their production and reception of sound which can impact communication, feeding, and predator-avoidance (Southall, 2007). The National Environmental Policy Act (42 U.S.C. §§ 4321 et seq.), the Marine Mammal Protection Act (16 U.S.C. §§1361-1383b, 1401-1406, 1411-1421h), and the Endangered Species Act (16 U.S.C. §§1531-1544) have language to protect marine mammals throughout their ranges and activities.

Under a robust regulatory framework, the Department of the Interior’s Bureau of Ocean and Energy Management (BOEM) manages offshore renewable energy development. BOEM oversees the exploration and development of offshore energy and mineral resources on the Outer Continental Shelf (OCS) under the Outer Continental Shelf Lands Act (OCSLA) of 1953 (43 U.S.C. §§ 1331 et seq.). The final regulations for the OCS Renewable Energy Program were authorized in 2009 by the Energy Policy Act (EPAct) of 2005 (42 U.S.C. §§15801). BOEM implements these regulations and provides a framework for issuing leases, easements and rights-of-way for OCS actions, including offshore energy development (BOEM, 2018).

The following states have been issued leases for offshore wind development: Massachusetts, Rhode Island, New York, New Jersey, Delaware, Maryland, Virginia, and North Carolina – all of which are on the East Coast of the US and shown in Figure 1. Legally required under the National Environmental Protection Act (NEPA) of 1969, BOEM is in charge of the
environmental reviews and compliance documents for each stage of development. Each ocean resource, including marine mammals, is given an environmental impact determination (42 U.S.C. §§ 4321 et seq.). BOEM also assesses the risks of laying cable, installing structures, lighting, vessel traffic, and surveys on the lease area. BOEM is also required to avoid, minimize, reduce, or eliminate impacts and currently attempts to use a “mitigation hierarchy” to prevent impacts over time (BOEM, 2018).

Figure 1. USA Outer Continental Shelf Renewable Energy Planning and Lease Areas. (Source: BOEM’s Office of Renewable Energy Programs, 2021)
Figure 2. Flowchart of the Assessment and Permitting Procedures of Article 6(3) and 6(4). (Source: European Environment Agency, 2019)
Wind energy leases follow a four stage authorization procedure: (1) planning and analysis; (2) lease issuance; (3) site assessment; and (4) construction and operation. This is comparable to the European procedure, as shown in figure 2. Areas suitable for wind energy leasing are identified in the planning and analysis stages. Under NEPA, BOEM conducts environmental compliance reviews and collaborates with impacted stakeholders including Federally-Recognized Tribes, States, and natural resource agencies (BOEM, 2018). These unique stages of development present separate opportunities for sound reduction.

To inform policy decisions regarding the management of offshore energy, such as the impacts of noise, BOEM leads environmental studies, and consults the public and stakeholders. While BOEM manages energy development on the OCS, collaboration across stakeholder groups is integral for responsible and sustainable development. To comply with NEPA and other environmental laws, including the Marine Mammal Protection Act (MMPA) of 1972 and the Endangered Species Act (ESA) of 1982, BOEM must collaborate with other federal agencies and developers. Collaboration is also integral for reviewing developer plans, including for Site Assessment Plans (SAP) and Construction and Operation Plans (COP), establishing monitoring protocols, and making sure mitigation measures are completed (BOEM, 2018). This is an area that currently lacks multisectoral collaboration.

Both the Atlantic and Pacific OCS present offshore wind energy potential. According to BOEM, successful delivery of the offshore renewable energy program relies on multi-sectoral collaboration between non-governmental organizations (NGOs), regulators, and industry. Knowledge sharing and technological advancement in industry, specifically as it relates to marine mammals, is imperative for effective mitigation. The Offshore Wind Strategy Committee of the American Wind Energy Association (AWEA) is another group that promotes offshore renewables (BOEM, 2018) and should be considered in the conversation.

Academia is an important actor in knowledge sharing around offshore renewables energy development. Research and monitoring can provide important information to assist in characterizing species and critical habitats to provide to BOEM. Further research is crucial to
comply with the mitigation hierarchy and to prevent avoidable marine mammal impacts, as has been done in Europe with the Natura 2000 sites, as exemplified in figure 3.

**Figure 3. Natura 2000 Network (terrestrial and marine areas). (Source: European Environment Agency, 2019)**

**Shipping**

The transport of people, possessions, and products via shipping drives the most significant amount of ocean noise within the water column. Cargo ships, container vessels, bulk carriers,
tankers, ferries, and cruise ships, make up the majority of large commercial vessels (NRDC, 2016). With increasing maritime trade and increasing vessel speed, ocean noise caused by shipping is widespread and growing. Large ships produce low-frequency sounds that many marine mammal species found on the US east coast use to communicate and feed (Hatch, 2016). For example, in Cape Cod Bay and within Stellwagen Bank National Marine Sanctuary, shipping noise has decreased the acoustic soundscape of North Atlantic right whales, limiting the distance to which they can vocalize. As a critically endangered species, right whales cannot afford threats to their communication and feeding (Hatch, 2012). Higher frequency sounds from vessels are thought to impact the diving and acoustic behavior of Blainville’s and Cuvier’s beaked whales (Aguilar Soto et al., 2006) and even can impair fish and invertebrates’ ability to feed, breed, and respond to predators (Nedelec, 2014).

Large vessels produce both loud and predominantly low-frequency sound that can travel large distances. Container ships and tankers produce sound levels below 40 Hz, while bulk carriers produce sound closer to 100 Hz (Hildebrand et al., 2012). Engine noise vibrates the hull and propeller cavitation causes large numbers of vacuum bubbles to implode causing a consistent and threatening sound (The Guardian, 2012). Designing more efficient ships through hull and propeller modifications has potential to reduce noise output but also the simple act of ship slowing can significantly reduce the amount of ocean noise (Hildebrand et al., 2012).

The reduction of speed does not eliminate the noise altogether and migratory species are still impacted. Migration corridors are routes that marine mammals follow between foraging and mating habitats. These corridors are constantly impacted by shipping noise, in addition to seismic testing and Navy sonar. National Marine Monuments and the National Marine Sanctuary System, a system of 16 of the most significant marine protected areas in United States waters, provide protections for threatened species within their borders, yet do not provide migratory corridors between them. Specifically on the East coast of the United States, several sanctuaries (Stellwagen Bank National Marine Sanctuary, Monitor National Marine Sanctuary, Gray’s Reef National Marine Sanctuary, etc.) provide habitat for acoustically dependent species (Hatch, 2012).
Sound not only impacts whales in their movement, but also with their health. Stress-related hormone metabolites have recorded decreases in North Atlantic right whales due to noise reduction (Rolland et al., 2012). Rolland et al.’s study exemplifies how exposure to low-frequency ship noise is correlated with chronic stress in marine mammals. When considering the recovery of North Atlantic right whales, if possible, these sound implications must be considered, especially in areas of heavy ship traffic.

Several of the same statutory and regulatory mechanisms are in place that inform policy regarding the conservation of marine mammals in respect to noise from shipping. The Marine Mammal Protection Act (MMPA) of 1972 under Title I establishes a general prohibition on the taking of marine mammals. Take is defined as to harass, hunt, capture or kill, or attempt to take. The MMPA defines the term “harassment” to mean both potential to injure and potential to disturb, by causing disruption of behavioral patterns, including migration, breeding, and feeding (16 U.S.C. §§1361-1383b, 1401-1406, 1411-1421h). Harassment is regulated through permitting, although shipping is not currently required to submit to a permitting process for incidental or unintentional takes.

The Endangered Species Act (ESA) of 1982 ensures that actions authorized, funded, or carried out by federal agencies will not jeopardize the continued existence of any listed species or result in the destruction or adverse modification of critical habitat. Multiple marine mammals are already listed as endangered or threatened under the ESA (16 U.S.C. §§1531-1544). The ESA includes the Final Rule to Implement Speed Restrictions to Reduce the Threat of Ship Collision with North Atlantic Right Whales, which implements a speed restriction of no more than 10 knots applying to vessels 65 feet or greater in length in certain locations at specific times of year to reduce the likelihood of collision with endangered North Atlantic right whales. Under the Final Rule, Dynamic Management Areas (DMAs) are created in response to observed aggregations of North Atlantic Right Whales within Seasonal Management Areas (SMA), as illustrated in figure 4. Areas to Be Avoided (ATBA) under the Final Rule are currently voluntary, encouraging but not requiring alternative ship routes during Right Whale presence (16 U.S.C. §§1531-1544).
While the MMPA and ESA provide the statutory frameworks to reduce ocean noise for marine mammals from shipping, the COVID-19 pandemic provides an exceptional example of how well reduction of noise can change the soundscape for these acoustically-sensitive species. Midway through 2020, transportation of public services were suspended, including ships. While essential goods and emergency services continued, the heavy ship traffic within the US OCS was reduced. The COVID-19 pandemic exemplified how the limitation of sound in the marine environment can have a positive impact on marine mammals (Chahouri et al., 2022). While the reduction of sound from ships does not solve the ocean noise problem, it presents one opportunity where sound can be reduced.

Figure 4. North Atlantic Right Whale Mitigation Measures. (Source: BOEM, 2018)
Geophysical Exploration

The ocean is often referred to as the last frontier, which is particularly applicable to exploring the geophysical properties of the ocean. Geophysical exploration poses significant noise risks to marine mammals from shallow to deep ocean surveys. In 2017, NOAA issued a notice of opportunity for public comment on Executive Order 13795, which established a national policy “to encourage energy exploration and production” within the National Marine Sanctuaries and Monuments. Comments were intended to reflect on the risks of energy and mineral exploration in the ocean (Columbia Law School, 2017). Sound from geophysical exploration is increasing, especially with new opportunities rising such as deep sea mining, so we are at a critical juncture to influence sound output.

Geophysical exploration uses physical methods such as electrical, electromagnetic, gravitational, magnetic, or seismic to measure the physical properties of the surface and subsurface of the seafloor and the anomalies present along the seafloor. While these anomalies can provide profitable resources, such as oil or gas pockets, precious minerals, or can be ideal areas for the laying of submarine cables or wind turbines, these methods can have negative impacts on the soundscape. For example, seismic airguns are used to explore geologic structures. The process includes the regular intervals of the production of explosive bubbles beneath the surface. These explosions can produce sound up to 240 dB (Bobbitt and Nieukirk, 2018). Meanwhile, a low-frequency active sonar can change whale behavior. During an experimental transmissions of low-frequency active sonar from an approaching vessel, tagged whales switched to a “non-foraging, non-resting state” (Isojunno et al., 2016). Geophysical methods are implemented globally and should be considered as an opportunity to reduce sound output.

The Marine Mammal Impact

The increase of offshore renewable energy development, shipping, and geophysical exploration has the potential to impact many marine species. Throughout the offshore wind energy development process, in addition to seabirds, marine mammals have the potential to be significantly impacted. Displacement, vessel strike risk, behavioral and distribution changes,
prey availability and ecosystem alterations are the resulting aspects from these industries suspected to impact marine mammals. Further research is necessary to confirm this within US waters. Specifically, increased sound from vessel traffic and structure installation in wind energy lease areas may cause animals to avoid preferred habitat. There is potential for ecosystem alterations, such as how the installation of structures may enhance foraging opportunities for some marine mammal species, such as seals. Large ships produce low-frequency sounds at the same decibel that many marine mammal species use to communicate and feed (Hatch, 2016), which may also cause habitat avoidance. Displacement can also put marine mammals at higher risk of vessel strike (Wiley et al., 2011). Habitat alteration impacts prey species distribution, density, patch structure, and availability to marine mammals (Goodale and Milman, 2019). More research is needed about behavioral and physiological changes, including call rates and intensities, foraging ecology, respiration and movement patterns, rates of physiological stress (Marine Mammal Commission, 2021). These diverse impacts from anthropogenic sound are tied with marine mammals' reliance on sound.

Marine mammals are inextricably reliant on sound for three essential behaviors including (1) communication: reproductive advertisement, maintaining contact, group and individual recognition; (2) feeding: foraging, echolocation, cooperative foraging, and deep diving; and (3) protection, specifically predator avoidance (Marine Mammal Commission, 2021). For example, higher frequency sounds from vessels impact the diving and acoustic behavior of Blainville’s and Cuvier’s beaked whales (Aguilar Soto et al., 2006). In Cape Cod Bay, shipping noise has decreased the acoustic soundscape of the critically endangered North Atlantic right whales, limiting the distance to which they can vocalize, which threatens their communication and feeding (Hatch et al., 2012). Considering the inextricable link between marine mammals and the impacts of anthropogenically produced ocean noise from offshore renewable energy development, shipping, and geophysical exploration, multi-sectoral solutions and innovative technology must be used to overcome this ocean challenge.
CHAPTER 1: LITERATURE SYNTHESIS

Approaches

To solve the challenge of ocean noise, we must first have a holistic understanding of what we know and what we do not know in order to inform the most productive conservation interventions and actionable steps. Evidence synthesis with the use of machine learning provides an opportunity for efficient meta-analysis of the pre-existing literature. Evidence synthesis is the process of identifying, sorting, and combining relevant data from a diversity of sources to identify relevant information so it is accessible for end-users, in this case decision makers (Cook et al., 2017). Published research often lacks actionable insight, yet many evidence synthesis methods, such as meta-analyses, systematic maps, and reviews, have high resource demands that prohibit decision makers from utilizing the information (Pullin & Knight, 2009; Elliott et al., 2014). Evidence synthesis can provide benefits for conservation planning and implementation, thus must be done in a way that reduces time, bias, and cost (Brooks et al., 2020).

Machine learning can help to lessen the challenges of evidence synthesis to guide evidence-based decision-making and identify areas where more targeted research is needed, while also making the process more efficient (Gill et al., 2021). Conceptual models can be used to identify and communicate complex concepts to decision makers once the evidence has been compiled. Conceptual models can also help to identify critical gaps in evidence, to see what information is still needed to inform a decision (DEHP, 2012).

By learning a set of rules and training data, computers can be programmed to automatically perform a set of tasks (Alpaydin, 2014). This is known as machine learning. Colandr is an open-access platform created to find relevant articles and extract desired information through sorting by relevance as specified by users and categorizing by topic (Cheng et al., 2018). Colandr provides an ideal machine learning platform to explore the evidence surrounding practical approaches to reduce ocean noise associated with offshore renewable energy development, shipping, and geophysical exploration impacting acoustically sensitive species.
Methods

Utilizing Colandr, a machine learning platform, I conducted a thorough evidence synthesis regarding the impacts of anthropogenically produced ocean noise on marine mammals. I developed a key research question and a series of key attributes relating to my question to inform the inclusion and exclusion criteria for peer-reviewed scientific articles and grey literature. The review begins with an abstract screening and then transitions into a full paper screening for included articles.

I developed a framework of social, ecological, and governance interventions and outcomes to approaches for ocean quieting, informed by the structure of similar evidence synthesis projects. This included existing frameworks from Brooks et al. 2020 and Duke University’s Bass Connections Ocean Evidence Gap Maps Project, which I participated in. I modified these existing frameworks to include offshore renewable energy development, shipping, and geophysical exploration, which was not considered in existing frameworks. I regrouped existing conservation interventions to more thoroughly consider the multi-sectoral approaches. I created a search string based on population, interventions, and outcomes related to the study. This search string was applied to a wide set of research databases and relevant websites to explore the evidence in both peer-reviewed and grey literature. Searches were in English and if articles were not in English, they were excluded.

All articles were screened at the title and abstract level and included articles were screened at the full text level. Data was coded thereafter. This methodology directly follows that of Brooks et al. 2020. Coded data is reported narratively and trends were summarized regarding the evidence, ocean quieting approaches, and outcomes. I identified gaps in the literature to provide additional information to consider the implication of research gaps for the reduction of sound for the benefit of marine mammals.

The framework I used identifies three distinct conservation intervention or ocean quieting approaches: (i) social interventions or behavior change, (ii) governance interventions, (iii) ecological interventions. Within these three categories, 10 conservation approaches categories
are considered. The following conservation approaches categories, subcategories, and definitions are adopted from *IUCN’s CMP Conservation Actions Version 2.0*. The ocean quieting conservation approaches include (1) land/water management, (2) species management, (3) awareness raising, (4) law enforcement and prosecution, (5) livelihood, economic, and moral incentives, (6) conservation designation and planning, (7) legal and policy frameworks, (8) legal and policy frameworks, (8) research and monitoring, (9) education and training, (10) institutional and organization development.

I believe these categories best encompass the elements related to my research question:

1. What is the extent and occurrence of evidence for practical approaches for reducing ocean noise to protect acoustically sensitive marine mammals?

*Table 1. Conservation interventions for reducing ocean noise. (Source: Brooks et al., 2020)*

<table>
<thead>
<tr>
<th>Intervention Category</th>
<th>Intervention Definition</th>
<th>Intervention Subcategory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Land / Water Management</td>
<td>Approaches directly managing or restoring sites, ecosystem and the wider environment</td>
<td>1a. Site / Area Stewardship 1b. Restoration 1c. Ecosystem &amp; Natural Process Management</td>
</tr>
<tr>
<td>2. Species Management</td>
<td>Approaches directly managing or restoring specific species or taxonomic groups</td>
<td>2a. Habitat management 2b. Fisheries management 2c. Species stewardship 2d. Species Reintroduction and Translocation 2e. Ex-situ Conservation</td>
</tr>
<tr>
<td>3. Awareness Raising</td>
<td>Approaches making people aware of key issues and/or feeling desired emotions, attitudes, opinion designed lead to behavior change</td>
<td>3a. Outreach &amp; Communication 3b. Protests &amp; Civil Disobedience 3c. Political Lobbying and Campaigning</td>
</tr>
<tr>
<td>5. Livelihood, Economic, and other incentives</td>
<td>Approaches using livelihood, other economic and more incentives to directly influence attitudes and behaviors</td>
<td>5a. Linked Enterprises &amp; Alternative Livelihoods 5b. Consumer or producer substitution, through technology or product innovation 5c. Corporate practices and</td>
</tr>
</tbody>
</table>
The goal of this section is to identify the pre-existing evidence about the social, governance, and ecological outcomes of conservation approaches to mitigate or minimize anthropogenic ocean noise, specifically as it relates to offshore renewable energy development, shipping, and geophysical exploration, as exemplified in table 2. From my research question, I developed these specific elements of the review question. The elements are intended to inform a map that highlights promising areas for action and evidence gaps where further research is needed. By
highlighting quieting approaches with little existing evidence, I can provide direction for multi-sectoral stakeholders to invest resources to mitigate or minimize ocean noise.

Table 2. Key elements of the review question. (Source: Lee, Juliette 2022)

<table>
<thead>
<tr>
<th>Population</th>
<th>Intervention</th>
<th>Comparator</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine mammals classified into the four different taxonomic groups: cetaceans (whales, dolphins, and porpoises), pinnipeds (seals, sea lions, and walruses), sirenians (manatees and dugongs), and/or marine fissipeds (polar bears and otters) as defined by the National Oceanic and Atmospheric Administration (NOAA, 2022)</td>
<td>Adoption or intended implementation of quieting measure (see table 1)</td>
<td>Comparison of implementation during one of the three ocean activities: offshore renewable energy development, shipping, OR seismic exploration</td>
<td>Impacts OR implementation of quieting measure</td>
</tr>
</tbody>
</table>

The systemic map intends to answer the following systemic review questions:

1. What is the extent and occurrence of evidence for practical approaches for reducing ocean noise to protect acoustically sensitive marine mammals?

I also consider the following secondary review questions:

1. What approaches are the most successful at reducing ocean noise?
2. What approaches and outcomes are less represented in the evidence base, requiring additional research?

Searching for Articles

I created a search string including four sub-strings. The four sub-strings include: population, intervention, comparator and outcome, as shown in table 2. Search terms included key terms: marine mammals, ocean noise, whales, sanctuary, technology, pile driving, shipping, offshore renewable energy. For each key term, I provided a list of synonyms and a group of associated
key terms. I used the search strings to conduct searches across a range of sources including: bibliographic databases, institutional websites, and grey literature.

**Article Screening and Eligibility Criteria**

Articles were first screened at the title and abstract level for the three sub-strings: population, intervention, comparator, and outcome, as shown in table 2. For the population, to capture the impact on social, governance, and ecological impacts of ocean noise, I included articles examining a population that considered all types of marine mammals. I excluded articles that do not have clearly defined affected populations (e.g. global populations more broadly), focus on marine mammal produced sound opposed to the impacts of sound, or focus on non-marine mammals.

For the intervention, I focused on articles that evaluate noise mitigation interventions that aim to mitigate or reduce ocean noise through social, governance, or ecological approaches. Intervention types include land/water management; species management; awareness raising; enforcement and prosecution; livelihood, economic, and other incentives; conservation designation and planning; legal and policy frameworks; research and monitoring; education and training; and institutional/organizational development, as shown in table 1. Specifically, I considered ocean quieting approaches that imposed mitigation strategies and/or quieting technologies. I considered measures applied for offshore renewable energy development, shipping, and seismic exploration. While a wider search of geophysical exploration could have been used in the search string, I chose ‘seismic’ to limit the sample size.

For the outcome, I included articles that describe impacts on the conservation of marine mammals. Specifically, I included articles that attempt to evaluate or document observed or intended outcomes of an implemented quieting measure.

I included articles that evaluate the impacts of quieting measures using a comparator of the three industries. I included articles where the methodology was experimental, non-experimental, narrative, or observations, but excluded theoretical studies, opinion pieces, and studies where the population is not defined. Quantitative and qualitative studies of both natural or social outcomes
are included, provided that interventions can be applied across sectors. Throughout screening, I erred on the side of inclusion.

**Resulting Actions**

**Results**

From 168 screened articles, I only retained 49 as relevant to the primary question. Many articles were automatically excluded based on the criteria outlined in table 2. Additional articles were excluded because they were duplicates or did not have an abstract. The histogram in figure 5 clearly illustrates the most popular conservation interventions. With the 49 remaining studies included in my review, I identified 77 combinations of conservation outcomes that impacted (a) social interventions or behavior change, (b) governance interventions, (c) ecological interventions. I created an evidence gap map, as shown in figure 6, to illustrate which intervention gaps need to be filled. Evidently, research and monitoring appeared the most frequently as the choice conservation intervention (n = 25). Many types of conservation interventions have not been explored as ways to reduce ocean noise.

![Figure 5. Intervention categories for each (a) social interventions or behavior change, (b) governance interventions, (c) ecological interventions (n = 77 outcomes in 49 studies). (Source: Lee, Juliette 2022)](image-url)
**CONSERVATION OUTCOMES:**

<table>
<thead>
<tr>
<th>INTERVENTION:</th>
<th>Social or Behavior</th>
<th>Governance</th>
<th>Ecological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land / Water Management</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Species Management</td>
<td>0</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Awareness Raising</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Enforcement &amp; Prosecution</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Livelihood, Economic, and other incentives</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Conservation Designation and Planning</td>
<td>0</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Legal and Policy Frameworks</td>
<td>1</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Research and Monitoring</td>
<td>1</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Education and Training</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Institutional / Organizational development</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 6. Distribution of outcomes (cases) by intervention for each (a) social interventions or behavior change, (b) governance interventions, (c) ecological interventions (n = 77 outcomes in 49 studies). The color and numbers within the cells represent the frequency of occurrences. The darker the cell, the more frequently the intervention/outcome combination occurred. (Source: Lee, Juliette 2022)

**Discussion**

This study provides a baseline of where gaps lie in some of the peer-reviewed and grey literature about quieting interventions. While the study was intended to holistically collect all literature on the topic, only four databases were used with a limited search string. With an expanded search string, this study has the potential to identify where additional gaps exist in the evidence. With the work provided above, I identified potential areas for future research and interventions on this topic.

According to the data, ecological research and monitoring is the most common intervention method taken to approach the challenge of anthropogenic ocean noise (n = 25). Yet, social interventions and behavior change were rarely used (n = 4). This exhibits an area that should be
explored. Social interventions, such as livelihood or economic or other incentives, could provide robust opportunities to change behavior of stakeholders that hold the power to change the trajectory of current quieting approaches. For example, market-based incentives or consumer pressure could influence industry leaders to make changes, but little evidence exists to prove if this is true or not. Additionally, awareness raising was only referenced once as a tool; key stakeholders, such as policy makers and industry leaders must become aware of the problem prior to implementing a solution.

For this dataset and for future study mapping, compiling descriptive statistics including frequency of comparator types, publication by year, frequency of study design, or geographic distribution of study locations could provide additional information on where the gaps lie about noise mitigation approaches for the three comparators: offshore renewable energy development, shipping, and geophysical exploration. Overall, this data exemplifies key opportunities where stakeholders should invest resources.

CHAPTER 2: OCEAN QUIETING WORKSHOP SERIES

Approach

Multi-sectoral dialogues provide the capacity to address ocean quieting in a way that initiates actionable steps. Through multi-sectoral use of principal ocean management tools, we have an opportunity to achieve the oceans sustainable development goals (SDG). 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, which causes the growth in ocean-based economic activity, must be balanced with conservation of marine resources. Use of marine resources leads 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. Multi-sector management is complicated by the spatial and temporal life functions of marine mammals (Schupp et al., 2019). Single sector and multi-sector management frameworks must simultaneously respond to changing ecological, governance, and social conditions in real time (Schupp et al., 2019). In the European Union, a new strategy has been adopted to achieve both sustainable marine resource use and economic expansion globally.

By providing a setting for multi-sectoral dialogues, participants can overcome obstacles to multi-sectoral management by addressing the lack of information 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 between strategically-invited, 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) shipping (3); and seismic exploration. The sequential series will culminate with a symposium that will synthesize the current state of science and technology from the three workshops and to develop strategic, actionable next steps with a focus on engaging new relevant entities.
The audience for the workshop series is external facing. Audience members do not have the ability to turn on their cameras or unmute their microphones but are able to contribute their thoughts and questions in the chat and in the questions & answer box. The primary audience is the multi-sectoral participants who are involved in the ocean noise space. This may include, but is not limited to, non-governmental groups, industry groups (shipping companies, energy development groups, environmental consulting firms, etc.) governing bodies, and academics. The secondary audience is ocean policy influencers such as NGOs who have staff that work full time on marine conservation issues. The tertiary audience is students in higher education who can engage with the challenges and solutions presented.

**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 exist between sectors to implementing ocean quieting approaches for offshore renewable energy development?

**Methods**

In collaboration with the GAMeON Sounding Board, I selected multi-sectoral stakeholders based on a criteria of having equal representation across sectors: government, private, non-governmental organization, and academia. Recruiting experts across these different sectors to be informants was not even, thus there is an uneven number of participants for the panel across sectors, as shown in table 3. Having additional representation across at different levels of organization (e.g. between individuals, groups, nations, etc.) and at multiple spatial scales was important to gain a holistic understanding. Thus participants were recruited from a global network of ocean noise and offshore renewable energy experts.
Table 3. Stakeholder entities were invited to represent their sectors during the workshop’s panel discussion. (Source: Lee, Juliette 2022)

<table>
<thead>
<tr>
<th>Public / Governmental Organization</th>
<th>Private</th>
<th>Non-Governmental Organization</th>
<th>Academia / Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Energy (DOE)</td>
<td>SMRU Consulting</td>
<td>International Fund for Animal Welfare (IFAW)</td>
<td>Bioacoustics Research Program, Cornell University</td>
</tr>
<tr>
<td>Department of Interior: Bureau of Ocean Energy Management (BOEM)</td>
<td>Heerema Marine Contractors Nederland SE</td>
<td>Wildlife Conservation Society</td>
<td>Bioacoustics and Engineering Laboratory, Duke University</td>
</tr>
<tr>
<td>Joint Nature Conservation Committee</td>
<td>Shell Renewables</td>
<td>Natural Resource Defense Council (NRDC)</td>
<td>Bioacoustics Research Program, Cornell University</td>
</tr>
</tbody>
</table>

Informants were invited to participate as either a panelist or a presenter via a formal email (note appendix). A preliminary research survey was administered to the workshop participants (n = 20), both presenters and panelists, with the intention of gaining their initial perspective on practical approaches for reducing ocean noise associated with offshore renewable energy. The survey also provided an opportunity for those who may typically be quieter in a panel discussion to voice their perspective. The survey questions addressed both the primary research question and specific topic interest for the panel (note appendix).

Before distributing surveys and hosting the workshop, I needed approval from Duke University’s Campus Institutional Review Board (IRB) because my research included human subjects. IRB conducts a scientific and ethical review of research studies to ensure protection of human research subjects. Since there were no risks associated with my research and in accordance with IRB protocol, I created an informed consent document which was shared with participants (see Appendix). For each survey, participants gave me permission to utilize their words and...
confirmed that they understood they were not obligated to this. For confidentiality, I have kept participants’ identities anonymous.

The workshop agenda was developed from a series of conversations with the GAMeON Sounding Board and meetings with workshop leads.

Presentations (60 minutes)

*Theme: Local to global*
- Baseline Monitoring with Wildlife Conservation Society (10 min)
- Noise mitigation engineering solutions (20 min)
- Wildlife and Offshore Wind (5 min)
- New Risk Assessment Methods (10 min)

Discussion (60 minutes)

*Theme: Synthesis assessment with actionable solutions*
- Noise mitigation and management lessons learned (20 min)
- Pairing noise monitoring and mitigation requirements for ongoing developments of noise management (10 min)
- Creating action items (10 min)

**Resulting Actions**

**Survey Results**

Survey participants were asked to provide their perspectives on (a) what barriers they think exist between sectors to implement ocean quieting approaches for offshore renewable energy development, (b) what action can be taken to best manage ocean noise associated with offshore renewable energy development, and (c) what are the most promising solutions to minimize ocean noise associated with offshore renewable energy development. Questions (a) and (b) were coded with the meeting minutes and workshop transcript in NVivo to explore opportunities and barriers. Regarding (c), out of all of the surveys (n = 13), ten identified noise minimizing
approaches during discrete phases of the development process as the most promising area for minimizing ocean noise associated with offshore renewable energy development, as shown in figure 6. This was closely followed by mitigation hierarchy or other risk assessment tools and engineering solutions.

![Most Promising Solutions Identified](image)

*Figure 6. Survey participants (n = 13) selected the solutions they identified as the most promising to overcome the challenge of ocean noise as it relates to offshore renewable energy development. (Source: Lee, Juliette 2022)*

**Quieting Workshop One**

Stakeholders across sectors debated, broke down barriers, and developed data-informed and technologically advanced solutions. The focal topics of the workshop included lessons learned from different projects and experiences and pairing monitoring and mitigation requirements for ongoing developments in science and research. This workshop culminated by identifying and proposing opportunities for actionable next steps.

The workshop was executed successfully with a high number of registrants (n = 438), a significant number of audience attendees (n = 266), and expert participants (n = 20) on March 3, 2022. A total of 44 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, I analyzed opportunities and barriers 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 7. The following social impact analysis of the workshop can be used by the GAMeON Sounding Board to facilitate discussion during subsequent workshops and during the synthesis workshop.
Certain barriers and opportunities that arose regarding sectoral conflicts included conflicts with government, conflicts with industry, conflicts with NGOs, and multi-sectoral conflicts. Regarding conflicts with the government (n = 6 references), a participant identified “a lack of dialogue between contractors and regulators to ensure regulations can be implemented practically during operations.” Several participants stated that regulations are often strict but not realistic or practical. Additionally, an industry participant said that the Bureau of Ocean and Energy Management (BOEM) was easy to work while the National Oceanic and Atmospheric Administration (NOAA), and specifically the National Marine Fisheries Service, struggled to provide “information and regulations on mitigations.” Another challenge was brought to light regarding how many non-governmental stakeholders fear reaching out to government stakeholders— a government participant encouraged non-governmental participants to reach out. Regarding conflicts with industry (n = 5), several participants pointed out that industry members are eager to implement technologies as soon as possible so that they may “come into revenues [as soon as possible].” Industry participants were encouraged by other participants to disassociate energy development from economic growth. Conflicts with NGOs were limited (n =

Figure 7. Hierarchy chart of identified barriers and opportunities compared by number of times they were coded. (Source: Lee, Juliette 2022)
1), yet industry participants argued that environmental NGOs are the “counter drivers” to rapid development. Conflicts with academia did not arise in this data.

Multi-sectoral conflicts were the most common (n = 12), where no specific sector was targeted as the culprit of “mistrust, lack of communication, lack of coordination, different goals, [and] different ‘languages’” and “over-conservatism.” While participants identified offshore renewable energy development as a positive outcome, stakeholders across sectors identified different challenges to the implementation. While multiple participants identified these conflicts as barriers to ocean quieting, many also identified the exact opposite as a clear opportunity. One participant emphasized: “There needs to be buy-in, collaboration and understanding from all sectors in order to successfully implement effective mitigation and noise reduction strategies.” Knowledge sharing and confidence building were seen as opportunities for all stakeholders. By sharing a common understanding of each others’ concerns, stakeholders may be able to compromise or come to a consensus on quieting capabilities.

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 was the most frequently coded area (n = 17). A participant emphasized the importance of “gathering in situ empirical data and not just relying on [acoustic] model predictions” and had support from others. Risk assessment was identified as an important aspect that must be conducted prior to development. Monitoring of species was identified as imperative through the entire development and operations process. There was additional emphasis on the importance of continued research and development around noise abatement, mitigation, and alternatives. Species management was considered (n = 2) in conjunction with risk frameworks and applying the precautionary principle.

Regarding governance interventions, barriers and opportunities were considered about both enforcement and prosecution (n = 1) and legal and policy frameworks (n = 5). Regarding enforcement, a participant emphasized the importance of being strict, yet also emphasized the importance of being realistic with the challenges of implementing quieting methods. Regarding
legal and policy frameworks, one participant encouraged a restriction of “harmful sound generating activities during times of higher marine mammal presence,” such as seasonal closures to construction. A participant suggested a specific regulatory measure: a noise cap, such as a greater than 6 to 10 dB reduction. A pattern of barriers arose about how regulations are not clear. A consistent opportunity arose in response: transparency throughout policy and legal procedures at all government levels. Another 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.

For the barriers and opportunities of the social interventions, the following were considered: awareness raising (n = 6), education and training (n = 1), institutional and organizational development (n = 3), and livelihood, economic, and other incentives (n = 8). Participants emphasized the importance of increasing awareness to drive a commitment to good practices of noise mitigation. Increasing awareness is not only important at the stakeholder level, but one participant pointed out that “grass-root community engagement” could provide opportunities to generate consensus on the importance of reducing noise. Technology awareness was identified as important to regulators. A disconnect exists between new and emerging technology and what regulators are aware of— a regulator suggested that due to their workload, “information needs to be spoon fed” to them to be implemented. Additionally, an emphasis on “centralized, standardized, accessible, transparent data” was paired with a suggestion for a “repository of information.” From the code, it appears several participants are dissatisfied with the current data streams. A barrier that arose multiple times was the challenge of cost feasibility, but was also paired with the opportunity to use an economic incentive to push industry toward quieting. One participant pointed out that there is technical readiness, yet cost limitations. An industry participant agreed that a cost incentive for developers could impact the development timeline, effectiveness, and resources. Additionally, a government representative offered the idea of federal funding opportunities to justify this. Technology was discussed as both a lack of (n = 2) and a desire for innovation (n = 16). A common theme of lack of technology arose, specifically regarding quieting around installation, maintenance vessels, and construction. Yet, this theme was often paired with a strong desire for increased technological innovation. Several participants suggested alternative foundations to
reduce the noise impacts of pile driving, as shown in figure 7 and others suggested a required use of current noise-abatement technologies such as bubble curtains and resonant curtains. There was a desire to bring new noise mitigation technologies to market, including direct drive turbines that eliminate the gear-box noise and vibration-isolation of moving parts such as the mast, stanchions, and bases. Others suggested considering the difference between protecting high-frequency species, such as harbor porpoises, and low-frequency species, such as North Atlantic right whales. This was particularly important as there was some push-back against simply taking lessons-learned from the European examples, where only high-frequency species live. While lessons learned from Europe are important, the marine mammals present are different from those that reside on the US Atlantic coast. The low-frequency great whales were not considered in Europe, but instead a short list of cetaceans and phocids, as listed in Annex II and IV of the European Union’s Habitats Directive, as shown in table 4.

![Figure 7. Offshore wind foundation types. Left to right: monopile, jacket, twisted tripod, floating semi-submersible, floating tension leg platform, and floating spar. (Source: Josh Bauer at the National Renewable Energy Laboratory, 2021)](image-url)

Table 6-5 Marine mammal (seal and cetacean) species included in Annex II and IV of the Habitats Directive. (Y = Yes; N = No)

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>Annex II (Natura 2000)</th>
<th>Annex IV (strictly protected)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CETACEA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Phocoena phocoena</em></td>
<td>Harbour porpoise</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><em>Tursiops truncatus</em></td>
<td>Bottlenose dolphin</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><em>Cetacea (all other species)</em></td>
<td>Whales, dolphins and porpoises</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td><strong>PHOCIDAE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halichoerus grypus</td>
<td>Grey seal</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td><em>Monachus monachus</em></td>
<td>Mediterranean monk seal</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><em>Pusa hispida botnica</em></td>
<td>Baltic ringed seal</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td><em>Pusa hispida salimensis</em>*</td>
<td>Saimaa ringed seal</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><em>Phoca vitulina</em></td>
<td>Harbour seal</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

* priority species, for the conservation of which the EU has particular responsibility because of the proportion of their natural range which falls within the European territory of the Member States to which the Treaty establishing the European Economic Community applies.

**Discussion**

Workshop One: ‘Practical Approaches for Reducing Ocean Noise Associated with Offshore Renewable Energy Development’ 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. Additional conversations, specifically relating to offshore renewable energy development is advisable since this first workshop only provided a short period of time to explore this complex challenge. Yet, clear patterns of barriers, such as sectoral conflicts and regulatory transparency, and clear patterns of opportunities, such as knowledge sharing and technology advancements, shows like minded perspectives amongst the stakeholders.
Future workshops including Ocean Quieting Workshop Two: ‘Practical Approaches for Reducing Ocean Noise Associated with Seismic Exploration,’ Ocean Quieting Workshop Three: ‘Practical Approaches for Reducing Ocean Noise Associated with Shipping,’ and a subsequent synthesis workshop will provide GAMeON with a more holistic perspective of the barriers and opportunities to reducing ocean noise, as it relates to other aspects of the blue economy. These future workshops would benefit from a longer agenda with more opportunities for discussion. Constructive dialogue creates ample opportunity to expand on sectoral conflicts, ecological interventions, governance interventions, social interventions, and technology.

CHAPTER 3: GEOSPATIAL ‘SMART SHIPPING’ TECHNOLOGY

Approach

Utilizing remote and autonomously collected ocean data paired with robust modeling efforts could yield ‘Smart Shipping Plans’ thus providing breakthroughs in ocean quieting to benefit marine mammals that rely on sound for their existence. Routing has the opportunity to minimize impacts on species by investing in extra distance to traverse, but results in a cost to industry. Many studies have explored the risk of ship strike verses the cost of vessel rerouting based on a predefined track (Best, 2016; Vanderlaan & Taggart, 2007; 2009; Fonnesbeck et al., 2008; Vanderlaan et al., 2008; 2009; Schick et al., 2009), yet have avoided a qualitative prescription. Yet, Best 2016 considered how routing using a prescriptive least-cost path can inform safe ship route planning (SRP). The methodology used to produce my user-interactive ‘smart-shipping’ technology derives from Best 2016’s spatial decision framework.

Dijkstra’s least-cost path algorithms are commonly used in online driving directions and other route-optimization applications. Graph-theoretic algorithms are used to route corridors of habitat and test connectivity of habitat patches for both terrestrial and marine applications (Best, 2016; Chetkiewicz et al., 2006; Urban & Keitt, 2001; Urban et al., 2009; Treml et al., 2008). The graph-theoretic algorithm minimizes the total cost of movement between two points traversing over a resistance surface (Best, 2016). For the sake of this conservation routing problem, the cost surface represents the risk of acoustic disturbance.
Prescriptive safe ship route planning is based on the idea of smart flight plans. Airlines have restricted areas where they are unable to traverse due to important human dimensions. For example, in Washington, District of Columbia (DC), flights are able to fly along the Potomac River or over areas of Arlington, but DC proper is restricted for the protection of those who live there. With this model, smart flight plans can be applied to ships to protect critical habitats of marine mammals that are impacted by ocean noise.

Avoiding whale strikes is a different spatial problem compared to considering the acoustic territory of marine mammals. From density surface maps and conservation areas of cetaceans, a cumulative cost surface can be calculated using least-cast routes between start and end locations, e.g. ports. Allowing for user-input start and end locations, to calculate the least-cost path is important to make this useful to shippers. These least-cost paths can be applied to decision frameworks to preemptively suggest human activity across spatio-temporal scales to minimize ocean noise. These decision frameworks rely on a tradeoff between conservation risk and industry profit (Best, 2016).

Least-cost paths have been applied to shipping lanes for marine mammal conservation contexts. Shipping lanes have been redrawn in Boston Harbor in consideration of conservation of the critically endangered right whale (Ward-Geiger et al., 2005). NOAA’s Office of National Marine Sanctuaries and NOAA Fisheries Service have explored the potential that a minor northward shift in the Boston shipping lanes may be able to significantly reduce the threat of whale-ship collision within the Sanctuary perimeter (Bonora, 2017). Whale-ship collisions are common amongst the critically endangered North Atlantic right whales and endangered humpback and finback which often travel through Stellwagen Bank. Anecdotally, NOAA reported that “shipping companies support the proposal, which scientists say could reduce whale strikes by a whopping 81 percent” (Bonora, 2017). Humpback whales and finback whales congregate in sandy areas near their prey of choice, sand lance fish, thus a 12-degree northward adjustment would place lanes in muddy-gravel seafloor (Ward-Geiger et al., 2005), as shown in figure 8. This has the potential to avoid right whale feeding grounds as well.
Figure 8. The proposed northward shift in the Boston shipping lanes showing whale concentrations in Stellwagen Bank National Marine Sanctuary. (Source: David Wiley and Michael Thompson, NOAA's Stellwagen Bank National Marine Sanctuary)

The objectives for this section are: (1) to explore the potential for technology and data to be used for a geoprocessing tool prototype; (2) to identify obstacles to the use of available data and technology to reduce noise; (3) to identify a solution to break through barriers that are preventing the development of this type of technology; and, (4) to pilot a prototype that attempts to minimize acoustic footprints. In an attempt to assess the management options for separating acoustic disturbance and vessel routes, I built a cost surface raster based on species critical habitat and applied it to optimize the routing of vessels to reduce any amount of risk.
Methods

Using ArcGIS Pro, I mapped out ‘Safe Shipping Tracks’ or ship route planning (SRP) to reduce noise impacts on migratory corridors and critical habitats. Migratory Corridors (MICO) could provide an alternative to ‘safe shipping’ paths by instead providing potential for ‘animal flight plans’ for migratory species, such as cetaceans. This could provide a powerful application of the MICO data and how noise could be incorporated into that model. This also could provide clarity on whether the National Marine Sanctuary System, as shown in figure 9, actually represents areas that are sanctuaries from anthropogenic sound. I created a cost surface raster within a GIS model that ranks areas by qualitatively prescribing values of acoustic avoidance so that the user can select a safe, and least-cost shipping path.
**Primary Research Questions:**

1. What does smart routing mean in respect to noise?
2. Do sanctuaries mean sanctuaries from noise?
3. Can shipping companies route around marine protected areas (MPAs)?

![Figure 10](image.png)

**Figure 10.** Polygons of biologically important areas, including migration, feeding, small-resident, and reproduction within the exclusive economic zone of the east coast of the US. (Source: Lee, Juliette 2022)

**Data**

- Biologically Important Areas for Cetaceans (both feeding and breeding) from the Marine Cadastre
- National Marine Sanctuary System from the Marine Cadastre
- USA Ports from ArcGIS Cloud Portal
- Cetacean sound-sensitivity data for low and high frequency populations from MDAT

To create the cost surface, Biologically Important Areas for Cetaceans (both feeding and breeding), National Marine Sanctuaries, and Cetacean sound-sensitivity data for low- and high-frequency populations were weighted by a conservation score according to table 5 and as shown in tables 6, 7, and 8. Trial-and-error was utilized to qualitatively prescribe the different data sources to best represent the most acoustically-sensitive areas.

Table 5. Qualitative prescription of cost surfaces. (Source: Lee, Juliette 2022)

<table>
<thead>
<tr>
<th>(BEST)</th>
<th>No interaction with marine mammals</th>
</tr>
</thead>
<tbody>
<tr>
<td>(OKAY)</td>
<td>Mild acoustic inference in migratory corridors</td>
</tr>
<tr>
<td>(HARMFUL)</td>
<td>Acoustic disturbance in National Marine Sanctuary System AND migratory corridor</td>
</tr>
<tr>
<td>(DANGEROUS)</td>
<td>Acoustic disturbance in Biologically Important Area</td>
</tr>
<tr>
<td>(WORST)</td>
<td>Collision risk where all three areas intersect</td>
</tr>
</tbody>
</table>

Table 6. Qualitative prescription of biologically important areas, NODATA areas were ranked highest to avoid land, followed by reproduction, then small/resident, then feeding, then migration. (Source: Lee, Juliette 2022)

<table>
<thead>
<tr>
<th>Polygon Type</th>
<th>Qualitative Prescription</th>
</tr>
</thead>
<tbody>
<tr>
<td>Migration</td>
<td>2000</td>
</tr>
<tr>
<td>Feeding</td>
<td>10000</td>
</tr>
<tr>
<td>Reproduction</td>
<td>20000</td>
</tr>
<tr>
<td>Small and Resident</td>
<td>15000</td>
</tr>
<tr>
<td>NODATA</td>
<td>50000</td>
</tr>
</tbody>
</table>
Table 7. Qualitative prescription of the National Marine Sanctuary System for the East Coast. (Source: Lee, Juliette 2022)

<table>
<thead>
<tr>
<th>Polygon Type</th>
<th>Qualitative Prescription</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanctuaries</td>
<td>100</td>
</tr>
<tr>
<td>NODATA</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 8. Qualitative prescription of the United States Exclusive Economic Zone on the East Coast, intended to ensure that the least cost path avoided a terrestrial path. (Source: Lee, Juliette 2022)

<table>
<thead>
<tr>
<th>Polygon Type</th>
<th>Qualitative Prescription</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Exclusive Economic Zone</td>
<td>1</td>
</tr>
<tr>
<td>NODATA</td>
<td>10000</td>
</tr>
</tbody>
</table>

Density surface model outputs were combined using a raster calculator to develop a marine mammal composite risk raster. This composite risk raster was utilized as the cost-surface map. Within the geoprocessing toolbox of ESRI’s ArcGIS Pro, the CostPath function was used to input the cost distance and the CostDistance function was used to generate the raster grid. The proposed routes shown in figures 11 and 12 were developed by using the Select function to choose a start and end port, from a list I generated of USA ports on the east coast.

**Resulting Action**

Utilizing the method described, the model was run and produced the least cost raster and resulting least cost path. Symbology and selected areas were chosen to exemplify how the method worked at creating a conservation-weighted composite map of biologically important areas for a proposed least-cost route for shippers from Miami, FL to Charleston, SC, resulting in the example shown in figure 11 and for shippers from Boston, MA to Charleston, SC, resulting in the example shown in figure 12.
Figure 11. Conservation-weighted composite map of biologically important areas and National Marine Sanctuaries with proposed least-cost route for shippers from Miami, FL to Charleston, SC. The least-cost route uses the conservation weighted cost surface. (Source: Lee, Juliette 2022)
I created a geoprocessing tool so that shipping companies can access these paths in a user-friendly way. This geoprocessing tool has the potential to be housed on GIS Online so that others can access and use it. The value of this simple tool, as shown in figure 13, is the user only needs to input their starting port and ending port to see a composite map of the least cost shipping path, as it relates to National Marine Sanctuaries, Biologically Important Areas, and Sound Sensitivity data. The least cost shipping path is presented by default without the additional polygons.
Discussion

By providing this simple framework for least cost routes for shippers, I exemplify how risk can be weighted for acoustically sensitive areas. This tool provides an objective assessment of the cost of travel distance versus the risk of impacting marine mammals. While this tool does provide a framework for reduced noise in certain areas, with measurable differences for marine mammals, the overall sound reduction for marine mammals would not be dramatic. Additionally, it is important to note that reduced speed was not considered but it is important to consider how speed impacts both noise and emissions. The smart shipping technology tool uses data management and visualization to organize these unique data sources into a meaningful interface. While a similar tool was produced by Best 2016 for ship strikes, there is value in considering how this may impact the soundscape within the US EEZ on the east coast. The tool facilitates thoughtful conversation about how technology can be used to overcome some of the challenges of anthropogenic ocean noise.

Moving forward, the tool should be revised to utilize data that considers marine mammal seasonality, shorter temporal scales, and that utilizes sound propagation data. In retrospect, the National Marine Sanctuary System is not the best data source for this purpose because sanctuaries are not sanctuaries for sound. The proposed northward shift in the Boston shipping lanes, shown in figure 8, actually takes the ship directly through Stellwagen Bank National
Marine Sanctuary because of the shape of the bank and the population models. The proposed northward shift into the sanctuary lessens the sound impact on marine mammals. Thus, the data used is important to ensure a measurable sound reduction. Yet, it is important to note increasing the distance between a ship and a marine mammal does not necessarily cause a reduction of sound impact on that mammal, because the location of the shelf and the bottom type can influence how the sound is propagated. Future variations of this tool should also consider using data on the location of the shelf and bottom type. Nevertheless, this tool could be used by both industry and resource managers as a prototype for how to reduce noise in marine mammal important areas.

**CONCLUSIONS**

Anthropogenic noise and its impacts on the ocean environment represent a complex of issues that expands past questions of bioacoustics and dips into questions of sectoral challenges, international comparisons, technological challenges, and regulatory transparency. From these three chapters considering practical approaches to reduce ocean noise, four key takeaways arose. First, multi-sectoral collaboration and partnerships allow stakeholders to capitalize on technological advancements in ocean quieting. Second, state-of-the art quieting technology is available and its cost must be driven down to be made accessible to all stakeholders. Third, regulators must increase transparency about the regulatory process to be more approachable and foster collaboration. Fourth, multi-sectoral collaboration and technological advancements must be used widely to tackle challenges in the ocean. I recommend utilizing these takeaways to strategically approach the application of quieting approaches globally.

Anthropogenic noise is being addressed from the east coast of the United States to international governing bodies. Nevertheless, this issue faces challenges at reaching solutions so we must consider it from different angles. Specifically, this issue pertains to private industry and regulatory interests alike so those sectors must prioritize deriving solutions together. While barriers exist for reducing ocean noise, promising opportunities exist amongst these types of multi-stakeholder collaboration and technological solutions. To realize a reduction in anthropogenic sound, unconventional solutions, such as those presented in this paper, must be
applied. As the blue economy continues to grow, we enter a critical juncture to change the trajectory of the way in which sound is produced in the ocean and the way in which we practically approach the reduction of anthropogenically produced ocean noise.

ACKNOWLEDGMENTS

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My colleagues at the Duke University Marine Lab within the Coastal Environmental Management (CEM) concentration challenged me to expand my curiosity around this topic – thank you to the CEM-cohort for allowing me to grow alongside you. Thank you to the entire Nowacek Bioacoustic and Engineering Lab for welcoming me into the ocean noise family. Thank you to my academic advisor Andrew Read, CEM Coordinator Kathleen Dunn, and CEM Co-Chairs Grant Murray and Patrick Halpin and all of the faculty at the Duke University Marine Lab for their continual guidance through this entire process. My greatest appreciation goes to my parents for their support and investment in my academic and personal development and to my older brother whose guidance has always led me down the right path.
APPENDIX

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**Team Charter**

**Juliette Lee** is a Master of Environmental Management candidate in the Nowacek Bioacoustics and Engineering Lab at Duke University’s Nicholas School of the Environment and is based at the Duke Marine Lab. She is a marine and coastal resource manager working on impact-based
environmental challenges. Her interests lie at the intersection of protected species management, ecosystem-based conservation and the “blue” economy. Juliette comes to Duke with a breadth of experiences, including tropical marine biology research, experiential teaching and marine policy. At Duke, Juliette is the co-founder and president of the Oceans@Duke Student Cabinet and a Research Assistant for two Bass Connections’ projects: “Empowering Youth Civic Action on Plastic Pollution,” utilizing unconventional storytelling methods to tell the story of plastic in Durham, NC and “Ocean Evidence Gap Maps,” synthesizing gaps in conservation interventions of coral reefs, mangroves, and seagrass.

**Dr. Douglas Nowacek** is the Randolph K. Repass and Sally-Christine Rodgers University Distinguished Professor of Conservation Technology in Environment and Engineering at Duke University and holds positions both with the Nicholas School of the Environment at the Duke Marine Lab and with the Pratt School of Engineering. He obtained his PhD from Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution and his Bachelor of Arts degree from Ohio Wesleyan University. Dr. Nowacek's research is focused on the acoustic ecology of marine animals, primarily mammals, specifically, how they use sound in ecological processes. One of his specific areas of research is the use of sound in the foraging ecology of these animals. Another focus of his current research is the effects of anthropogenic noise on marine mammals, including pioneering the Global Alliance for Managing Ocean Noise with Dr. Southall. He has published over 100 peer-reviewed scientific papers, and has given hundreds of presentations nationally and internationally to scientific, regulatory, Congressional, and general public audiences on the issue of ocean noise.

**Dr. Brandon Southall** is President and Senior Scientist for Southall Environmental Associates (SEA), Inc. based in Santa Cruz, CA, a Research Associate with the University of California, Santa Cruz (UCSC), and an Adjunct Assistant Professor at Duke University. He obtained Masters and Ph.D. degrees from UCSC, studying communication, hearing, and the effects of noise on seals and sea lions. He directed the U.S. National Oceanic and Atmospheric Administration (NOAA) Ocean Acoustics Program and has been centrally involved in developing systematic noise exposure criteria for marine mammals and the first-ever acoustic guidelines for the agency. He founded and runs SEA, a research and consulting small business
conducting and applying science to support environmental management assessments and environmentally responsible development. He has directed large-scale, multidisciplinary field research programs on behavioral responses of various marine mammals to human noise disturbance around the world for over a decade. He also serves as a technical advisor to international corporations and environmental organizations regarding the impacts of conventional and alternative offshore energy development and commercial shipping. He has published over 100 peer-reviewed scientific papers, 50 technical reports, and has given hundreds of presentations on related subjects to scientific, regulatory, Congressional, and general public audiences around the world.

Table 9. Breakdown of team responsibilities.

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Affiliation</th>
<th>Role</th>
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<tbody>
<tr>
<td>Juliette lee</td>
<td>Nowacek Bioacoustic and Engineering Lab</td>
<td>Project Lead</td>
</tr>
<tr>
<td>Douglas Nowacek, Ph.D.</td>
<td>Nowacek Bioacoustic and Engineering Lab</td>
<td>Advisor</td>
</tr>
<tr>
<td>Brandon Southall</td>
<td>Southall Environmental Associates</td>
<td>Advisor and Workshop Collaborator</td>
</tr>
<tr>
<td>Jesse Clearly</td>
<td>Marine Geospatial Ecology Lab</td>
<td>Geospatial component Collaborator</td>
</tr>
<tr>
<td>Patrick Halpin</td>
<td>Marine Geospatial Ecology Lab</td>
<td>Geospatial component Collaborator</td>
</tr>
<tr>
<td>GAMeON Sounding Board</td>
<td>multi-sectoral</td>
<td>Client</td>
</tr>
</tbody>
</table>

**GAMeON Sounding Board:**
- Doug Nowacek, Duke University
- Brandon Southall, Southall Environmental Associates
- Jill Lewandowsk, Department of Interior: Bureau of Ocean Energy Management
- Sonia Mendes, Joint Nature Conservation Committee (JNCC)
- Nadia Deckert, UN Environment Programme World Conservation Monitoring Centre
- Koen Broker, Shell Renewables
- Giulia Carbone, World Business Council for Sustainable Development
- Michael Jasny, Natural Resource Defense Council (NRDC)
- Howard Rosenbaum, Wildlife Conservation Society (WCS)
- Bastian Blonk, Sakhalin Energy Investment Company (SEIC)
- Kathy Metcalf, Chamber of Shipping of America
Workshop Participant Recruitment Invitation:
SUBJECT: GAMeON Workshop One, You’re Invited!

Dear [panelist name],

As a coordinator of the Global Alliance for Managing Ocean Noise (GAMeON) workshop series, I would like to invite you to participate as a panelist in our first quieting workshop “Practical Approaches for Reducing Ocean Noise Associated with Offshore Renewable Energy Development” on March 1, 2022, to be held via zoom webinar from 11:00 AM - 1:00 PM ET.

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. Workshop One: ‘Practical Approaches for Reducing Ocean Noise Associated with Offshore Renewable Energy Development’ intends to foster a productive setting for stakeholders across international governing bodies, industry leaders, non-governmental organizations, and academia to debate, break down barriers, and ultimately develop data-informed and technologically advanced solutions that fit within a realistic business model and continue to benefit a sustainable blue economy. The focal topics of this workshop will include (1) lessons learned for noise mitigation and management and (2) pairing noise monitoring and mitigation requirements for ongoing development in science and research. This workshop will culminate by identifying and proposing opportunities for actionable next steps.

Your expertise on [expertise/skills] would add compelling depth and context to our discussion and would contribute a unique perspective amongst a diverse group of experts. Please let me know if you are interested in participating and we can schedule a call to discuss your role in this event. Thank you for your consideration, and I look forward to hearing from you.

Best,

Juliette Lee, Brandon Southall, and Doug Nowacek

Juliette Lee (she/her/hers)
Master of Environmental Management Candidate
Coastal Environmental Management
Duke University Marine Laboratory | Nicholas School of the Environment

Informed Consent:

Introduction: This research is being conducted by Juliette Lee. I am a master’s student at the Duke Nicholas School of the Environment and am conducting a workshop as a part of my master’s project.
Purpose: I am interested in learning about your views on the barriers of multisectoral collaboration to resolve the challenge of ocean noise as it is produced by offshore renewable energy development. Additionally, I am interested in your perspective of what actions can be taken to best manage ocean noise associated with offshore renewable energy development. Lastly, I am curious about what the most promising solutions are to minimize ocean noise associated with offshore renewable energy development.

Procedures: If you agree to participate in my master’s project, I will use your responses and information shared during the discussion panel – and available on the GAMeON website – for analyses.

Risks: N/A. There are no anticipated risks associated with participating in this research.

Benefits: N/A. There are no anticipated benefits from participating in this research.

Confidentiality: I will not include your name or title in the products stemming from this research. However, I may attribute information from the workshop and the survey to your organization/company/agency in our final report. If you are uncomfortable with us using your organization/company/agency in our final report let us know and we will only attribute information from your survey to your general industry. Our report will be stored in the Duke University’s library database and will be presented to professors and students at Duke University in April 2022.

Public/Future Use: It is possible that information from this study, without identifiers that can be linked back to you, may be made public or used for future research purposes.

Voluntariness: Your decision to let me use your information in our research is voluntary.

Compensation: N/A

Questions: Please let us know if you have any questions. You can contact us by email at juliette.lee@duke.edu. For questions about your rights as a participant contact the Duke Campus Institutional Review Board at campusirb@duke.edu. Please reference Protocol ID# 2022-0380 in your email.

Statement of Consent: If you agree to participate in this research please indicate below:

I agree to participate in this research:
YES, the name of organization/company/agency can be used
NO, keep my identity confidential

Preliminary Workshop Survey Questions:

1. What barriers exist between sectors to implementing ocean quieting approaches for offshore renewable energy development?
2. What actions can be taken to best manage ocean noise associated with offshore renewable energy development?
3. What are the most promising solutions to minimize ocean noise associated with offshore renewable energy development?
4. What topic(s) do you think should be prioritized during the panel discussion? (Multiple Choice Options)
   a. Alternative macro-siting procedures
   b. Time area closures
   c. Mitigation hierarchy or other risk assessment tools
   d. Gaps in monitoring and mitigation knowledge
   e. Noise minimizing approaches during discrete phases of the development process
   f. Government actions and policy steps
   g. Engineering solutions
   h. Multi-sectoral collaboration

**Workshop Panel Questions:**

*Noise mitigation and management lessons learned*
1. What barriers exist between sectors to driving solutions?
2. What is the feasibility of alternative macro-siting procedures to reduce risk?
3. What are the pros and cons of time area closures?
4. How can the mitigation hierarchy or other risk assessment tools be applied to ocean noise?

*Pairing noise monitoring and mitigation requirements for ongoing developments of noise management*
1. Where are the gaps in our knowledge about assessing impacts?
2. How can noise be minimized during discrete phases of the development process? (leasing and area process, site assessment surveys, installation, construction, operational)

*Creating action items*
1. What government actions and policy steps should be prioritized?
2. What are the most promising engineering solutions?
3. How can multi-sectoral collaboration be harnessed?