Atlantic States Marine Fisheries Commission

Habitat Committee

Draft Agenda

Wednesday, October 23, 2024 (1:00 – 5:00 p.m.)
Thursday, October 24, 2024 (8:30 a.m. – 12:00 p.m.)

Webinar Link: *https://v.ringcentral.com/join/462557844*

The times listed are approximate; the order in which these items will be taken is subject to change; other items may be added as necessary

Wednesday, October 23

1. Welcome and Introductions *(R. Babb)* — 1:00 p.m.

2. Committee Consent *(R. Babb)* — 1:15 p.m.
   - Approval of agenda
   - Approval of Summer 2024 virtual meeting minutes

3. Habitat Hotline Atlantic (HHA) — 1:30 p.m.
   - Approve format for 2024 issue
     i. State Updates Questionnaire
   - Discuss future direction of HHA (content, audience, etc.)
     i. Audience engagement & outreach
     ii. Format, content, type of medium, etc.

Break — 3:00 p.m.

4. Reconvene — 3:15 p.m.

5. Habitat Management Series: Shell Recycling Programs *(S. Kaalstad)* — 3:20 p.m.
   - Review outline
   - Assign articles and develop timeline
   - Discuss Shell Recycling Program Survey

6. Adjourn Day 1 — 5:00 p.m.

Thursday, October 24

1. Reconvene — 8:30 a.m.
   - Habitat Management Series: Shell Recycling Programs *(continued)*

2. General Business — 9:30 a.m.
   - Updates to FMP Habitat Sections
   - Updates to Fish Habitats of Concern (FHOC)
   - Next steps

The meeting will be held at The Westin Annapolis (100 Westgate Circle, Annapolis, Maryland; 888.627.8994) and via webinar; click here for details

3. Guest Speaker: Oyster Recovery Partnership Shell Recycling Program — 10:00 a.m.
   (W. Slacum)

4. Guest Speaker: MAFMC Fishing Gear Impacts to EFH Database — 11:00 a.m.
   (D. Stevenson & T. Kentner)

5. Adjourn — 12:00 p.m.

Atlantic States Marine Fisheries Commission

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Habitat Committee Virtual Meeting Summary
July 22, 2024

ASMFC Staff: Tina Berger, Simen Kaalstad, Toni Kerns

Committee Members: Alan Bianchi (NC), **Tiffany Birge** (VA), **Dave Dippold** (PA), **Alexa Fournier** (NY), **Robert LaFrance** (CT), **Wilson Laney** (NCCF), **Paul Medders** (GA), **Mark Rousseau** (MA), **Eric Schneider** (RI), **Kent Smith** (FL), **Marek Topolski** (MD), **Kate Wilke** (TNC, Committee Vice-Chair), **Michelle Bachman** (NEFMC)

Guests: Victoria Blakey (NCCF), Erin Fleckenstein (NCCF), and proxy for Rachael Peabody

The ASMFC Habitat Committee reviewed and finalized the Habitat Management Series (HMS) document on "Anthropogenic Noise Impacts on Atlantic Fish and Fisheries." Kate Wilke and Dr. Brendan Runde led this effort, completing the document and preparing it for submission to the ISFMP Policy Board. Key decisions included removing incomplete sections, such as the Case Study and Data Gaps, and adding a direct link to the NYSERDA document for further research. Contributors will be acknowledged in a separate section rather than as authors.

The committee also discussed the outline for a new HMS document on shell recycling along the East Coast. Volunteers from various states, including Kent Smith, Russ Babb, Alexa Fournier, and others, will contribute to different sections of the outline. The draft is expected by May 2025, with collaborative writing facilitated through a shared Google document. The focus will be on the best uses for shell material, alternative substrates, and successful program guidelines.

For the 2024 Habitat Hotline (HH), the committee considered broadening its audience and modernizing the content. The proposed format includes recaps of recent activities, state updates on shell recycling, and highlights of FHOC and acoustic impacts. A timeline was set for drafting sections by October 2024, finalizing by November 2024, and distributing by December 2024.

Action items include submitting the finalized Acoustic Impacts document for ISFMP Policy Board approval, creating a Google Doc for the Shell Recycling Outline, and drafting HH sections. The next meeting will follow up on these items and discuss progress on the Shell Recycling Outline and HH content and format. The meeting concluded with consensus on these action items and plans for the next steps.

Habitat Hotline 2024: State Shell Recycling Program Questionnaire

1. Contact Information

- Name:
- Organization/Agency:
- Email:
- State:

2. Does your state have an active shell recycling program?
Please provide a brief overview of the program, including when it was established and its main goals.

3. What are the key reasons for shell recycling in your state?
Explain the primary motivations for shell recycling, such as habitat restoration, ecosystem services, scarcity of shells, or economic benefits.

4. Who manages the shell recycling program?
Describe the key organizations or agencies involved (e.g., state government, nonprofits, or private entities), and how they collaborate.

5. What are the main destinations for recycled shell?
Explain where the recycled shell is used (e.g., shoreline restoration, reef building, aquaculture) and any notable projects.

6. What challenges or obstacles does your program face?
Please mention any logistical, funding, or public participation challenges the program encounters.

7. How do you measure the success of the shell recycling program?
Provide information on how you track progress, such as the amount of shell collected or ecological impacts.

8. Are there any future plans to expand or enhance the shell recycling program?
Share any upcoming developments, such as new partnerships, expanded collection efforts, or program improvements.

Shuck & Share: 10 Years of Community and Conservation

When Shuck & Share was established in 2013, there was a significant amount of forethought that brought the program to life. The first question that needed to be answered was *"Why is there a need for this program?"* Others that followed included considerations of monetary support, supplies needed, and a strategic plan of practice that would foster a successful and sustainable program. Over 10 years later, the program has evolved into a leading source of material for habitat restoration in the Indian River Lagoon and across the state of Florida.

The Why

The base of Shuck & Share was rooted in overall sustainability – to divert oyster shell material from landfill and implement it in community restoration efforts in the Northern Indian River Lagoon and surrounding areas. The host site of Shuck & Share is at Marine Discovery Center (MDC) in New Smyrna Beach, a 501(c)(3) organization whose mission is to protect and restore Florida's coastal and Indian River Lagoon ecosystems through education, research, and community stewardship. As such, community partnerships are at the foundation of MDC programming.

Oyster shell recycling programs existed in Coastal areas of the United States and around the world, many of which were used as references for establishment and operational procedures. It was known that oyster shell material could provide substrate for larval oysters in search of place to settle, but oyster shell was typically sent to landfill once disposed of by restaurants. Phone calls and in-person visits created a network of restaurant partners that were committed to making a more environmentally conscious decision for their businesses and patrons alike. Typically, restaurants pay local waste management companies for removal services which significantly increased in cost with the weight of discarded oyster shells. Most restaurants approach the opportunity to join Shuck &

Share with relief, knowing that their operational costs would go down while having the chance to market their business as a more sustainable option for customers.

The shell was there, but who would create the demand from the restoration side of the market? From multiple perspectives, it was essential that Shuck & Share was supported by and successful because of a network of community partners. Aside from restaurants and waste management companies, collaborations were found in state agencies like Florida Fish & Wildlife Conservation Commission (FWC), local universities, and public land areas like state parks and a National Seashore. This larger network of partners would allow for a consistent structure of permitting, implementation, monitoring, and management of habitat restoration sites.

Volunteers use shovels, custom-built tubes, and buckets to fill oyster bags.

Shuck & Share and its research partners have standardized all efforts to focus on community restoration from the creation of units to the deployment of materials. Ultimately, Shuck & Share has involved over 6,630 volunteers who have committed over 15,470 hours to the program. When considering novel materials, it is essential that practices can be shifted to be volunteer-friendly for a large range of age groups. If materials can only be produced in an industrial setting or if finished products are too heavy to carry, transport, and deploy – they are not considered as a viable option for Shuck & Share. Because of volunteer efforts, there has been a significant improvement in habitat function through over 22,000 linear feet of shoreline stabilization and over 6 acres oyster reef restoration in the Northern Indian River Lagoon and other estuarine wetlands. The community aspect of Shuck & Share continues to shape the decisions that drive the future of the program, ultimately creating a ripple effect of knowledge for local residents, visitors, stakeholders, lawmakers and more.

Logistical Thinking

It was known that there would be costs associated with building the Shuck & Share program, but with a non-profit organization leading the charge this meant that funding would need to be sought from external sources. Since its inception, Shuck & Share has been financially supported by grants from groups like the Indian River Lagoon National Estuary Program and FWC. The various formats of grants have supported staff, project logistics, oyster recycling supplies, gas for transportation, and marketing materials while continuing to bolster partnerships and community involvement. It has always been imperative that program coordinators nurture our network of community partners – in all aspects of Shuck & Share.

Shuck & Share would address the issue of oyster shell disposal, but also needed to ensure that joining the program wouldn't create more work for the restaurants involved. Weekly collections are provided to each restaurant either by MDC volunteers or WastePro, a local waste management company. The volume of oyster shells that were processed each week would determine the collection format for each restaurant. For most collections, Shuck & Share provides 5-gallon buckets that have sealed lids to guarantee compliance with health safety standards. On average, these buckets hold 30 pounds of oyster shells – a number that helps program coordinators track cumulative totals. These buckets are also labeled with a Shuck & Share-branded sticker to distinguish program supplies from others and to create consistency in marketing opportunities. Restaurants that contribute over 150 pounds each week are provided with 32-gallon toters, which have capacity for 350 pounds of oyster shell material. WastePro provides weekly collection and drop-off to MDC with specialized equipment, all as an in-kind service to the program.

Restaurants are given marketing materials like window stickers and table tents so that staff and patrons can have a more comprehensive understanding of what it means to be a Shuck & Share partner. Additionally, they would receive an annual gift of gratitude along with a note of their total contributions for the year – ultimately reinforcing what a positive impact they're making in the community and the local environment. Marketing would eventually develop into a dedicated page, shuckandshare.org, which would give people the opportunity to learn about the program and even research which businesses to support based on Shuck & Share involvement. As this collection of resources grew, more organizations on Florida's coasts were interested in how to establish their own oyster shell recycling program. Though the host program started in Volusia County, Shuck & Share now reaches a total of 9 counties across the state.

Oyster shell piles marked by month to assist with tracking of the curing process.

As oyster recycling programs started to proliferate in the world of restoration and conservation, so did concerns of bacteria, diseases, parasites, and invasive species from harvest areas to restoration sites in other regions or states. Ultimately, the National Oceanic and

Atmospheric Administration established protocols to "cure" or decontaminate oyster shells for at least six months. At this point, they can be safely introduced to local waterways without posing a risk to native species and habitats.

Overcoming Challenges

Shuck & Share has shifted with changing ecosystems and an evolution in scientific understanding. This has applied to not only restoration site selection, but also materials used to transform oyster shell into living habitat. While the program has always supported experimentation of novel materials, there was a major shift from marine-grade plastic units like oyster bags and oyster mats, to non-plastic alternatives that were also biodegradable. The key in the Northern Indian River Lagoon region was to find a material that lasted 3-5 years to allow oysters to recruit and establish themselves, while also making sure that the material degraded after a self-sustaining reef was formed. For shoreline restoration, there was a shift towards double-galvanized steel mesh that is consistently implemented as crab trap material. After two years of monitoring the "soft gabions", it was recognized that the materials were starting to degrade and in some cases were completely gone. In this case, program coordinators and research partners decided to discontinue the use of gabions and instead focus on volcanoes, which are formed using jute fiber and pH-balanced cement. Though this material doesn't implement oyster shell, experimental applications continue to support Shuck & Share materials.

Top left: Naltex mesh oyster bags. Top right: double-galvanized steel "soft gabions".
Bottom: jute and cement volcano.

In oyster reef restoration, Shuck & Share had previously worked with BESE elements (Netherlands), a mat that is created by combining potato starch and other bio-starch byproducts.

Two layers of this material are fastened together to create a matrix, which is then ready for drilled oyster shells to be attached with stainless steel zip ties. These materials are more fragile for volunteers to handle in the creation and transport processes, but shell BESE mats continue to illustrate success in recruitment and growth of oysters, ultimately contributing ecological services to local habitats.

BESE elements oyster mats deployed at oyster reef restoration site.

Aside from the continuous advancement in restoration materials, there are also challenges in the community aspect of Shuck & Share. Like many things in the world, the COVID-19 pandemic drastically changed how Shuck & Share was able to operate. Restaurants temporarily or permanently closed and if re-opened, were decreasing interstate seafood purchases – ultimately decreasing the number of oysters that were being sold each week. Community and research partners also altered operations to ensure the safety of staff and volunteers, which reduced field work opportunities. As restrictions lifted, the Shuck & Share remained intentional about protocols to maintain enduring success.

Grand Total:	1,096,034
2023-2024	136,560.0
2022-2023	141,625.0
2021-2022	123,300.0
2020-2021	90,734.0
2019-2020	97,832.5
2018-2019	107,306.0
2017-2018	118,085.0
2016-2017	120,901.0
2015-2016	107,954.0
2014-2015	51,736.0

Even with challenges, Shuck & Share has continued to thrive as an oyster recycling program that contributes to community restoration practices. After 10 years and one million pounds, this program has proven that people can make a difference in the health of local habitats – one oyster at a time.

ASMFC Habitat Management Series – Shell Recycling – Practices and Management Strategies:

Table of Contents

I. Executive Summary

- Brief overview of the importance of oyster shell recycling for habitat restoration and ecosystem health.

II. Acknowledgements

- Recognition of partners and contributors to the development of shell recycling programs.

III. Preface

- Introduction to the Atlantic States Marine Fisheries Commission (Commission) and its role in fisheries conservation.
- *"The Atlantic States Marine Fisheries Commission (Commission) was formed in 1942 as a means to conserve and enhance interjurisdictional fisheries of the Atlantic coast. The Commission and its 15 member states…"*

IV. Introduction/Background

- Explanation of the significance of shell recycling.
- Overview of the reasons for recycling shell, including scarcity, habitat restoration, ecosystem services, and economic benefits.

V. Why Recycle Shell?

- Scarcity and/or competition for other uses

VI. Who is Recycling Shell?

- Case studies and examples from states with successful shell recycling programs (with links).

VII. Considerations - Building a Successful Shell Recycling Program

- Discussion of program practices and elements for successful shell recycling programs.

VIII. Program Practices & Elements (i.e., BMP-type guidance)

- Breakdown of the key components of a successful shell recycling program, including
  - Defining goals / purpose for your program
  - Shell destination considerations (where is it going?)
    - What type of restoration?
      - Shell bags for living shorelines
      - Shell for on-bottom reef enhancement

        - Resource agency input
        - Permits required for restoration (incl. links to state guidance & resources)
    - Storage area requirements
        - Permitting (links to pertinent state permits and contacts)
        - State/federal permits? (Feds consider shell = fill)
        - Solid/food waste considerations
        - Condition of your shell
        - Local state health rules may apply (solid waste?)
        - Odor
        - Attractive nuisance for animals, etc.
        - Good neighbor considerations
            - Odors
            - Noise
            - Pests
    - Curing and staging
        - Disease considerations (*Dermo* – 6 mo. minimum curing recommendation)
            - Refer to Bushek et al. Citation to build this section
        - Distance from water?
        - Spreading vs. piles (How can you achieve most efficient curing process?)
        - Seasonality of curing (Is it less effective during winter?)
        - Trash minimization
    - Access to Sites
        - Minimize handling for staging and restoration work (saves $)
    - Operational, equipment, and maintenance considerations
        - Examples of best equipment types, etc.
    - Record Keeping
        - Tracking collections/volumes of shell
        - Valuation of shell
        - Novel tax incentive approaches to encourage shell recycling

- Education
    - Links to resources for education and awareness
    - Practitioners educating the public as to why shell recycling is important

IX. Practices/Elements

- Program-level format
- Blank Program-level BMP Template
- Completed Example of a Program-level BMP
  - Concept is to create fillable pdfs to guide practitioners through the various elements that they should be considering (items above) as they begin to develop a shell recycling program.

X. Literature Cited and Additional References

- List of sources and references used in the document.

XI. Appendix I: Points of Contact Responsible for State, Regional, and NGO Shell Recycling Programs

- Contact information for individuals and organizations involved in oyster shell recycling programs.

Atlantic States Marine Fisheries Commission
Habitat Management Series #17
Fall 2024

Anthropogenic Noise Impacts on Atlantic Fish and Fisheries:
Implications for Managers and Long-Term Productivity

Enhancing, preserving, and protecting Atlantic diadromous, estuarine, and coastal fish habitats

Atlantic States Marine Fisheries Commission
Habitat Management Series #17
Fall 2024

Anthropogenic Noise Impacts on Atlantic Fish and Fisheries:

Implications for Managers and Long-Term Productivity

prepared by the
ASMFC Habitat Committee

Approved by the ISFMP Policy Board
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A report of the Atlantic States Marine Fisheries Commission pursuant to
U.S. Fish & Wildlife Service Grant No. F19AF00174

Cover Photo Credit: Jxxxxxxxxxxxxxxxx

Anthropogenic Noise Impacts on Atlantic Fish and Fisheries

Table of Contents

Top: Drone footage of rack and bag grow-out structures at Bay Ridge Oyster Farm, Cape May, New Jersey. Photo credit: Ned Gaine, Bay Ridge Oyster Company.

Center: Cage-cultured oysters being processed aboard FV Stormy Bay, Delaware Bay, NJ. Photo credit: Jay Rutkowski, Atlantic Capes Fisheries.

Bottom: Exposed oyster racks as the tide recedes. Photo credit: Jay Rutkowski, Atlantic Capes Fisheries.

ACKNOWLEDGEMENTS

Major contributions from R. Grant Gilmore, Jr., Michelle Bachman, Kate M. Wilke, Jessica Coakley, and Claire Enterline.

Edited by Brendan J. Runde

OBJECTIVE AND INTRODUCTION

Objective

Many types of human-generated noise impact coastal and marine fishes through disruption of physiological processes and interruption of auditory communication. In turn, fish health and behavior can be affected. These impacts might be short-term or long-term and can lead to changes in spawning aggregations, habitat use, reproductive success, and mortality. The purpose of this report is to summarize the importance of the impacts of anthropogenic noise to fishes managed by the Atlantic States Marine Fisheries Commission.

While there is vast literature on the production and use of sound by marine mammals, including the effects of human-generated sound on these taxa, this is beyond the scope of this report, given ASMFC's fisheries management focus.

Top: Shellfish seed are grown in nurseries before they are moved to aquaculture leases for further growout. Photo credit: Florida Department of Agriculture and Consumer Services.

Center: Floating oyster cages. Photo credit: Andrew Button, Virginia Marine Resources Commission.

Bottom: Floating bags are a common gear type for growing oysters in the water column in Florida. Photo credit: Florida Department of Agriculture and Consumer Services.

Introduction

The oceans are full of both natural and anthropogenic sounds. The auditory system is the most important sensory system for many aquatic organisms, including most fishes (Au and Hastings, 2008; Richardson et al., 2013; Staaterman et al., 2014, 2013; Stocker, 2002; Tavolga, 1980, 1960). Because water is denser and more viscous than air, the propagation of light and the diffusion of chemicals in water are both severely inhibited. In contrast, sound can move over four times faster and travel farther with less transmission loss underwater than it can through the air (Rogers and Cox, 1988; Ward, 2015).

Many human activities occurring in coastal and marine habitats add noise to the natural soundscape, and these noises affect aquatic organisms and their interactions with one another (Duarte et al., 2021). For example, as rates of sound production correlate to rates of spawning and reproductive success, any disruptions to the effective communication range for fish and invertebrate species has the potential to reduce reproductive output and recruitment.

This report aims to provide general information about the importance of sound to marine species, the impacts that anthropogenic noise can have on marine species, and the characteristics of natural sounds and anthropogenic noise. This document also describes mitigation measures for certain human-induced noise. Finally, the report provides references to a list of data gaps and research needs to improve our understanding of the impact of noise on marine organisms, including fish.

The Natural Soundscape and Its Importance to Fishes

The natural soundscape of the ocean environment includes abiotic activity such as tectonic activity, sea surface agitation, and sea ice activity. These sounds range from <10 Hz to >150,000 Hz with varying intensities and intermittency. Ocean waves and tectonic activity produce constant low frequency noises of a moderate intensity, while dramatic seismic events, such as earthquakes or volcanic eruptions, and glacier calving produce relatively short bursts of very loud sounds. Weather, such as precipitation or high wind speeds, contributes to surface agitation causing increased abundance of 100-10,000 Hz noise (Martin et al., 2014; Nowacek et al., 2007; Peng et al., 2015). Sea surface agitation results in secondary sources of noise such as bubbles or spray.

Some fishes and other marine animals produce sound intentionally as part of their communication, reproduction, predator avoidance, foraging, or navigation and orientation (Peng et al., 2015), as well as unintentionally while they move, forage, and release gas (Fine and Parmentier, 2015). Field and laboratory studies of fish physiology and behavior indicate that sound is a preferred sensory mechanism to detect predators or prey, find suitable habitat, orient, migrate, communicate, attract mates, and coordinate spawning (Putland et al., 2018). Not only do many species use sound to locate reproductive partners or indicate reproductive intent (Bass et al., 1997; Lamml and Kramer, 2005; Maruska and Mensinger, 2009; Montie et al., 2017), but some species, like the Pacific marine toadfish, *Porichthys notatus*, become more sensitive to certain frequencies of their counterpart's sounds during periods of reproductive availability (Maruska et al., 2012; Sisneros, 2009). Rates of sound production correlate to rates of spawning and reproductive success. Territorial species use aggressive, threatening calls to delineate an individual's territory and intimidate or deter competitors or predators (Ladich, 1997; Maruska and Mensinger, 2009; Vester et al., 2004). Other uses of sound include navigation and orientation, especially for planktonic larval stages of fishes and invertebrates (Radford et al., 2011; Vermeij et al., 2010), avoidance of predators (Hughes et al., 2014; Remage-Healey et al., 2006), communication (Buscaino et al., 2012; Janik, 2014; Van Oosterom et al., 2016), and the determination of suitable habitats for settlement (Simpson et al., 2004).

Soniferous fishes managed by the ASMFC include most prominently members of the family Sciaenidae (e.g., Atlantic croaker, *Micropogonias undulatus*; red drum, *Sciaenops ocellatus;* and spotted seatrout, *Cynoscion nebulosus*). However, evidence also exists of sound production from members of Clupeidae (e.g., Atlantic menhaden, *Brevoortia tyrannus* and other shads and herrings), Acipenseridae (e.g., Atlantic sturgeon, *Acipenser oxyrhincus*), Moronidae (e.g., striped bass, *Morone saxatilis*), Serranidae (e.g., black sea bass, *Centropristis striata*), Pomatomidae (e.g., bluefish, *Pomatomus saltatrix*), and more (Fish et al., 1952; Fish and Mowbray, 1970; Johnston and Phillips, 2003; Rice et al., 2022; Wilson et al., 2004).

Crew of the FV Stormy Bay tending subtidal oyster cage in Delaware Bay, NJ. Photo credit: Jay Rutkowski, Atlantic Capes Fisheries.

Sources of Anthropogenic Noise in the Oceans

Noise generated from human activities covers the full frequency of sound energies used by marine fishes (Duarte et al., 2021). The contribution of human noise to the ocean soundscape has increased over time as activities such as shipping, mineral and oil mining, and coastal construction have grown in scale (Pijanowski et al., 2011). Novel and emerging human activities, such as offshore aquaculture and renewable energy development, also produce noise during construction, operation, maintenance, and eventual decommissioning.

Anthropogenic sources of ocean noise are acute (episodic) and chronic (ongoing or continuous). Both types may occur within estuaries, on the continental shelf, or in open-ocean regions. Acute sources include construction activities such as pile driving, dredging, cable laying, bridge removal, and seismic surveys. Chronic sources include vessel traffic (i.e., commercial and recreational boating and shipping activities) and energy production (e.g., operation of wind turbine generators, or oil and gas extraction).

Figure 1 from Duarte et al. (2021) shows the duration and spatial scale of both natural sounds and anthropogenic noise in the ocean. It also compares the frequencies of marine animal sound production and hearing ranges with anthropogenic noise sources. These visual displays demonstrate that the scale, frequency, and extent of anthropogenic noise overlaps with the activity of marine animals' behavior in different ways.

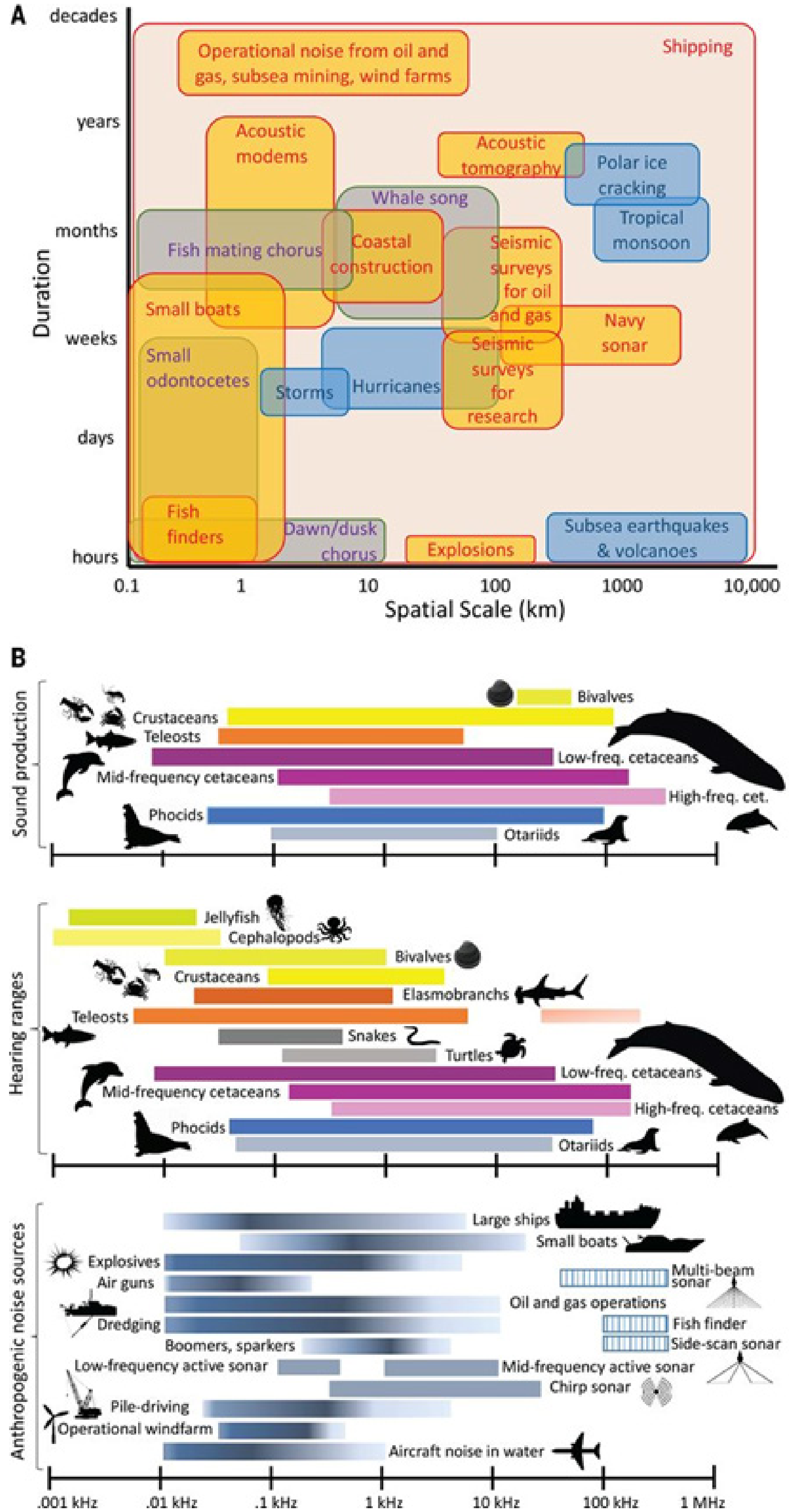

*Figure 1 (from Duarte et al 2021). Caption reproduced verbatim. **(A)** Stommel diagram showing the spatial extent and duration of selected biophony (rounded gray squares), geophony (rounded blue squares), and anthrophony (rounded yellow squares) events. Events (rounded squares) reflect the spatial and temporal period over which* *signals or bouts of signals typically occur. Although some sound sources, such as those used in hydrographic surveys, do not propagate particularly far, survey efforts can cover a large spatial extent (an entire Exclusive Economic Zone). "Dawn/dusk chorus" refers to the daily sounds produced by a collection of species (e.g., fish, snapping shrimp). Shipping noise encompasses the full range of spatial and temporal scales.* ***(B)*** *Approximate sound production and hearing ranges of marine taxa and frequency ranges of selected anthropogenic sound sources. These ranges represent the acoustic energy over the dominant frequency range of the sound source, and color shading roughly corresponds to the dominant energy band of each source. Dashed lines represent sonars to depict the multifrequency nature of these sounds.*

VESSEL ACTIVITY

Watercraft of all kinds produce undersea noise and are the most common sources of anthropogenic noise in coastal waters (Stocker, 2002). These sources of noise can be amplified due to surface and seafloor reflections as well as scattering and reverberating because of the geography and geology of the submerged shoreline and bottom. Many watercraft generate low-frequency sound from propeller action, propulsion machinery, generators, and water flow over the hull (Hildebrand, 2005). The sounds generated from a large container vessel can exceed 190 decibels (dB) at the source (Jasny, 1999). Metropolitan areas and ports contain a diverse array of watercraft which constitute the dominant human-derived soundscape: commercial and private fishing boats, recreational watercraft, industrial vessels, public transport ferries, military craft, personal watercraft, and others. Significant underwater sound production can also be generated from bridge automobile traffic, particularly during peak traffic periods.

Additionally, most vessels have sonar systems for navigation, depth sounding, and "fish finding" that may cause acute or episodic noise disturbance. Some commercial fishing boats also deploy various acoustic deterrent devices to prevent negative interactions with dolphins, seals, and turtles (Stocker, 2002). There is little information on the effects of acoustic deterrent devices on fish, however.

Rack and bag oyster culture. Photo credit: Jay Rutkowski, Atlantic Capes Fisheries.

GEOLOGICAL AND GEOPHYSICAL SURVEYS

Geological and geophysical (G&G) surveys are performed to gather information about the seafloor including bathymetry, surficial sediment, sub-surface sediment, and the topology of an area. These surveys are performed for a multitude of uses including resource extraction and wind power siting. Not all G&G surveys produce noise that is known to be within the hearing range of marine animals.

Sonar systems are used for a wide variety of civilian and military operations. Active sonar systems send sound energy into the water column. Sonar systems can be classified into low (<1,000 Hz), mid (1,000 – 20,000 Hz), and high frequency (>20,000 Hz). Low and mid frequency systems emit sound that overlaps with the acoustic detection of many marine animals. Sub-bottom profilers are a type of high-resolution seismic system that produce imaging of the seafloor's sub-surface. These can be shallow penetration (2–20 m) or deep penetration systems and operate at a wide range of frequencies (400 – 24,000 Hz) and produce varying levels of peak sound (212- 250 dB; (Mooney et al., 2020)). Seismic air guns are used for a deeper penetration of acoustic

Commercial aquaculture bottom gear (cages) used for culturing oysters in South Carolina. Photo credit: South Carolina Department of Natural Resources.

sound into the seafloor and are used primarily for oil and gas exploration and siting of offshore cables. Air guns generally produce sound at 200-210dB at a range below 100 Hz. While morbidity of fish and other animals has not been associated with air gun exposure, changes in behavior have been observed. Following exposure in a laboratory setting, American lobster, *Homarus americanus*, changed their feeding levels, and physiological changes were also measured (Payne et al., 2007).

Studies investigating the effect of full-scale G&G surveys on wild fish populations have shown effects in some cases. Atlantic herring, *Clupea harengus,* schools in the wild were not observed to change their swimming speed, swimming direction, or school size during exposure to a full-scale seismic survey (Peña et al., 2013). However, other studies have found that trawl and long-line fish catches during full-scale G&G surveys decreased within the area of the seismic survey and at ranges of up to 33 km (Engås et al., 1996). When catch rates and behavior were observed to change during seismic surveys, fish were observed to return to the site of the survey within hours or days after the survey completion (Løkkeborg et al., 2012).

High frequency sonar telemetry is associated with vessel positioning, locating, steering, and remotely operated vessel control. Ultrasonic frequencies (generally 200,000 - 400,000 Hz), also known as multibeam echosounders, are used for sonar mapping. Multibeam echosounder surveys collect bathymetry and seafloor hardness information used for nautical chart updates, benthic habitat characterizations, fisheries habitat modeling, and surficial sediment analysis. These ultrasonic frequencies are generally outside of the known range of acoustic detection by marine animals.

RENEWABLE ENERGY CONSTRUCTION & OPERATION

Renewable energy is a growing segment of the United States' electrical generation portfolio as we attempt to combat climate change and become more energy secure (Chow et al., 2003; Dincer, 1999; Pimentel et al., 2002; Valentine, 2011). While the nation's renewable energy portfolio has to date been mainly composed of land-based technologies, coastal and marine energy sources in the form of tides, currents, waves, and especially offshore wind have the potential to provide a large amount of energy to the future power grid (Pelc and Fujita, 2002). These energy sources are not without impacts to marine fish welfare, movements, and behavior. The impacts of offshore wind development on the marine environment have been widely discussed in recent years, and monitoring of wind farms in Europe has generated some knowledge about long-term effects (e.g., Gimpel et al., 2023; Stenberg et al., 2015), from which we along the U.S. Atlantic coast can learn. Along the U.S. Atlantic only a handful of projects are built or currently under construction, although many more have been or will soon be permitted. The effects of offshore wind farms on this ecosystem are just beginning to be examined, thus it is likely we will learn more as construction continues and additional projects enter the operational phase. The impact of noise produced by wind farms can occur during construction, operation, maintenance, and decommissioning.

Of the studies performed to assess these impacts, construction noise, specifically pile driving, has produced high levels of sound pressure and acoustic particle motion in the water column and seabed (Nedwell and Howell, 2004; Thomsen et al., 2006; Tougaard et al., 2012). During pile driving for offshore wind construction, the broadband peak sound pressure level has been measured at 189 dB at 400 m and a modeled level of 228 dB at 1m with a dominant frequency of 315 Hz, however these levels depend on the size of the piles (Thomsen et al., 2006; Tougaard et al., 2012). These noise levels are within the perception ranges of Atlantic cod, *Gadus morhua*; dab *Limanda limanda*, Atlantic salmon, *Salmo salar;* and Atlantic herring, *Clupea harengus* (Thomsen et al., 2006). Documented behavioral reactions in Atlantic cod and sole *Solea solea* were observed up to tens of kilometers from the source (Andersson, 2011).

Planned wind turbine generator capacities are increasing, which will require ever larger pile sizes. Alternative foundation types such as gravity based or suction buckets reduce installation noise substantially, but these are less commonly proposed for U.S. east coast projects. To date, most offshore wind installations worldwide have used fixed turbines. Floating offshore wind technology, which will have substantially reduced installation noise and is required for deeper waters, is in its nascent stages (although sites that would require floating technology have been leased along the U.S. west coast) and thus little is known about differences in operational noise between floating and fixed turbines. There is some evidence that jacketing monopile turbines reduces the chronic noise from operation (Thomsen et al., 2015), however to date, actual noise levels emitted by floating platforms has not been documented. As this technology advances, there is a need to determine the noise levels and frequencies which different floating platform types emit and at what distances.

Photo credit: Andrew Button, Virginia Marine Resources Commission. Aquaculture leases in Florida are used for the production of clams, oysters and live rock. Photo credit: Florida Department of Agriculture and Consumer Services.

Operational noise at offshore wind farms includes sound produced by both the turbines (Tougaard et al., 2020) and increased vessel traffic (Nedwell and Howell, 2004). Underwater sound produced by turbine operation is generated by the moving mechanical parts within the nacelle (i.e., turbine housing) as well as possible wind-induced vibration of the tower (Tougaard et al. 2020). Operational noise of a 1.5MW turbine (at 110m distance) has been measured between 120 – 142 dB with dominant frequencies at 50, 160, and 200 Hz at wind speeds of 12 m/s (Thomsen et al., 2006). Distance from the noise source, wind speed, and turbine size all impact noise levels measured during turbine operation (Tougaard et al. 2020). Also, vessel noise in the Tougaard et al. (2020) analysis was louder than that of turbines, but distance from the noise source varied as did turbine size (max turbine size was 6MW). Noise produced during wind turbine operation was found to be detectable at a distance of several kilometers by fishes sensitive to sound pressure, however species sensitive to motion (as opposed to pressure) were found to be affected within only tens of meters (Andersson, 2011). It is estimated that operational noise of wind turbines is within the perception range of Atlantic cod and herring up to a distance of approximately 4 km, while for dab and Atlantic salmon up to 1 km (Thomsen et al., 2006).

OIL, GAS, AND MINERAL EXTRACTION

Some of the loudest anthropogenic noises are generated by marine extraction industries such as oil drilling and mineral mining (Stocker, 2002). The most common source of sounds is from air guns used to create and read seismic disturbances (Hawkins and Popper, 2016; Popper et al., 2014, 2005; Popper and Hastings, 2009). Air guns are used to generate and direct huge impact noises into the ocean substrate. The sound pressure wave created aids in reflection profiling of underlying substrates for oil and gas exploration. Peak source sound levels typically are 250-255 dB. Following the exploration stage; drilling, coring, and dredging are performed during extraction.

Resource extraction in marine waters produces chronic noise disturbance including from vessel noise (the impacts of vessel noise are described above); noise is also produced by the operation of extraction machinery, depending on platform type. Spence (2007) reviewed research on noise generated by oil and gas extraction found that fixed platforms had lower underwater radiated noise levels than floating platforms, and gravel islands appear to have the lowest source levels of any oil and gas industry activity. Semisubmersible platforms were found to generate the most underwater noise, which was highest when thrusters were operating and drilling was occurring. Levels were measured at 20-50+ dB in the frequency range of 20 – 1000 Hz during drilling operations, with the dominant frequencies at 130, 200, 350, and 600 Hz (Spence, 2007). On all platform types, noise from large power generation equipment is likely to be a dominant cause of underwater noise, for example from the operation of turbines, compressors, and large pumps (e.g., mud pumps). This noise is thought to be more significant when equipment is hard mounted directly to the platform (Spence, 2007).

COASTAL AND MARINE CONSTRUCTION

Inshore industrial and construction activities drastically alter the aquatic soundscape and have caused documented mortality and severe behavioral change in fishes and other marine animals. Underwater blasting with explosives is sometimes used for dredging new navigation channels in rocky substrates, decommissioning and removing bridge structures and dams, and construction of new in-water structures such as gas and oil pipelines, bridges, and dams. The potential for injury and death to fish from underwater explosives has been well-documented (Hubbs and Rechnitzer, 1952; Keevin et al., 1999; Linton et al., 1985; Teleki and Chamberlain, 1978). Moreover, some construction (including that related to offshore wind) requires pile driving. This typically occurs at frequencies below 1000 Hz, and has been documented to cause negative or disruptive physiological and behavioral effects on fish (Mueller-Blenkle et al., 2010), including Atlantic cod (Thomsen et al., 2012) and sturgeons (Popper and Calfee, 2023).

Transferring fish from an in-tank grader to a small grader. Photo credit: Dr. Wade Watanabe, University of North Carolina at Wilmington.

Impacts of Anthropogenic Noise on Fishes

Sound energy is transmitted through both sound pressure and water particle motion. Thus, to understand whether and how noises are likely to impact fishes, it is necessary to understand their sensitivity to both sound pressure and particle motion. Fishes have very complex and diverse interactions with sound and how they perceive it. Hearing systems and capabilities vary based on anatomy, including presence of a swim bladder or other gas-filled organs and position relative to the inner ear, as well as other factors (Popper and Hawkins, 2018). Sensitivity varies by species and among larval, juvenile, and adult stages (Wright et al., 2010). Many species have the same hearing frequency sensitivity that humans do (10 to 20,000 Hz; (Fay, 2009; Fine, 1977a; Popper and Fay, 2011; Popper and Hastings, 2009; Tavolga, 1960, 1980), and most fish produce sounds below 200,000 Hz (Fay, 2009; Fine, 1977a; Tavolga, 1960, 1980). Sound frequencies below 100,000 Hz scatter and dissipate least, travel farthest underwater (Au and Hastings, 2008; Popper and Fay, 2011; Wenz, 1962), and are used for communication among fishes (Au and Hastings, 2008; Bass et al., 1997; Popper and Fay, 2011). Certain groups of fish, such as *Clupeidae* (herrings, shad, sardines, and menhaden), can detect ultrasound frequencies above 100,000 Hz (Fine, 1977b; Mann et al., 2001, 1997; Narins et al., 2013; Nestler et al., 1992), however the strongest response has been documented at 40,000 Hz (Wilson et al., 2009).

The frequency at which different species perceive sound is highly variable (Monczak et al., 2017), however for most fishes, sound production and habitat soundscape acoustic signatures are at frequencies below 5,000 Hz (Fish and Mowbray, 1970; Myrberg and Fuiman, 2002). For example, black drum (*Pogonias cromis*) were found to have the highest neurological response to sounds at 82, 166, and 249 Hz (Monczak et al., 2017). This is also the range of frequencies where underwater sound propagates best. Most human-generated chronic noise is below 5,000 Hz (Au and Hastings, 2008; Richardson et al., 2013), which is of concern as fish are very sensitive to intense sounds below 1,000 Hz.

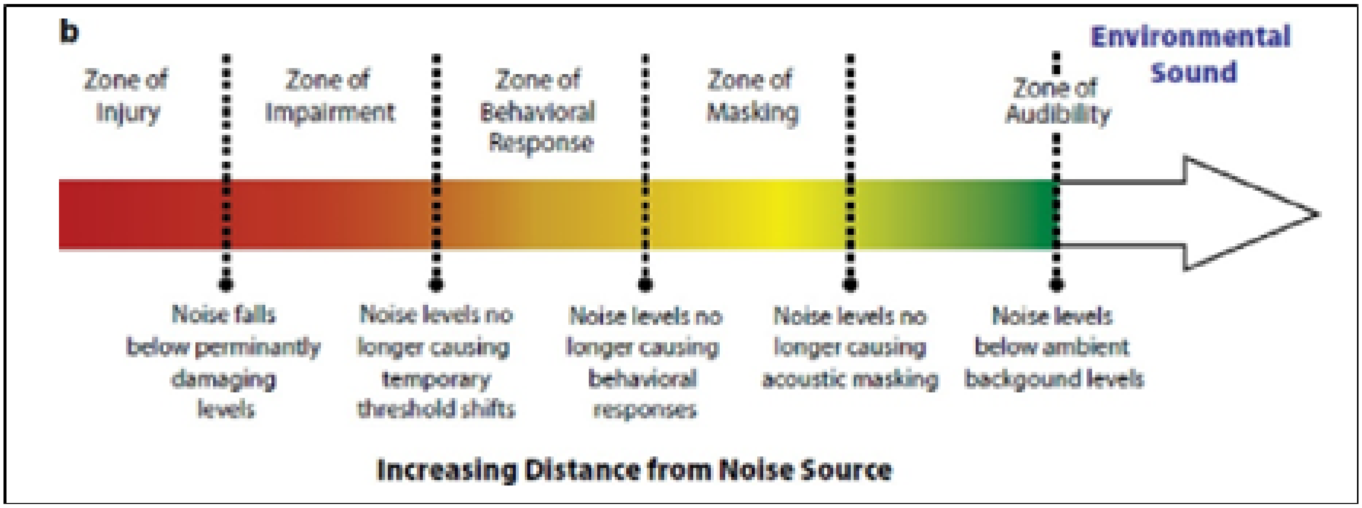

Figure 2. The potential effects of noise with distance from source. Generally, noise and impact on individual animals may be greater closer to the source. Effects change with increasing distance from the source because acoustic signals change, for example decreased dB. Figure from Mooney et al. 2012, modified from Dooling and Blumenrath (2013).

PARTICLE MOTION VERSUS SOUND PRESSURE

Although there is growing evidence that fish and invertebrates are sensitive to the particle motion caused by underwater noise (Casper and Popper, 2010; Hawkins and Popper, 2017; Mooney et al., 2020, p. 201; Mueller-Blenkle et al., 2010; Nedelec et al., 2016; Popper and Hawkins, 2018; Solé et al., 2017), particle motion itself is technically challenging to measure. This difficulty has led to poor assessments of the impacts of particle motion on fish and invertebrates (Popper and Hawkins, 2018). There is more information and research on effects of sound pressure in bony fishes and to a lesser extent invertebrates. As such, much of the information below describes the impact of sound pressure.

PHYSIOLOGICAL EFFECTS

Physiological impacts of sound to fish include damage to ear, nerve, and lateral line tissue that can lead to sound sensing loss or threshold shifts in hearing (Hastings and Popper, 2005; Heathershaw et al., 2001; Jasny, 1999). Threshold shifts result from exposure to low levels of sound for a relatively long period of time or high levels of sound for shorter periods, which may be temporary or permanent. Recovery from threshold shifts appears to require more time for fish species that vocalize (Amoser and Ladich, 2003). Threshold shifts can impact a fish's ability to carry out its life functions. Any organ with a markedly different density than seawater (e.g., swim bladder) may be susceptible to pressure-related impacts. Some of the resulting effects on fish include rupturing of organs and death (Hastings and Popper, 2005).

Near field (close proximity) percussion events produced by pile driving and explosions can have a lethal impact on fish through particle motion and sound wave compression. However, the distance from the disturbance and environmental setting (water density, turbulence, etc.) undoubtedly has major influences on potential physiological effects from particle motion and need further study before they can be treated in detail (Keevin et al., 1999; Thomsen et al., 2015). The lethality of underwater blasts on fish is dependent upon the intensity of the explosion; however, a number of other variables may play an important role including the size, shape, species, and orientation of the organism to the shock wave; the amount, type, and detonation depth of explosive; water depth; and bottom type (Linton et al., 1985).

Fish with swim bladders are the most susceptible to underwater blasts due to the effects of rapid changes in hydrostatic pressures on this gas-filled organ. The kidney, liver, spleen, and sinus structures are other organs typically injured after underwater blasts (Linton et al., 1985). Smaller fish are more likely to be impacted by the shock wave of underwater blasts than are larger fish, and eggs and embryos tend to be particularly sensitive (Wright and Hopky, 1998). However, early fish larvae tend to be less sensitive to blasts than eggs or post-larval fish, probably because the larval stages do not yet possess swim bladders (Wright and Hopky, 1998). Cephalopods can experience significant trauma to their statocysts, structures necessary for balance and position, at cellular and subcellular levels (André et al., 2011). Additionally, playback of seismic air gun recordings induced delayed development and malformation of New Zealand scallop larvae (De Soto et al., 2013).

Effect of anthropogenic noise on zooplankton is a relatively recent topic of interest, tangential to the main subject of the paper but relevant as physiological impacts to zooplankton indirectly affect fishes since many species feed on zooplankton. Abundance of dead larval and adult zooplankton increases two to threefold within one hour after passage of an active seismic air gun; elevated mortality extended at least 1.2 km from the air gun signal (McCauley et al., 2017). Simulations based on these findings estimate a 22% reduction of zooplankton population within the survey area and declining to 14% within 15 km and 2% within 150 km (Richardson et al., 2017, p. 201). In contrast, the copepod, *Calanus finmarchicus*, was only negatively affected when in close proximity (≤ 10 m) to an active seismic air gun (Fields et al., 2019).

Anthropogenic noise that falsely trigger fish responses may cause animals to expend energy without benefit (Stocker, 2002). Masking biologically significant sounds may compromise feeding, spawning, community bonding, and schooling synchronization. For species in which males broadcast calls to attract females to a spawning location (e.g., oyster toadfish, *Opsanus tau*; silver perch, *Bairdiella chrysoura*; black drum, *Pogonias cromis;* spotted seatrout, *Cynoscion nebulosus*; red drum, *Sciaenops ocellatus*), masking of these acoustic signals by noise may interfere with reproduction (Smott et al., 2018). Further, the effect of noise on each of these behaviors is compounded when considering that the behaviors are inter-related; for example, a change in the ability or desire to feed compounded with reduced communication may lead to a more severe reduction in spawning success.

Behavioral response of fishes to noise is varied and dependent on the species sound perception and the characteristics of the source of noise. While not a comprehensive list, the following provide some examples of behavioral responses.

- When exposed to noise from piling installation, Atlantic cod initially responded by freezing in place. Following the initial onset of noise, Atlantic cod and sole increased swimming speed for the duration of the piling installation activity. In contrast, other fish species appeared to habituate to the repetitive noise (Andersson, 2011).

- Elasmobranch species that are more active swimmers appear to be more sensitive to sound than more sedentary species. Elasmobranchs have been shown to be sound curious, often seeking out the source. Sudden noises that are ~20-30 dB above ambient sound can induce a startle response, but habituation over time has been known to occur (Casper and Popper, 2010).

- Turbine and tidal turbine noise can obscure sounds associated with mudflats resulting in delayed metamorphosis of estuarine crabs (Carroll et al., 2017).

- Increased ambient noise created by watercraft activity potentially reduces the ability of marine organisms, particularly larval forms, to receive the appropriate sound cues to settle in critical habitats (Hastings and Popper, 2005; Holles et al., 2013; Jasny, 1999; Lillis et al., 2016; Scholik and Yan, 2002; Simpson et al., 2016; Staaterman et al., 2014; Stanley et al., 2012).

CUMULATIVE EFFECTS

The most chronic and pervasive impacts on regional fish stocks occur when human generated sounds cause behavioral changes that affect critical life history activities required to maintain healthy populations. Several studies have indicated that increased background noise and sudden increases in sound pressure can lead to elevated levels of stress in many fish species (Hastings and Popper, 2005). Chronic noise levels ≥123 dB can elicit physiological (weight loss, decreased condition, and elevated and variable heterophil:lymphocyte ratio), behavioral (increased piping and tail adjustments and reduced stationarity), and vocal (increased clicking) stress responses in the lined seahorse, *Hippocampus erectus* (Andersson, 2011). Similarly, Southern Australia scallops, *Pecten fumatus,* exposed to seismic air gun signals resulted in altered physiology (hemolymph biochemistry) and behavior (development of a flinch response and increased recessing reflex) which intensified with repeated exposure (Day et al., 2017).

These examples, as well as others described in this report, demonstrate that noise impacts key life events (e.g., foraging, navigation, and spawning) in many species. This can produce cumulative impacts at many scales. For instance, individual animals that experience repeat exposure to acute noise impacts or experience chronic noise are most likely to have cumulative physiological impacts that reduce their individual fitness. Yet, population level impacts may occur if the acute or chronic noise impacts spawning aggregations or behavior over multiple occasions or locations. Either of these scenarios could lead to population level effects over time if, for example, spawning success or aggregations are interrupted. Examining these cumulative impacts at a range of scales is a priority for future research, especially as sound-producing ocean uses – including offshore wind construction – continue to intensify.

EFFECTS ON BIOGENIC HABITATS

Alteration of the soundscape has the potential to impact biogenic fish habitats. Eastern oyster, *Crassostrea virginica,* larval settlement increased in the presence of oyster reef habitat sounds (Lillis et al., 2013). In response to sediment vibrations, blue mussel, *Mytilus edulis* respiration rates decreased resulting in altered valve gape, oxygen demand, and waste removal (Roberts et al., 2015). Unlike shellfish, Scleractinian corals appear resistant to soft tissue and skeletal damage after repeated exposure to a 3D seismic survey (Heyward et al., 2018). Seagrass meadows, which provide not only a structural habitat for species to forage and avoid predators, but also act as an acoustic refuge for prey species including fishes by attenuating high frequency sounds (100,000 Hz) such as those used by bottlenose dolphin, *Tursiops truncatus* (Wilson et al., 2013), may be impacted by noise. Submerged aquatic vegetation exposed to low frequency sounds (50-400 Hz at 157 ± 5 dB re 1 μPa^2) can develop physical damage to root and rhizome cellular structures, specifically amyloplasts responsible for starch production and storage, gravity sensing, and vibration reception (Solé et al., 2021).

EFFECTS ON FISHERIES CATCH RATES

Anthropogenic noise has been demonstrated to affect catch rates. Several studies indicate that catch rates of fishes decreased in areas exposed to seismic air gun blasts (Engås et al., 1996; Hastings and Popper, 2005); abundance and catch rates for Atlantic cod, *Gadus morhua;* and haddock, *Melanogrammus aeglefinus*, did not return to pre-disturbance levels during the five-day monitoring period (Engås et al., 1996). These results imply that fish relocate to areas beyond the impact zone (area of highest sound intensity), which have been corroborated with visual studies on fish abundance before and after seismic surveys (Paxton et al., 2017). One study indicated that catch rates increased 30-50 km away from the noise source, implying that redistribution of fish populations may occur over broad areas (Hastings and Popper, 2005). Seismic surveys may have positive, no change, or negative effect on fishery catch rates due to variable responses among fish species such as no response, dispersal, avoidance, and decreased responsiveness to bait (Carroll et al., 2017). While fish abundance can decrease due to increased anthropogenic noise, such as from wind farm operation, it is unclear the extent to which the increased noise from wind farm operation affects individual behaviors (Mooney et al., 2020).

MITIGATION

When noise cannot be avoided, measures could be implemented to mitigate certain anthropogenic acoustic impacts. New technologies continue to emerge that reduce vessel noise, rendering them less acoustically intrusive. For instance, the use of alternative propeller designs and propulsion systems such as diesel-electric hybrid, electric motors, liquid natural gas pumps, and rotor sails that are quieter than internal combustion engines can be employed. Ship generators are also a substantial source of vessel noise. Insulated or sound proofed ship hulls may be used aboard ships with generators to further reduce acoustic impacts. Furthermore, when in port, vessels could power down their generators and connect to onshore power systems when possible.

Transferring fish from an in-tank grader to a small grader. Photo credit: Dr. Wade Watanabe, University of North Carolina at Wilmington.

In addition to modifying hardware and ship practices, informed marine spatial planning can be used to manage location and timing of when harmful sounds are generated. Acoustic transects can be used to isolate and map specific sites based on sound production of fishery aggregations (Gilmore et al., 2003; Gilmore Jr, 1994; Luczkovich et al., 1999; Rountree et al., 2002) as well as the broader ambient soundscape (Chou et al., 2021). For example, critical spawning and aggregation sites can be designated as off limits to vessels, dredging, seismic, construction, and other sound generating activities at night which is when spawning chorus events typically occur. These sites can be remotely monitored with vessel tracking technologies such as automatic identification systems (AIS) to identify violating vessels. To mitigate episodic noise impacts, such as from offshore construction, seasonal restrictions on activities could be combined with spatial planning.

Novel seismic survey methods, including higher sensitivity hydrophones, benthic stationary fiber-optic receivers, parabolic reflectors, and non-impulsive, very low frequency marine vibroseis, may reduce the potential detriment caused by these activities (Chou et al., 2021). Continued study of these technologies and their relative impact on marine life should be prioritized.

The construction of some infrastructure types, including offshore wind turbine foundations, generally involves pile driving at present. However, other foundation types including "quiet" technologies such as pulse prolongation, vibropiling, foundation drilling, gravity base foundation, suction bucket jacket, mono bucket foundation, and floating foundations, are all potentially viable alternatives (Koschinski and Lüdemann, 2020). When possible, one or more sound dampening measures such as bubble curtains, isolation casings, hydro sound dampers, dewatered cofferdams, and double/mandrel piles should be used in conjunction with pile driving.

Multiple sound exposure level metrics such as cumulative, peak, single-strike, and number of strikes should be considered when evaluating the potential effect of pile driving and other impulsive sounds and establishing allowable exposure criteria (Halvorsen, 2011). Furthermore, deterrence strategies such as soft-start and ramp-up are intended to scare away mobile species as noise levels are gradually increased (Andersson, 2011; Chou et al., 2021). Each of these are areas for continued research to better inform best practices, exposure criteria, and noise thresholds.

Data Gaps and Research Needs

There are still many unknowns about the impact of anthropogenic noise on the physiology and behavior of fishes. Some of these include species-specific effects, the impact on fishing catch rates, synergistic impacts of multiple sources of anthropogenic noise, and many other questions. In 2020, the New York State Energy Research and Development Authority (NYSERDA) convened a working group of over 40 stakeholders and experts who identified and prioritized data gaps and research needs specific to the effects of sound and vibration on fishes and invertebrates (Popper et al., 2021). We direct the reader to this document for more information on research needs.

Transferring fish from an in-tank grader to a small grader. Photo credit: Dr. Wade Watanabe, University of North Carolina at Wilmington.

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