9 May 2025

Record of the 2024 North Atlantic Right Whale Vessel Strike Risk Reduction Technology Workshop

Mary Colligan, Lisa C. Neyman, Eric M. Patterson, and Caroline Good

With contributions from Bennett Brooks, Pat Field, Elizabeth Cooper, and Stephanie Horii of the Consensus Building Institute, the Workshop Steering Committee, and all Workshop Participants.

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

The following document represents a summarized record of the North Atlantic Right Whale (NARW) Vessel Strike Risk Reduction Technology Workshop, which was convened by the Biden Administration in 2024. This record was drafted during the Biden Administration. NOAA Fisheries is releasing this record for the public's awareness. NOAA Fisheries will not be accepting public comments on this record, and we will not be pursuing further revisions or finalization.

Table of Contents

Appendices

List of Figures and Tables

Acronyms

AI	Artificial intelligence
AIS	Automatic Identification System
APA	American Pilot's Association
ATON	Aid(s) to Navigation
AUV	Autonomous underwater vehicle
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
CBI	Consensus Building Institute
CFR	Code of Federal Regulations
DL	Deep learning
DFO	Fisheries and Oceans Canada
DMA(s)	Dynamic Management Area(s)
DMON	Digital monitoring device
DMS	Dimethyl sulfide
eDNA	Environmental DNA
ESA	Endangered Species Act
FACA	Federal Advisory Committee Act
FR	Federal Register
GPS	Global positioning system
IFAW	International Fund for Animal Welfare
IMO	International Maritime Organization
IR	Infrared
LMR	Living Marine Resource Program (U.S. Navy)
ML	Machine learning
MMC	Marine Mammal Commission
MMO(s)	Marine mammal observer(s)
MMPA	Marine Mammal Protection Act
NARW(s)	North Atlantic right whale(s)
NASA	National Aeronautics and Space Administration
NAVTEX	Navigational telex
NEFSC	Northeast Fisheries Science Center
NGO(s)	Non–government organization(s)
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
OLE	Office of Law Enforcement
ONR	Office of Naval Research
OPR	Office of Protected Resources
PACM	Passive Acoustic Cetacean Map
PAM	Passive acoustic monitoring
PBR	Potential Biological Removal
PGN	Parameter group number
PSO	Protected species observer
QA/QC	Quality Assurance/Quality Control
RPAS	Remotely piloted aircraft system
RWSC	Regional Wildlife Science Collaborative for Offshore Wind
SC	Steering Committee
SMA(s)	Seasonal Management Area(s)
SME(s)	Subject Matter Expert(s)

TC	Transport Canada
TRL(s)	Technology readiness level(s)
UAV	Uncrewed aerial vehicles
UME	Unusual Mortality Event
USCG	United States Coast Guard
USV	Unmanned surface vehicle
VHF	Very high frequency
VHR	Very–high resolution
WAVS	Whale and Vessel Safety
WHaLE	Whales, Habitat, and Listening Equipment
WHOI	Woods Hole Oceanographic Institute
WSC	World Shipping Council

Definitions

Term	Definition
Dynamic Application Scenario	Risk Reduction actions within defined areas in response to near real–time whale detections in those areas.
Public sector	The public sector includes organizations owned by and funded with government financial support and which provide goods and services for the benefit of the community.
Private sector	The private sector is composed of businesses and entities funded with private funds, they represent the part of the economy run by individuals and companies for profit.
Promising	The terms 'promising' and 'most promising' were provided to workshop participants as labels for them to use to identify which technology and/or approaches they believe have the greatest potential to successfully reduce vessel strike risk to NARW based on their sense of impact and feasibility.
NGO	The non–governmental organization (NGO) sector primarily includes environmental NGOs, but also includes advocacy groups representing industry.
Risk Chain Component	Risk Chain Component refers to each of a series of linked necessary actions to reduce NARW vessel strike risk. The workshop focused on the following Risk Reduction Chain Components: (1) NARW detection and classification; (2) modeling the spatial and temporal density of NARWs; (3) aggregating classified detections; and (4) dissemination and integration of NARW data and risk reduction areas in a manner which facilitates decision–making.
Static Application Scenario	Risk reduction actions within static seasonal zones where there is high confidence that NARWs will be present and at risk of vessel strikes.
Vessel–Specific Application Scenario	Risk reduction system internal to a vessel where technology/methods on the vessel are used to detect NARWs and inform real–time navigational decisions in situ. Also includes vessel modifications.
Vessel–use profile	Vessel–use profiles are a description of the different vessel types and operational categories, their different requirements, capacity for notification, and any constraints or limitations for reaction including possible reaction times based on vessel size, weight, speed, and maneuverability. As used in this report, vessel-use profile does not include the human element that also influences navigational decisions.

Acknowledgements

We offer our sincere appreciation and respect to Bennett Brooks, Pat Field, Elizabeth Cooper, and Stephanie Horii of the Consensus Building Institute for their insights, patience, creativity, and positivity in helping to plan and execute this challenging workshop. We also thank the Workshop Steering Committee for their engagement and guidance. Special thanks to Alex Carbaugh-Rutland for his role in the early stages of workshop planning and Colin Perkins-Taylor for his attention to detail and assistance in editing the workshop report. We wish to acknowledge MITRE's contributions to the Detection and Classification technology literature review contained in Appendix 6 and for their technical review of the workshop report.

Industry representatives, technology developers, agency representatives, non-governmental organizations, and other interested parties generously gave their time and expertise and became true partners in the planning and successful convening of this workshop. We are incredibly grateful for that and believe the workshop experience and this report are greatly improved because of that collaboration. We appreciate the manner in which participants engaged in the workshop providing critical information and sharing key insights and perspectives through presentations, conversations, polls, and various other tools. Collectively, a great deal of information and a variety of insights were collected that we hope will help pave the path forward. Although the challenge of reducing North Atlantic right whale vessel strike risk remains daunting, we are optimistic about the potential contribution of technology and appreciate the collaborative spirit, and tenaciousness of those we have had the pleasure to interact with before, during, and after this workshop.

Executive Summary

The 2024 North Atlantic Right Whale (*Eubaleana glacialis*; NARW) Vessel Strike Risk Reduction Technology Workshop was convened to identify and discuss existing and emerging technology capable of reducing the risk of vessel strikes to NARWs while maintaining vessel operational and safety needs. The scope of the workshop was broad and intended to encompass all vessel sectors and operations that co–occur with NARWs. Discussion focused on how technology can facilitate: (1) whale detection; (2) efficient aggregation and analysis of whale detection data; (3) communication of whale presence to vessels; (4) modification of vessel design; (5) changes in vessel operations and strike avoidance options; and (6) better understanding interactions between NARWs and vessels.

Workshop planning and preparations included consultation with a Steering Committee composed of federal agency staff and hosting a series of open–access webinars with presenters and subject matter experts. The first day of the workshop was designed to provide workshop participants with background information on NARW vessel interactions, the role of NARW biology and ecology in vessel strike risk, lessons learned from vessel strike mitigation strategies, and technology considerations from an enforcement standpoint. This information was supplemented by Fact Sheets and Background Papers made available prior to the workshop. The second day of the workshop focused on an in–depth look at specific vessel strike risk components, and opportunities for sectors to share their perspectives and for participants to share what they saw as promising tools and approaches. Immediately following the workshop, a closed–door meeting was held among federal agency representatives to discuss key takeaways from the previous two days of the public workshop. Consistent with the Federal Advisory Committee Act, the purpose of the public workshop was to foster an exchange of ideas and obtain unique viewpoints from individual attendees, not advice, opinions, or recommendations from the group acting as a collective.

Four frameworks were presented to workshop participants to help frame discussions. The first was a Risk Factor graphic, which identified key characteristics of vessels, NARWs, the environment, and captains and crew that affect the probability of NARW vessel strikes occurring and the efficacy of risk reduction technology. Secondly, workshop participants were asked to consider how technology could be applied in Static, Dynamic, or Vessel–Specific Scenarios. The third framework introduced was a Risk Reduction Chain—a series of linked actions (referred to as Risk Components) necessary to reduce vessel strike risk. Workshop participants identified and discussed technology and methods influencing the individual Chain Components (i.e., whale detection and classification, data aggregation, modeling, information dissemination and integration, evaluation of risk reduction, and other) but emphasized that vessel strike risk reduction can only be achieved if the entire Chain was implemented. The final framework discussed at the workshop was the need to match technology to the characteristics, operational capabilities, and constraints of vessels.

The workshop offered both in–person and remote attendance. In–person invitations were sent to experts in vessel operations, whale science, vessel design, technology design, testing and deployment, and agencies with responsibilities related to vessel strikes (e.g., Endangered Species and Marine Mammal Protection Acts, and U.S. Coast Guard safety and marine navigation mandates). The workshop was intended to provide an opportunity for diverse groups and individuals to share information and perspectives on current and emerging technology and to foster new and ongoing connections/dialogue. The workshop also aimed to engage researchers and entities outside of those already working on this issue to bring new perspectives, ideas, and expertise.

A total of 586 individuals registered to participate in the workshop with 139 in–person participants and 447 remote registrants representing the following categories: (1) Federal Government

(N=173); (2) Tech/Engineer/Manufacturer (N=100); (3) Vessel Operator/End User (N=81); (4) Non–Governmental Organization (N=81); (5) External Science/Academic (N=68); (6) International Government (Canada; N=25); (7) State Government (N=23); (8) Tribal Government (N=5); (9) Congressional (N=9); (10) Media (N=5); and (11) Other (N=16). A variety of methods were used throughout the workshop to provide participants the opportunity to share information and perspectives including panels, discussions, question–and–answer periods, and online polls and forms. Every effort was made to accurately capture the variety of perspectives shared by participants within this report.

When asked to identify the most promising technology or approaches to reduce vessel strike risk to NARWs, workshop participants most frequently identified thermal/infrared cameras, improvement of information dissemination/communication methods, passive acoustic monitoring, and Automated Identification System messaging. Participants also offered strong support for investing in vessel strike outreach and education, and partnerships. Workshop participants noted that a combination of technologies (e.g., combined visual and acoustic methods to detect whales) and the integration of these tools into a functioning system is necessary to effectively address this issue. Specifically, participants emphasized the importance of recognizing that there is no single solution to the problem, and that it will be necessary to pursue multiple technologies and combinations of technology, matched to different geographies, vessel types, and vessel operational modes.

Within the Detection and Classification Risk Chain Component, participants stated that a combination of tools was most likely needed and encouraged the continued use of visual surveys and passive acoustic monitoring. They also encouraged investment to advance the technology readiness levels of promising technology including satellite and thermal/infrared imagery, environmental DNA, whale tagging, dimethyl sulfide, and artificial intelligence/machine learning to process large quantities of data quickly and accurately. Participants recommended prioritizing investments in technology based on relative readiness, scaling ability, and utility for different vessel–use profiles. Recommendations for the Modeling Risk Chain Component included additional collaboration and discussion among modelers and with interested parties, sharing of and access to data for use in modeling efforts, prioritization of both near–term and long–term predictive outputs, and the potential for models informing risk reduction evaluation. Regarding the data Aggregation Component, participants noted that suitable tools were already in existence but recommended additional customization of aggregation platforms to improve utility for mariners and expanding awareness of available options. Participants further recommended clarification of data permissions and display characteristics to better understand how they could be used to inform risk reduction actions. Regarding the NARW data Dissemination and Integration Risk Chain Component, workshop participants cautioned that matching vessel operational profiles with the types of decisions they are making should come before any discussion of means to disseminate information to specific vessels. However, there was strong support for expanded use of AIS messaging and exploring dissemination of NARW data via existing navigational equipment already in use by mariners. A greater focus on actionability and improving our understanding of what vessels can do once they receive information was recommended to narrow down what information is worthwhile to send to specific vessels. During the discussion about other ways technology has the potential to reduce vessel strike risk (not covered by the Risk Chain Components mentioned above), participants recommended additional research to improve our understanding of how whales perceive and react to vessel traffic, maximizing the use of existing data on vessel strikes, investigating additional modeling efforts to simulate vessel strikes, and exploring vessel design modifications.

Collaboration and partnerships were common themes when workshop participants were asked to identify what was needed from each sector to advance vessel strike risk reduction technology. In general, workshop participants identified the role of the Federal Government as setting performance metrics and protocols for the development, testing, and evaluation of vessel strike risk reduction technology and risk reduction strategies. Workshop participants emphasized the importance of the private sector identifying technology and vessel strike risk reduction strategies they consider most usable for different vessels and operational modes. Some stated that technology developers/manufacturers/engineers were best suited to provide vessel strike risk reduction technology tools in an effective, scalable, and commercially available manner. Workshop participants emphasized the importance of establishing long–lasting communication and partnerships in which federal agencies clearly specify goals, vessel operators and owners describe areas where they are able and most likely to make changes, and technology developers ensure that developing products address these needs. Workshop participants expressed a desire to maintain communication and connection among those who attended the workshop and to have regular meetings to collaborate on technology development and emphasized the importance of doing so across the different sectors to provide a forum for learning from each other.

Workshop participants identified three primary cross–cutting actions to establish a foundation and framework for advancing vessel strike risk reduction technology. Specifically, they recommended creating vessel–use profiles as a critical step to understanding the feasibility of vessel strike risk reduction measures and actions for different vessel categories. These use profiles would identify the different vessel types and use categories, their different requirements, capacity for notification, and real-time whale avoidance operational constraints based on vessel size, weight, speed, and maneuverability. They noted that specifics on when, where, and how the vessels operate may help facilitate connections to viable and appropriate technology for vessel strike risk reduction. Secondly, they recommended a technology inventory containing a comprehensive review of available and emerging technology relevant to vessel strike risk reduction detailing capabilities, limitations, readiness, likely use, and time and funding to achieve full development. Once these two foundational reviews have been compiled, workshop participants recommended matching end users/case profiles with technology systems to create effective risk reduction strategies. The third cross–cutting recommendation was the establishment of clear and transparent standards and testing protocols using a rigorous scientific methodology. This would allow for consistent evaluation of technology, comparison across technologies, and would inform strategic decisions about technology, advancements, investments, and adoption.

Some workshop participants expressed an urgency in reducing vessel strike risk given the status of NARWs. Others, while recognizing the threat to NARWs, tempered expectations and stated that it would take time to test and evaluate technologies and gain approval for their use. Workshop participants placed a priority on obtaining a more comprehensive understanding of what information mariners consider actionable and what action(s) they intend to take upon receipt of that information. Participants advocated for a social science study to interview a diversity of vessel operators to identify what information they need, when and how they want to receive it, and what actions they can/will take upon receipt. They argued that technology needs to focus more on changing human behavior than perfectly predicting and detecting animal behavior.

The Vessel Strike Risk Reduction Technology Workshop provided a solid foundation to launch informed evaluations of vessel uses and viable risk reduction technologies, and combinations of technologies, most worthy of investment and implementation moving forward. While workshop participants recognized that there are no simple solutions or shortcuts, they did identify tools (technologies, combinations of technologies, and actions) with the potential to reduce vessel strike risk when used in the right situations and with the right training. Expanding awareness, use, and effectiveness of these tools can inform and facilitate human actions that reduce vessel strike risk and is expected to improve the safety of both mariners and endangered NARW.

1. Workshop Introduction and Background

1.1 Background

The National Oceanic and Atmospheric Administration (NOAA) Fisheries' 2008 North Atlantic Right Whale Ship Strike Reduction Rule (hereafter "Speed Rule"; 50 Code of Federal Regulations (CFR) § 224.105) stated that the most desirable approach to minimize or eliminate the threat of vessel strikes to the North Atlantic right whale (*Eubalaena glacialis;* hereafter, right whale or NARW) is the use of technological solutions (73 Federal Register (FR) 60173, October 10, 2008). Within the Speed Rule, NOAA Fisheries committed to explore and test such technology and noted that it had provided substantial funding for research and development of technological solutions (73 FR 60181 October 10, 2008). Identified characteristics of technology were that it must be: (a) proven to be directly effective in reducing the threat, and (b) environmentally benign (i.e., not adversely affecting right whales, other organisms, or their habitats). At the time of the 2008 Speed Rule, NOAA Fisheries stated that it was not aware of any existing or imminently available technology that satisfies both these criteria, but that it may consider taking appropriate steps to allow for the use of technology that became available that can reduce the risk of vessel strike mortalities. Further, NOAA Fisheries said it would consider rulemaking to allow the use of such technology in lieu of compliance with the 2008 Speed Rule if the technology could be used in a manner that is at least as protective of right whales (73 FR 60182, October 10, 2008).

In 2008, NOAA Fisheries held a workshop to identify and assess technology to reduce vessel strikes of large whales (Silber et al., 2009 as contained in Appendix 8). The 2008 workshop was convened to: (a) identify existing or emerging technology that might be useful in reducing vessel strikes; (b) assess the feasibility of each in reducing vessel strikes; and (c) identify research and development timelines needed to make a given technology useful in reducing the threat. The workshop concluded that the problem of vessel strikes is a complex one; there are no easy technological "fixes"; that no technology exists or is expected to be developed in the foreseeable future that will completely ameliorate, or reduce to zero the chances of vessel strikes of large whales; and no single technology will fit all situations.

The 2024 NARW Vessel Strike Risk Reduction Technology Workshop was convened in furtherance of NOAA Fisheries' goal to identify technological tools with the potential to reduce right whale vessel strike risk. NOAA Fisheries aims to have a greater variety of effective vessel strike risk reduction measures available for deployment in the future and held this workshop to identify, coordinate, and focus efforts on technology that holds the greatest promise for further vessel strike risk reduction.

1.2 Workshop Purpose and Objectives

The purpose of the workshop was to bring together interested parties to collaboratively identify existing and emerging technology capable of reducing the risk vessel strikes pose to NARWs while maintaining vessel operational and safety needs. To the extent possible, technology was described using attributes such as their:

- Role in risk reduction
- Current or potential availability for application in vessel strike risk reduction efforts
- Potential efficacy under various conditions (e.g., weather, vessel type, alone or in combination with other technology/actions)
- Cost
- Ability to verify/measure contribution to vessel strike risk reduction

- Implement-ability, including identification of any potential challenges to testing, adoption, and approval

In addition to sharing information and perspectives on current and emerging technology, the workshop was intended to foster new and ongoing connections/dialogue among the many diverse groups pursuing potential vessel strike risk reduction technology advancements. Lastly, the workshop aimed to engage new researchers and entities outside of those already working on this issue to bring new perspectives, ideas, and expertise. The workshop agenda can be found in Appendix 1.

Consistent with the Federal Advisory Committee Act (FACA), the purpose of this workshop was to foster an exchange of ideas and obtain unique viewpoints from individual attendees, not advice, opinions, or recommendations from the group acting as a collective given that this is not a formal Federal Advisory Committee under FACA. No collective decisions were made at the workshop. Rather, the information collected at the workshop will help inform next steps for advancing vessel strike risk reduction technology. The workshop and this report are intended to serve as a springboard for ongoing and further discussions.

Workshop participants were asked to participate actively and respectfully, remain open–minded, and to explore with good questions, deep background knowledge, and a "can do" spirit. To promote productive discussion, the workshop was not recorded, and participants were also asked to refrain from doing so themselves. Members of the media participated remotely in the workshop. Remote participants were able to observe both plenary and breakout group deliberations, comment verbally during Risk Component breakout sessions, and contribute to discussions via various written avenues (i.e., question–and–answer feeds, chat, online forms). The facilitation team occasionally used online polls to get a sense of perspectives on issues under discussion. This polling was used to inform workshop deliberations and understand the sector distribution of participant responses and was not intended nor used nor used as a "vote" on any issues under discussion.

1.3 Steering Committee (SC)

A SC composed of federal agency representatives was created to provide input to NOAA Fisheries Office of Protected Resources (OPR) in the detailed planning and execution of the workshop (see Appendix 2 for a list of SC members). Specific areas where advice was sought from the SC included, but were not limited to, the following: (1) identification of desired products from the workshop; (2) workshop scope; (3) agenda; (4) plans for external engagement; (5) preparatory materials; (6) participants; (7) technology evaluation/performance criteria; and (8) workshop follow–up. As will be discussed in Chapter 4, the SC was particularly helpful in brainstorming options for framing the review of vessel strike risk reduction technology.

1.4 Scope

The scope of the workshop was broad and included how technology can facilitate: (1) whale detection; (2) the efficient aggregation and analysis of whale detection data; (3) communication of whale presence to vessel operators; (4) modification of the design of vessels; (5) vessel evasive action; and (6) the improvement of our understanding of interactions between vessels and large whales. The scope also intentionally included all vessels whose operations overlap with NARWs. In discussing this broad scope with the SC, the workshop organizers recognized that the workshop could not discuss any one technology in detail but would instead have to look more broadly at the use of technology across all six areas to reduce vessel strike risk.

The planning team[1] recognized that it was equally important to specify what was not within the scope of the technology workshop. The 2022 proposed modifications to the NARW Speed Rule (87 FR 46921; August 1, 2022) were not the focus of this workshop, and participants were asked to keep their discussion and comments to technology and not the existing or proposed amendments to the Speed Rule. Similarly, efforts to mitigate fishing gear entanglement risk for large whales were outside of the scope of the workshop. The focus of the workshop was on the vessel strike risk reduction technology tools themselves and not on if or how they might be included in a management program. Despite being outside of the specified scope of the workshop, some participants provided comments on the 2022 proposed modifications to the Speed Rule and how technology might be included in management programs. Those comments are included in the report for completeness and accuracy. NOAA Fisheries recognizes and appreciates the strong interest in how technology could be implemented into the risk reduction strategy and whether it would supplement or replace existing measures. These discussions are important and the agency indicated it looked forward to having them after and outside of the scope of the workshop.

1.5 Approach and Methodology

Workshop preparation, with support and guidance from the SC, included conducting literature reviews of technology and speaking with technical experts and others investigating vessel strike risk reduction technology. The planning team reached out to individuals, sectors, and interest groups as necessary and appropriate to fill in gaps in knowledge, expertise, and interests to inform workshop planning efforts. In addition, the planning team identified other relevant past, current, or planned future workshops or related efforts to ensure this workshop would be adding value and not duplicating effort.

Preregistration for the workshop opened on November 1, 2023, to solicit interest and continue to develop a list of interested parties. Notification of the opportunity to pre–register was sent to a mailing list maintained by NOAA Fisheries as well as individuals who had responded to a save–the–date notice previously distributed to that same mailing list and posted on the agency website. Registrants were asked to identify their affiliation, primary area of expertise, and to describe why they were interested in the workshop (specifically what they hoped to learn and/or contribute), which provided critical input to help with workshop planning.

An informational webinar was held December 2023 to discuss the workshop scope and objectives and share planning efforts to date. Six additional webinars were held throughout February 2024. The first of these served to review the workshop scope and objectives, to present the framework being used to identify risk factors, Components in the Risk Reduction Chain, and technology linked to the Risk Reduction Chain Components (Chapter 4), and to review the approach being used to develop the workshop agenda. Draft versions of the Risk Factor Graphic, Risk Chain Components, risk reduction Scenarios, and a technology table were posted on the workshop website for public viewing following this webinar. The second of the February webinars was geared towards vessel operators and vessel industry representatives. During this webinar, plans for two workshop plenary panels were discussed, including the questions intended to be posed and the information requested from the panelists. The four remaining webinars each focused on a Risk Chain Component (i.e., dissemination and integration, modeling/forecasting, aggregating, and dissemination and classification). These webinars were held primarily for the panelists and invited subject matter experts (SMEs) for each of these planned workshop sessions; however, any interested parties were welcome to attend. The Risk Chain Component webinars provided the planning team assistance in shaping each of the respective workshop sessions and facilitated

[1] The workshop planning team consisted of NOAA Fisheries OPR staff, NOAA Affiliates, and facilitators.

coordination among the panelists to maximize the likelihood of presenting the most critical information with minimal duplication.

1.5.1 Approach to Issuance of In–Person Invitations

As of early January, more than 300 individuals had expressed interest in participating in the workshop (by pre–registering), vastly exceeding the in–person venue capacity of 150 people. Given the broad scope of technology to be discussed and the diversity of vessels and interested parties (e.g., individuals, companies, entities, and organizations) involved, NOAA Fisheries wanted to ensure inclusivity and was therefore committed to providing a meaningful hybrid experience. The process for determining to whom to issue in–person or remote invitations began with first assigning pre–registrants, invited experts, and interested parties into one of the following groups: Group 0: Support; Group 1: Presenters and Panelists; Group 2: Key Participants for the Federal Only meeting immediately following the public workshop; Group 3: Technology Companies, Consultants, and Invited Technical SMEs; Group 4: Vessel Operators/Users/Affected Parties ; and Group 5: Interested Public. Priority for in–person invitations was given to those in Group 0–4, and individuals in Group 5 were issued remote invitations. A list of presenters, panelists, and SMEs can be found in Appendix 3. Within these groups it was necessary to limit in–person invitations, in most cases, to one individual per entity/organization to ensure the representation of as many entities as possible. Each of the approximately 35 technology companies/consultants who pre–registered for the workshop were issued one in–person invitation with many having additional remote participants (Group 3). Similarly, each of the approximately 28 affected interested parties/user groups (wind, recreational, cruise, ferry, container, pilot, support, commercial fishing) were issued one in–person invitation, and additional representatives were invited to participate remotely (Group 4). Finally, just over 20 non–governmental organizations (NGOs) pre–registered for the workshop and one representative from each was invited to attend in person, and remote invitations were provided to any additional representatives. Following issuance of invitations, registration remained open to remote participation until the close of the workshop.

The approach to issuing invitations was implemented with the goal of having all relevant sectors represented with both remote and in–person workshop participants. Additional information on final numbers of workshop participants and sector representation can be found in Chapter 2. The perspectives of the various sectors are presented and summarized in Chapter 10. Adjustments were made, as possible, leading up to the workshop to offer in–person participation opportunities to those who requested it as seats became available due to declined or canceled in–person invitations. The planning team was not, however, able to accommodate all in–person participation requests and appreciate those who participated remotely and who made the extra effort to actively participate by sharing insights, asking questions and otherwise contributing to the workshop.

1.5.2 Approach to the Workshop Report

This report presents the information, opinions, and perspectives of workshop participants as shared during presentations, panels, discussions, question–and–answer periods, online polls, and online forms both in detail and in summary. The primary purpose of the report is to provide an accurate and complete account of the workshop itself. It is important for the reader to note that statements and opinions of workshop participants are captured in the workshop report without additional commentary, corrections, or caveats. These statements represent the speaker's perspective, unless otherwise noted, and it is not possible to provide additional contextual background to the reader within this report. In some cases, as noted below, background literature review conducted by the planning team leading up to the workshop is provided in the main body and appendices, and we direct the reader to those sections and related references for available published literature on the technology discussed at the workshop. We also note that wherever possible we have not referenced specific products, trade names, or manufacturers as the intent of the workshop was to discuss available and emerging technology in a general and broad sense. However, products, trade names, or manufacturer names were retained if they were mentioned specifically by a presenter or workshop participant. Any mention of a specific commercial company, product, or trade name does not imply or constitute an endorsement by NOAA Fisheries.

Wherever possible, statements are attributed to individuals who have been provided the opportunity to review their statements for accuracy prior to inclusion in this report. Input received through online polls, as well as some provided through the question–and–answer feeds, was provided anonymously. In these cases, the input is presented as coming from a workshop participant, or in some cases due to how the polls were set up, the input can be attributed as coming from a participant in a particular sector. Similar comments were grouped together, where appropriate, and presented as coming from multiple participants rather than providing the names of each contributor. The intent of providing this input at this level of specificity and detail is so that this report may serve as a comprehensive record of the workshop for both those who were able to participate and for those who were not.

While the primary purpose of the workshop report, as stated above, is to document what occurred during the 2024 NARW Vessel Strike Risk Reduction Technology Workshop, this report also contains general background information that guided the approach to the workshop, the identification of presentation topics, and in some cases expands upon presentation content. In particular, Chapters 5–9 begin with literature reviews of vessel strike–related technology to provide relevant background to the reader. These literature reviews helped shape and narrow the focus of the workshop sessions and, while not shared with workshop participants in their entirety, are being included in the report to provide additional context for the workshop sessions themselves. The literature review for the Detection and Classification session is contained in Appendix 6 rather than as a section in Chapter 5 due to the high volume of research in this area. Some, but not all, of this information was made available to the workshop participants prior to the workshop through the Background Papers and Fact Sheets.

The terms ’promising’ and ‘most promising’ were provided to workshop participants in the online polls, online forms, and discussion periods as labels for them to use to identify which technology and/or approaches they believe have the greatest potential to successfully reduce vessel strike risk to NARW based on their sense of impact and feasibility. Identifying and discussing what individual workshop participants viewed as promising technology allowed for the collection and exchange of unique viewpoints and facilitated productive discussions. The use of these terms in this report is solely to represent the viewpoints of the individual workshop participants and is not a representation of the opinion of the Agency. Similarly, references to technology effectiveness or readiness in the report are included when presenters or workshop participants provided such an assessment or as presented in published literature. Such statements do not reflect a comprehensive assessment of the technology or the official position of NOAA Fisheries.

1.5.3 Workshop Welcome

The workshop began with Janet Coit, NOAA Fisheries Assistant Administrator, welcoming and thanking all workshop participants both in the room and joining remotely to what she characterized as an important workshop at a critical time for NARWs. She also expressed thanks to the workshop SC, Consensus Building Institute (CBI), and Saxman One for their help in planning the workshop. Assistant Administrator Coit stated that NOAA Fisheries recognized long ago that the conservation of NARWs needs everyone to bring their best forward when it comes to monitoring, developing, and deploying technology, and sharing information to mitigate the threats that are leading to the decline in the small remaining NARW population. She emphasized the importance of working together to reduce the two primary threats to NARWs: entanglement in fishing gear and vessel strikes. Assistant Administrator Coit expressed appreciation for workshop participants dedicating their time and expertise to working with NOAA Fisheries and other federal agencies to explore and advance vessel strike risk reduction technology. She stated that collaboration across industry, technology and engineering firms, interested and affected parties, and government is needed to expand our "toolbox" for successfully reducing risks to this endangered species. Assistant Administrator Coit shared that after seeing some of the latest technology, she felt that with collaboration, and based on science, progress could be made quickly.

Assistant Administrator Coit characterized NARWs as a species in crisis with an estimated population of approximately 360 individuals including only about 70 reproductively active females. She noted that female NARWs are even more vulnerable to vessel strikes given the time they spend at the surface when they have a calf. Assistant Administrator Coit stated that an Unusual Mortality Event (UME) had been declared in response to the over 120 deaths, serious injuries, and illnesses observed since 2017, which represent over 20% of the population. She highlighted losses of calves and juveniles in 2024 including: (1) Juno's calf, which was seen in January with severe propeller gashes on its head and was found dead over the weekend prior to the workshop; (2) a 1–year–old female found off Savannah, Georgia, whose necropsy revealed a skull fracture and signs of blunt force trauma consistent with a vessel strike; and (3) the death of a 3–year–old female found near Martha's Vineyard who had been entangled as a yearling and trailed ropes and gear for more than 2 years. She said she was encouraged by the 19 new calves in 2023/2024 but deeply saddened by each reported death and injury. Assistant Administrator Coit also noted that climate change is impacting every aspect of NARW survival including their migratory patterns, location and availability of prey, and their risk of becoming entangled in fishing gear or struck by vessels.

Assistant Administrator Coit said NOAA Fisheries is working overtime—along with conservation partners—to develop and implement management measures to stem the decline of NARWs and enable their recovery. She referred to the announcement in September 2023 of the availability of a historic $82 million in Inflation Reduction Act (IRA) funding for NARWs, which provides a once–in–a–lifetime opportunity to address the NARW crisis and the primary threats to their survival (entanglements and vessel strikes) through new technology and new approaches, such as this workshop. She indicated that NOAA Fisheries planned to use the IRA funding to increase near–real–time whale detection capacity and distribution monitoring using new technology and improved models, to invest in technology to reduce the risk of vessel strikes, increase the use of on–demand fishing gear, and improve enforcement of existing federal regulations. Assistant Administrator Coit stated that the IRA funds complement NOAA Fisheries annual appropriations and further support the NARW Road to Recovery, NOAA Fisheries' overarching strategy to recover the species, address threats to NARWs, and monitor progress.

Assistant Administrator Coit said NOAA Fisheries is developing new partnerships with the private sector and other agencies centered on developing innovative technology to reduce risks to right whales. She highlighted a new agreement with the National Aeronautics and Space Administration (NASA) to identify, advance, and develop innovative technology to support NARW recovery efforts related to vessel strike risk reduction and satellite tag development. She also referenced an announcement made in January 2024 of a new $10 million partnership with MITRE's Center for Enterprise Modernization to focus on the development of technology and engineering approaches related to whale detection, vessel strike avoidance, and on–demand or "ropeless" fishing gear. Assistant Administrator Coit indicated that in the coming weeks, NOAA Fisheries hoped to share another new IRA–funded partnership with the National Fish and Wildlife Foundation

(NFWF)[2] that is directly related to this workshop and will further support NARW conservation. She closed by expressing hope that advancements and innovations identified by workshop participants would be broadly useful to ensure large whale conservation while accommodating commercial, industrial, and recreational uses of the ocean.

Following Assistant Administrator Coit's welcome, Kim Damon–Randall, Director of NOAA Fisheries OPR, acknowledged that all workshop participants share an interest in preventing vessel strikes and reducing the impact of these events on right whale recovery. She noted that the development and implementation of technology, new engineering approaches, and other options will help build our vessel strike mitigation toolbox.

Damon–Randall expressed her appreciation for people taking time to participate in the workshop, emphasized that the door is "wide–open," and noted that she is looking forward to their engagement and to hearing their ideas and suggestions. She encouraged workshop participants to identify potential challenges and key considerations openly and transparently. She noted that NOAA Fisheries had deliberately gathered a diverse group of experts from industry, the commercial sector, scientific and engineering fields, environmental conservation, and vessel operator groups to hear everyone's ideas and perspectives. She encouraged participants to listen, discuss options openly, think innovatively, and to take the time to meet new people and forge new partnerships and collaborations.

Damon–Randall said that the workshop was likely the first of many productive discussions across numerous different forums. She cautioned workshop participants to be prepared for homework as she anticipated that the discussions at the workshop would identify the need for more information, data, or investigations across the many sectors gathered at the workshop. She noted that as workshop participants were discussing technology and tools for addressing right whale vessel strike risk, they should not limit those discussions to vessels regulated under the current Speed Rule or those proposed for regulation. She reiterated that NOAA Fisheries is focused on all vessel activity, including federal vessels, that overlaps with right whale habitat. Damon–Randall expressed hope that participants would leave the workshop with new ideas to be explored, a to–do list for next steps, and pathways forward. She closed by stating she hoped that participants would view this workshop as evidence of NOAA Fisheries' sincere commitment to work collaboratively to advance new tools to address right whale vessel strike risk.

---

[2] The National Fish and Wildlife Foundation is a non-profit conservation foundation that works with both public and private sectors to support conservation efforts throughout the U.S. More information can be found at their website nfwf.org. NOAA Fisheries announced a $6 million partnership with NFWF to support vessel strike prevention technology on May 22nd 2024. [Available at https://www.fisheries.noaa.gov/feature-story/noaa-fisheries-partners-national-fish-and-wildlife-foundation-support-north-atlantic#:~:text=NOAA%20Fisheries%20is%20providing%20%246,whales%20and%20other%20large%20whales]

2. Participants

As described in the previous section, the scope of the workshop was broad and intended to encompass all vessel sectors and operations that co–occur with NARWs as well as all technology with the potential to reduce NARW vessel strike risk including, but not limited to, vessel design modifications, whale detections, and communications. It was important to have experts in vessel operations, whale behavior, vessel design, technology design, testing and deployment, and agencies with applicable mandates who could integrate technology into management strategies present at the workshop to be able to identify technology with the potential to reduce vessel strike risk.

The goal was to have workshop participants with expertise and experience in all of the areas to be discussed at the workshop, which resulted in casting a wide net to include vessel operators, vessel industry representatives, whale scientists, technology designers, developers and manufacturers, NGOs, international entities, and local, state, federal, and tribal governments. These broad categories are referred to in this report as "sectors." It is worth emphasizing that there is a great deal of diversity within each of these sectors. For instance, the vessel operator sector includes commercial shipping (tankers, cargo, Ro–Ro, tug/push), recreational (pleasure, sailing, fishing), commercial fishing, cruise/passenger/ferry/tour boats, offshore wind development (construction phase, maintenance phase, long term), pilots, dredging/minerals/marine surveying, and government vessels (research, law enforcement, search and rescue, military). The NGO sector primarily includes environmental NGOs but also includes advocacy groups representing industry. It is not realistic to expect a representative from one company, vessel, industry, organization, or entity to speak on behalf of everyone in that group, let alone the larger sector it is nested within. As explained previously, the purpose of the workshop was not to seek consensus or make decisions, but rather to share information and perspectives and collect a range of views. Consistent with this purpose, the workshop pre–registration process was used to seek engagement from many sectors with the goal of having a diversity, but not the universe, of views represented at the workshop.

2.1 In–Person and Remote Participants

Given the high response to the pre–registration and the overall interest expressed in the workshop, the planning team recognized the need for a hybrid workshop with both in–person and remote participants. In order to determine the type of invitation (in–person or remote) to be issued to each individual, potential workshop participants were placed into the following groups[3]:

- Group 0: Support
- Group 1: Presenters, Panelists and SC Members
- Group 2: Key Participants for the Federal Only third day
- Group 3: Invited Experts
- Group 4: Affected Parties
- Group 5: Interested Public

As noted above in Section 1.5, priority for in–person invitations was offered to those in Groups 0–4, and within those groups it was necessary to limit in–person invitations to, in most cases, one individual per entity/organization as designated by that entity/organization. Some sector representatives declined the in–person invitation and chose to participate remotely. Federal agency

[3] Some individuals fell into multiple groups. For example, SC members could also be presenters and key third day participants. For the purposes of the participant list (Appendix 4), they were placed into one of the applicable groups and their attendance was counted once.

staff who were identified as key participants on the third day were recommended for an in–person invitation for the public workshop.

2.2 Composition of Workshop Participants

A total of 586 individuals registered to participate in the workshop with 139 in–person participants and 447 remote registrants (Figure 1; Appendix 4). During pre–registration registrants were asked to self–identify with one of the following sectors: (1) Federal Government; (2) Tech/Engineer/Manufacturer; (3) Vessel Operator/End User; (4) NGO; (5) External Science/Academic; (6) Media; and (7) Other, where registrants were asked to supply more information. Not all registrants provided a sector and some selected multiple sectors. Following the workshop, and upon review of the final registration list, participants were grouped into the following categories: (1) Federal Government; (2) Tech/Engineer/Manufacturer; (3) Vessel Operator/End User; (4) NGO; (5) External Science/Academic; (6) International Government (Canada); (7) State Government; (8) Tribal Government; (9) Congressional; (10) Media; and (11) Other. The Other group included registrants from non–governmental international organizations, councils, lobbyist groups, those who did not provide specific affiliations, and workshop facilitators. Self–identified sectors were prioritized during grouping and any registrants without a self–identified sector were assigned one based on their provided affiliation.

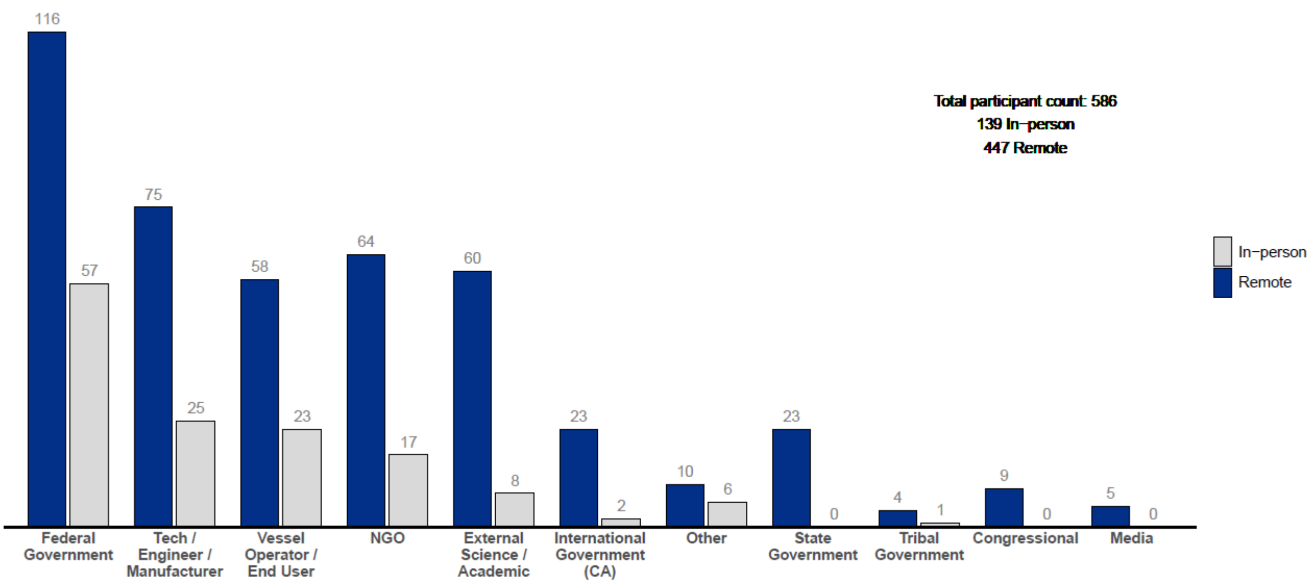

Figure 1. 2024 NARW Vessel Strike Risk Reduction Technology Workshop registrants by sector and participation type. Blue bars represent remote participants and gray bars represent in–person participants. Labels above each column indicate the total number of participants within each category.

2.3 Breakout Sessions

A few weeks prior to the workshop, registered participants were provided with the opportunity to select which of the four concurrent breakout sessions they wished to attend on the second morning of the workshop. After confirming that each breakout session had representatives from the various sectors and vessel operational categories, individuals were assigned to their first choice for breakout sessions. Those who did not respond were assigned to a breakout session, taking into consideration what was known about their interest and expertise and with the goal of achieving balanced and diverse expertise in each session. Those who registered closer to the date of the actual workshop were either assigned to a breakout session randomly or allowed to choose their own. The workshop session focused on NARW detection and classification was held in plenary so all registrants had the opportunity to participate.

3. NARWs and Vessel Interactions

3.1 Background

The successful identification and operationalization of technology to reduce vessel strike risk depends on collaboration among experts in whale biology and ecology, vessel design, operations (including safety considerations), engineering, policymaking, and enforcement. Recognizing that most workshop participants were experts in one, but not all, of these fields, the planning team made efforts to provide background information to workshop registrants to establish a common baseline body of knowledge for collaborative problem solving. Two Fact Sheets discussing the key aspects of NARW biology and ecology and vessel operation relevant to interactions between NARWs and vessels were prepared and made available in advance of the workshop (Appendix 5). In addition, key information was extracted from existing documents (e.g., scientific publications, NOAA reports, etc.) to create Background Papers on NARW vessel strikes and vessel strike risk reduction regulations and programs. These Background Papers were also made available to participants prior to the workshop. Given that the Background Papers were composed of text extracted from other publicly available documents, they are not appended to the report. The most relevant information is provided in the background sections, associated presentations, and elsewhere in this report as appropriate.

3.2 Workshop Session: Background on Vessel Strikes and NARWs and Context for Considering the Role of Technology in Vessel Strike Risk Reduction

Recognizing the importance of this background information for participants to engage effectively in the workshop and that many workshop participants may not have had the time to read the documents provided prior to the workshop, the first morning included presentations covering the following four key topics:

- Caroline Good, NOAA Fisheries OPR, introduced NARW vessel interactions.
- Danielle Cholewiak, NOAA Fisheries Northeast Fisheries Science Center (NEFSC), reviewed key aspects of NARW biology and ecology that influence vessel strike risk.
- Shannon Bettridge, NOAA Fisheries OPR, reviewed lessons learned from implementation of strategies to mitigate vessel strike risk.
- Casey Brennan, NOAA Fisheries Office of Law Enforcement (OLE), provided an overview of how technology is viewed from an enforcement perspective.

Summaries of the presentations are provided below, each followed by the questions posed to the presenters by workshop participants.

3.2.1 NARW Vessel Interactions

Good informed workshop participants that there are approximately 360 NARWs remaining, and that the population continues to decline. NARWs are approaching extinction primarily due to elevated levels of mortality and serious injury resulting from entanglement in fishing gear and from collisions with vessels. Between 2017 (when NOAA Fisheries declared a UME for the species) and the time of this presentation, scientists have documented 123 NARWs killed, seriously injured, or suffering from ongoing sub–lethal injuries in U.S. and Canadian waters. Vessel strike events are categorized as resulting in mortality, serious injury, or non-serious injuries. NOAA Fisheries defines serious injuries as those that are more likely than not to result in the death of the animal. Non–serious injuries are those which are not expected to result in a whale's death. Good explained that a vessel collision or strike is any impact between a part of the vessel including the hull, propeller, or any vessel attachment and a whale. Collisions often result in physical trauma, injuries, and death to the whale and may cause substantial damage to the vessel, including risk of injury to vessel passengers and crew. She explained that collisions with whales are not a new phenomenon, but that the increasing size, speed, and density of vessel traffic along the east coast of North America is exacerbating the problem of vessel strikes for right whales.

Good outlined the two primary types of injuries—lacerations and blunt force trauma—that typically result from collisions between whales and vessels. She explained that lacerations can be caused by contact with propellers, skegs, rudders, and the vessel hull and that blunt force trauma can result in skull, mandible, and vertebral fractures and contusions to the blubber and muscles along with other possible injuries. She reiterated that these injuries could result from contact with any part of a vessel, and in some cases, there is very little external evidence of blunt force trauma injuries.

Good explained that in many cases, dead, floating, or stranded whales are reported by members of the public, local authorities, mariners, or observed during aerial or boat–based whale surveys. In some cases, vessel operators report having struck whales to NOAA or the U.S. Coast Guard (USCG). These events typically involve smaller or more modest sized vessels, which often sustained damage because of the collision. Large vessels are not usually aware that they have struck a whale due to the large difference in mass between the vessel and the whale. Live right whales with vessel strike laceration injuries are often first detected by researchers as part of aerial or boat–based survey operations, although they have also been reported by members of the public or identified via social media photo or video posts. However, unlike laceration injuries, blunt force trauma injuries rarely leave visible external marks on live whales—meaning there is no reliable way of visually identifying blunt force trauma injuries in live whales. Good reported that most right whale vessel strikes go undetected with only about 36% of all NARW mortalities (range–wide) detected/documented by researchers.

NOAA Fisheries, as Good stated, makes every effort to comprehensively document right whale strike events, including performing full necropsies on dead whales whenever possible. NOAA Fisheries has documented 27 lethal right whale vessel strikes since 1999 occurring all along the U.S. East Coast. Calves, juveniles, and females are disproportionately represented in the strike data relative to their proportion in the population overall (Figure 2). She further detailed that documented vessel strikes involve a variety of vessel sizes and are not limited to one vessel size class (Figure 2).

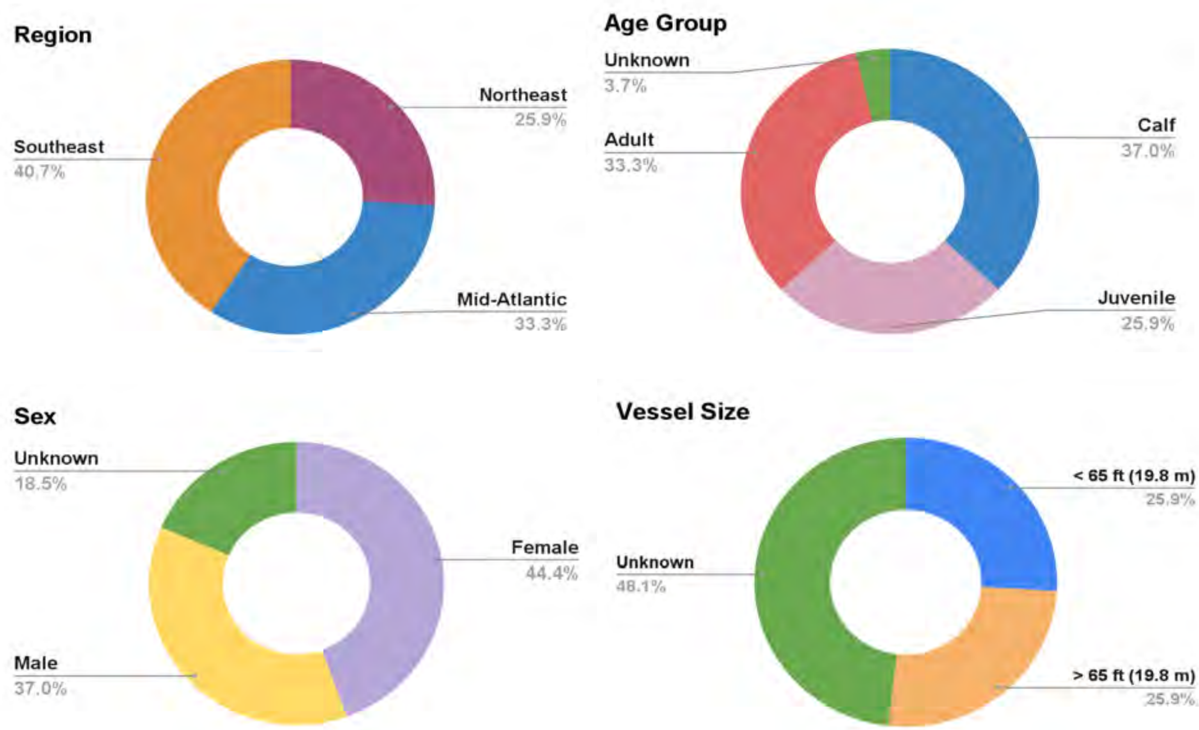

Figure 2. Lethal NARW vessel strikes documented in U.S. waters between 1999 and 2024 (N=27; as presented by Good at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop).

Good explained that the substantial overlap of right whale habitat with extremely dense vessel traffic provides the opportunity for NARW vessel strikes (Figure 3, right panel). NARWs inhabit U.S. waters year–round with nearly the entire population found in the U.S. during late fall through early summer. The Northeast region, off New England, is a primary foraging habitat for right whales; the Mid–Atlantic between NY and NC serves both as a migratory and foraging habitat; and the only known NARW calving ground is found off the Southeast coast in the nearshore waters off northern Florida, Georgia, and South Carolina. This same range is also characterized by extensive commercial, industrial, and recreational vessel traffic. In fact, these areas have some of the densest vessel traffic anywhere in the world with numerous large ports and a coastal geography conducive to ocean access.

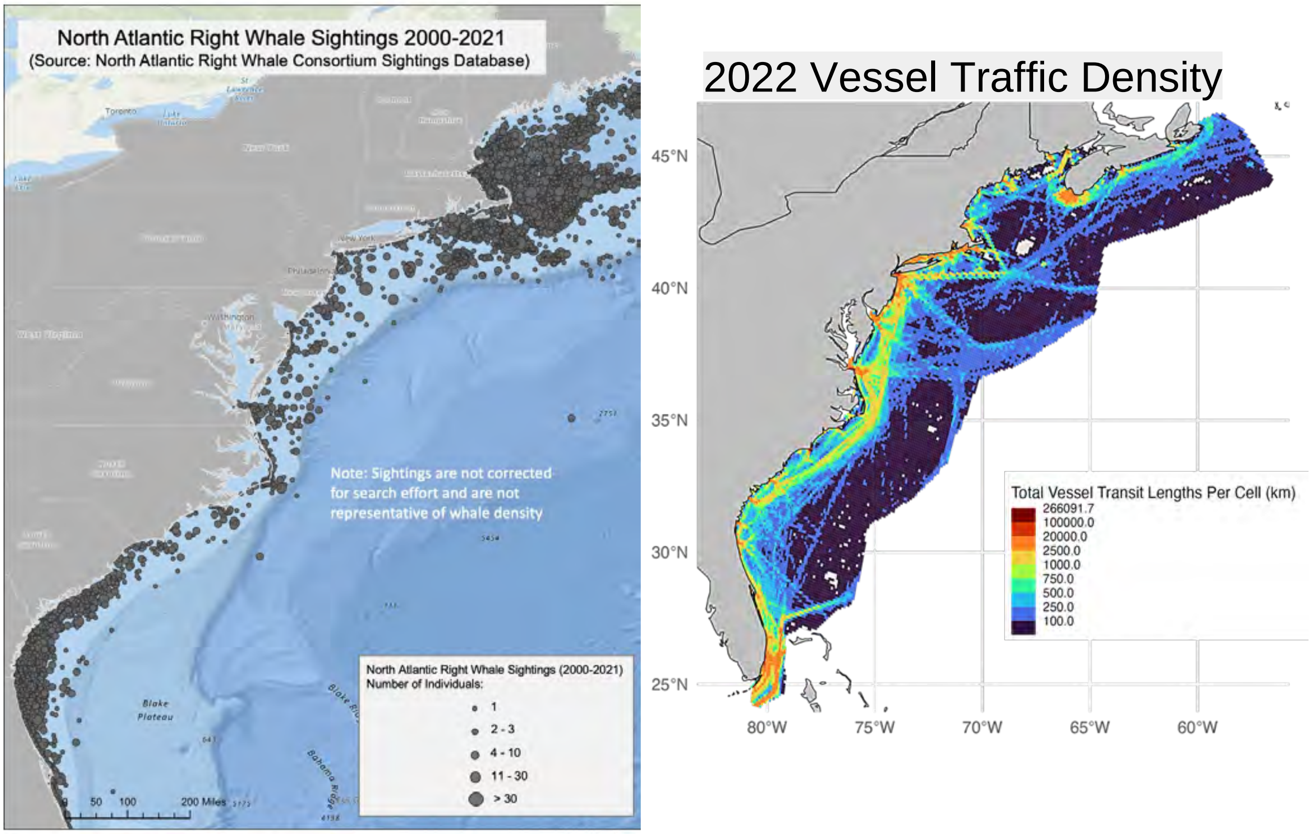

Figure 3. Left panel: Distribution of NARW sightings from 2000–2021. Right panel: Vessel transit density for AIS–carrying vessels detected in 2022 (as presented by Good at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop).

Good provided an overview of 2022 Automatic Identification System (AIS) vessel data for U.S. waters along the Atlantic coast to provide workshop attendees with insights into the sizes, types, and activities of vessels operating along the U.S. East Coast (Figure 4). She cautioned that these data include only vessels that carry AIS and have it turned on, and that there are many vessels that are not required to do so and are therefore not captured within her summaries. Vessels represented in the AIS data ranged in reported size (2–396 meters) and included the following types:

- Commercial (commercial fishing, pilot, passenger vessels)
- Industrial (dredging, towing/pushing, port tenders/work vessels)
- Government (law enforcement, military)
- Large Vessels/Trade (general cargo, other cargo, tanker, bulk carrier, vehicle carriers, container, cruise ships)
- Recreational (sailing, rec/pleasure)
- Other (including search and rescue, research, undetermined)

Examining the number of unique vessel types, there are thousands of recreational and sailing vessels, commercial fishing boats, and undetermined vessels active off the U.S. East Coast. Undetermined vessel types are those which may have reported more than one vessel type and thus are challenging to identify. Further, there are a substantial number of active tankers and bulk carriers. Container ships, towing/pushing vessels, tankers and commercial fishing vessels make up a large proportion of the on–water transit distance. Other vessels including sailing and recreational vessels, passenger vessels, and bulk and vehicle carriers also represent a substantial portion of total vessel transit distance.

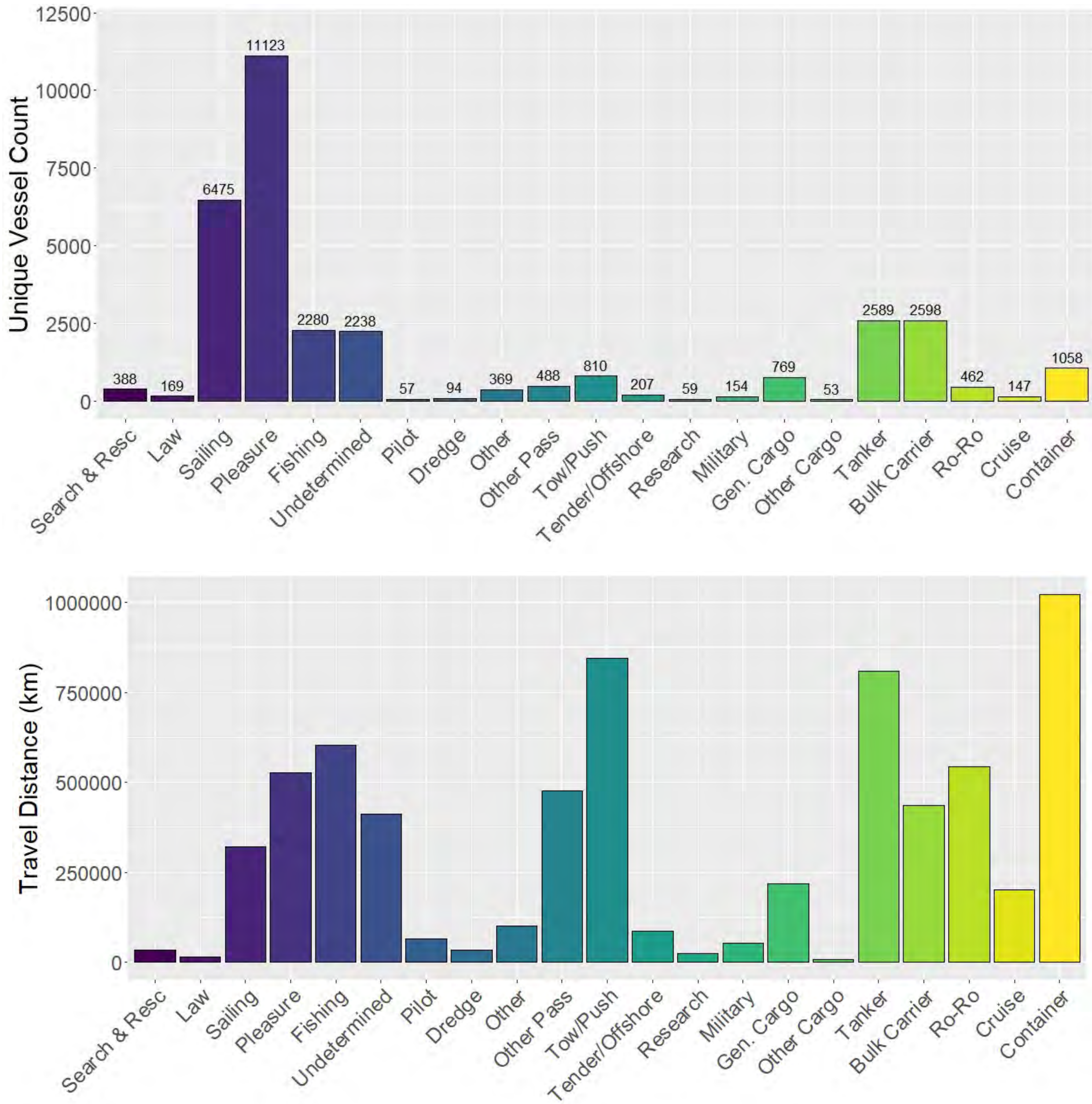

Figure 4. Top panel: Number of all unique AIS–carrying vessels detected along the U.S. East Coast in 2022. Bottom panel: Total travel distances, in kilometers, for all AIS-carrying vessels detected along the U.S. East Coast in 2022 (as presented by Good at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop).

Good concluded by cautioning that the problem of vessel strikes is likely to grow unless addressed systematically and coastwide. She reminded workshop participants that although the workshop was focused on NARWs, vessel strikes impact all large whale species in U.S. waters. She noted that just in the past couple of weeks both NARW and humpback whale vessel strike deaths had been documented. She warned that the situation will only get worse without change given the expanding industrial, commercial, and recreational use of coastal waters and, hopefully, increasing large whale populations due to successful conservation initiatives.

3.2.2 Role of NARW Biology and Ecology in Vessel Strike Risk

Cholewiak opened her presentation with a map depicting the geographic range of the NARW. Their distribution spans the entire eastern seaboard of the U.S. and Canada with their foraging habitat extending north of Cape Hatteras and into the Gulf of St. Lawrence and their calving grounds extending south of Cape Hatteras through central Florida. Providing the example of an adult female NARW, which was observed traveling 431 nautical miles over an 8–month period, Cholewiak explained that NARW are highly mobile and transit through many habitats and risk landscapes. Their movement is variable and they can travel long distances in short periods of time, as demonstrated by presented tag data. Both visual sightings and tagging data demonstrate that individuals may spend time very close to shore, which increases their risk of being struck by a vessel. She shared a visualization of the migratory path of a 1–year old NARW satellite–tagged off the Virginia/North Carolina coast in March 2021 overlapping with AIS–carrying vessel traffic[4]. Cholewiak noted that while NARWs have a strong affinity for coastal habitats, they have also been observed at the shelf edge, primarily in the spring, and occasionally very far offshore in the Central North Atlantic Ocean.

Cholewiak explained that an additional component of NARW behavior impacting their exposure to vessel strikes is that they can form large surface aggregations, which can persist for weeks or dramatically change in size over the course of a few days as whales disperse. Cholewiak shared an example from January to May of 2023 when 201 unique NARWs (approximately 56% of the entire population) were identified in aggregations offshore of southern Massachusetts. The data also demonstrated that aggregations can exhibit high individual turnover. She also presented data from aerial surveys conducted by the Center for Coastal Studies in Cape Cod Bay documenting the same NARWs returning annually to the area, indicating that NARWs exhibit strong site fidelity. Strong site fidelity was also documented in the Gulf of St. Lawrence with 60% of the individual NARWs being sighted in at least 3 of 5 years of a previous study (2015–2019; Crowe et al., 2021).

Cholewiak reviewed scientific literature documenting that NARWs are frequently at or near the surface when skim feeding and when calving/nursing, which places them at increased risk of vessel interactions. She also presented data from a whale equipped with a biologging suction-cup tag, showing the variability in its dive profile across a 12–hour period. Seasonal variability in dive behavior affects both the risk of vessel strike and the probability of detection (depending on the method of detection being used). Furthermore, despite spending significant time at the surface in certain areas or times of year, NARWs are difficult to detect visually due to their low profile, dark coloration, and lack of a dorsal fin. This has implications both for strike avoidance and monitoring. Cholewiak reviewed additional scientific literature demonstrating that sound production rates can be low and/or variable depending on whale behavior, habitat, season, and demographic. She presented estimated probabilities of detection of localized NARW upcalls, demonstrating that while passive acoustic monitoring (PAM) is an important and powerful detection tool, it also has limitations, as do all monitoring tools.

Cholewiak concluded her presentation by summarizing the following life history traits that lead to high risk of vessel interactions for NARWs: (1) very mobile; (2) widespread distribution; (3) high degree of interchange but also strong fidelity to some habitats; (4) can spend a high proportion of time near the surface; and (5) can be difficult to detect visually and acoustically.

---

[4] NOAA Fisheries. 2021. Reducing Vessel Strikes to North Atlantic Right Whales. [Available at https://www.fisheries.noaa.gov/national/endangered-species-conservation/reducing-vessel-strikes-north-atlantic-right-whales]

3.2.3 Questions for Clarification Regarding Presentations from Good and Cholewiak

In response to a question from Mike Waine, American Sportfishing Association, Good explained that due to the close monitoring of the population, only 36% of all right whale deaths are detected (Pace et al., 2021). She explained that the Agency can identify almost every single animal and uses modeling to evaluate which ones went missing from the population. Matthew Zimmerman, FarSounder, noted that AIS data is very informative, but he reiterated that when used to estimate vessel traffic it underestimates small vessels since most small vessels are not required to transmit their position over AIS (and therefore do not want the expense of the transmitting equipment). However, he noted that many small vessels have AIS receivers, which would allow them to receive virtual electronic aids to navigation messages. Good agreed that not all vessels are required to use AIS, so the information on vessels is an underestimate, particularly of those vessels less than 65 feet. Most vessels over 65 feet in length are federally mandated to carry and transmit AIS.

Joshua Grier, Yamaha Motor Corporation, asked whether the same site fidelity was observed for calves once they have separated from their mothers. Cholewiak responded that that varied by individual with some calves exhibiting fidelity to the foraging area used by their mothers. In response to a question from Blanca Montoya, Oceaneering International, about aerial survey effort and tagging, Cholewiak explained that there is extensive aerial survey effort in the U.S. and Canada. She further replied that more effort has been directed at the deployment of biologging suction cup tags to collect high-resolution behavioral data, and less effort has been conducted to deploy implantable satellite telemetry tags due to animal health concerns. One participant asked how spread out the NARW aggregations are and Cholewiak responded that it depended on how concentrated or patchy the food is distributed, but that at certain times of year, individuals can be found distributed from Florida to the Gulf of Maine.

Responding to a question from Jill Head, Bureau of Safety and Environmental Enforcement (BSEE), regarding the population's trend, Cholewiak explained that the NARW population decline coincided with shifts in their habitat use around 2010–2011 in the U.S. and Canada. She noted that NARWs moved into areas that did not have protections in place to reduce the likelihood of vessel strikes and fishing gear entanglements, which likely contributed to the increase in mortality. Samantha King, Protected Seas, asked what is known about how NARWs behave in the vicinity of vessels and how vessels behave in the vicinity of NARWs. Good responded that NOAA Fisheries does not have a full understanding of how NARWs react to vessels. She further noted that no mariner wants to strike a whale, so if they can detect it and are able to safely do so, they tend to take evasive action. She noted, however, as explained by Cholewiak, that NARWs can be difficult to detect.

Jason Roberts, Duke University, suggested that the presenters address why it is not possible to just tag and track every NARW. Good directed workshop participants to a report from a recent NARW tagging workshop, noting that it is unrealistic to tag and track the entire population for many reasons including potential health impacts, inability to approach all individuals, and duration limitations of current tagging technology[5].

3.2.4 Lessons Learned: Vessel Strike Mitigation Strategies

Bettridge identified three options for mitigating NARW vessel strikes: (1) reducing the overlap between vessels and whales; (2) vessel speed reductions; and (3) emerging technology/engineering approaches. Outreach and education, enforcement of mandatory measures,

[5] Marine Mammal Commission (MMC). 2024. North Atlantic Right Whale Tagging Workshop. [Available at https://www.mmc.gov/events-meetings-and-workshops/other-events/narw-tagging-workshop/]

monitoring, continued research to inform management, and the evaluation of management measures were identified as necessary concurrent activities.

In 1997, NOAA Fisheries implemented a regulation prohibiting approaching within 500 yards of a NARW and requiring vessels that find themselves within 500 yards of a NARW to steer a course away and immediately leave the area at a safe speed (50 CFR 224.103(c)(1–3)). Exceptions are allowed if compliance would create an imminent or serious threat to a vessel (50 CFR 224.103(c)(3)). Bettridge further detailed that, in addition to the 500 yard rule, NOAA Fisheries collaborated with the USCG, National Marine Sanctuaries (NMS), and International Maritime Organization (IMO) to develop the following three types of routing measures designed to reduce the risk of vessel strike by separating whales and vessels in time and space: (1) modification of the Boston Traffic Separation Scheme (TSS) to avoid high–use large whale habitat; (2) creation of Recommended Routes in seasonal high–use right whale habitats in Cape Cod Bay and off northern Florida/southern Georgia; and (3) creation of a seasonal Area to be Avoided in the Great South Channel east of Massachusetts.

Bettridge reported that NOAA Fisheries first implemented mandatory vessel speed restrictions in 2008. The Speed Rule requires most vessels 65 feet or longer to transit at or under 10 knots within designated Seasonal Management Areas (SMAs). Certain vessel categories including military vessels, federally owned or operated vessels, and law enforcement vessels actively engaged in enforcement or search and rescue responsibilities are not subject to the Speed Rule as their impacts are evaluated and mitigated through other avenues. Additionally, the Speed Rule includes a safety deviation provision which allows vessels to exceed the 10 knots speed limit in certain circumstances, such as if they encounter severe maneuverability constraints.

Bettridge explained that concurrent with the release of the 2008 Speed Rule, NOAA Fisheries also created a voluntary Dynamic Management Area (DMA) program. These DMAs are aimed at protecting visually detected whale aggregations (defined for the purposes of the DMA program as groups of three or more whales within a discrete area) in areas/times not captured by the static SMAs defined in the Speed Rule. NOAA Fisheries provides maps and coordinates to vessel operators indicating areas where right whales have been detected. Under the DMA program, for a period of 15 days after a detection, mariners are encouraged to avoid these areas or reduce speeds to 10 knots or less while transiting through them. Right Whale Slow Zones are an additional voluntary program that NOAA Fisheries recently implemented and are identical to DMAs when triggered by visual sightings but may also be based on acoustic triggers. NOAA Fisheries announces Right Whale Slow Zones and DMAs to mariners through multiple communication channels. All boaters from Maine to Virginia, and any additional interested parties, can sign up for email or text notifications about the latest Right Whale Slow Zones. Bettridge noted that mariner cooperation with these programs remains poor.

In 2013, NOAA Fisheries committed to publish a report evaluating the conservation value and economic and navigational safety impacts of the 2008 NARW vessel speed regulations. The report was finalized in June 2020 (National Marine Fisheries Service, 2020) and evaluates four aspects of the right whale vessel Speed Rule: biological efficacy, mariner compliance, impacts to navigational safety, and economic cost to mariners. Key findings from this assessment include: (1) NARW mortalities/serious injuries have declined since the Speed Rule was put in place, but additional action is warranted; (2) compliance with the Speed Rule is generally high; (3) there is limited cooperation with voluntary DMAs; (4) no impacts on navigational safety were documented; (5) yearly costs to industry are approximately $28.3 to $39.4 million; and (6) there is a need to address all vessel types involved in lethal events.

Bettridge reviewed current science and outreach activities being undertaken by NOAA Fisheries to conserve NARW, including efforts to understand whale distribution through aerial and vessel surveys, PAM, habitat modeling, and drone research. Vessel traffic studies and a port access route study are also being conducted to improve the understanding of vessel distribution. Outreach efforts including alerting mariners to the presence of whales, issuing vessel speed advisories, and a range of educational efforts are ongoing. She reviewed the many notification methods being used by NOAA Fisheries including, but not limited to, NOAA weather radio, Broadcast Notices to Mariners, compliance guide brochures, Prudent Mariner CDs, mariner training modules, NOAA nautical charts, whale alerts, and the NOAA Fisheries' vessel strike reduction web pages.

Bettridge identified several lessons NOAA Fisheries has learned from implementing the above approaches, including that measures must be tailored to the unique characteristics of the problem and that the effectiveness of measures must be monitored. She noted that collaboration with the mariner community and others is essential and that mandatory measures must be enforceable. Bettridge mentioned that, while it appears that the vessel Speed Rule is helping, it is not sufficient, and voluntary measures are not reducing risk. Finally, she noted that all vessel types and classes may be involved in lethal vessel strikes. Therefore, it is important to consider risk reduction strategies across all vessel types and classes.

Experience in managing vessel strike risk has also helped identify key characteristics of effective risk reduction tools. Bettridge said tools which separate whales and vessels in time and space are effective at preventing strike events and so are those that reduce the chances of a lethal outcome should a strike event occur. She also noted that tools which increase the chance that one or both parties can detect a potential interaction with enough time and opportunity to avoid contact would also be effective in reducing risk. Finally, Bettridge emphasized the importance of evaluating the effectiveness of risk reduction options and further noted that any such evaluation requires assessing the performance and efficacy of each part of the Risk Reduction Chain.

3.2.5 Questions for Clarification Regarding Bettridge's Presentation

Clay Diamond, American Pilots' Association (APA), stated that the figures regarding percentage of vessels not complying with the vessel strike Speed Rule are misleading as they include vessels legally using the regulatory navigation safety deviation clause to appropriately exceed 10 knots. He further commented that saying there is no impact on navigational safety from the 10 knot speed restriction is also misleading as it ignores the times vessels had to utilize the navigation safety deviation clause to ensure navigational safety of the vessel. Jeff Parker, Kirby Corporation, recommended more outreach with companies and parent corporations to work with them to establish a culture of compliance, recognizing that individual mariners may be under pressure from their companies to maintain their speed to meet schedules or reduce economic impacts.

In response to a question about voluntary vessel strike risk reduction measures on the U.S. West Coast, Bettridge said that voluntary measures specific to NARW have not been successful but agreed that the voluntary measures implemented on the U.S. West Coast have been more successful. She further stated that there might be lessons learned from those programs that could be applied to incentivize compliance with voluntary measures on the Atlantic Coast. Peter Thomas, Marine Mammal Commission (MMC), observed that evaluating how to execute a voluntary system of coastwide collaboration is a greater challenge on the Atlantic Coast given differences in bathymetry, the number of ports, and how ports are managed compared to the Pacific Coast. Mark Baumgartner, Woods Hole Oceanographic Institute (WHOI), also commented that air quality issues on the West Coast are driving a lot of the initiatives for vessels to slow down, providing a different context for incentives.

3.2.6 Considering Technology from an Enforcement Perspective

Brennan explained that enforcement is essential to make measures for fisheries and protected species management effective. He noted that enforcement actions are the tool of last resort but are essential for creating a level playing field. As of February 27, 2024, 66 cases have been charged for violations of the speed restrictions (50 CFR 224.105) that occurred during the 2021/22 and 2022/23 seasons (November to July). During these same seasons, NOAA assessed over $1 million in penalties for violations of the speed restrictions.

Brennan encouraged workshop participants to consider how any technology tools or systems being considered could be enforced. He said effective regulations are simple, easy to understand, concise, and must be limited in number. He discussed challenges with gear requirements and noted some potential parallels with vessel strike risk reduction technology. Brennan provided the example that regulations using ocean bottom contours as a boundary are challenging to enforce compared to those using a box or a circle because set boundaries are easier for mariners to comply with. He offered the view that technology can play a major role in vessel strike risk reduction if done right. He recommended that participants consider the standard of the burden of proof and how a mariner could prove they complied with any technology requirement or how the agency could prove lack of compliance to the standard of admissibility in court. Finally, Brennan shared with workshop participants that the NOAA Fisheries Office of Law Enforcement (OLE) is interested in and open to ideas for new technology to facilitate enforcement such as checking gear that is underwater and enforcing vessel speed rules in the absence of AIS data. He also noted that they are currently investigating shore–based radar and uncrewed aerial vehicles (UAVs; commonly also called drones) and long duration UAVs.

3.2.7 Questions for Clarification Regarding Brennan's Presentation

Hannah Mark, Fisheries and Oceans Canada (DFO), asked for more details on the challenges referred to for AIS. Jorge Arroyo, USCG, aided in response to this question and stated that USCG lacks legal authority to expand AIS carriage to recreational boats or commercial vessels below 65 feet. In response to questions from Alex Parker, Astraeus Ocean Systems, and Shadi Awwad, Oceaneering International, about underwater vehicles used by NOAA Fisheries OLE, Brennan stated that OLE is currently issuing contracts for the use of underwater vehicles for enforcement and exploring smaller UAVs that may be more viable for the nearshore environment, and that they would be interested in learning more about other uncrewed systems that could be used for enforcement.

3.3 Online Poll

At the end of the session providing background on vessel strikes and NARWs and context for considering the role of technology in vessel strike risk reduction, participants were provided the opportunity to indicate through an online poll which of the following areas they wanted to learn more about as it relates to vessel strike risk reduction: (1) NARW biology; (2) NARW vessel interactions to date; (3) vessel strike risk reduction strategies; (4) technology from an enforcement standpoint; (5) vessel design and operations; or (6) other. Participants were permitted to select more than one response. A total of 261 workshop participants, including 104 in–person and 157 remote attendees, participated in the poll and self–identified in the sectors as follows: Government (N=102); Vessel Operator or Industry Representative (N=41); NGO (N=41); Tech Engineer/Manufacture (N=37); External Scientist/Academia (N=27); and Other (N=13). As illustrated below in Figure 5, the two areas respondents most wanted to learn more about as it relates to vessel strike risk reduction were: risk reduction strategies (N=199) and technology from an enforcement standpoint (N=118).

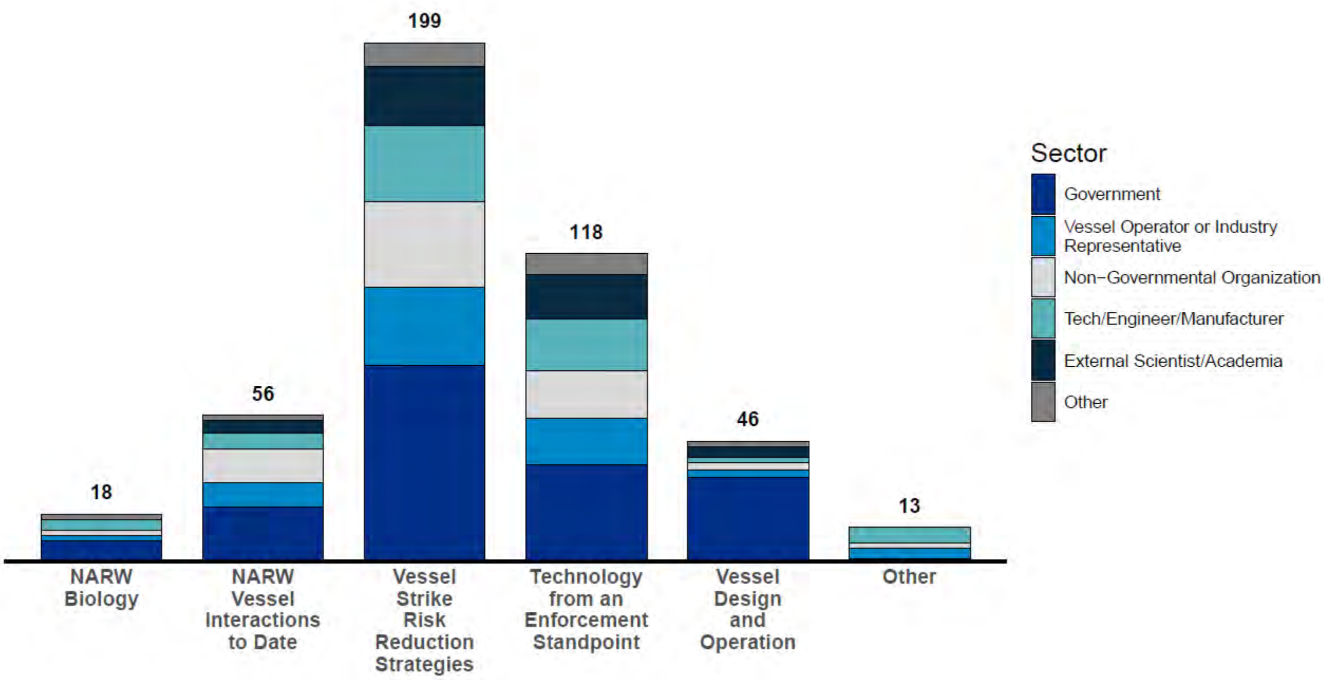

Figure 5. Areas poll respondents want to learn more about as it relates to vessel strike risk reduction. Collected during the 2024 NARW Vessel Strike Risk Reduction Technology Workshop. Labels above each column indicate the total number of poll respondents that chose that response. Bars are colored in accordance with the sector composition of those selecting that option.

4. Risk Graphic, Risk Scenarios, and Risk Reduction Chain Components

The workshop sought to consider all ways in which technology can reduce vessel strike risk for any vessel operating in areas overlapping with NARWs. Because of this broad scope, establishing a framework to organize information and discussion was key to ensuring the workshop was a success. The workshop planning team, with guidance from the SC, focused on four key frameworks for the workshop. Three of the frameworks (referred to as Risk Factors, Risk Reduction Scenarios, and the Risk Reduction Chain) were presented by Mary Colligan during the pre-workshop webinars and on Day 1 of the Workshop. The fourth framework, which explored the need to match vessel characteristics and operational needs (see section 4.4), was not presented as a structured framework due to complexity, and was instead incorporated into questions and discussion points raised throughout the workshop. Workshop participants were provided the opportunity to comment on these frameworks during the pre–workshop webinars, through poster boards and verbal discussion at the workshop, an online form (N=17), and using the question–and–answer feed available to remote participants.

4.1 Framework 1: Risk Factors

The planning team recognized the value of identifying the risk factors that influence the probability of NARW vessel strike mortality and/or the efficacy of risk reduction technology. To illustrate the complexity of these factors, and based on scientific literature, the planning team developed the Risk Factor graphic below (Figure 6). The center of the graphic depicts the overlap in time and space of vessels and NARWs, which creates the opportunity for a vessel strike. There are many different scales at which one can view time/space—from whether a vessel operates seasonally in an area where NARWs congregate to the draft of a specific vessel and the depth at which a NARW feeds at or near the surface. Both the probability of a vessel strike and the effectiveness of risk reduction technology may be influenced by vessel characteristics and operation; environmental conditions; the biology, ecology, and behavior of NARWs; and the behavior and choices of mariners.

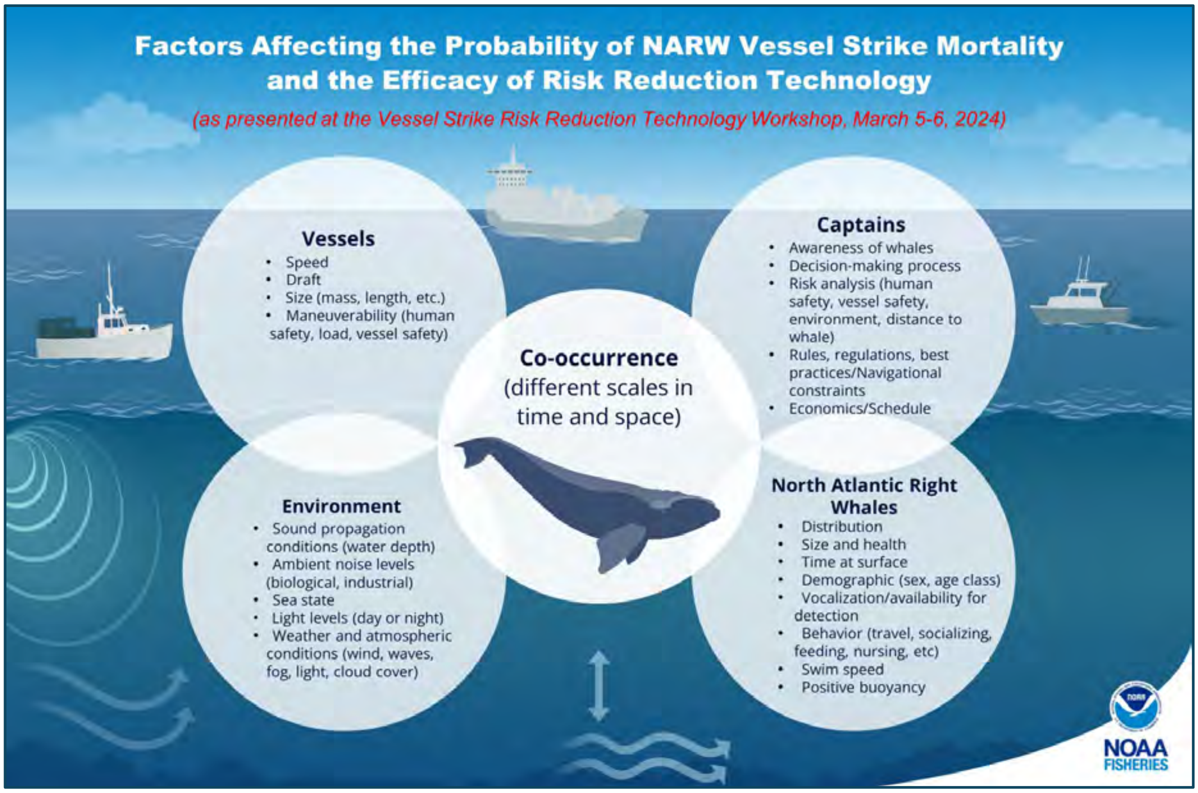

Figure 6. Risk Factor Graphic as presented at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop.

Once the factors that affect vessel strike risk are identified, then one can begin to determine which factors could be influenced by technology. For instance, if a mariner's awareness of whales influences the likelihood that a whale will be identified and that an avoidance action will be taken, then the ability of detection technology and dissemination and integration technology to increase the likelihood that a mariner will be aware of the presence of a whale can be examined. However, it is important to note that environmental conditions such as sea state, light (day, dusk, night), or atmospheric conditions (fog, precipitation, etc.) may affect the ability of a specific technology to detect a whale, and therefore its risk reduction efficacy at that moment. One must also consider the impact of whale behavior on the cue being used by a particular sensor. For instance, mothers and calves have relatively low vocalization rates in the southeast U.S., which reduces their detectability to PAM tools in this region, whereas NARWs engaged in socializing behavior may vocalize at much higher rates leading to higher availability for acoustic detection.

Workshop participants were provided with the opportunity to ask clarifying questions about the Risk Factor graphic and to recommend the addition of risk factors to the graphic. One workshop participant asked about how the Risk Factor graphic addressed interactions between the various components, such as between vessel characteristics and whale behavior. It was acknowledged that the graphic is a simplistic picture of the components affecting risk that is intended to illustrate that they all influence the likelihood of a vessel strike but there are interactions between and among all the factors. For instance, the draft of a vessel and the behavior of a whale both influence whether the whale is in the strike zone and vulnerable to a vessel strike. Additionally, environmental conditions such as sea state can influence whether a whale can be detected through visual means and whether it is safe for a mariner to change course or speed.

In terms of vessel–associated factors with the potential to affect the probability of NARW vessel strike mortality or the efficacy of risk reduction technology, participants suggested the addition of the following factors:

- Ability to integrate technology (i.e., compatibility with other onboard systems)
- Onboard power supply and connectivity
- Vessel design (e.g., bow/hull shape, propeller design)
- The field of view available for use in whale detection (e.g., deck height, obstructions)
- Subsurface and on–deck acoustic characteristics
- Consideration of the abundance/density of vessels in the area
- Type of activity or work being undertaken by the vessel

In terms of captain–associated factors, workshop participants recommended expanding this factor to include crew and adding the following factors:

- Whether the captain and crew have been trained in the use of onboard technology and viable mitigation actions
- The influence of mariner culture and corporate guidance on the decision–making of captains and crew
- Crew size as it influences the ability to have a dedicated observer
- Crew experience in identifying/detecting whales
- Likelihood of compliance due to such factors as broad acceptance of the need, probability of non–compliance being detected, and cost of non–compliance

Participants also provided feedback on environmental–associated factors with the potential to affect the probability of NARW vessel strike mortality or the efficacy of risk reduction technology. One participant recommended adding the depth of water on or adjacent to the vessel route. In terms of NARW–associated factors, the addition of regional variation was recommended given how it impacts NARW behavior including time spent at the surface, vocalization, and other behaviors that affect the detectability of whales. Finally, a participant recommended including the size and placement of ports and wharves, recognizing their influence on vessel traffic. Modifications to the Risk Factor graphic considering these recommendations are discussed and presented in a modified graphic contained in Chapter 12.

One workshop participant expressed general concern about the Risk Factor graphic as a whole and recommended that the "efficacy of risk reduction technology" be removed from the title as, in their view, the graphic was just focused on detection and not mitigation. To this point, the graphic does identify several factors that influence the ability to detect a whale and the probability of a strike even if a whale has been detected. For instance, vessel speed and maneuverability must be considered alongside the reliable detection range of a technology to determine whether a detection can be made in time for effective evasive action to be taken or not. Large vessels, for instance, may detect a whale, but if not at sufficient range, the vessel may not be able to change course in time. Factors such as safety, navigational rules and regulations, and navigational constraints do not affect the detectability of a whale, but they do affect a mariner's ability to reduce strike risk through a change in course, speed, or other action. While it is true that environmental factors affect detection, it is important to recognize that specific environmental conditions have varying impacts on the efficacy of specific detection technology. For instance, ambient noise levels reduce the efficacy of PAM to detect NARW calls but do not affect the ability of thermal/infrared (IR) to detect a whale, whereas fog does not affect PAM technology but reduces the efficacy of thermal/IR technology.

4.2 Framework 2: Risk Reduction Scenarios

The second framework identified by the SC as a useful way of considering how technology can reduce vessel strike risk was through the lens of Application Scenarios. Specifically, the planning team identified and used three Risk Reduction Application Scenarios—Static, Dynamic, and Vessel–Specific—as a method to organize the evaluation and discussion of technology throughout the workshop. Risk reduction actions in seasonal static areas are appropriate where there is high confidence that NARWs will be present and at risk of vessel strikes. Because these zones are used in more predictable locations and times, technology tools that require greater time for processing are more suited to a Static Scenario, such as traditional modeling. Dynamic risk reduction actions occur in response to near–real–time detections of NARWs outside of static zones. Technology tools applicable to the Dynamic Scenario are those that provide actionable information to mariners quickly to inform navigational decisions that reduce the probability of a strike. Finally, technology can be incorporated into risk reduction systems internal to a vessel, termed the Vessel–Specific Scenario. This Scenario can include whale detection technology onboard vessels that can inform real–time navigational decisions but can also include changes in vessel design intended to reduce strike lethality. Some technology may be useful in informing more than one of these Scenarios, and a comprehensive NARW vessel strike strategy will most likely include components from all three Scenarios.

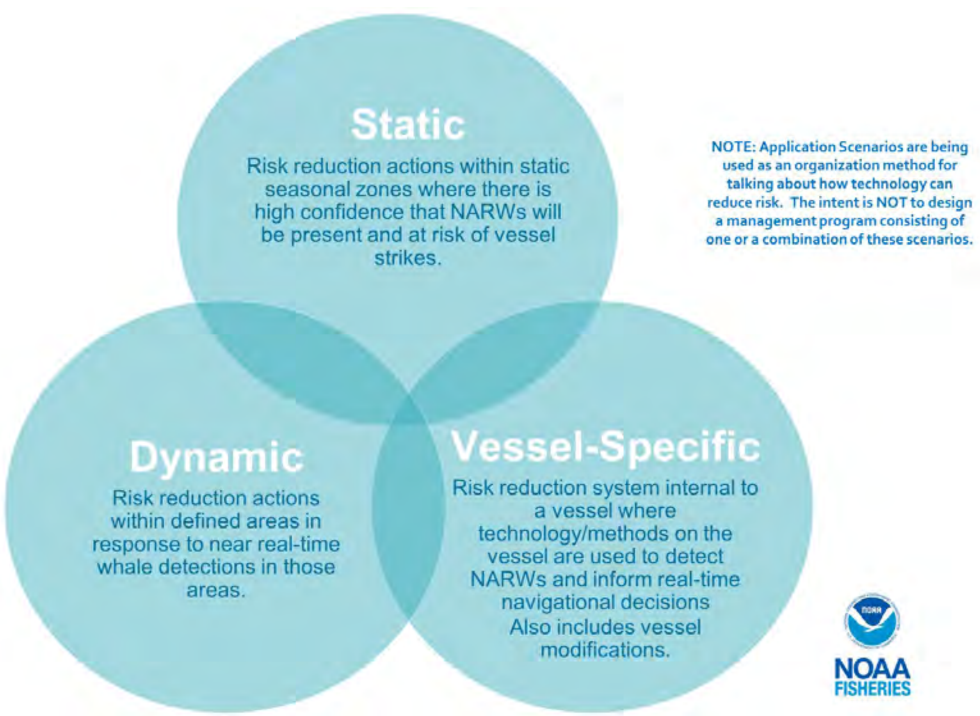

Figure 7. Application Scenarios as presented at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop.

The discussion of the Application Scenarios starts to bridge the gap between vessel profiles and characteristics of technology or systems of technology identified by workshop participants. When discussing different vessel sectors and operations as well as specific technology, effort was made to specify whether they were suitable for the Static, Dynamic, or Vessel–Specific Scenario. For instance, the low maneuverability and large size of commercial shipping vessels make the Static Scenario more feasible than the Dynamic or Vessel–Specific Scenarios because these vessels typically cannot adjust their speed, course, and/or operational state as readily as other vessel types. By contrast, the Dynamic Scenario is more feasible for smaller and more maneuverable recreational vessels. Some technology, such as vessel design or thermal/IR cameras, were discussed under the Vessel–Specific Scenario. Satellite imagery and environmental DNA (eDNA) both involve time delays related to data collection and analysis, which makes them currently incompatible with a Dynamic Scenario.

Workshop participants were asked whether the three proposed Application Scenarios sufficiently capture the different potential paradigms for using technology to reduce NARW vessel strike risk. The majority of those who responded confirmed that the Scenarios did sufficiently capture the paradigms.

One commenter asked if there should also be a cultural paradigm for risk reduction that is based around education and awareness. Education and awareness is viewed as playing a key role in each of the three technology–informed Risk Reduction Scenarios and not as an independent scenario. That same workshop participant asked whether the three paradigms should be presented equally or weighted in terms of their effectiveness. As noted previously, the Scenarios were being used simply as an organizational framework. The role of each of the Scenarios and their relative contribution to vessel strike risk is likely to vary depending on geographic location, vessel type, whale behavior, and other factors identified in the Risk Factor Graphic (Figure 7). One individual asked how the Vessel–Specific Scenario dealt with the unseen whale, the one just below the surface or surfacing near the vessel. All three scenarios must deal with the challenge of undetected whales and could incorporate technology to detect subsurface whales. One commenter suggested that one way to reduce risk is to enhance NOAA OLE enforcement of existing regulations, either in Static or Dynamic Scenarios. The commenter suggested modeling scenarios with much bigger penalties and/or modeling scenarios with more effective enforcement, such as those closer to shore where Joint Enforcement Agents could participate. While some workshop participants appear to be providing input on a broader question of what additional actions can be taken to reduce vessel strike risk, it is important to note that these Application Scenarios were constructed to consider ways in which technology, and not such things as outreach and enforcement, can be applied to reduce vessel strike risk.

4.3 Framework 3: Risk Reduction Chain Components

There are multiple opportunities for incorporating technology in vessel strike risk reduction efforts and it must be noted that risk reduction can only be achieved if a series of actions are completed and ultimately a decision is made that results in a strike being avoided. This concept of a series of linked necessary actions (referred to as Risk Components) was used to create the Risk Reduction Chain framework in consultation with the SC and the Whale and Vessel Safety (WAVS) Taskforce[6]. The Risk Reduction Chain (Table 1) was used as a reference when identifying different places where technology could influence risk and as a reminder that action across all links, and connections between them, is necessary to achieve effective risk reduction. Workshop participants were asked to consider the Risk Reduction Chain as a framework when describing the risk reducing

[6] The WAVS Taskforce is composed of a variety of interested parties convened with the goal of 'exploring all possible options to bridge the gap between monitoring equipment and boat owners/operators', particularly as it relates to the North Atlantic right whale. The stated mission of the WAVS Taskforce is to identify, develop, and implement technology and monitoring tools in the marine industry and boating community with the goal of mitigating the risk of vessel strikes to all marine mammals, with special attention to NARWs. More information can be found on their website wavstaskforce.com.

technologies and their connection with each other as well as to help in identifying any missing steps.

Table 1. Risk Reduction Chain Components and the Application Scenarios to which they are relevant as developed for the 2024 NARW Vessel Strike Risk Reduction Technology Workshop.

RISK COMPONENT	DESCRIPTION	APPLICATION SCENARIOS
Modeling spatial and temporal density of NARWs	Includes technology and methods to forecast the spatial and temporal density of NARWs. These methods primarily inform the Static Scenario but may have applicability to the Dynamic Scenario.	Static Dynamic (partially)
Detect and classify NARWs	Includes: (1) technology and methods to detect whales; (2) technology and methods to promptly and accurately classify detections to inform near–real–time risk reduction actions; and (3) methods to consistently evaluate performance of technology.	Static Dynamic Vessel–Specific
Aggregate classified detections/ forecasts	Collecting forecasts and classified detections to a central clearing house (includes establishing quality assurance/quality control (QA/QC) procedures for accepting data, handling of data, precision of data, age of data, etc.).	Static Dynamic Vessel–Specific
Collate info on vessel traffic and combine with whale data to ID high risk areas	Includes technology to: (1) collect information on spatial and temporal distribution of vessels by class/operation; (2) collect data and model forecasts of NARW density; (3) model the overlap of vessel data and whale data to identify areas and times with high vessel strike mortality risk.	Static
Disseminate NARW data and risk reduction areas	Sending aggregated NARW data and information on risk reduction measures out for interested party/end user receipt in an efficient and timely manner. Also included is the ability to collect whale detections (2–way communication).	Static Dynamic Vessel–Specific
Integrate NARW data and facilitate decision–making	Includes technology to: (1) integrate disseminated whale data into onboard navigation software; and (2) consider whale data in conjunction with other information (e.g., weather conditions, sea state, navigational constraints) in an efficient manner to allow for risk reduction actions when safe and possible. Also included is the ability to integrate whale–specific voluntary or mandatory measures into onboard navigation software.	Static Dynamic Vessel–Specific
Track and evaluate risk reduction measures	Determine whether risk reduction measures have been implemented and whether they have achieved the anticipated reduction in NARW vessel strike–related mortality.	Static Dynamic Vessel–Specific
Modify vessel design	Technology to modify vessels and/or how they are operated to reduce the risk of vessel strike–related mortality.	Static Vessel–Specific

Due to time constraints and the broad scope of the workshop, Risk Reduction Chain Components were discussed during concurrent breakout discussions rather than sequentially moving through the Risk Chain. Efforts were made to reinforce the necessary linkage between the Risk Reduction Chain Components, and workshop participants were reminded that vessel strike risk reduction would not be achieved unless the full Chain was completed and effective action was taken. There was a great deal of interest expressed about quantifying the effectiveness of specific technology and, again, the importance of considering the full Risk Reduction Chain was emphasized. A specific technology may be highly effective at detecting NARWs, but if the rest of the Chain is not completed (i.e., the information does not get to a mariner in time for them to make a navigation decision that avoids the strike), then the detection technology has not reduced vessel strike risk.

Some workshop participants offered support for the identified components and commented that they appeared to contain the primary steps. Other participants suggested adding such things as: enforcement, further legislation, education and awareness, metrics to evaluate measures under variable conditions, and the testing of measures using scientific rigor. The “track and evaluate risk reduction measures” step was intended to be broad and cover ways in which technology could help assess effectiveness and provide feedback to the overall system. Education, outreach, and enforcement are methods to facilitate implementation of and compliance with risk reduction measures and are therefore not considered as part of this technology–focused framework.

One workshop participant asked if there should be a step in the Chain regarding interpretation of data to make it easier for mariners to put it in context. This was further discussed in both the Modeling/Forecasting and Dissemination and Integration workshop breakout sessions. Discussions between those providing the data and those receiving and being expected to act upon it are critical. While some of those discussions were started at the workshop, it was recognized that further discussion is warranted.

In discussions at the workshop, some participants expressed concern that there was too much emphasis on individual Risk Components and not enough recognition that none of the other steps mattered unless the final step of taking a risk reducing action was successful. In each of the steps in the Risk Reduction Chain, the goal was to identify how technology could influence that Component such that the necessary information would get to the mariner in the right format and with enough time so that they could act and reduce the probability or severity of a strike. The workshop participants rightly pointed out that this is not just a technology challenge but a human challenge, and there should be a companion effort to examine all of the influences on that human decision of whether to take evasive action, and not just those that can be influenced by technology (e.g., providing timely and accurate information on whale presence and delivering that information in an efficient manner to the wheelhouse). This simplistic technology Risk Reduction Chain exists in a larger vessel strike risk reduction strategy that includes all the Risk Components identified in the first framework including human decisions, vessel constraints, whale behavior and ecology, and environmental conditions.

4.4 Framework 4: Vessel Characteristics and Operating Mode

The SC frequently raised the need to match technology to the characteristics, capabilities, and constraints of vessels and their operational mode. This was not presented as a framework to workshop participants for the sake of reducing complexity but was instead embedded in the questions asked and approaches used in the Risk Component workshop sessions. However, given how strongly this message was reinforced throughout the workshop, it is appropriate to consider it as an additional framework.

Determining whether a specific technology is a good match to a particular vessel type requires consideration of the full Risk Reduction Chain. Further, there may be cases where some intrinsic characteristic or current capability of a technology inhibits the ability to make a timely decision and effectively avoid a strike by a specific vessel type. For instance, it may be possible to mount a thermal/IR[7] camera system at an appropriate height from the deck of a commercial shipping vessel,

[7] The terms thermal imaging and IR are used interchangeably in this report given that they function virtually the same for the purposes of whale detection. Thermal imaging relies on mid to long wavelengths and creates images based on temperature differences between a subject and its environment. Infrared cameras use short wavelengths longer than visible light that reflect some light back to the device when capturing images and measure temperature directly. Source: Optics Mag. 2024. Infrared vs. Thermal Cameras: How Are They Different? [Available at https://opticsmag.com/infrared-vs-thermal-cameras]

and that camera may be effective at reliably detecting whales at a reasonable distance. However, if an avoidance action cannot be taken by the vessel within that reliable detection range, then it is an ineffective application of the technology. Though it is possible that the placement of that camera on that vessel may still be valuable to risk reduction efforts as it could contribute data to a broader network and, under a Dynamic Scenario, inform the actions of smaller more maneuverable vessels in the area. Conversely, it may be possible to mount a thermal/IR camera on a smaller recreational vessel, but lack of sufficient deck height and stability in higher seas may limit the range and effectiveness of the detection even though the vessel itself could in fact take relatively quick evasive action.

4.5 Application of the Frameworks in Planning and Implementation of the Workshop

The four frameworks described above served as prompts and reminders throughout the workshop and were used to help frame conversations and discussions in a consistent and comparable manner. In working with the SC, the planning team realized that there are countless ways in which to organize information and think about the application of technology to reduce vessel strike risk. A specific framework may be developed to apply to specific circumstances or case studies. Components that should be common to all would include the consideration of the factors that affect the likelihood of a NARW vessel strike, the factors that affect the efficacy of technology, the identification of the necessary steps and connections between the factors/technology, and ultimately the action that is necessary to reduce the likelihood of a vessel strike.

Discussions with the SC during workshop planning resulted in the prioritization of the following Risk Reduction Chain Components contained in Table 1 for focus during the workshop: (1) NARW detection and classification; (2) modeling the spatial and temporal density of NARWs; (3) aggregating classified detections; and (4) dissemination and integration of NARW data and risk reduction areas in a manner which facilitates decision–making. A fifth category of "Other Technology'' was created to provide an opportunity to identify and discuss ways in which technology could reduce vessel strike risk outside of the four previously mentioned focus areas. The information presented and discussed for each of the Risk Reduction Components and the Other Technology category is contained in the following five chapters. As explained in Section 1.5.2, Chapters 5–9 begin with a brief background on the technology associated with that Risk Chain Component acquired through a literature review conducted in preparation for the workshop. As previously noted, due to the volume of published literature on detection and classification technologies, the majority of the literature review for that Risk Chain Component can be found in Appendix 6. In the interest of time and to focus the workshop, this background information in its entirety was not presented during the workshop but is included in this report to help frame the workshop sessions for the reader. Statements and opinions as expressed by workshop participants are provided in the report as an accurate reflection of the workshop proceedings, without additional commentary, corrections, or caveats.

5. Detection and Classification

5.1 Introduction

The workshop planning team conducted a literature review of existing and potential technology to detect and classify NARWs during initial planning stages. This literature review helped shape and narrow the focus of this workshop session and, while not shared with workshop participants in its entirety, it is included in Appendix 6 to provide additional context for the workshop session itself. Some, but not all, of this information was made available to the workshop participants prior to the workshop through the Background Papers and Fact Sheets. While the literature review content serves to provide context, the remainder of each chapter is intended to provide an accurate and complete account of the workshop itself. It is important for the reader to note that statements and opinions of workshop participants are captured in the workshop report without additional commentary, corrections, or caveats provided by the workshop report authors.

The results of the literature review were reviewed by the SC to determine the appropriate focus for this workshop session. Given the broad audience attending the workshop, it was decided that this session would serve to provide a general overview of the state of NARW detection and classification technology rather than a detailed look at all available options. Presenters were asked to review the suite of tools currently in use and to introduce those currently being explored for possible future applications. The literature review illustrated that the application of artificial intelligence (AI) and machine learning (ML) to process and analyze large datasets—specifically vast numbers of images and sound files—has made a significant contribution in recent years and holds promise moving forward. Additionally, the use of thermal/IR onboard vessels was determined to be worthy of discussion as this innovative technology, with thus far more limited presence in scientific publication, is actively being tested in detecting whales in real world situations. Furthermore, the potential for discussions amongst the variety of workshop attendees could help to illuminate what role thermal/IR could play, alone or in combination with other technology, in evolving risk reduction strategies and which vessel operational categories these thermal/IR systems are most compatible with.

5.2 Workshop Session: NARW Detection and Classification

The goals for the NARW Detection and Classification session were to: (1) identify and characterize existing and potential technology to detect and classify NARWs for the purposes of informing Static, Dynamic, or Vessel–Specific risk reduction actions; and (2) characterize the state of play for detection and classification technology to identify the most promising and determine the priority next steps to advance their development and deployment. Most of the individuals who pre–registered for the workshop indicated expertise and/or interest in NARW detection and classification. As a result, this session was held in plenary so that all workshop participants could attend. Please see Chapter 2 for a breakdown of workshop participants by sector.

5.3 Presentations

5.3.1 Fisheries and Oceans Canada: NARW Detection Technology and their Application for Canadian Monitoring and Management

In preparing for the workshop, the presenters for this session agreed that the first presentation would describe NARW detection and classification technology and methods generally, to serve as a foundation, while the remaining presentations would focus on the application. Consistent with this agreement, Katia McKercher, DFO, presented on NARW detection technology and their application in Canadian monitoring and management. McKercher placed these technologies into the following three technology readiness levels (TRLs) for the purposes of this presentation[8]: (1) Green—currently operational and in use as a monitoring and surveillance tool; (2) Yellow—promising results, but further testing is needed; and (3) Red—significant testing is still needed. She also provided a framework for identifying technology in one of the four categories presented in Figure 8, each generally categorized with a TRL.

Figure 8. NARW detection and classification technology and methods and associated technology readiness levels (TRLs): (1) Green—currently operational and in use as a monitoring and surveillance tool; (2) Yellow—promising results, but further testing is needed; and (3) Red—significant testing is still needed (as defined and presented by McKercher at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop).

Visual (Green)	Acoustic (Green)	Satellite (Red)	Thermal (Yellow)
Detecting whales above the water using camera systems and human observers	Detecting whales below the water using Passive Acoustic Monitoring (PAM) and detection-classification software	Detecting whales above the water using Very-High Resolution satellite imagery	Detecting whales above the water using Infrared (IR) cameras

McKercher detailed three visual detection methods currently in use for NARWs in Canadian waters. She first described aerial surveillance in which aircraft fly surveys in predetermined flight patterns while marine mammal observers (MMOs) scan the surface of the ocean for visual cues of whale presence. She noted that cameras may also be deployed to take images for further analysis or photo–identification (photo–ID). The second visual detection method identified was the use of drones (also known as UAVs or remotely piloted aircraft system (RPAS)), which use cameras to capture images or video which are then transmitted to human observers for analysis and verification. The drone imaging systems can also be equipped with automated detection or classification software. The last visual method described was the placement of MMOs on large and small vessels engaged in conservation, research, and enforcement activities.

McKercher said that for the past 6 years, Canada has conducted multi–species, systematic aerial surveys in eastern Canada. Up to five planes flew at peak times during these surveys and monitored both fishing areas and shipping lanes to inform dynamic management measures. In addition to the systematic aerial surveys with manned aircraft, whale surveillance and detection operations were conducted in the Gulf of St. Lawrence using a fixed–wing RPAS from 2018 through 2022. Detection–classification software was used to detect whales in imagery captured by the RPAS, and findings were relayed to experts for validation. She also noted that testing of a new drone technology capable of vertical take–off and landing began in 2023.

The acoustic detection methods identified by McKercher included the mounting of hydrophones on fixed platforms (either at the surface or submerged) or on mobile platforms such as autonomous underwater vehicles (AUVs) or gliders. Detection–classification software is housed on board these

[8] Note that the three TRL categories presented by McKercher were for the purposes of this presentation only. The TRLs used by the Navy are presented below in section 5.3.3.

platforms to identify whale vocalizations, which are then transmitted to land via satellite, cell connection, or cables for verification.

McKercher explained that Canada's PAM efforts include the deployment of a fleet of nine Viking Buoys, which each have a detection range of approximately 30 kilometers with actual detection range varying depending on local environmental conditions in the Gulf of St. Lawrence seasonally from May to November. The buoys are equipped with custom–built detection–classification software and transmit detections to shore every 30 minutes for validation. In addition to these fixed platforms, six autonomous gliders are deployed annually with two assigned specifically to monitor shipping lanes in the Gulf of St. Lawrence and Cabot Strait and four to monitor NARWs in the Gulf of St. Lawrence and Scotian Shelf. The detection range for these gliders is approximately 20 kilometers but can vary depending on environmental conditions. These systems are also equipped with detection–classification software and transmit data to shore every few hours for validation.

To summarize the pros and cons of visual and acoustic detection, McKercher presented the following lists and recommended that a mixture of approaches is needed to see the full picture as it provides the best overall coverage (Table 2).

Table 2. Positive and negative attributes of visual and acoustic detection methods (as presented by McKercher at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop).

Positive Attributes	Negative Attributes
Visual Detection	
✓ Identify the number of whales and their behaviors	✗ Misses whales below the surface
✓ Obtain information on body condition	✗ Dependent on weather and light conditions
✓ Suitable for identifying individuals	✗ Human risks
✓ High spatial coverage	✗ Costly
	✗ Greenhouse gas emissions
Acoustic Detection	
✓ Listen 24/7 for vocalizing whales	✗ Misses non–vocalizing whales
✓ Able to detect subsurface whales	✗ Cannot determine the number of whales
✓ Lower human risk	✗ Current systems cannot be used to determine the location of whales
✓ Lower greenhouse gas emissions	✗ Generally, has lower spatial coverage
	✗ Detection range is site–specific and can be limited by various sources of background noise

McKercher described satellite detection methods as using Very–High Resolution (VHR) satellite technology to detect or count whales in optical satellite imagery. It has proven successful in detecting fin (*Balaenoptera physalus*), sei (*Balaenoptera borealis*), humpback (*Megaptera novaeangliae*), gray (*Eschrichtius robustus*), beluga (*Delphinapterus leucas*), narwhal (*Monodon monoceros*), southern right whales (*Eubalaena australis*), and NARWs, but more research and development is necessary before it can become operationalized. The government of Canada recently completed a 3–year research initiative called SmartWhales, which aimed to advance the use of space–based technology in NARW research. Five consortia were funded to work on the detection, monitoring, and prediction of NARW and their habitat using space–based technology. Publications from this initiative can be expected to be released soon.

Finally, McKercher reviewed thermal imaging detection, which involves using a thermal/IR camera to sense heat/infrared waves generated by a whale's body or the warm air they exhale. Canada is currently testing several IR systems on both the East and West Coasts, which she noted would be covered in more detail by Dan Zitterbart, WHOI.

5.3.2 NOAA Fisheries: NARW Detection Technology and their Application for U.S. Monitoring and Management

Danielle Cholewiak, NOAA Fisheries NEFSC, used the framework provided by McKercher to report on the application of detection technology for U.S. monitoring and management of NARWs. She added an additional detection modality of "other technology/methods" to include such things as eDNA analysis, which involves detecting whale presence using genetic material in the water. Cholewiak described the use of aerial surveys, conducted using a NOAA twin otter plane, as multi–functional by providing data to produce population estimates, monitor injuries and health, inform model development, and inform dynamic management. Multi–institutional partners have collaborated since 1998 to conduct aerial surveillance of NARWs in U.S. waters. These surveys occur year–round in the Northeast and seasonally in the Southeast, and five or more planes may be flying at any one time across the multi–institutional partners. In addition to aerial surveys, NOAA Fisheries conducts vessel–based surveillance, typically from December through May, using dedicated large and small research vessels. These surveys include data collection for photo–ID, genetics, and visual health assessments, in addition to supporting the deployment of biologging tags, plankton sampling, PAM deployments, and drone data collection. Like aerial surveys, vessel–based surveillance is conducted and supported by many partners including the Navy, U.S. Army Corps of Engineers, Sanctuaries, state agencies, and partner institutions, including Canadian institutions and DFO Canada. Cholewiak also reported that NOAA Fisheries conducts PAM using a combination of archival and near–real–time platforms, both moored and mobile. NOAA Fisheries' near-real-time PAM effort is conducted in collaboration with WHOI. Biologging tags are also used to quantify individual call rates to assist with interpretation of PAM data. The multi–institutional PAM infrastructure supported by NOAA, Bureau of Ocean Energy Management (BOEM), state agencies, and offshore wind developers includes over 100 archival moorings, multiple near–real–time moorings, and five regions covered by multiple deployments of gliders each year. Future plans include adding additional archival and near–real–time moorings to this network.

Cholewiak closed her presentation describing an inter–agency collaboration working to develop an operational system for detecting whales from VHR satellite imagery. Currently, NOAA Fisheries is focused on tasking imagery over whale hotspots to build an annotated library and has been collaborating with Microsoft AI for Good to develop tools for processing imagery using an active learning workflow. Additionally, NOAA Fisheries is investigating eDNA as an emerging tool to explore the detectability of marine species under varying conditions/habitats, and as well as to investigate prey signatures in fecal samples.

5.3.3 Promising Technology for Monitoring NARWs

Anu Kumar, Living Marine Resource (LMR) Program Manager, presented promising technology for monitoring NARWs on behalf of Mike Weise, Office of Naval Research (ONR) Program Manager. Kumar described the three programs in the Navy that develop and transition technology from basic research and development to operations as illustrated below by the Navy-defined TRLs[9]. Under this program, basic research on technology begins with the ONR Marine Mammals and Biology team. This exploratory stage is time and resource intensive starting with paper studies of a concept and moving through invention, research, and development to test technology in a laboratory or simulated environment (TRL 1–5). The technical risk is highest at this stage given the lack of data and amount of uncertainty associated with the concepts. Technology that successfully moves past the Navy's TRL 5 is then moved on to the LMR program, which focuses on testing representative models or prototype systems in an operational environment (TRL 6–8). The final stage is with the Navy Marine Species Monitoring team where testing of the system in its final configuration is conducted under the expected range of environmental conditions (TRL 8–9; Figure 9).

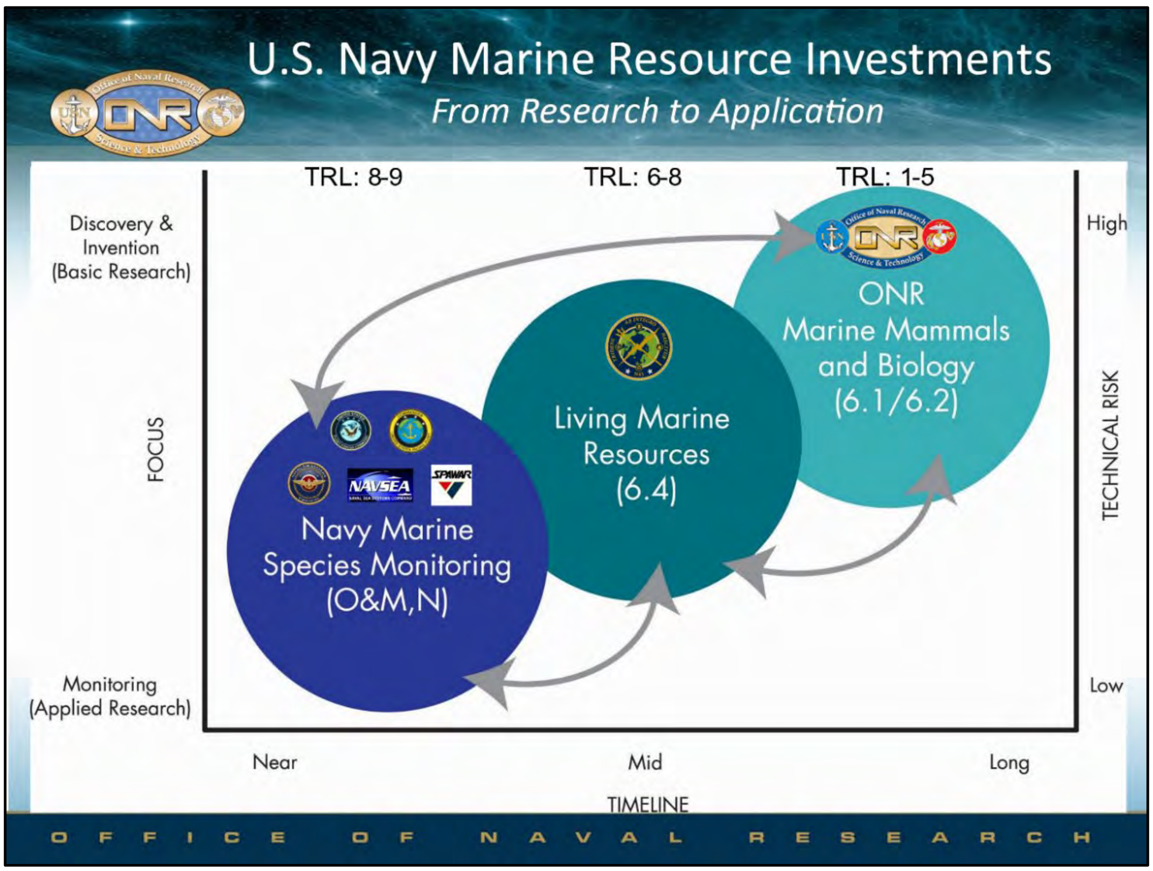

Figure 9. U.S. Navy Marine Resource Investments that develop and transition technology from basic research and development to operations (as presented by Kumar at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop).

[9] The Navy's Technology Readiness Levels (TRLs) are a scale of nine levels used to measure a technology's progress, starting with paper studies of a basic concept and ending with a technology that has proven itself in actual usage in the product's operational environment (U.S. Government Accountability Office (GAO), 2020). Note—these are different from the TRLs used in McKercher's presentation above.

The U.S. Navy has used numerous technologies to monitor for NARWs including PAM, satellite tagging, eDNA, Whales from Space/satellite imagery, and thermal/IR. Kumar described ONR support, beginning in 2008, to Mark Baumgartner, WHOI, which has resulted in the development of a Digital Monitoring Device (DMON). A DMON includes three hydrophones running a low–frequency detection and classification (LFDCS) system—an automated processing system designed to identify baleen whale calls and is operational on several autonomous vehicles, profilers, and floats. A new DMON in the configuration of an array is now moving to LMR for demonstration and validation. He noted limitations with the system including missing non–vocalizing animals and finite spatial coverage. ONR has also funded an 8–week field trial of a prototype long–endurance acoustic profiling float built by Julien Bonnel, WHOI. Kumar reported that the long–term goal is to include acoustic monitors on 10% of the approximately 4,000 Argo[10] floats deployed globally. Reports would be received every 10 days from the floats and localization would not be possible.

Kumar then explained that ONR also supports tag development including providing funding to Alex Zerbini, NOAA Fisheries Alaska Fisheries Science Center, and collaborators for over a decade to develop Type C satellite tags. He explained that Type A tags are Low Impact Minimally Percutaneous Electronic Transmitter (LIMPET) style tags where the electronics are housed externally and are attached with a dart into the blubber. Tags where the electronics are embedded in the body of the animal are called Type C tags and can be embedded in the blubber (short) or inserted more deeply into the muscle (long). The average duration of Type A tags is approximately 1–2 weeks when deployed on NARWs, Type C short tags about 3–4 weeks when deployed on southern right whales, and Type C long tags about 3–4 months when deployed on southern right whales. He reported that it is not possible to tag all NARWs given the limitations of satellite tagging including the difficulty of finding animals to tag, the challenges of attaching the tag, limitations due to poor weather, relatively short duration of tags, and concerns about health risks to NARWs given their poor body condition. Kumar provided a summary of a workshop held in September 2023 focused on NARW tagging (MMC, 2024). He also indicated that ONR is interested in using eDNA to monitor marine life in real time at the ocean basin scale. While lab–based approaches currently exist, autonomous approaches are in the early stages of development, and it will be many years before such a system can be deployed. The Navy is also adapting detectors originally used to find vessels in satellite imagery to instead find whales. Although initial results are very promising, with a reported 95% probability of finding whales in the test dataset, Kumar cautioned that acquiring satellite images is very expensive (approximately $6M for a single image of the entire western North Atlantic) and it provides a snapshot in time, not real–time detections. Kumar also highlighted that ONR had provided over a decade of support for Zitterbart's work to develop a thermal/IR imaging system consisting of a camera, 3D stabilization, and detection algorithm, and said the Navy is transitioning the technology to LMR for demonstration and validation on unmanned surface vehicles (USVs).

5.3.4 Thermal Imaging for Automatic Whale Detection and Classification from Vessels for Real–Time Vessel Strike Mitigation

As noted previously, in preparing for the workshop, the use of thermal/IR in the Vessel–Specific and Dynamic Scenarios was identified as worthy of focus and discussion. Daniel Zitterbart, WHOI, provided an overview of his work developing thermal imaging for automatic whale detection from vessels for real–time vessel strike mitigation. He identified the following lessons learned from the trials implemented across the globe in the last 15 years: (1) thermal imagery whale detection works

[10] Argo is an international program that collects information from inside the ocean using a fleet of robotic instruments that drift with the ocean currents and move up and down between the surface and a mid–water level. Scripps Institute of Oceanography. 2024. What is Argo? [Available at https://argo.ucsd.edu/]

(but it has not been tested in equatorial waters); (2) sea state is not a significant problem, but dense fog is; and (3) critical factors for success include deployment location, elevation, and stabilization.

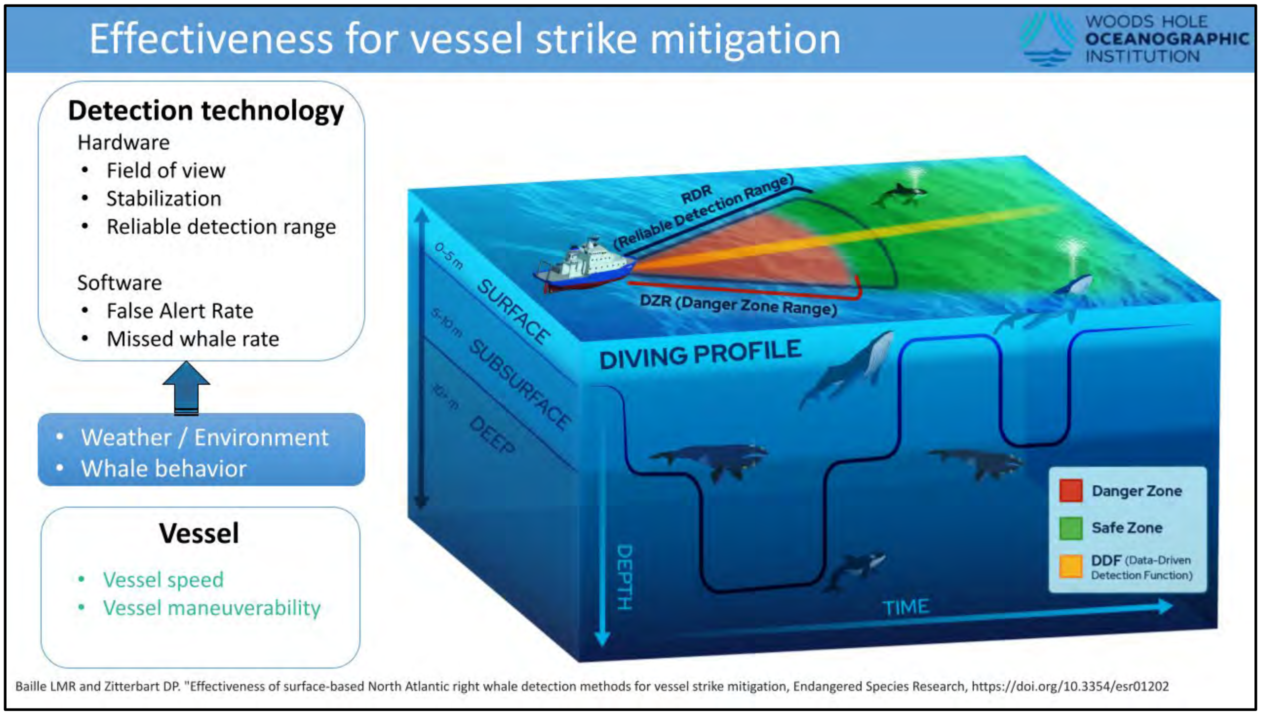

Figure 10. Factors influencing the effectiveness of thermal/infrared (IR) imagery systems for vessel strike mitigation (as presented by Zitterbart at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop).

Zitterbart described a land–based system deployed in Atlantic Canada consisting of a pair of thermal cameras and a visual camera deployed at the constricted channel entrance to the Gulf of St. Lawrence. He also described vessel–based systems deployed on ferries in the Gulf of St. Lawrence and on a ferry transiting between Nova Scotia and Newfoundland. He said the key question is how likely it is that an animal will be detected in time for the vessel to react. Aspects that influence the effectiveness of thermal/IR systems for vessel strike mitigation are illustrated in the following slide from Zitterbart's presentation (Figure 10).

Zitterbart explained that surface–based detection systems mounted on board vessels with fast reaction times are likely to allow the mariner to be able to take evasive action in response to detections regardless of transiting speed due to high maneuverability. Larger and less maneuverable vessels with slow reaction times are only able to respond to detections if they are transiting at speeds of 10 knots or less (i.e., in time detection probability). He plotted the probability of detection by distance (i.e., detection function) and identified the peak as the reliable detection range. Regarding the classification software, Zitterbart reported that using AI alone produced a false alert rate that was deemed too high given it would likely result in mariners having alert fatigue, being frustrated, and generally having little confidence in the detection system. By combining an initial screening by AI with a human to verify detections, requiring less than 20 seconds, they were able to achieve zero false alerts and reliable mariner confidence in the system.

Zitterbart described the current WHOI vessel strike evaluation system, which is intended to identify whales for the purposes of preventing collisions and to provide insights into whale distribution. The unit included in this system is approximately 30 x 20 x 20 centimeters, weighs 2 kilograms, and can be used on any vessel class. It has a reliable detection range of 1–2 nautical miles and has zero false alerts. He noted that this system needs to be mounted at least 20 feet above the surface of the water to be effective. This system made over 15,000 detections of toothed and baleen whales in 2023 across 15 installations worldwide.

5.3.5 Clarifying Questions on Presentations

Ross Eaton, Charles River Analytics, asked how frequently satellites can take images of the same area. McKercher and Cholewiak said that even if a satellite was over the same area, it may not be available to task due to conflicting tasking requests and noted that cloud cover also affects the ability to acquire useful images. Esteban Rodofili, Knauss Fellow, also offered that the image obtained from a satellite was also affected by the satellite's angle, so it might be over the same area in 24 hours, but it would likely be 4 days or more before it was in the same area at the same angle as previously to obtain comparable images.

A participant asked how NARW calls are distinguished from calls of other cetaceans, suggesting that they are not as vocal as other cetaceans. McKercher said upcalls are used for classifying calls for NARWs using algorithms and confirmed by an expert. Cholewiak said she hoped that there was not a misperception that NARWs do not vocalize or that PAM is not useful as a monitoring strategy. She said NARWs do vocalize and PAM is very useful for detection, but interpreting PAM data (particularly when there is an absence of calls) is complicated by the fact individuals do not vocalize at a fixed rate and that their vocal activity is variable, since they use vocalizations for social purposes.

Pat Field, CBI and workshop facilitator, asked if the presenters could talk about the ability to localize NARWs based on PAM. Cholewiak stated that the detection range for any particular type of signal is variable depending on bathymetry, ambient noise, sound propagation, and conditions of the hydrophone, but that it is possible to estimate the range of detection for a vocalizing animal with enough information. However, she noted that it is also important to remember the animals continue to move. McKercher said the management measures in Canada are established so as not to require localization and said that the acoustic detections are complimented by aerial data. In response to a question from Morgan Martin, BOEM Center for Marine Acoustics, regarding the reliable detection range of a Viking Buoy, McKercher said that since they do not require a localized call to implement management measures, the estimated 30 kilometer range of a Viking Buoy will be well within the dynamic fisheries management area that is activated by a NARW detection.

Jeff Angers, Center for Sportfishing Policy, asked the panel about the remarkable data points they had highlighted: the volume, detail, and breadth were amazing. He noted many boaters are not aware of much of the data being discussed. He asked if any of this is communicated to the end–user on the water (i.e., America's boating public). The presenters responded that the information has been made publicly available online (e.g., WhaleMap, PACM, NOAA Fisheries' websites), communicated through the WhaleAlert app, and additional communication methods are utilized when DMAs are triggered. Angers noted that public–private partnerships that have not existed previously need to promptly engage to directly communicate with boaters regarding available data streams.

In response to many questions regarding tagging of NARWs, Peter Thomas, MMC, was asked to summarize the NARW tagging workshop held in partnership with MMC, NOAA Fisheries, ONR, and DFO in September 2023. Thomas said the purpose of the workshop was to identify and evaluate the capabilities of existing tag technologies relative to answering research and management questions for NARWs. He noted that it is logistically impossible to tag every NARW, and that even if one could, the tags do not last long–term. He said that to date for NARWs, existing tag technology has proven better suited for the study of fine scale short–term behaviors. Thomas suggested it was important to determine if tagging was the right tool to answer a specific question and acknowledged that there are serious health concerns regarding the use of longer–term tags for NARWs. He said it would likely only be the healthiest adult animals who would be considered as candidates for such tagging. The link to the workshop report was posted for those who wanted additional details (MMC, 2024), and additional discussion is contained in Appendix 6. In summary, Thomas's explanation detailed that while it may seem desirable and achievable to tag and track all NARWs to reduce vessel strike risk (since there are so few of them), numerous factors make this an unrealistic approach.

A remote participant asked why sonar was not a viable technology to detect whales. Kumar responded that the Navy had invested in sonar in the past but had little success and noted that adding noise to the ocean on a broad scale to detect animals has negative impacts. Baumgartner said discussions on the use of sonar went back over 20 years and noted that WhaleSounder tried to test this technology and that the range was very limited.

Zitterbart was asked to clarify the difference between IR and thermal and he said that they are basically the same technology, but that IR does not work at night and thermal does. He was also asked to clarify if thermal/IR was ineffective on smaller vessels given his statement that you need to mount the camera at least 20 feet above the water. He replied that at lower mounting heights the detection range is very limited, and it would be very difficult to judge the range to the whales. In response to another question, Zitterbart said that for smaller animals like killer whales (*Orcinus orca*) it is the body that is being detected, whereas for larger animals the blow can be detected, which increases the detection range. He also acknowledged the challenge of studying the false negative rate but said compared to humans it is between 30–50%[11]. In response to a question from Steve White, Marine Exchange of Alaska, Zitterbart said that the cost of the research camera systems ranged between $20K and $30K. Eaton asked if Zitterbart had tested mid–wave as well as long–wave IR. Zitterbart said they had one camera that could use both mid– and long–wave and they found that the mid–wave provided higher spatial resolution, but was more expensive and more susceptible to glare.

Field asked the panelists to speak more generally about the cost of the different technology. Cholewiak said that the cost depended on the level of effort but generally noted that aerial surveys are very expensive and that fuel costs are a limiting factor. She further explained that many of the hydrophones used for acoustic monitoring are relatively inexpensive, but the time to process the data is costly and noted near–real–time PAM systems (buoys/gliders) were more expensive than other archival acoustic devices.

Vince Premus, Ocean Acoustical Services and Instrumentation Systems (OASIS), said that in the private sector there are many very capable high resolution acoustic arrays being used in the offshore wind industry. He expressed interest in working with the government to truth real–time classification results and validate models of system detection performance. Paul King, SMRU Consulting, asked whether the data from different visualization tools (e.g., WhaleMap for the U.S. and Whale Insight for Canada) was being exchanged. McKercher confirmed that there is a data pipeline between WhaleMap and Whale Insight and Hansen Johnson, New England Aquarium,

[11] The thermal/IR system has 30–50% of the false negative rates that humans do, largely attributed to the larger coverage of the cameras compared to a human view (a 360° system was tested; Zitterbart et al., 2020).

further added that WhaleMap displays the data for the U.S. and Canada and noted that there is also a data pipeline between Whale Alert and WhaleMap.

Laura Morse, Invenergy, asked Zitterbart to talk about using dimethyl sulfide (DMS) as a tool for whale detection. Zitterbart explained that DMS is released when zooplankton eat phytoplankton and said that this is not well understood yet (and suggested it would be a red dot in the categorization offered by DFO or a very early/low TRL). Cholewiak noted that NOAA Fisheries is partnering with Zitterbart to test the use of DMS in Cape Cod Bay, George's Bank, and other areas.

5.4 Discussion and Input from Workshop Participants

Following the session presentations, in–person workshop participants were asked to work together at their tables to discuss what they saw as the most promising technology based on their sense of impact and feasibility, noting that the most promising technology could vary by location, vessel type, and scenario. They were also encouraged to recommend combinations of technology to be considered for vessel strike risk reduction. Finally, they were asked to recommend priority next steps. Input from in–person and remote participants was also obtained through an online poll and an online form. The input from these various methods is provided and summarized below.

5.4.1 Small Table Discussions

Katie Guttenplan, TetraTech, reported that her table talked about alternative tags with fewer injury risks and longer deployments as being very promising in addition to the use of AI in detection algorithms. She said they discussed the use of active acoustics to detect animals, recognizing that the trade–off of introducing harassment to avoid mortality would need to be evaluated. Matt Adams, MITRE, reported that his table also discussed tag technologies and specifically the newer 3D printed Type C tags, which have been demonstrated to last between 200 and 300 days on southern right whales. He said they recognized the health concerns, but felt it was an underexplored area and offered that if you could develop a tag to last a year and could theoretically tag hundreds of whales, it would be hard to beat the persistence of that method in terms of whale locations.

Martin said that her table talked about the value of placing thermal/IR detection technology on transiting vessels for the detection of mother and calf pairs, recognizing that thermal/IR cameras are only reliable in certain sea states and weather conditions. They identified PAM as an effective technology for vocalizing animals and suggested that using thermal/IR and PAM in combination could be effective. Genevieve Davis, NOAA Fisheries NEFSC, reminded workshop participants that the goal is to reduce the human impact on the whales and encouraged everyone to keep that in mind and to focus on non–invasive technology.

David Kennedy, Boat US, said his table talked about the communications side of the issue and specifically how boaters are informed that they are in an area where there are whales and what to do when they see or become aware of the presence of a whale. Jorge Arroyo, USCG, suggested there should be discussion of how to get vessels to report whale sightings.

Johnson recommended a focus on optimizing across different types of detection technology to make the best use of resources. Mike Waine, American Sportfishing Association, supported that recommendation and encouraged more discussion about optimizing where the dollars are spent and emphasized the importance of evaluating the effectiveness of risk reduction measures. Adams responded that MITRE is helping NOAA Fisheries develop a framework to guide optimized investment of resources. Brian Krevor, American Clean Power, suggested that knowing what is trying to be achieved with technology and establishing performance–based standards would help focus efforts and investments.

In terms of next steps, Martin reported that her table discussed merging all the data from detection technology into one main source and providing that to mariners quickly and in a manner that facilitated interpretation. The facilitator Field shared a comment submitted remotely by Doug Nowacek, Duke University, offering support for the use of thermal/IR camera technology for true 'heads up' detection of whales in the path of vessels. Nowacek stated that near–real–time PAM systems are important and should be developed for detection around areas of interest/concern (e.g., shipping lanes). He noted that there are existing systems like Baumgartner's buoy and wave glider systems that can do real–time detection and localization, using a towed hydrophone array. Nowacek acknowledged that PAM has its limitations but offered that it could be used more effectively than is currently the case.

Field also shared a comment from Alex Parker, Astraeus Ocean Systems, stating that his company is exploring the use of very small, long–duration USVs equipped with thermal/IR, visual, and PAM systems as pseudo–tags; trailing NARW at safe range to provide continuous location updates on location, behavior, and condition—without the body condition impact of tagging.

Baumgartner noted that industries are affected differently by a potential wide application of speed restrictions and asked whether those sectors should be thought about differently. He offered that applying certain technology coast–wide did not seem to be a wise approach and it would be better to tailor monitoring technology to specific regions and vessel classes. He suggested considering the vessel strike problem specific to each sector, where it exists, and how the technology might apply to that specific situation. Morse offered support for Baumgartner's suggestion and emphasized the importance of looking at the sectors separately.

Kyle Baker, BOEM, said that applying technology to every vessel in the Atlantic was a daunting task, suggested looking at systems other than tags, and rather than putting cameras on vessels, think about placing them at strategic locations. He encouraged participants to think outside the box to come up with innovative solutions.

5.4.2 Online Poll

In–person and remote participants were provided the opportunity to participate in an online poll that asked them to identify what sector they belonged to and for vessel operators or industry representatives to identify the type of vessel they use or are associated with. They were asked to identify the top two promising technology categories based on their sense of impact and feasibility and to explain their prioritization. This poll solicited information on the types of vessels operated by workshop participants to provide insight into the vessel sectors represented at the workshop. It is important to note that poll respondents (N=123) were not limited to individuals who selected vessel operators or industry representatives as their primary sector, but also includes those who identified as having performed functions of a vessel operator while affiliated with the full range of sectors participating in the workshop (Figure 11; e.g., Government (N=52), Vessel Operator or Industry Representative (N=21), NGOs (N=19), Tech/Engineer/Manufacturer (N=16), External Scientist/Academia (N=8), and Other (N=7)).

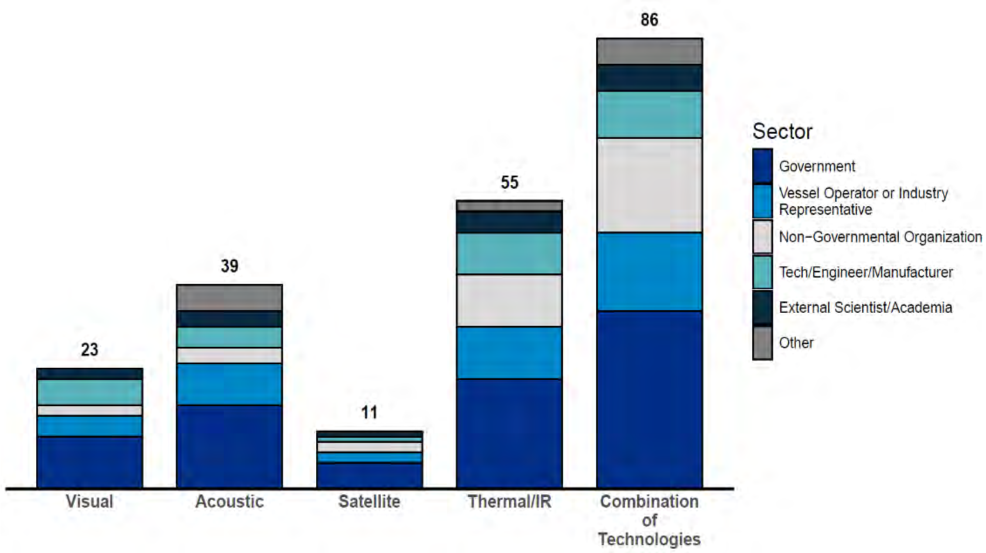

Figure 11. Identification of vessel types operated by 2024 NARW Vessel Strike Risk Reduction Technology Workshop participants. Labels above each column indicate the total number of poll respondents that chose that response. Bars are colored in accordance with the sector composition of those selecting that option.

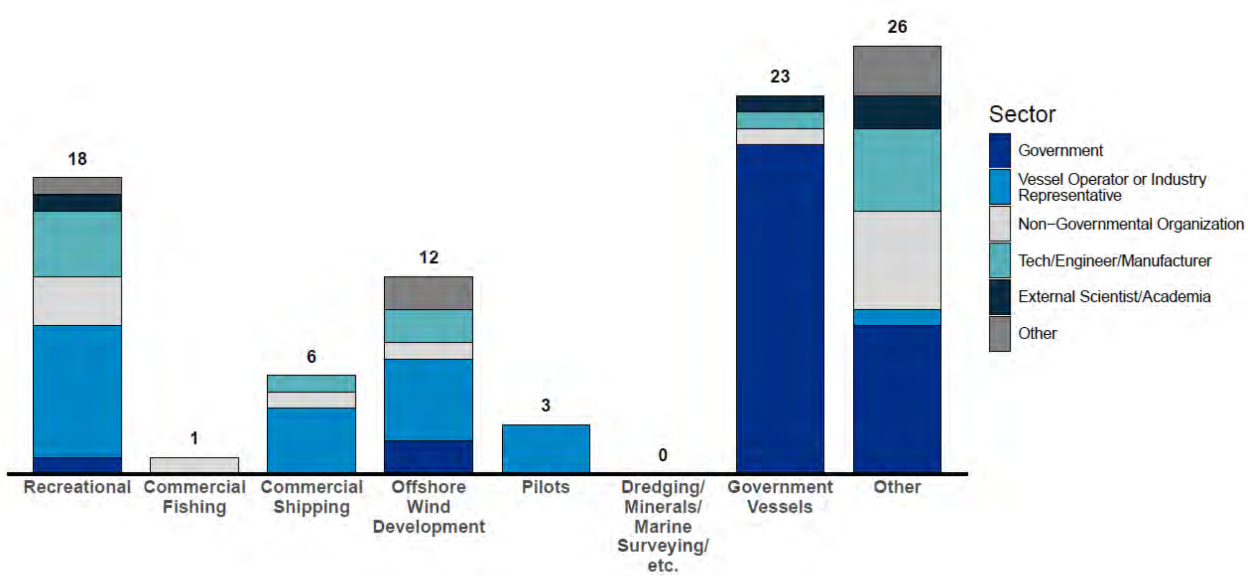

Figure 12. Identification of the top two most promising technology categories as identified by participants on Day 1 of the 2024 NARW Vessel Strike Risk Reduction Technology Workshop. Labels above each column indicate the total number of poll respondents that chose that response. Bars are colored in accordance with the sector composition of those selecting that option.

Workshop participants selected Combinations of Technology (N=86) and Thermal/IR (N=55) as the top two most promising technologies based on impact, followed by Acoustic (N=39), Visual (N=23), and Satellite (N=11; Figure 12). The rationale provided by respondents for their selections in the poll is summarized below.

Visual
Those who identified visual detection as one of the most promising technologies based on impact and feasibility emphasized that it is a proven technology that is ready today, has been proven to be highly reliable, has less room for error, and provides actionable information. One participant categorized satellite imagery as infeasible and thermal/IR as too expensive on a per vessel basis. Another participant commented that there are all sorts of sonar, radar, and below surface technologies available that can map the ocean and detect the whales and subsequently lead to avoidance. One participant identified real–time visual methods as most realistic in Southeast calving grounds where calving females are near the surface and do not vocalize loudly/often.

Acoustic
Affordability, feasibility, scalability, and proven effectiveness under certain conditions were provided as rationales for identifying acoustic detection as one of the most promising technologies based on impact and feasibility. One respondent identified the fact that it does not require active participation from vessel users and that it can be automated/has the opportunity for AI involvement as positive attributes. One individual cautioned that acoustics are not a "silver bullet" but are a key component of any combination program. One individual suggested using acoustic monitoring specifically for improved monitoring of federal navigation channels.

Satellite
Respondents saw promise in the future advancement of satellite imagery and specifically highlighted the broad spatial coverage that could be achieved without risk to humans. The current high cost of VHR satellite imagery was identified as a limiting factor.

Thermal/IR
Workshop participants were encouraged by the science and data presented on thermal/IR imaging and saw it is very promising for application on large vessels with high risk of collisions with whales. The hyper–local and real–time nature of the information was identified as being highly likely to be accepted as actionable by mariners. Another benefit identified was the ability to detect whales at night and in a variety of environmental conditions. One respondent noted that everything needs to breathe, so thermal blows should always be present when whales are present whereas acoustic crypsis[12] leaves out the most vulnerable (e.g., mother–calf pairs). Others cautioned that it would not be feasible to deploy thermal/IR systems on individual vessels at a sufficient scale to reduce the risk of what are rare events for vessels, but too common for whales. Others expressed additional concern about scalability and questioned the feasibility of having a human verify all thermal/IR detections across a fleet.

Combinations of Technology
The combination of technology received the most support, and rationales for this included variability in whale behavior, vessel operations, environmental conditions, and human error. Participants commented that this is not a one size fits all problem, and combinations of technology help fill in gaps (including targeting different whale cues, surface and subsurface monitoring). Another commented that a toolbox of technologies was needed, every tool has its strengths and weaknesses, and combinations needed to be leveraged to

[12] Acoustic crypsis is a form of stealth–like behavior to avoid predator detection used by NARW mother–calf pairs (significantly reducing the number of high amplitude, long–distance communication signals produced; Parks et al., 2019).

find the best fit for each scenario. Some respondents specifically mentioned using visual and acoustic detection methods on a broad scale and complementing that with thermal/IR in priority areas or on priority vessels. One respondent specifically observed that for offshore wind a combination of acoustic, visual, and thermal/IR detection methods are appropriate and being used but said that they needed regulators to identify acceptable standards of efficacy. Participants suggested a combination was necessary to maximize detection rates and suggested layering in predictive presence models.

Other Comments
One commenter took issue with the questions in the poll and stated that the value of detection methods is highly dependent on the application with which you plan to use it (e.g., which vessel type, which industry sector). Similarly, another observed that sector specific detection system approaches might be most effective. Others suggested that the problem was not lack of detection technology, but the lack of a mechanism to present all this information to vessel captains in a timely manner. Another expressed concern that the data from gliders and other detection technology appeared to undergo bureaucratic delays before reaching vessel captains. Respondents commented that for each type of detection there is a need to establish a baseline by which to evaluate each technology to allow consistent comparison across technology. They also noted the need to identify combinations of technology, fit them into risk reduction systems, and evaluate the effectiveness and cost of those systems. Others encouraged focusing on technology that does not negatively impact whales. Finally, one respondent stated that tagging should not be viewed as a mitigation method.

5.4.3 Online Form

An online form was provided for all workshop participants but was targeted for remote attendees that did not have the opportunity to join the small group discussions and to allow the submission of any additional input on detection and classification technology. The form was filled out by 12 individuals. A summary of the responses to the open–ended questions in the online form is provided below.

Most promising technology based on impact and feasibility (Noting this can vary by location, vessel type, scenario):
Tagging: One respondent offered support for tagging and remote tracking of whales as the most promising technology. Another shared that his company was exploring the concept of developing low–cost autonomous surface vessel (ASV) platforms specifically for long–duration marine wildlife monitoring by replacing tagging with small ASV "escort vessels."

Acoustics: Support was offered for PAM as an effective detection technology, but the lack of ability to provide the location of the whale was identified as a significant shortcoming. Multi–array integration and better decision–making systems (based on ML and Deep Learning (DL) algorithms) were offered as having potential to solve this issue and reduce the amount of visual data acquisition required to assess location and distribution.

Thermal/IR Imagery: Respondents identified thermal/IR imaging as very promising given the high detection probabilities presented, but some questioned the feasibility of scaling this technology to meet needs/demands. They expressed appreciation for the rigorous testing that has been conducted and the availability of performance details for the WHOI thermal/IR system in multiple peer–reviewed publications. Respondents characterized thermal/IR as being at an advanced TRL.

Combinations of Technology: Workshop participants noted that there did not appear to be a single most promising technology, and each has its benefits and limitations from a detection and application perspective. One respondent cautioned that the absence of data is not data on absence, noting that combining the technology can enhance detection probabilities overall and best inform risk reduction actions. Combinations of acoustic and visual technology were recommended with verification by a human–in–the–loop process and quickly disseminated to inform near–real–time decisions.

Workshop participants supported combining PAM, visual observations, and thermal/IR imaging to fill different gaps. Some offered suggestions beyond detection and classification and supported robust decision–making tools (probably based on ML/DL models), reliable and convenient user experience, and data aggregation. Support was offered for the combination of existing and proven non–invasive technology into an integrated system. Another suggested everything (satellite identification, AIS alerts, PAM arrays, aerial surveys, thermal/IR) should be on the table to increase the likelihood a whale will be detected and protected. One respondent stated that the most appropriate combination depended on vessel size classes and operator experience and noted that each detection technology had its benefits and limitations. Finally, one participant supported any combination of technology that brings together the public needs and regulatory needs.

Other: One participant specifically stated that they did not see any detection technology on the immediate horizon as "promising" (equivalent to risk reduction from a 10–knot vessel speed restrictions) and expressed the importance of not sending a message to Congress or the public that there is some real–time monitoring solution on the immediate horizon. It is important to note that for the purposes of the workshop and in the questions posed to participants, the term “promising” was used generally to encompass such things as the potential of the technology to be implemented as part of a risk reduction system and for which no significant obstacles to implementation were identified.

Recommendations for developing a consistent evaluation method for whale detection and classification technology:

One participant recommended using historical tag data to parameterize cue rates (blows for thermal/IR, up–calls for PAM, surfacing events for visual monitoring/satellite), and then designing a simulation to compare the efficacy of each technology type and combinations of technology for detecting these cues in a set field of interest given a range of environmental conditions (fog obscuring thermal/IR, anthropogenic noise obscuring PAM, clouds obscuring PAM, weather limiting vessel and aerial surveys, etc.). Another stated that first you needed to establish current TRL levels for existing technology and the required testing and performance metrics needed to advance to the next TRL level. They stated that performance data should be made publicly available and peer–reviewed. They recommended looking at the example of the certification required for the deployment and operation of vessel radar.

One respondent encouraged addressing the cost of deployment and time to functional deployment for each detection system more directly. One attendee suggested thinking about an operations center for the shipping lanes, like air–traffic control. Another observed that none of the methodologies are new and therefore suspected that detection evaluation methodologies were already in place (for example, detections between aerial and acoustics have been previously evaluated). They recommended focusing evaluation on the ability of vessel operators to receive information, use it appropriately, and respond to the detections in a manner that avoids hitting a whale.

Continuous Verification of Performance:

Some recommended building the archiving of data into technology to allow for verification of performance. Comparing and cross–validating different technology was also recommended as a means of verifying performance. One respondent stated that verification is critical, and it would also need to be done in real–time and supported the inclusion of a human–in–the–loop to verify detections at least until AI algorithms improve.

One respondent offered a potential key performance indicator as a measurement of how regularly every surviving whale in the NARW population is re–sighted, and the maximum time gap between successive detections of distinct NARWs; the goal being decreasing this key performance indicator toward some target. Another stated that to design and optimize the integrated system and to verify the performance, an accurate and validated coupled ocean–acoustic model was needed. Another respondent recommended that the USCG require all boats greater than 35 feet to have AIS. They further recommended using AIS data to compare vessel operation before and after information on whale detections was received by the vessel to see if it had slowed down or changed course.

5.5 Primary Takeaways

Presentations in the Detection and Classification session identified and characterized existing and potential technology to detect and classify NARWs. Visual (aerial surveys, drones, vessel surveys) and acoustic methods (fixed platforms, mobile platforms (AUVs or gliders)) are currently operational and in use as monitoring and surveillance tools. Thermal/IR detection was identified as promising but requires further testing. Other technologies also identified as promising for vessel strike risk reduction efforts but that need significant testing or further development include satellite imagery, eDNA, and DMS. There was also strong interest in Type C satellite tags, which are well developed, but have yet to be permitted and demonstrated on NARWs. Ongoing efforts to develop a shorter Type C tag to address concerns about anchor length in the shallower blubber depth of NARW will require several more years of development and demonstration. While Type C tags have been identified as having potential to address priority research questions, their specific role as a technology for whale detection in order to reduce vessel strike risk must consider that only a few animals would be able to be tagged, and therefore the absence of a tagged animal in an area would not be a reliable indicator of species presence and associated vessel strike risk. The contribution of ML and AI, specifically to data processing, was noted; however, the use of a human–in–the–loop for verification was recommended in most cases. The need to match detection technology to specific situations and vessels while considering such things as reliable detection range, environmental conditions, whale behavior, and vessel maneuverability was emphasized. Participants recognized that combinations of technology could complement each other's weaknesses and improve overall detection performance. The need for development of performance metrics and testing protocols was recognized, and the challenge of testing integrated systems was noted. In addition, participants discussed the need to optimize the deployment of detection technology as well as the investment in that technology. These key points were captured and summarized by the facilitators and shared back with participants at the close of the session using the table below (Table 3).

Table 3. Promising Pathways and Next Steps—Detection and Classification. This table was filled in by the facilitator during the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Detection and Classification breakout session, based on session discussion, and modified to improve clarity for use in this report.

Most Promising Detection Technology	Next Steps to Advance	Role of Government, Private Sector, Partnerships, and Questions
A **combination** of tools is most likely needed.	Identify the unique challenges of vessel types/users and develop approaches tailored to each (i.e., one size does not fit all). Explore and pilot **combinations** of tools to test and measure risk reduction.	Lay out **performance standards** for detection technology so that developers/innovators can develop products to meet the goal. (Government role) Develop a **risk framework** to evaluate multiple technologies in combination. (Unassigned role) **Investment and collaboration** across sectors is needed to advance technology innovation and technology readiness. (Everyone's role)
Thermal/IR has high interest to detect whales at the surface by many (not all vessels).		Investigate how **AI** can be further used to more quickly advance and improve thermal/IR technology (including the potential to function completely autonomously). (Unassigned role)
PAM/acoustic remains a powerful tool that is advancing in terms of localization, but depends on whale calling, which is not necessarily regular and consistent.	Address the challenge of moving from tools that have been used primarily for monitoring (both individuals and populations) to tools that can achieve high success at reducing individual NARW vessel strike risk (transition from monitoring to mitigation).	
Some interest remains in continuing to use **human observers** and in aggregating sightings across numerous vessels.		
Interest in but strong caution about tagging given impermanence, risk to animals, cost, complexity, and impracticality of finding and tagging all whales.	Continue efforts to develop a longer lasting and less invasive tag and deployment method.	

6. Modeling/Forecasting

6.1 Introduction

Technology–based advancements that can forecast the spatial and temporal distribution of NARWs and vessel traffic can be used to identify areas of relatively high vessel strike risk. Forecasting involves making predictions about the future based on specific and relevant time–series data. Forecasts are likely the most informative for the Static Scenario but may also be able to inform the Dynamic Scenario. A NARW Predictive Tools Workshop was hosted by BOEM in December 2023 to discuss the current state of the science for NARW predictive modeling. As part of preparing for the workshop, BOEM developed a white paper that reviewed the literature on current, emerging, and future tools that predict or could predict NARW presence (Cusano et al., 2024). A few key predictive tools covered in BOEM's workshop are highlighted below. In addition, a literature review was conducted by the workshop planning team to help shape and narrow the focus of the workshop modeling and forecasting session and, while not shared with workshop participants in its entirety, elements are being included in this chapter to provide additional context for the workshop session itself. While the literature review content serves to provide context, the remainder of each chapter is intended to provide an accurate and complete account of the workshop itself. It is important for the reader to note that statements and opinions of workshop participants are captured in the workshop report without additional commentary, corrections, or caveats provided by the workshop report authors.

In 2017, Hazen et al. published on their development of an automated, near–real–time whale density prediction for Eastern North Pacific blue whales (*Balaenoptera musculus musculus*), which incorporates abundance estimates, a satellite–telemetry–based habitat model, and up–to–date environmental data. This near–real–time tool was developed to provide a more accurate representation of the year–round spatiotemporal overlap of blue whales with potentially harmful human activities, such as shipping, along the U.S. West Coast. The authors stated they believed mandatory dynamic management approaches could be successful for blue whales in the California Current due, in part, to the fact that the obligate prey of blue whales (krill) are more strongly tied to dynamic features (Croll et al., 2005; Santora et al., 2011) than the prey of NARWs (diapausing copepods, specifically *Calanus finmarchicus*; Baumgartner et al., 2003 as cited in Hazen et al., 2017). While predictive models have primarily been aimed at static zone management, Hazen et al. (2017) argue that static management approaches that are sufficient now may become less effective in the future given climate–induced distribution shifts in marine species (Hazen et al., 2013). They note that increased technological capacity from animal telemetry, environmental data from satellite remote sensing, and computationally intensive models offer opportunities for targeted management applications responsive to environmentally driven changes in species distributions (Hazen et al., 2017).

Madon et al. (2017) similarly noted that the wide variety of data sources (e.g., VHR sensors onboard satellites, acoustical measurements, satellite tagging, direct reports from commercial vessels, social media, live–streaming earth observation data) will allow the development of high precision, real–time maps of the likelihood of whale encounters. Their work sought to develop high–resolution maps of the probability of whale encounters in real–time using all available data sources. As noted in the discussion of whale detection and classification in this report, advances in AI and ML can also help make real–time prediction modeling a possibility (Chapter 5 and Appendix 6). However, when using any such probability forecast model for management purposes, there are several policy decisions that need to be made including what data to include or exclude, the desired level of confidence in the detections, and the willingness to tolerate false positives.

The focus of this workshop's Modeling/Forecasting Risk Component session was primarily on the technology used to forecast the distribution of NARWs. However, it is important to recognize that advances in modeling have broader implications for vessel strike risk reduction including examining risk as a combination of both whale and vessel presence and behavior. Considering the challenge of evaluating individual whale detection systems via field trials, let alone attempting this for combined tools, Verfuss et al. (2018) suggest that a more effective way to understand the overall efficiency of combined systems would be to simulate combined detector performance. The parameters of these simulations would describe the performance of individual systems informed by field trials and include realistic information on patterns of cue production and movements for the marine mammal species of concern.

6.2 Workshop Session: Modeling/Forecasting NARW Presence

The goals for the workshop session on modeling/forecasting whale presence and vessel strike risk were to: (1) identify and characterize existing and potential technology to model/forecast the spatial and temporal distribution of NARWs for the purposes of informing Static, Dynamic, or Vessel–Specific risk reduction action; and (2) characterize the state of play for forecasting/modeling and identify the most promising technology/methods and the priority next steps to advance their development and deployment. There were 156 attendees assigned to this breakout session, of which 39 were in–person participants and 117 were remote (Figure 13).

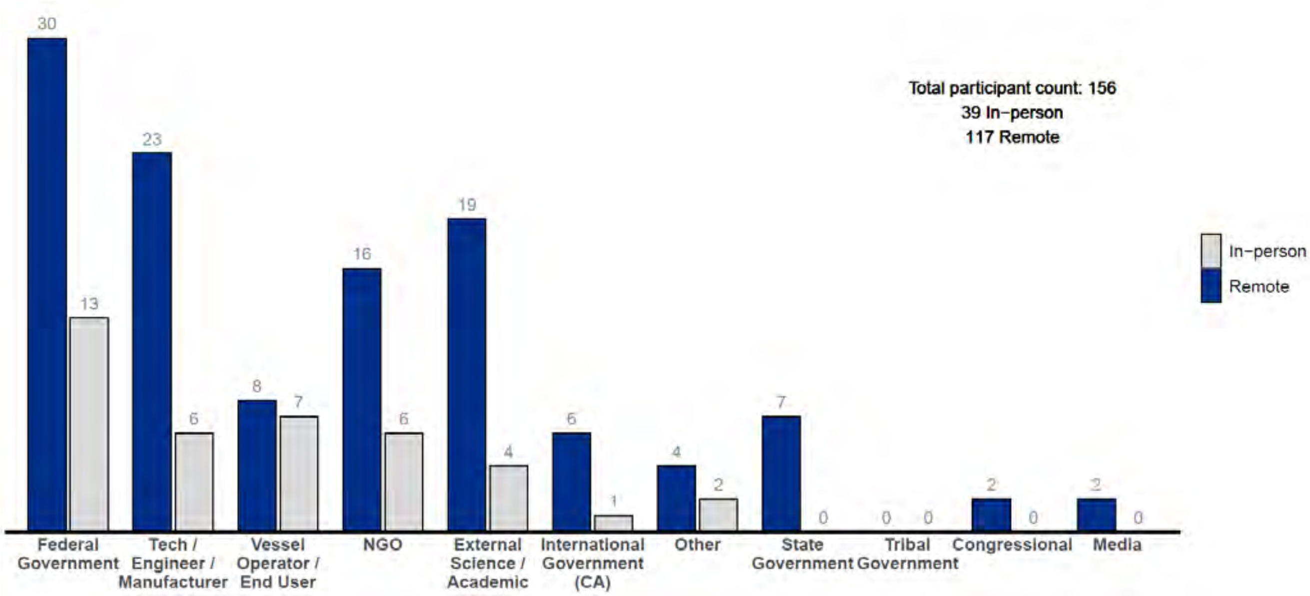

Figure 13. Participants in the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Modeling/Forecasting breakout session. Blue bars represent remote participants and gray bars represent in–person participants. Labels above each column indicate the total number of participants within each category.

6.3 Presentations

Summaries of the four presentations in this session are provided below. In addition to the four presenters, this session included the eight following technical SMEs: Joel Caplan, Rutgers University; Nathan Crum, Florida Fish and Wildlife Conservation Commission; Ramy Imam, Lautec; Alexandra Mayette, Canadian Wildlife Federation; Erin Meyer–Gutbrod, University of South Carolina; Daniel Pendleton, NOAA Fisheries NEFSC; Jessica Redfern, New England Aquarium; and Rob Schick, Duke University. The session was facilitated by Elizabeth Cooper, CBI.

Eric Patterson, NOAA Fisheries OPR, provided an introductory presentation to set the stage for the session. When considering how modeling can reduce NARW vessel strikes, Patterson identified the following key observations: (1) the ocean is very big; (2) monitoring, regardless of method, will always be imperfect; (3) vessel–based detection will likely always be challenging; and (4) evasive action by vessels is not always possible. He suggested that models can help by, among other things, characterizing NARW distributions, assessing vessel strike risk, and informing conservation measures. He reminded participants that the focus of the workshop session was to discuss how existing and future modeling efforts could be enhanced to more effectively address the issue of NARW vessel strikes.

Following this background, Patterson reviewed past, current, and planned NOAA Fisheries investments in modeling efforts. Development of the first NARW habitat–based density distribution model began in 2012 as part of the U.S. Navy's Atlantic Fleet Training and Testing Environmental Impact Statement and resulted in habitat–based average monthly NARW densities, with associated measures of uncertainty (Roberts et al., 2016). Patterson reported that NOAA Fisheries and Duke University entered into a 5–year cooperative agreement (2020–2025) to expand upon the initial model including incorporating additional data sources and covariates and developing separate models prior to and following the 2010 NARW habitat shift. He identified the following additional ongoing modeling efforts supported by NOAA Fisheries: (1) updates to the Garrison et al. (2022) vessel strike encounter risk model; (2) development of a transboundary model expected to be released in 2025; and (3) collaboration with Duke and BOEM on a near–real–time model.

Jason Roberts, Marine Geospatial Ecology Lab, Duke University, presented on behalf of himself and Pat Halpin on Duke's NARW density models. He noted that the point of modeling efforts is to consolidate raw data into useful theories of the world such as using photographs taken of whales to derive estimates of whale abundance and using data from line transect surveys to develop whale density maps. Models help compensate for gaps in survey coverage or variations in effort as well as variations in detection probability across survey platforms, sampling teams, ocean conditions, whale dive behavior, and other important factors. Roberts reviewed cetacean survey programs conducted by a diversity of partners and showed how models account for things such as how detection probability changes by distance.

Roberts reviewed two parallel modeling projects being conducted by Duke University on the U.S. East Coast and their applicability to NARW vessel strikes. First, he described the long–term hindcast model Patterson previously introduced that produces maps of mean monthly NARW density (averaged over several years) and explained that model outputs are widely used for management of NARWs and approximately 30 other cetaceans[13] (Roberts et al., 2016, Roberts et al., 2024). Secondly, Roberts discussed a near–real–time nowcast modeling project, jointly funded by NOAA and BOEM with an expected release in 2027–2028. This effort will produce maps of predicted daily density issued in near–real–time that could inform Dynamic Scenarios. Roberts indicated he was very interested in hearing what outputs people felt would be most useful from the near–real–time nowcast and specifically asked for feedback on the most useful spatial resolution for the model, noting the current plan is to use a 5-kilometer resolution.

Lance Garrison, NOAA Fisheries Southeast Fisheries Science Center, reviewed how models can be used to assess the risk of vessel strikes to NARWs. He reviewed the encounter risk model currently being used by NOAA Fisheries that Patterson mentioned, which evaluates the encounter rate between vessels and whales by integrating information on whale and vessel distribution, speed,

---

[13] Duke Marine Geospatial Ecology Laboratory. 2024. Habitat-based Marine Mammal Density Models for the U.S. Atlantic: Latest Versions. [Available at https://seamap.env.duke.edu/models/Duke/EC/]

and size (Garrison et al., 2022). Garrison clarified that the spatial and temporal distribution of vessel traffic was characterized by AIS data. He noted that small vessel traffic is underrepresented in the AIS data and therefore the total risk of small vessel strikes is not well represented in the model, and that understanding the variability in whale behavior and response to vessels was likely the biggest challenge moving forward.

Garrison reviewed ongoing refinements to the encounter model, which will include the incorporation of regional variation in whale diving and surface behavior and will likely result in regional differences in vessel strike vulnerability. He also reviewed a biophysical model looking at vessel strike mortality that indicated that the probability of lethality depends on the size and speed of the vessel involved (Kelley et al., 2021). He further explained that models can characterize the spatial and temporal variation in strike risk in response to whale and vessel distribution, identify areas of highest risk to allow tailoring of management efforts, predict the effectiveness of proposed measures for reducing risk, and characterize risk by different vessel categories. Finally, Garrison noted that models that used near–real–time or forecasted predictions of whale occurrence, and which fully accounted for uncertainty and variation in whale behaviors, could likely provide regional or sub–regional scale predictions of relative risk that would be informative for Dynamic Scenarios.

Jacob Levenson, Division of Environmental Sciences, BOEM, reviewed the NARW Predictive Tools Workshop hosted by BOEM in December 2023, which reviewed current, emerging, and potential future tools for predicting NARW presence. The goal of that workshop was to identify ways to improve the ability to predict NARW occurrence to improve dynamic management. Levenson identified the tools and approaches reviewed at the workshop and the rubric used for their evaluation. He shared a link to the literature review noted above (Cusano et al., 2024) and said that a report of the BOEM 2023 workshop would be available soon.

One of the potential approaches discussed at the BOEM workshop was the use of DMS to predict NARW presence. Levenson shared that BOEM had entered into an interagency agreement to carry out a DMS study with NOAA and WHOI in FY24. The above–referenced BOEM–supported literature review contains the following regarding DMS:

> Dimethyl sulfide is a volatile compound found in the ocean, primarily resulting from the breakdown of phytoplankton (Hulswar et al., 2022). Because a small amount of DMS is released into the atmosphere, increased concentrations of DMS in the ocean result in enriched atmospheric concentrations (Lana et al., 2011). DMS is a scented compound that acts as a biogenic cue and adds to the olfactory landscape of the ocean (Nevitt et al., 1995). DMS has been associated with the presence and foraging of animals that predate on plankton. Therefore, it is hypothesized that increased DMS concentrations may provide a way for species that rely on chemosensory methods for prey detection to locate dense patches of prey (Procter et al., 2019). This includes copepods, the primary prey of NARWs, which perceive phytoplankton using chemosensory cues (Poulet and Marsot, 1978).
>
> It is unknown how NARWs locate prey (Kenney et al., 2001). It has been proposed that some mechanisms may include chemical cues originating from copepods, detected via gustatory or olfactory senses. However, there is no empirical evidence to support this at present. Additionally, there is currently no established scientific method for detecting copepods directly. However, seawater concentrations of DMS can be measured (e.g., Bates et al., 1994; Owen et al., 2021) and predicted from climatology models (e.g., Owen et al., 2021; Hulswar et al., 2022). Additionally, recent research has indicated that there is a correlation between zooplankton biomass and DMS concentrations in both air and seawater

(Owen et al., 2021). The authors conclude that DMS concentrations could act as a foraging cue that attracts zooplankton predators, such as copepods. Because NARWs prey on copepods, it may be possible to predict where NARWs will occur based on the presence of high DMS concentrations.

6.3.1 Clarifying Questions on Presentations

In response to a question, Roberts clarified that data from an acoustic array that allows vocalizations to be localized can be used in the model in the same way as visual data. Garrison responded to a question to clarify that vessel strike risk was not considered uniform in space and time in his model. Roberts also clarified that the near–real–time model being developed should be viewed initially as experimental.

6.4 Contributions of Subject Matter Experts (SMEs)

Pendleton noted the complexity of integrating surveys using different platforms and methodologies into a single model. This challenge explains why it would take many years to develop the near–real–time model. Caplan suggested the consideration of micro–contexts when analyzing vessel strike risk, which involves examining the geospatial details associated with vessel strike incident location patterns to better understand particular spaces and times where the interactions of vessels and whales are most likely to occur in the future. Meyer–Gutbrod noted that it was important to acknowledge that the situation with NARWs was made worse by the 2010 ocean regime shift, which led to NARWs shifting their distribution in unexpected ways and therefore exposed them to unmitigated risks. She cautioned that the need to address the possibility of future regime shifts in addition to modeling based on the current regime must be recognized. Redfern offered support for Meyer–Gutbrod's caution and stated that models have potential to evaluate how much risk reduction is likely to be achieved by technology. Crum noted that the presentations covered a select few sets of models, but noted there are other types of models available. He said the Florida Fish and Wildlife Conservation Commission is developing capture–recapture models that incorporate survey effort, sightings, photo–ID, environmental data, migration and movement rates, and detection rates from historic data in the Southeast. Crum expressed openness to exploring the potential application of that model to vessel strike mitigation if there was interest in doing so but noted more evaluation of the model would be required first.

6.5 Discussion and Input from Workshop Session Participants

Workshop participants were provided with the following questions to prompt discussion: (1) Can spatial/temporal whale distribution modeling be useful for dynamic decisions regarding vessel operations? If so, what is needed for dynamic models to effectively complement near–real–time observations?; (2) For vessel operators and industry representatives, what would make model outputs more useful for dynamic management and help you make decisions? What information regarding uncertainty would you find most useful?; and (3) For vessel operators and industry representatives, what formats and types of interface would make this model easiest to integrate into decision–making?

Vince Premus, Ocean Acoustical Services and Instrumentation Systems (OASIS), shared that they are deploying acoustic arrays that provide information on marine mammal presence with high spatial resolution and have the potential for instantaneous localization. He expressed interest in contributing information to support density estimation and measurement of spatial distribution, standardization of metrics and model assumptions, and validation of modeled detection performance. Rob Schick, Southall Environmental Associates, said he was working on a model trying to fuse line transect data and calling rates. This is part of an unpublished manuscript that was in review at *Annals of Applied Statistics* and focused on data from Cape Cod Bay, MA (Schliep[14]). Elliot Horowitz, Viam, said he is working with several people in the government and private sector to facilitate data collection at a faster rate by placing sensors on commercial vessels. He said the next step would be to get that data from vessels into an organized and public dataset, increase the number of vessels participating dramatically, and conduct analysis using modern AI/modeling approaches. Roberts responded that changes in zooplankton are the primary driver in shifts in NARW behavior, and other metrics like salinity, depth, bottom temperature, etc., are only proxies of what whales really care about—but he expressed general support for collecting more data.

Pendleton discussed the challenge of providing fine scale resolution and that anything finer than a daily 5-kilometer scale may not be useful/interpretable. He further commented on the statistical constraints in incorporating as much data as possible in these sorts of models. Regina Asmutis–Silvia, Whale and Dolphin Conservation, supported the value of models, but stated that, from a vessel operator standpoint, they can never tell you that there is no risk in an area. She also supported the value of technology but stressed that it is not mitigation in and of itself. Jolie Harrison, NOAA Fisheries OPR, asked if anyone was looking at time of day as a covariate. Recognizing the limitations of existing datasets, she suggested using models to enhance the allocation of resources to collect priority data to feed models.

Mike Waine, American Sportfishing Association, emphasized the importance of improving interested parties' confidence in the risk models and recommended interested parties provide input on model assumptions (e.g., vessel characteristics). He suggested that a Take Reduction Team process for vessel strikes would allow more collaboration, planning, and connection between researchers, modelers, and interested parties. Garrison and Patterson expressed support for obtaining additional input and providing opportunities to talk about model assumptions and associated sensitivity analyses. One participant noted the challenge of determining what level of uncertainty is acceptable from the perspective of the whale versus the vessel operator.

6.5.1 Online Poll

Of the 156 attendees who selected or were assigned to this breakout session, 34 chose to participate in the session's online poll, 21 of whom were remote participants and the remaining 13 were in–person participants. Online poll participants were distributed across sectors as follows: Government (N=11); NGOs (N=9); Vessel Operator or Industry Representative (N=5); External Scientist/Academia (N=5); and Tech Engineer/Manufacturer (N=4). The poll included the following three questions: (1) Where do you see modeling has the greatest potential to inform our understanding of NARW distribution and/or co–occurrence risk?; (2) What issues or opportunities do you see as most important to focus on for improving models?; and (3) Anything else you want to share regarding the application of modeling to reduce risk from vessel strikes? Below is a summary of the input provided via the online poll.

> ***The potential of modeling to inform our understanding of NARW distribution and/or co–occurrence risk:***
> Poll participants identified the value of models integrating data from multiple monitoring sources (acoustic, multiple visual survey types) in a broader monitoring framework rather than relying on just one monitoring source. They also acknowledged that models can help inform risk assessment in areas where survey effort is limited or challenging to obtain and

[14] Schliep, E. M., A. E. Gelfand, C. W. Clark, C. M. Mayo, B. McKenna, S. E. Parks, T. M. Yack, and R. S. Schick. 2024. Assessing marine mammal abundance: a novel data fusion. Annals of Applied Statistics. 18(4):3071–3090. https://doi.org/10.1214/24-AOAS1924

provide a basis for management schemes that is unachievable with raw data alone. One participant said models are the best tool available now to inform management, but acknowledged additional effort is needed to continue to make these tools more applicable to the temporal and spatial scales needed to inform risk reduction actions.

The majority of respondents indicated that providing probabilities of NARW occurrence or NARW–vessel co–occurrence is the greatest role for modeling. They expressed support for continued work on the incorporation of covariates into models, particularly zooplankton. One participant suggested that zooplankton and physical oceanographic modeling may elucidate a more predictive model that can forecast whale densities based on preceding conditions. Respondents were cautiously optimistic about the ability of models to predict future regime shifts. One participant expressed appreciation for the level of coordination that appeared to be occurring among modelers but encouraged a focus on models providing actionable intelligence.

Most important issues or opportunities to focus on for improving models:
Poll participants suggested that it was most important to focus on NARW behavior and movements (e.g., exploring if environmental covariates can predict migration/movement into or out of risky regions). They also identified the importance of incorporating covariates (which may vary regionally) into models to forecast future regime shifts. Some recommended focusing on zooplankton modeling. The need to find a way to improve the incorporation of smaller vessels in models was also identified as important, recognizing they are not required to use AIS. Participants prioritized identifying how models can best be used to test likely efficacy of new vessel strike reduction technology or methodologies. Matt Adams, MITRE, shared that MITRE is working with NOAA Fisheries to develop a risk model to evaluate the effectiveness of various technology–based mitigation strategies.

To get more people involved in modeling, it was recommended that the data and standards used to inform, validate, and test models be made available. Some participants felt it was most important to focus on the end user of model outputs, and specifically to address whether model outputs can be useful to the average vessel captain making decisions or if they are limited to influencing policy. Others identified the importance of customizing model predictions to each vessel size/type category (i.e., not one–size–fits–all).

Other thoughts regarding the application of modeling to reduce risk from vessel strikes:
One poll participant observed that modeling has advanced and has merit, but it cannot predict where there is no risk, thus precautionary vessel speed restrictions are necessary. Another recommended using modeling to quantify the many environmental benefits of large vessels slowing to 10 knots in addition to reducing strike risk (e.g., reduced ocean noise, air pollution, and greenhouse gas emissions). One response identified the importance of fully considering the likelihood that vessel operators will comply with dynamic management areas created from nowcast and forecast models.

One poll participant pointed out the importance of defining the outputs desired from a model so that they can be compared with identified metrics of vessel strike risk reduction success. Another emphasized the importance of allocating surveys and detection efforts to areas where whales might be transiting, even if these areas are not "preferred" or suitable habitats, to better model movement. One highlighted the importance of reducing the amount of time from data collection to data processing, to model output to improve the value of those outputs for vessel strike risk reduction. One participant noted the importance of discussing uncertainty with interested parties with the goal of understanding and agreeing on a risk tolerance level. Finally, one participant reinforced the need to make full use of available data to inform models.

6.6 Primary Takeaways

The most promising next steps to advance the contribution of modeling to NARW vessel strike risk reduction were identified by considering the presentations, input of technical SMEs, and discussion among breakout session participants. The five most promising pathways and the associated next steps to advance them are summarized in Table 4. A theme across many of these pathways is the desire for more discussion amongst modelers and interested parties. Such discussions could increase the understanding of and comfort with model inputs, outputs, and assumptions, and could help identify model outputs that are both useful and actionable. Many comments emphasized the value of discussions about how to deal with uncertainty. While outside of the scope of this modeling session, participants identified other ways in which models could reduce vessel strike risk including through virtual testing of the efficacy of new technology and combinations of technology and methodologies.

Table 4. Promising Pathways and Next Steps—Modeling/Forecasting. This table was filled in by the facilitator during the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Modeling/Forecasting breakout session, based on session discussion, and modified to improve clarity for use in this report.

Key Issues and Opportunities	Next Steps to Advance
Provide opportunities for **greater collaboration/coordination among modelers**. There is a desire among some interested parties for further engagement in modeling efforts, including model assumptions.	Consider **additional collaboration among modelers** and ways to increase transparency and sharing of information about how modeling efforts are related; consider ensemble models. **Compare** multiple competing models and techniques to help validate findings. Allow for/develop a process to **increase engagement with interested parties.**
Consider how models can be used to **evaluate risk reduction potential** of technology.	**Explore development of a modeling framework to evaluate potential risk reduction** that may be achieved using different technology and combinations of technology.
Explore how models can be used to better understand and forecast long–term **ecological and climatological shifts**.	**Investigate what covariates or inputs should be integrated into models** to help them be most responsive to ecological and climatological shifts (e.g., prey density). In developing near–real–time models, eventually consider including long–term oceanographic and climate forecasts.
Develop formats for **daily forecasts** or other near–real–time approaches most useful in various use/user contexts.	**Solicit input from model users** on what temporal and spatial scale would be useful to inform modeling efforts, consider the validity and accuracy of model resolution given user specified requirements.

Key Issues and Opportunities	Next Steps to Advance
Improve data availability, quality, quantity, transparency, and opportunities for interested party/user data contribution.	Create standard approaches for collecting **high quality data from a broad range of users** to help inform models and ensure all these data are widely available to the modeling community. Convey value of data to help engage a wide variety of potential data collectors. Develop targeted **educational and outreach campaigns** directed at obtaining data necessary to inform modeling efforts. Work to ensure **data are open source and available to the public**; **develop partnerships** with individuals and entities in the private sector who are engaged in providing data to the public.

7. Aggregating and Assembling Data

7.1 Introduction

The aggregation of detections informs the Static and Dynamic Scenarios and may supplement Vessel–Specific whale detection methods. Technology is likely not a significant factor currently impeding aggregation efforts. More critical issues are: (1) accountability; (2) consistent rules applied to all data; and (3) data ownership and associated considerations. The actual delivery of the aggregated data to users/interested parties is addressed in Chapter 8. The workshop planning team conducted a literature review to help shape and narrow the focus of the Aggregating and Assembling workshop session and, while not shared with workshop participants in its entirety, a summary is included in this chapter to provide additional context for this workshop session. While the literature review content serves to provide context, the remainder of each chapter is intended to provide an accurate and complete account of the workshop itself. It is important for the reader to note that statements and opinions of workshop participants are captured in the workshop report without additional commentary, corrections, or caveats provided by the workshop report authors.

Effective evasive action to reduce the probability of vessel strikes of NARWs depends on mariners having access to accurate, complete, and timely information on the presence of NARWs. Platforms that aggregate detections (visual and/or acoustic) generally have some criteria or validation of those detections before adding them to the aggregated collection. Given the importance of providing real–time or near–real–time data, the validation process conducted by the aggregator is, by necessity, limited, and the data may be considered valid simply if they come from a verified, reliable provider. It is important to note that data providers use a variety of detection and classification methods, which may introduce inconsistencies across contributed datasets and has implications for the interpretation of the aggregate dataset. For example, one data provider may use a method which requires 100% confidence to classify a detection as the target species whereas another may employ a method which classifies a detection as the target species using a 51% probability threshold. In other words, the aggregate dataset may be composed of detections determined using different error acceptance rates (i.e., the likelihood of a true detection being missed or the likelihood of a false detection being classified as the target species), which makes the data challenging to interpret when making a time–sensitive decision or to inform management actions.

In some cases, researchers have collaborated to agree upon protocols intended to make data more consistent. When aggregated data are used for informational purposes, a higher false positive rate (i.e., saying a target species is present when in fact it is not) may be acceptable. Conversely, if aggregated data are used to impose significant regulatory burdens, a preference may be given to ensuring a low false positive rate while accepting a higher false negative rate (i.e., having a higher tolerance for missing true detections). Setting such a performance metric may restrict the number of acceptable data sources or the amount of acceptable data incorporated into data aggregation portals. The data aggregation platforms may, at a minimum, choose to report these metrics to make the user aware of the relative confidence associated with displayed detections. Mariners are trained not to make assumptions based on "scanty" information (see USCG Rule 7 Risk of Collision, International Rules of the Road, 33 CFR § 83.07; Gende et al., 2019). Therefore, conversation and investigation may be appropriate to reconcile the degree of detection certainty mariners see as necessary to trigger avoidance behavior with the need to sufficiently reduce vessel strike risk in support of the recovery of the NARW. If reconciliation can lead to greater consistency across datasets, it could simplify interpretations from aggregate datasets.

Platforms or services that aggregate data often do so with disclaimers noting that the data is preliminary, subject to change, and that permission is required for the use of the data. The first two caveats are understandable given the desire to provide the data in as close to real–time as possible, but it does shift the burden of deciding how much weight to give the data to the viewer. The data may be more useful to the end user if it is provided with an explicit measure of confidence or probability. Otherwise, it may be challenging for a mariner to know how to balance this detection data (with an unknown uncertainty) with other factors such as weather, safety considerations, schedules, and economic impacts. The common caveat that permission is required to use the data speaks to the data ownership issue identified in the first paragraph. To reduce vessel strike risk, mariners who receive aggregated information on NARW presence need to use that information to influence their navigational choices. It is likely that this caveat is intended to speak more to the use of the raw data in analysis and subsequent publication before the data contributor/owner can do so themselves. Regardless, this disclaimer should be clarified to remove any confusion as to the purpose and intended use of the aggregated whale data.

Following is a description of select data aggregation methods and platforms for NARW detections including: the NARW Consortium, the Whale Alert app, WhaleMap, Whale Insight, Mysticetus, Robots4Whales, the Whales, Habitat, and Listening Experiment (WHaLE) Project, and the Passive Acoustic Cetacean Map (PACM). Whale Watch and Whale Safe, data portals for whale data on the West Coast, are also briefly reviewed. These platforms are summarized below in Table 5.

Table 5. Selected data aggregation platforms for NARWs and other whale species.

Platform	Data Type(s)	Website
North Atlantic Right Whale Consortium Databases	Survey and Sightings Database, Identification Database	https://www.narwc.org/narwc-databases.html
Whale Alert	Visual	https://www.whalealert.org/
WhaleMap	Visual, Acoustic	https://whalemap.org/
Whale Insight	Visual, Acoustic	https://www.dfo-mpo.gc.ca/species-especes/mammals-mammiferes/narightwhale-baleinenoirean/alert-alerte/index-eng.html
Mysticetus	Visual, Acoustic	https://mysticetus.com/about/
Robot4Whales	Acoustic	https://dcs.whoi.edu/
Whales, Habitat, and Listening Experiment (WHaLE) Project	Acoustic	https://apps.cwf-fcf.org/whales/
NOAA Fisheries NEFSC Passive Acoustic Cetacean Map (PACM)	Acoustic	https://apps-nefsc.fisheries.noaa.gov/pacm/#/narw
Whale Watch	Predicted density/hot spots	https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/whalewatch
Whale Safe	Visual, Acoustic, Vessel traffic, Management areas	https://whalesafe.com/
Whale Safe North America	Vessel traffic, Management areas	https://na.whalesafe.com/

The NARW Consortium includes U.S. and Canadian members and maintains comprehensive databases containing records of thousands of NARW sightings, the majority of which are from the late 1970s to the present, but some date back to the 18th Century. The valuable databases contain extensive sightings information, and a photo–ID catalog used to monitor the status of the NARW population. These databases are not suitable for near-real-time data aggregation nor Dynamic Scenario purposes and are instead best suited to inform the Static Scenario, assess the status of the NARW population, and evaluate the effectiveness of management measures aimed at reducing human caused serious injuries and mortalities.

The Whale Alert app was launched by Conserve.IO in 2012 as a citizen science tool aimed at reducing the risk of vessel strikes to large whales in general. It displays aerial survey data, verified sightings, and acoustic detections for a variety of species (including the NARW) on nautical charts within the app's interface and requires an internet connection to get updated information. Mariners can also use the app to report whale sightings which, if made while connected to the internet and verified by the Whale Alert team, are posted to the app in near–real–time. An extensive list of network partners for Whale Alert can be found on their website.

WhaleMap is a web–based system built to collate and display near–real–time whale detections (both visual and acoustic) and survey effort (Johnson et al., 2021). This interface was designed with the following goals: (1) incorporate whale detection and survey effort from survey methods in near–real–time; (2) allow survey teams to easily contribute and retain complete control over their data; (3) provide the latest data in an accurate, user–friendly, and publicly accessible format; and (4) operate transparently using open–source tools and with limited supervision. It is important to note that WhaleMap does not: (1) perform any quality control or take responsibility for the validity of contributed data; (2) provide a long–term database for survey results; or (3) allow access to raw or processed data without approval from the data contributor. The process for survey data to be uploaded, combined with existing data, and displayed online in WhaleMap is approximately 15 minutes.

In Canada, DFO has developed an interactive map called Whale Insight, which was modeled after WhaleMap and displays NARW detections (visual observations by aerial or at–sea surveillance or acoustic detections) in eastern Canadian waters. Validated detections are usually available on the map within 24 hours, and the map is updated every 15 minutes.

Mysticetus developed an integrated risk mitigation platform, which is used by protected species observers (PSOs)/MMOs for situational awareness, data communications, and reporting. Their software automatically standardizes data collection and sharing between vessels to enhance situational awareness and provide support for marine mammal mitigation decisions.

Robots4Whales, the WHaLE Project, and PACM are three aggregation platforms focused solely on acoustic detections. Mark Baumgartner, WHOI, maintains the Robots4Whales website, which displays marine mammal acoustic detections made by autonomous platforms (including PAM gliders and buoys) that he and his collaborators have deployed. The Canadian Wildlife Federation launched the WHaLE Project, which is using underwater drones to listen for whales in the Northwest Atlantic. A map displaying detections can be found on their project website. The NOAA Fisheries NEFSC maintains the PACM website, which shows when and where specific whale and dolphin species have been acoustically detected by using bottom–mounted moorings, surface buoys, autonomous gliders, and towed arrays in the North Atlantic Ocean and allows the user to explore spatial and temporal patterns in the detections.

It may also be instructive to look at data aggregation portals used in other regions to aggregate detection data from other whale species. On the U.S. West Coast, a near–real–time tool called WhaleWatch was developed using blue whale and environmental data to provide monthly estimates of the likelihood of occurrence (Hazen et al., 2017). This platform, a NASA–funded project coordinated by NOAA Fisheries' West Coast Region, was also discussed in the Modeling/Forecasting breakout session. Whale Safe is another data aggregation portal focused on the U.S. West Coast and is hosted by University of California, Santa Barbara's Benioff Ocean Science Laboratory. It is an online technology–based mapping and analysis tool that displays both whale and vessel data with the goal of preventing fatal vessel strikes in the vicinity of the Santa Barbara Channel and the San Francisco Bay region. Recently, the Benioff Ocean Science Laboratory launched Whale Safe North America, which was expanded to include the U.S. East Coast and displays vessel traffic as obtained through AIS and mandatory and voluntary management areas, but does not include whale sightings.

7.2 Workshop Session: Aggregating/Assembling NARW Detections

The goals for the workshop breakout session focused on aggregating/assembling NARW detections were to: (1) identify and describe existing and potential technology/methods to aggregate/assemble NARW detection data; (2) for each method, identify the incoming data sources and types, any method for verification, and note any time lag (between detection to aggregation); (3) characterize the state of play for aggregating NARW detections; and (4) identify the most promising technology/methods and the priority next steps to advance their development and deployment. Issues proposed for discussion during this workshop session included identifying the: (1) challenges of aggregating data from different detection sources and methods; (2) degree of standardization or consistency necessary to ensure functionality, certainty, and a common playing field for technology developers; and (3) characteristics of an effective aggregation platform.

There were 126 workshop participants who selected or were assigned to this breakout session, 28 of whom were in–person participants and 98 were remote (Figure 14).

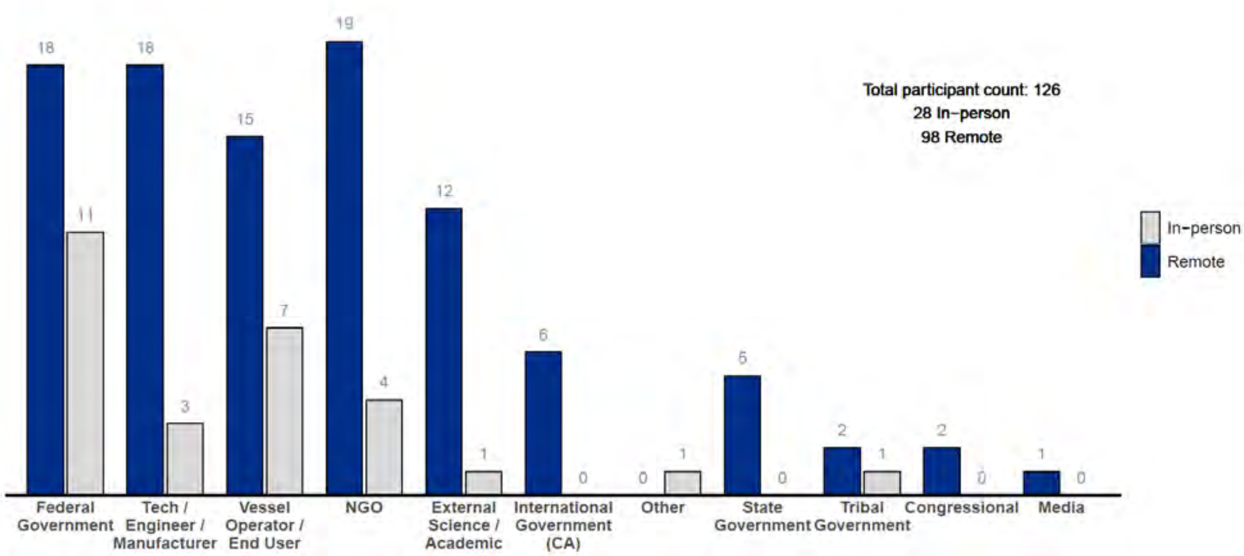

Figure 14. Participants in the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Aggregating/Assembling breakout session. Blue bars represent remote participants and gray bars represent in–person participants. Labels above each column indicate the total number of participants within each category.

7.3 Presentations

Mike Asaro, NOAA Fisheries NEFSC, opened this breakout session by acknowledging that there are other NARW databases, such as the sightings and identification databases held by the NARW Consortium, that are critical to assessing the status of the species. He stated that the focus of this session was on sites that aggregate archival and near–real–time data to inform real–time actions. Asaro clarified that the term aggregation has been used to refer to the assembling of data in a single location or site for near–real–time decision–making to reduce vessel strike risk. Additionally, these aggregation sites aim to serve up those NARW detections in a user–friendly manner for any interested party. Aggregation sites may receive data from several different detection sources and may serve a diverse set of clients. In general, it is the responsibility of the aggregation site client/user to understand the data's attributes and caveats when they use it to inform actions. He acknowledged that another workshop session was focusing on technology and tools to disseminate information and integrate it into the wheelhouse (Chapter 8).

Asaro provided an overview of the diverse characteristics of existing aggregation tools including: the type of detection data they accept; the level of confidence they might require; whether they include details of the detection method and platform; whether they are strictly for informational purposes or whether they directly inform management actions; and whether they are housed on a website or an app. He also said that the presentations would provide a variety of models for who is responsible for reviewing, approving, and operating the aggregation platforms.

Hansen Johnson, New England Aquarium, introduced and described WhaleMap, an open–source software system for collating and displaying NARW survey results in near–real–time. WhaleMap is designed to: (1) incorporate whale detection and survey effort from survey methods in near–real–time; (2) allow survey teams to easily contribute and retain control over their data; (3) provide the latest data in an accurate, publicly accessible, and user–friendly format; and (4) operate transparently using open–source tools and with limited supervision. Hansen identified the strengths of WhaleMap to be the speed at which data aggregation occurs (<15 minutes), the quick resolution of any issues, public availability of results, and that the system is maintained by NARW researchers. He also explained the limitations of WhaleMap, specifically that it is somewhat resource intensive and that the data are preliminary and cannot be shared without permission. He noted that WhaleMap currently processes data from U.S. contributors and shares data with Canada's Whale Insight to provide coast–wide coverage. Johnson also said that WhaleMap provides real–time data required for dynamic management. Finally, Johnson closed by explaining that the MMC has provided funding to build a stable infrastructure that will allow WhaleMap to be maintained in perpetuity.

For her presentation, Genevieve Davis, NOAA Fisheries NEFSC, described PACM. Davis explained that PACM aggregates detection data for both mysticetes (baleen whales) and odontocetes (toothed whales) from archival PAM and near–real–time PAM provided by over 19 organizations. She said that a Google Cloud Platform is currently being built to host a national NOAA Fisheries PACM that will allow external organizations to enter, manage, and edit their own data, and will incorporate quality assurance/quality control (QA/QC) checks upon data entry prior to acceptance into the database. Davis explained that some important considerations to keep in mind when using PACM include that it requires a basic understanding of acoustic detection data for proper interpretation (e.g., absence of detection does not equal absence of animals), and that, like the other aggregation sites, PACM relies upon the data contributors' expertise and appropriate methodology documentation for detection and classification.

Virgil Zetterlind, Conserve.IO, introduced Whale Alert, a marine mammal vessel strike reduction and outreach platform started in 2012 by Conserve.IO with principal funding by International Fund for Animal Welfare (IFAW). He explained that Whale Alert is a free mobile app and web–based map that has an opportunistic and effort–based sighting service, as well as being a sightings and information aggregator. Whale Alert aggregates information including marine mammal management zones and key marine protected areas, regional species information such as stranding network contacts, and other information such as nautical charts. Users of Whale Alert include the boating and coastal public, industry, government, NGOs, and academic institutions. Zetterlind identified the strengths of Whale Alert as the established relationships for sourcing and distributing sightings, it's over 10–year track record, and that it was born out of a marine e–navigation company with a strong understanding of the particular challenges of the marine environment. In terms of challenges, he identified the mitigation of the potential downsides of sharing sightings, the fact that Whale Alert is almost entirely funded through private philanthropy but is being used by industry and government, and the need to increase awareness and use by establishing local partnerships with boater organizations and communities.

The final presentation in this breakout session was given by Olivia Pisano, DFO, who discussed Whale Insight, a near–real–time data aggregation and dissemination tool launched in May 2022 for NARW management and protection in Canadian waters. She explained that Whale Insight is a DFO–led, publicly accessible bilingual visualization tool modeled after WhaleMap and was launched primarily to facilitate the operationalization and implementation of Canada's dynamic management measures in an open and transparent manner. Whale Insight collects validated visual and acoustic detections and trackline data in near–real–time and provides it to decision–makers and the public in near–real–time through two interactive interfaces. Pisano explained that all detections on Whale Insight are contributed or validated by qualified marine mammal experts. She summarized that the platform transforms scientific data into actionable insights that inform the management and protection of NARWs in Canada and observed that it has succeeded in building meaningful partnerships, encouraging trust and collaboration within the community, and fostering new whale detection technology. However, Pisano also noted that it is important to consider that aggregating and disseminating scientific data in near–real–time requires significant resources with regards to time, funding, and personnel, and that reporting this data in near–real–time places additional demands on data contributors. Finally, she noted that DFO is continuing to seek opportunities to improve the platform, with new features and improvements coming in 2025.

7.3.1 Clarifying Questions on Presentations

Paul King, SMRU Consulting, asked how acoustic detections are defined. Johnson replied that WhaleMap is not classifying the detections, the provider is doing that and said that generally it is the developer of the acoustic system (primarily Baumgartner) who has developed the process for defining a confirmed detection. Heather Hennessey, Yamaha Marine, asked Johnson to speak more about the tangled web he referenced (in terms of the complexity of the WhaleMap system) and asked if it is becoming less tangled as people get used to it over time. Johnson said initially there was a lot of opposition to providing data that would then be made available to the public, so they had to put assurances in place to limit the sharing of data to get buy–in from data contributors. In response to a question from a remote participant about data availability timelines, Johnson replied that some groups upload their data within 2 hours of acquiring it and some at the end of the survey day when they have connectivity. Laura Morse, Invenergy, shared that they are required by their permits to submit their data to NOAA Fisheries, and that data is then provided by NOAA Fisheries to WhaleMap at a slight delay. A remote participant also asked about and received information on how to submit data to WhaleMap.

Michael Faran, Deep Voice Foundation, noted that currently people can use PACM to view data, and it sounded like in the future users will also be able to submit a request to download data for analysis and use in publications. Johnson observed that real–time acoustic platforms appeared to be represented in both WhaleMap and PACM, but the distinction was that PACM also contains detections from archival systems. WhaleMap has both visual and acoustic detections, but only back to 2010.

In response to a question from Johnson, Zetterlind said that Whale Alert uses its own survey effort platform, Spotter Pro. Heather Genievich, New Jersey Department of Environmental Protection, commented that she did not think the existence of Whale Alert was widely known. Morgan Martin, BOEM Center for Marine Acoustics, asked Johnson and Zetterlind whether a mariner would have to have WhaleMap or Whale Alert open on their phone on the bridge and if not, to describe how the information is communicated to a mariner. Johnson said that WhaleMap is not designed to be used at sea. While it can be used at sea, you would need to have connectivity, and he said he was interested in the idea of seamless integration into a chart plotter. Zetterlind said that cruise ships in Alaska run a desktop version of Whale Alert on the bridge (they have onboard internet) and that Whale Alert can be used via satellite. In response to a question from Graham Tuttle, BSEE, Zetterlind said that the National Park Service in Alaska uses Whale Alert on a private network so that sightings are only shared with people who have the log in. Jeff Angers, Center for Sportfishing Policy, said connectivity, aided by cell service (quite a distance from shore) and other forms of communication, are available and that should not be a significant obstacle. Morse expressed frustration that data is being sent to multiple, but not all platforms uniformly and said it was unlikely that there would ever be one tool that could meet everyone's needs. As an example of this, she said that her company uses commercial software called Mysticetus, which meets their regulatory data collection and requirement needs and can send out sightings data and receiving external sightings in a very efficient way. While Mysticetus can and does receive sighting and acoustic detection information from other data providers, it is not receiving all right whale sightings that show up on WhaleMap. She stated that all right whale sightings should be shared to all available platforms (e.g., WhaleMap, Whale Alert, and software such as Mysticetus). Brendan O'Shea, APA, recommended additional coordination with the USCG regarding how to push verified data related to marine mammal sightings and the safety of navigation out to vessels.

In response to a question from a remote participant, Pisano explained that while DFO does not have the ability to analyze users of Whale Insight by sector, they do know that the site is used by researchers quite a bit as well as by industry members and fishermen. She reiterated that Whale Insight is primarily a visualization tool, and they encourage mariners to get their regulatory and management instructions from the appropriate sources, as Whale Insight does not replace those tools (i.e., Fisheries Notices), but rather is complementary. Johnson commented that the differences between WhaleMap and Whale Insight is a good example of how a one size fits all approach is not being taken by all aggregation portals, nor is it appropriate, but rather that specialized systems are being built for specific uses.

Zetterlind observed that there is an inherent bias in the data collected because all detections must be concurrent with the presence of a human or detection system. He said how likely a whale is to be in an area where there is no sensor is not known. Johnson noted that that was part of the impetus for adding effort data to WhaleMap and suggested this topic may be discussed in the concurrent modeling session.

7.4 Discussion and Input from Workshop Session Participants

Pat Field, CBI and session facilitator, shared that he was hearing that for many vessel types the existing tools, with some modification, can address the need, but it was less clear what tools are available for the diverse smaller boating community. Esteban Rodofili, Knauss Fellow, observed that until the connectivity issue for smaller vessels was resolved, these tools could only be used for conservation and not compliance. King said that the use cases (type, operating mode, other mariner aspects) need to be established and understood. He said that only one source for detection cannot be relied upon (i.e., PAM, thermal/IR camera), and data from multiple sources needed to be fused to create an integrated situational awareness dashboard for the operator. Angers agreed with Field, highlighting that the recreational boating sector's diversity requires tailored approaches rather than one–size–fits–all regulatory mandates. Johnson observed that he felt the aggregating task was in pretty good shape as evidenced by the fact the conversation was bleeding into the task of disseminating the information to mariners.

Emily Shumchenia, Regional Wildlife Science Collaborative for Offshore Wind (RWSC), offered that there might be value in adding contextual data along with detections in the apps. She wondered whether the predictive model outputs could be overlaid on the apps as well and suggested it could be useful to display this additional data to provide users with more information and context to what they are seeing (or not seeing). Casey Corrado, MITRE, asked for clarification on constraints on data access. Davis responded that data contributors want to be able to publish their data first and want to be notified before it is shared but recognized all the data contributors are part of a community. Johnson said it would have been easier to make all the data wide open, but if they had done that no one would have contributed their data. He said the restrictions establish respect and maintain the ownership of the data. O'Shea said he would like to see a commitment to assembling better marine mammal location data such as satellite imagery, new camera and other visual detection technology, and acoustic detection. Johnson noted that what data is important for a mariner to aid in their decision–making varies a lot depending on the user and situation. He suggested it was more important to focus on disseminating seasonal and dynamic management areas than bombarding users with tons of data.

Workshop participants identified REPCET[15] as an additional whale aggregation platform. REPCET is a software system that allows cetacean sighting reporting, sharing, and receiving in real time within a network of subscribers. Sightings are transmitted by satellite to a shore server where they are centralized and vessels equipped with REPCET receive alarms if they are likely to encounter the cetaceans on their route.

7.4.1 Online Poll

Approximately 39% (49 out of 126) of the participants in this workshop session chose to participate in the online poll, 36 of these were remote participants and 13 were in–person participants. However, this online poll was not shared in the breakout room but instead shared in the main workshop room prior to the next plenary session. A total of 21 poll respondents indicated they did not attend the Aggregating and Assembling breakout session. Those who participated in the poll were distributed across the sectors as follows: Government (N=16); Vessel Operator or Industry Representative (N=8); NGO (N=8); Tech/Engineer/Manufacturer (N=8); External Scientist/Academic (N=5); and Other (N=4). The poll asked which characteristics are most important for aggregation platforms and for respondents to identify the next steps.

[15] REPCET. 2018. What is REPCET? [Available at https://www.repcet.com/en/what-is-repcet/]

Most Important Characteristics of Aggregation Platforms:
Some poll participants commented that the identification of important characteristics of an aggregation platform depended on the end user. Others identified interoperability, accessibility, clarity, timeliness, reliability, and ease of use. Some felt an aggregation site should incorporate data from multiple sources and present a single integrated information stream that was easily interpreted by the end user. Others highlighted the importance of an intuitive and customizable user interface, including the ability to display results in a manner suitable to a specific vessel category. Some respondents placed a priority on protection of data ownership. The importance of seamless integration with the dissemination mechanism was also identified as critical.

Recommended Next Steps:
Some respondents suggested focusing on effective dissemination as the priority next step. One participant suggested exploring the possibility of a shared data pool for a single data stream that would allow for types of observations to be filtered in/out based on the user's needs. Support was expressed for analyzing the different end user needs (including both information needs and connectivity/access constraints) and mapping those to existing systems to identify gaps. One participant suggested bringing together those working on aggregation platforms on the East and West Coasts. Another suggestion was to increase outreach and education to the recreational boating community to make them aware of existing platforms.

7.5 Major Takeaways

The points raised during this breakout session are summarized in Table 6. Generally, participants indicated the other Risk Chain Components, primarily detection and classification and dissemination and integration, were a higher priority for focus than aggregation. Participants generally observed that the technology for aggregation platforms was already in place and in use, and that the remaining needs included increasing awareness and customization for specific uses and users. Participants discussed developing a single aggregation site, but ultimately there did not appear to be widespread support for this approach. It was emphasized that it is important to understand the characteristics of the data being provided on any aggregation site, recognizing that both the methods of collection and the thresholds for classification (i.e., tolerance for false positives/false negatives) may be different across contributed datasets. When consulting an aggregation site to inform an action (that of an individual mariner or to trigger voluntary or mandatory measures in an area), proper interpretation of the aggregated data is dependent upon an awareness and understanding of the characteristics of the contributed data.

Participants suggested developing a framework or flow–chart to match users of aggregated data (managers, enforcers, large shipping, recreational vessels, commercial fishing, etc.) with available aggregation platforms, considering aspects of the platforms such as whether the data was provided for regulatory or voluntary use and the action intended when the data was received (on–water evasion, planning, research, modeling, etc.). Related to this, participants emphasized the need to focus on using cases/profiles to understand the end user and their needs, what they can use, and how they can/will act with the information. Identifying appropriate and effective aggregation platforms for the recreational boating sector was recognized as a difficult challenge given the diversity of communication methods and capabilities within this sector. Participants discussed what information is important to share with mariners, and some suggested that the focus should be on seasonal and dynamic management areas with clear instructions of what action the mariner is requested or required to take versus providing a wealth of NARW detection data that is very difficult to interpret in real–time/near–real–time. The importance of an intuitive and customizable user interface, including the ability to display results in a manner suitable to a specific vessel category, was highlighted by other participants. Ultimately, participants recognized that while technology was part of the challenge, effective tools were equally reliant upon human connections, partnerships, networks, and relationships.

Table 6. Promising Pathways and Next Steps—Aggregation. This table was filled in by the facilitator during the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Aggregation/Assembling breakout session, based on session discussion, and modified to improve clarity for use in this report.

Most Promising Aggregating/Assembling Technology or Methods	Next Steps to Advance	Role of Government, Private Sector, Partnerships
The existing platforms have made great strides in the last decade, and maturing aggregation platforms now exist.	Aggregation is **only as good as the data being aggregated.** Detection and classification tools need to be advanced to improve aggregation further.	Governments can help develop the **framework** or approach, require data quality standards if used in regulatory actions, but not necessarily create nor run such platforms.
The idea of a single platform is not likely possible or desirable. What is desirable is more coordination, interoperability, and connection and tailoring to different users.	**Develop a framework** or flow chart of users (managers, enforcers, large shipping, rec vessels, commercial fishing, etc.), intent (regulatory/compliance, voluntary), purpose (on–water evasion, planning, research, modeling, etc.) to place this in context.	Continue to advance as these platforms are examined **across providers, sectors, and countries** to learn, adjust and provide.
Streamline some of the data permissions to make it more generic and easier across platforms where applicable.	Human connection, **partnerships, networks, relationships** are essential and, in some ways, the harder part than technology advancement, which is well on its way.	
Regarding data presentation, more context provided to users could help with interpretation.	What sector faces the largest challenges here? Smaller boats, highly maneuverable, but less able perhaps to get and use information? Large vessels, capitalized, able to invest in improvements, professionalized, but not very maneuverable.	
Focus on use cases/profiles to understand the end user and what they need, can use, and how they will act when provided with the information.		

8. Dissemination and Integration

8.1 Introduction

The focus of this Risk Reduction Component is to: (1) ensure mariners receive what they accept as actionable NARW information integrated with information on other factors that influence navigation decisions; and (2) ensure that the consideration of that information is done in an efficient manner to maximize/preserve safe navigation options. The workshop planning team conducted a literature review to help shape and narrow the focus of the Dissemination and Integration workshop session and, while not shared with workshop participants in its entirety, a summary is included in this chapter to provide additional context for this workshop session. While the literature review content serves to provide context, the remainder of each chapter is intended to provide an accurate and complete account of the workshop itself. It is important for the reader to note that statements and opinions of workshop participants are captured in the workshop report without additional commentary, corrections, or caveats provided by the workshop report authors.

There are many ways to communicate whale information (e.g., general presence; reporting sightings; tracking individuals or groups; notifications about warnings, compliance, and enforcement) to various entities. These pathways include vessel–to–shore, shore–to–vessel, vessel–to–vessel, platform–to–vessel, platform–to–platform, or a combination of these. This is done using a variety of communication systems including via radio frequency, cellular networks, satellite communications, and cable connections. However, providing this information in a manner that requires onboard connectivity (e.g., cellular, satellite) means that some mariners may have limited access to these platforms while at sea. Additionally, having NARW information provided separately from the existing onboard data streams that mariners already rely upon for safe navigation may mean that they are less likely to consider it when making navigation decisions. Furthermore, the added time involved actively seeking out that information may limit options available to the mariner and limit the vessel strike risk reduction effectiveness of any change in course or speed they may enact. Integrating NARW data into onboard data streams already in use, thereby reducing the number of independent disconnected information sources that need to be considered in real–time, could facilitate timely and effective decision–making.

Reimer et al. (2016) reported on a survey, distributed by the Shipping Federation of Canada, to determine mariner knowledge and awareness of endangered whales and existing conservation measures, and to assess mariner receptivity to near–real–time conservation technology on the bridge. Most respondents (84%; N=43) indicated a preference for receiving whale alerts via Navigational telex (NAVTEX[16]), and 79% listed NAVTEX as a non–disruptive means of receiving the alerts. However, the authors note that NAVTEX messages are sent at 4–hour intervals, which may be insufficient for vessel strike risk reduction. AIS was identified as "not disruptive" by 72% of the respondents, and 59% identified AIS as the preferred reception format. The authors suggest that their survey results indicate that future conservation programs should use communication formats that are most familiar to, and favored by, mariners while being the least disruptive to bridge protocols (Reimer et al., 2016).

Under contract with NOAA Fisheries, Azura Consulting LLC conducted an online survey of large pleasure vessel operators in coastal Northeast, Mid–Atlantic, and Southeast Regions (Azura Consulting, 2022). A total of 79 responses were received over 179 days (29 from the Northeast, 19

[16] NAVTEX is Navigational Telex, an automated direct–printing (FAX) service used to transmit printed alerts to mariners at sea. NAVTEX alerts are prepared and distributed by the Canadian Coast Guard (Reimer et al., 2016).

from the Mid–Atlantic, and 31 from the Southeast). The survey sought to gain insights into factors motivating compliance within specific vessel operator communities subject to speed measures, assess the effectiveness of various education and outreach materials used to reach these communities, and determine if there are better communication methods to enhance vessel operator awareness of speed measures. Respondents were asked to select from a list of resources provided to gather information for boating purposes (e.g., rules and regulations). The list and the percentage of respondents (N=77) who selected each is as follows (multiple selections were permitted): Whale Alert app (27%), Nautical Charts/Coast Pilot (70%), USCG (i.e., Local/Broadcast Notices to Mariners, very high frequency (VHF) radio CH–16; 78%), NOAA Fisheries Materials (e.g., handouts, forms, posters, port meetings; 19%), NOAA Fisheries websites (e.g., National Data Buoy Center[17]; 34%), local harbor master (38%), other mariners (56%), text messages containing boating information (22%), email/shipping list serves (13%), social media (36%), or other (1%). When asked to select all applicable nautical charts they use for boating (multiple selections were permitted), 71% selected their boat's chart plotter, 38% selected NOAA Fisheries charts, 47% selected private apps designed for nautical navigation, and 54% selected "other charts."

There are many possible ways to incorporate whale sighting information directly into navigation software, if that is the desire, that may take many forms depending on the characteristics of the target vessels. One option that frequently comes up in relevant discussions may be to use the AIS[18]. AIS is a maritime navigation safety communications system standardized by the International Telecommunication Union (ITU) and adopted by the IMO. In the U.S., AIS is required onboard most vessels greater than 65 feet (33 CFR §164.46(d)) and is also used voluntarily by other vessels not covered by this regulation. This system provides vessel information, including the identity, type, position, course, speed, navigational status, and other safety–related information automatically to appropriately equipped shore stations, vessels, and aircraft[19]. It can also deliver information directly to the Electronic Chart Display and Information System (ECDIS), a computer–based navigation information system that complies with IMO regulations and is used onboard many vessels. A variety of other electronic charting systems are used by vessels less than 65 feet, and coordination would need to occur to ensure that all systems were integrating whale sighting information in a similar manner (i.e., when updates would be provided, how it would be displayed, etc.). In addition to the technology–related questions of integrating whale sighting information into navigation software, questions such as who would manage that process, verification of the receipt of data, and whether the system would just deliver sightings or would also accept sightings information would need to be addressed. Finally, as is discussed in the next section, there is the important question of what type of integration would make transmittals regarding whales most likely to be seen and acted upon by mariners.

8.1.1 Facilitation of Decision–Making

User interfaces which integrate and display safety and navigation–related information efficiently for mariners can expedite the process resulting in actions necessary to reduce vessel strike risk. Ditria et al. (2022) defined a user interface as a space where humans interact with machine processes and states that user interfaces can be designed to be "user friendly" to assist interaction

[17] NOAA. 2024. National Data Buoy Center. [Available at https://www.ndbc.noaa.gov/]
[18] United States Coast Guard Navigation Center. 2024. Automatic Identification System (AIS) Overview. [Available at https://www.navcen.uscg.gov/automatic-identification-system-overview]
[19] United States Coast Guard Navigation Center. 2024. AIS Frequently Asked Questions. [Available at https://www.navcen.uscg.gov/ais-frequently-asked-questions]

at an appropriate level of user understanding. AI, ML, and reinforcement learning[20] may allow a user interface to provide suggestions to the mariner. User interfaces designed to support management decision–making have been designed and are in use for coral reef management[21] and may serve as examples and templates for vessel strike risk reduction (Ditria et al., 2022).

Before investigating how technology can help in the design of systems that facilitate effective whale avoidance decisions, it is important to have a full understanding of the factors that influence a mariner's decision to take action, what action to take, and when to take it. There are several mechanisms being used to share whale data with mariners (e.g., Whale Alert, WhaleMap, Notice to Mariners). However, these approaches have not been fully evaluated in terms of how well they are reaching mariners and whether they result in behavior change (e.g., avoid whales). Insights into what factors equate to a reduction in vessel strike risk would inform potential improvements on how information is transmitted, when and how it is received by the operator, or other relevant factors (Gende et al., 2019).

Gende et al. (2019) generated a conceptual model for active whale avoidance by mariners and, as a proof of concept, applied data derived from observations of humpback whales surfacing in proximity to large cruise ships to the model, and ran simulations in a full–mission bridge simulator and commonly used pilotage software (SEA*iq*). The application of the model demonstrated that: (1) the opportunities for detecting a surfacing whale are often limited and temporary; (2) the cumulative probability of detecting one of the available 'cues' of whale presence (and direction of travel) decreases with increased vessel–to–whale distances; and (3) time delays occur following whale detection as mariners evaluate competing risks, decide upon an appropriate action, and the operational state of the vessel changes (if a change was deemed appropriate).

The simulations conducted under this conceptual model revealed that processes that occur on the vessel's bridge (i.e., an onboard observer making a whale sighting, assessing the strike risk, and compliance with commands), coupled with maneuvering constraints, produce an important time lag between detections and achieving a new operational state that reduces collision risk. This time lag contributes to the inverse relationship between time available to make an avoidance maneuver and the range of maneuver options available. In the simulations, marine pilots showed a preference for taking a slight change in course over slowing the vessel speed based on their knowledge of the time it would take to achieve the new speed and their evaluation of competing risks (Gende et al., 2019). Decisions by the marine pilots were founded on the principle of do–no–harm, firstly to people, secondly to the ship, and thirdly to the environment.

Interestingly, Gende et al. (2019) noted that they are not aware of any simulator modules for whale avoidance. Such a module could provide useful experience in determining realistic opportunities for whale avoidance, depending on the speed and maneuverability of the vessel and the distance to the detected whale. The authors state that the development of a whale avoidance module in a full–

[20] Reinforcement learning is a type of ML process that focuses on decision–making by autonomous agents. An autonomous agent is any system that can make decisions and act in response to its environment independent of direct instruction by a human user. In reinforcement learning, an autonomous agent learns to perform a task by trial and error (see IBM. 2024. What is reinforcement learning? [Available at https://www.ibm.com/topics/reinforcement-learning]).

[21] Examples include (1) Australian Institute of Marine Science. 2024. ReefCloud. [Available at https://reefcloud.ai/]; (2) Arizona State University. 2024. Allen Coral Atlas. [Available at https://allencoralatlas.org/]; and (3) MERMAID. 2024. MERMAID: Transform your coral reef monitoring. [Available at https://datamermaid.org]

mission ship simulator could advance whale avoidance by training mariners, through repetition and experimentation (Gende et al., 2019).

A decision support system was developed in the form of a simulator to inform management and planning in a portion of the St. Lawrence Estuary in Canada (Parrott et al., 2011). The simulator (3MTSim) reproduced the spatiotemporal movement of marine mammals and maritime traffic to allow users to test different management scenarios (e.g., area closures, speed limits, regulations concerning the observation of marine mammals) to assess their effects on navigational patterns and the corresponding exposure of marine mammals to vessels. This type of modeling allows for a higher–level analysis of management and policy options and their corresponding impact on vessels and marine mammals.

Autonomous vessel collision avoidance technology is an emerging area of research and testing. Mathematical models, algorithms, and AI can be used to assist or replace human navigation. Uncrewed vessels or minimally crewed vessels are being utilized now and are of great interest for commercial and military applications (Negenborn et al., 2023). In a study comparing human's cognitive abilities for collision avoidance with autonomous collision avoidance algorithms, it was found that human's critical decisions are highly subjective, which can lead to error and potentially collision (Statheros et al., 2008). The authors note that under the 1972 Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), the IMO has defined international rules for collision avoidance in order to limit the human subjectivity factor. Whether and how information on whale presence in an area may be considered by autonomous vessel collision avoidance technology is worthy of investigation. Understanding how such systems balance maintaining speed and direction with reducing collision risk (in light of environmental conditions and other factors) could be informative in determining how to provide whale presence data to autonomous platforms to effectively influence navigational decisions.

8.2 Workshop Session: Dissemination and Integration of NARW Detections and Management Areas into Navigational Systems

The goals for this workshop breakout session discussing dissemination and integration of NARW detections and management areas to mariners were to: (1) identify and characterize existing and potential technology to deliver information on NARW presence and management areas in a manner that facilitates timely and effective evasive action; (2) characterize the state of play for dissemination of such information and integration of it into navigational software for a variety of vessel operational categories; and (3) identify the most promising technology/methods and the priority next steps to advance their development and deployment.

There were 153 workshop participants who selected or were assigned to this breakout session, of whom 40 were in–person participants and 113 were remote (Figure 15).

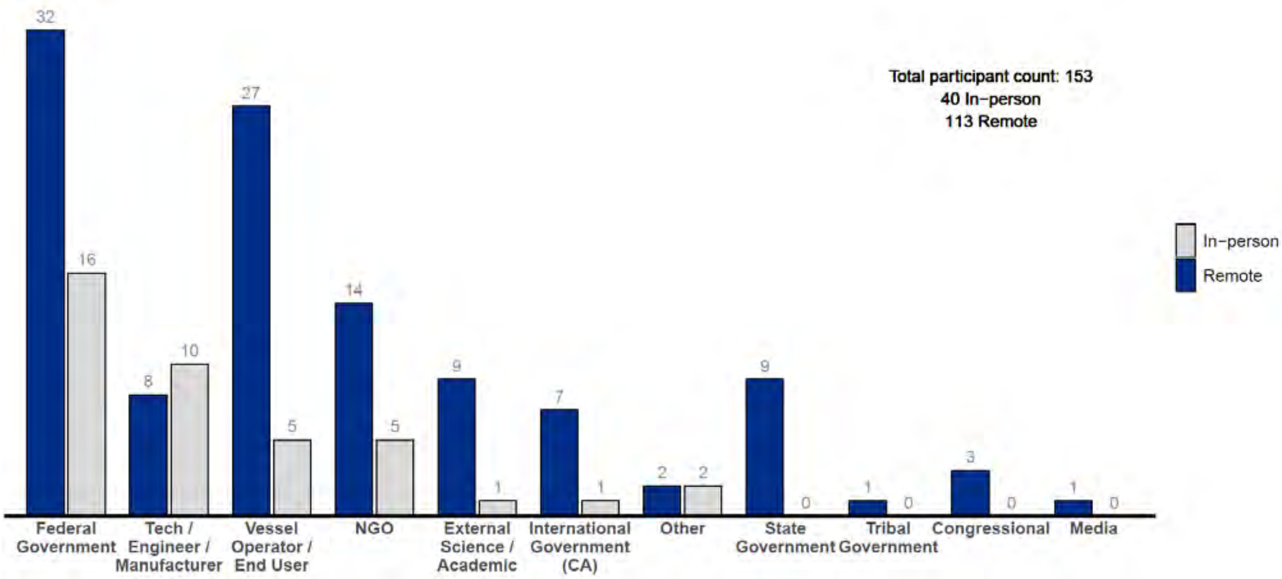

Figure 15. Participants in the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Dissemination and Integration breakout session. Blue bars represent remote participants and gray bars represent in–person participants. Labels above each column indicate the total number of participants within each category.

8.3 Presentations

Summaries of the four presentations in this session are provided below. The session included the following technical SMEs in addition to the four presenters: Jeff Adams, NOAA Fisheries OPR; Alex Mitchell, Ocean Wise; David Steckler, Mysticetus; and Darren Wright, NOAA Office of Coast Survey—Precision Navigation System. The session was facilitated by Bennett Brooks, CBI, who provided some initial framing before the individual presentations. He noted that the previous afternoon's discussion had focused on detection and classification, which is a critical step, but alone does not reduce risk. He also noted that a concurrent session was focused on aggregating/assembling detections (Chapter 7), while this session was focused on getting the aggregated detections and whale management areas in the right hands at the right time so that mariners could take action. Brooks noted that based on discussions with the panelists, recreational and commercial vessels would be discussed separately due to their significantly different operating procedures. He encouraged participants to focus on identifying the current tools for delivering information to vessels, exploring whether those tools are being used to their maximum extent, identifying promising opportunities on the horizon, and identifying technology gaps or other barriers to getting whale–related information to recreational and commercial vessels effectively.

Jorge Arroyo, USCG, provided an overview of the USCG including noting that it is the only agency with authority to enforce all U.S. laws at sea, and reviewed its diverse mission, which includes marine environmental protection, aids to navigation, and living marine resource protection. He identified methods used by the USCG to disseminate information to mariners in printed form, including but not limited to the following: Local Notice to Mariners; Marine Information Bulletins; Notice to Mariners; and the U.S. Coast Pilot. The USCG also disseminates information through radio broadcast Notice to Mariners which focus on distress, urgent marine safety information, and other recent or dynamic marine information not in the Local Notice to Mariners. The radio broadcast Notice to Mariners, which are also now available via email, are provided through VHF radio, Satellite Service, and FM/NAVTEX.

Arroyo provided an overview of AIS and explained that the vessels required to use AIS include: tankers; commercial self–propelled vessels over 65 feet; towing vessels over 26 feet and 600 horsepower; passenger vessels as determined by the USCG (i.e., self–propelled vessels certified for over 150 passengers); other vessels over 300 gross tonnage (GT); and those deemed necessary by the USCG for safety (i.e., dredges and vessels moving certain dangerous, flammable, or combustible liquid cargo in bulk). Arroyo shared a sample message as received through AIS and provided a sample of vessels tracked by the nationwide AIS (NAIS) system on a sample day showing that 43% of the total vessels tracked on that day were voluntary users.

Looking to the future, Arroyo outlined a phased plan to move to full digital charts and navigational aids. Of note, he shared that the S–100 universal hydrographic data model will be implemented by 2026 and that the S–122 marine protected area data package design is currently in the planning phase with deployment scheduled for 2029. He also explained that the next generation AIS, which will include repurposing the VHF–FM radio public correspondence band, is currently under discussion at the IMO and is planned to be available in 2026.

Shaun Ruge, Garmin, presented on the dissemination and integration of NARW detections and related management areas to commercially available software via marine cartography and through AIS. He identified the following types of data which can be transmitted to vessels: (1) points (observations, aids to navigation); (2) polygons which provide boundaries around an area; (3) attribution or descriptive data fields which can apply to both points and polygons; and (4) text–based messages notifying mariners of important information. Ruge described the dissemination process in marine cartography starting with the procurement of data, integration of that data into a database, chart publishing, distribution, and finally the onboard electronic display of the data. He said the process could be completed in as fast as 24 hours, was operationally available at low cost, and could be distributed in a wide variety of ways and supported by a wide variety of manufacturers. However, Ruge identified the processing/production time and dependency on internet (mobile, WiFi, or satellite) connectivity as weaknesses of this approach.

Ruge presented a near–real–time example of dissemination via marine cartography layers in which detections from the Whale Alert mobile phone app were sent to a vessel chart display. He pointed out the less than 1 minute timeframe for transferring data between mobile devices and a typical hourly update conducted by the manufacturer from mobile to display. Strengths identified for this method include low cost, operational availability, ability to allow for crowd source contributions, and that it is supported by several manufacturers. Conversely, internet connectivity is required, the chart plotter is only updated once an hour, and development would be required to specifically support the integration of whale information.

Ruge described three paths to Chartplotter integration. The first path involves one–to–one development such as the integration of a forward–looking infrared (FLIR) camera with a Garmin chart plotter; the second would involve HTML5 integration, which allows two–way display and control (e.g., Sea.AI detection system); and the third would support one–to–many distribution. To expand on this third method, Ruge described work between the WAVS Taskforce and the National Marine Electronics Association (NMEA) to draft a NMEA standard parameter group number (PGN) for endangered species to allow for interoperability. A PGN is a unique numeric identifier used to categorize and define specific sets of data, which then allows devices on a network to recognize and interpret information efficiently. Ruge presented an integration example in which vessel–specific detection technology detects a whale, translates that event to NMEA2000 PGN, broadcasts it over a public network onboard, as well as offboard, so that another vessel listening to that signal receives the PGN to be displayed on their plotter similar to how Man Overboard notifications are done today.

Ruge then identified the strengths and weaknesses of using AIS for dissemination and integration. He identified the strengths as standardization, low cost, widespread use and adoption, not being reliant upon internet connection, integration with navigational displays, and the incorporation of audible alarms. The noted weaknesses included broadcast distances and that changes may be necessary to support whale specific points and polygons. Ruge stated that, in summary, marine electronics are widely available onboard both leisure and commercial vessels, a variety of dissemination methods can be deployed in parallel to achieve a broader reach, and that rapid cartography dissemination and integration is operationally available and used today. He further highlighted that hardware capable of AIS–based real–time dissemination is commonly adopted, removes dependence on the internet, and can be used to disseminate and receive whale data. Ruge proposed NMEA standards as a method by which to achieve widespread integration and interoperability for detection systems and aggregated data structure.

Moses Calouro, Maritime Information Systems, Inc., presented on–going work to use AIS to generate automatic alerts for mariners. He reviewed the USCG AIS carriage requirements as presented by Arroyo, explained the Class A designation for commercial vessels and Class B for recreational vessels, and that AIS is currently capable of reaching most vessels greater than 65 feet. Calouro described a shoreside AIS transmit network to relay safety–related text messages to vessels in a 25 nautical mile radio range. Currently in Phase 1, automatic text notifications are being sent to individual non–compliant AIS–equipped vessels in active NOAA Fisheries SMAs in/near Cape Cod Bay, MA. In Phase 2 (May–October 2024), interfacing with Whale Alert, WhaleMap, and NOAA Fisheries whale detection datasets will occur, and coverage will be expanded along the U.S. East Coast. Calouro's plans for Phase 3 (November 2024) include the ability to send polygons to mariner screens and to fully cover NOAA Fisheries SMAs, except for portions of the Great South Channel.

Calouro identified the benefits of this system as being capable of putting near–real–time whale information on the bridges of vessels and being able to send automated, targeted messages to non–compliant vessels. As illustrated in the presentation, this system is operational and active in Cape Cod Bay, MA during the first phase of the project. He noted that permits from the USCG and Federal Communications Commission (FCC) to be able to implement the additional phases and expand geographic coverage are in process.

The final presentation in the session was given by Steve White, Marine Exchange of Alaska. The mission of the Marine Exchange of Alaska is to provide information, communications, and services to aid safe, secure, and environmentally responsible maritime operations. White provided some history on the formation of marine exchanges as public–private non–profit ventures up through the current status of the Maritime Information Services of North America (MISNA) network. He provided a map of marine safety sites in Alaska including weather sensors, AIS receivers and transceivers (some located on Aids to Navigation (ATONs)), digital selective calling (DSC) receivers, VHF–FM radio transceivers, tidal current sensors, and sea surface cameras. He emphasized that regulations are not enough, and communication and the provision of information to mariners is critical.

Sea traffic management services provided by the Marine Exchange of Alaska include digital virtual navigation aids, deconflicting marine use, providing environmental data, minimizing impacts to wildlife, assisting vessels in distress, and preventing disasters. White reviewed specific applications for minimizing impacts to wildlife including notifications regarding North Pacific right whales (*Eubalaena japonica*), haul out protections for Pacific walruses (*Odobenus rosmarus divergens*), blue whale voluntary speed restrictions in Southern California, and a program in the Channel Islands National Marine Sanctuary establishing an Area to be Avoided for marine mammal protection. White described the multiple tools used to contact and provide information to vessels, including the escalation options that are triggered depending on the behavior of the vessel being monitored. He reviewed the diverse parties involved and the tools available for use during the round–the–clock surveillance including AIS, satellite phones, email, and VHF radio voice contact.

8.4 Discussion and Input from Workshop Session Participants

The presenters and SMEs were asked to identify the areas they felt were most in need of improvement in terms of the dissemination and integration of information. Ruge identified the need for consensus on the type of information that is impactful to the mariner (i.e., what they want to see on their display). Calouro identified the need to continue to work with NOAA to expand the functionality of available technology. White identified the need for a quicker way to share dynamic information with mariners, whether through displays on plotters, email, radio, or other means. Mitchell said that Ocean Wise directly sends whale presence data, via app or text, to participating mariners when they are in the vicinity of a real–time (within 30 minutes) sighting. He said Ocean Wise would be willing to share lessons learned from their experience working with pilots to upload whale information onto portable pilot units.

Session participants were asked to share their perspectives on the state of play of various technologies and identify important characteristics/considerations. Participants were also encouraged to identify any other promising technology that should be considered. For technology identified as most promising, participants were asked to discuss the role of government, private sector, and vessel operators, and to identify collaborations that may be needed to propel progress.

Workshop participants suggested that matching vessel operational profiles with the types of decisions they are making should come before any discussion on how to disseminate information to specific vessels. Some suggested a greater focus on actionability and improving our understanding of what vessels can do once they receive information to narrow down what information is worthwhile sending. They also emphasized the importance of integrating the various devices, information flows, and electronics used onboard a vessel. Focusing on technological advances to identify and avoid any object in the water was suggested rather than narrowly considering NARWs or even marine mammals in general. One workshop participant suggested assigning relative risk to vessel profiles or operational categories and using that to prioritize action.

Some mariner participants expressed frustration with receiving latitude and longitude coordinates for DMAs, which need to be manually entered into navigation systems, rather than receiving a simpler–to–use polygon. Wright recommended creating a dynamic polygon representing whale sighting areas and potentially utilizing the S–100 standard/S–124 Navigational Warnings, so that navigational systems could upload and display said polygon. A remote participant pointed out that some vessels, particularly government fleet vessels, may not connect their navigation systems directly to the internet due to security concerns, and therefore cannot rely on the automatic display of dynamic areas/zones potentially available while connected. Instead, data must be manually moved into the systems.

Overall, participants identified the need to disseminate information through multiple means to help address different vessel types, operations, equipment, and personal preferences. They cautioned that there will never be one way to reach all mariners given the diversity of commercial and recreational users. One participant observed there is low compliance with voluntary measures and wondered if that is because people consider a 15–day window too long a time and will only react to more real–time information. The ability to provide information directly on the display in the wheelhouse and to be able to send targeted messages to specific vessels were also identified as important needs.

Vessel class was identified as a likely determining factor in connectivity options for getting information to mariners. Matching the connectivity requirements of delivery mechanisms with the capabilities of vessels was identified as essential and perhaps challenging for the recreational sector. Several comments also spoke about the potential for unintended consequences. For example, one attendee voiced concern that if devices designed primarily for safety, such as AIS, are used for other means it could result in people paying less attention to them over time. Another participant encouraged a focus on prevention and information exchange rather than enforcement. One participant speculated that the use of AIS information for enforcement could result in much lower voluntary use of AIS, regardless of the safety implications of that decision being made by the mariner.

In the question–and–answer feed, a remote participant commented that the digitalization of maritime information and navigation services presents great opportunities but offered support for the point made by White that it is also key to have personnel 24/7 to help monitor and convey information in support of real–time context. Mark Reedenauer, NMEA, expressed appreciation for the excellent presentations during this session and stated it was just the beginning of the technology options that electronics can serve to protect all whales. A remote participant, in the question–and–answer feed, questioned the operational feasibility of commercial vessels changing course or speeds in real–time based on real–time whale presence information. The commenter said their understanding is that considerable planning time is needed to plan for reduced speeds to respond in ways that mitigate risk.

The breakout session participants strongly supported spending time to learn from mariners what information they need and when and how they need to receive it to reduce their likelihood of striking a whale. One suggested approach was to first find out what mariners' need on the water, look at what tools are available today that can be used or modified for this purpose, and then identify what needs to be done to fill remaining gaps. Another participant emphasized the importance of outreach and noted that many recreational vessel operators likely do not recognize the need for whale information or know how to get it. A remote participant stated that communicating sightings information to recreational boaters is complex because of the potential for that to lead to attempts to actively approach the whale. Others suggested that the near–term priority should be to focus on getting the most out of the existing underutilized technology and infrastructure. Finally, one participant suggested a marine app or quick response (QR) code at marinas that boaters could scan that would provide local and up–to–date information (like Waze or Google Maps).

8.4.1 Online Poll

There were 72 participants in this breakout session, evenly split between remote and in–person, who chose to participate in the session's online poll. Poll participants were distributed across sectors as follows: Government (N=29); Vessel Operator or Industry Representative (N=14); NGO (N=11); Tech/Engineer/Manufacture (N=9); External Scientist/Academia (N=6); and Other (N=3). Of those who indicated an association with a vessel type, 38 indicated commercial vessels and 23 indicated recreational vessels. The poll asked respondents to identify the most promising technology (up to three), based on the discussion during this workshop session, using their own words.

The technology identified as most promising by the most respondents was AIS, which was mentioned in approximately 55% of all unique submissions. The reasons listed included that it already exists and seemed like the best option to reach mariners, offers the possibility to monitor vessels and alert them in real–time, and is relatively inexpensive and flexible. Participants said that AIS is already used for navigation, so integrating whale information into it would be efficient and would not require the mariner to take additional steps. Some cautioned that AIS should only be used to communicate management areas and not whale detections. While offering support for the use of AIS, one respondent noted it was crucial to figure out the response times and evasive capabilities by vessel/use type. Some cautioned that the use of AIS needed to be limited to safety and not include enforcement.

While the importance of AIS as a tool was supported by some, they emphasized the importance of companion private communication methods to maximize the benefit of AIS and cited the Maritime Information System and Marine Exchange as examples. Respondents highlighted the number of tools used by these systems to individually monitor and contact vessels as being very effective. Others emphasized that cartography would need to supplement AIS to reach recreational vessels. Specific support for the NMEA and WAVS Taskforce initiative was offered.

Some respondents commented that technology was not the limiting factor for effective dissemination and integration of whale information. They suggested that the existing technology needed to be better deployed and supported. Others suggested focusing on coordination or a central repository to ensure the information is distributed in all formats to ensure all vessels that need it receive it. Standardization and interoperability were mentioned by several participants with an emphasis on creating polygons in a standardized format so that they could be picked up and integrated into existing navigation systems.

Other areas of focus recommended by poll respondents included methods to distribute dynamic information to mariners and developing the ability to display information on chart plotters quickly. The integration of whale information with other navigational services, virtual aids for route planning, and decision–support for mariners were identified by others. Support for onboard detection systems which report to a centralized open–source database was offered as well. A remote participant provided an example of how dynamic zones are communicated to mariners in Canada by explaining that they are marked as virtual ATONs and are accompanied by AIS messages, which are visible to any vessel capable of receiving AIS. The Canadian Coast Guard also issues navigational warnings to inform mariners, including those without AIS capabilities, of when these zones are active, and calls vessels to inform them of speed restrictions, especially when they are observed to not be slowing down. The remote participant explained that they offered this example to illustrate that a human component is just as important as a technological approach.

Poll respondents reiterated support for stepping back and having a conversation to understand what information needs to be provided to mariners, what mariners can and will do when they receive that information, and how best to deliver it to them. One respondent observed that there was little value in systems that transmit real–time whale sightings information to commercial mariners as they had limited time to respond, that such alerts would cause fatigue, and that it should not be their duty to decide how to respond to that information. One respondent suggested a greater focus on decision–support tools for mariners. Support for partnerships to disseminate information, explore technology and test systems was also offered. Finally, one respondent noted that just like an AIS target has both a track and a projected path, tracks and movement models for species of marine mammals could help mariners avoid a strike.

8.5 Primary Takeaways

Workshop participants suggested that matching vessel operational profiles with the types of decisions they are making should come before any discussion on means to disseminate information to specific vessels. A greater focus on actionability and improving our understanding of what vessels can do once they receive information was recommended to narrow down information worthwhile to send to specific vessels. Support was offered for disseminating information through multiple means to help address different vessel types, operations, equipment, and personal preferences. The need to improve methods for the distribution of dynamic information to mariners, including the ability to quickly display it on chart plotters, was identified as a priority.

Session attendees were highly supportive of disseminating data via AIS and chart plotters so that the data is directly accessible to mariners. AIS technology is widely available, and participants recommended focusing on expanding the functionality of that available technology for the dissemination of NARW information in support of vessel strike reduction. It was suggested that the private sector could develop mechanisms to efficiently and effectively deliver information to recreational boaters if consensus could be reached between what information is impactful to that mariner and what information the government wants to provide. Support was voiced for the development of user interfaces which integrate and display information efficiently for mariners, thereby speeding up the decision–making process and resulting in actions being taken to reduce vessel strike risk.

The key roles for government identified by participants in this workshop session include setting standards for what information is to be provided to mariners (e.g., whale detections, polygons, AIS messaging formats), outlining expectations for what the mariner is expected to do upon receipt of that information, and collaborating to expand the capabilities of AIS. Specifically, participants requested that NOAA Fisheries provide DMAs in a polygon format and put SMAs on electronic charts utilizing the S–100 format. Identified priority data gaps included the identification of the data the government wants vessels to receive and of the data vessel operators consider actionable. Finally, session participants identified the need to map existing tools to needs to identify gaps that can be filled by improving existing technology (e.g., faster, more integrated, smarter) or through the development of new technology.

Table 7. Promising Pathways and Next Steps—Dissemination and Integration. This table was filled in by the facilitator during the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Dissemination and Integration breakout session, based on session discussion, and modified to improve clarity for use in this report.

Most Promising Vessel Strike Risk Reduction Technology
For commercial vessels and vessels using AIS, focus on integration of existing tools
Using a variety of tools and electronic charting to improve dissemination of dynamic information
Leveraging two–way communication (from mariners, trans–boundary) to reduce vessel strike risk
Exploring the potential of public–private partnerships like Marine Exchange of Alaska as a way to get information from federal agencies to boaters
Using on–vessel, buoy relays, offshore wind structures, etc. to repeat out notices beyond 25 nm
Adoption by developers of NMEA standards (protocols for technology/communication) to ensure products can be integrated.
NOAA putting SMAs on electronic charts (via S–100) standard format and providing DMAs in a polygon format.
Priority Information Gaps/Needs
Develop an understanding of use/operational vessel profiles to identify what information needs to be provided to whom in what timeframe to reduce vessel strike risk (one size does not fit all)
Assess the ability of existing technology to address user needs: ● What technology exists today that is available to address user needs? ● What is needed to meld existing technology and methods with mariner needs (e.g., untapped potential in AIS)? ● What are critical gaps and how to figure out future technology needs to address gaps?
Need government to establish standards of what information will be provided to recreational vessels and then industry can develop the needed delivery and integration tools.
Reach consensus on what information is impactful for a mariner.
Other Comments
Emphasize preventing vessel strikes/safety considerations
Strengthen education and outreach to improve mariner awareness (e.g., dockside “tap–in” technology)
Focus on human dimensions to understand what information mariners want, how they want to receive it and how they are likely to use it

9. Other Technology

9.1 Introduction

The scope of the workshop included consideration of all ways in which technology has the potential to reduce NARW vessel strike risk. Based on the comprehensive literature review conducted during workshop planning, discussions with involved and interested parties, and consultation with the SC, the decision was made to have breakout sessions focused on technology within the four Risk Components of detection and classification, aggregation, modeling/forecasting, and dissemination and integration. However, the planning team recognized that there were other existing or potential opportunities for technology to reduce vessel strike risk, and therefore, a fifth session was added to explore and discuss this other technology. The workshop planning team conducted a literature review to help shape and narrow the focus of the Other Technology workshop session and, while not shared with workshop participants in its entirety, a summary is included in this chapter to provide additional context for this workshop session. While the literature review content serves to provide context, the remainder of each chapter is intended to provide an accurate and complete account of the workshop itself. It is important for the reader to note that statements and opinions of workshop participants are captured in the workshop report without additional commentary, corrections, or caveats provided by the workshop report authors.

Other technologies identified that have the potential to contribute to reducing vessel strikes but which do not fit within the categories discussed elsewhere in this report include vessel modifications, acoustic reflectors integrated into the bow of a vessel, mechanical brake–clutch systems that could disengage and stop propellers upon contact with a whale, and capacitive touch technology that could be leveraged to disengage power and brake rotating machinery when it contacts a whale (Gass[22]; Collins et al., 2009; Cabrera et al., 2023; Lu et al., 2023). Vessel modification technology that has the potential to reduce whale strike risk includes modifying the hull to reduce blunt force trauma and laceration injuries and those that would prevent whale contact with the propeller. Modifications to the hull of a vessel may have an impact on decreasing the severity of a vessel strike, but there is currently a lack of literature in this area. Propeller and engine modification technologies are currently in use, but their impact with respect to vessel strike reduction has not been fully quantified. Propulsion technology such as jet drives and ducted propellers have the potential to decrease strike risk by creating a barrier between whales and the propeller. These may also decrease vessel noise, but the impact of noise reduction on vessel strike risk is unknown. A jet drive is a propulsion system that houses a rotating impeller inside the hull of the vessel, thereby eliminating the risk of a propeller strike. In addition, at least one study has found that jet drives are quieter underwater than both inboard and outboard motors (Hildebrand et al., 2006). Currently, their use is limited to slow, mid–size vessels such as ferries and planning–hull military boats (Mayville, 2019). Ducted propellers, also referred to as shrouded propellers or nozzles, have the potential to reduce the probability of an oblique strike by shielding the propeller in a rigid shroud. They offer increased efficiency at lower speeds due to low pressure created at the inlet duct (Celik et al., 2011), and ducts inspired by the pectoral fins of humpback whales have demonstrated up to 11 decibels of noise reduction (Stark and Shi, 2021; Stark et al., 2021). It is important to note that some designs do not physically surround the propeller, making the exact impact on the survivability of whale–vessel interactions challenging to predict. Significant investment has been made in new marine power options, particularly vessel electrification (Burkov and Kuvshinov, 2017; Emblemsvag, 2017; Koumentakos, 2019; Anwar et al., 2020;

[22] Gass, S. F., D. A. Fanning, J. D. Fulmer, and R. J. Huebner. 2007. Apparatus and method for detecting dangerous conditions in power equipment. Patent No. US7231856B2. [Available at https://patentimages.storage.googleapis.com/35/e8/c1/d84671a4db244a/US7231856.pdf]

Korican et al., 2023). While these technologies have primarily focused on reduced carbon emissions and increased efficiency, they offer improved noise reduction over their traditional power and propulsion counterparts. For example, one study found that compared to a conventional tug, a diesel–electric model produced 15–30 decibels less underwater noise (Rutenko et al., 2020). As stated previously, the impact of decreased noise levels on vessel strike risk has not yet been determined.

Another potential technological approach to reduce vessel strike risk is the use of acoustic deterrents. Acoustic deterrents have previously been considered for deterring marine mammals from areas that may do them harm, including areas containing fishing nets (Kraus, 1999), aquaculture facilities (Todd et al., 2021), and offshore construction (Brandt et al., 2013). Whales are known to exhibit behavioral responses to some man–made sounds, including active military sonar operating below 10 kilohertz, although these responses are varied and not fully predictable (Southall et al., 2016). Gulland et al. (2008) attempted to herd a mother and calf humpback whale pair in the Sacramento River using multiple methods, including playing tones meant to cause alarm as well as humpback and killer whale sounds, without any clear evidence of success. More demonstrable reactions were documented by Nowacek et al. (2004) who found that while NARWs exhibited no responses to the sounds of simulated or actual vessels and only a mild response to the playback of NARW social sounds, they showed a strong reaction to a low–frequency alert signal. However, the NARW response to the alert signal was to spend more time at or near the surface, an outcome that Nowacek et al. (2004) concluded was more likely to increase than decrease the risk of vessel strike.

9.2 Workshop Session

The goals of the Other Technology breakout session were to: (1) identify areas other than those covered in the other workshop sessions where technology has the potential to reduce NARW vessel strike risk; (2) characterize the state of play for technology in those other areas; and (3) identify and understand highly promising technology/methods and the priority next steps to advance their development and deployment. There were no presenters in this session, facilitated by Stephanie Horii, CBI, as it was designed as a brainstorming session. There were 144 workshop participants who selected or were assigned to this breakout session, 27 of whom were in–person participants, and 117 were remote (Figure 16).

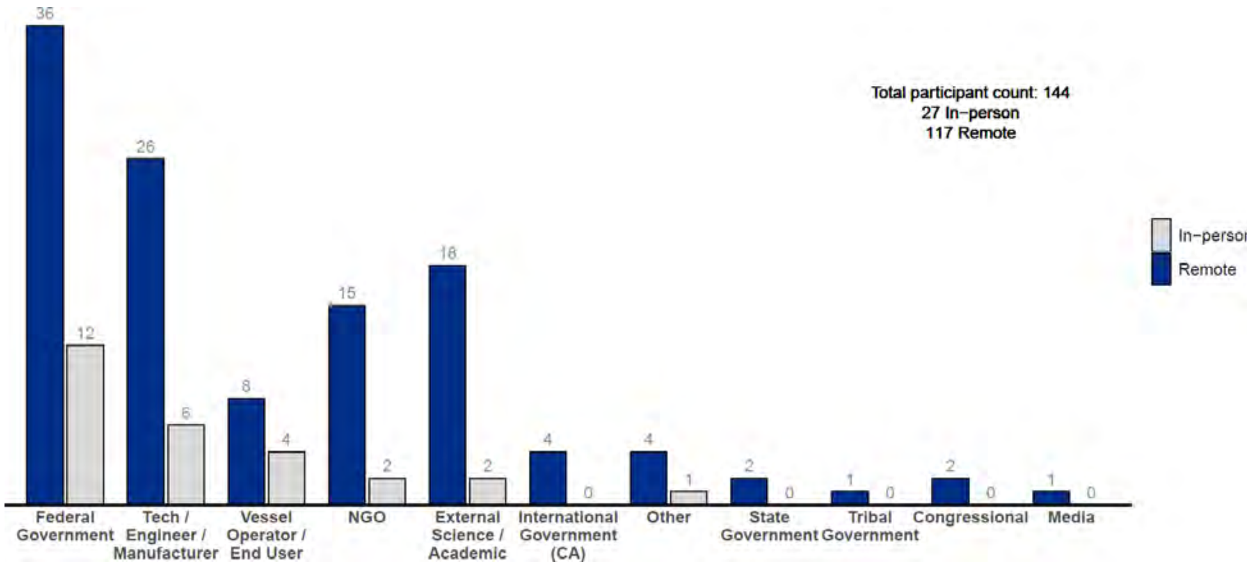

Figure 16. Participants in the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Other Technology breakout session. Blue bars represent remote participants and gray bars represent in–person participants. Labels above each column indicate the total number of participants within each category.

9.3 Participant Discussion and Input

Session participants were asked to brainstorm ideas for additional technology tools and for each, describe the technology, explain how it would contribute to a reduction in vessel strike risk (i.e., where it might fit in the Risk Reduction Chain), and describe its technology readiness (e.g., conceptual, research and development, pilot testing, deployed). Ideas for other technology were solicited during each of the pre–workshop planning webinars. Based on the literature reviews conducted during workshop planning and the input obtained during those webinars, it was recommended that participants in this workshop session explore how technology could help: (1) vessels detect and avoid whales (noting this was mainly covered in other sessions); (2) whales detect and avoid vessels, including the consideration of acoustic deterrence methods; (3) reduce the lethality of vessel strikes, including the consideration of vessel design and propulsion system modifications; and (4) improve monitoring, communications, and enforcement through such means as tracking and evaluating the effectiveness of risk reduction measures, vessel strike detection, and modeling for purposes other than spatial/temporal NARW density and co–occurrence (e.g., whale behavior, optimal detection device deployment).

To reduce the lethality of vessel strikes, Peter Thomas, MMC, suggested that the difficulty of modifying vessels to reduce blunt force trauma meant that lethality would best be reduced if whales detected and avoided vessels. He stated that a better understanding of whale behavior relative to vessels was needed before you could identify technology to influence that behavior in a way that reduced the likelihood of a lethal strike. Thomas asked if there are studies that could be conducted with short–term tags to obtain further data about NARW behavior around vessels. Caroline Good, NOAA Fisheries OPR, agreed that a full understanding of how whales perceive and react to vessel traffic is lacking and said that this is a research priority for NOAA Fisheries. She noted that in addition to the behavior of the whale at the time of exposure, the number and distribution of vessels in an area could also be important as that may influence how whales react. Bryan Wood–Thomas, World Shipping Council (WSC), commented that many species are known to spend considerable time at or near the surface at night. Considering the importance and risk associated with this nighttime behavior, he suggested that NOAA should research technologies that might be effective to aid both whale detection and avoidance at night. Mark Baumgartner, WHOI, relayed an experience with a humpback whale near Stellwagen Bank that had a suction cup tag on it, and when the captain shined a bright light on the whale, it had a very strong reaction. Baumgartner commented that whales do not typically have light shining on them from above and suggested that it would be a relatively easy experiment to test if this is a predictable response to this type of sensory input.

Workshop participants discussed options for better use of existing infrastructure or placing integrated systems on single platforms to increase opportunities for data collection and dissemination. An offshore wind developer suggested looking at how to best utilize the current infrastructure and reported ongoing work with Cornell University to use existing fiber optic cables to detect whale vocalizations (i.e., Distributed Acoustic Sensing). They also indicated other possibilities, such as mounting hydrophones on offshore wind–energy structures. Doug Nowacek, Duke University, suggested placing 'smart buoys' in shipping lanes that could house multiple sensors to collect and distribute PAM, satellite imagery data, visual/thermal/IR, alerts for whales, and alerts for mariners.

Sarah Wilkin, NOAA Fisheries OPR, commented that multiple factors influence the chance of lethality given a strike event including the location on the body where a whale is struck, the behavior and position of the animal, and the force of the strike (related to the speed/size of the vessel). She suggested more work could be done to better understand the types of strikes and circumstances under which they occur where whales have a chance of survival, compared to those situations that would be fatal. She also suggested building theoretical strike models using available strike injury data (varying whale positions and vessel forces) to determine what could be survivable. Good agreed that more could be gleaned from existing necropsy data, including a better understanding of the orientation of the whale relative to the vessel at the time of a strike. Alex Angilella, MITRE, suggested that if 3D models of NARWs were made freely available it could lower the cost of the research. Another suggestion was to conduct hindcast modeling to refine or determine when and where a vessel collision occurred when a whale carcass is encountered.

Alyson Azzara, U.S. Maritime Administration (MARAD), agreed that modeling strikes to compare those that occur with the propeller versus the vessel's bow would be informative for vessel design and modification. She suggested that there is a very timely opportunity to try and integrate that information into ongoing work to produce more efficient, quieter vessels through hull and wake flow optimization. She noted that any changes in vessel design and propulsion systems (for ocean-going vessels specifically) would need to meet IMO regulations for efficiency and greenhouse gas emissions reductions, emphasizing the importance of including considerations of other existing regulatory and policy requirements. A participant from Canada offered that from an operational perspective, it would be interesting to investigate what actions vessels can take, and at what distances, to effectively avoid strikes.

One participant noted that his company developed an internal policy for how they would respond if they hit a NARW, as there was no set guidance or requirement for what to do. It was noted that NOAA does not mandate reporting, but because of USCG regulations, there is an expectation that mariners would report any strikes. Alanna Keating, Boat U.S. Foundation, commented that on the

USCG form (CG–3865; Recreational Boating Accident Report), there is a place to indicate wildlife interactions.[23]

Keating commented that propeller guards are commercially available. Doug Grimes, ThayerMahan, said they have been looking at hull and propeller designs for a long-time regarding noise and efficiency. He said hull design modifications are decades out and that timeline does not incorporate modifications specifically geared towards NARWs. Angilella referenced a study on the hydrodynamics of vessel/whale collisions, which included some discussion of orientation as well as hull versus propeller contact (Silber et al., 2010). Zack Klyver, Gotham Whale, asked whether an airbag deployment system to reduce mortality at the point of contact has been considered. Sean Brillant, Canadian Wildlife Federation, posed the out–of–the–box idea that giant “feelers” be placed out in front of vessels that drag through the water (and will not break or affect movement), but could safely come into tactile contact with animals and perhaps stimulate an avoidance response by the animal.

The group then turned its focus to discussing acoustic deterrents. Good stated that adding more sound to the ocean can be problematic and noted that some marine mammals appear to ignore certain sounds or may react detrimentally while others may become habituated to sounds. She asked if there is some sensory stimulus that could be used to alert whales to the presence of vessels—whether it be sound or lights like Baumgartner had suggested. In response, Baumgartner noted that one of the challenges with acoustics is that sound propagates a long distance but suggested that perhaps the sound could be placed just above the surface, which could be annoying to the vessel crew, but may be able to alert animals close to the bow. Azzara commented that light or sound at the surface would be incredibly challenging in anything other than a perfectly calm sea state. She asked whether a vessel’s horn could be used to startle whales in cases where there are many individuals in the area. She noted that their behavioral response may be to go just below the surface rendering them similarly, or more, vulnerable. George McIntyre, Wave Front, asked if forward–looking sonar had been considered to avoid whales and mentioned that there are several that are outside the hearing frequency of NARWs and most marine fauna.

Brillant reminded the group that creating an acoustic signal intended to be detected by a whale is only effective if it creates a behavioral response. He noted that there had been some research on the response of NARWs to noise, and evidence suggests that they do not respond in a way that removes them from risk. Nowacek also cautioned against assuming that whales will know how to respond if alerted to the presence of a vessel. He noted that NARWs get passed by vessels all the time without a negative consequence, so the whales have not been conditioned to react to avoid a collision (i.e., a behavioral response to avoid/reduce collision risk is lacking from their repertoire). He also cautioned that whales may become habituated over time. Wood–Thomas commented that our knowledge is not very good when it comes to acoustic signals that may cause marine mammals in immediate danger of being struck to move. He said that some operators elsewhere in the world believe they have found an acoustic signal that works, and we need to reach out to learn what acoustic signature is thought to be effective and to pursue appropriate research on the matter. He said that if we are successful in finding a noise that generates a behavioral response that reduces vessel strike risk, then the appropriate solution is not to generate that noise on a routine basis, but to generate that signal if you have identified a whale in front of you that poses an immediate strike risk where the vessel is already proceeding slowly and is unable to maneuver around it.

[23] It should be noted that while the form offers “submerged object”, “floating object”, or “other” as options for the cause of a collision, it does not include a specific option to indicate a wildlife interaction, such as striking a whale.

Kathi George, The Marine Mammal Center, said she wanted to highlight that technology is being used to generate data now, and those data need to be integrated and shared effectively with different vessel sectors. She pointed to Whale Safe as a good example of integrating and sharing data in a digestible format. Brillant suggested the scope should include ideas and technology that target human behaviors. One participant asked, looking at it from a mariner's perspective, whether everything we already have access to in terms of tools to reduce vessel strike risk has been exhausted. They observed that long–term solutions are exciting and promising but noted the tools currently in the toolbox can probably be used better (like vessel speed). They emphasized the importance of work to educate and alert mariners. Brillant also mentioned the recent population viability analysis by Runge et al. (2023) that could provide risk reduction targets needed to prevent the extinction of NARWs.

John DePersenaire, Viking Yacht Company, was asked to comment about the possible use of jet propulsion. DePersenaire said that accommodating jet propulsion on their vessels would require many changes to their vessel designs and would add weight to the vessels. He said it would cost millions to go down that path and would need much more research and clear guidance on expected risk reduction from hull or propulsion modifications before investing in this area. DePersenaire suggested that when the effectiveness of technology for reducing NARW vessel strike risk is evaluated, the focus should be on safety. He offered that representatives of the marine insurance industry should be part of these conversations to contribute their expertise in evaluating technology for safety improvements.

Azzara asked if there was something preventing the integration of drones into the detection space. She noted it seemed cheaper and more applicable to conduct surveys daily or twice daily (e.g., dawn/dusk) of shipping lanes and known convergence points, particularly in areas with whale watching and other recreational vessels that could be seasonally contracted to deploy the drones. She suggested that linking drone path global positioning system (GPS) with buoy detections and AIS would likely provide rich, spatially explicit whale and vessel location data and help to identify areas of highest risk in real time. Michael Johnson, Mashantucket Pequot Tribal Nation, expressed concern over the introduction of increased vessel traffic because of new construction activities on the outer continental shelf as well as increased traffic in state waters and its impact on the protection of various whale species, including the NARW. He suggested two areas for focus in the short term: (1) increasing monitoring and communication to all vessels (large and small) to notify whale position when detected; and (2) identifying the most effective communication technology that can be made available to all mariners immediately.

Clay George, NOAA Fisheries Southeast Regional Office, observed that the discussions covered many different types of vessels and vessel operators and suggested increased specificity about which vessel sectors were being referred to in conversations. He stressed the importance of keeping in mind that many of the vessels that operate in the NARW calving grounds are below the size (35 ft) proposed to be regulated but still pose a risk to right whales.

9.3.1 Online Poll

There were 43 participants in this workshop session who participated in the session's online poll, 23 of whom were in–person participants. Those who participated in the poll were distributed across the sectors as follows: Government (N=16); NGOs (N=9); Vessel Operator or Industry Representative (N=6); Other (N=5); Tech/Engineer/Manufacturer (N=4); and External Scientist/Academia (N=3). The poll asked the following open–ended questions—what technology has high promise to help: (1) reduce the lethality of vessel strikes; (2) improve monitoring, communication, enforcement, etc.; (3) whales detect/avoid vessels; (4) vessels detect/avoid whales; and (5) what else (e.g., other technology serving other purposes?).

Technology to reduce the lethality of vessel strikes:
Most online poll respondents identified whale detection technology as the technology with high promise to help reduce the lethality of vessel strikes. Offboard detection for medium to large vessels and onboard radar and infrared detection were suggested by one respondent. Vessel–based detection systems, including but not limited to thermal/IR, were cited by several participants. Real–time PAM was mentioned by several participants as was aerial surveillance via drones, recognizing the need for coordination with the Federal Aviation Administration (FAA). Another respondent suggested following whales (virtual tags) and generating areas to be avoided. The importance of integrating information from a variety of detection methods was highlighted. One respondent supported detection technology and commented that the burden should not be placed on whales to avoid vessels. Another respondent recommended focusing on nighttime detection, one emphasized forward–looking sonar, and another suggested fluid lensing (e.g., NASA's FLUID–CAM and/or Multispectral Imaging, Detection, and Active Reflectance (MiDAR)).

Poll respondents recommended research on a wide range of topics, with a number suggesting more research was needed to understand the main contributors to lethality. Additional analyses of necropsy and strike data for all whales were recommended to improve our understanding of how whales are being struck (i.e., what part of the vessel, what speeds). One respondent recommended research to identify sounds that would cause a whale to leave an area. Another recommended evaluating if there is a way to funnel the noise of the engine on large vessels forward to the bow to reduce the influence of the bow null effect without adding more noise to the ocean. Working with insurance companies to evaluate vessels that have hit something and sustained damage was recommended, including exploring whether any tissue from around the propeller could be genetically analyzed. Poll respondents recommended research to understand how whales behave in proximity to vessels prior to a strike and to also investigate whether the animals are aware of the vessel.

Several poll participants identified communication technology as having high potential to reduce the lethality of vessel strikes. Efficient communication to mariners (especially recreational and other small vessel operators) regarding the location of whales and what they can do to operate more safely was identified. The importance of providing mariners with real–time or near–real–time information was emphasized along with providing actionable guidance (e.g., slow down, avoid an area). One respondent recommended actions to incorporate whale alertness and avoidance into mariner culture at all levels of technological advancement.

Changes to vessels were identified as having high potential to reduce the lethality of vessel strikes. One respondent suggested changes that would allow for safe and efficient transit at speeds less than 10 knots. Other suggestions included altering hulls that do not cause lethal strikes (e.g., bumpers), jets around the point of contact at the bow to reduce lethality, and sonar at the bow that triggers the release of a cushion or system that deflects the whale, container, or other floating object that could damage the vessel. One respondent more generally recommended collision avoidance systems that reduce the risk of hitting any object. Jet drives, new propulsion systems, and propeller covers were recommended by some participants, with acknowledgment that these options are limited to small and medium vessel sizes.

Other technologies identified as having high potential to reduce lethality of vessel strikes included warning technology (lights, sounds) on vessels and enhanced instrumentation and decision support tools to alter human behavior on smaller vessels. Modeling using existing strike data was recommended, and using biophysical whale models to understand what constitutes a lethal strike was identified by one respondent. A few respondents identified mandatory speed restrictions and expanding the vessel speed reduction as having high potential to reduce lethality of vessel strikes. One respondent noted that the opportunity to reduce the lethality of a vessel strike is limited for large vessels and more promising for smaller craft. Another recommended expanding AIS requirements to provide a better understanding of all types of vessel presence in areas of high probabilities of co–occurrence with NARWs.

Technology to improve monitoring, communication, enforcement, etc.:
Technology to help improve monitoring identified by poll respondents include real–time PAM, thermal/IR imaging, radar, high–resolution satellite imagery, and multi–sensor data processed through AI, eDNA, and satellite tagging. A few respondents encouraged using long duration uncrewed platforms in DMAs and SMAs to monitor vessel speeds, issue warnings to vessels, alert authorities, and record data on whales. Another recommended significantly increasing offboard sensors (buoys, gliders, etc.). The integration of hydrophones into offshore wind infrastructure was recommended to expand the PAM network. The possibility of using vibration/accelerometer readings from vessel bows to monitor for vessel strikes was recommended by one workshop participant. Finally, one respondent recommended increasing support for the stranding network to fund carcass recovery, necropsy, and analysis to maximize information gained from each carcass.

In general, respondents recommended an increase in sharing information on new technology and distributing and encouraging the use of that technology. Support for expanding AIS coverage was expressed, and one respondent specifically recommended using vessels as relay platforms. Developing a singular electronic platform and notification protocol between NOAA, USCG, and Transport Canada (TC) was identified as an important step to improve communication with mariners. The transmission of whale zones to vessel plotters using AIS as well as automatic AIS messaging when entering a seasonal or dynamic speed zone were identified. Providing mariners with guidance on what to do with the whale data they receive was identified as critical to avoid information overload or misinterpretation of data/response. Another recommended making it easier for vessel operators to report whale sightings (without concern about specific species). The use of local or regional marine exchanges and Atlantic coast–wide collaboration among the exchanges was identified as a communication action with the potential to reduce vessel strike risk. Identifying standard modes of communication to mariners and posting local, regional, and general alerts using those modes was recommended. One respondent suggested that Congress allocate more funding to make more communication equipment available to all mariners regardless of craft size. Another emphasized the importance of communicating to the public to raise awareness and inform them of actions they can take to reduce vessel strike risk.

A few recommendations did not fit into the above categories. One respondent stated that fishing derbies should be requested to abide by both voluntary and mandatory speed restrictions by changing how they conduct the derbies in a way that does not promote speeding to the site. Another observed that some shippers and offshore wind–associated vessels might be reluctant to slow down and recommended exploring both "carrot and stick" approaches to increase compliance with speed restrictions. One respondent suggested that vessel operators should be required to show evidence they have reviewed whale alert/sightings information before they leave the dock and are abiding by recommendations or regulations and offered that documentation may be of interest to insurance companies.

Technology to help whales detect and avoid vessels:
Several workshop participants stated that there is no technology available to help whales detect and avoid vessels, and several discouraged investing in this area, citing the unpredictable nature of whale behavior, adverse effects of potential technology, or simply stating that the focus should be on changing human and vessel behavior, not the whales.

Many workshop participants recommended further research to determine if any technology had the potential to help whales detect and avoid vessels. Specifically, further investigation into lights, lasers, sounds, and smells was recommended, although some cautioned that whale responses to these stimuli would likely not be entirely predictable. Others commented that adding more noise to the ocean should not be viewed as a viable option, and one respondent said that while they were generally opposed to the idea of introducing sound into the environment, they felt it must be explored given the dire status of NARWs. One respondent recommended playing orca calls in areas of high vessel activity.

Technology to help vessels detect and avoid whales:
Respondents identified a wide range of detection technologies including acoustics, radar, Lidar, sonar, aerial monitoring, drone monitoring, thermal/IR imaging, eDNA, satellite tagging, and satellites. One respondent recommended placing observers on commercial vessels, and another recommended port/shipping channel groups that are solely focused on observing shipping channel activities and marine mammals in a specific area. Some noted the importance of matching technology to vessel class–specific considerations. One respondent said thermal/IR cameras held promise for large vessels but said that for small vessels there are no promising technologies to detect/avoid whales, so static and occasional dynamic slowdowns are essential. Further investment in modeling was recommended as well as integration of whale data into charts and onboard software. One respondent identified regional thermal/IR and acoustic networks that are correlated and then delivered in a simple, public–facing platform as a step to improve situational awareness. The use of AI was recommended for processing detections and for providing insights into movement patterns of certain mammals who have been studied in terms of their behavior patterns. Concentrated aids to navigation in shipping channels and other high–risk areas paired with enhanced AIS transmission were also identified as holding promise.

Identification of other technology to reduce vessel strike risk not covered above:
<u>Forensics</u>: One respondent recommended improved modeling to understand mortality (i.e., death) versus morbidity (illness or disease) associated with vessel strikes, including investigation of whether it matters more where the whale is hit or the type of boat involved in the strike. Another underscored the importance of wound forensics.

<u>Modeling and Simulations</u>: Virtual reality training for captains with scenarios involving whale avoidance and detection was recommended. The integration of whale alertness into mariner training courses and exams was identified by one participant. Another recommended data analysis and modeling to identify the most salient operator measures to avoid vessel strikes and allow for targeted compliance.

Research: One respondent recommended more research into NARW behavior to inform modeling, and another specifically recommended investigating the use of cameras installed on bows to monitor the reactions of whales to approaching vessels. Several participants recommended more thorough investigations of available data on vessel strikes and using that knowledge to inform vessel design changes. Computational fluid dynamics (CFD) work and the study of the hydrodynamics of NARW–vessel collisions at varying scales to inform an evaluation framework were identified by one respondent.

Safety Focus: One respondent recommended looking for analogues to the NARW vessel strike problem to better evaluate risk (e.g., vessel avoidance of floating marine debris or vessel pilot response to busy ports). Another recommended looking into USCG data on accidents.

Expanding Surveillance Opportunistically: Several workshop participants supported adding hydrophones or cameras to infrastructure on the outer continental shelf, including wind turbines. Another expressed interest in integrating detection into fiber optic cables in offshore wind areas.

Enforcement: One respondent highlighted the need for remote enforcement methods other than AIS (noting that operators can choose not to install AIS or turn it off).

Other: One respondent recommended updating the USCG reporting requirements to include wildlife interactions. Another recommended focused monitoring and communication to recreational/small vessels, commenting that this sector seems to have the significant capability to injure animals and has received disproportionately less attention than the large commercial vessel industry. Finally, one respondent recommended taking a whole traffic approach with a focus on what vessels could be reduced in terms of operation and at what time(s) of the year.

9.4 Primary Takeaways

The scope of the Other Technology workshop session was intended to be broad and allow for brainstorming that resulted in a wide range of ideas and suggestions. Table 8 identifies the following five promising pathways: (1) sensory alert signals; (2) combining whale detection with dynamic sensory alert signals; (3) modifying propulsion systems; (4) additional/improved communication with mariners concerning whale locations; and (5) assessing risk reduction.

Participants identified the primary need for research on whale response to alert stimuli as necessary to inform whether acoustic or visual stimuli could be used to alert whales to a vessel. If alert signals were deemed likely to be effective, then it was suggested they be used as a deterrent only when a whale was detected near a vessel. Similarly, while vessel and propulsion system modifications were identified as promising, session participants emphasized the need for research to determine how successful different or modified vessel propulsion systems, such as jet propulsion or propeller guards, would be in reducing the lethality of strike events.

Session participants acknowledged that a full understanding of how whales perceive and react to vessel traffic is lacking, and that learning more about this is important to be able to predict and perhaps use technology to influence whale behavior around vessels. The need for more information on the factors that contribute to vessel strike lethality (e.g., impact location on the vessel, orientation of whale to the strike, body part of whale directly impacted) was identified, and mining existing necropsy and strike data was recommended. Session participants suggested that the data acquired could be used to inform vessel strike models, and that simulations of different vessel types/operational modes and detection technology could be used to investigate what actions vessels can realistically take, at what distances, and under what conditions to effectively avoid strikes. One participant recommended using those simulation models and available data to identify the most salient operator measures to avoid vessel strikes. Virtual reality training for captains with scenarios involving whale avoidance and detection as well as the integration of whale alertness into mariner training were also recommended.

In general, session participants recommended an increase in sharing information on new technology and distributing and encouraging the use of that technology. They also emphasized the importance of providing mariners with guidance on what to do with the whale data they receive to avoid information overload or misinterpretation. Discussions within this session also supported those occurring in the other Risk Chain Component workshop sessions, including the valuable contribution of whale detection and communication technology to vessel strike risk reduction.

Table 8. Promising Other Technologies or Methods. This table was filled in by the facilitator during the 2024 NARW Vessel Strike Risk Reduction Technology Workshop Other Technology breakout session, based on session discussion, and modified to improve clarity for use in this report.

Promising "Other Technology or Methods"	Purpose(s) (reduce lethality, monitoring, detect/avoid whales or vessels)	What's Next? (Research questions, outreach/education, etc.)
Sensory Alert Signals	Use acoustic, visual, or other sensory stimuli to alert whales to a vessel's presence.	Additional research: Whale response to alert stimuli; types of effective stimuli.
Combining whale detection with dynamic sensory alert signals	Use alert stimuli only when whales are detected near a vessel to reduce the need to continuously produce or transmit alert signals which may be disturbing to wildlife and/or increase the likelihood of habituation	
Modified propulsion systems	Different or modified vessel propulsion systems, such as jet propulsion or propeller guards, may reduce the lethality of strike events, should they occur.	Substantial research is needed to better understand potential benefits.
Additional/improved communication with mariners concerning whale locations	Help mariners to better avoid strike events via best available whale information where they are operating.	
Assessing risk reduction		Reach out to the marine form insurance industry.

Priority Data/Information Gaps related to Other Technology or Methods
Need to better understand whale perceptions and reactions to vessel traffic in general; mine more information from NARW and other large whale species necropsies to better understand impact of whale orientation during strike, nature of injuries, and influence of impact by different parts of the vessel (hull, rudders, propellers, etc.).

10. Sector Perspectives

10.1 Introduction

The range of perspectives shared during the workshop verbally and through polls, online forms, and question–and–answer feeds are presented in this section. The first morning of the workshop included a panel of vessel operators and industry representatives convened to share their/their sector's perspectives on how, in the context of their operational needs, they envision technology reducing vessel strike risk to NARWs. Additionally, a representative of NOAA Fisheries shared their perspective on the issue and what they hoped to get out of the workshop. During the afternoon of the second day of the workshop, a panel of vessel operators, industry representatives, and federal government agency representatives was convened to share thoughts on compelling themes they observed throughout the workshop and on the potential of partnerships moving forward. Information from this second panel is also included in Chapter 12.

Given the workshop was intended to include all vessels whose operations overlap with NARWs, it was not possible to have a representative of each vessel category and operational use represented on these panels. In addition, there are other sectors who share a vested interest in vessel strike risk reduction technology including, but not limited to, Technology Developers and Manufacturers, NGOs, Academics/External Scientists, State Agency Representatives, and Tribal Governments. Other tools were used to provide an opportunity for all workshop participants to share their perspectives. The perspectives of representatives from various sectors were solicited and shared during the workshop verbally and through various electronic options.

Workshop participants were also asked for recommendations on how to build upon the discussions and collaborations happening during the workshop and to identify what is needed to make progress in applying technology to reduce NARW vessel strike mortality. Initially, the focus was on identifying what was needed most from each sector (Federal agencies, Technology Developers and Providers, Researchers, Vessel Operators and Industry Representatives, NGOs, and others) individually to advance vessel strike risk reduction technology. Input was received both verbally, and through polling, online forms[24], and the question–and–answer feed. A summary of the input received is provided in this chapter following the summary of the sector perspectives shared at the workshop. Key areas for collaboration among the sectors and partnerships necessary to advance vessel strike risk reduction technology will be discussed later in this chapter after the sector–by–sector analysis.

A total of 586 individuals registered to attend the workshop in person or remotely (Figure 18, see Chapter 2 for details). At the opening of the workshop, participants were asked to identify which sector they belonged to via a poll. Approximately 57% of registrants participated in the poll (N=334; Figure 17).

[24] Specifically, this section contains responses to the online form used in session V: Understanding the Range of Perspectives (N=26) and in session XIV: Public Private Partnerships (N=34), with some overlap in participants.

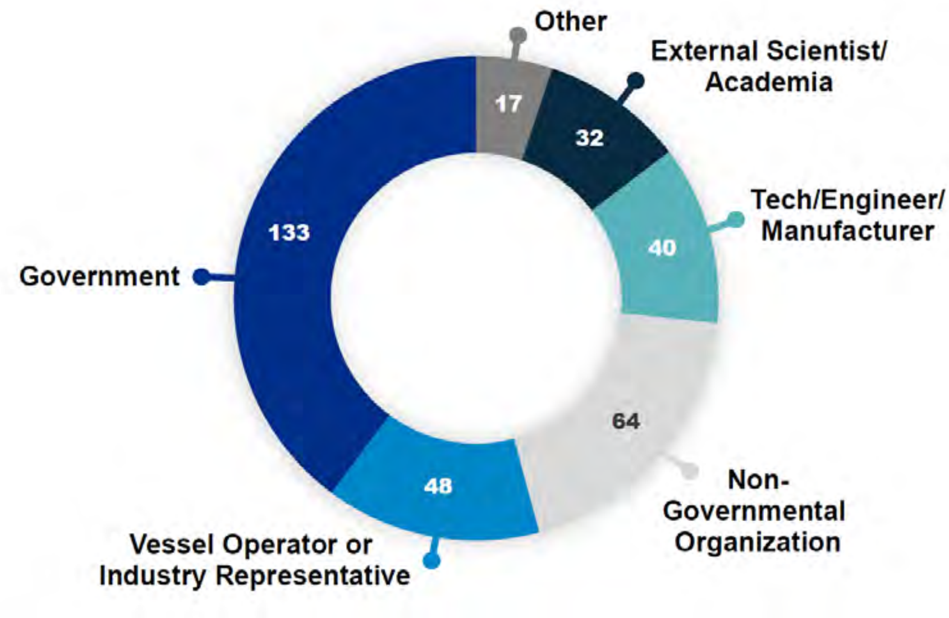

Figure 17. Sector composition of 2024 NARW Vessel Strike Risk Reduction Technology Workshop participants based on a Day 1 online poll.

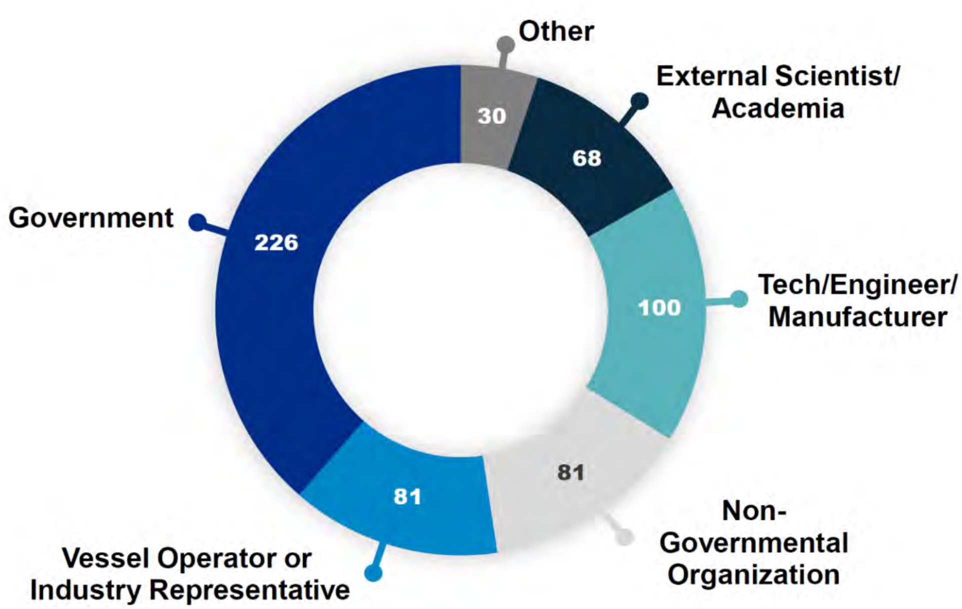

Figure 18. Sector composition of all 2024 NARW Vessel Strike Risk Reduction Technology Workshop registrants. To allow comparison with online poll results where the sector options were limited, more fine scale sectors were grouped. The Government group includes registrants categorized as international, federal, state, and tribal while the Other group includes media, congressional, and other.

10.2 Perspectives of Workshop Participants

At the opening of the workshop, participants were asked to identify, using no more than two words, what they most wanted to get out of the workshop. Submissions from over 300 respondents were minimally cleaned for consistency in preparation for this report, and a word cloud was created to identify common themes and visualize the results (Figure 19). The 10 most frequently submitted words included: learn, understanding, collaboration, knowledge, innovation, solutions, ideas, right whale conservation, progress, and awareness. Expanding out from the center, many of the smaller words or phrases reflect a similar sentiment to those at the center, and if these were grouped together, the areas of convergence would grow.

Figure 19. Word cloud of responses from over 300 participants to the question of what they wanted to get out of the 2024 NARW Vessel Strike Risk Reduction Technology Workshop. Word size reflects the number of individuals who submitted similar phrases and the words that were submitted at higher rates are located at the center of the cloud.

The perspectives shared by panelists, questions and input from workshop participants, responses to an online poll (N=171), and input from an online form (N=26) were categorized and summarized by sector below.

10.2.1 External Scientists/Academics

10.2.1.1 Perspectives

Some external scientists and academics participating in the workshop expressed an interest in working more closely with vessel operators to test detection technology under real–world operational conditions and to understand better what outputs from detection technology and/or modeling efforts would be considered both informative and sufficient to prompt evasive action. Mark Baumgartner, WHOI, stated that it is not possible to tell mariners where the whales are all the time, and asked vessel operators to think about the uncertainty that exists and how precautionary the notifications should be. External scientists and academics participating in the workshop remotely recommended focusing on facilitating vessels avoiding whales, not whales avoiding vessels. They also emphasized the critical importance of considering vessel limitations when determining the appropriateness of specific technology for different vessel types. Of particular concern was the consideration of time frame available for vessels of different types and operational states to take effective evasive action and any time lags inherent to technologies. The external scientists and academics recognized that whale detection can be improved but will be limited by the biology of the species, and encouraged the use of competitive grant solicitations to spur innovation among technology developers.

10.2.1.2 What is Most Needed

When asked what was most needed from researchers to advance vessel strike risk reduction technology, respondents identified the following:

Collaboration and Communication
Workshop participants identified the need for external scientists to work directly with industry to improve the commercial viability of products; accelerate the development process; and to learn how vessel operators from different industries operate, what their decision process looks like, and narrow down what would help them make the best mitigation decision. Another suggestion was the development of a dedicated open–source journal that aggregates relevant papers. The need for external scientists to communicate progress and current research to the public and to mariners at an accessible level was also noted as a key need to improve overall understanding of the state–of–play. Development of freely and publicly available training resources on various cetaceans, their characteristics and behaviors, how to identify them, and the impact of available strike reduction tools was also identified as a role for this sector.

Research Focus
Workshop participants identified the need for external scientists to continue collecting NARW visual and acoustic data and to standardize data collection methods to allow for efficient incorporation into near–real–time models. Scientists, researchers, and academics were encouraged to incorporate regime shifts/climate uncertainty into models, to support covariate data collection (i.e., zooplankton distributions, sea surface temperature, etc.), and explore additional variables that could influence NARW distribution. Increased communication between modelers was recommended as well as the establishment of modeling tools to assess deployment plans for detection systems and mitigation strategies and technology. Research to better understand NARW vessel strike risk was encouraged as well as the continuation of vessel strike forensics work on all species to help better understand how best to address the vessel strike problem. Finally, workshop participants identified the need for external scientists to work with social scientists to better understand constraints, needs, and motivations of vessel operators.

10.2.2 Federal Government Representatives (U.S. and Canada)

10.2.2.1 Perspectives

Kim Damon–Randall, NOAA Fisheries OPR, acknowledged that we have an unprecedented opportunity to address vessel strike risk with new technology and approaches. She expressed appreciation for the wide variety of perspectives shared at the workshop and recognized that suitable technology will differ by sector. She emphasized that detection is an important step, but it alone does not reduce vessel strike risk—the mariner must take evasive action in response to that information to reduce risk.

Federal Government representatives participating in the workshop remotely identified a key role for the Federal Government in establishing requirements and ensuring compliance through monitoring and enforcement. They encouraged additional research and development, enforcement, incentives, and better dissemination of information. Continuing to provide funding was also identified as an important Federal Government role, and weighing the costs and benefits of current and emerging technology to make informed investments was encouraged. Federal agency representatives met immediately following the public workshop to share observations from the open sessions and discuss opportunities for collaboration to advance vessel strike risk reduction technology (Appendix 7).

10.2.2.2 What is Most Needed

Workshop participants were asked to participate in a poll to (1) identify the area they felt was most in need of government support and engagement, and (2) identify the three most promising vessel strike risk reduction technologies. A total of 171 individuals, including both remote and in–person, participated in the poll and were spread across the sectors as follows: Government (N=66); Vessel Operators/Industry Representatives (N=28); NGOs (N=28); Tech/Engineer/Manufacturer (N=24); External Scientist/Academic (N=16); and Other (N=9). Poll respondents overwhelmingly identified the dissemination and integration of NARW data and management areas (N=93) and detection and classification (N=42) as the areas most in need of government support and engagement (Figure 20). The remaining four options (aggregation, modeling, vessel design, and other) were chosen significantly less often.

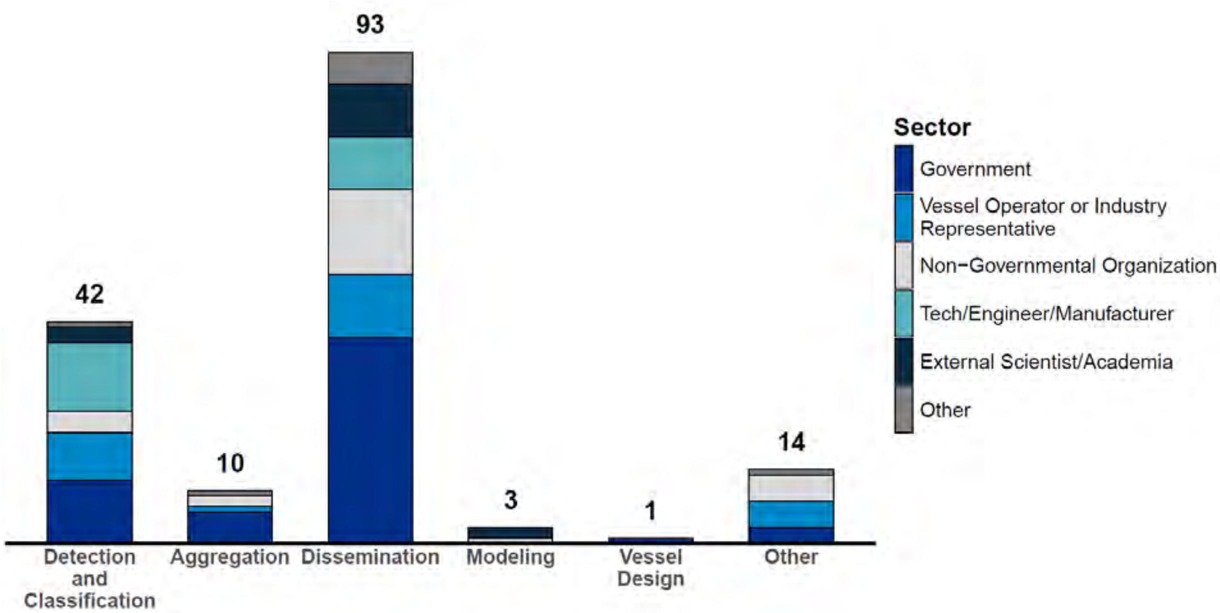

Figure 20. Areas identified by poll at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop as most in need of government support and engagement. Participants were permitted to select only one option. Labels above each column indicate the total number of poll respondents that chose that response. Bars are colored in accordance with the sector composition of those selecting that option.

When asked what specifically was most needed from the Federal Government to advance vessel strike risk reduction technology, workshop participants identified the following:

Performance Standards/Metrics, Associated Evaluation Method, and Consequences
According to workshop participants, clarity on performance–based goals and metrics and on the process and protocols for the testing, validation, and acceptance of results is the action most needed from the Federal Government. Participants expressed that it was the role of the Federal Government to hold itself and others accountable to a scientifically

rigorous evaluation process and to clearly articulate full system requirements and goals so that technical developers can work towards and meet those requirements. Participants said that risk reduction targets for vessel strikes and an explanation of how risk is being measured are also most needed from the Federal Government. Workshop participants further identified a need for clarity in the implications if performance standards were met.

Technology Roadmap
Another role for the Federal Government prioritized by workshop participants was the development of a technology roadmap, which would identify the current TRL of vessel strike risk reduction technology and match them to appropriate vessel–use profiles. It was recommended that once the roadmap has been built and metrics for measuring success identified, the Federal Government should develop and maintain a dashboard to display the status of various technologies relative to those metrics at any given time (to include outreach, compliance, technology development, vessel–struck whales, etc.).

Collaborations and Partnerships
Workshop participants stated that to advance vessel strike risk reduction technology, the Federal Government needed to establish and strengthen partnerships and collaborations among federal agencies, industry, mariners, NGOs, and the research community. Such partnerships were identified as instrumental in providing opportunities to test technology, gain insights into the potential feasibility of new/emerging technology for different vessel types, and spur innovation. In particular, NOAA Fisheries was encouraged to consider all perspectives as it moves forward in advancing public private partnerships.

Communication and Outreach
The need for the Federal Government to disseminate information on whale presence and management areas to vessel personnel and shoreside teams in a streamlined, timely, and standardized manner was identified as another key need by workshop participants. Specifically, they recommended that the federal agencies either operationalize AIS transmitting, allow the private sector to do it, and/or pursue legislative changes to expand AIS carriage requirements to include a greater range of vessels. The dissemination of information on available technology to mariners in an efficient manner was also identified as a role for the Federal Government. Workshop participants also suggested that the Federal Government needed to engage with the public, vessel operating companies, and cargo owners/shippers to raise awareness of the importance of strike risk reduction tools.

Funding and Incentives
Workshop participants identified the need for the Federal Government to provide resources (e.g., people, money, convening power) to support innovation, incentives to encourage the adoption of new technology (e.g., rules, tax breaks, penalties/fines), and to establish stable funding for large–scale technology installations such as PAM networks. The need for new regulations/initiatives that encourage and direct technological development was also identified. Workshop participants also identified the need to reduce the complexity of initiating partnerships with government agencies and recommended rapid funding programs to get detection and risk reduction technology off the ground.

Regulatory
Federal agencies were encouraged to collaborate with industry prior to proposing new regulations incorporating technology and to work with industry to develop a mandatory dynamic management program. Others identified the need for federal agencies to issue strong regulations, monitor them, and enforce compliance. The need for federal agencies to

develop regulatory frameworks that are flexible and able to adopt proven technology was also noted by workshop participants.

Scientific Research
Workshop participants identified the need for federal agencies to continue to monitor the NARW population, to specifically investigate any vessel strikes, and to publicize all reports of suspected or possible collisions promptly, whether they are lethal or non lethal. Federal agencies were also encouraged to sponsor more scientific research into the risk itself, including a 2D sliding scale of both vessel size and speed as it relates to potential mortality.

10.2.3 Non–Government Organizations (NGOs)[25]

10.2.3.1 Perspectives

Select workshop participants representing various NGOs spoke about the urgency of reducing NARW vessel strike risk and, in response to industry's request for performance metrics, stated that the goals of the Marine Mammal Protection Act (MMPA) and Endangered Species Act (ESA) were clear and that elimination of vessel–strike–related serious injuries and mortalities was the target. Jane Davenport, Defenders of Wildlife, stated that there is no debate on how much risk the vessel industry must reduce—the estimated Potential Biological Removal (PBR)[26] rate per year for NARW is 0.7, and nearly three times that many had already been killed by vessel strikes in the U.S. between the start of the year and the workshop. Remote workshop participants representing NGOs utilized the online form to support the use of combinations of technology and methods for detection (PAM, thermal/IR, and aerial surveys), and noted that a single risk reduction strategy is unlikely because different vessel classes have different fields of vision (e.g., height off water), ability to maneuver or slow down, onboard connectivity, and available resources (how many crew, amount of dashboard in the wheelhouse for additional screens, etc.). They further recommended investigating new vessel designs that could reduce lethality in the event of a strike. Commenters also cautioned that detection alone cannot reduce vessel strikes and expressed some skepticism that technology can achieve risk reduction comparable to that achieved by a reduction in speed.

Some NGO workshop participants stated that vessel operator compliance with mandatory measures and participation with voluntary measures is far too low to achieve the goal of vessel strike reduction. Others stated that they found reluctance on the part of some vessel operators to consider altering their operations to reduce vessel strike risk as no longer an acceptable option. They expressed appreciation for the vessel operators who had implemented change but expressed concern that despite a tremendous amount of effort over the last three decades, the number of vessel strike mortalities is still too high. Others stated that they felt they were hearing industry representatives using detection as a proxy for vessel strike risk reduction and encouraged greater focus on what vessel operators would do once they detected or were notified about the presence of whales.

---

[25] It is important to note that the term NGO was not limited to environmental NGOs. Participants were able to select their affiliation, and some organizations/groups representing the vessel industry or vessel operators selected NGO.

[26] The PBR level is defined by the MMPA as the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal population while allowing that population to reach or maintain its optimum sustainable population (16 U.S.C. § 1362 (20)).

10.2.3.2 What is Most Needed

When asked what was most needed from NGOs to advance vessel strike risk reduction technology, workshop participants identified the following:

Advocacy
Workshop participants identified the need for NGOs to advocate for: (1) the resources needed for technological innovation and adoption; (2) regulatory changes, where applicable and appropriate; and (3) practical solutions that NOAA Fisheries can use to prevent NARW extinction. They also encouraged NGOs to find ways to highlight the positive actions that mariners are taking, including encouraging positive press to acknowledge risk reduction behavior and actions.

Collaboration and Partnerships
The need for NGOs to explore ways to work with industry and regulators in a less adversarial way to develop implementable and effective strategies was noted by workshop participants. NGOs were encouraged to spend time learning how vessel operators from different industries operate, what their decision processes look like, and identify what would help them make the most effective risk reduction decision. Workshop participants also noted the need for NGOs to work with the shipping industry to encourage compliance with mandatory and voluntary measures and collaboration in technology testing. Some participants suggested that NGOs could offer insight in collaborative meetings with agencies and mariners or private groups and help bridge the gaps between these groups.

Outreach and Education
Workshop participants identified the need for NGOs to develop and distribute training resources on various cetaceans, their characteristics and behaviors, how to identify them, and the impact of strike reduction tools already available and as new ones become available. Conducting outreach to the public, vessel operating companies, and cargo owners/shippers to educate and raise awareness of the importance of strike reduction risk mitigation tools was also suggested as a key role for NGOs.

Funding
Funding for innovation, research, and validation of new vessel strike risk reduction technology was identified as a priority need from NGOs. Workshop participants identified a role for NGOs in leveraging resources across agencies and entities to support priority initiatives.

10.2.4 Technology Developers and Manufacturers

10.2.4.1 Perspectives

Technology developers and manufacturers spoke in support of the establishment of performance metrics so that they would know how their products would be evaluated and what would be categorized as acceptable. Remote participants shared their work with aerial and satellite images, drones, thermal/IR cameras from boats and shore, and camera–based detections. They highlighted the importance of marine–centric navigational software that can support dynamic responses from mariners. Technology developers recommended focusing on the development and deployment of a one–stop app/visualization tool that integrates detections from multiple sensors, improving methods to notify mariners, increasing focus on decision–making models, using a streamlined human–in–the–loop protocol for detection validation and reliability, and concentrating acoustic monitoring at the beginning and end of the seasonal speed zones.

10.2.4.2 What is Most Needed

When asked what was most needed from technology developers and providers to advance vessel strike risk reduction technology, workshop participants identified the following:

Technology Development
Workshop participants identified the need for technology developers and providers to understand government standards and to develop technology that meets those standards with demonstrated rigor. Another identified role was in the development of consolidated catalogs of available equipment/technology and their capabilities matched to the needs and operating methods of each affected industry. Technology developers and providers were also asked to conduct a full system–level analysis of the requirements for a complete vessel strike reduction solution across all relevant domains and to provide life cycle cost estimates for such full systems (from concept through deployment, operation, and system end of life). Workshop participants emphasized the need for technology developers and providers to make technology scalable by addressing such things as ease of use, number and type of users, and appropriate and attainable pricing. They identified the need for the validation of technology performance and the capability of integrated systems as well as the ability to troubleshoot and provide feedback on new technology. Participants also recommended work specifically focused on testing how detection technology (visual, acoustic, thermal/IR, vessel, modeling) can complement each other, how satellite and thermal/IR imaging technology could better contribute to risk reduction, and improved methods to communicate with mariners.

Innovation, Flexibility, and Interoperability
To best advance vessel strike risk reduction technology, workshop participants stated that technology developers needed to brainstorm on improvements to existing technology and vessel designs. They also identified the need to adapt technology to work with different vessel categories and operational modes as well as to work within management programs. Workshop participants also identified the need for technology developers and providers to ensure that vessel strike risk reduction technology could be used on multiple platforms and be integrated with other technology. They emphasized ensuring that any developing technology is accessible, compatible, and/or integrated with other data sources and systems already in use by mariners. The need for continuous support of technology throughout its lifecycle was also identified.

Collaboration and Partnerships
The need for technology developers to work with a wide variety of partners and to bridge existing gaps was noted as essential to advancing vessel strike risk reduction technology. Specifically, technology developers and providers were encouraged to: (1) work with marine mammal experts to verify their technology is accurately detecting marine mammals; (2) establish dialogue with regulatory agencies to field test new technology and improve the likelihood the developing technology will be acceptable under their standards; (3) work with end users to understand needs and constraints; and (4) work with the USCG, marine architects/engineers, and others to ensure new technology does not interfere with vessel operations and safety. Workshop participants also identified the need for technology developers and providers to transparently share trial results.

10.2.5 Tribal Governments

Bettina Washington, the Tribal Historic Preservation Officer for the Wampanoag Tribe of Gay Head (Aquinnah), shared the importance of whales in their culture—in the Wampanoag culture, they share common ancestors and are considered relatives. She observed that the number of people participating in the workshop was approximately the same as the number of NARWs left in the world. She said whales are not a navigational hazard because the ocean is their home and it is humans that are making the ocean more crowded. She expressed appreciation for the efforts being made to protect not just whales, but all animals in the ocean, and encouraged accelerated efforts moving forward.

10.2.6 Vessel Operators and Industry Representatives

10.2.6.1 Perspectives

As was stated repeatedly throughout the workshop, there is significant and meaningful diversity in the vessel operator industry and community. The perspective of the vessel operator subsectors of commercial fishing, commercial shipping, passenger vessels, pilot vessels, recreational vessels, and vessels associated with offshore wind is provided below.

10.2.6.1.1 Commercial Fishing

The representatives of the commercial fishing industry that participated in the workshop did so remotely and offered some insights by using the online forms. They identified timely communication to the fleet as a priority. One representative suggested the use of hull sensor technology on larger vessels that would detect collisions, noting that only 36% of whale deaths are documented and most larger vessels would not notice if they had a collision with a whale.

10.2.6.1.2 Commercial Shipping Industry

Bryan Wood–Thomas, WSC, who sat on both the Day 1 and Day 2 panels, stated that they move 90% of the containers in the world and that they are supportive of both the existing and proposed speed regulations[27]. He spoke in support of both static and dynamic areas. He further noted that static areas allow vessel operational planners to plan for and incorporate known speed reduction zones into voyage planning. He added that routing measures should be employed where feasible as they can deliver the highest certainty in risk reduction when the measures effectively separate vessels from whales where there are known and predictable concentrations of whales. He acknowledged that dynamic areas will continue to be necessary due to the continuing movement of whales and stressed the importance of vessel operators receiving timely information. He advocated for looking ahead to anticipated changes in navigation and their potential impact on vessel strike risk. In response to a question, Wood–Thomas said that information on dynamic management areas should be presented in a concise manner that is immediately usable by the navigation officer, and said that sending those areas directly to navigational systems in a geofencing format would be ideal (as compared to reading through a page of lat/long coordinates). He also noted that the information made available to the officers on the bridge needs to bear in mind what kind of information is actionable. With respect to the latter point, Wood–Thomas added that “flooding a navigation officer with data points collected over extended time periods will not serve our objective of reducing vessel strike risk,” and urged participants to think about what they consider to be actionable and useful data.

[27] As stated at all planning webinars and at the opening of the workshop, proposed modifications to the North Atlantic Right Whale Speed Rule and management actions that may ultimately implement technology tools were outside of the scope of the workshop. References made by participants to the speed rule or implementation actions, while outside of the established scope of the workshop, are included throughout this report for accuracy and completeness.

10.2.6.1.3 Passenger Vessels

Mike Glasfeld, representing the Passenger Vessel Association, was also a Day 1 panelist. He advocated for geographically specific technology options, particularly for operations that go in a predictable pattern between two locations. He also requested more specificity as to where animals are and when they are there to develop areas that are more manageable in size. He said that currently, though the regulations call for DMAs 400 square miles in area, they continue to be over 1,600 square miles in area and stated that an area of 100 square miles would permit vessels to navigate around the DMA[28]. Representatives of the cruise ship industry were invited to attend the workshop in person and participate on the panels but were only able to attend remotely.

10.2.6.1.4 Pilot Vessels

Clay Diamond, APA, represented the pilot's perspective on both the Day 1 and Day 2 panels. He explained that the pilots have two perspectives—one from operating the pilot boats, which travel up to 20 miles offshore primarily in an east–to–west/west–to–east direction along the coast, and the second from navigating large commercial vessels. Diamond stated that most of the large ocean–going vessels are transiting east–to–west/west–to–east and are using offshore, narrow, federally–improved dredged channels to get in and out of port. He said that there are only around 25 pilot boats navigating at any given time and that their operations are critical to the supply chain. Diamond encouraged NOAA Fisheries to work with the APA to find technology options appropriate for their vessels and operational mode. He suggested that mountable technology (high resolution cameras and thermal/IR cameras) was best suited for pilot boats. He also suggested that enhanced detection technology would enable more dynamic speed zones and avoid large scale permanent speed rules. He suggested that most pilots carry portable pilot units and that it would be useful to have a system where dynamic speed zones are automatically fed into those units. Diamond stated that the role and official responsibility of pilots is to protect the safety of navigation and the marine environment on the waters for which they are licensed, which is closely aligned with the goal of reducing NARW vessel strike risk. He spoke of the historically antagonistic relationship with NOAA Fisheries and expressed a desire that all parties work to develop a more productive and respectful working relationship.

10.2.6.1.5 Recreational Vessels

John DePersenaire, Viking Yacht Company and representing the WAVS Taskforce, was invited to sit on both the Day 1 and Day 2 panels to speak to the perspectives of both the very diverse recreational sector and the manufacturer sector. He said he was very proud of his sectors and the way they had responded to the issue with a focus on developing practical and scalable technology–based risk reduction options. He shared that safety is an essential design and engineering component of any vessel and part of that is collision avoidance. DePersenaire said that their vessels (Viking Yachts) are designed to go fast, and some of the trips they are designed for are not possible under the new speed limits. He encouraged the Federal Government to take advantage of the collaboration at the workshop and warned that the interest and engagement of industry would lessen over time, particularly without active engagement from the government. He advocated strongly for the

[28] Information on NOAA Fisheries' Dynamic Management Area (DMA) program is available at https://www.fisheries.noaa.gov/national/endangered-species-conservation/reducing-vessel-strikes-north-atlantic-right-whales#right-whale-slow-zones%C2%A0and-dynamic-management-areas.

establishment of performance metrics and the quantification of risk reduction so that the private sector knew what target they were aiming for and the results of achieving it.

Jeff Angers, Center for Sportfishing Policy, sat on the Day 1 panel and expressed appreciation for convening the workshop, but stated that it should have happened years ago. He highlighted the importance of NOAA Fisheries avoiding “one size fits all” regulations because all the sectors are different and that there are significant differences even within the recreational boating sector. He said that boaters rely heavily on technology tools for safety and navigation, suggesting that similar tools for vessel strike risk reduction would be similarly utilized. Angers advocated for the measurement of risk reduction achieved through technology and supported private–sector partnerships to develop real–time whale alert systems (i.e., existing initiatives in Alaska and Puget Sound).

10.2.6.1.6 Vessels Associated with Offshore Wind

Representatives from companies holding leases for offshore wind energy production and several technology companies working with them were active participants at the workshop. American Clean Power was invited to participate in the vessel operator panel but was unable to do so. Individuals associated with the offshore wind industry spoke in support of the establishment of performance metrics and the evaluation of detection technology. They also urged identification of implications for the use of technology. Priority steps identified by representatives of the offshore wind industry via online forms included development of performance metrics, detection validation, demonstration of technology, and further advancements to support information sharing in real time. They further identified support for a long–term effort to advance predictive presence models that can inform day–to–day planning. One participant recommended that vessel operators be required to have a marine mammal strike avoidance plan that follows certain prescriptive measures.

10.2.6.2 What is Most Needed

The polling question was not broken down by vessel operator subsector, so responses below are to the general question of what is most needed from the vessel operators and vessel industry representatives to advance vessel strike risk reduction technology.

Expertise

Workshop participants identified the need for vessel operators and vessel industry representatives to partner with technology developers, external scientists, and government to jointly develop products, implement pilot projects to test feasibility of technology and acceptance by industry, and provide feedback to the developing entity. The need for vessel operators to share their critical knowledge of vessel operation capabilities, needs, and limitations for different use categories was also noted as key. Including vessel operators from various industries, size classes, operational modes, and with varying levels of experience in identifying whales in all technology trials was encouraged. Workshop participants highlighted the need for vessel operators to communicate realistic assessments of what they are likely to do/use to agencies and technology developers (e.g., sharing what technology they would use and what they would pay for them). Transparency in sharing what they are seeing and experiencing when operating in the vicinity of marine mammals was also identified as a need. Finally, workshop participants requested that vessel operators provide recommendations on the best strategy to reach their specific vessel sector with information and updates about whales and vessel strike reduction efforts.

Engagement, Cooperation, and Collaboration
Workshop participants stated that vessel strike risk reduction technology will advance if vessel operators and vessel industry representatives are able to focus on the shared goals of increasing safety and environmental compliance and work to develop trust. In addition, workshop participants identified the value of vessel operators and vessel industry representatives actively participating in meetings, establishing relationships, and engaging with the agencies related to potential regulations and management actions. The specific need for a meeting between harbor pilots and NOAA Fisheries was identified by some participants.

Awareness, Vigilance, and Planning
Workshop participants identified the need for vessel operators to increase their awareness of NARW distribution, detections, and the importance of actions to reduce the risk of vessel strikes. They encouraged vessel operators to be vigilant and to make efforts to sensitize bridge teams so they know what they are or may be seeing on their existing equipment. Within larger vessel industries, training for staff on the use of new technology/apps as they become available and educating others on their importance was encouraged. Preplanning and identification of appropriate actions to minimize the risk of vessel strike under different scenarios was also identified as a need.

Communication
Workshop participants offered that vessel strike risk reduction technology would be advanced if vessel operators identified and shared how they want to receive information, what information they want to receive, and what they can/will do when they receive it. The evaluation of communication protocols was encouraged to identify streamlining opportunities to reduce time between being made aware of the presence of a whale and taking effective evasive actions. The value of having a plan for how to appropriately make decisions about whale avoidance (in full consideration of safety) when in receipt of actionable data was identified.

Compliance
Some workshop participants identified the need for vessel operators and vessel industry representatives to implement interim measures (speed reductions) until comparable risk mitigation (based on scientifically tested metrics) is in place. Others more generally identified the need for compliance with any mandatory measures, participation in voluntary measures, and setting a good example for the fleet.

10.3 Who/What is Missing from this Workshop and Conversation?

On the second afternoon of the workshop, participants were asked which perspectives or specific people or groups were missing from the workshop and the conversation. The near absence of social scientists and communications experts and the lack of understanding of how people relate to information and what they would find actionable was noted by several people. It was also suggested that the inclusion of more economists might allow for cost–benefit analyses of technology or technology–informed risk reduction systems and the ranking of options. Greater participation from Harbor Safety Committees and state agency representatives was recommended for future conversations. One workshop participant suggested including vessel owners, cargo owners, and vessel charterers, stating that vessel operators should not shoulder the full responsibility of vessel strike avoidance on their own.

11. Public Private Partnerships

Collaboration and partnerships were common themes when workshop participants were asked to identify what was needed from each sector to advance vessel strike risk reduction technology. Participants were asked to further consider and discuss how to build on collaboration developed at the workshop and to identify what types of partnerships would be most effective in compelling progress in applying technology to reduce NARW vessel strikes.

In general, workshop participants identified the public sector's role as setting performance metrics and protocols for the development and testing of vessel strike risk reduction technology. The public sector was also identified as being responsible for establishing methods to monitor the effectiveness of risk reduction strategies to reach defined goals. Participants emphasized the importance of having a clearly defined and streamlined path to technology approval to reduce uncertainty and provide an incentive for private sector investments in vessel strike risk reduction technology.

Workshop participants emphasized the importance of the private sector identifying those technology and vessel strike risk reduction strategies they consider most usable. Some stated that the private sector was best suited to provide vessel strike risk reduction technology tools in an effective, scalable, and commercially available manner. The private sector was encouraged to make technology open source where possible and appropriate, work to minimize costs to the end user, and openly share results and performance assessments. Comments also emphasized the importance of private sector adherence to rules and regulations and encouraged communication so that companies would get credit for actions taken for the conservation of marine mammals.

11.1 Collaboration and Co–Development

Workshop participants stated that all sectors need to continue to engage and work together for vessel strike risk reduction technology to be effectively and efficiently advanced. They cautioned that failure to engage in a constructive manner would result in delays and misalignment that could compromise the end goal. They emphasized the importance of establishing long–lasting communication and partnerships in which federal agencies clearly specify goals, private mariners and vessel operators describe areas where they are able and most likely to make changes, and technology developers ensure that developing products address these aspects. Participants warned that technology must be scalable and supported by coordination and collaboration if it is to be widely adopted. Workshop participants expressed a desire to maintain communication and connection among those who attended the workshop, to have regular meetings to collaborate on technology development, and emphasized the importance of doing so across the different sectors and entities to provide a forum for learning from each other.

Mechanisms suggested by workshop participants to foster collaboration and co–development include:

- Online Forum: One suggestion called on NOAA Fisheries to establish and maintain a live open–access database of inquiries, responses, and commentary for use by all collaborators associated with the workshop as well as referred colleagues and other interested parties.
- Workshops: Participants recommended additional workshops to facilitate discussion of current and emerging technology. Some suggested that future workshops be held in smaller groups and focus on testing, piloting, evaluating, and implementing technology. Another

suggestion was to hold a broader conference with sessions providing interested parties with a platform to make presentations, air views, and pose questions.

- Working Groups:
  - *Multiple Topic–Specific Working Groups:* Some participants recommended smaller working groups with more frequent interactions to focus on specific Risk Components, technology, and/or vessel sectors. They recommended that such working groups could continue connecting researchers, technology developers, users, and decision–makers. Recommendations for efficiency and flexibility included considering having them be organized by an entity other than the Federal Government and splitting them into commercial and recreational groups, or perhaps even into more specific user profiles.

  - *Vessel Strike Risk Reduction Technology Working Group:* Some participants recommended creating a standing technology working group that would meet regularly and include representatives from applicable agencies, industry (both vessel owner/operators and pilots (as applicable), technical experts (technology and vessel development), and scientists to identify feasible emerging technology and develop best practices.

- Advisory Committee: Some workshop participants recommended creating a more formal Advisory Committee.

11.2 Action Plan/Roadmap

Some workshop participants recommended developing a roadmap for the development and implementation of vessel strike risk reduction technology. Specifically, some workshop participants recommended that NOAA Fisheries commit to a timeframe to develop metrics to evaluate risk reduction technology and enforcement protocols, as well as a process that would provide opportunities for interested parties' involvement. Others recommended the development of a shared plan identifying a few priority items that the sectors agree to support.

11.3 Workshop Discussion on Collaboration

Bennett Brooks and Pat Field, both CBI, asked workshop participants to share their ideas of how to build on the collaboration at the workshop. Kyle Baker, BOEM, encouraged industry representatives to proactively reach out to government partners and to serve as partners in testing new vessel strike risk reduction technology. Matt Adams, MITRE, recommended additional task forces like the WAVS Taskforce, but focused on additional vessel groups. He further commented that having such groups organized by entities other than the Federal Government would likely provide additional flexibility. Jason Roberts, Duke University, stated that he had heard a preference for surgical dynamic measures over broad, static management. Given that, he offered support for mandatory dynamic management and recommended additional discussions with industry to inform and facilitate effective implementation of dynamic management. Other workshop participants stated that both static and dynamic management measures were necessary. Francine Kershaw, Natural Resources Defense Council (NRDC), cautioned that scientific rigor should not be sacrificed in the rush to develop, test, and deploy technology. One participant recommended using species other than NARWs as a proxy for testing technology. Greg Reilly, IFAW, supported the need for scientific rigor, but noted that the dissemination and communication piece is not complex and that action in this area is very important, as it makes all other technology solutions more valuable. He said that this is essentially leveraging existing technology and encouraged rapid implementation to make meaningful progress. Bettina Washington, Wampanoag Tribe of Gay Head (Aquinnah), reaffirmed the need to work fast to address this issue because of the urgent need to protect against the loss of the species. Jolie Harrison, NOAA Fisheries OPR, stated that she understood additional technology workshops were being held soon and asked about coordination between the efforts. Baker stated that the U.S. Department of Energy (DOE) was helping to plan a workshop focused on offshore wind construction and detection of whales, specifically at night or in conditions of poor visibility. Finally, Eric Patterson, NOAA Fisheries OPR, stated that there had been coordination between the planning teams, and specifically with Emily Shumchenia, RWSC, with the goal of ensuring the efforts were complementary rather than duplicative. He further stated that NOAA Fisheries was working with MITRE on how to evaluate the risk reduction achieved by various technologies.

11.4 Priority Actions to Foster Collaboration in Technology Development

Workshop participants were asked to recommend priority short–term (next 6 months to 1 year) and mid–term (beyond 1 year) actions to foster collaboration in technology development. The input received is summarized below.

Short–term priority actions to foster collaboration in technology development:

- Increased Communication: Workshop participants recommended continued and increased communication among federal agencies, researchers, modelers, technology developers, and vessel operators regarding outreach and current/emerging technology. Some recommended establishing a dedicated mechanism to facilitate that communication. Other recommendations were to: (1) connect specific people from the workshop and give them assignments and deadlines; (2) identify groups working on similar challenges or technology and foster collaboration between them; (3) identify and establish connections between individuals in various sectors (research organizations, Federal Government, industry) that should be partnered; (4) maintain pathways for ad hoc encounters across dissimilar disciplines to stimulate innovative, outside–the–box conversations; (5) issue a public request for information/ideas on a webpage and provide a dedicated email for submitting ideas; and (6) continue outreach to industry and the public to learn what vessel needs are, and how existing/mature technology might be able to address identified gaps.

- Action Plan/Roadmap: Some workshop participants recommended development of a short–term action plan with interim steps, while others recommended a more comprehensive roadmap for technology development that, for each of the technologies discussed at the workshop, describes its status and potential role in vessel strike risk reduction (e.g., what sectors it may match with, under what management scenarios it could be deployed). Others also suggested working on a regulation that would allow the use of technology proven to be effective in the future.

- Increased Funding: Workshop participants recommended increased funding be dedicated to testing new technology and specifically recommended seed grants to spark innovation and support development of technology with potential broad application and rapid results.

- Working Groups/Workshops/Meetings: In the short term, workshop participants recommended creating working groups to continue discussion between the sectors on key issues such as assessing the current state of how information is communicated to mariners. Others recommended creating a technical working group and convening it regularly to address specified tasks. Support was offered for an annual meeting of all the interested parties to keep the issue on the front burner.

- Continued Technology Assessment and Testing: Workshop participants recommended further documentation and assessment of vessel strike risk reduction technology and progress toward establishing performance metrics.

Mid–Term priority actions to foster collaboration for technology development:

- Technology Inventory: Some workshop participants recommended the development of a technology inventory to share and use as a common mechanism to communicate and track development progress. They recommended that the inventory create predictable technology maturation/readiness ladders with identification of the funding and steps necessary to move a technology up the readiness scale. They recommended continued robust testing of promising technology and scaling up production for those that are the most promising.

- Meetings/Working Groups/Workshops: More frequent meetings between technology developers, scientists, and end users was identified as a priority action in the next year and beyond. Participants had different ideas about the frequency of the meetings and the structure, but there was general support for gatherings to continue communicating what progress has been made on vessel strike risk reduction technology, discuss where future efforts should focus, and ensure people remain connected and communicative with each other. Some expressed support for smaller working groups to make more progress and others supported the inclusion of all sectors in future meetings.

- Incentives/Funding: Workshop participants stated that collaboration for technology development in the next year and beyond would be enhanced by providing funding, offering incentives for vessel operators to test new technology, and creating regulatory incentives for testing and adoption of new technology. Identifying ways to support conceptual technology ideas with minimal overhead and red tape was also identified as helpful in fostering collaboration.

12. Key Takeaways and Workshop Summary

12.1 Introduction

Following a detailed look at technology within and across Risk Chain Components, a session was held to discuss the development of action plans for the most promising technology. Goals for this session of the workshop included: (1) identifying common and compelling themes and takeaways from across all workshop sessions; (2) discussing the connections needed between Risk Components; (3) beginning to identify concrete next steps and strategies for moving forward; and (4) identifying the most critical data gaps. The input of workshop participants was obtained by convening a panel discussion (covered in Sections 12.4.1, 12.5.1, and 12.6.1), questions–and–answers from participants, online polling (N=171), and an online form (N=19). The panelists included:

- Kyle Baker, BOEM
- Kimberly Damon–Randall, NOAA Fisheries OPR
- John DePersenaire, WAVS Taskforce
- Clay Diamond, APA
- Candace Nachman, USCG
- Bryan Wood–Thomas, WSC

Prior to the panel discussion, Nachman addressed questions from the breakout sessions regarding the USCG's recent establishment (launched 2 weeks prior to the workshop) of a Cetacean Desk in the Pacific Northwest. Nachman explained that the 2022 USCG Appropriations Act directed the USCG to establish this Cetacean Desk specifically within the Puget Sound Vessel Traffic Service. She clarified that the purpose of the USCG Cetacean Desk was not to direct mariners to take certain actions, but instead to share information about the presence of whales with mariners so that they can make informed navigation decisions. Nachman stated that the USCG is not seeking to establish additional Cetacean Desks around the country.

Discussions and participant input submitted through the various means listed above is consolidated and summarized in this chapter. Modifications to the Risk Factor Graphic (Chapter 4) based on participant feedback are presented first. The next section contains identification of the most promising technology or approaches using input from online polls and the consolidated input from each Risk Reduction Chain Component breakout session. Then the connections or synergies across technologies and Risk Chain Components are summarized using input from an online form, the panelists, and again the consolidated breakout session summaries. Next, the section lays out compelling themes as informed by the panel discussion, questions asked of the panelists, and input from an online form. Following that is a summary regarding workshop participant input about barriers, data gaps, and critical next steps.

12.2 Modifications to the Risk Factor Graphic

The Risk Factor Graphic prepared by the workshop planning team and presented in Chapter 4 was modified in response to comments submitted (Figure 21). The following were added to the vessel–associated factors: (1) ability to integrate technology (i.e., compatibility with other onboard systems); (2) onboard power supply and connectivity; (3) vessel design (e.g., bow/hull shape, propeller design); (4) the field of view available for use in whale detection (e.g., deck height, obstructions); (5) subsurface and on–deck acoustic characteristics; and (6) consideration of the abundance/density of vessels in the area. A seventh suggested factor, type of activity or work being undertaken by the vessel, was not added as it is encompassed in the risk analysis element in the "Captains and Crew" component (i.e., the captain and crew would need to consider vessel work limitations as a component of their risk analysis).

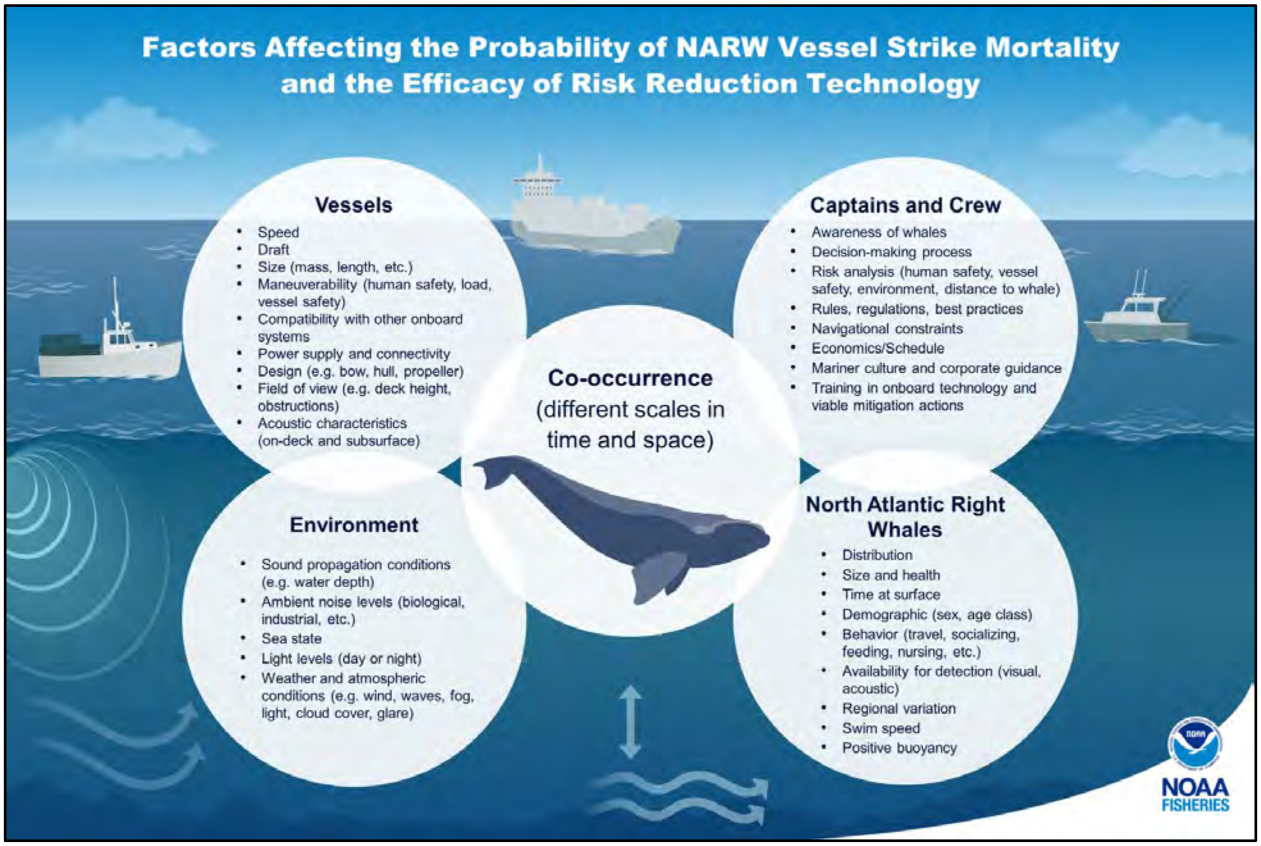

Figure 21. Risk Factor Graphic as modified based on 2024 NARW Vessel Strike Risk Reduction Technology Workshop participant input.

As recommended by workshop participants, the portion of the Risk Factor Graphic previously labeled as "Captains" has been expanded to be "Captains and Crew." In addition, the factor of whether the captain and crew have been trained in the use of onboard technology and viable mitigation actions has been added. Mariner culture and corporate guidance have been added given their ability to influence the decision–making of captains and crew. Crew size as it influences the ability to have a dedicated observer and crew experience in identifying/detecting whales were not added as additional separate elements as they are secondary factors that affect the primary factor of "Awareness of whales."

Another suggested factor—the depth of water on or adjacent to the vessel route—was not added as a separate element in the environmental–associated factors as it is encompassed in the draft of the vessel (in the vessel component) and the risk analysis (in the "Captains and Crew" component). As an example, a mariner piloting a container ship may need to remain in a dredged designated navigation channel due to insufficient water depths to allow changing route as a possible risk avoidance action. As recommended by a workshop participant, regional variation has been added in the NARW–associated factors given the impact of regional variation in time at surface, vocalization, and other behaviors on a whale's availability to be detected. The size and placement of ports and wharves was not added as a separate factor to the Risk Factor Graphic because it is a secondary factor that influences the density of vessels, which is already considered in the vessel component.

12.3 Most Promising Technology or Approaches

12.3.1 Online Poll

An online poll offered workshop participants the opportunity to again identify the three most promising technologies or approaches at the end of Day 2. The three technologies or approaches identified most frequently by those who filled out the poll (N=118, providing 278 individual entries) were thermal/IR cameras (N=39), dissemination/communication (N=38), and PAM (N=25), with a large variety of individual entries contributing to the other category (N=38; Table 9).

Table 9. Most promising technology or approaches as identified by participants on Day 2 of the 2024 NARW Vessel Strike Risk Reduction Technology Workshop.

Category	Number of Responses	Selected Text (from responses)
Thermal/IR	39	• Thermal cameras integrated with maps for vessels for situational awareness • IR detection to alert mariners of whale presence • IR cameras are exciting but have some limitations
Dissemination/ Communication	38	• Disseminating information to vessels 35–65 ft • Information push out to vessels • Communication between vessels • Cohesive and concise dissemination of the right information to the right people • Most other technology will do little to reduce risk unless information is disseminated efficiently to mariners • Use Alaska Exchange as example for commercial vessels and private tech companies for recreational vessels • Real–time information dissemination • More timely, simplified and consistent messaging • GPS polygons on charts in near–real–time
Other	38	• Seafarer lookout training • Private technology for small vessels (e.g., portable position units) • Marine electronics • Needs assessment with mariners • Improved camera technology • Clearinghouse for resources on the issue • Strong enforcement technology • Incentives for compliance with existing measures • Drone surveying • Acoustic deterrent devices
PAM	25	• Acoustic arrays • Fine–tuning PAM to include better localization tools • Real–time PAM

Category	Number of Responses	Selected Text (from responses)
AIS	22	• AIS dissemination • AIS for all • AIS to disseminate whatever data is decided upon by the group (are you disseminating individual detections or DMAs?) • AIS two–way communication • Only use AIS for safety • Mariner alerts to AIS
Outreach/ Education/ Partnerships	19	• Consistent, helpful information to mariners • Increase awareness • Target sport and leisure class vessels at boat ramps, tackle shops and marine stores • Use existing technology for education (e.g., weather apps as every mariner checks the weather) • WAVS Taskforce • Academic/NGO/Industry collaboration
Data Aggregation	18	• Singular platform that aggregates data to be disseminated to multiple platforms • Aggregation of different technology into a single data source • Whale Alert • Whale Map • Smartphone app for recreational boaters and anglers • Necessity for government involvement in aggregation and dissemination
Modeling	13	• Risk Assessment Models • Predictive modeling to establish slow zones • Forecasting for management • Behavioral models such as WhaleSafe
Combinations	12	• Combined PAM, visual observers and thermal cameras • Multiple sensors with data fusion • Technology that can be layered with speed restrictions to provide additional NARW and mariner safety • An integrated multi–modality system backed by coupled ocean acoustic modeling
Detection	6	• General detection of obstacles • Increased efforts and other improvements in detection of whales as a basis for near–real–time alerts • Onboard detection technology
Standards/ Protocols	6	• Specific performance standards tailored to the risk profiles and operational constraints of each vessel type and industry • Performance–based standards and process for technology to be accepted • Platform–agnostic approach that communicates performance standards of each technology and risk thresholds that are necessary to achieve sufficient mitigation
Visual	6	• Visual observations (PSOs) • Tools that are currently working and effective at detecting/observing NARWs (e.g., visual observations)

Category	Number of Responses	Selected Text (from responses)
Speed	5	● Slow Zones/DMAs ● Static slow downs
Data	4	● Cloud data access ● Working to make ways of sharing data interoperable ● Large data sharing and model building
Satellite	4	● We can make progress on using this technology in the near term (i.e., in months not years)
Sonar	4	● Forward looking sonar
Tagging	4	● Better tag technology
AI/ML	4	● AI processed multi–sensor detection capabilities ● AI supported visual detection
Research and Monitoring	4	● More monitoring using established methods ● Investigating necropsy data to understand lethal strike and cause
Leverage existing technology	4	● Put the technology available in practice in the coming months ● Accept current technological limitations and act on an emergency basis
Dynamic	3	● Rapid, efficient development and dissemination of dynamic management areas

12.3.2 Breakout Session Input Summaries

As noted previously (section 2.3), all workshop participants had the opportunity to participate in the session focused on the detection and classification Risk Chain Component. They then either chose or were assigned to participate in one of the workshop sessions focused on the other Risk Chain Components (i.e., modeling/forecasting, aggregation, dissemination and integration, or other technology). Recognizing that many participants had expertise and/or interest in more than one of these sessions, report outs from each breakout were provided in plenary to provide an opportunity for input and discussion. In addition, following the workshop the tables produced during each of the Risk Component workshop sessions were provided to workshop participants in an online form to allow another opportunity to provide feedback and comments.

The lists below, by Risk Chain Component, capture the technology, methods, and actions most frequently identified by workshop participants across multiple avenues for providing input. This is a summary of the information presented in Chapters 5, 6, 7, 8 and 9, which should be consulted for additional detail.

12.3.2.1 Detection and Classification

- Current operational methods including visual surveys (aerial and vessel–based) and PAM are playing a critical role in vessel strike risk reduction and monitoring the status of NARWs.
- Investment should continue to advance the TRL of promising technology including satellite imagery, thermal/IR, eDNA, tagging, DMS, and the enhanced use of AI/ML to process large quantities of images and data quickly and accurately.
- Combinations of technologies are most promising and should be explored and evaluated.

- Performance standards for detection technology (and combinations of technology) should be established to provide consistency and a target for technology developers.
- Detection and classification technology and approaches need to be matched with and tailored to the unique challenges of vessel types/operational modes.
- While tagging appears to be an attractive technology, it poses many challenges that suggest it is a valuable but limited tool to reduce vessel strike risk.

12.3.2.2 Modeling/Forecasting

- Additional collaboration among modelers is encouraged, as well as providing opportunities for interested parties' engagement to increase transparency on model assumptions, discuss the handling of uncertainty, and help identify model outputs that are useful and actionable.
- Data availability, quality, quantity, and transparency should be improved, and additional opportunities should be provided for interested parties to contribute data to inform models.
- The following priorities for model development/refinement were identified: (1) develop formats for daily or other near–real–time predictive outputs; (2) use models to evaluate the risk reduction potential of technologies; and (3) incorporate covariates or other inputs to make models more responsive to long–term ecological and climatological shifts.

12.3.2.3 Aggregating/Assembling

- Aggregation platforms exist and technology is not the largest barrier in this Risk Chain Component.
- A framework or flow chart of users (managers, enforcers, large shipping, recreational vessels, commercial fishing, etc.), intent (regulatory/compliance, voluntary), and purpose (on–water evasion, planning, research, modeling, etc.) should be developed to place aggregation platforms and efforts in context.
- Vessel–use profiles should be developed to improve understanding of the diversity of aggregation platform end users and what they need, can use, and how they will act with the information provided.
- Existing platforms need to be better customized for specific users and uses (with emphasis on intuitive and customizable user interfaces); investment in human connections, partnerships, and relationships must continue for these platforms to be effective. Consideration should be given to providing more context or otherwise assisting users in interpreting the information provided.

12.3.2.4 Dissemination and Integration

- Use case/operational profiles must be developed to inform dissemination and integration efforts by identifying what information needs to be provided to whom, in what way, and in what timeframe to influence vessel operations such that the risk of a whale strike is reduced.
- Matching vessel operational profiles with the types of decisions they are making should come before any discussion on means to disseminate information to specific vessels. A greater focus on actionability and improving our understanding of what vessels can actually do once they receive information was recommended to narrow down what information is worthwhile to send to specific vessels.
- Once vessel–use profiles are developed, then existing dissemination and integration technology and methods should be matched to user needs to identify untapped potential and critical gaps.
- For commercial vessels and those using AIS, the focus should be on better integration and utilization of existing tools to maximize the benefit of AIS.

- For recreational vessels, it was recommended that NOAA Fisheries first establish a standard of information to be provided; once done, industry can then develop appropriate delivery and integration tools.

12.3.2.5 Other Technology

- Additional research should be conducted to improve our understanding of how NARWs perceive and react to vessel traffic.
- Research should be conducted and existing data should be mined to improve our understanding of the factors that influence the lethality of vessel strikes, including maximizing the data obtained from necropsies and strike events (e.g., whale orientation during strike, nature of injuries, involving what portions of the vessel (hull, rudders, propellers, etc.)).
- A variety of possible modeling efforts were identified including modeling how strikes occur and investigating what actions vessels can take and at what distances to effectively avoid strikes.
- Virtual reality training for captains with scenarios involving whale avoidance and detection and the integration of whale alertness into mariner training courses and exams should be explored.
- Data analysis and modeling to identify the most salient operator measures to avoid vessel strikes and allow for targeted compliance should also be pursued.

12.4 Connections or Synergies Across Technologies or Risk Chain Components

12.4.1 Panelists

Panelists and workshop participants were asked to identify connections or synergies across technologies or Risk Chain Components. Pat Field, CBI facilitator, shared that he was hearing vessel and mariner safety as a strong and common interest as well as protecting whales. Damon–Randall stated the most important outcome was to continue the conversation, and she emphasized the importance of understanding each sector's interests and priorities (a process that began at the workshop). Diamond recommended creation of a formal advisory committee to include representatives from industry to provide recommendations to NOAA Fisheries on protective measures for NARWs. DePersenaire stated he was pleased at how his industry had become constructively engaged in this issue in a relatively short period of time, and he emphasized the importance of reaching out to his sector to create partnerships to build on the enthusiasm at the workshop.

12.4.2 Online Form

Workshop participants were provided with an online form, which included the opportunity to identify connections or synergies across technologies or Risk Chain Components (N=19). Participants noted that all Components are strongly reliant on the others and are therefore not effective in isolation. Others noted that there is no one technology that is the answer to this complex problem and that a combination of technology will work best as all technologies have their challenges. The technologies that would work best together are those that fill in the gaps where others are lacking. Another participant noted that each technology has individual costs and benefits and that synergies have not yet been established.

Several participants emphasized the tight connection that must exist between technology for detection and data dissemination. Another commented that AIS and notices to mariners have real potential for dissemination if whale detection methods improve. That individual encouraged acknowledgement and acceptance of the reality that individual whale detection will likely not be possible across the full range of NARW and vessel co–occurrence, at least for a long time, so larger SMAs may be necessary.

Another workshop participant recommended improved communication with maritime industries and recreational boaters who have expressed an interest in supporting vessel speed limits. They stated that many NGOs have been working with allies in these sectors on other issues of mutual concern and these synergies need to be encouraged. They further suggested that NGOs such as the IMO and IWC that work on ocean noise both in the U.S. and internationally can bring extensive expertise to this issue.

12.4.3 Workshop Discussion and Outputs

Workshop participants identified a sequence of cross–cutting actions to establish a foundation and framework for advancing vessel strike risk reduction technology. Specifically, they recommended creating vessel–use profiles and technology descriptions, each of which describe key characteristics and constraints, as a necessary first step before technologies can be appropriately matched with end users to create effective risk reduction strategies. The establishment of clear goalposts was also emphasized so that informed and strategic decisions can be made about technology investments and advancements. While it was encouraging that technology is already being applied in several ways to reduce vessel strike risk, it was clear that significant time and funding is required to move a technology from conceptual through to an operational state. The recognition that combinations of technology are most promising also highlights the challenge of evaluating the risk reduction achieved through the implementation of systems composed of multiple technologies within and across Risk Chain Components.

12.5 Compelling Themes

Some may have hoped or expected to walk away from a NARW Vessel Strike Risk Reduction Technology Workshop with a list of priority technologies to target for research and development. As was made clear during the workshop, the situation is more complicated, and promising technologies depend on the circumstances of their application. The most promising technology or system of technologies will depend on the specifics of the vessel, environment where it is being deployed, likely behavior of whales in the area, and ultimately, application by the user. In this context, application includes both the use of appropriate technologies and the willingness to use the information generated to take action(s) to reduce vessel strike risk. Given the circumstance–specific nature of identifying the most promising technology, a generic list is of little value. Instead, the following common themes and recommended actions based on workshop participant feedback were identified across multiple Risk Chain Components that, if addressed, would significantly contribute to successful vessel strike risk reduction technology.

12.5.1 Panel Discussion

Each of the panelists were asked to identify common and compelling themes that resonated with them from their participation in the workshop.

Damon–Randall identified the common message that vessel strike risk reduction is going to require the use of multiple technologies and time to fully develop and test integrated systems. She said she heard a desire for creation of a framework that could be used to prioritize investments in technology. Damon–Randall also identified improved communication and outreach to mariners, including regarding data on whale presence as a compelling message. Finally, she identified the theme of the potential for improved public and private partnerships to act as force multipliers.

Wood–Thomas said he was encouraged by the discussions at the workshop and recommended continued informal collaboration across sectors moving forward. In the near term, he stated he would like to see the USCG, NOAA, and TC work together to develop a common digital platform for communication with mariners. He stated that if the USCG, NOAA, and TC could identify the most appropriate platform to get information out in a timely and efficient way, that could be standardized and normalized. Wood–Thomas commented that reducing the risk of vessel strikes to marine mammals is a serious challenge across the globe and offered that he hoped the benefits of the actions being taken in North America would be transferred to help with issues elsewhere.

Baker identified three themes across the workshop. First, he shared that he heard the desire to incentivize partnerships in helping to develop technology to reduce vessel strike risk and to use existing technology and systems more efficiently and effectively. Secondly, he said he heard support for centralizing and optimizing the data stream so that whale data can be aggregated and disseminated quickly and provided in a common format that is packaged efficiently and effectively. Baker specifically mentioned considering whether more can be done dynamically and cited examples of daily updates which could include predictive models based on the previous day's sightings. Finally, he acknowledged that no one agency or industry can take on this challenge alone and identified the need to work together to combine funding, develop incentives, and advance the most promising technology.

Nachman offered support for the themes Baker identified and further stated that she heard a lot about making sure the right information reaches the right people at the right time. She suggested one of the homework assignments from the workshop could be to develop a matrix identifying the needs by vessel type and the capabilities that are available to match those needs. Nachman identified the need to expand education and outreach efforts to reach both operational mariners as well as those they report to within their agency or company, if anyone. She recommended a focus in the near term on tools that could be used to reduce vessel strike risk. Finally, she noted that a variety of definitions were used for "near–real–time" over the course of the workshop and suggested it be standardized.

Diamond stated he found the workshop useful and productive and that it increased his awareness of technology available to locate and track whales. He stated that the real challenge was to disseminate information to a wide range of parties and to better utilize the existing technology to protect NARWs. He reflected upon his experience in rulemaking while an officer/attorney in the USCG and said that the challenges of rulemaking were very apparent at the workshop, noting that all representatives have very real and valid concerns about how NARWs are protected. Diamond referenced the Founding Fathers by saying that you can be totally free or totally safe (i.e., you could make those worried about safe vessel operations totally free by removing all restrictions or you could make the whales totally safe by prohibiting all kinds of human behavior). He said you cannot be both totally free and totally safe and noted the challenge with rulemaking is coming to an equitable balance. He offered that the workshop was helping to meet the challenge of looking at what is required in the MMPA and ESA and balancing all the interests, including vessel navigation safety and safety of life at sea, to come up with an equitable approach.

DePersenaire stated that he had made several valuable connections at the workshop and shared that his biggest takeaway was that it all comes back to safety. He said the marine industry has a lot of experience in avoiding objects in the water; hence this effort is not starting from zero. DePersenaire observed that there was a great deal of untapped resources with the various vessel sectors represented at the workshop from the standpoint of data collection, communication, relaying information across the fleet, and technology testing. He encouraged more effort to bring vessels on the water into the discussions and work related to whale detections. DePersenaire identified the need for a formal structure for routine engagement like that which occurred at the workshop and suggested that could occur perhaps through the NARW Recovery Plan Northeast Implementation Team. He recommended directing resources to the private sector to spark rapid progress on technology development, testing, and deployment.

12.5.1.1 Questions for the Panelists

Esteban Rodofili, Knauss Fellow, observed that much of the risk reduction technology being discussed is not feasible in the short term, questioned whether there was sufficient time to advance the technology recognizing the emergency situation of NARWs, and asked panel members what urgent actions they plan to take for their sector. Baker stated that there have been no known NARW vessel strike incidences with offshore wind. He identified the following ongoing mandatory requirements affecting offshore wind: (1) slow zones; (2) PAM; and (3) PSOs on every vessel. Damon–Randall stated that NOAA Fisheries shares the strong sense of urgency expressed by Rodofili. She referenced the Road to Recovery as the agency's holistic strategy[29]. DePersenaire stated the following actions could be taken immediately: (1) outreach; (2) a decision by NOAA Fisheries regarding what data needs to be distributed to mariners; and (3) leveraging the expertise of the private sector to accelerate progress.

Mike Waine, American Sportfishing Association, asked Damon–Randall to provide a bit more context by addressing how what was discussed at the workshop fits into the NARW Road to Recovery and to identify differences. Damon–Randall responded that one of the three priorities in the NARW Road to Recovery is addressing vessel strikes. Regarding what was new from the workshop and not explicitly reflected in the Road to Recovery, she identified the recommended focus on communication and dissemination of data and greater emphasis on outreach and engagement. Baker recognized the challenge of getting the public to care about NARWs and other ocean animals compared to more accessible terrestrial animals. In terms of what more can be added to the current effort, he recommended more funding, more partnerships, and more workshops (noting those were only possible with associated funding).

Desray Reeb, BOEM, built on the comments by Waine and Baker and recognized the challenge of engaging people when we want and need them to care about an issue. She noted that the social science aspect of this challenge had been raised multiple times during the workshop. Reeb stated that technology needs to be implemented by people, and a greater understanding of how people need to receive information as well as what information and concerns are meaningful to them is necessary before they can be expected to support or trust any technological solutions. She recognized the need for progress on the social science side to be successful with vessel strike risk reduction technology. Secondly, Reeb addressed the issue of barriers and asked that members of the panel and others consider opportunities to accelerate authorizations and permits (e.g., fast pass for NARW vessel strike risk reduction technology approval for field validation/testing or implementation, as appropriate).

12.5.2 Workshop Participant Discussion and Input

Throughout the workshop, participants shared input and engaged in discussion via verbal means, online polls, online forms, and question–and–answer feeds. Using input collected across both days of the workshop, several compelling and consistent themes emerged.

Broaden the Use of Modeling

[29] NOAA Fisheries. 2024. North Atlantic Right Whale: Road to Recovery. [Available at https://www.fisheries.noaa.gov/species/north-atlantic-right-whale/road-recovery]

The workshop session on modeling and forecasting focused primarily on models for NARW distribution, with some consideration of modeling vessel distribution and co–occurrence. Broader and more diverse modeling applications were identified across Risk Components including the following potential modeling applications: (1) virtual testing of the efficacy of new technology and combinations of technology; (2) exploring options for optimizing technology deployment options; (3) agent models and simulations to better understand viable evasive options by vessel profile; and (4) simulations for training mariners on whale awareness and avoidance. These recommended applications of modeling appear to reflect the urgency in making progress on this issue while acknowledging data limitations and practical limitations on experiments.

Establish Performance Standards, Testing Protocols, and Risk Reduction Targets
Within each Risk Reduction Chain Component, the need for performance standards or metrics was repeatedly noted. When viewed within a specific Risk Reduction Chain Component, the metric is narrow and evaluates how effective a particular piece of technology is at detecting whales, aggregating detections, or disseminating and integrating them into a chart plotter. Ultimately, vessel strike risk reduction is only achieved if technology and methods are effective within each link in the Chain, but also across the entire Risk Reduction Chain.

Develop a Technology Inventory and Vessel–Use Profiles ("One size does not fit all")
Identifying the most appropriate technology or methods within each and across Risk Reduction Chain Components requires a baseline assessment of available/developing technology and of vessel characteristics and operational modes so that appropriate matches can be made. For detection and classification technology, the inventory should include such things as reliable detection range, intrinsic factors affecting performance, extrinsic factors affecting performance (from both the environment and the whale), and TRL (with an estimated cost and time to advance through the remaining steps). Vessel–use profiles should also be developed to describe such things as the characteristics of the vessels themselves (draft, speed, maneuverability), areas, times, methods of operation, and communication capabilities. Vessel–use profiles will help identify the right information to provide to whom, when, and how. When baseline inventories have been completed for each of the Risk Chain Components, then the focus should shift to matching technology to vessel profiles. Essentially this is reverse engineering by looking at what vessel operation behavior would reduce vessel strike risk and building the chain of events necessary to trigger the desired vessel behavior. Completing this exercise would inform future investment of resources in technology development, with a focus on those that are best suited to vessel use categories and perhaps at a higher TRL (prototype validation, system integration, or operational).

Integrate Multiple Technologies/Tools
The presentations on technology to reduce vessel strike risk and the feedback provided by vessel operators throughout the workshop reinforced the point that there is no one tool or set of tools that will reduce vessel strike risk. It was apparent from the information presented and the discussions that different vessel types and use cases will require different methods of communication and different whale detection methods for effective vessel strike risk reduction. The characteristics of vessel operations also influenced the acceptability of different Application Scenarios. Representatives of the commercial shipping sector spoke in favor of long–term planning whereas representatives of the recreational

sector expressed a preference for dynamic measures suitable to their highly maneuverable vessels.

A combination of technologies within Risk Components (e.g., visual and acoustic methods to detect whales) and across Risk Components—as well as the integration of these tools into a functioning system—was identified as necessary. Participants emphasized the importance of recognizing that there is no single solution to the problem, and it would be necessary to pursue multiple technologies and combinations of technologies and to match those with specific geographies, vessel types, and operational modes.

Funding
The critical importance of funding to support technology innovation, testing, and evaluation was emphasized throughout the workshop. Some argued that getting funds to the private sector was the most effective way to make progress quickly. Support was voiced for investing in partnerships of many combinations including between government and the private sector, between whale researchers and vessel operators, and between whale researchers and technology developers. The lack of a unified framework for prioritizing investments was identified as a barrier to efficiency. Sustaining existing tools and platforms with on–going funding was also noted. Funding future workshops was also recommended to maintain momentum, share information, and support collaboration.

Time
Some workshop participants expressed an urgency in reducing vessel strike risk given the status of NARWs. Others, while recognizing the dire situation for NARWs, tempered expectations and stated that it would take time to test and evaluate technology and suites of technology and to gain approval for their use. They encouraged greater transparency regarding the limitations, constraints, and readiness of various technologies. Similarly, some noted that developing and testing combinations of technologies integrated into risk reduction systems was complicated. The evaluation of such systems under a variety of environmental and operational conditions would take time. Vessel operators and industry representatives advocated for clear action soon to maintain momentum and the desire stated at the workshop to work collaboratively to reduce vessel strike risk. The point was made that this spirit of cooperation and goodwill may be fleeting and should be built upon so as not to miss opportunities.

Unite Around Common Interests
Some workshop participants advocated for considering NARW vessel strikes under the broader category of safety. They stated that mariners were very accustomed to dealing with navigational hazards from how vessels are designed to how they are operated. They recommended tapping into the extensive experience and expertise of the maritime industry in anticipating and preparing for the presence of objects in the water. Some cautioned that the behavioral characteristics of whales are unique, and therefore distinguish them from other, more fixed navigational hazards.

Concern over the status of NARWs was also a common theme at the workshop. It was stated that no one, regardless of their sector or expertise, wants vessels to strike NARWs, or any marine mammal. Keeping that common goal in mind may help focus the diverse interests on collaborating to identify technological tools for reducing vessel strike risk.

Centering on the Human Component

Across Risk Reduction Chain Components, the need to engage social science experts and take the time to understand the factors motivating human behavior was emphasized. The Risk Reduction Chain ends with a human deciding whether to take an action and what action to take. The risk of a vessel strike is only reduced if timely and effective action is taken. Given that, workshop participants placed a priority on obtaining an improved understanding of what information mariners consider actionable and what action they intend to take upon receipt of that information (whether provided from detection and classification technology, modeling efforts, an aggregation platform, or disseminated and integrated into their chart plotter).

Improve Communication with Mariners

The need for efficient and effective communication was a repeated theme in the workshop. Participants advocated for a social science study to interview a diversity of vessel operators to identify what information they need, when, how they want to receive it, and what actions they will take when they receive it. This information could then be used to match information and delivery systems appropriately to vessel operators. It was suggested that those in leadership positions in maritime companies be engaged and encouraged to adopt measures to reduce NARW vessel strike risk as part of their company culture. Others advocated for developing a matrix to match communication methods with vessel capabilities.

Another noted priority centered on seeing NOAA Fisheries, USCG, and TC agree on a common platform to communicate with mariners. Some argued that a disproportionately low amount of funding dedicated to outreach and communication, and more resources should be directed toward continuing conversations with interested parties given the necessity of this step in reducing vessel strike risk. In general, participants advocated for optimization of communication through centralizing data streams and making information flow faster and more efficiently and dynamically.

Public/Private Partnerships

In general, workshop participants spoke about the benefit of bringing together different perspectives and working together for collaborative risk reduction measures. One workshop participant stated that the most compelling theme was the need for scientists, managers, and interested parties to work together to address the complex problem of NARW vessel strikes, considering the need for vessel safety and vessel strike reduction. Another acknowledged that all sectors have very real and valid concerns and identified the challenge as finding an equitable balance. The ability of the private sector to accelerate progress and the overall effect of partnerships in serving as force multipliers was acknowledged.

Differing views were expressed on the value of formal or informal structures and processes for partnerships and collaboration. Some appeared to advocate for a government–led coalition while others acknowledged that privately formed coalitions could be more nimble and flexible.

Identified benefits of partnerships with vessel operators included additional sources of data collection; enhanced communication achieved by their ability to relay information among the fleet; and additional platforms for testing technology in real world rather than academic scenarios, particularly for detection technology. Participants suggested investigating ways to incentivize the participation of vessel operators and industry representatives, including looking at programs on the U.S. West Coast.

12.6 Barriers or Data Gaps

12.6.1 Panelists

The panelists were also provided with the opportunity to identify critical barriers or data gaps important to address in the next few years to advance vessel strike risk reduction technology.

Baker stated that the development of communication and technological standards should be a priority action. Diamond stated he thought the biggest barrier is the human element, more so than technology. He stated that the mariners he encounters feel targeted, and the relationship with NOAA Fisheries feels adversarial. Diamond advocated turning the temperature down and placing the emphasis on safety more than enforcement. He referenced the role and official responsibility of pilots to protect the safety of navigation and the marine environment as being very consistent with the goal of vessel strike risk reduction. Damon–Randall stated she hoped the workshop was a positive step towards repairing the relationship between mariners and regulators and noted that the adversarial nature does not benefit NARWs. She welcomed continued open and honest communication.

Nachman emphasized the important connections between the various Risk Chain Components (e.g., detection and dissemination). She noted the importance of providing information to mariners in a succinct way and recognized the national relevance of the vessel strike risk reduction issue and encouraged thinking about national tools that could be implemented with regional specificity.

12.6.2 Workshop Participant Discussion and Input

Barriers and data gaps were identified by workshop participants in discussions and through input provided in online polls, online forms, and question–and–answer feeds. The barriers and data gaps that were most frequently pointed out included the following:

Development of Standards/Performance Metrics
Participants identified the critical importance of developing standards and performance metrics for technology. Some spoke about the need to articulate how success would be measured to ensure transparency. They stated that technology development will come from the commercial sector, but that they need to drive towards a standard. Some argued for a consistent framework for evaluating and comparing detection technologies against each other, which should include such things as reliable detection range, probability of detection, cost, and false positives/false negatives, amongst other metrics. Others stated that the MMPA provided a clear performance metric in terms of the PBR, which, in the case of NARWs, is 0.7.

Humans are the Barrier More Than Technology
Workshop participants acknowledged that effective risk reduction strategies will require technological tools as well as changes in human behavior. They argued that technology needs to focus more on changing human behavior than perfectly predicting and detecting animal behavior. Changing human behavior is frequently met with resistance, can be challenging, is usually iterative, and takes time. Both government and vessel operator representatives spoke of the need to move from an adversarial to a cooperative relationship and expressed hope that the workshop would be seen as a step in repairing that relationship. Vessel operators and industry representatives stated that most risk reduction

technology will require the active input and participation of professional mariners to develop and refine, which reinforces the importance of establishing a working relationship with government. Some participants identified the need for realistic expectations when it comes to the ability to prescribe technology risk reduction strategies and cautioned that they will take time and funding to develop, and in the meantime, the tools available are speed and area restrictions.

Need for Common Terminology and Definitions
Participants recommended developing common terminology and definitions for such things as real–time and near–real–time. Clearly and consistently defining such terms can improve communication, facilitate comparison across technologies, and reduce misunderstandings. One participant cautioned against conflating concepts that are not equivalent. For example, compliance does not equal conservation, notification of whales does not equal avoidance by a vessel, and deterrents do not equal avoidance behavior by whales.

Dealing with Uncertainty
The inherent limitations of detection technology and the effect of whale behavior on the effectiveness of that technology (i.e., availability and detectability biases) were acknowledged by participants. One participant identified whale detection as the greatest barrier and stated that given that the PBR for NARWs is 0.7, whatever risk reduction strategies are devised need to bear in mind that only working some of the time is likely not sufficient. It was noted that vessel operators will continue to deal with uncertainty in the locations of whales in time and space. Given the difficulties in predicting NARW distribution, one participant identified one of the greatest barriers as figuring out how to get available information out to vessels fast enough to avoid vessel strikes.

Data Sharing
Progress in the near term to improve awareness of and access to data was identified as a priority to increase opportunities for more people to contribute to analysis and modeling using that data.

Ability to Predict Changes in Vessel Strike Risk
The ability to predict how navigational patterns and NARW distribution are likely to change in response to market forces, industry changes, and a changing environment was identified as important to explore in the coming years. Specifically, understanding the intersection of these changes with vessel strike risk and the effectiveness of existing risk reduction approaches was highlighted. Participants also supported expanding risk models to include whale demographics and behavior, not just presence or absence of whales.

12.7 Critical Next Steps

Workshop participants provided input on what they think are the most critical next steps to advance vessel strike risk reduction technology. Input provided by participants through workshop discussion, online polls, online forms, and question–and answer–feeds generated the following list of recommended next steps.

Conduct a Technology Review
A comprehensive realistic review of available and emerging technology was recommended including the identification of capabilities, limitations, readiness, likely use, and time and funding to full development. The importance of understanding the range and reliability of whale detection systems was identified as critical. It was suggested that the review be comprehensive and consider a wide range of technologies but exclude those that are not

feasible or do not have evidence of likely success. The comprehensive review should match technology to different geographies, vessel types, operational modes, and other relevant contexts. Combinations of complementary technologies within Risk Components as well as systems across all Risk Components should be described and evaluated, where possible. The next critical steps are to put together a toolbox of existing technologies and how they work together.

Establish and Communicate Performance Metrics
The establishment of standards and testing protocols using a rigorous scientific methodology was identified as essential to be able to evaluate any one technology and to compare across technologies. Participants emphasized the importance of establishing methods for how the effectiveness of vessel strike risk reduction technology systems will be evaluated and what target they will be compared against. Participants noted the need for a clear process of how NOAA Fisheries will pilot the use of experimental technology, how data will be collected and analyzed, an estimated timeline from testing to commercial use, and specification of risk reduction measures to be employed in the interim. As was apparent during exchanges at the workshop on this issue, establishing performance metrics is challenging given that the goal is to eliminate NARW vessel strikes. Participants pointed out that while the overall amount of risk reduction that is needed may seem very straightforward, there needs to be a strategy for how to achieve it with evaluation and adjustments built in. They also suggested that the establishment of milestone targets that track meaningful progress towards the goal within and across Risk Components would provide a common roadmap.

Create Vessel Profiles
Participants recommended outlining the different vessel types and use categories and their different requirements and capacity for notification as well as constraints and limitations for reaction (and associated reaction time) as a critical step to understanding what is feasible for each vessel category. Specifics on when, where, and how the vessels operate may help make appropriate connections to viable and appropriate technology for vessel strike risk reduction.

Map the Technology to the Vessel Profiles and Geographic Locations
The comprehensive technology review mentioned above should match technology to different geographies (including priority locations), vessel types, operational modes, and other relevant contexts. This mapping exercise will likely identify whether Static, Dynamic, or Vessel–Specific approaches are most appropriate. Participants also identified the need to include monitoring to verify compliance with the use of the technology and its ongoing effectiveness against the performance standards.

Frame Effort Around Safety
It was recommended that there be consideration of including NARW vessel strike risk reduction in the broader context of navigational safety and hazard avoidance, including identification of the implications of such a framing and the appropriate entities to be involved. Participants recommended expanding awareness of this issue by updating captain and mariner safety trainings to include whale alertness, detection, and strike avoidance.

Investigate How to Incentivize Involvement in Technology Innovation, Development, and Testing
It was recommended that voluntary vessel strike risk reduction programs on the West Coast and elsewhere be investigated to see if there are lessons learned, in terms of

incentivizing cooperation, that could be applied to the NARW vessel strike risk reduction issue. Similarly, it was suggested that a broad review of federal agency authorities and programs be conducted to identify opportunities to incentivize industry cooperation and involvement in vessel strike risk reduction technology advancement. A focus on developing ways to streamline permitting and approval to test technology was recommended (i.e., a fast pass for technology testing). Participants noted that vessel strike risk cannot be reduced without vessel operators changing their behavior, so more effort should be spent on incentivizing mariner behaviors, whether through regulations, enforcement, corporate, societal responsibility, or financial incentives (e.g., more carrots and less sticks).

Funding
Identifying sources of reliable and continuous funding was identified as a key next step priority as well as prioritizing the use of that funding to support the full development cycle of the most promising technology. The funding should be linked to the comprehensive technology review and the vessel–use profiles to match technology to use and to have a full lifecycle plan.

Invest in Outreach and Dissemination
Participants recommended increased investment in outreach and tools/methods to disseminate information to mariners. Specifically, conducting baseline social science research to understand what information mariners need, how they want to receive it, and what action they will take considering the information was recommended. This would allow the appropriate information, timing, and method of deployment to be matched to specific vessel sectors and operational modes to achieve a reduction in vessel strike risk.

Continue to Engage this Broader Community
Participants identified the importance of building off the momentum of the workshop and keeping the discussion active among vessel operators, technology developers, vessel operators and industry representatives, marine mammal biologists and conservationists, and government agencies. Specific recommendations for how to accomplish that ranged from establishing working groups to holding webinars and additional workshops. Some suggested tiering off and holding vessel sector specific workshops where technology could be more suited to specific circumstances, and others recommended annual or biennial workshops focused on vessel strike risk reduction technology more broadly. Representatives of technology companies participating in the workshop encouraged engaging with them to consider whether the existing technologies can be tweaked or scaled rather than starting from scratch.

12.8 Closing

There was a high level of interest in the 2024 NARW Vessel Strike Risk Reduction Technology Workshop and positive and constructive attitudes expressed from workshop participants. Continuing to keep all sectors—Government, Technology Developers/Manufacturers/Inventors, Vessel Operators and Industry Representatives, External Scientists, and NGOs—engaged is critical to success and will require dedicated attention. The workshop provides a solid foundation upon which to build more specific and focused effort into understanding vessel uses and the appropriate technology and combinations of technology to identify risk reduction pathways most worthy of investment of time and resources moving forward. The key takeaways from workshop participant discussions and input included the importance of matching technology to specific situations and vessel–use profiles, combining technologies for improved performance, and developing performance metrics and testing protocols to ensure effectiveness. Working collaboratively to test and evaluate vessel strike risk reduction technology will require time, communication, transparency, scientific rigor, and trust amongst parties. There are no simple solutions or shortcuts, but there are promising tools (technology, combinations of technologies, and actions) with potential to reduce vessel strike risk when used in the right situations and with the right training. Identifying ways in which technology can inform and facilitate human actions that reduce vessel strike risk has benefits to mariners and their safety and is essential to further reducing the likelihood of mortalities and serious injuries to endangered NARWs from vessel collisions.

Literature Cited

Anwar, S., M. Y. I. Zia, M. Rashid, and G. Z. D. Rubens. 2020. Towards ferry electrification in the maritime sector. Energies. 13(24):6506. https://doi.org/10.3390/en13246506

Azura Consulting. 2022. North Atlantic right whale vessel speed rule human dimension study. Final Report, 290 p.

Bates, T. S., R. P. Kiene, G. V. Wolfe, P. A. Matrai, F. P. Chavez, K. R. Buck, B. W. Blomquist, and R. L. Cuhel. 1994. The cycling of sulfur in surface seawater of the northeast Pacific. Journal of Geophysical Research: Oceans. 99(C4):7835–7843. https://doi.org/10.1029/93JC02782

Baumgartner, M. F., T. V. N. Cole, R. G. Campbell, G. J. Teegarden, and E. G. Durbin. 2003. Associations between North Atlantic right whales and their prey, *Calanus finmarchicus*, over diel and tidal time scales. Marine Ecology Progress Series. 264:155–166. http://doi.org/10.3354/meps264155

Brandt, M. J., C. Höschle, A. Diederichs, K. Betke, R. Matuschek, S. Witte, and G. Nehls. 2013. Far-reaching effects of a seal scarer on harbour porpoises, *Phocoena phocoena*. Aquatic Conservation: Marine and Freshwater Ecosystems. 23(2):222–232. https://doi.org/10.1002/aqc.2311

Burkov, A. F., and G. Y. Kuvshinov. 2017. Study of ships electrification. 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM). 1–6. https://doi.org/10.1109/ICIEAM.2017.8076185

Cabrera, D., L. Shuai, J. Holmes, and M. Yadav. 2023. The potential of focusing acoustic retroreflectors for architectural surface treatment. Applied Sciences. 13(3):1547. https://doi.org/10.3390/app13031547

Çelik, F., A. Doğrul, and Y. Arıkan. 2011. Investigation of the optimum duct geometry for a passenger ferry. Surfaces. 1(1):1.

Collins, J. A., H. Busby, and G. Staab. 2009. Mechanical design of machine elements: a failure prevention perspective, 2nd ed., 896 p. John Wiley and Sons, Hoboken, NJ.

Croll, D. A., B. Marinovic, S. R. Benson, F. P. Chavez, N. A. Black, R. Ternullo, and B. R. Tershy. 2005. From wind to whales: trophic links in a coastal upwelling system. Marine Ecology Progress Series. 289:117–130. https://doi.org/10.3354/MEPS289117

Crowe, L., M. Brown, P. Corkeron, P. Hamilton, C. Ramp, S. Ratelle, A. Vanderlaan, and T. V. N. Cole. 2021. In plane sight: a mark-recapture analysis of North Atlantic right whales in the Gulf of St. Lawrence. Endangered Species Research. 46:227–251. https://doi.org/10.3354/esr01156

Cusano, D., A. Dangerfield, J. Bender, S. Driscoll, D. Wiley, J. M. Smith, M. Martin, D. Reeb, and J. J. Levenson. 2024. A review of current, emerging, and potential future tools for predicting North Atlantic right whale presence. OCS Study. BOEM 2024–010, 23 p.

Ditria, E. M., C. A. Buelow, M. Gonzalez-Rivero, and R. M. Connolly. 2022. Artificial intelligence and automated monitoring for assisting conservation of marine ecosystems: a perspective. Frontiers in Marine Science. 9:918104. https://doi.org/10.3389/fmars.2022.918104

Emblemsvag, J. 2017. The electrification of the marine industry [Viewpoint]. IEEE Electrification Magazine. 5(3):4–9. https://doi.org/10.1109/MELE.2017.2718821

Garrison, L. P., J. Adams, E. M. Patterson, and C. P. Good. 2022. Assessing the risk of vessel strike mortality in North Atlantic right whales along the U.S. East Coast. NOAA Tech. Memo. NMFS–SEFSC–757, 42 p.

Gende, S. M., L. Vose, J. Baken, C. M. Gabriele, R. Preston, and A. N. Hendrix. 2019. Active whale avoidance by large ships: components and constraints of a complementary approach to reducing ship strike risk. Frontiers in Marine Science. 6:592. https://doi.org/10.3389/fmars.2019.00592

Gulland, F. M. D., F. B. Nutter, K. Dixon, J. Calambokidis, G. Schorr, J. Barlow, T. Rowles, S. Wilkin, T. Spradlin, L. Gage, J. Mulsow, C. Reichmuth, M. Moore, J. Smith., P. Folkens, S. F. Hanswer, S. Jang, and C. S. Baker. 2008. Health assessment, antibiotic treatment, and behavioral responses to herding efforts of a cow-calf pair of humpback whales (*Megaptera novaeangliae*) in the Sacramento River Delta, California. Aquatic Mammals. 34(2):182–192. https://doi.org/10.1578/AM.34.2.2008.182

Hazen, E. L., S. Jorgensen, R. R. Rykaczewski, S. J. Bograd, D. G. Foley, I. D. Jonsen, S. A. Shaffer, J. P. Dunne, D. P. Costa, L. B. Crowder, and B. A. Block. 2013. Predicted habitat shifts of Pacific top predators in a changing climate. Nature Climate Change. 3:234–238. https://doi.org/10.1038/nclimate1686

Hazen, E. L., D. M. Palacios, K. A. Forney, E. A. Howell, E. Becker, A. L. Hoover, L. Irvine, M. DeAngelis, S. J. Bograd, B. R. Mate, and H. Bailey. 2017. WhaleWatch: a dynamic management tool for predicting blue whale density in California Current. Journal of Applied Ecology. 54(5):1415–1428. https://doi.org/10.1111/1365-2664.12820.

Hildebrand, J. A., M. A. McDonald, J. Calambokidis, and K. Balcomb. 2006. Joint Institute for Marine Observations report on cooperative agreement NA17RJ1231: whale watch vessel ambient noise in the Haro Strait. Marine Physical Laboratory of the Scripps Institution of Oceanography University of California, San Diego Report. MPL TM–490, 24 p.

Hulswar, S., R. Simó, M. Galí, T. G. Bell, A. Lana, S. Inamdar, P. R. Halloran, G. Manville, and A. S. Mahajan. 2022. Third revision of the global surface seawater dimethyl sulfide climatology (DMS-Rev3). Earth System Science Data Discussions. 14(7):2963–2987. https://doi.org/10.5194/essd-14-2963-2022

Johnson, H., D. Morrison, and C. Taggart. 2021. WhaleMap: a tool to collate and display whale survey results in near real-time. Journal of Open Source Software. 6(62):3094. https://doi.org/10.21105/joss.03094

Kelley, D. E., J. P. Vlasic, and S. W. Brillant. 2021. Assessing the lethality of ship strikes on whales using simple biophysical models. Marine Mammal Science. 37(1):251–267. https://doi.org/10.1111/mms.12745

Kenney, R. D., C. A. Mayo, and H. E. Winn. 2001. Migration and foraging strategies at varying spatial scales in western North Atlantic right whales: a review of hypotheses. Journal of Cetacean Research and Management. Special Issue 2:251–260. https://doi.org/10.47536/jcrm.vi.283

Korican, M., L. Frkovic, and N. Vladimir. 2023. Electrification of fishing vessels and their integration into isolated energy systems with a high share of renewables. Journal of Cleaner Production. 425:138997. https://doi.org/10.1016/j.jclepro.2023.138997

Koumentakos, A. G. 2019. Developments in electric and green marine ships. Applied System Innovation. 2(4):34. https://doi.org/10.3390/asi2040034

Kraus, S. O. 1999. The once and future ping: challenges for the use of acoustic deterrents in fisheries. Marine Technology Science Journal. 33(2):90–93. https://doi.org/10.4031/MTSJ.33.2.15

Lana, A., T. G. Bell, R. Simó, S. M. Vallina, J. Ballabrera-Poy, A. J. Kettle, J. Dachs, L. Bopp, E. S. Saltzman, J. Stefels, J. E. Johnson, and P. S. Liss. 2011. An updated climatology of surface dimethyl sulfide concentrations and emission fluxes in the global ocean. Global Biogeochemical Cycles. 25(1):GB1004. https://doi.org/10.1029/2010GB003850

Lu, S., D. Cabrera, J. Holmes, and R. Ferraro. 2023. Cube-corner retroreflectors for acoustic support outdoors: A comparison of simple and optimized designs. Building and Environment. 236:110268. https://doi.org/10.1016/j.buildenv.2023.110268

Madon, B., R. David, L. Pendleton, R. Garello, and R. Fablet. 2017. Strike-alert: towards real-time, high resolution navigational software for whale avoidance. 2017 IEEE Conference on Technologies for Sustainability (SusTech). 1–5. http://doi.org/10.1109/SusTech.2017.8333534

Marine Mammal Commission (MMC). 2024. North Atlantic right whale tagging workshop report. MMC Report, 37 p.

Mayville, C. 2019. Marine jet drives: operation and maintenance, 1st ed., 18 p. SUNY Canton, Canton, NY.

National Marine Fisheries Service. 2020. North Atlantic right whale (*Eubalaena glacialis*) vessel speed rule assessment. NOAA Fisheries OPR Report, 44 p.

Negenborn, R. R., F. Goerlandt, T. A. Johansen, P. Slaets, O. A. Valdez Banda, T. Vanelslander, and N. P. Ventikos. 2023. Autonomous ships are on the horizon: here's what we need to know. Nature. 615:30–33. https://doi.org/10.1038/d41586-023-00557-5

Nevitt, G. A., R. R. Veit, and P. Kareiva. 1995. Dimethyl sulphide as a foraging cue for Antarctic procellariiform seabirds. Nature. 376:680–682. https://doi.org/10.1038/376680ao

Nowacek, D. P., M. P. Johnson, and P. L. Tyack. 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. Proceedings of the Royal Society of London Series B: Biological Sciences. 271(1536):227–231. https://doi.org/10.1098/rspb.2003.2570

Owen, K., K. Saeki, J. D. Warren, A. Bocconcelli, D. N. Wiley, S. Ohira, A. Bombosch, K. Toda, and D. P. Zitterbart. 2021. Natural dimethyl sulfide gradients would lead marine predators to higher prey biomass. Communications Biology. 4:149. https://doi.org/10.1038/s42003-021-01668-3

Pace, R., R. Williams, S. Kraus, A. Knowlton, and H.Pettis. 2021. Cryptic mortality of North Atlantic right whales. Conservation Science and Practice. 3. http://dx.doi.org/10.1111/csp2.346

Parks, S. E., D. A. Cusano, S. M. Van Parijs, and D.P. Nowacek. 2019. Acoustic crypsis in communication by North Atlantic right whale mother–calf pairs on the calving grounds. Biology Letters. 15(10):20190485. https://doi.org/10.1098/rsbl.2019.0485

Parrott, L., C. Chion, C. C. A. Martins, P. Lamontagne, S. Turgeon, J. A. Landry, B. Zhens, D. J. Marceau, R. Michaud, G. Cantin, N. Menard, and S. Dionne. 2011. A decision support system to assist the sustainable management of navigation activities in the St. Lawrence River Estuary, Canada. Environmental Modelling and Software. 26(12):1403–1418. https://doi.org/10.1016/j.envsoft.2011.08.009

Poulet, S. A., and P. Marsot. 1978. Chemosensory grazing by marine calanoid copepods (Arthropoda: Crustacea). Science. 200(4348):1403–1405. https://doi.org/10.1126/science.200.4348.1403

Procter, J., F. E. Hopkins, E. S. Fileman, and P. K. Lindeque. 2019. Smells good enough to eat: dimethyl sulfide (DMS) enhances copepod ingestion of microplastics. Marine Pollution Bulletin. 138:1–6. https://doi.org/10.1016/j.marpolbul.2018.11.014

Reimer, J., C. Gravel, M. W. Brown, and C. T. Taggart. 2016. Mitigating vessel strikes: the problem of the peripatetic whales and the peripatetic fleet. Marine Policy. 68:91–99. https://doi.org/10.1016/j.marpol.2016.02.017

Roberts, J. J., B. D. Best, L. Mannocci, E. Fujioka, P. N. Halpin, D. L. Palka, L. P. Garrison, K. D. Mullin, T. V. N. Cole, C. B. Khan, W. A. McLellan, D. A. Pabst, and G. G. Lockhart. 2016. Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. Scientific Reports. 6:22615. https://doi.org/10.1038/srep22615

Roberts, J. J., T. M. Yack, E. Fujioka, P. N. Halpin, M. F. Baumgartner, O. Boisseau, S. Chavez-Rosales, T. V. N. Cole, M. P. Cotter, G. E. Davis, R. A. DiGiovanni Jr., L. C. Ganley, L. P. Garrison, C. P. Good, T. A. Gowan, K. A. Jackson, R. D. Kenney, C. B. Khan, A. R. Knowlton, S. D. Kraus, G. G. Lockhart, K. S. Lomac-MacNair, C. A. Mayo, B. E. McKenna, W. A. McLellan, D. P. Nowacek, O. O'Brien, D. A. Pabst, D. L. Palka, E. M. Patterson, D. E. Pendleton, E. Quintana-Rizzo, N. R. Record, J. V. Redfern, M. E. Rickard, M. White, A. D. Whitt, and A. M. Zoidis. 2024. North Atlantic right whale density surface model for the U.S. Atlantic evaluated with passive acoustic monitoring. Marine Ecology Progress Series. 732:167–192. https://doi.org/10.3354/meps14547

Runge, M. C., D. W. Linden, J. A. Hostetler, D. L. Borggaard, L. P. Garrison, A. R. Knowlton, V. Lesage, R. Williams, and R. M. Pace III. 2023. A management-focused population viability analysis for North Atlantic right whales. NOAA Tech. Memo. NMFS–NE–307, 103 p.

Rutenko, A. N., M. Y. Fershalov, and V. G. Ushchipovskii. 2020. Acoustic noise generated on a shallow-water shelf by vessels with electric motors. Acoustical Physics. 66:517–527. https://doi.org/10.1134/S1063771020050127

Santora, J. A., W. J. Sydeman, I. D. Schroeder, B. K. Wells, and J. C. Field. 2011. Mesoscale structure and oceanographic determinants of krill hotspots in the California Current: implications for trophic transfer and conservation. Progress in Oceanography. 91(4):397–409. https://doi.org/10.1016/J.POCEAN.2011.04.002

Silber, G. K., S. Bettridge, and D. Cottingham. 2009. Report of a workshop to identify and assess technologies to reduce ship strikes of large whales: Providence, Rhode Island, 8–10 July 2008. NOAA Tech. Memo. NMFS–OPR–42, 55 p.

Silber, G. K., J. Slutsky, and S. Bettridge. 2010. Hydrodynamics of a ship/whale collision. Journal of Experimental Marine Biology and Ecology. 391(1–2):10–19. https://doi.org/10.1016/j.jembe.2010.05.013

Stark, C., and W. Shi. 2021. Hydroacoustic and hydrodynamic investigation of bio-inspired leading-edge tubercles on marine-ducted thrusters. Royal Society Open Science. 8:210402. https://doi.org/10.1098/rsos.210402

Stark, C., W. Shi, and M. Troll. 2021. Cavitation funnel effect: bio-inspired leading-edge tubercle application on ducted marine propeller blades. Applied Ocean Research. 116:102864. https://doi.org/10.1016/j.apor.2021.102864

Southall, B. L., D. P. Nowacek, P. J. O. Miller, and P. L. Tyack. 2016. Experimental field studies to measure behavioral responses of cetaceans to sonar. Endangered Species Research. 31:293–315. https://doi.org/10.3354/esr00764

Statheros, T., G. Howells, and K. M. Maier. 2008. Autonomous ship collision avoidance navigation concepts, technologies and techniques. The Journal of Navigation. 61(1):129–142. https://doi.org/10.1017/S037346330700447X

Todd, V. L. G., L. D. Williamson, J. Jiang, S. E. Cox, I. B. Todd, and M. Ruffert. 2021. Prediction of marine mammal auditory-impact risk from acoustic deterrent devices used in Scottish aquaculture. Marine Pollution Bulletin. 165:112171. https://doi.org/10.1016/j.marpolbul.2021.112171

U.S. Government Accountability Office (GAO). 2020. Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects. TRA Guide. GAO–20–48G.

Verfuss, U. K., D. Gillespie, J. Gordon, T. A. Marques, B. Miller, R. Plunkett, J. A. Theriault, D. J. Tollit, D. P. Zitterbart, P. Hubert, and L. Thomas. 2018. Comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys. Marine Pollution Bulletin. 126:1–18. https://doi.org/10.1016/j.marpolbul.2017.10.034

Zitterbart, D. P., H. R. Smith, M. Flau, S. Richter, E. Burkhardt, J. Beland, L. Bennett, A. Cammareri, A. Davis, M. Holst, C. Lanfredi, H. Michel, M. Noad, K. Owen, A. Pacini, and O. Boebel. 2020. Scaling the laws of thermal imaging-based whale detection. Journal of Atmospheric and Oceanic Technology. 37(5):807–824. https://doi.org/10.1175/jtech-d-19-0054.1

Appendix 1: Workshop Agenda

North Atlantic Right Whale Vessel Strike Risk Reduction Technology Workshop

March 5-6, 2024 | Hilton National Landing, Arlington, VA
Main Meeting Room: Adams/Madison

Workshop Purpose and Objectives
The purpose of this workshop is to identify existing and emerging technologies capable of reducing the risk vessel strikes pose to North Atlantic right whales (NARW) while maintaining vessel operational needs. The objective is to describe technologies using attributes such as role in risk reduction, technological readiness, potential efficacy and under various conditions (e.g., weather, vessel type, alone or in combination with other technology/actions), cost, ability to verify/measure contribution to vessel strike risk reduction, potential challenges to testing, adoption, and approval.

In addition to sharing information and perspectives on current and emerging technologies, the workshop is intended to foster new and ongoing connections/dialogue among the many diverse groups - public, private and nonprofit - pursuing potential vessel strike risk reduction technology advancements. We want to foster an exchange of ideas and obtain unique viewpoints from individual attendees, not advice, opinions or recommendations from the group acting as a collective. Information collected at the workshop will contribute to the range of knowledge that will inform next steps for advancing vessel strike risk reduction technology.

Federal Constraints to Deliberations

- F*ederal Advisory Committee Act (FACA):* The purpose of this workshop is obtaining information and viewpoints from individual attendees, not advice, opinions or recommendations from the group acting as a collective given that this is not a formal Federal Advisory Committee under FACA. No collective decisions will be made at the workshop. Rather, the information provided and viewpoints expressed will contribute to the range of data that informs next steps.
- *Statement to Manufacturers and Service Providers:* This workshop is not a demonstration or examination of your products or their capabilities. Please limit your commentary to the nature and qualities of various technologies, systems, and standards without specific reference to your products.

Workshop Ground Rules

- Participate actively and respectfully.
- Remain open-minded.
- Explore with good questions, deep background knowledge, and a spirit of "can do."
- Focus on the practical and technical.
- Non-decisional and not seeking consensus from the group, i.e., points should be from individual attendees and not from the collective group.
- We are not recording audio or video of the workshop. To promote productive discussion, we ask that all workshop participants also refrain from recording audio or video.
- Remote participants will have an opportunity to observe deliberations in both plenary and breakout groups; remote participant contributions will most typically be provided in writing (via chat, Google docs, etc.), but there may also be opportunities to comment verbally.

- The facilitation team will occasionally use polling to get a sense of perspectives on issues under discussion. This polling is being used to inform workshop deliberations; it is not intended as a "vote" on any issues under discussion.

<u>**Information for Workshop Participants**</u>

- As noted above and in the spirit of creating an atmosphere that encourages a more candid exchange of views, we ask that workshop participants not record any portion of the workshop. That said, we note that this is a public meeting, and participants should be advised that some participants may not honor our request and may choose to record the proceedings.
- Participants should be advised that members of the media are participating as remote participants in the workshop.

Agenda Day 1: 5 March 2024

Time	Session, Presenter, Materials, and Discussion
8:00	**Registration**
	Room: Adams/Madison (All of Today's Sessions)
8:30 I	**Welcome** ● Janet Coit, NOAA Fisheries Assistant Administrator
8:45 II	**Workshop objective, agenda and ground rules** ● Why are we holding the workshop, what we hope for the next 2 days, and what we ask of workshop participants ● Agenda review, ground rules and general workshop approach ● Session Slides ● <u>Documents/Tools for this Session</u>: o 2 Polls (links will be shared in slides)
9:00 III	**Background on Vessel Strikes and North Atlantic Right Whales** <u>Session Goal</u>: Develop a shared understanding of the factors that affect vessel strike risk and which of these may be influenced by technology. ● NARW vessel interactions 101 o *Caroline Good, NOAA Fisheries, Office of Protected Resources* o Question and Answer Session ● The role of NARW biology and ecology in vessel strike risk o *Danielle Cholewiak, NOAA Fisheries, Northeast Fisheries Science Center* o Question and Answer Session ● <u>Documents/Tools for this Session</u>: o North Atlantic Right Whale Information Fact Sheet o Vessel Information Fact Sheet o Background Paper on Vessel Strike Risk Reduction Regulations and Programs o Background Paper on North Atlantic Right Whale Vessel Strikes
10:00	**Break**
10:15 IV	**Context for Considering the Role of Technology in Vessel Strike Risk Reduction** ● Lessons learned: vessel strike mitigation strategies o *Shannon Bettridge, NOAA Fisheries, Office of Protected Resources*

- Considering technology from an enforcement perspective
    - *Casey Brennan, NOAA Fisheries, Office of Law Enforcement*
- Question and Answer Session
- Documents/Tools for this Session:
    - Poll (link will be shared in slides)

11:15 V **Understanding the Range of Perspectives**

Session Goal: Help participants understand from the outset the range of perspectives and considerations the agency and different vessel operators are bringing to this discussion.

- Session Slides
- **NOAA Fisheries' Perspective**: What does NOAA Fisheries hope to get out of the workshop? How could the workshop discussions inform future agency actions? What does NOAA Fisheries envision as productive next steps that might emerge from this workshop?
    - *Kim Damon-Randall, Director, NOAA Fisheries Office of Protected Resources*
- **Vessel Industry Perspective**: Recognizing the operational constraints of their vessels, how vessel industry representatives envision technology reducing vessel strike risk?
    - Vessel Industry Panel
        - *Clay Diamond, American Pilots' Association*
        - *Bryan Wood Thomas, World Shipping Council*
        - *John DePersenaire, Whale and Vessel Safety Taskforce*
        - *Eric Empey, DEME on behalf of American Clean Power*
        - *Jeff Angers, Center for Sportfishing Policy*
        - *Mike Glasfeld, Bay State Cruise Company on behalf of the Passenger Vessel Association*
- Documents/Tools for this Session:
    - Online form for workshop participants to share their perspective (NOTE: This link will remain open until 15 March)

12:00 **Lunch Break (lunch on your own)**

1:15 VI **Introduction to Risk Reduction Application Scenarios and Risk Reduction Components**

Session Goal: Introduce the Conceptual Thinking that is Shaping the Workshop: Explanation of Application Scenarios and Risk Reduction Components.

- Plenary Presentation: *Mary Colligan, NOAA Affiliate*
- Opportunity for Workshop Participants, through table discussions, to identify any key elements missing from the Framework and to identify what is important to understand better before we move into more in-depth conversations.
- Opportunity for Workshop Participants to provide comments on the application scenarios, risk chain components or risk factor graphic on posters throughout the room and in Google sheets online. Provide input on Risk Chain Components through table discussions and comments in Google sheet.
- Documents/Tools for this Session:
    - Comments on the documents can be provided on poster boards in the meeting room, on hard copies distributed to tables during the session and/or in this online form. (NOTE: This link will remain open until 15 March)

1:45 VII **Risk Chain Component: North Atlantic Right Whale Detection & Classification**

Session Goal: Identify and characterize existing and potential technology to detect and identify NARW for the purposes of informing zone, dynamic or vessel-specific action to reduce vessel strike risk.

- Session Slides
- Presentations
  - *Overview of technology for NARW detection & identification of what is currently being used by the Government of Canada, Katia Mckercher, Fisheries and Oceans Canada*
  - *Technology currently being used by NOAA Fisheries Northeast Fisheries Science Center, Danielle Cholewiak*
  - *Technology being Investigated and Tested for Future Use, Mike Weise, Office of Naval Research (Remote)*
  - *Infrared Technology – Daniel Zitterbart, Woods Hole Oceanographic Institution*
- Questions for Clarification

3:00 **Break**

3:15 VIII **Risk Chain Component: North Atlantic Right Whale Detection & Classification**

- Discussion to identify most promising technologies based on impact and feasibility and for those, identify productive next steps (by government, partnerships, private sector, etc.
- Session Slides
- Documents/Tools for this Session:
  - Poll (link will be shared in slides)
  - Discussion questions for use in breakout groups in the room
  - Online form for workshop participants to share their perspective (NOTE: This link will remain open until 15 March)

4:15 IX **Close out of Day 1, Preview of Day 2**

- Session Slides

4:30 **Adjourn**

Agenda Day 2: 6 March 2024

Time **Session, Presenter, Materials, and Discussion**

8:30 X **Welcome, Agenda Review and Reflections from Day 1 (Room: Adams/Madison)**

- Session Slides

8:45 XI **4 Concurrent Sessions focused on Risk Chain Components:** Workshop participants will participate in one of the four concurrent sessions. Each session will begin with a series of presentations, followed by an opportunity for input from invited subject matter experts, vessel operators, and other workshop participants, as time allows.

Room: Adams/Madison

XI M **Session M: Modeling/Predicting/Forecasting Whales**

Session Goals: (1) Identify and characterize existing and potential technology to predict/forecast/model the spatial and temporal distribution of NARWs for the purposes of informing zone, dynamic or vessel-specific vessel strike risk reduction action; and (2) Characterize the state of play for predicting/forecasting/modeling, identify the most promising technologies and the priority next steps to advance their development and deployment.

- Session Slides

Presentations

- *Eric Patterson, NOAA Fisheries Office of Protected Resources: Review of past, current and planned agency investments in modeling*
- *Jason Roberts, Duke: NARW Density model and work on a predictive model*
- *Lance Garrison, NOAA Fisheries Southeast Fisheries Science Center: What role can models play in reducing vessel strike risk?*
- *Jake Levenson, Bureau of Ocean Energy Management (BOEM): Summary of recent BOEM NARW modeling workshop (Remote)*

Invited Subject Matter Experts

- *Joel Caplan, Rutgers*
- *Nathan Crum, Florida Fish and Wildlife Commission (Remote)*
- *Daniel Pendleton, NOAA Fisheries, Northeast Fisheries Science Center*
- *Rob Schick, Duke (Remote)*
- *Ramy Imam, Lautec*
- *Alexandra Mayette, Canadian Wildlife Federation*
- *Erin Meyer-Gutbrod, University of South Carolina*
- *Jessica Redfern, New England Aquarium (Remote)*

Documents/Tools for this Session:

- Poll (link will be shared in slides)

Room: Washington III

XI A Session A: Aggregating/Assembling Whale Detections

Session Goals: (1) Identify and characterize existing and potential technology to aggregate information on NARWs; (2) identify the incoming data sources and types, any methods for verification and discuss the time lag (between detection to aggregation); (3) characterize the state of play for aggregating NARW detections; and (4) identify the most promising technologies and the priority next steps to advance their development and deployment.

- Session Slides

Presentations:

- *Hansen Johnson, New England Aquarium, WhaleMap*
- *Genevieve Davis, NOAA Fisheries Northeast Fisheries Science Center, Passive Acoustic Cetacean Map*
- *Virgil Zetterlind, Conserve.iO, Whale Alert*
- *Olivia Pisano, Fisheries and Oceans Canada, Whale Insight (Remote)*

Invited Subject Matter Expert

- *Dave Wiley, NOAA Office of National Marine Sanctuaries (Remote)*

Documents/Tools for this Session:

- Poll (link will be shared in slides)

Room: Washington I/II

XI DI Session DI: Disseminating & Integrating NARW detections & management areas into navigational systems

Session Goals**:** (1) Identify and characterize existing and potential technology to deliver information on NARW presence and management areas in a manner that facilitates timely and effective evasive action; (2) Characterize the state of play for disseminating such information and integrating it into navigational software for a variety of vessel operational categories; and (3) Identify the most promising technologies and the priority next steps to advance their development and deployment.

- Session Slides

Presentations:

- *Jorge Arroyo, U.S. Coast Guard: Overview of how the USCG disseminates information to mariners.*
- *Shaun Ruge, Garmin: Methods and opportunities to integrate whale information into commercially available navigational equipment.*
- *Moses Calouro, Maritime Information Systems: Use of AIS to provide mariners information on NARW detections and restrictions.*
- *Captain Steve White, Marine Exchange of Alaska: Sea Traffic Management*

Invited Subject Matter Experts

- *Jeff Adams, NOAA Office of Protected Resources*
- *David Steckler, Mysticetus*
- *Alex Mitchell, Ocean Wise*
- *Darren Wright, NOAA Office of Coast Survey: Precision Navigation System (remote)*

Documents/Tools for this Session:

- Poll (link will be shared in slides)

Room: Monroe I/II

XI O Session O: Other Opportunities for Technology to Reduce NARW Vessel Strike Risk

Session Goals: To identify other opportunities for technology to reduce NARW vessel strike risk including but not limited to: (1) modifying vessel design and propulsion systems; (2) tracking and evaluating the effectiveness of risk reduction measures; and (3) vessel-strike detection.

- Session Slides

Format: This will be a facilitated brainstorming session. Session participants will be asked to identify technology that can contribute in ways not identified in other workshop sessions, discuss the state of that technology, and identify next steps to advance the development or deployment of that technology.

Documents/Tools for this Session:

- Poll (link will be shared in slides)

Room: Adams/Madison

11:00 XII Report out from Breakout Groups

Documents/Tools for this Session

- Online forms will be prepared and shared soon after the workshop.

12:00 Lunch Break (lunch on your own) (additional time to allow informal discussions in preparation for afternoon sessions)

Room: Adams/Madison

1:30 XIII Developing Action Plans for Technology with the Most Promise

Session Goal: Identify common and compelling themes and takeaways from across all component panels, begin to identify concrete next steps and strategies for moving forward, including identification of the most critical data gaps. Identify the most important next steps to advance the vessel strike risk reduction technology with the most potential/promise. Acknowledge and discuss necessary linkages between risk components.

- Session Slides

Panelists: Reflections from a panel composed of federal agency and vessel industry representatives on synergies, conflicts, needed next steps, potential role for federal partners, promising collaborations, etc.

- *Kim Damon-Randall, NOAA Fisheries*
- *Candace Nachman, U.S. Coast Guard*
- *Kyle Baker, Bureau of Ocean Energy Management*
- *Bryan Wood Thomas, World Shipping Council*
- *John DePersenaire, Whale and Vessel Safety Taskforce*
- *Clay Diamond, American Pilots' Association*

Documents/Tools for this Session:

- Online form for workshop participants to provide answers to same questions posed to the panel (NOTE: This link will remain open until 15 March)
- Poll (link will be shared in slides) online

2:45 Break

Room: Adams/Madison

3:00 XIV Public / Private Partnerships to Advance Technology to Reduce Vessel Strike Risk

Session Goal: Discuss how to build on the discussions and collaborations from the workshop and identify what is needed to compel progress in applying technology to reduce vessel strike mortality of NARWs.

- Session Slides

Format: We will pose questions for workshop participants to discuss at their tables/on-line, ask for report outs and discuss recommendations.

Documents/Tools for this Session:

- Document for use at tables.
- Online form for workshop participants (NOTE: This link will remain open until 15 March)

Room: Adams/Madison

4:15 XV Next Steps and Closeout

Session Goal**:** Provide an opportunity for NOAA Fisheries to share plans for the Federal agency session the next day and provide the agency's initial thoughts of next steps.

- Session Slides

Appendix 2: Steering Committee

North Atlantic Right Whale Vessel Strike Risk Reduction Technology Workshop Steering Committee.

Name	Affiliation	Role
Michael Asaro	NOAA Fisheries, Northeast Fisheries Science Center	Member
Deborah Austin	Fisheries and Oceans, Canada (DFO)	Member
Kyle Baker	Bureau of Ocean Energy Management (BOEM) Office of Renewable Energy Programs	Member
Alison Butko	Transport Canada	Member
Shawn Choy	NOAA National Ocean Service, Management and Budget Office	Member
Laura Engleby	NOAA Fisheries, Southeast Regional Office	Member
Lance Garrison	NOAA Fisheries, Southeast Fisheries Science Center	Member
Monique Goit	Fisheries and Oceans, Canada (DFO)	Member
Jean Higgins	NOAA Fisheries, Greater Atlantic Regional Fisheries Office	Member
Kenneth Keene	NOAA Fisheries, Office of Science and Technology	Member
Candace Nachman	U.S. Coast Guard	Member
Veronique Nolet	Transport Canada (TC)	Member
Eric Patterson	NOAA Fisheries, Office of Protected Resources	Member
Michael Weise	Office of Naval Research	Member
Bennett Brooks	Consensus Building Institute (CBI)	Facilitator
Pat Field	Consensus Building Institute (CBI)	Facilitator
Alex Carbaugh-Rutland	NOAA Fisheries, Greater Atlantic Regional Office - Affiliate	Coordinator
Mary Colligan	NOAA Fisheries, Greater Atlantic Regional Office - Affiliate	Coordinator

Appendix 3: Presenters, Panelists, and Subject Matter Experts

North Atlantic Right Whale Vessel Strike Risk Reduction Technology Workshop panelist, presenter, and subject matter expert list. Refer to the Workshop Agenda (Appendix 1) for details on the sessions each participated in.

Name	Affiliation	Role	Session
Angers, Jeff	Center for Sportfishing Policy	Panelist	V
Baker, Kyle	Bureau of Ocean Energy Management (BOEM) Office of Renewable Energy Programs	Panelist	XIII
Damon-Randall, Kim	NOAA Fisheries, Office of Protected Resources	Panelist	V and XIII
DePersenaire, John	Whale and Vessel Safety Taskforce (WAVS)	Panelist	V and XIII
Diamond, Clay	American Pilots' Association	Panelist	V and XIII
Glasfeld, Mike	Bay State Cruise Company; Passenger Vessel Association (PVA)	Panelist	V
Nachman, Candace	U.S. Coast Guard	Panelist	XIII
Wood Thomas, Bryan	World Shipping Council (WSC)	Panelist	V and XIII
Arroyo, Jorge	U.S. Coast Guard	Presenter	XI
Bettridge, Shannon	NOAA Fisheries, Office of Protected Resources	Presenter	IV
Brennan, Casey	NOAA Fisheries, Office of Law Enforcement	Presenter	IV
Calouro, Moses	Maritime Information Systems, Inc.	Presenter	XI
Cholewiak, Danielle	NOAA Fisheries, Northeast Fisheries Science Center	Presenter	III and VII
Davis, Genevieve	NOAA Fisheries, Northeast Fisheries Science Center	Presenter	XI
Garrison, Lance	NOAA Fisheries, Southeast Fisheries Science Center	Presenter	XI
Good, Caroline	NOAA Fisheries, Office of Protected Resources	Presenter	III
Johnson, Hansen	New England Aquarium	Presenter	XI
Levenson, Jake	Bureau of Ocean Energy Management (BOEM)	Presenter	XI
McKercher, Katia	Fisheries and Oceans Canada (DFO)	Presenter	VII
Patterson, Eric	NOAA Fisheries, Office of Protected Resources	Presenter	XI
Pisano, Olivia	Fisheries and Oceans Canada (DFO)	Presenter	XI
Roberts, Jason	Duke University	Presenter	XI
Ruge, Shaun	Garmin	Presenter	XI
White (Captain), Steve	Marine Exchange of Alaska	Presenter	XI
Zetterlind, Virgil	Conserve.iO	Presenter	XI
Zitterbart, Daniel	Woods Hole Oceanographic Institution	Presenter	VII
Adams, Jeff	NOAA Fisheries, Office of Protected Resources	SME	XI

Name	Affiliation	Role	Session
Caplan, Joel	Rutgers University	SME	XI
Crum, Nathan	Florida Fish and Wildlife Conservation Commission	SME	XI
Imam, Ramy	Lautec	SME	XI
Mayette, Alexandra	Canadian Wildlife Federation	SME	XI
Meyer-Gutbrod, Erin	University of South Carolina	SME	XI
Mitchell, Alex	Ocean Wise	SME	XI
Pendleton, Daniel	NOAA Fisheries, Northeast Fisheries Science Center	SME	XI
Redfern, Jessica	New England Aquarium	SME	XI
Schick, Rob	Duke University	SME	XI
Steckler, David	Mysticetus	SME	XI
Wright, Darren	NOAA National Ocean Service, Office of Coast Survey	SME	XI

Appendix 4: List of Participants

North Atlantic Right Whale Vessel Strike Risk Reduction Technology Workshop participant list. In-person participants are listed first followed by remote participants. Within each of those groupings, participants are organized by sector and within each sector presented alphabetically by affiliation.

In-person Participants

Name	Affiliation	Sector
Wahl, Lauren	A.I.S., Inc.	External Science/Academic
Stevens, Tara	CSA Ocean Sciences	External Science/Academic
Roberts, Jason	Marine Geospatial Ecology Lab, Duke University	External Science/Academic
Flammang, Brooke	New Jersey Institute of Technology/NUWC/RemoraTech	External Science/Academic
Shumchenia, Emily	Regional Wildlife Science Collaborative for Offshore Wind	External Science/Academic
Caplan, Joel	Rutgers University	External Science/Academic
Baumgartner, Mark	Woods Hole Oceanographic Institution (WHOI)	External Science/Academic
Zitterbart, Daniel	Woods Hole Oceanographic Institution (WHOI)	External Science/Academic
Hooker, Brian	Bureau of Ocean Energy Management (BOEM)	Federal Government
Levenson, Jake	Bureau of Ocean Energy Management (BOEM)	Federal Government
Martin, Morgan	Bureau of Ocean Energy Management (BOEM)	Federal Government
Reeb, Desray	Bureau of Ocean Energy Management (BOEM)	Federal Government
Baker, Kyle	Bureau of Ocean Energy Management (BOEM) Office of Renewable Energy Programs	Federal Government
Tuttle, Graham	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Rodofili, Esteban	Knauss Fellow	Federal Government
Leach, Lauri	Marine Mammal Commission	Federal Government
Thomas, Peter	Marine Mammal Commission	Federal Government
Coit, Janet	NOAA Fisheries	Federal Government
Borggaard, Diane	NOAA Fisheries, Greater Atlantic Regional Fisheries Office	Federal Government
Higgins, Jean	NOAA Fisheries, Greater Atlantic Regional Fisheries Office	Federal Government
Colligan, Mary	NOAA Fisheries, Greater Atlantic Regional Fisheries Office - Affiliate	Federal Government
Gibbs, Briana	NOAA Fisheries, Greater Atlantic Regional Fisheries Office - Affiliate	Federal Government

Name	Affiliation	Sector
Carbaugh-Rutland, Alexander	NOAA Fisheries, Greater Atlantic Regional Office - Affiliate / University of Miami	Federal Government
Asaro, Michael	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Cholewiak, Danielle	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Davis, Genevieve	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
McNally, Sean	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Pendleton, Dan	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Sartwell, Tim	NOAA Fisheries, Office of Assistant Administrator	Federal Government
Westfall, Katherine	NOAA Fisheries, Office of Assistant Administrator	Federal Government
Brennan, Casey	NOAA Fisheries, Office of Law Enforcement	Federal Government
Adams, Jeffrey	NOAA Fisheries, Office of Protected Resources	Federal Government
Beatty, Karen	NOAA Fisheries, Office of Protected Resources	Federal Government
Bettridge, Shannon	NOAA Fisheries, Office of Protected Resources	Federal Government
Daly-Fuchs, Jaclyn	NOAA Fisheries, Office of Protected Resources	Federal Government
Damon-Randall, Kim	NOAA Fisheries, Office of Protected Resources	Federal Government
Davis, Leah	NOAA Fisheries, Office of Protected Resources	Federal Government
Di-Lernia, Megan	NOAA Fisheries, Office of Protected Resources	Federal Government
Frungillo, Jaime	NOAA Fisheries, Office of Protected Resources	Federal Government
Good, Caroline	NOAA Fisheries, Office of Protected Resources	Federal Government
Hager, Rachel	NOAA Fisheries, Office of Protected Resources	Federal Government
Harrison, Jolie	NOAA Fisheries, Office of Protected Resources	Federal Government
Lisi, Niki	NOAA Fisheries, Office of Protected Resources	Federal Government
Patterson, Eric	NOAA Fisheries, Office of Protected Resources	Federal Government
Scholik-Schlomer, Amy	NOAA Fisheries, Office of Protected Resources	Federal Government
Stadler, Lindsey	NOAA Fisheries, Office of Protected Resources	Federal Government
Wilkin, Sarah	NOAA Fisheries, Office of Protected Resources	Federal Government
Neyman, Lisa	NOAA Fisheries, Office of Protected Resources - Affiliate	Federal Government
Chilton, Liz	NOAA Fisheries, Office of Science and Technology	Federal Government

Name	Affiliation	Sector
Gedamke, Jason	NOAA Fisheries, Office of Science and Technology	Federal Government
Blondin, Hannah	NOAA Fisheries, Southeast Fisheries Science Center	Federal Government
Garrison, Lance	NOAA Fisheries, Southeast Fisheries Science Center	Federal Government
Engleby, Laura	NOAA Fisheries, Southeast Regional Office	Federal Government
George, Clay	NOAA Fisheries, Southeast Regional Office	Federal Government
Choy, Shawn	NOAA National Ocean Service, Management and Budget Office	Federal Government
Hatch, Leila	NOAA National Ocean Service, Office of National Marine Sanctuaries	Federal Government
Huanca, Paulina	NOAA Office of Public and Constituent Affairs - Affiliate	Federal Government
Wagner, Katie	NOAA Office of Public and Constituent Affairs	Federal Government
Bonine, Nicole	U.S. Army Corps of Engineers	Federal Government
Arroyo, Jorge	U.S. Coast Guard	Federal Government
Nachman, Candace	U.S. Coast Guard	Federal Government
St. Jeanos, Mike	U.S. Coast Guard	Federal Government
Moore, Kathleen	U.S. Coast Guard, Atlantic Area Enforcement	Federal Government
Kumar, Anu	U.S. Navy, Living Marine Resources Program	Federal Government
Colbert, Benjamin	U.S. Navy, Chief of Naval Operations	Federal Government
McKercher, Katherine	Fisheries and Oceans Canada (DFO)	International Government
Virc, Stephen	Fisheries and Oceans Canada (DFO)	International Government
Gandolfo, Ericca	Animal Welfare Institute	NGO
Horton, Chris	Congressional Sportsmen’s Foundation	NGO
Fuller, Erica	Conservation Law Foundation	NGO
Zetterlind, Deanna	Conserve.iO	NGO
Zetterlind, Virgil	Conserve.iO	NGO
Davenport, Jane	Defenders of Wildlife	NGO
Reilly, Greg	International Fund for Animal Welfare (IFAW)	NGO
Foxall, Damian	Marine Mammal Advisory Group	NGO
Sayre, Michael	Marine Retailers Association of the Americas	NGO
Bolen, Ellen	National Fish and Wildlife Foundation (NFWF)	NGO
Redding, Gray	National Fish and Wildlife Foundation (NFWF)	NGO
Kershaw, Francine	Natural Resources Defence Council (NRDC)	NGO

Name	Affiliation	Sector
Johnson, Hansen	New England Aquarium	NGO
Rogan, Andy	Ocean Alliance	NGO
Mitchell, Alex	Ocean Wise	NGO
Singer, Julia	Oceana	NGO
Asmutis-Silvia, Regina	Whale and Dolphin Conservation	NGO
Brooks, Bennett	Consensus Building Institute (CBI)	Other
Cooper, Elizabeth	Consensus Building Institute (CBI)	Other
Field, Patrick	Consensus Building Institute (CBI)	Other
Horii, Stephanie	Consensus Building Institute (CBI)	Other
O'Loughlin, Lydia	International Whaling Commission	Other
Swanson, Jake	Natural Resource Results Lobbyists	Other
Sullivan, Allyn	Attentive Energy / TotalEnergies	Tech/Engineer/Manufacturer
Gavin, Kim	BlueiQ	Tech/Engineer/Manufacturer
Shropshire, Taylor	Fathom Science, Inc.	Tech/Engineer/Manufacturer
Cooper, George	Forbes Tate Partners	Tech/Engineer/Manufacturer
Imam, Ramy	Lautec	Tech/Engineer/Manufacturer
Mann, David	Loggerhead Instruments	Tech/Engineer/Manufacturer
Tally, Todd	Marine Electronics Professional	Tech/Engineer/Manufacturer
Calouro, Moses	Maritime Information Systems, Inc.	Tech/Engineer/Manufacturer
Adams, Matt	MITRE	Tech/Engineer/Manufacturer
Corrado, Casey	MITRE	Tech/Engineer/Manufacturer
Lustig, Jay	MITRE	Tech/Engineer/Manufacturer
Weber, Tom	MITRE	Tech/Engineer/Manufacturer
Steckler, David	Mysticetus LLC	Tech/Engineer/Manufacturer
Hoyt, Callie	National Marine Manufacturers Association (NMMA)	Tech/Engineer/Manufacturer
Thomas, Steve	Navico Group	Tech/Engineer/Manufacturer
Montoya, Blanca	Oceaneering International inc.	Tech/Engineer/Manufacturer
King, Samantha	ProtectedSeas	Tech/Engineer/Manufacturer
King, Paul	SMRU Consulting	Tech/Engineer/Manufacturer
Premus, Vince	ThayerMahan/OASIS	Tech/Engineer/Manufacturer
Horowitz, Eliot	Viam	Tech/Engineer/Manufacturer
DePersenaire, John	Viking Yachts/Whale and Vessel Safety Taskforce (WAVS)	Tech/Engineer/Manufacturer

Name	Affiliation	Sector
Ruge, Shaun	Whale and Vessel Safety Taskforce (WAVS) task group - Garmin	Tech/Engineer/Manufacturer
Mun, Wei-Jun	World Shipping Council	Tech/Engineer/Manufacturer
Hennessey, Heather	Yamaha Marine	Tech/Engineer/Manufacturer
Grier, Joshua	Yamaha Motor Corporation	Tech/Engineer/Manufacturer
Washington, Bettina	Wampanoag Tribe of Gay Head (Aquinnah)	Tribal Government
Krevor, Brian	American Clean Power Association	Vessel Operator/End User
Diamond, Clayton	American Pilots' Association	Vessel Operator/End User
O'Shea, Brendan	American Pilots' Association	Vessel Operator/End User
Waine, Michael	American Sportfishing Association	Vessel Operator/End User
Khalsa, Atma	Avangrid	Vessel Operator/End User
Glasfeld, Michael	Bay State Cruise Company	Vessel Operator/End User
Kennedy, David	BoatU.S.	Vessel Operator/End User
Keating, Alanna	BoatU.S. Foundation	Vessel Operator/End User
Angers, Jeff	Center for Sportfishing Policy	Vessel Operator/End User
Empey, Eric	DEME Group	Vessel Operator/End User
Sturke, Peter	Dominion Energy	Vessel Operator/End User
Guntermann, Wolfram	Hapag-Lloyd AG	Vessel Operator/End User
Morse, Laura	Invenergy LLC	Vessel Operator/End User
Parker, Jeffrey	Kirby Corp	Vessel Operator/End User
White, Steve	Marine Exchange of Alaska	Vessel Operator/End User
Drenkard, Molly	National Marine Manufacturers Association (NMMA)	Vessel Operator/End User
Spawn, Ariana	Orsted	Vessel Operator/End User
Patch, Richard	Passenger Vessel Association (PVA)	Vessel Operator/End User
Loring, Joseph	Savannah Pilots	Vessel Operator/End User
Perry, Ruth	Shell Renewables and Energy Solutions	Vessel Operator/End User
Guttenplan, Katherine	Tetra Tech	Vessel Operator/End User
Marsjanik, Elizabeth	Vineyard Offshore	Vessel Operator/End User
Wood-Thomas, Bryan	World Shipping Council	Vessel Operator/End User

Remote Participant

Name	Affiliation	Sector
Christie, Jeanne	Office of Congresswoman Pingree	Congressional
Walker, Harrison	Office of U.S. Senator Thom Tillis	Congressional
Peterson, Miranda	Rep. Frank Pallone	Congressional
Meckley, Chad	Senate Commerce (min)	Congressional
Hunter, Chelsea	Senate Committee on Commerce, Science, and Transportation	Congressional
Routt, Bianca	Senator Ed Markey	Congressional
Li, Caroline	Senator Ossoff	Congressional
Allard, Tyler	U.S. Rep. Seth Moulton	Congressional
Utter, Molly	U.S. Senate Commerce, Science, and Technology Committee (Majority)	Congressional
DePerte, Allison	Atlantic Marine Conservation Society	External Science/Academic
DiGiovanni, Robert	Atlantic Marine Conservation Society	External Science/Academic
Merrick, Richard	Atlantic Scientific Review Group (ASRG)	External Science/Academic
Ono, Kathryn	Atlantic Scientific Review Group (ASRG)	External Science/Academic
Lang, Chris	Benioff Ocean Science Laboratory, UCSB	External Science/Academic
Rhodes, Rachel	Benioff Ocean Science Laboratory, UCSB	External Science/Academic
Ridings, Debbie	BHCC	External Science/Academic
Voss, Julika	BioConsult SH GmbH & Co. KG	External Science/Academic
Silber, Gregory	Biologist	External Science/Academic
Weinrich, Mason	Center for Coastal Studies/Whale Center of New England	External Science/Academic
Siemann, Liese	Coonamessett Farm Foundation	External Science/Academic
Clark, Christopher	Cornell University	External Science/Academic
Ubani, Solomon	Department of Social Sciences, Science Digest, Faisalabad-38090, Pakistan	External Science/Academic
Curtice, Corrie	Duke University	External Science/Academic
Nowacek, Douglas	Duke University	External Science/Academic
Schick, Rob	Duke University	External Science/Academic

Name	Affiliation	Sector
Tiwari, Ajay	Fugro B.V	External Science/Academic
Souder, Trisha	Geo SubSea LLC	External Science/Academic
Mallette, Sarah	George Mason University	External Science/Academic
Trudeau, Véronique	Green Marine	External Science/Academic
Aschettino, Jessica	HDR Inc.	External Science/Academic
Engelhaupt, Dan	HDR Inc.	External Science/Academic
Johnson, Zack	HiDef Aerial Surveying	External Science/Academic
Oryem, Paul	Innovium Marine and Associates	External Science/Academic
Kitchell, Lindsey	Johns Hopkins University Applied Physics Laboratory (JHU APL)	External Science/Academic
Morissette, Lyne	M - Expertise Marine	External Science/Academic
Harrington, Amalia	Maine Sea Grant	External Science/Academic
Halpin, Patrick	Marine Geospatial Ecology Lab, Duke University	External Science/Academic
Watts, Jes	Mid-Atlantic Regional Council on the Ocean	External Science/Academic
Haas, Sydney	New College of Florida	External Science/Academic
Knowlton, Amy	New England Aquarium	External Science/Academic
Hager, Mark	New England Marine Monitoring	External Science/Academic
Shantz, Phillip	New England Marine Monitoring	External Science/Academic
Gerrior, Pat	NOAA Fisheries - Retired	External Science/Academic
Getchell, Mike	North Atlantic Right Whale Recovery Plan Southeast Implementation Team (SEIT)	External Science/Academic
Kirby, Jordan	Protected Species Observer/Passive Acoustic Monitoring	External Science/Academic
Laspada, Christian	Regional Wildlife Science Collaborative for Offshore Wind (RWSC)	External Science/Academic
Brill, Deborah	Regional Wildlife Science Collaborative for Offshore Wind (RWSC) / Duke University	External Science/Academic
Yack, Tina	Research Scientist	External Science/Academic
Stokes, Ashley	Seacoast Science Center, Marine Mammal Rescue	External Science/Academic
Woodruff, Jess	Simrad Fisheries	External Science/Academic
Smith, Garrett	Simsi	External Science/Academic

Name	Affiliation	Sector
Stevens, Anna	SMRU Consulting	External Science/Academic
Napoli, Chelsi	Stony Brook University	External Science/Academic
Parks, Susan	Syracuse University	External Science/Academic
Wilson, David	The Biodiversity Consultancy	External Science/Academic
McShane, Tom	The Dewey Square Group	External Science/Academic
Klimkowski, Robert	UAS Consultant	External Science/Academic
Leiphardt, Callie	University of California Santa Barbara	External Science/Academic
Driscoll, CP	University of Maryland	External Science/Academic
Howes, Laura	University of Massachusetts Boston	External Science/Academic
Chirayath, Ved	University of Miami	External Science/Academic
Indeck, Katherine	University of New Brunswick	External Science/Academic
Lonati, Gina	University of New Brunswick Saint John	External Science/Academic
McLellan, Bill	University of North Carolina Wilmington	External Science/Academic
Meyer-Gutbrod, Erin	University of South Carolina	External Science/Academic
Trainer, Vera	University of Washington	External Science/Academic
Morgan, Allison	University of Washington-Student	External Science/Academic
Moore, Michael	Woods Hole Oceanographic Institution (WHOI)	External Science/Academic
Tang, Bo	Worcester Polytechnic Institute (WPI)	External Science/Academic
Stoni, Taylor	Bureau of Ocean Energy Management (BOEM)	Federal Government
Arzt, Tamara	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Ashford, Bronia	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Fish, David	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Fitzgerald, Shelly	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government

Name	Affiliation	Sector
Fraser, Jonathan	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Head, Jill	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Heckman, Andrea	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Hunter, Cheri	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Martin, Shannon	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Modrich, Jennifer	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Owens, Brandon	Bureau of Safety and Environmental Enforcement (BSEE)	Federal Government
Dwyer, Alexandra	Environmental Protection Agency - Region 1 New England	Federal Government
Wagner, Annalee	Intern with the US Navy Marine Mammal Program	Federal Government
Allen, Dee	Marine Mammal Commission	Federal Government
Brookens, Tiffini	Marine Mammal Commission	Federal Government
Heinemann, Dennis	Marine Mammal Commission	Federal Government
Onens, Phinn	Marine Mammal Health and Stranding Response Program	Federal Government
Peavey Reeves, Lindsey	National Marine Sanctuary Foundation / NOAA	Federal Government
Ryan, Kendra	National Renewable Energy Lab (NREL)	Federal Government
Angliss, Robyn	NOAA Fisheries, Alaska Fisheries Science Center	Federal Government
Eich, Anne Marie	NOAA Fisheries, Alaska Regional Office	Federal Government
Leonard, Kathleen	NOAA Fisheries, Alaska Regional Office	Federal Government
Malek, Jenna	NOAA Fisheries, Alaska Regional Office	Federal Government

Name	Affiliation	Sector
Grewal, Corie	NOAA Fisheries, Greater Atlantic Regional Fisheries Office	Federal Government
Schuler, Alicia	NOAA Fisheries, Greater Atlantic Regional Fisheries Office	Federal Government
Sisson, Nick	NOAA Fisheries, Greater Atlantic Regional Fisheries Office	Federal Government
Smith, Ainsley	NOAA Fisheries, Greater Atlantic Regional Fisheries Office	Federal Government
Moise, Meredith	NOAA Fisheries, Greater Atlantic Regional Fisheries Office - Affiliate	Federal Government
Stockwell, Georgia	NOAA Fisheries, Greater Atlantic Regional Fisheries Office - Affiliate	Federal Government
Galvez, Brian	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Hayes, Sean	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Henry, Allison	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Van Hoeck, Rebecca	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Van Parijs, Sofie	NOAA Fisheries, Northeast Fisheries Science Center	Federal Government
Naughten, Kate	NOAA Fisheries, Office of Assistant Administrator	Federal Government
Fellas, Christy	NOAA Fisheries, Office of Habitat Conservation	Federal Government
Anderson, Amy	NOAA Fisheries, Office of Law Enforcement	Federal Government
Boots, Benjamin	NOAA Fisheries, Office of Law Enforcement	Federal Government
Leslie, Jesse	NOAA Fisheries, Office of Law Enforcement	Federal Government
Corcoran, Kim	NOAA Fisheries, Office of Protected Resources	Federal Government
Dahl, Soren	NOAA Fisheries, Office of Protected Resources	Federal Government
Driskell, Rory	NOAA Fisheries, Office of Protected Resources	Federal Government
Esch, Carter	NOAA Fisheries, Office of Protected Resources	Federal Government

Name	Affiliation	Sector
Gahm, Meghan	NOAA Fisheries, Office of Protected Resources	Federal Government
Gatzke, Jennifer	NOAA Fisheries, Office of Protected Resources	Federal Government
Goldstein, Howard	NOAA Fisheries, Office of Protected Resources	Federal Government
Griffin, Mackenzie	NOAA Fisheries, Office of Protected Resources	Federal Government
Hardy, Robert	NOAA Fisheries, Office of Protected Resources	Federal Government
Hernandez, Allison	NOAA Fisheries, Office of Protected Resources	Federal Government
Keller, Elizabeth	NOAA Fisheries, Office of Protected Resources	Federal Government
Lang, Kaitlen	NOAA Fisheries, Office of Protected Resources	Federal Government
Lock, Karolyn	NOAA Fisheries, Office of Protected Resources	Federal Government
Manley, Steve	NOAA Fisheries, Office of Protected Resources	Federal Government
Marzin, Catherine	NOAA Fisheries, Office of Protected Resources	Federal Government
McMichael, Erin	NOAA Fisheries, Office of Protected Resources	Federal Government
Rowles, Teri	NOAA Fisheries, Office of Protected Resources	Federal Government
Salz, Ron	NOAA Fisheries, Office of Protected Resources	Federal Government
Spradlin, Trevor	NOAA Fisheries, Office of Protected Resources	Federal Government
Taylor, Jaclyn	NOAA Fisheries, Office of Protected Resources	Federal Government
Thornton, Steven	NOAA Fisheries, Office of Protected Resources	Federal Government
Gray, Laura	NOAA Fisheries, Office of Protected Resources - Affiliate	Federal Government
Hilt, Rachel	NOAA Fisheries, Office of Protected Resources - Affiliate	Federal Government
Taylor, Jessica	NOAA Fisheries, Office of Protected Resources - Affiliate	Federal Government

Name	Affiliation	Sector
Keene, Kenneth	NOAA Fisheries, Office of Science and Technology	Federal Government
Lettrich, Matthew	NOAA Fisheries, Office of Science and Technology - Affiliate	Federal Government
Belskis, Lisa	NOAA Fisheries, Southeast Fisheries Science Center	Federal Government
Fetherston, Elizabeth	NOAA Fisheries, Southeast Regional Office	Federal Government
Garrett, Allison	NOAA Fisheries, Southeast Regional Office	Federal Government
Meehan, Sean	NOAA Fisheries, Southeast Regional Office	Federal Government
Shervanick, Kara	NOAA Fisheries, Southeast Regional Office	Federal Government
Solari, Steve	NOAA Fisheries, Southeast Regional Office	Federal Government
Feldman, Lindsey	NOAA Fisheries, Southeast Regional Office - Affiliate	Federal Government
Hazen, Elliott	NOAA Fisheries, Southwest Fisheries Science Center	Federal Government
Dishman, Diana	NOAA Fisheries, West Coast Regional Office	Federal Government
Fahy, Tina	NOAA Fisheries, West Coast Regional Office	Federal Government
Lawson, Dan	NOAA Fisheries, West Coast Regional Office	Federal Government
Miller, Hanna	NOAA Fisheries, West Coast Regional Office	Federal Government
Ruvelas, Penny	NOAA Fisheries, West Coast Regional Office	Federal Government
Wright, Darren	NOAA National Ocean Service, Office of Coast Survey	Federal Government
DeCola, Peter	NOAA National Ocean Service, Office of National Marine Sanctuaries	Federal Government
Hastings, Sean	NOAA National Ocean Service, Office of National Marine Sanctuaries	Federal Government
Ingulsrud, Laura	NOAA National Ocean Service, Office of National Marine Sanctuaries	Federal Government

Name	Affiliation	Sector
Lyman, Ed	NOAA National Ocean Service, Office of National Marine Sanctuaries	Federal Government
Morten, Jessica	NOAA National Ocean Service, Office of National Marine Sanctuaries	Federal Government
Silva, Tammy	NOAA National Ocean Service, Office of National Marine Sanctuaries	Federal Government
Wiley, David	NOAA National Ocean Service, Office of National Marine Sanctuaries	Federal Government
Ben-David, Deborah	NOAA Office of General Counsel	Federal Government
Heckwolf, Joseph	NOAA Office of General Counsel	Federal Government
Sakowski, Scott	NOAA Office of General Counsel	Federal Government
Dziedzic, Katherine	NOAA Office of Legislative Affairs	Federal Government
Weise, Michael	Office of Naval Research	Federal Government
Richlen, Michael	Pacific Northwest National Laboratory (PNNL)	Federal Government
Severy, Mark	Pacific Northwest National Laboratory (PNNL)	Federal Government
Lebow, Kathryn	U.S. Army Corps of Engineers	Federal Government
Aaronson, Benjamin	U.S. Coast Guard	Federal Government
Adams, William Christian	U.S. Coast Guard	Federal Government
Ford, Randall	U.S. Coast Guard	Federal Government
Hogan, Jessica	U.S. Coast Guard	Federal Government
Jones, Noel	U.S. Coast Guard	Federal Government
Ramassini, Steven	U.S. Coast Guard	Federal Government
Saunders, Chandra	U.S. Coast Guard	Federal Government
Woodbridge, Margaret	U.S. Coast Guard	Federal Government
Mazzuca, Lori	U.S. Coast Guard, Pacific Area	Federal Government
LaMacchio, Elijah	U.S. Coast Guard, Sector Southeastern New England	Federal Government
Bourbeau, David	U.S. Coast Guard, WWM-1	Federal Government
Azzara, Alyson	U.S. Department of Transportation, Maritime Administration	Federal Government
Cowan, Christy	U.S. Navy	Federal Government
Dour, Margaret	U.S. Navy	Federal Government

Name	Affiliation	Sector
Fowler, Amy	U.S. Navy	Federal Government
Gormley, Jaime	U.S. Navy	Federal Government
Sleeman, Stephanie	U.S. Navy	Federal Government
Rees, Deanna	U.S. Navy, NAVFAC Atlantic	Federal Government
Creager, Shelby	U.S. Navy, NAVSEA	Federal Government
Bell, Joel	U.S. Navy, NAVFAC Atlantic	Federal Government
Bort, Jacqueline	U.S. Navy, NAVFAC LANT	Federal Government
Dargavel, Ryan	Canadian Coast Guard	International Government
Emond, Susanne	Canadian Coast Guard	International Government
Austin, Deborah	Fisheries and Oceans Canada (DFO)	International Government
Ellis, Lauren	Fisheries and Oceans Canada (DFO)	International Government
Goit, Monique	Fisheries and Oceans Canada (DFO)	International Government
Labbe, Adele	Fisheries and Oceans Canada (DFO)	International Government
Landry, Melissa	Fisheries and Oceans Canada (DFO)	International Government
Mark, Hannah	Fisheries and Oceans Canada (DFO)	International Government
Millar Lapointe, Genevieve	Fisheries and Oceans Canada (DFO)	International Government
Pisano, Olivia	Fisheries and Oceans Canada (DFO)	International Government
Vanderlaan, Angelia	Fisheries and Oceans Canada (DFO)	International Government
Walker, Robyn	Fisheries and Oceans Canada (DFO)	International Government
Beaufils, Pierre	Transport Canada (TC)	International Government
Doucette, Paula	Transport Canada (TC)	International Government
Gopeechund, Vandana	Transport Canada (TC)	International Government
Lacaille, Élise	Transport Canada (TC)	International Government
Lecavalier, Laurence	Transport Canada (TC)	International Government
Lessard, Josée	Transport Canada (TC)	International Government
Mansfield, Sam	Transport Canada (TC)	International Government
McKeeman, Mark	Transport Canada (TC)	International Government
Nolet, Veronique	Transport Canada (TC)	International Government

Name	Affiliation	Sector
Terpenning, Meghan	Transport Canada (TC)	International Government
Talbot, Stephanie	Transport Canada (TC) - Marine Safety & Security	International Government
Esposito, Tony	International Boat Industry (IBI)	Media
Walton, Marsha	Media	Media
Hain, Jim	Right Whale News (Editor)	Media
Pulver, Dinah	USA Today	Media
Moore, Kirk	WorkBoat / National Fisherman	Media
Timm, Richard	Amelia Island Whale Ambassadors	NGO
Hancock, Georgia	Animal Welfare Institute	NGO
O'Connell, Kathleen	Animal Welfare Institute	NGO
Durham, Kimberly	Atlantic Marine Conservation Society	NGO
Stepanuk, Julia	Biodiversity Research Institute	NGO
Albert, Julie	Blue World Research Institute	NGO
Stolen, Megan	Blue World Research Institute	NGO
Lougheed, Heather	BoatU.S.	NGO
Brown, Moira	Canadian Whale Institute	NGO
Durette-Morin, Delphine	Canadian Whale Institute	NGO
Brillant, Sean	Canadian Wildlife Federation	NGO
Jian-Javdan, Shiva	Canadian Wildlife Federation	NGO
Mayette, Alexandra	Canadian Wildlife Federation	NGO
Sakashita, Miyoko	Center for Biological Diversity (CBD)	NGO
Bartlett, Annie	Center for Coastal Studies (CCS)	NGO
James, Amy	Center for Coastal Studies (CCS)	NGO
Millan Ambert, Ashley	Center for Coastal Studies (CCS)	NGO
Schosberg, Ryan	Center for Coastal Studies (CCS)	NGO
Azubel, Avihai	Deep Voice Foundation	NGO
Moss, Daniel	Defenders of Wildlife	NGO
Collins, Kathleen	International Fund for Animal Welfare (IFAW)	NGO
Gallagher, Patrick	Marine Exchange of Puget Sound	NGO
Murch, Chad	Marine Mammal Stranding Team	NGO
Ellis, Sara	Marineland Right Whale Project	NGO

Name	Affiliation	Sector
Aronson, Rachel	Maritime Blue, Quiet Sound	NGO
Lam, Hannah	National Fish and Wildlife Foundation (NFWF)	NGO
Miller, Michaela	National Marine Sanctuary Foundation	NGO
Wells, Greg	National Marine Sanctuary Foundation	NGO
Li, Wei	Natural Resources Defence Council (NRDC)	NGO
Covington, Kellie	Nekton Team	NGO
Mahoney Robinson, Kara	New England Aquarium	NGO
Redfern, Jessica	New England Aquarium	NGO
Feinberg, Pasha	Ocean Conservancy	NGO
Freeman, Michael	Ocean Conservancy	NGO
Stocker, Michael	Ocean Conservation Research	NGO
Bachert, Ashley	Ocean Wise	NGO
Dracott, Karina	Ocean Wise	NGO
Robinson, Chloe	Ocean Wise	NGO
Jones, Kayla	Ocean Wise Conservation Association	NGO
Aines, Alex	Oceana	NGO
Glass-Hill, Hermina	Oceana	NGO
O'Donnell, Katie	Oceana	NGO
Nielsen, Kimberly	Oceans Initiative	NGO
Keaveney, Emer	ORCA Ireland	NGO
Keaveney, Emer	ORCA Ireland	NGO
Keaveney, Emer	ORCA Ireland	NGO
Keaveney, Emer	ORCA Ireland	NGO
Edmonds, Melissa	Southern Environmental Law Center	NGO
George, Kathi	The Marine Mammal Center	NGO
Humberstone, Jennifer	The Nature Conservancy	NGO
O'Morchoe, Caitlin	The Quiet Sound Program at Washington Maritime Blue	NGO
Purcell, Elizabeth	Turtle Island Restoration Network (TIRN)	NGO
Brogan, Gib	Vessel Operations; Policy	NGO

Name	Affiliation	Sector
Rowlands, Carrie	Virginia Aquarium Stranding Response Program	NGO
Wright, Debbie	Volusia County Marine Mammal Stranding Team	NGO
Fogarty, Grace	Wildlife Conservation Society	NGO
King-Nolan, Carissa	Wildlife Conservation Society	NGO
Papadopoulos, Maria	Wildlife Conservation Society	NGO
Rekdahl, Melinda	Wildlife Conservation Society	NGO
Rosenbaum, Howard	Wildlife Conservation Society	NGO
Trabue, Sarah	Wildlife Conservation Society	NGO
Kadwa, Farheen	World Wildlife Fund (WWF) Canada	NGO
Powell, Kristen	World Wildlife Fund (WWF) Canada	NGO
Scott, Kailee	World Wildlife Fund (WWF) Canada	NGO
Spiessl, Maureen	City of Savannah	Other
McCoy, Caitlin	Commission for Environmental Cooperation	Other
Coffey, Timothy	Independent	Other
Bennett, Brittiny	Independent Consultant	Other
Haag, Fredrik	International Maritime Organization (IMO)	Other
McCarron, David	New England Fishery Management Council	Other
Maroju, Purnend	Non-Government	Other
Berstler, Gretchen	Self	Other
Jones, Sharon	Supporter	Other
Costidis, Alexander	Unaffiliated	Other
Bartling, Ryan	California Department of Fish and Wildlife	State Government
Crum, Nathan	Florida Fish and Wildlife Conservation Commission	State Government
Jackson, Katie	Florida Fish and Wildlife Conservation Commission	State Government
Kindley, Emma	Florida Fish and Wildlife Conservation Commission	State Government
Pitchford, Tom	Florida Fish and Wildlife Conservation Commission	State Government

Name	Affiliation	Sector
Dodd, Mark	Georgia Department of Natural Resources	State Government
Thompson, Jessica	Georgia Department of Natural Resources	State Government
Murray, Anita	Maine Department of Marine Resources	State Government
Summers, Erin	Maine Department of Marine Resources	State Government
Ware, Megan	Maine Department of Marine Resources	State Government
Wilkinson, Erin	Maine Department of Marine Resources	State Government
Driscoll, C	Maryland Department of Natural Resources	State Government
Whitmore, Kelly	Massachusetts Department of Marine Fisheries	State Government
Burke, Erin	Massachusetts State Government	State Government
Genievich, Heather	New Jersey Department of Environmental Protection	State Government
McGarigal, Caitlin	New Jersey Department of Environmental Protection	State Government
Fede, Catherine	New York State Department of Environmental Conservation	State Government
Rickard, Meghan	New York State Department of Environmental Conservation	State Government
Brown, Chris	South Carolina Department of Natural Resources	State Government
O'Brien, Jonathan	South Carolina Department of Natural Resources	State Government
Von Harten, Herman	South Carolina Department of Natural Resources	State Government
Smott, Somers	Virginia Marine Resources Commission	State Government
Galuska, Tara	Washington State, Governor's Salmon Recovery Office	State Government
Quiroga, Pablo	Alseamar	Tech/Engineer/Manufacturer
Pappu, Ravi	Apeiron Labs	Tech/Engineer/Manufacturer
Veirs, Scott	Arcatia	Tech/Engineer/Manufacturer
Parker, Alex	Astraeus Ocean Systems	Tech/Engineer/Manufacturer
Campbell, Elise	Avangrid	Tech/Engineer/Manufacturer

Name	Affiliation	Sector
Rudzinsky, Maximilian	Avangrid	Tech/Engineer/Manufacturer
Pilot, Juergen	Avangrid Renewables	Tech/Engineer/Manufacturer
McGurrin, Rob	BlueiQ	Tech/Engineer/Manufacturer
Eaton, Ross	Charles River Analytics	Tech/Engineer/Manufacturer
Barkaszi, Mary Jo	CSA Ocean Sciences	Tech/Engineer/Manufacturer
Gruenwald, Dave	Davinci Engineering	Tech/Engineer/Manufacturer
Faran, Michael	Deep Voice Foundation	Tech/Engineer/Manufacturer
Michelashvili, Michael Moshe	Deep Voice Foundation	Tech/Engineer/Manufacturer
Land, Eva	Equinor	Tech/Engineer/Manufacturer
Zimmerman, Matthew	FarSounder, Inc.	Tech/Engineer/Manufacturer
Warrillow, Jennifer	Fathom Science, Inc.	Tech/Engineer/Manufacturer
Milanette, Tom	FLIR Maritime Thermal Imaging	Tech/Engineer/Manufacturer
Klyver, Zack	Gotham Whale	Tech/Engineer/Manufacturer
Dawson, Daniel	Integral Consulting Inc.	Tech/Engineer/Manufacturer
Raghukumar, Kaustubha	Integral Consulting Inc.	Tech/Engineer/Manufacturer
Antipina, Marin	JASCO Applied Sciences	Tech/Engineer/Manufacturer
Carr, Scott	JASCO Applied Sciences	Tech/Engineer/Manufacturer
Delarue, Julien	JASCO Applied Sciences	Tech/Engineer/Manufacturer
Hillers, Michael	Kongsberg Discovery	Tech/Engineer/Manufacturer
Echols, Kelly	LeVanta Tech	Tech/Engineer/Manufacturer
Moniz, Rhonda	LeVantaTech - Underwater Investigative Group (UIG)	Tech/Engineer/Manufacturer
Locke, James	Marine Electronics Equipment Provider for Marine Pilots	Tech/Engineer/Manufacturer
Tingen, Sarah	Master's Microbial Biotechnologist North Carolina State University	Tech/Engineer/Manufacturer
Allegra, Alexis	MITRE	Tech/Engineer/Manufacturer
Angilella, Alex	MITRE	Tech/Engineer/Manufacturer
Black, Zoe	MITRE	Tech/Engineer/Manufacturer
Gladding, Colin	MITRE	Tech/Engineer/Manufacturer
Lindblom, Margo	MITRE	Tech/Engineer/Manufacturer
Rolt, Kenneth	MITRE	Tech/Engineer/Manufacturer
Davenport, Christian	MITRE FFRDC	Tech/Engineer/Manufacturer
Nahum Gefen, Shai	ML Engineer	Tech/Engineer/Manufacturer

Name	Affiliation	Sector
Donlan, Paul	Mysticetus LLC	Tech/Engineer/Manufacturer
Kane, Brian	National Marine Electronics Association (NMEA)	Tech/Engineer/Manufacturer
Reedenauer, Mark	National Marine Electronics Association (NMEA)	Tech/Engineer/Manufacturer
Sharkey, Eddie	National Marine Electronics Association (NMEA)	Tech/Engineer/Manufacturer
Malagon, Jo	Navfeas, Inc.	Tech/Engineer/Manufacturer
Malagon, Sam	Navfeas, Inc.	Tech/Engineer/Manufacturer
Gallaudet, Tim	Ocean STL Consulting LLC	Tech/Engineer/Manufacturer
Awwad, Shadi	Oceaneering International inc.	Tech/Engineer/Manufacturer
Bouvier, Madeleine	Open Ocean Robotics	Tech/Engineer/Manufacturer
Ziegwied, Andy	Open Ocean Robotics	Tech/Engineer/Manufacturer
Harrer, Shannon	Palantir	Tech/Engineer/Manufacturer
Jenkins, Carmen	Palantir	Tech/Engineer/Manufacturer
Banning, Jackie	REGENT	Tech/Engineer/Manufacturer
King, James	Roffer's Ocean Fishing Forecasting Service, Inc. (ROFFS)	Tech/Engineer/Manufacturer
Upton, Matthew	Roffer's Ocean Fishing Forecasting Service, Inc. (ROFFS)	Tech/Engineer/Manufacturer
Schwartz, Sheri	RPS Group	Tech/Engineer/Manufacturer
Sparling, Kimberly	Saildrone	Tech/Engineer/Manufacturer
Kukulya, Amy	Scibotics LLC	Tech/Engineer/Manufacturer
Amdur, Adam	Scientific Solutions, inc	Tech/Engineer/Manufacturer
Stein, Peter	Scientific Solutions, Inc.	Tech/Engineer/Manufacturer
Darling, Donald	SeaRobotics Corporation	Tech/Engineer/Manufacturer
Chevitarese, Marcus	Sightir Inc.	Tech/Engineer/Manufacturer
Mueller, Tom	Simsi	Tech/Engineer/Manufacturer
Lichtenheld, Tosca	Sofar Ocean	Tech/Engineer/Manufacturer
Höschle, Caroline	SPACEWHALE - BioConsult SH	Tech/Engineer/Manufacturer
Gruhl, Amy	SSI	Tech/Engineer/Manufacturer
Murphy, Adam	Teledyne FLIR Maritime	Tech/Engineer/Manufacturer
Lanterman, Kim	Tetra Tech	Tech/Engineer/Manufacturer
Misa, Paula	Tetra Tech	Tech/Engineer/Manufacturer
Phillips, Becky	Tetra Tech	Tech/Engineer/Manufacturer

Name	Affiliation	Sector
Campbell, Jasper	ThayerMahan, Inc.	Tech/Engineer/Manufacturer
Glander, Christian	ThayerMahan, Inc.	Tech/Engineer/Manufacturer
Grimes, Doug	ThayerMahan, Inc.	Tech/Engineer/Manufacturer
Halvordson, Alexandra	ThayerMahan, Inc.	Tech/Engineer/Manufacturer
Lopes, Kevin	ThayerMahan, Inc.	Tech/Engineer/Manufacturer
Murphy, Elizabeth	ThayerMahan, Inc.	Tech/Engineer/ Manufacturer
Salazar, Anthony	ThayerMahan, Inc.	Tech/Engineer/ Manufacturer
McIntyre, George	Wavefront Systems Ltd	Tech/Engineer/ Manufacturer
Charry Tissier, Emily	Whale Seeker, Inc.	Tech/Engineer/ Manufacturer
Johnson, Michael	Mashantucket Pequot Tribal Historic Preservation Office	Tribal Government
Weeden, David	Mashpee Wampanoag Tribe	Tribal Government
Brown, Phillip	Shinnecock Indian Tribe	Tribal Government
Devine, Kevin	Wampanoag Tribe of Gay Head (Aquinnah)	Tribal Government
Roy, Kathryn	AECOM	Vessel Operator/End User
Hughes, Glenn	American Sportfishing Association	Vessel Operator/End User
Weber, Theresa	American Sportfishing Association	Vessel Operator/End User
Morcroft, Liam	American Waterway Operators	Vessel Operator/End User
Hagger, Carly	Atlantic Shores Offshore Wind	Vessel Operator/End User
Kaubisch, Isabel	Attentive Energy	Vessel Operator/End User
Whitehead, Edward	Attentive Energy	Vessel Operator/End User
Lawler, Bob	Boston Harbor Cruises	Vessel Operator/End User
Duke, David	BP	Vessel Operator/End User
Gordon, Lee	Brunswick Corporation	Vessel Operator/End User
Schliewe, Stacy	Center for Sportfishing Policy	Vessel Operator/End User
Metcalf, Kathy	Chamber of Shipping of America	Vessel Operator/End User
Cameron, John	Charleston Branch Pilots Association	Vessel Operator/End User
Tezza, Luke	Charleston Pilots	Vessel Operator/End User
Walters, Crayton	Charleston Pilots	Vessel Operator/End User
Gallinaro, Meghan	Chevron	Vessel Operator/End User
Naughton, Brandi	Chevron	Vessel Operator/End User
Marion, Labrousse	CMA CGM	Vessel Operator/End User

Name	Affiliation	Sector
Roux, Caroline	CMA CGM	Vessel Operator/End User
Baughman, Kelly	Crowley	Vessel Operator/End User
Gill, Sascha	Cruise Line International Association	Vessel Operator/End User
Gross, Joseph	d'Amico Shipping USA Limited	Vessel Operator/End User
Curic, Dusan	Diamond Offshore Wind	Vessel Operator/End User
Cowan, David	Diamond Offshore Wind, Maine Research Array	Vessel Operator/End User
Gaston, Caleb	Dominion Energy	Vessel Operator/End User
Lirette, Brent	Edison Chouest Offshore	Vessel Operator/End User
Carduner, Jordan	Equinor	Vessel Operator/End User
Dupont, Jennifer	Equinor	Vessel Operator/End User
Aranke, Naval	Executive Shipping Services (USA) Inc	Vessel Operator/End User
Olsen, Virginia	Fisherman	Vessel Operator/End User
Winters, Gretchen	Florida Harbor Pilots Association	Vessel Operator/End User
Daves, Nancy	Georgia Interfaith Power and Light	Vessel Operator/End User
Cole, Melinda	Guysborough Co. Inshore Fishermen's Assoc	Vessel Operator/End User
Schrader, Rolada	Guysborough County Inshore Fishermen's Association (GCIFA)	Vessel Operator/End User
Dupuis, Pierre	Homarus, (Maritime Fishermen Union Science Branch)	Vessel Operator/End User
Lilly, Laura	Hyannis Whale Watcher Cruises	Vessel Operator/End User
DiDomenico, Greg	Lund's Fisheries	Vessel Operator/End User
McCarron, Patrice	Maine Lobstermen's Association	Vessel Operator/End User
Tokowicz, Chad	Marine Retailers Association of the Americas	Vessel Operator/End User
Lyman, Stephen	Maritime Association of the Port of NY & NJ	Vessel Operator/End User
Crabtree, Clay	National Marine Manufacturers Association (NMMA)	Vessel Operator/End User
Whitesell, Sharon	Orsted	Vessel Operator/End User
Picherit, Marie-Lou	Orsted - Operations	Vessel Operator/End User
Welch, Edmund	Passenger Vessel Association (PVA)	Vessel Operator/End User
Sprague, Phineaas	Portland Yacht Services Inc.	Vessel Operator/End User

Name	Affiliation	Sector
Soltero, Luis	PredictWind	Vessel Operator/End User
Gies, Meaghan	Royal Caribbean Group	Vessel Operator/End User
Hackley, Elizabeth	Royal Caribbean Group	Vessel Operator/End User
Kozhuharov, Stan	Royal Caribbean Group	Vessel Operator/End User
Pyc, Cynthia	RWE Renewables	Vessel Operator/End User
Thompson, Trey	Savannah Pilots Association	Vessel Operator/End User
Zales, Robert	Southeastern Fisheries Association (Executive Director)	Vessel Operator/End User
Sumner, Todd	U.S. Wind	Vessel Operator/End User
McIntyre, Jennifer	Vancouver Fraser Port Authority	Vessel Operator/End User
Emo, Catherine	Virgin Voyages	Vessel Operator/End User
Koumasidis, Eleftherios	Virgin Voyages	Vessel Operator/End User
Hawn, Robert	West Gulf Maritime Association (WGMA)	Vessel Operator/End User
Neyman, Roy	Yacht Operator	Vessel Operator/End User

February 2024

NOAA FISHERIES

Office of Protected Resources

About the Workshop

The North Atlantic Right Whale (NARW) Vessel Strike Risk Reduction Technology Workshop aims to explore and promote new technologies to reduce vessel strike risk.

This factsheet highlights aspects of NARW biology and ecology that influence the risk of mortality from vessel strikes and/or the efficacy of risk reduction measures (including detection methods). It is not intended as a comprehensive review.

North Atlantic Right Whale Facts Relevant to Vessel Strike Risk

Endangered North Atlantic right whales are approaching extinction. There are approximately 360 individuals remaining, including fewer than 70 reproductively active females. Human impacts continue to threaten the survival of this species.

DISTRIBUTION AND HABITAT

- NARWs primarily occur in Atlantic coastal waters on the continental shelf.
- They are present in U.S. waters year round with nearly the entire population found along the U.S. East Coast between November and early May.
- The population migrates seasonally and may travel alone or in small groups.
- They forage year round off New England and intermittently off the Mid-Atlantic coast (mostly in winter/early spring). In late spring, many move into Canadian waters (and farther afield) to feed, returning to U.S. waters in late fall.
- Some travel more than 1,000 miles from these feeding grounds to the shallow, coastal waters of their calving grounds off of South Carolina, Georgia, and northeastern Florida each fall.
- Recent broad-scale NARW distribution shifts began in 2010 or 2011.
  - Sightings increased in Cape Cod Bay, Massachusetts, USA and in two lesser known historical feeding habitats: one south of Nantucket, Massachusetts and one in the Gulf of St. Lawrence, Canada.
  - Passive acoustic data also show an increased occurrence of NARW calls off the Mid-Atlantic.
- Habitat use varies substantially by age, sex, behavior, and across years.
- The location of much of the population is unknown for most of the year and exposure to human activities in these locations is unknown.

Top photo: Clearwater Marine Aquarium Research Institute, NOAA permit 26919. Bottom: Florida Fish and Wildlife Conservation Commission, NOAA permit #15488

BEHAVIORS AND CHARACTERISTICS THAT PLACE NARWs AT RISK OF VESSEL STRIKES

NARWs are particularly vulnerable to vessel strikes due to their coastal distribution and frequent occurrence at or near the water surface. This exposes them to interactions with numerous types of vessels of all sizes and drafts. In fact, NARWs have the highest number of vessel strikes per capita of any large whale population in the world.

NARWs spend a significant amount of time at or near the surface for a variety of reasons:

- **Reproduction:** NARW mothers nurse their calves for up to a year following birth. During this period mother/calf pairs are frequently found at or near the water surface, and during the calf's first several months are often resting. Lactating baleen whales are known to maintain close proximity with their calves and modify their behavior to accommodate their calf's limited abilities (i.e., take shallower and shorter dives).
- **Foraging Behavior:** NARWs are known to forage both at the surface and at depth.
  - In U.S. waters, NARWs mostly skim feed at the water surface during winter and spring.
  - Skim feeding NARWs spend much of their time just below the surface where they cannot be seen but are shallow enough to be vulnerable to strikes from vessels of all sizes.
  - There is a strong correlation between NARWs dive depth and the depth of their prey. NARW prey distribution changes seasonally and vertical distribution has been found to change between day and night.
- **Physiology:** NARW's thick blubber means they are slightly, positively buoyant. As a result, they require more energy and force to dive which may reduce their ability to rapidly maneuver away from oncoming vessels. Also, to maximize swim efficiency while traveling or migrating, smaller NARWs travel at depths closer to the surface than larger whales.
- **Behavior:** There is variability in surface-related behavior within and between NARW demographic groups (i.e., age, sex) that makes it difficult to effectively predict or define universal behavioral patterns. NARWs may be less attentive to surrounding activity and noise while skim feeding, nursing, and mating, which frequently occur at the ocean surface.

SURFACE TIMES ESTIMATED FROM TAGGING STUDIES

On average, NARWs on the feeding grounds during the spring spent between 72 percent and 84 percent of their time in the upper 10 meters of the water column.

On the calving grounds, lactating NARWs spent up to 80 percent of their time at depths less than or equal to 3.5 meters, while other demographic groups in the region spent a maximum of 30 percent within that same depth range.

Tagging NARWs is logistically challenging and limited by a number of factors including whale health concerns, technology restrictions, and permitting requirements.

The orange suction cup tag is attached to the back of endangered North Atlantic right whale "Smoke" (#2605). The inset shows the details on the tag. Credit: HDR Inc. (NOAA permit #21482).

NARW RESPONSE TO VESSELS

Our understanding of NARW perception and response to vessels is incomplete. Modeling indicates that NARWs regularly encounter vessels and it is likely that they detect and avoid these vessels to some degree. However a variety of factors may compromise the acoustic or visual cues a whale can use to detect and localize an oncoming vessel. NARWs have been observed to ignore recordings of large vessel sounds. Whales, including NARWs, may also become habituated to vessel noise.

OTHER INFORMATION THAT MAY INFORM RISK REDUCTION STRATEGIES

The time NARWs spend at different ocean depths affects their ability to be detected through ***visual monitoring methods***.

- Visual monitoring methods require whales to be visible at or near the surface to be detected.
- When relying on visual cues to detect NARWs, one should consider that whales may be present in the area at greater ocean depths and not be visible for detection.

The amount of time NARWs spend vocalizing and the type of calls generated affect our ability to detect them via ***acoustic monitoring methods***.

- NARW calling behavior has been characterized as ephemeral, highly variable, and dependent on their behavior rather than the number of individuals.
- Calling rates vary based on behavior. For example, NARWs have been found to vocalize less during foraging activities and more during socializing activities.
- NARW mother-calf pairs demonstrate very low call rates in the Southeast Region and researchers have noted the limited propagation of these calls in shallow waters. This is a very important consideration if relying upon acoustic cues as a method for detecting NARW mother-calf pairs.
- Cetacean species such as NARWs may alter their vocal behavior in response to approaching survey vessels, which affects their ability to be detected from vessel-based acoustic monitoring tools.

Learn more about North Atlantic Right Whales at:
https://www.fisheries.noaa.gov/species/north-atlantic-right-whale

OR scan this code:

References

Baille, L.M.R. and D.P. Zitterbart. 2022. Effectiveness of surface-based detection methods for vessel strike mitigation of North Atlantic right whales. Endanger Species Res 49:57-69. https://doi.org/10.3354/esr01202

Baumgartner, M.F., Wenzel, F.W., Lysiak, N.S.J., and M.R. Patrician. 2017. North Atlantic right whale foraging ecology and its role in human-caused mortality. Mar Ecol Prog Ser 581:165-181. https://doi.org/10.3354/meps12315

Crowe, L.M., Brown, M.W., Corkeron, P.J., Hamilton, P.K., Ramp, C., *et al*. 2021. In plane sight: a mark-recapture analysis of North Atlantic right whales in the Gulf of St. Lawrence. Endanger Species Res 46:227-251. https://doi.org/10.3354/esr01156

Cusano, D.A., Conger, L.A., Van Parijs, S.M., and S.E. Parks. 2018. Implementing conservation measures for the North Atlantic right whale: considering the behavioral ontogeny of mother-calf pairs. Anim Conserv 22(3):228-237. https://doi.org/10.1111/acv.12457

Davis, G.E., Baumgartner, M.F., Bonnell, J.M., Bell, J., Berchok, C., *et al.* 2017. Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014. Sci. Rep. 7:13460. https://doi.org/10.1038/s41598-017-13359-3

Dombroski, J.R.G., Parks, S.E., and D.P. Nowacek. 2021. Dive behavior of North Atlantic right whales on the calving ground in the Southeast USA: implications for conservation. Endanger Species Res 46:35-48. https://doi.org/10.3354/esr01141

Fonnesbeck, C.J., Garrison, L., Ward, L., and R. Baumstark. 2008. Bayesian hierarchical model for evaluating the risk of vessel strikes on North Atlantic right whales in the SE United States. Endanger Species Res 6:87-94. https://doi.org/10.3354/esr00134

Franklin, K.J., Cole, T.V.N., Cholewiak, D., Duley, P.A., Crowe, L., *et al*. 2022. Using sonobuoys and visual surveys to characterize North Atlantic right whale (*Eubalaena glacialis*) calling behavior in the Gulf of St. Lawrence. Endanger Species Res 49:159-174. https://doi.org/10.3354/esr01208

Gowan, T.A., Ortega-Ortiz, J.G., Hosteller, J.A., Hamilton, P.K., Knowlton, A.R., *et al.* 2019. Temporal and demographic variation in partial migration of the North Atlantic right whale. Sci Rep 9:353. https://doi.org/10.1038/s41598-018-36723-3

Hain, J.H.W., Hampp, J.D., McKenney, S.A., Albert, J.A., and R.D. Kenney. 2013. Swim Speed, Behavior, and Movement of North Atlantic Right Whales (*Eubalaena glacialis*) in Coastal Waters of Northeastern Florida, USA. PLoS ONE 8(1):e54340. https://doi.org/10.1371/journal.pone.0054340

Harcourt, R., van der Hoop, J., Kraus, S., and E.L. Carrol. 2019. Future directions in *Eubalaena* spp: comparative research to inform conservation. Front Mar Sci 5:530. https://doi.org/10.3389/fmars.2018.00530

Hayes, S.A., Josephson, E., Maze-Foley, K., Rosel, P.E., McCordic, J., *et al* (editors). 2023. US Atlantic and Gulf of Mexico Marine Mammal Stock Assessments 2022. NOAA Technical Memorandum NMFS NE 304:262 p. https://doi.org/10.25923/42zk-w456

Kite-Powell, H.K., Knowlton, A.R., and M. Brown. 2007. Modeling the effect of vessel speed on right whale ship strike risk. Project report for NOAA/NMFS Project NA04NMF47202394, April 2007.

Laist, D.W., Knowlton, A.R., Mead, J.G., Collet, A.S., and M. Podesta. 2001. Collisions between ships and whales. Mar Mammal Sci 17(1):35-75. https://doi.org/10.1111/j.1748-7692.2001.tb00980.x

McKenna, M.F., Calambokidis, J., Oleson, E.M., Laist, D.W., and J.A. Goldbogen. 2015. Simultaneous tracking of blue whales and large ships demonstrates limited behavioral responses for avoiding collisions. Endanger Species Res 27:219-232. https://doi.org/10.3354/esr00666

Moore, M.J., Rowles, T.K., Fauquier, D.A., Baker, J.D., Biedron, I., *et al.* 2021. Assessing North Atlantic right whale health: threats, and development of tools critical for conservation of the species. Dis Aquat Organ 143:205-226. https://doi.org/10.3354/dao03578

Nousek McGregor, A.E. 2010. The cost of locomotion in North Atlantic right whales (*Eubalaena glacialis*). Dissertation, Duke University. 160p. Retrieved from https://hdl.handle.net/10161/3088. Accessed on: 11/02/2023.

Nowacek, D.P., Johnson, M.P., and P.L Tyack. 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. P Roy Soc Lond B Bio 271:227-231. https://doi.org/10.1098/rspb.2003.2570

Parks, S.E., Warren, J.D., Stamieszkin, K., Mayo, C.A. and D. Wiley. 2011. Dangerous dining: surface foraging of North Atlantic right whales increases risk of vessel collisions. Bio Letters 8(1):57-60. https://doi.org/10.1098/rsbl.2011.0578

Record, N.R., Runge, J.A., Pendleton, D.E., Balch, W.M., Davies, K.T.A., *et al.* 2019. Rapid climate-driven circulation changes threaten conservation of endangered North Atlantic right whales. Oceanography 32(2):162–169. https://doi.org/10.5670/oceanog.2019.201

Van Parijs, S.M., Clark, C.W., Sousa-Lima, R.S., Parks, S.E., Rankin, *et al.* 2009. Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Mar Ecol Prog Ser 395:21-36. https://doi.org/10.3354/meps08123

U.S. Secretary of Commerce
Gina M. Raimondo

Under Secretary of Commerce for Oceans and Atmosphere
Richard W. Spinrad, Ph.D.

Assistant Administrator for Fisheries
Janet Coit

FEBRUARY 2024

www.fisheries.noaa.gov

OFFICIAL BUSINESS

National Marine Fisheries Service
1315 East-West Highway
Silver Spring, MD 20910

February 2024

NOAA FISHERIES

Office of Protected Resources

General Vessel Information Relevant to Whale Strike Risk

About the Workshop

The North Atlantic Right Whale (NARW) Vessel Strike Risk Reduction Technology Workshop aims to explore and promote new technologies to reduce vessel strike risk.

This factsheet highlights information relevant to workshop discussions and is not meant to be comprehensive.

OBSERVATIONS CONCERNING VESSEL STRIKE RISK AND AVOIDANCE

- Vessels are becoming larger, faster, and more numerous, increasing the frequency and lethality of whale strikes.
- Whales are at risk of vessel strikes when present within or near the depth range overlapping with a vessel's draft. Further, hydrodynamic modeling indicates that submerged right whales in proximity to a large ship can actually be drawn towards the hull via the suction effect of the propeller.
- There are limited opportunities to detect a surfacing whale and, following detection, it takes time to to implement and effect a change in the vessel's operational state in order to avoid the whale.
- Whales can be challenging for mariners to detect, even when they are close to a vessel. Since 2005, in seven of eight NARW strike events reported by mariners operating vessels less than 65 feet in length, the vessel operators never saw the whales prior to the events.
- The distance between a vessel and a whale when first detected, along with the vessel's speed and maneuverability, influences the navigational options available to a mariner and their likely effectiveness in reducing strike risk.
- Smaller vessels are more likely to detect/feel a strike whereas larger vessels may be unaware that a strike has occurred.

Credit: Florida Fish and Wildlife Conservation Commission; NOAA permit #775-1600-10

Top: Credit: Florida Fish and Wildlife Conservation Commission; NOAA permit #775-1875
Middle: right whale #3853; Credit: Clearwater Marine Aquarium Research Institute; NOAA permit #549-1759
Bottom photo: Credit: Florida Fish and Wildlife Conservation Commission; NOAA permit #20556-01.

VESSEL CHARACTERISTICS THAT AFFECT VESSEL STRIKE RISK

- ***Size:*** Larger vessels have deeper drafts and larger strike zones.
- ***Maneuverability*:** Real-time strike avoidance by a vessel requires both detecting and avoiding a whale. Taking evasive action may be an unrealistic option for large vessels with limited maneuverability.
- ***Speed*:** Vessel speed influences the time available to detect a whale and react to the whale prior to a potential collision. Speed generally also impacts the severity of a strike, if one occurs.

MARINER CHARACTERISTICS THAT AFFECT VESSEL STRIKE RISK

- Mariners need ***adequate information and capabilities*** when deciding whether to take evasive action (e.g., change of vessel's course or speed) to avoid a detected whale.
- Mariners must have ***adequate communication systems and response times*** to take evasive actions.
- Mariners must ***analyze risks*** (e.g., human safety, vessel safety, environmental conditions, regulatory and best practice constraints) of changing the vessel's operational state in order to avoid a detected whale.

OTHER INFORMATION THAT MAY INFORM RISK REDUCTION STRATEGIES

- Substantial distances may be required for some vessels to change course or speed to avoid a detected whale.
- Vessel reaction time (time needed to change a vessel's operational state) is influenced by a vessel's maneuverability and the time between whale detection and action. This is informed by the reliable detection range of technology, the time it takes to alert the captain of the detected whale, and the decision-making process to take action.
- Slower speeds may accommodate a wider variety of real-time and near-real time whale detection options, which may also reduce the vessel crew's active involvement in whale detection, and provide more time to assess optimal evasive maneuvers.
- The size and restricted maneuverability of ocean going vessels likely limits their ability to detect a whale and take evasive action to avoid a strike.
- A variety of federal and state regulations, including specific navigational responsibilities, apply to vessels of different sizes, types, and operational states. These regulations can also vary depending on where a vessel is operating (e.g. shipping lanes, harbor entrance channel, etc.).

References

Baille, L.M.R. and D.P. Zitterbart. 2022. Effectiveness of surface-based detection methods for vessel strike mitigation of North Atlantic right whales. Endanger Species Res 49:57-69. https://doi.org/10.3354/esr01202

Garrison, L.P., Adams, J., Patterson, E.M., and C.P. Good. 2022. Assessing the risk of vessel strike mortality in North Atlantic right whales along the U.S. East Coast. NOAA Technical Memorandum NOAA NMFS-SEFSC-757: 42p. https://doi.org/10.25923/pcpj-0k72

Gende, S.M., Vose, L., Baken, J., Gabriele, C.M., Preston, R. and A.N. Hendrix. 2019. Active Whale Avoidance by Large Ships: Components and Constraints of a Complementary Approach to Reducing Ship Strike Risk. Front Mar Sci 6:592. https://doi.org/10.3389/fmars.2019.00592

Laist, D.W., Knowlton, A.R., Mead, J.G., Collet, A.S., and M. Podesta. 2001. Collisions between ships and whales. Mar Mammal Sci 17(1):35-75. https://doi.org/10.1111/j.1748-7692.2001.tb00980.x

Moore, M.J., Rowles, T.K., Fauquier, D.A., Baker, J.D., Biedron, I., *et al.* 2021. Assessing North Atlantic right whale health: threats, and development of tools critical for conservation of the species. Dis Aquat Organ 143:205-226. https://doi.org/10.3354/dao03578

National Marine Fisheries Service (NMFS). 2020. North Atlantic Right Whale (*Eubalaena glacialis*) Vessel Speed Rule Assessment. National Marine Fisheries Service, Office of Protected Resources, Silver Spring, MD.

Schoeman, R., Patterson-Abrolat, C. and S. Pion. 2020. A Global Review of Vessel Collisions with Marine Animals. Front Mar Sci 7:Article 292. https://doi.org/10.3389/fmars.2020.00292

Silber, G.K., Slutsky, J., and S. Bettridge. 2010. Hydrodynamics of a ship/whale collision. J Exp Mar Biol Ecol 391:10-19. https://doi.org/10.1016/j.jembe.2010.05.013

Silber, G.K., Bettridge, S., and D. Cottingham. 2009. Report of a workshop to identify and assess technologies to reduce ship strikes of large whales, 8-10 July, 2008, Providence, Rhode Island, U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-OPR-42. 55p. https://repository.library.noaa.gov/view/noaa/23529

Vanderlaan, A.S.M, and C.T. Taggart. 2007. Vessel collisions with right whales: the probability of lethal injury based on vessel speed. Mar Mammal Sci 23:144-156. https://doi.org/10.1111/j.1748-7692.2006.00098.x

Zitterbart, D.P., Kindermann, L., Burkhardt, E., and O. Boebel. 2013. Automatic round-the-clock detection of whales for mitigation from underwater noise impacts. PLoS ONE 8(8):e71217. https://doi.org/10.1371/journal.pone.0071217

U.S. Secretary of Commerce
Gina M. Raimondo

Under Secretary of Commerce
for Oceans and Atmosphere
Richard W. Spinrad, Ph.D.

Assistant Administrator for Fisheries
Janet Coit

FEBRUARY 2024

www.fisheries.noaa.gov

OFFICIAL BUSINESS

National Marine Fisheries Service
1315 East-West Highway
Silver Spring, MD 20910

Appendix 6: Detection and Classification Literature Review

List of Acronyms

AI	Artificial intelligence
ASV(s)	Autonomous surface vehicle(s)
ATR	Automatic target recognition
AUV	Autonomous underwater vehicle
BMAR(s)	Bottom–mounted acoustic recorder(s)
CNN	Convoluted neural networks
DCS	Detection and classification system
DL	Deep learning
DFO	Fisheries and Oceans Canada
eDNA	Environmental DNA
GPS	Global positioning system
HF	High frequency
IR	Infrared
LEO	Low–earth orbit
LIDAR	Light Detection and Ranging
ML	Machine learning
MMC	Marine Mammal Commission
MMO(s)	Marine mammal observer(s)
NARW(s)	North Atlantic right whale(s)
NOAA	National Oceanic and Atmospheric Administration
PAM	Passive acoustic monitoring
RPAS	Remotely piloted aircraft system
SAR	Synthetic aperture radar
UAS(s)	Unmanned aerial system(s)
UAV(s)	Uncrewed aerial vehicle(s)
USV(s)	Unmanned surface vehicle(s)
VHR	Very–high resolution

1. Introduction

North Atlantic right whale (*Eubaleana glacialis*; NARW or right whale) vessel strike risk is influenced by the location (in space and time) and behavior of whales, among other factors. Whale location and behavior data can be obtained directly through visual and acoustic detections, by tagging individuals or through remote detection methods. Once obtained, these data can be assessed to help determine if a risk reduction action is necessary and, if so, what action is appropriate under the Static, Dynamic, and Vessel–Specific Risk Reduction Scenarios presented in Chapter 4 of this report. Here, we review methods and technologies currently used for or with the potential to detect and classify NARWs and their relevant characteristics and potential applicability to the three Scenarios. This Appendix focuses on technology and methods to directly detect NARWs—indirect measures and proxies are discussed in Chapter 6 (e.g., zooplankton monitoring, dimethyl sulfide (DMS), environmental correlates). General concepts and considerations applicable to whale detection technology are presented first accompanied by some select examples. Following this, technology types are discussed individually, including how these general considerations specifically apply to each. Due to the volume of literature on detection and classification technology, this information is being provided here rather than the main body of the report. This Appendix contains information from a literature review of existing and potential technology to detect and classify NARWs conducted by the workshop planning team. This literature review helped shape and narrow the focus of this workshop session and, while not shared with workshop participants in its entirety, it is included in this Appendix to provide additional context for the workshop session itself. Some, but not all, of this information was made available to the workshop participants prior to the workshop through the Background Papers and Fact Sheets (see Appendix 5).

2. Important Considerations

When evaluating NARW detection methods it is important to first identify the observation characteristics necessary for effective vessel strike risk reduction (i.e., what type of information and level of specificity is needed to trigger risk reduction action—is it enough to know a marine mammal is nearby or is species identification and precise location required?). Under the Static Scenario, detections are aimed at subsampling the NARW population to gain an understanding of overall distribution and thus inform relevant risk reduction efforts. Under the Dynamic and Vessel–Specific Scenarios, the identification of appropriate risk reduction actions and the subsequent amount of risk reduction achieved are both directly influenced by the percentage of animals present in an area that are successfully detected. When evaluating different NARW detection technology, it is important to recognize that typically only a subset of the whole picture is reported in scientific literature. When evaluating the risk reduction potential of a given approach, one must consider the effectiveness of each step in the process individually as well as the system as a whole.

There are many important factors influencing successful detection and classification that should be considered including, but not limited to the relative number of: (1) NARWs present in the sampled area that are available to be detected (i.e., availability bias); (2) those available to be detected that are likely to actually be detected by the method in use (i.e., perception/detection bias and detection range); (3) detections properly classified as NARWs (true positives); (4) detections incorrectly classified as something other than a NARW (false negatives); and (5) detections incorrectly classified as NARWs (false positives). It should be recognized that these are not static variables, but are instead dynamic variables that can change seasonally, geographically, and, in some cases, annually.

This Appendix focuses on technology for the detection and classification (and in some cases localization and tracking) of NARWs. A description of each technology is provided, followed by methods of deployment, factors that influence its effectiveness (availability bias, detection bias, and intrinsic and extrinsic factors), and available information on the testing and use of each technology. It is important to recall, as described in Chapter 4, that detecting NARWs is a critical step, but vessel strike risk is not reduced unless the entire Risk Reduction Chain is completed efficiently and effectively (i.e., the classified detection is communicated to a mariner who is able to receive and incorporate that information and safely take an evasive action with enough time and distance to reduce the likelihood of a strike).

2.1 Availability Bias

Availability bias occurs when an animal is present in the study area but is missed because it was not available to be detected. This happens, for example, when a whale is submerged and thus not visible or when it is not vocalizing and therefore not acoustically detectable. Specifically, availability biases affect the probability that a given cue (e.g., whale call or surfacing event) is detectable by the method being deployed. ‘Time in view’ is a component of availability bias and measures the length of time an animal provides a cue within the search range of the detection method being deployed. One such example would be the amount of time an animal is at the surface and is visible to observers during a visual survey. Time in view is dependent on the field of view of the individual or equipment being used to observe whales, the distance and angle between the whale and the observer, and, in the case of moving observation platforms, the speed of the platform (Caughley, 1974; Ganley et al., 2019). Furthermore, there must be spatial and temporal alignment between the display of a cue and the search effort/field of view. In other words, the cue must be both detectable and occur within the detection range of active search efforts. The greater the misalignment between cues and search effort, the greater the number of NARWs, despite providing cues, will go undetected. Where possible, we identify the animal–related extrinsic factors that affect the performance of specific detection technology.

Many factors influence the likelihood and frequency of different cues including behavior, season, water depth, background noise, life stage, and individual preferences. To the extent possible, it is important to consider these factors to allow for a realistic estimation of the detection rate of a given technology or method. The depth of submerged whales and water turbidity likely influence availability (Laake et al., 1997; Laake and Borchers, 2004 as cited in Ganley et al., 2019). Data on NARW dive cycles are limited and indicate considerable variation among geographic areas, behaviors, and between sexes and age classes (Winn et al., 1995; Hain et al., 1999; Baumgartner and Mate, 2003; Clark et al., 2010; Hain et al., 2013; Roberts et al., 2016, Baumgartner et al., 2017; Ganley et al., 2019; Dombroski et al., 2021). Feeding NARWs follow the vertical distribution of their prey (Baumgartner and Mate, 2003; Parks et al., 2012; Baumgartner et al., 2017), which varies seasonally. The resulting variation in dive durations through time likely causes seasonal changes in the whales' availability to observers. For example, Ganley et al. (2019) stated that it is essential to factor intra–seasonal variation in whale availability in Cape Cod Bay into the calculation of abundance estimates derived from aerial surveys, particularly during January and February when long dives result in a reduction in availability compared with April. Likewise, NARW aerial surveys in the Southeast U.S., although effective for describing distribution, have resulted in imprecise daily estimates due to low availability (Hain et al., 1999; Ganley et al., 2019).

2.2 Perception or Detection Bias

Detection or perception biases are factors that affect the probability of detecting an available cue. In terms of technology, this is influenced by both intrinsic and extrinsic factors. Intrinsic factors are those properties that can be influenced by the humans managing the detection system (e.g., deployment design, height of camera mount). Extrinsic factors can influence performance but cannot be influenced by the humans managing the detection system (e.g., sea state, light conditions, precipitation). Therefore, it is important to account for both during detection effort and in the assessment of any data obtained. Where possible, we identify intrinsic and extrinsic factors likely to affect the performance of detection methods and technology.

2.3 Detection Range

The range at which NARWs can reliably be detected by any specific technology is key in assessing the technology's contribution to vessel strike risk reduction. Although detection range and probability of detection are reported in many studies of detection technology and methods, there are inconsistencies in how they are reported (Theriault et al., 2020). Standardizing the methods and metrics to be used to evaluate systems would facilitate comparison across those systems and would facilitate the selection of a detection method suitable for the specific vessel operational characteristics and constraints. When evaluating risk reduction technology for a specific application or use, it is important to consider if the desired detection probability can be achieved at a distance that allows the vessel to take effective evasive action to reduce the probability of a vessel strike. In the Static Scenario, more time can be spent validating detections compared to the Vessel–Specific or Dynamic Scenarios.

3. Detection, Classification, Localization, and Tracking

Regardless of the detection technology and deployment platform utilized, collected data must be processed and converted into useful information. Detection is the process of deciding whether a signal is present or absent and classification is the process of labeling the detected signal (Hildebrand et al., 2022). Detection is a necessary first task followed by classification, and, when possible and necessary, localization, and tracking. Using multiple and complementary detection methods is likely to improve overall detection performance (Smith et al., 2020), and, where possible, automatic detection algorithms can be applied effectively as pre–screeners for human observers (Zitterbart et al., 2013, Baumgartner et al., 2019). Detection algorithms usually require a balance between false positive detections, which risk unnecessary actions, and false negatives, which risk inaction when needed. See Sections 3.1, 4.2.1, 4.4.1, and 4.5.1 below for discussion of the use of artificial intelligence (AI), deep learning (DL), machine learning (ML), and convoluted neural networks (CNN)[30] with detection and classification technology.

Classification refers to assigning the detection to a source–species, subspecies, or non–biological (vessel, pile driving equipment, seismic activity). There are four possible outcomes when it comes to classifying a detection (informed by descriptions in Theriault et al., 2020):

- True positive—a whale is present within the detection range of the system and is successfully detected/classified (the detector–classifier is correct);
- True negative—a whale is not present within the detection range of the system and no detection/classification occurs (the detector–classifier is correct);
- False positive—a whale is not present within the detection range of the system, but a detection/classification occurs; also called a false alarm (the detector–classifier is incorrect);
- False negative—a whale is present within the detection range of the system, but no detection/classification occurs; also called a missed detection (the detector–classifier is incorrect).

Different detection and classification system (DCS) parameters can be chosen depending on the application or study question. Thresholds are set for classifications that influence the accuracy (i.e., the number of false negatives) and processing time (Davis et al., 2017). Baille and Zitterbart (2022) speculated that crews were likely to start ignoring warnings even at relatively low false negative/false alarm rates. They cited studies of alarms in intensive care units noting that frequent alarms lead to alarm fatigue (Blum and Tremper, 2010 as cited by Baille and Zitterbart, 2022) and state that false alerts are a major reason why automatic vessel–based whale detection systems cannot be directly used by the vessel crew. It must be noted, however, that if one wants to minimize false positives/false alarms, then one must accept higher false negatives. Once again, it is challenging to characterize the performance of a DCS given it varies depending on the chosen parameters as well as environmental and animal behavioral characteristics (Theriault et al., 2020). Hildebrand et al. (2022) discuss four metrics for assessing the performance of marine mammal signal detection and classification algorithms, including receiver-operating-characteristic curves. These curves plot the false positive rate on the x-axis and the true positive rate on the y-axis to illustrate the trade-off between the probability of detection and the probability of false alarms.

Localization is the process by which one can determine the bearing, distance to, or location of a detected animal. Depending on the detection and analytical method, it may only be possible to identify a range in which the detected animal is likely to be/have been present (Theriault et al., 2020). Van Parijs et al. (2021) explain that multiple fixed or mobile omnidirectional hydrophones can be arranged in a configuration that allows for the localization of the vocalizing animal using the difference in the time of arrival of a call (or calls; e.g., Stanistreet et al., 2013; Hastie et al., 2014; Risch et al., 2014; Gillespie et al., 2020; Gervaise et al., 2021). They further state that localization can also be achieved by using multiple sensors that can calculate

[30] CNNs are a type of network architecture for DL that learns directly from the data.

bearing (e.g., directional autonomous seafloor acoustic recorders). Analysis conducted by Johnson et al. (2020) demonstrated that the uncertainty in whale location following visual or acoustic detection increased rapidly following the initial detection and can vary by an order of magnitude after 96 hours depending on whale behavior. They estimated the median uncertainty in whale location to be 103 kilometers for traveling whales, 28 kilometers for feeding whales, and 10 kilometers for socializing whales 96 hours after the initial detection. Because of this, the authors recommend using a combination of visual and acoustic detections to inform dynamic management of NARWs instead of relying on only one approach. The localization capabilities of different technology and the behavior of the detected animal will impact the amount of uncertainty associated with the location of a detected animal and should therefore be taken into consideration when identifying detection technology appropriate for various vessel strike risk reduction measures.

Lastly, tracking refers to the process of following the movement of the whale over time (speed and direction; Theriault et al., 2020). It can be informative for the prediction of likely future movements and involves a single detection modality or an integration of multiple modalities. Tracking of tagged NARWs has provided information on movement, dive depth and profile, and behavioral response to stressors (MMC, 2024). Marine mammal observers (MMOs, discussed below in Section 4 below) can provide accurate tracking information for individual marine mammals, but this depends on visibility and whale behavior. Theriault et al. (2020) report that tracking can only occur while the animal remains at the surface or between subsequent surfacings if dives are short enough and there are several surfacing events within the field of view. Given that NARWs can be individually identified visually by the unique pattern of raised tissue on their heads (called callosities), point observational data can be used to track individuals over space and time and provide broad scale information on movement patterns.

3.1. Automation and Semi–Automation: the role of ML, AI, and DL

While advancements in aerial digital photography onboard manned and unmanned aircraft, satellite imagery, and the broader application of acoustic monitors are generally seen as positive developments for the detection of NARWs, they generate large amounts of data that require transmission, storage, and analysis. The lack of scalable, standardized, and automated image and acoustic analysis solutions limit the speed and cost–effectiveness of taking full advantage of these detection technologies to reduce vessel strike risk (Harcourt et al., 2019). DL[31] and AI have greatly advanced automated wildlife recognition (Boulent et al., 2023). While whales had been successfully located using high–resolution imagery, the time required for analysis precluded application to broad spatial or temporal scales (Borowicz et al., 2019). Tuia et al. (2022) observed a growing mismatch between the growing volume of data acquired for ecological studies and the ability to process and analyze this multi–source data to derive conclusive ecological insights rapidly and at scale. They also noted that ecology has entered the age of big data and is increasingly reliant on sensors, advanced methodologies, and computational resources. Furthermore, Davis et al. (2017) pointed out the importance of considering the balance between accuracy and processing type when choosing a detection system for a specific species, study, or application.

The development and implementation of detection and classification algorithms has helped automate species identifications, ease data burdens (Gillespie and Caillat, 2008; Baumgartner and Mussoline, 2011; Gillespie et al., 2013; Harcourt et al., 2019), and limit performance bias and uncertainty associated with the manual scanning and classification of imagery by multiple observers (Bamford et al., 2020). Automation is defined here as the use of technology to replace or reduce human intervention (Ditria et al., 2022). The use of AI to partially automate data processing helps relieve conservation managers of some limitations imposed by inadequate sampling, data

[31] Deep learning is a type of machine learning that uses artificial neural networks to mimic the learning process of the human brain.

processing bottlenecks, and insufficient staffing. AI also provides managers with access to greater information, thereby facilitating timely and effective management (Ditria et al., 2022).

Ecologists can capitalize on large datasets generated by modern sensors by incorporating ML into ecological workflows (Tuia et al., 2022). ML generally refers to a category of algorithms that can automatically generate predictive models by detecting patterns in data (Christin et al., 2019). Presented with large input quantities (e.g., images, sound recordings) and a corresponding training set of expected outcomes or labels for these inputs (e.g., the species depicted in each image or species calls), a supervised ML algorithm learns a mathematical function leading to the correct outcome prediction when confronted with new, unseen images or recordings (Tuia et al., 2022). ML algorithms use experience through data exposure to improve performance and, as a result, can make accurate predictions from large volumes of data obtained in an automated framework (Mohri et al., 2018). One of the challenges with this approach is to integrate ecological knowledge, such as underlying biological processes, into ML models, and Tulia et al. (2022) report the emergence of an interdisciplinary community of computer scientists and ecologists to tackle this technological and societal challenge together.

4. Technology and Methods

4.1 Aerial and Vessel-based Visual Surveys

Visual surveys conducted by human observers (MMOs) on aircraft or vessels can provide information about whale abundance, identity, health, mortality, population genetics, and behavior[32]. Dedicated NARW visual surveys inform dynamic risk management strategies and enable collection of additional data, such as photographs or biological samples, which inform assessments of the population (Franklin et al., 2022). Visual surveys provide information for both tracking individual NARW life histories and for detailed assessments of the population, both of which are critical given the endangered status of the population. Furthermore, the accurate assessment of the NARW population is essential to provide feedback on vessel strike risk reduction measures and to indicate whether additional risk reduction actions are necessary. Visual surveys provide results to which alternative methods and technology are frequently compared so as to measure relative effectiveness and will likely continue to inform both Vessel–Specific and Dynamic Scenarios risk reduction measures (e.g., Verfuss et al., 2018; Ganley et al., 2019; Smith et al., 2020; Ceballos et al., 2022; Franklin et al., 2022).

A standard whale aerial survey is conducted from several hundred meters above sea level with a trained MMO on both sides of the aircraft equipped with camera and data recording equipment (Cole et al., 2007). Aerial photography (stills, video, and infrared (IR) imagery) and the associated location data are used for multiple purposes including cataloging new whales (and other marine animals), obtaining animal counts, health assessments, and tracking of individuals as they move throughout their range. Survey flights are conducted during the daytime and in good weather to maximize safety and the probability of sighting whales, which is impacted by factors such as glare, sea state, and precipitation (Fairfield and Mizroch, 1990).

Vessel–based surveys have been conducted for decades using human observers, sometimes equipped with high–power binoculars, and more recently using cameras (visible–wavelength and IR; See Section 4.4 for a review of IR and Section 4.5 for a review of cameras) to visually scan the area around the vessel for whales. Line–transect vessel–based surveys are often used to better understand the presence, distribution, and abundance of marine mammals within a study area while vessel–based focal–follow studies allow for the observation of individual behaviors. Vessel–

[32] Pettis, H. M., R. M. Pace III, and P. K. Hamilton. 2022. North Atlantic Right Whale Consortium 2022 annual report card, 15 p. [Available at https://www.narwc.org/report-cards.html]

based surveys also provide avenues by which to locate and identify NARWs, and are specifically needed for tagging, biological sampling, and other close–range research. While not considered an official vessel–based survey, MMOs are frequently located on vessels or platforms related to activities such as offshore wind construction, oil and gas exploration, and dredging based on permit conditions to ensure that an exposure or safety zone is clear of marine mammals prior to initiation of work (Verfuss et al., 2018). Harwood and Joynt (2009) report that the effectiveness of MMOs deployed in this way is influenced by several environmental factors including the amount of daylight, sea state, swell height, and visibility (e.g., fog, rain, glare, snow). In the Canadian Beaufort Sea, they found that one or more of these factors could reduce the effectiveness of MMO mitigation in the following approximate proportions: 25–60% MMO down–time due to darkness; 25–40% down–time due to sea states/swell height; and 10% down–time due to poor visibility associated with fog (Harwood and Joynt, 2009).

Currently, crewed aerial and vessel–based surveys are among the most common methods for locating and identifying NARWs. In U.S. waters, various institutions, including National Oceanic and Atmospheric Administration (NOAA) Fisheries, the U.S. Army Corp of Engineers, the New England Aquarium, HDR Inc., state agencies, and others, regularly conduct aerial surveys in the primary calving area off the Southeast coast from December through March and throughout the year along the migratory path and feeding grounds in the Mid–Atlantic and Northeast[33] (Clark et al., 2010; Ganley et al., 2019). There are also regular and extensive aerial surveys conducted in Canadian waters during summer months when the whales are present. The U.S. and Canadian teams regularly collaborate, and extensive reports exist for both efforts (e.g., Crowe et al., 2021).

Aerial surveys have several advantages over vessel–based surveys, particularly the ability to cover a large area quickly and decreased disturbance to surrounding wildlife (Broker et al., 2019). Conversely, vessel–based surveys spend a longer period in a study area and therefore provide more time for MMOs to detect any animals present (Ceballos et al., 2022). A simulation developed to quantitatively compare the probability of detecting a NARW cue as a function of survey platform found that vessels performed better than either aircraft or remotely piloted aerial systems (RPAS)[34] because of the greater amount of time they spent in the survey area due to their slower transit speed (Ceballos et al., 2022).

The primary source of availability bias during visual surveys is the requirement that whales be at or near the surface when the observer is present and looking for cues (Ceballos et al., 2022; Franklin et al., 2022). A whale's blow is the most obvious cue, but it is visible for only a few seconds (Zitterbart et al., 2013; Zitterbart et al., 2020). Visual detection is often subjective and happens in an instant, so there is limited ability to confirm or review a detection at a later stage (Verfuss et al., 2018). The effectiveness of an MMO in visually detecting an animal is reduced by weather conditions such as fog, rain, high sea state, sun glare, or the lack of light (e.g., Palka, 1996; Harwood and Joynt, 2009; Parente and de Araujo, 2011; Zitterbart et al., 2020), and is also influenced by experience level, fatigue, and field of vision (Smith et al., 2020). Animal behavior, such as diving and an undemonstrative presence at the sea surface, can also reduce detection probability (Verfuss et al., 2018). Detection biases in NARW surveys include monitoring effort, poor visibility (e.g., light levels, weather conditions), and sea state during visual surveys (Clark et al., 2010). Visual surveys

[33] See WhaleMap for survey effort by platform: Hansen Johnson. 2024. WhaleMap: Interactive Map. [Available at https://whalemap.org/WhaleMap/]

[34] RPAS, unmanned aerial systems (UASs), and uncrewed aerial vehicles (UAVs) are all different terms used to describe "drones", the term by which they are more commonly known. Any use of these terms throughout this Appendix are therefore referring to drones, and hereafter the term drones will be used when referring to these platforms more generally.

are subject to several limitations including cost, platform endurance, day length, and safety considerations (Baumgartner and Mussoline, 2011; Ganley et al., 2019; Ceballos et al., 2022).

Reported detection ranges for various species of large whales detected during vessel based visual surveys range between 500–9000 meters depending on the specific tool or methodology being used. A whale's availability for detection is impacted by behavior, surface time, and group size, all of which can vary seasonally, regionally, and by demographic group (Williams et al., 2016; Ganley et al., 2019; Dombroski et al., 2021; Franklin et al., 2022). Observations collected on Alaska cruise ships estimated the probability of detection of surfaced whales by a dedicated observer to be near 100% at a range of 500 meters or less in excellent visibility conditions, decreasing to 50% at a range of 1000 meters (Williams et al., 2016). These results align with estimates used by Hammond et al. (2013) when conducting scientific surveys aimed at measuring whale abundance. However, Harwood and Joynt (2009) state that during dedicated surveys for cetacean abundance, such as the Small Cetacean in European Atlantic Waters and the North Sea (SCANS) surveys, six trained observers working in two independent teams of three were engaged in observing 180° ahead of the vessel (Hammond et al., 1995), and even under these conditions a significant portion of the sightings were missed. They state it is difficult or impossible for a single observer to cover 360° reliably, especially as the best vantage points are often obscured by elements of the ship's structure (Lewis et al., 1999; Harris et al., 2001).

Due to their dark color and lack of dorsal fin, NARWs are amongst the most difficult whales to visually detect, and vessel strikes have occurred even with trained MMOs onboard (Wiley et al., 2016). Detection ranges for human observers drop significantly in inclement weather or in moderate wave conditions (Baldacci et al., 2005) and are ineffective during nighttime. Furthermore, these reported detection probabilities and ranges may decrease when observers are engaged in other activities in addition to visually scanning for whales. A field comparison of real–time detections made by MMOs, a rotating IR camera, and PAM was conducted on a 38-meter research vessel offshore Atlantic Canada (Smith et al., 2020). Overall detection rates were found to increase when complementary methods were used with the combination of MMOs and PAM being the most effective pairing during high seas and precipitation. The authors note that PAM and IR can be used in darkness and in good visibility, and adding PAM or IR to MMOs should increase detection (Smith et al., 2020). The authors state that when employed alone, none of the three methods investigated do a particularly good job of detecting marine mammals. MMOs, PAM operators, and the IR system were found to detect only approximately 20–30% of the encounters detected by one of the other methods tested (Smith et al., 2020).

A Canadian simulation comparing visual and acoustic surveys for the detection and dynamic management of NARWs set a 0.5 probability of an aircraft or vessel detecting a whale at the surface at a distance of 1.5 kilometers (Williams et al., 2016; Ceballos et al., 2022 citing Ganley et al., 2019). Single transits of a management zone by visual surveys were only able to reliably (>0.5 probability) detect right whales when more than 20 whales were present within the simulated study area. The authors note that all management measures in the Gulf of St. Lawrence are triggered by the detection of a single right whale, but they found that the probability of sighting a single right whale on a single simulated transit (with good visual conditions) were very low (<0.1 for an aircraft, <0.05 for a RPAS, and <0.2 for a vessel). They conclude that a single transit by visual surveys cannot reliably detect single right whales in Fisheries and Oceans Canada (DFO) or Transport Canada (TC) management zones, and as such cannot be used to confidently rule out NARW presence. The authors state that effective detection and risk management of single whales requires multiple visual survey transits, increased reliance on acoustic platforms, alternative technologies, or some combination thereof (Ceballos et al., 2022). This simulation is also noteworthy for the detailed cost estimates it includes for single and multiple transits by various platforms to detect at least one of

10 individuals with both 50% certainty (0.5 detection probability) and 95% certainty (0.95 detection probability). Ceballos et al. (2022) focused on a single dynamic management zone, but stated that scaling up the efforts needed to detect a single NARW with 95% certainty covering the 200 DFO zones in the Gulf of Saint Lawrence would require approximately 1,500 hours of aircraft surveillance (~$2.1 million Canadian), 3,000 hours of vessel surveillance (~$2 million Canadian), and 7,800 hours of glider surveillance ($240,000 Canadian). They note that these cost estimates do not address the logistics of site–specific survey implementations or the associated economic constraints, such as compensating operators, maintaining platforms, or traveling to the management zone in question.

While aerial and vessel–based surveys are the most widely used method in NARW detection efforts, they are costly and aircraft surveys in particular pose significant risk to humans, so there is a strong incentive to find viable alternatives. Remote sensing technology (Section 4.5) and the potential for using remotely operated or unmanned aircraft equipped with very high–resolution (VHR) cameras to collect information comparable to that currently obtained through visual surveys is being explored (Rodofili et al., 2022).

4.2 Passive Acoustic Monitoring (PAM)[35]

PAM is a method commonly used to detect whales and involves using near–real time or archival recording units (ARUs) to passively document and identify acoustic signals (e.g., vocalizations, non–biological sounds) within the platform's acoustic frequency range. Specifically, PAM relies on capturing whale vocalizations, which include tonal or band–limited sounds like rumbles, thumps, songs, and chirps that range from very low frequencies (20 hertz) to roughly 5 kilohertz (Matthews and Parks, 2021) depending on the species and call type. PAM can provide continuous coverage of areas that are otherwise hard to survey, data on multiple species simultaneously, and information on the acoustic environment, including natural and anthropogenic sounds (Davis et al., 2017). PAM systems vary widely in coverage range, depending on deployment method and unit specifications, and often also include the capability to perform initial data analysis using automated detector and classifier software.

The PAM process involves four steps: (1) acquire acoustic data using a hydrophone capable of detecting sounds in the target frequency range; (2) condition signals coming in from the hydrophone to remove noise, filter out unwanted frequencies, and amplify desired frequencies; (3) digitize, record, and store signals for later analysis or conduct initial analysis onboard in real time; (4) classify vocalizations by type (clicks, whistles, songs) and source (Heinemann et al., 2016). Typically, any onboard data processing is verified by a human once the data has been received or collected from the PAM platform.

PAM systems can be mobile or fixed and are typically deployed using the following approaches: (1) fixed bottom–mounted acoustic recorders (BMARs) that can record up to several years in a single deployment and can be deployed as a singular unit or as an array of multiple units (e.g., large fixed seabed arrays such as those used by the Integrated Undersea Surveillance System (IUSS; Agarwala, 2022); (2) hydrophone arrays towed behind survey vessels that can be used to survey large areas and are easy to combine with visual survey; (3) acoustic tags that record are attached to individual animal and can record their vocalizations or those of animals in close proximity (e.g., digital acoustic recording tags (DTags)); (4) electric gliders; (5) buoyancy–drive autonomous underwater vehicles (AUVs—including both gliders and floats; deployed as single units or arrays); (6) wind/wave powered unmanned surface vehicles (USVs) capable of navigating along assigned

[35] A comprehensive discussion of PAM technology and deployment methods can be found in Van Parijs et al. (2021).

routes (deployed as single units or arrays); (7) free–drifting buoys which periodically surface to upload their location and data and receive control instructions; or (8) anchored surface–mounted acoustic recorders (SMARs) that transmit underwater acoustic data to a land–based location in near real–time and, like BMARs, can be deployed as a singular unit or as an array of multiple units (Van Parijs et al., 2015; Heinemann et al., 2016; Baumgartner and Lin, 2019; Johnson et al., 2022; Zeh et al., 2024). Hull–mounted hydrophones have also been considered for whale detection (Harland and Armstrong, 2004; Nielsen and Bertel, 2006). Furthermore, Harland and Armstrong (2004) developed software capable of real–time detection, classification, and localization of a variety of whale species from acoustic data collected using both passive hull–mounted and towed arrays deployed during navy sonar operations conducted for purposes other than whale detection. As discussed in Section 4.2.1, Baumgartner and Mussoline (2011) developed a generalized automated DCS for application to PAM data. Additionally, fiber optic cables on the ocean seabed may also provide a means for detecting and localizing whales using Distributed Acoustic Sensing (DAS; e.g., Bouffaut et al., 2022 and Wilcock et al., 2023).

NARW calls have been characterized into several types and subtypes (Parks and Tyack, 2005; Matthews and Parks, 2021) and have been shown to vary by region, season, activity, and demographic group (McCordic et al., 2016; Cusano et al., 2018; Dombroski et al., 2021), and individual animals have been shown to go long periods of time (e.g., more than 10 hours) between vocalizations (Parks and Tyack, 2005). It is important to recognize these significant differences in behavior–dependent vocalizations when considering the likely effectiveness of PAM in detecting NARWs in a given area and time of year. It is also important to understand how sound interacts with and propagates through the environment when using PAM as a mitigation tool.

The sound waves generated by whale vocalizations interact with the ocean environment in a variety of ways that affect how far the sound travels while remaining at a detectable level (e.g., reflect off the seafloor and ocean surface). In some environments, oceanographic conditions provide ducts in which acoustic energy is 'trapped' and can travel long distances, such as in the deep ocean where sound waves generated at low frequencies can travel across ocean basins (e.g., the Sound Fixing and Ranging (SOFAR) ocean channel). Conversely, in shallow water it is often the case that interactions with the ocean boundaries limit the range at which sounds can travel. The loudness of the call, the anticipated loss of acoustic energy as the sound travels through the ocean (spreading, absorption, and scattering losses) between the whale and an acoustic receiver, and the background noise present in the same frequency band as the whale call all play a role in the effectiveness of a PAM system detecting a NARW call. Keeping these considerations in mind, detection ranges for NARW upcalls have been estimated at ranges from several kilometers to a few dozen kilometers (Gervaise et al., 2021). For NARWs in shallow–water near–coastal environments, call detections have been demonstrated at ranges up to 20 kilometers on both stationary buoys and gliders carrying single hydrophones (Baumgartner and Lin, 2019).

Intrinsic factors that influence PAM performance include array design, array gain, bit depth, deployment depth, detector configuration, filter setting, self–noise, and frequency range (see Table 2 in Verfuss et al., 2018 for definitions of these terms). Additionally, the appropriate detectors, filters, and classifiers must be selected to accurately capture the species or acoustic signals of interest. Extrinsic environmental factors that affect PAM performance include acoustic background noise (natural and anthropogenic), seabed properties, topographical variability, water column characteristics, and water depth (Verfuss et al., 2018; Vagle et al., 2021; Johnson et al., 2022). Additional extrinsic animal–related factors affecting performance include whether or not a whale is producing a vocalization when it is within the range of a detector, the characteristics of the whale's vocalization, as well as group size, behavior, diving behavior, and movement in relation to the monitoring system (Marques et al., 2013; Verfuss et al., 2018; Johnson et al., 2022). Detection biases in NARW acoustic surveys include sources of noise such as vocalizations by other species (that may overlap in characteristics) or non–biological noise (e.g., vessel noise) that can mask NARW calls and interfere with the ability to detect or successfully classify a given call (Johnson et al., 2022).

PAM has been utilized in all three Application Scenarios, although archival systems can only inform the Static Scenario and near–real–time systems are also applicable to the Dynamic and Vessel–Specific Scenarios (Van Parijs et al., 2009). The utility of PAM in the Dynamic and Vessel–Specific Scenarios is related to the degree to which a vocalizing whale can be localized, which depends on the number, type, and location of hydrophones. When using PAM systems in the Dynamic Scenario, a choice must be made as to the degree of acceptable certainty/uncertainty in the identification and classification of vocalizations in real/near–real time. Baumgartner et al. (2019) developed a protocol that encouraged the analyst to score "detected" only with convincing evidence of a species' acoustic presence because marine mammal mitigation applications often have significant costs associated with false detections. Similarly, Gervaise et al. (2021) set a target performance NARW detection classification at a minimal probability of detection of 0.5 combined with a constant probability of false alarm of 1 per day to minimize the risk of falsely applying protective measures triggered by NARW presence. It must be recognized, however, that establishing a low threshold for false positives increases the probability of missed detections or false negatives.

4.2.1 Application of AI, ML, and DL to Large Whale Acoustic Data

There is strong interest in the development and use of automated detectors and classifiers for the processing of both near–real time and archival acoustic data (Baumgartner et al., 2020; Kowarski et al., 2020; Vickers et al., 2021). The goal of automation in this context is to provide effective and efficient mechanisms by which to process large acoustic datasets for understanding marine mammal presence and their bioacoustic behaviors (Dugan et al., 2016). Tuia et al. (2022) observed that while ML had been extensively applied to camera trap images, its application to long–term PAM datasets was still generally in its infancy. They noted that significant challenges remain when utilizing AI/ML for PAM analysis, the most notable of which is that handling and analyzing the large datasets efficiently requires access to advanced computing infrastructure and solutions. They also note the need for noise–robust algorithms given the inherent complexity of soundscapes and the lack of large and diverse labeled training datasets (Tuia et al., 2022).

A generalized automated DCS was developed to efficiently and accurately identify low–frequency baleen whale calls (Baumgartner and Mussoline, 2011). The DCS accounts for persistent narrowband and transient broadband noise, characterizes temporal variation of dominant call frequencies via pitch–tracking, and classifies calls based on attributes of the resulting pitch tracks using quadratic discriminant function analysis. Automated detections of sei whale (*Balaenoptera borealis*) downsweep calls and NARW upcalls were evaluated using recordings collected in the southwestern Gulf of Maine during the spring seasons of 2006 and 2007. The accuracy of the DCS was found to be similar to that of a human analyst (Baumgartner and Mussoline, 2011).

Baumgartner et al. (2019; 2020) report on applying a human review method to evaluate digital acoustic monitoring instrument (DMON)/low–frequency detection and classification system (LFDCS) data relayed in near–real–time from moored buoys and gliders. The protocol utilized was conservative and prompted the analyst to score a signal as a detection only with convincing evidence of a species' acoustic presence so as to minimize false detections. They report a strong association between acoustic detection and aerial survey sightings of NARWs on a key feeding ground off the coast of Massachusetts noting that when NARWs were seen they were typically also heard, particularly over 30–40 kilometers spatial scales and 24–48 hour temporal scales (Baumgarter et al., 2019). Furthermore, it was found that including a human review step decreased false detection rates, though perhaps at the cost of higher missed detections (Baumgartner et al., 2020). The greatest advantage of having an analyst review the detection data is the assessment of context. The human analyst can consider context in a way that is not yet available in an automated DCS for marine mammal sounds (Baumgartner et al., 2019).

Schall et al. (2024) tested and evaluated three DL approaches in marine bioacoustics using three metrics: true classification rate, noise misclassification rate, and call misclassification rate. They surveyed numerous statistical and threshold–based methods for automated acoustic detection and classification and concluded that available methods suffered from either low sensitivity (i.e., high false negative rates) or low selectivity (i.e., high false positive rates). They conclude that further work should focus on the reduction of false positives created by noise to achieve algorithm usability. Miller et al. (2022) conducted a head–to–head comparison of automated detectors and human analysts' performance in detection of Antarctic blue whale (*Balaenoptera musculus intermedia*) calls. They determined the advantages of the automated detector included increased efficiency and higher precision and recall, and they concluded that ML algorithms for detecting blue whale D–calls outperformed the human analyst and were cheaper and more reliable (Miller et al., 2022). Compared to the automated detector, the analyst appeared to rely upon contextual information, which prompted them to classify a questionable call when other calls were already present (Miller et al., 2022).

Rasmussen and Širović (2021) used CNNs to automatically detect and classify baleen whale social calls using datasets with few or no calls of interest as well as those with many calls. Their goal was to create a detector that resulted in high recall and precision rates when calls were present while minimizing the overall number of false positives. When processing recordings with few calls, the detectors yielded less than two false positives per hour. They concluded that full automation may not be achievable, and it may be that some subsets of data or detections may need to be manually verified. Similarly, Van Parijs et al. (2021) state that some degree of visual review will likely continue to be required when dealing with acoustic detection of rare species such as NARWs and to ensure accuracy and minimize errors.

4.3 Tagging

A comprehensive discussion of the history of tag development is beyond the scope of this Appendix, but further information can be found in the referenced literature (Mate et al., 2007; Andrews et al., 20193). Additionally, the Marine Mammal Commission (MMC), NOAA Fisheries, and the Office of Naval Research (ONR), in coordination with DFO, convened a workshop in September 2023 to: 1) review key knowledge gaps and data needs regarding the movements, life history, and ecology of NARWs; 2) review the history of satellite telemetry and evaluate progress in tag attachment technologies and follow–up studies; and 3) generate knowledge to inform planning and permitting decisions regarding potential tagging of NARWs (MMC, 2024). Information about this workshop, key takeaways and outcomes, and a link to the workshop report can be found on the MMC's workshop webpage.[36] Bio–logging tags, hereafter referred to as 'tags', are physical monitoring devices used to provide a variety of environmental, physical, and behavioral data from the animal to which they are attached. There are two general types of tags used for tracking whales, invasive and non–invasive tags, which have different attachment mechanisms, and thus deployment durations. They typically also have different tracking accuracies and capabilities, data storage limits, and transmission capacities. The data from these tags can either be stored onboard for later recovery (archival) or transmitted in near–real–time via electromagnetic or acoustic signals. Modern tags that utilize global positioning system (GPS)–accurate locations are a particularly promising technology for maintaining persistent near–real–time position of whales for the duration

[36] Marine Mammal Commission (MMC). 2024. North Atlantic Right Whale Tagging Workshop. [Available at https://www.mmc.gov/events-meetings-and-workshops/other-events/narw-tagging-workshop/]

of the tag attachment (Johnson and Tyack, 2003; Guzman et al., 2020; Irvine et al., 2020; Murname, 2021).

Non–invasive tags are commonly attached to whales, including NARWs, using suction cups that are deployed via hand poles or uncrewed aerial vehicles (UAVs; Andrews et al., 2019; Wiley et al., 2023; MMC, 2024). Suction cup tags are useful research tools, providing acoustic, video, and position data at high rates. However, their useful duration is short with attachments ranging from hours to days, making them unrealistic for long–term tracking applications such as for vessel strike mitigation.

Longer–duration invasive whale tags can be broken down into three categories: Type A (Anchored), Type B (Bolt–on to dorsal fin, not applicable to NARWs which do not have dorsal fins), and Type C (Consolidated; Andrews et al., 2019; IWC, 2020). Type A tags have retention barbs that are designed to anchor in a whale's blubber beneath the skin layer, with an electronics package that remains on the outside of the whale's body. These tags are typically implanted using darts fired from pneumatic rifles. However, these systems are limited by duration, lasting only days to weeks (Oleson et al., 2020), only slightly longer than the non–invasive suction cup tags.

Type C tags are similar to Type A tags, but with all sensors, antennae, and retention mechanisms consolidated into a single package. Type C tags use retention barbs to anchor in either the blubber or penetrate the fascia to attach at the blubber/muscle interface, depending on barb length. Type C tags that penetrate the fascia are considered the most invasive tag type and have not yet been considered for NARWs (MMC, 2024). Zerbini reported that early Type C tags had an average duration on southern right whales of 47 days. He stated that welding of the anchor articulation and the anchor/transmitter interface resulted in increased deployment durations averaging 112 days on southern right whales, which was extended to an average of 211 days with an integrated 3D printed Type C (MMC, 2024). These studies found minimal behavioral impacts and no long–term adverse health outcomes or evidence of infection from transdermal tags (Zerbini et al., 2023). It should be noted that tag duration times could be increased by providing only positional data rather than using limited battery power for multiple additional sensors. Given these developments, recent tagging workshops have discussed revisiting the restrictions on Type C tags and continuing to improve and study them (IWC, 2020; MMC, 2024). Research into making smaller, more powerful, longer lasting, and less invasive tags is ongoing.

Factors intrinsic to tags that influence their effectiveness include battery life, storage capacity, biofouling, sterilization, and composition of materials (i.e., tag should be composed of materials that are biocompatible and safe for skin contact; Andrews et al., 2019; MMC, 2024). Tag design should reduce interference with body movements and impacts on energy expenditure (Andrews et al., 2019). Extrinsic factors include damage or loss of the tag caused by animal–to–animal or seafloor contact, tag loss due to issues with attachment including at the anchor/transmitter interface, breakage of the dart attachment and the difficulty of retrieving some sensors to download data (MMC, 2024). In addition, the tagged animal must be present at the surface for sufficient time to allow for data transmission (MMC, 2024). In a study of southern right whales, the tag position on the body and the angle of penetration of the Type C tag significantly influenced the health effects observed (MMC, 2024). Tag placement was also found to affect site tissue response in North Atlantic humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine (presented by Jooke Robbins in MMC, 2024). In addition to the health and welfare concerns associated with tagging marine mammals, there are risks to personnel involved in tagging operations (Andrews et al., 2019).

Tagging has provided key insights into NARW movement, how they use the water column during certain behaviors or in certain habitats, and has the potential to offer insights into the location of unaccounted for whales, all of which can inform vessel strike risk assessments. There are, however, several factors that need to be considered when evaluating tagging as a vessel strike risk reduction tool including the short life spans for most tagging options, potential for adverse effects from attachment (e.g., increased drag, disruption/distress during attachment, attachment site infection), and the potential to alter the physiology and behavior of the tagged animal, which in turn can influence the validity of the data collected (Andrews et al., 2019).

At present, tagging is not a widely used approach for studying NARWs; however, available tag data does inform vessel strike risk reduction actions including, but not limited to, informing models used to make Static Scenario decisions. Tagging data has been more widely incorporated into Dynamic Scenario applications for other species such as was done for the Eastern Pacific blue whale (*Balaenoptera musculus musculus*; Hazen et al., 2017). Data from satellite–telemetry–tagged blue whales was combined with previously published abundance estimates to predict short-term, future habitat preference and densities. The resulting predictions have been used to operationalize an automated, near–real time whale density prediction tool based on up–to–date environmental data for use by managers and other stakeholders (Hazen et.al., 2017). A fine–scale dynamic model that uses ocean data is used to make daily predictions of blue whale habitat (Abrahms et al., 2019). The Whale Safe Tool[37] displays visual and acoustic whale detections as well as a blue whale habitat model that updates daily based on oceanographic conditions. Each day these three data sources are combined to indicate whether whale presence is low, medium, high, or very high. The Whale Safe Tool also displays shipping activity from Automatic Identification Systems (AIS), shipping lanes, and voluntary vessel speed reduction zones.

4.4 Thermal Imaging/IR Cameras

The use of thermal/IR in the Dynamic and Vessel–Specific Scenarios was determined to be worthy of focus at the 2024 NARW Vessel Strike Risk Reduction Technology Workshop as it is currently undergoing field trials, but there is less in the published literature on these technologies and the application to large whales. The workshop Steering Committee and planning team felt that discussions at the workshop could help illuminate what role thermal/IR could play in wider–scale risk reduction efforts (alone or in combination with other detection technology), and which vessel operational categories are most likely to benefit from vessel–based use of these systems. Please see Chapter 5 for a summary of the presentation made at the workshop by Dan Zitterbart, Woods Hole Oceanographic Institute (WHOI), on thermal/IR and the subsequent discussion.

Thermal imaging relies on the temperature difference between the above–surface body parts of the animal or its exhalation and the ocean. IR exploits the radiance difference between a marine mammal cue (e.g., body or blow) at or above the water's surface and the ocean background. Detection of marine mammals using thermal/IR (these two imaging approaches are often referred to simultaneously) relies on the animal being available for detection at the surface with exhalations and exposed body parts (i.e., flukes, flippers—the insulation on a whale's back makes it a less effective cue) being the main cues for these systems (Cuyler et al., 1992; Zitterbart et al., 2013). These systems have been used for marine mammal detection during nighttime hours for a few decades (Perryman et al., 1999; Schoonmaker et al., 2008 as cited in Zitterbart, 2023).

Thermal/IR cameras may be handheld or mounted on a vessel, plane, or land–based platform. These cameras work in what are considered good visual survey conditions (daylight, minimal precipitation, etc.) as well as in darkness and moderately high sea states (≤Beaufort 4). Performance (e.g., detection range) is affected by the height above water at which the camera is

[37] University of California Santa Barbara Benioff Ocean Science Laboratory. 2024. Explore the Whale Safe Tool. [Available at https://whalesafe.com/whale-safe-tool/]

mounted and the method of stabilization when mounted on a vessel (Baille and Zitterbart, 2022; Zitterbart et al.,2020). Documented detection ranges vary with most effective ranges for the detection of whale blows being reported around 2–5 kilometers (Zitterbart et al., 2013; Zitterbart et al., 2020), while others report greater ranges of up to 9 kilometers in favorable weather conditions (Baldacci et al., 2005).

Intrinsic factors affecting thermal/IR performance include the height of the camera, number of cameras, field of view, camera stabilization method, whether the sensor is cooled, and image filtering and detection algorithms. Extrinsic animal–based factors affecting thermal/IR performance include the ratio of the whale's surface time versus dive time and their temperature difference with the surrounding environment. Extrinsic environmental factors affecting IR performance include fog, precipitation, sea state, glare, water and air temperatures, and ambient brightness (Zitterbart et al., 2013). Baldacci et al. (2005) noted that IR clutter may be present even during nighttime and that high humidity may also present challenges due to the attenuation of thermal radiation as it propagates through water vapor. Some have cautioned that it is important to consider the abundance and behavior of non–target species in the study area when planning the deployment of IR imaging systems (Smith et al., 2020). In field studies, false alerts were produced by small fishing vessels, birds, and breaking waves (Zitterbart et al., 2020). Additionally, for vessel–mounted systems, vessel speed and maneuverability were found to determine the probability of being able to detect a whale early enough to take evasive action (Baille and Zitterbart, 2022).

Recent efforts in California (Sullivan et al., 2020) and Canada (Zitterbart et al., 2020) have aimed to couple automated target recognition (ATR) with shore–based thermal IR cameras to detect gray whales (*Eschrichtius robustus*) and NARW, respectively. Their results suggested that the agreement between human MMO and ATR computed methods was excellent for surfacing gray whales. In Canada, four thermal/IR cameras were deployed overlooking the Cabot Strait from 2022–2023 to assess their capacity to automatically detect NARW in near–real–time; however, these results have not yet been published. Thermal/IR cameras have also been mounted underneath aerial survey aircraft in Canada and have been demonstrated to detect NARW at and below the surface (Theriault et al., 2020; sub–surface detection depths have not yet been published).

Thermal/IR detections sometimes, but not always, outperform human observers, and the two combined approaches have been suggested as complementary techniques (Smith et al., 2020). In a study comparing experienced MMOs and vessel–mounted IR cameras, Zitterbart et al. (2020) found that in short ranges (2–3 kilometers), the IR system outperformed the MMO in detecting surfacing whales. They state that this result was expected as the detection function's peak falls within this range, indicating the IR system should detect most of the cues within 2–3 kilometers, and considering that the tested camera system had a 360^{o} field of vision whereas the MMOs were not able to scan a full 360^{o} field of vision at all times. The MMO outperformed the IR system at distances greater than 3 kilometers as the system's perceptibility (i.e., how well a whale cue in the video stream is perceived by an informed human observer) and detection function starts to drop at 3 kilometers. It is important to note that the IR system being tested was not intended to operate unsupervised, but rather to alert the MMO to likely whale blows while providing instant playback and documentation of the thermographic recordings. The intention was to allow the operator to easily verify the event and quickly determine whether a shut–down request should be issued or not (Zitterbart et al., 2020). Thermal/IR systems and MMOs were found to complement one another in terms of making detections. With few exceptions, one method detected <40% of the detections made by the other method (Zitterbart et al., 2020), meaning that using a combination of both methods results in a higher combined detection rate and lower false negative rate. Baille and

Zitterbart (2022) suggest that technological improvements are needed to achieve reliable detection ranges beyond what is currently possible so that fast and poorly maneuverable vessels, such as ultra–large container ships, could benefit from onboard detection systems.

4.4.1 Application of AI, ML, and DL to Thermal/IR Cameras

While an automatic detection system has been described and tested in recent years (Zitterbart et al., 2013; Smith et al., 2020), analysis and deployment methods have not yet been standardized (Zitterbart et.al., 2020). Automatic detection algorithms can be used to pre–screen the data and subsequently present only short video sections that resemble a whale blow or surfacing animal to a human observer for verification (Zitterbart et al., 2013; Verfuss et al., 2018). Classification of thermal/IR detections can be done in near real time if the system is constantly monitored by an experienced technician (Smith et al., 2020). Zitterbart et al. (2020) examined the effects of environmental conditions on the capability of a human to perceive a whale cue in a thermal imaging/IR data stream at different distances, the influence of environmental conditions on the performance of automatic thermal/IR–based detection and derived an algorithm to facilitate automatic detection under varied environmental conditions. They found that site–specific knowledge of expected false alert triggers needed to be used to create filters or modify the algorithm to decrease the false positive rate.

4.5 Remote Sensing Imagery

NOAA Fisheries' 2008 workshop to identify and assess technology to reduce vessel strikes of large whales identified remote sensing as having potential to reduce risk while simultaneously allowing certain marine commerce and other activities to proceed with limited biological and economic impact (Silber et al., 2009 as contained in Appendix 8). In addition, an Expert Working Group convened by the National Marine Fisheries Service (NMFS) NARW Steering Committee recommended that satellite image data be explored as a potential option for identifying NARWs and documenting distribution shifts as a component of a comprehensive monitoring strategy for NARWs (Oleson et al., 2020).

Remote sensing imagery can be obtained from satellites or cameras placed on vessels, airplanes, shore stations, or drones, and can capture demographic information, spatial distribution, and habitat selection of animals (Charry et al., 2021; Crowe et al., 2021). Cameras used to capture images can operate in either the visible or IR spectrum—this section focuses on visible spectrum cameras and IR systems are discussed above in Section 4.4. These systems operate either passively, by receiving and processing existing energy within the environment (e.g., solar radiation), or actively by transmitting energy and receiving subsequent reflections. In addition to detecting objects through the processing of passive or active data streams, remote sensing systems also classify, identify, localize, track, and export data via communication systems. Finally, remote sensing camera systems can be stationary or mobile and operated either autonomously or with remote human intervention (e.g., drones).

Cameras are currently used for vessel strike risk reduction, are commercially available, applicable both onboard and offboard vessels, and can supplement trained human observers (Lyu et al., 2023). Their size, weight, and power are also conducive to autonomous platform use. Cameras offer advantages for object detection and classification using ML approaches if sufficient training data is available (Prasad et al., 2017). It is worth noting that the small size of the NARW population makes the development of a robust training set challenging. These cameras and their analog precursors have long been used in visual surveys and for cataloging individual NARWs (Hamilton et al., 2024). Factors such as the angle of the sun, glare, amount of ambient light, sea state, NARW posture when surfacing, and camera elevation above sea level influence the camera's effectiveness for detection and identification (Khan et al., 2022).

Satellite imagery provides the potential to survey large and remote areas and to monitor at a daily time scale, cloud–cover permitting (Borowicz et al., 2019); however, cost and the challenges associated with analyzing large files still constitute limiting factors for many studies (Höschle et al., 2021; Rodofili et al., 2022). Bamford et al. (2020) includes a discussion on availability bias associated with satellite imagery in which they note that satellite images exaggerate the effects of availability bias and may result in undercounting compared to vessel or aerial surveys. Environmental conditions also affect satellite images with only cloudless images with few or no white caps, low glare, and low swell representing ideal conditions (Cubaynes et al., 2019; Höschle et al., 2021). Furthermore, the use of satellite imagery to survey for a specific species has been found to be most effective if other large marine mammals of similar size to the target species are absent (Cubaynes et al., 2019; Bamford et al., 2020; Charry et al., 2021; Höschle et al., 2021). Morphological differences have been found to influence the detectability of marine mammals in satellite images and availability bias will change as dive times and surface detectability differ across locations, season, behavior, and demographic group (Cubaynes et al., 2019; Harcourt et al., 2019). As the resolution offered by satellites has increased, the possibility of identifying whale–defining features in satellite imagery has become a reality (Höschle et al., 2021). When using satellite imagery as a detection method, it is critical to estimate or directly measure the water column penetration depth capability of the satellite sensor and to understand how that depth varies with water turbidity and surface roughness, two factors that may change spatially and over short time spans within a single image (Fretwell et al., 2014). Despite these challenges, large marine mammals have been identified in satellite images (Abileah, 2002; Fretwell et al., 2014, Cubaynes et al., 2019, Bamford et al., 2020, Corrêa et al., 2021), including 25 NARWs in Cape Cod Bay on April 24, 2021, based on the presence of visible callosity patterns (Hodul et al., 2022).

Drones can collect higher resolution multispectral imagery than satellites, offer researchers more freedom in terms of survey timing, can provide coverage in regions of perennial overcast weather (Rodofili et al., 2022), and impose less risk to human life than other aerial survey methods (Harcourt et al., 2019). Furthermore, UAV platforms are less expensive than manned flights; however, they are impeded by battery life and data storage limitations. Combustion–drive fixed wing UAVs flying at high altitudes and airplanes can overcome battery limitations, but are significantly more costly than UAVs and, due to self-generated noise and the associated possibility of disturbance of the animal, are not well suited for close approaches for visual measurements of animals. Additional downsides that have been identified for the use of UAVs include potential disturbances to animals, cost associated with covering large areas, limitations imposed by civil aviation regulations, public perception, and the need to develop or apply advanced automated image detection algorithms specifically designed for this task (Rodofili et al., 2022; Tuia et al., 2022; Álvarez–González et al., 2023). Using drones to survey marine environments requires good water clarity, relies on the monitoring target using shallow waters (Ditria et al., 2022), is affected by the angle of the sun, sea state and glare and requires the target animals close enough to the surface to be visible (Rodofili et al., 2022).

Synthetic aperture radar (SAR) uses a small antenna to produce high–resolution images (Moreira et al., 2013) from an aircraft or satellite and is commonly used in remote sensing to produce images of the earth and sea surface and even in aerial surveillance of fish schools (Petit et al., 1992). SAR is currently used for monitoring Pacific Walrus (*Odobenus rosmarus divergens*) populations during haulouts (Fishback and Douglas, 2021) but suffers from similar challenges to shore–based radar when applied at sea. Sea surface clutter makes detection of marine mammals challenging, and no demonstrations of this application were found in published literature. A study was conducted to determine if SAR detections of internal waves (i.e., gravity waves that oscillate within a stratified layer, rather than at the surface) could be used to predict the presence of humpback whales.

However, the hypothesis that humpback whale distribution is partially determined by internal waves was found to not be supported by the data (Pineda et al., 2015).

Ceballos et al. (2022) utilized a simulation–based model to compare visual and acoustic survey results, including from a RPAS, for the detection and dynamic management of NARWs in Canada. They identified substantial differences in performance among visual survey platforms with vessels performing better than either the aircraft or RPAS, and acoustic gliders detected NARWs in every scenario. The RPAS that was tested had a limited detection range, which was nearly an order of magnitude smaller than that of the vessel or aircraft. The authors state that the RPAS performance may improve substantially by increasing the system detection range, and, to a lesser extent, by reducing the transit speed such that the system spends a greater amount of time surveying a given area. Once operational, a potential benefit of the RPAS as an autonomous platform would be the ability to scale up monitoring effort by deploying multiple platforms.

4.5.1 Application of ML and AI to Remote Sensing Images

Images obtained from remote sensing platforms can be reviewed multiple times unlike visual observations made during aerial or vessel-based surveys, and individual whales can be identified within VHR images. Overall, UAVs have been used effectively to carry out wildlife monitoring surveys; however, in many cases the extensive post–processing effort required has been cited as negating any convenience or time savings afforded by UAVs when compared to conventional survey methods (Gonzalez et al., 2016). However, the growing use of automated methods (ML, AI, and DL) to manage and process large volumes of images efficiently has increased interest in and viability of using remote sensing survey methods to survey marine environments (Borowicz et al., 2019; Tuia et al., 2022; Boulent et al., 2023). Automation further provides the potential of acquiring and analyzing VHR satellite images from more extensive survey areas, thereby closing the gap between VHR satellite images and crewed surveys (Rodofili et al., 2022).

Variation in observers has been demonstrated to represent a sizable source of the uncertainty associated with manual scanning and classification of imagery, with data being prone to user performance bias (Bamford et al., 2020). Automation of the initial image scanning and classification process using ML tools could reduce this bias. However, the parameters used to train the automatic systems would themselves be subject to a degree of bias introduced by the process of building the training set itself. Larger datasets are necessary to increase sample size and reduce error brought about by extreme differences in individual perception (Bamford et al., 2020).

While the potential for using DL as a tool for processing image–based data has been recognized and demonstrated in recent years, there are challenges and limitations to this approach. These include the identification and better understanding of the level of error and confidence in the predictive models, the potential to require substantial computing power, and the requirement for large, labeled datasets for training (Christin et al., 2019; Beyan and Browman, 2020; Malde et al., 2020; Ditria et al., 2022). In supervised learning, algorithms are presented with training datasets that have been labeled with accurate information on the region/species/sound of interest, and the algorithms then learn to associate the labels with the examples (Christin et al., 2019). The training dataset must include a wide array of example images of different species of whales, in different environmental conditions, and displaying different postures/behaviors, as well as features that could be mistaken for a whale (Höschle et al., 2021). With enough training material, the algorithms can produce models that automatically recognize and identify new and unseen examples in other datasets (LeCun et al., 2015).

Data ownership, management, and storage as well as resistance to data sharing pose barriers to the development of robust training sets and have been cited as roadblocks to implementing AI solutions in ecology (Pimm et al., 2015; Ditria et al., 2022). Further, the lack of knowledge–sharing between AI experts and wildlife managers has also been noted as a challenge (Boulent et al., 2023). Finally, the constantly changing nature of the marine environment as well as changing whale behavior make it difficult to develop an automated classification tool that is reliable (Boulent et al., 2023). Considering these challenges and limitations, classification systems frequently include a human–in–the–loop approach, which utilizes AI to speed up the initial phase of analysis and narrow the need for human participation in the broad scale analysis of initial raw datasets (Höschle et al., 2021). Authors such as Boulent et al. (2023) propose using a semi–automated/human–in–the–loop approach to couple the power of DL–based automation with the expertise of biologists to develop a reliable AI assisted annotation tool for cetacean monitoring.

Automated analysis of satellite imagery has been demonstrated to achieve a good match with manual counts, but how closely these counts match the actual number of available (e.g., both at the surface and visible) whales in the survey area remains unclear (Fretwell et al., 2014). Automated and semi–automated processes have been increasingly used to detect whales in images and match whales to a catalog of known individuals. Bogucki et al. (2018) identified distinct NARWs with 87% accuracy using a series of CNNs in a fully automated pipeline with no need for user input. The CNN approach has been increasingly utilized to analyze satellite and drone images of whale hotspots (Rodofili et al., 2022).

4.6 Active Sonar (Sound Navigation and Ranging)

Active vessel–borne sonar systems transmit pulses of sound into the surrounding water. When the sound interacts with an object (e.g., animal, seabed, sea surface), some portion of the pulse is scattered back toward the acoustic sensor as an echo. The time at which the echo is received, which indicates the distance to the object, as well as the angle from which it came, can then be used to localize the detected object. Sonar is categorized by the frequency (low, mid, high) and type of signals (wavelength, duration) produced. Sonar effectiveness and detection range can be influenced by these features as well as by background noise, certain oceanographic characteristics, and background clutter (e.g., signals from things like zooplankton or sea surface/waves masking signals from targets; Monahan and Lu, 1990; Ainslie, 2010; Geoffroy et al., 2012). Additional intrinsic and extrinsic factors which affect the performance of sonar systems include system parameters (e.g., source level, directivity, operating frequency), the acoustic scattering properties of the target (i.e., the whale), the environment (ambient noise or reverberant properties, temperature, salinity, sea state; Urick, 1975; Geoffroy et al., 2012), and the placement/location of vessel-mounted systems (Ainslie 2010).

Marine sonar is typically used to create a depiction of seafloor bathymetry or to estimate the number or biomass of plankton or nekton (fish and squid) in the water column (Heinemann et al., 2016) and is also used in active harbor defense systems (Crawford and Crowe, 2007; Kessel and Hollet, 2006). While sonar is well established as a technology for detecting, localizing, and tracking objects in the water, limited testing (including on the ability to distinguish between whales and other objects) has been conducted of the specific application of sonar to whale vessel strike avoidance. Published studies on the use of sonar for detecting marine mammals are described below.

Verfuss et al. (2018) reviewed available information on the use of sonar systems to detect marine mammals, and they and others have noted that the active transmission of sounds required for sonar may negatively impact marine mammals by causing physiological impacts, behavioral responses, or by masking vocalizations (Weilgart, 2007; Roman et al., 2013). However, many commercial active sonar systems use high frequency (HF) ultrasound, which is not thought to impact marine mammals (Bowles et al., 2010; Daly and Harrison, 2012).

Vessel–mounted sonar systems have been used to detect killer whales (*Orcinus orca*) in Norway (Knudsen et al., 2008) and bowhead whales (*Balaena mysticetus*) in the Canadian Beaufort Sea (Geoffroy et al., 2016). An analysis from the Beaufort Sea demonstrated some of the complexities introduced by the background environment with average bowhead detection ranges varying from less than 1000 meters to 5000 meters depending on oceanographic conditions (Geoffroy et al., 2012). These detection ranges are similar to those found by Lucifredi and Stein (2007), who used a bottom–mounted sonar array to detect gray whales off the coast of California, with an estimated maximum detection range of 1000 meters. A cylindrical sonar array operating at higher frequencies was used at short range (<100 meters) to track near–surface humpback whales (Bernasconi et al., 2013) and was reported as being able to reliably detect killer whales at ranges up to 400 meters (Knudsen et al., 2008). Other higher frequency systems have used planar sonar arrays, including the experimental work by Miller and Potter (2001) to detect both humpback whales and NARWs at ranges of 30–84 meters, although a maximum range was not reported. Similar systems are available commercially and report much larger detection ranges for submerged hazards of up to several hundred meters. Finally, split–beam echo sounders have also been used to detect, localize, and track killer whales at approximately 200-meter distances, though a maximum detection range was not reported (Xu et al., 2012).

4.7 Radar (Radio and Detection and Ranging)

Radar systems emit a beam of electromagnetic waves from a transmit aperture (or antenna). Any targets intersecting this beam reflect or scatter the waves back to the radar receiver, where they are detected and visibly displayed for the user. On vessels, radar antennas are typically constructed to form a narrow beam, defining the radar's angular resolution. This antenna is then mechanically rotated to provide a 360° view of targets on or near the water surface surrounding the vessel. However, scattered returns from signals of interest can be obscured by unwanted returns, known as clutter (e.g., returns from wind–waves, spray, and rain). Marine vessels commonly use S–band (2–4 gigahertz) or X–band (8–12 gigahertz) radar with higher–frequency radar generally offering better resolution, but lower detection ranges. Radar systems using even higher frequency (>20 gigahertz) also exist but are limited in range and may be more applicable to detecting marine mammals from slower–moving autonomous surface vehicles (ASVs; Rahman et al., 2023).

Radar can detect marine mammals at the surface using the reflection of the radar pulse from the exposed body of the animal, an exhalation, or from a disturbance on the sea surface (e.g., wake; Verfuss et al., 2018). Thus, Verfuss et al. (2018) state that radar is most effective for detecting larger animals in low sea state conditions. There has been a great deal of interest in exploring the potential use of radar to detect marine mammals as a relatively low–cost and multi–use technology. If systems already in use for vessel–vessel collision avoidance in low visibility conditions could be modified to also detect marine mammals, that could reduce the cost and inconvenience of installation and use to vessel operators.

To date, testing of radar for marine mammal detection has had mixed results with vessel–based detection ranges ranging from 700 meters for *Stenella* dolphins to 8 kilometers for humpback whales (DeProspo[38]) but differentiating whale detections from other noise sources has proven problematic, resulting in high false positive rates (Forsyth[39]). Work using an X–band commercial radar aboard the NOAA vessel McArthur II following DeProspo was less successful in detecting and

[38] DeProspo, D. F., J. Mobley, W. Hom, and M. Carron. 2005. Radar based detection, tracking and speciation of marine mammals from ships, 7 p. Areté Associates Project Report. Award Number: N00014-04-1-0729. [Available at https://apps.dtic.mil/sti/citations/ADA482441]

[39] Forsyth, C. P. 2011. Radar detection of marine mammals, 5 p. Areté Associates Project Report. Award Number: N00014-07-C-0885. [Available at https://apps.dtic.mil/sti/citations/ADA505246]

tracking marine mammals, with the results attributed to too many false alarms and a low–pulse–length resolution setting on the radar system (Forsyth).

McCann and Bell (2017) successfully detected and tracked killer whales at approximately a 1-kilometer range using shore–based X–band radar. They identified several beneficial circumstances of their experiment, including that the whales were breaching the surface with their full bodies and were oriented broadside to the radar, both of which contribute to a large target for the radar thus resulting in a strong radar return. The authors noted that similarities between whale behavior and sea surface clutter made automated detection challenging. Although McCann and Bell (2017) demonstrated successful whale tracks, they concluded that more work was needed to catalog radar signatures from a wide range of whale species and behaviors. It is possible that modifications to radar hardware and/or filtering techniques could increase the probability of detecting whales while reducing false alarms (Anderson and Morris, 2010). More recently, shore–based X–band radars have been demonstrated to detect bottlenose dolphins (*Tursiops truncatus*) in the Mediterranean at distances up to approximately 4 kilometers (Mingozzi et al., 2020). Although the authors' automated target recognition algorithms were able to perform real–time detections, they only detected 17% of the dolphins that were visually sighted.

In a comprehensive assessment of comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys, Verfuss et al. (2018) concluded that there is currently a lack of empirical data on the ability of radar to detect marine mammals in real world conditions. Their assessment concluded that the ability to use radar detection at night and potentially in fog or rain are clear advantages, while cue masking, especially when targets have small cue amplitudes and when the sea state is high, is considered radar's most significant shortcoming. Additional weaknesses include the inability to differentiate between species, the scarcity of empirical detection data (notably for smaller animals/cues) in a range of low visibility field conditions, the lack of any available and tested automated systems to assist in marine mammal detection, and identification/removal of false positives (Verfuss et al., 2018).

4.8 Light Detection and Ranging (LIDAR)

LIDAR uses pulsed lasers in the same way that active sonar uses sound waves and radar uses electromagnetic waves. LIDAR instruments emit millions of targeted laser pulses per second that bounce off a surface or object to measure distances and directions (Wandinger, 2005). LIDAR was first used for lunar ranging in 1962, but advances in the technology have led to widespread use by surveying and mapping professionals to capture geospatial data; for wind speed measurements; and for construction of buildings, mining, forestry, and robotics (Yang et al., 2023; Takhtkeshha et al., 2024).

Airborne or towed LIDAR systems can provide subsurface geospatial information at high resolution, with large variations in precision (<2-centimeter range resolution; Dawson et al., 2017). Oceanographic LIDARs can penetrate the ocean at depths up to 100 meters and have a wide range of oceanographic and fisheries applications (Churnside, 2013). Undersea LIDAR systems have been developed for detecting and classifying marine life (Dalgleish et al., 2017); airborne systems have been designed specifically for marine mammal detection (Dawson et al., 2017). However, while LIDAR systems have provided ecologically relevant data on animal behavior and have had some success with coral reefs and seabirds, there is no documentation that this technology has been successful for marine mammal detection (Ditria et al., 2022).

4.9 Stable Isotopes

Stable isotopes are commonly used as biological tracers in ecology to aid in the understanding of how an animal fits within a food web, where and what it eats, and how it moves throughout its range via migrational patterns (Newton, 2016). Specifically, isotope analysis can provide insight into patterns of movement and the relative value of certain feeding grounds, provided there is sufficient variation in the isotopic signature of prey. For example, Forbes et al. (2023) used stable isotope analysis to document the distribution shift of NARWs expanding their range into the Gulf of St. Lawrence following an ocean regime shift in 2010. This technology is of more general application to understanding the dynamics of the NARW population, and its relevance for vessel strike reduction is limited to the Static Scenario.

4.10 Environmental DNA (eDNA)

eDNA is DNA that is produced and discarded by an organism in the form of body cells or waste that is then collected from the environment after their departure from the immediate area. Trace DNA collected from environmental samples, such as water and soil, can be used to document the presence (though not the abundance) of species in an area without the need for extensive visual monitoring (Barnes and Turner, 2016 as cited in Ditra et al., 2022). One of the early uses of marine eDNA is the work by Foote et al. (2012) who found that eDNA detections were less reliable than acoustic detections but held promise with optimized methodologies. Baker et al. (2018) assessed the use of eDNA for detecting killer whales for up to 2 hours after their passage in waters that had been tidally advected by several kilometers, although there was considerable variation in detection times and detection levels, and not all encounters produced detectable eDNA levels. Alter et al. (2022) used eDNA to detect the presence of humpback whales and dolphins in the New York Bight, finding that there was significant eDNA degradation over time scales of tens of minutes. They hypothesized that their observed fast degradation times may be attributed to their eDNA detection methodology—metabarcoding rather than the more sensitive polymerase chain reaction (PCR) techniques used by Baker et al. (2018).

Current challenges associated with the use of eDNA include understanding the rate of eDNA degradation, the fate and transport of eDNA as it is mixed and advected within the ocean environment, and the cost and time associated with sample analysis. Therefore, this technique is currently limited in its ability to contribute to vessel strike risk reduction (Harcourt et al., 2019; Ditra et al., 2022). Questions regarding eDNA persistence and detection levels limit the utility of eDNA for vessel strike risk reduction. This is, however, an active and rapidly developing area of research including the development of low–cost and automated methods for sample collection (Formel et al., 2021; Preston et al., 2023), and new technology aimed at improving eDNA assessment (Ramírez–Amaro et al., 2022).

5. Deployment Platforms—A General Discussion

The method in which a detection system is deployed ultimately impacts its coverage, performance, capabilities, and endurance. Non–vessel–based detection technology may be deployed either as stationary installations, such as shore–based, bottom mounted, on a buoy, or aboard mobile platforms such as uncrewed surface vessels, aircraft, undersea vehicles, and satellites. Each of these deployment platforms have common considerations and tradeoffs that will be discussed in this section.

5.1 Stationary

Stationary systems relevant to marine mammal detection are typically deployed on shore (Graber et al., 2011; Sullivan et al., 2020), moored buoys (Baumgartner and Lin, 2019), or the seafloor (Agarwala, 2022). The primary advantage of stationary deployments is their power capacities, either through large batteries or shore–connected cables, and their data processing capabilities. Because stationary systems do not move, size, weight, and power considerations are less of a concern, and data processing and communications are simpler as compared to non–stationary systems. Target localization becomes simpler and less computationally intensive due to the sensor's consistent frame of reference. Data can be offloaded either through shore–based cables, satellite (Baumgartner et al., 2019), or HF/very high frequency (VHF) radio (Tomisa et al., 2008), all at a more predictable cadence and speed than generally available with mobile systems. These factors allow stationary systems to provide persistent coverage over their field of view for long durations as well as regularly communicate their detections.

The primary disadvantage of stationary systems is that they must remain in a fixed position, and thus their coverage area is limited and fixed. Because of this, multiple units are required to provide persistent coverage over large areas. While a mobile system can dynamically allocate its resources to revisit suspected targets and form tracks, stationary systems must work together, either through a local network or a centralized node, or operate over limited areas without long–distance tracking.

5.2 Mobile

Mobile systems typically consist of detectors that are mounted to some type of vehicle such as uncrewed surface vessels (Boisseau et al., 2020; Oedekoven and Thomas[40]), aircraft (Angliss et al., 2018; Álvarez–González et al., 2023), and submersible vehicles (Verfuss et al., 2019; Kowarski et al., 2020). These systems have the advantage of dynamically monitoring large areas and can be tasked to specific areas of interest, either through pre–planned routes or *in situ* decision making. This allows larger areas to be covered with fewer units, potentially reducing costs and increasing persistence and efficiency. However, mobile systems also require maintaining knowledge of their position and orientation to accurately localize detections and communicate information to a decision–maker. They must also be able to transport their own power, any required computation hardware, and any data transmission equipment when desired. Autonomous systems must also be able to navigate and detect safely and effectively without human intervention, which increases the complexity of their use. Applications involving crewed vessels and aircraft are discussed in Section 4.2, and mobile deployments using AUVs, ASVs, UAVs, and satellites are discussed below.

5.2.1 Autonomous Underwater Vehicles (AUVs)

AUVs are commonly used for oceanography and have been directly used for tracking and identifying whales, including NARWs (Dreyfust et al., 2022). Researchers have been using AUVs in oceanography and ecologic monitoring for over 2 decades (Hoagland et al., 1999), with NOAA releasing their AUV vision in 2006 (Manley, 2006).

AUVs come in all shapes and sizes, but compact cylindrical hulls are common for low hydrodynamic drag resistance to hydrostatic pressure. AUV sizes generally occupy four main categories: Man Portable (<100 pounds), Light Weight (~500 pounds), Heavy Weight (~3000 pounds), and Large (~20,000 pounds; Office of the Chief of Naval Operations, 2004). Because they are intended for mostly submerged use, AUVs rely on battery power for propulsion, maneuvering, and control. Most commercially available AUVs can operate with rechargeable lithium–ion batteries, boosting endurance to multiple days for mid–size AUVs. AUVs are typically equipped with a GPS antenna for position fixing at the start and end of a programmed dive and an Iridium antenna for communication at sea.

Undersea gliders are an important exception to the short (few days or less) duration of a propeller–powered AUV. Gliders have either no propeller, or one they use very infrequently,

[40] Oedekoven, C., and L. Thomas. 2022. Effectiveness of Navy lookout teams in detecting cetaceans, 106 p. [Available at https://navymarinespeciesmonitoring.us/reading-room/project-profiles/effectiveness-navy-lookout-teams-detecting-cetaceans-2/]

relying instead on wings to generate horizontal speed from ascending and descending glides driven by buoyancy changes (Griffiths et al., 2007; Javaid et al., 2014). This allows them to travel long ranges with very low power expenditures. Glider speeds are slow, but they can stay at sea for up to 1.5 years and can travel ranges reaching 7,000 kilometers, which is significantly longer than propeller–based Long Range AUVs (Rudnick et al., 2004; Rudnick, 2016). Gliders are well–suited to NARW PAM detection because of their low self–noise and high endurance (time at sea), and recent work has focused on using gliders for passive acoustic detection of NARW using ML techniques to distinguish NARW from other whales in near real–time (Kowarski et al., 2020; Johnson et al., 2022).

5.2.2 Autonomous Surface Vehicles (ASVs)

An ASV, a boat–like uncrewed drone that travels on the ocean surface, is a technology utilized for ocean research. They offer substantial platform volume for accommodating many sensors including active and passive acoustic sensors and meteorological sensors. ASVs typically operate under diesel power or by using renewable energy sources including solar, ocean wave, or wind power (Arima, 2016; Verfuss et al., 2016; Zhixiang et al., 2016; Verfuss et al., 2019). With proper energy management they can work unattended for many months and travel thousands of miles (Manley, 2008). ASVs can tow hydrophone arrays for PAM (Premus et al., 2022) and often carry optical sensors for object detection and collision avoidance. Furthermore, given that they travel at the surface, they have access to both GPS and a variety of communication methods (e.g., satellite, cellular, radiofrequency). A disadvantage of ASVs as compared to AUVs is that they are subject to ocean surface weather conditions, which degrade their sensing and communications capabilities in high sea states (Liu et al., 2016).

5.2.3 Uncrewed Aerial Vehicles (UAVs) and Unmanned Aerial Systems (UASs)

A UAV/UAS, commonly referred to as a drone, is an autonomous aircraft with either propellers (rotary–wing) or fixed wings. Many different UAV types have been used for surveying marine mammals (MMC, 2016; Ferguson et al., 2018) with a variety of research missions (e.g., photo–ID, line–transect surveys, photogrammetry, behavioral studies, etc.; Verfuss et al., 2019). UAVs commonly carry camera equipment, and some also have the payload capacity to carry radars and LIDAR.

UAVs offer many advantages over manned aircraft, including greater flexibility in operation, decreased disturbance of wildlife, smaller environmental footprint, decreased cost, and reduced risk for field researchers (MMC, 2016). However, UAVs have several distinct disadvantages as well such as limited range, speed, endurance, and payload capability. In addition, weather, sea state, altitude, and camera angle all degrade detection and classification more than they do an experienced MMO on a crewed aircraft (Aniceta et al., 2018). Offshore monitoring of NARWs, without a nearby support vessel, requires range and endurance, which favors fixed–wing UAVs and hybrid fixed–winged UAVs (Hodgson et al., 2017). Unconventional wingless drones may offer advantages in terms of mission endurance and station–keeping (i.e., hovering in place).

5.2.4 Satellites

Spaceborne low–earth orbit (LEO) satellite imaging operating at multiple wavelengths is a rapidly evolving technology that has been used to detect NARWs and other whale species (Höschle et al., 2021; Cubaynes and Fretwell, 2022; Hodul et al., 2022; Besl[41]). Satellite image quality is limited by

[41] Besl, J. 2023. Can satellites really detect whales from space?. [Available at https://www.smithsonianmag.com/science-nature/can-satellites-really-detect-whales-from-space-180981607/]

earth surface weather, pointing angle with respect to the earth surface, sun illumination, and camera resolution (which continues to improve). Satellite imagery is often available commercially; however, coverage is limited by the number of available satellites, their orbits, sensor field–of–view, pointing scheme, and weather. Automated detection of whales from satellite imagery lends itself well to ML algorithms (e.g., Cubaynes and Fretwell, 2022).

Although satellite imagery has been demonstrated to be possible for NARW detection, significant hurdles remain to implement the detections for vessel strike risk reduction. Classifying detected whales as NARW, particularly in areas where other whale species are co–occurring, is challenging. Satellite coverage is also fundamentally limited. For example, there is only one WorldView–3 satellite, and this satellite would need to be tasked to image areas of interest. The satellite has a limited field of view and operates in a sun–synchronous orbit and, similar to other LEO satellites, has a revisit rate of less than 1 day. Poor weather (e.g., cloud cover) limits the efficacy of these systems. Lower resolution satellites, such as the WorldView–2, have been used for southern right whale detection and classification (Corrêa et al., 2021; Cubaynes and Fretwell, 2022), so further advances in this field (Kapoor et al., 2023) could provide additional coverage for NARW vessel strike risk reduction.

6. Detection Technology Summary Table

The table below summarizes key aspects of the information presented in this Appendix to characterize and allow for easy comparison of detection technology. The information contained within the table cells is not listed in any particular order.

NARW Detection Technology Summary Table based on a literature review conducted by the 2024 NARW Vessel Strike Risk Reduction Technology Workshop planning team as part of workshop preparations. Please note this table is not exhaustive of all technology types or factors that should be considered but intended to provide a summary overview for comparison purposes. [42]

Technology/ Method	Description	Method of Deployment	Cue	Type of Info that can Potentially be Obtained	Intrinsic Factors Affecting Performance (device)	Extrinsic Factors Affecting Performance (animal)	Extrinsic Factors Affecting performance (environment)	Actionable Scale
Tagging – Suction Cup	Physical monitoring devices that attach to the whale using suction cups and can collect a variety of environmental and animal–based data. These tags typically have short–term deployments (hours to days) and must be collected to retrieve the data.	Whale–based, deployed from vessels using poles or drones.	N/A	Location, dive depth and profile, 3D movement within the water column, acceleration, acoustics, water temperature. Some also include video capabilities.	Storage capacity, battery life, successful attachment and post–detachment flotation to allow for retention and retrieval, ability for a tag to transmit its location if/when detached	Can become detached due to interactions with other animals or the seafloor.	Ability to retrieve tag to download data, sea state and weather conditions to allow for successful deployment	Static, Dynamic
Tagging – Anchored (Type A and Type C)	Physical monitoring devices that attach to the whale using retention barbs and can collect a variety of environmental	Whale–based, deployed from vessels using poles or drones.	N/A	Location, dive depth, water temperature, some can measure fine–scale movements.	Storage capacity, battery life, must be at the surface for sufficient time to offload/ transfer data, ability for a tag to transmit its	Can become detached due to interactions with other animals or the seafloor, impacts on whale health.	Sea state and weather conditions to allow for successful deployment	Static, Dynamic

[42] As discussed in this Appendix, for a detection to be possible, the method/technology's detection range must overlap with the cue being searched for. Consideration of effective detection range is therefore critical when evaluating detection technology, methods, and systems. Some of the intrinsic and extrinsic factors listed in this table have the potential to increase or decrease a detection method/technology's detection range.

Technology/ Method	Description	Method of Deployment	Cue	Type of Info that can Potentially be Obtained	Intrinsic Factors Affecting Performance (device)	Extrinsic Factors Affecting Performance (animal)	Extrinsic Factors Affecting performance (environment)	Actionable Scale
	and animal–based data. These tags typically have mid to longer–term deployments (days to months) and can transmit data via satellite or cellular networks when the whale surfaces.				location if/when detached			
Passive Acoustic Monitoring (PAM)	Passive detection of an acoustic signal using hydrophones. Can have real–time recording and processing capabilities or archival and can be deployed on stationary or mobile platforms.	Buoys, gliders, towed arrays, drifters, platform–mounted, shore–cabled, bottom mounted	Primarily vocalizations, rarely blows and other surface activities	Presence, species identification, location, range, behavior, ocean noise conditions	Array design, array gain, bit depth, deployment depth, detector configuration, classification method, filter setting, flow noise, self–noise, frequency range, sensitivity	Behavior, movement in relation to monitoring system, location relative to sensor, group size, vocalization characteristics (e.g., frequency, source level, pattern)	Acoustic background noise (including masking by other biological or non-biological signals), seabed properties, sea state, sound speed profile, water depth	Static, Dynamic, Vessel–specific
Active Sonar	Pulsed acoustic signals are emitted by the system, and the return signals (echoes) are recorded and analyzed to provide information on the location and characteristics of	Vessels, USVs, buoys, bottom–mounted	Body and, to a lesser extent, wake	Presence, proximity	Motion compensation, pulse bandwidth/duration/frequency, sonar blind spot, source and receiver design, source level, system noise, placement location in	Behavior, size, movement in relation to monitoring system, position relative to surface or seafloor, group size	Acoustic background noise, seabed properties, sea state, temperature, salinity, vertical sound–speed profile, water depth, surface/ volume/seafloor reverberation	Vessel–specific

Technology/ Method	Description	Method of Deployment	Cue	Type of Info that can Potentially be Obtained	Intrinsic Factors Affecting Performance (device)	Extrinsic Factors Affecting Performance (animal)	Extrinsic Factors Affecting performance (environment)	Actionable Scale
	the detected object(s).				relation to the environment (proximity to seafloor and surface)			
Thermal/IR Imaging Cameras	An electro–optical imaging sensor detects temperature differences between the whale's body or exhalation and that of the surrounding environment.	Handheld, vessel–mounted, aerial drones, plane–mounted, shore–based	Surfacing, exhalation, exposed body parts at the surface	Presence, species identification	Camera band, field of view, spatial resolution, stabilization, thermal resolution, whether cooled or not[43], device height in relation to sea surface, bit depth, signal conditioning (e.g., filtering), detection/classifi-cation algorithm	Surface behavior, insulation of exposed body part, size, exhalation strength and temperature, movement in relation to monitoring system, group size	Aerosols, fog, glare, light level, rain, sea state, snow, water temperature, relative humidity, visibility, wind force	Static, Dynamic, Vessel–specific
Visual Surveys	Surveys conducted by plane, boat or remotely piloted aircraft. Those conducted by plane or boat rely upon human observers aided by binoculars and photo images of targets can be captured for	Aerial, vessel–based, remotely piloted aircraft, shore–based	Surfacing, exhalation, body shape, behavior	Presence, species and individual identification, behavior, body condition/health status, group dynamics, visual assessment of the risk environment (e.g., number of	Monitoring effort, available tools (i.e., binoculars), deck height, observer experience, fatigue, field of vision, aircraft ceiling height	Surface behavior, dive duration, group size, coloring, animal size, strength of exhalation, movement in relation to observer, position relative to water surface	Light level, glare, sea state, fog, rain, snow, visibility, surface expression of non–targets	Static, Dynamic, Vessel–specific

[43] Cooled systems generally have a higher signal-to-noise ratio (i.e., higher thermal resolution resulting in higher detection probabilities) but are more expensive to purchase and maintain (Verfuss et al., 2018).

Technology/ Method	Description	Method of Deployment	Cue	Type of Info that can Potentially be Obtained	Intrinsic Factors Affecting Performance (device)	Extrinsic Factors Affecting Performance (animal)	Extrinsic Factors Affecting performance (environment)	Actionable Scale
	subsequent analysis.			vessels/whales present)				
Remote Sensing – Satellite and VHR Imagery	Obtaining images from satellites, remotely piloted or unmanned aircraft	Satellite Images, RPAS, unmanned systems	Surfacing	Species presence, individual identification, demographic information, habitat selection, health assessments using imagery (i.e., from drones/UAVs)	Resolution of images, drones/UAVs: battery life, range, and data storage and transfer limitations and capabilities	Surface behavior presence of other animals of similar size, coloration, body shape	Satellite: cloud cover, white caps, glare, swell, and limited availability of imagery based on satellite task time. UAVs/RPAS/ drones: water clarity, civil aviation regulations	Static, Dynamic (drone/UAVs only)
Radar	Radio waves are emitted into the air and echoes from the animal's body, its exhalation, or from disturbance on the surface are picked up by an array of receivers.	Vessel–based, USVs, shore–based	Exhalation, body, surface disturbance	Presence of and distance to an object	Antenna height, antenna type, frequency modulation, scan rates, solid state core, system power transmission, system resolution	Surface behavior, size, strength of exhalation, movement and orientation in relation to monitoring system, position relative to water surface, group size	Fog, glare, rain, sea state, snow, surface expression of non–targets	Static, Dynamic, Vessel–specific
LIDAR	Sending laser pulses to bounce off an object or surface.	Vessels, UAVs, USVs, crewed aircraft	Body	Presence, behavior	Stabilization, wavelength, angular resolution, scan rate, detector noise, etc.	Behavior, size		Dynamic, Vessel–specific

Technology/ Method	Description	Method of Deployment	Cue	Type of Info that can Potentially be Obtained	Intrinsic Factors Affecting Performance (device)	Extrinsic Factors Affecting Performance (animal)	Extrinsic Factors Affecting performance (environment)	Actionable Scale
Stable Isotope Analysis	Stable isotope ratios vary among food webs and are incorporated into an animal's tissue via its diet. Tissue analysis can sometimes provide insights into animal movement.	Tissue analysis (obtained through biopsy of live whales at sea or necropsy)	N/A	Diet, prey, food web niche, habitat, migration patterns	Laboratory analysis—factors affecting performance of the device to collect the sample are outside the scope of this table.	Laboratory analysis—animal factors affecting ability to collect the sample are outside the scope of this table.	Laboratory analysis—environmental factors affecting collection of the sample are outside the scope of this table.	Static
eDNA	The analysis of water samples for the detection and identification of a single species' DNA.	Vessels (to collect samples)	N/A	Presence	Laboratory analysis—factors affecting performance of the device to collect the sample are outside the scope of this table.	Laboratory analysis—animal factors affecting ability to collect the sample are outside the scope of this table.	Signal persistence (affected by currents, oceanographic conditions, sea state)	Static

7. Literature Cited

Abileah, R. 2002. Marine mammal census using space satellite imagery. U.S. Navy Journal of Underwater Acoustics. 52(3): 709–724.

Abrahms, B., H. Welch, S. Brodie, M. G. Jacox, E. A. Becker, S. J. Bograd, L. M. Irvine, D. M. Palacios, B. R. Mate, and E. L. Hazen. 2019. Dynamic ensemble models to predict distributions and anthropogenic risk exposure for highly mobile species. Diversity and Distributions. 25(8):1182–1193. https://doi.org/10.1111/ddi.12940

Agarwala, N. 2022. Integrating UUVs for naval applications. Maritime Technology and Research. 4(3):254470. https://doi.org/10.33175/mtr.2022.254470

Ainslie, M. A. 2010. Principles of sonar performance modeling, 1st ed., 707 p. Springer Berlin, Heidelberg, Germany.

Alter, S. E., C. D. King, E. Chou, S. C. Chin, M. Rekdahl, and H. C. Rosenbaum. 2022. Using environmental DNA to detect whales and dolphins in the New York Bight. Frontiers in Conservation Science. 3:820337. https://doi.org/10.3389/fcosc.2022.820377

Álvarez-González, M., P. Suarez-Bregua, G. J. Pierce, and C. Saavedra. 2023. Unmanned aerial vehicles (UAVs) in marine mammal research: a review of current applications and challenges. Drones. 7(11):667. https://doi.org/10.3390/drones7110667

Anderson, S. J., and J. T. Morris. 2010. On the detection of marine mammals with ship–borne polarimetric microwave radar. OCEANS'10 IEEE Sydney. 1–6. https://doi.org/10.1109/OCEANSSYD.2010.5603942

Andrews, R. D., R. W. Baird, J. Calambokidis, C. E. C. Goertz, F. M. D. Gulland, M. P. Heide-Jørgensen, S. K. Hooker, M. Johnson, B. Mate, Y. Mitani, D. P. Nowacek, K. Owen, L. T. Quakenbush, S. Raverty, J. Robbins, G. S. Schorr, O. V. Shpak, F. I. Townsend Jr., M. Uhart, R. S. Wells, and A. N. Zerbini. 2019. Best practice guidelines for cetacean tagging. Journal of Cetacean Research and Management. 20:27–66. https://doi.org/10.47536/jcrm.v20i1.237

Angliss, R. P., M. C. Ferguson, P. Hall, V. Helker, A. Kennedy, and T. Sformo. 2018. Comparing manned to unmanned aerial surveys for cetacean monitoring in the Arctic: methods and operational results. Journal of Unmanned Vehicle Systems. 6(3):109–127. https://doi.org/10.1139/juvs-2018-0001

Aniceta, A. S., M. Biuw, U. Lindstrøm, S. A. Solbø, F. Broms, and J. Carroll. 2018. Monitoring marine mammals using unmanned aerial vehicles: quantifying detection certainty. Ecosphere. 9(3):e02122. https://doi.org/10.1002/ecs2.2122

Arima, M., and A. Takeuchi. 2016. Development of an autonomous surface station for underwater passive acoustic observation of marine mammals. 2016. OCEANS 2016–Shanghai. 1–4. https://doi.org/10.1109/OCEANSAP.2016.7485551

Baille, L. M. R., and D. P. Zitterbart. 2022. Effectiveness of surface-based detection methods for vessel strike mitigation of North Atlantic right whales. Endangered Species Research. 49:57–69. https://doi.org/10.3354/esr01202

Baker, C. S., D. Steel, S. Nieukirk, and H. Klinck. 2018. Environmental DNA (eDNA) from the wake of the whales: droplet digital PCR for detection and species identification. Frontiers in Marine Science. 5:133. https://doi.org/10.3389/fmars.2018.00133

Baldacci, A., M. Carron, and N. Portunato. 2005. Infrared detection of marine mammals. NATO Undersea Research Centre (NURC) Tech. Report. SR–443, 32 p.

Bamford, C. C. G., N. Kelly, L. Dalla Rosa, D. E. Cade, P. T. Fretwell, P. N. Trathan, H. C. Cubaynes, A. F. C. Mesquita, L. Gerrish, A. S. Friedlaender, and J. A. Jackson. 2020. A comparison of baleen whale density estimates derived from overlapping satellite imagery and a shipborne survey. Scientific Reports. 10:12985. https://doi.org/10.1038/s41598-020-69887-y

Baumgartner, M. F., and B. R. Mate. 2003. Summertime foraging ecology of North Atlantic right whales. Marine Ecology Progress Series. 264:123–135. https://doi.org/10.3354/meps264123

Baumgartner, M. F., and S. E. Mussoline. 2011. A generalized baleen whale call detection and classification system. Journal of the Acoustical Society of America. 129(5):2889–2902. https://doi.org/10.1121/1.3562166

Baumgartner, M., and Y. Lin. 2019. Evaluating the accuracy and detection range of a moored whale detection buoy near the Massachusetts Wind Energy Area. OCS Study. BOEM 2019–061, 64 p.

Baumgartner, M. F., F. W. Wenzel, N. S. J. Lysiak, and M. R. Patrician. 2017. North Atlantic right whale foraging ecology and its role in human-caused mortality. Marine Ecology Progress Series. 581:165–181. https://doi.org/10.3354/meps12315

Baumgartner, M. F., J. Bonnell, S. M. Van Parijs, P. J. Corkeron, C. Hotchin, K. Ball, L. Pelletier, J. Partan, D. Peters, J. Kemp, J. Pietro, K. Newhall, A. Stokes, T. V. N. Cole, E. Quintana, and S. D. Krauss. 2019. Persistent near-real time passive acoustic monitoring for baleen whales from a moored buoy: system description and evaluation. Methods in Ecology and Evolution. 10(9):1476–1489. https://doi.org/10.1111/2041-210X.13244

Baumgartner, M. F., J. Bonnell, P. J. Corkeron, S. M. Van Parijs, C. Hotchkin, B. A. Hodges, J. B. Thornton, B. L. Mensi, and S. M. Bruner. 2020. Slocum gliders provide accurate near real-time estimates of baleen whale presence from human-reviewed passive acoustic detection information. Frontiers in Marine Science. 7:100. https://doi.org/10.3389/fmars.2020.00100

Bernasconi, M., R. Patel, L. Nøttestad, G. Pedersen, and A. S. Brierley. 2013. The effect of depth on the target strength of a humpback whale (*Megaptera novaeangliae*). Journal of the Acoustical Society of America. 134(6):4316–4322. https://doi.org/10.1121/1.4826178

Beyan, C., and H. I. Browman. 2020. Setting the stage for the machine intelligence era in marine science. ICES Journal of Marine Science. 77(4):1267–1273. https://doi.org/10.1093/icesjms/fsaa084

Bogucki, R., M. Cygan, C. B. Khan, M. Klimek, J. K. Milczek, and M. Mucha. 2018. Applying deep learning to right whale photo identification. Conservation Biology. 33(3):676–684. https://doi.org/10.1111/cobi.13226

Boisseau, O., R. McLanaghan, and A. Moscrop. 2020. Testing the feasibility of unmanned surface vehicles to estimate the distribution and abundance of cetacean species. *In* Report of the Eighth

Meeting of the Parties to ACCOBAMS; Malta, 29 November–2 December 2022, ACCOBAMS–MOP8/2022/Inf22, 20 p. Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS).

Borowicz, A., H. Le, G. Humphries, G. Nehls, C. Höschle, V. Kosarev, and H. J. Lynch. 2019. Aerial-trained deep learning networks for surveying cetaceans from satellite imagery. PLoS ONE. 14(10):e0212532. https://doi.org/10.1371/journal.pone.0212532

Bouffaut, L., K. Taweesintananon, H. J. Kriesell, R. A. Rørstadbotnen, J. R. Potter, M. Landrø, S. E. Johansen, J. K. Brenne, A. Haukanes, O. Schjelderup, and F. Storvik. 2022. Eavesdropping at the speed of light: distributed acoustic sensing of baleen whales in the Arctic. Frontiers in Marine Science. 9:901348. https://doi.org/10.3389/fmars.2022.901348

Boulent, J., B. Charry, M. M. Kennedy, E. Tissier, R. Fan, M. Marcoux, C. A. Watt, and A. Gagné-Turcotte. 2023. Scaling whale monitoring using deep learning: a human-in-the-loop solution for analyzing aerial datasets. Frontiers in Marine Science. 10:1099479. https://doi.org/10.3389/fmars.2023.1099479

Bowles, A. E., S. L. Denes, and M. A. Shane. 2010. Acoustic characteristics of ultrasonic coded transmitters for fishery applications: could marine mammals hear them? Journal of the Acoustical Society of America. 128(5):3223–3231. https://doi.org/10.1121/1.3493438

Bröker, K. C. A., R. G. Hansen, K. E. Leonary, W. R. Koski, and M. P. Heide-Jørgensen. 2019. A comparison of image and observer based aerial surveys of narwhal. Marine Mammal Science. 35(4):1253–1279. https://doi.org/10.1111/mms.12586

Caughley, G. 1974. Bias in aerial survey. The Journal of Wildlife Management. 38(4):921–933. https://doi.org/10.2307/3800067

Ceballos, V., C. Taggart, and H. Johnson. 2022. Comparison of visual and acoustic surveys for the detection and dynamic management of North Atlantic right whales (*Eubalaena glacialis*) in Canada. Conservation Science and Practice. 5(2):e12866. https://doi.org/10.1111/csp2.12866

Charry, B., E. Tissier, J. Iacozza, M. Marcoux, and C. A. Watt. 2021. Mapping Arctic cetaceans from space: a case study for beluga and narwhal. PloS ONE. 16(8):e0254380. https://doi.org/10.1371/journal.pone.0254380

Christin S., É. Hervet, and N. Lecomte. 2019. Applications for deep learning in ecology. Methods in Ecology and Evolution. 10(10):1632–1644. https://doi.org/10.1111/2041-210X.13256

Churnside, J. H. 2013. Review of profiling oceanographic lidar. Optical Engineering. 53(5):051405. https://doi.org/10.1117/1.OE.53.5.051405

Clark, C. W., M. W. Brown, and P. Corkeron. 2010. Visual and acoustic surveys for North Atlantic right whales, *Eubalaena glacialis*, in Cape Cod Bay, Massachusetts, 2001–2005: management implications. Marine Mammal Science. 26(4):837–854. https://doi.org/10.1111/J.1748-7692.2010.00376.X

Cole, T. V. N., P. Gerrior, and R. L. Merrick. 2007. Methodologies and preliminary results of the NOAA National Marine Fisheries Service aerial survey program for right whales (*Eubalaena glacialis*) in the Northeast U.S., 1998-2006. NOAA NEFSC Ref. Doc. NEFSC 07–02, 14 p.

Corrêa, A. A., J. H. Quoos, A. S. Barreto, K. R. Groch, and P. P. B. Eichler. 2021. Use of satellite imagery to identify southern right whales (*Eubalaena australis*) on a Southwest Atlantic Ocean breeding ground. Marine Mammal Science. 38(1):87–101. https://doi.org/10.1111/mms.12847

Crawford, A. M., and D. V. Crowe. 2007. Observations from demonstrations of several commercial diver detection sonar systems. OCEANS 2007. 1–3. https://doi.org/10.1109/OCEANS.2007.4449325

Crowe, L. M., M. W. Brown, P. J. Corkeron, P. K. Hamilton, C. Ramp, S. Ratelle, A. S. M. Vanderlaan, and T. V. N. Cole. 2021. In plane sight: a mark–recapture analysis of North Atlantic right whales in the Gulf of St. Lawrence. Endangered Species Research. 46:227–251. https://doi.org/10.3354/esr01156

Cubaynes, H. C., and P. T. Fretwell. 2022. Whales from space dataset, an annotated satellite image dataset of whales for training machine learning models. Scientific Data. 9:245. https://doi.org/10.1038/s41597-022-01377-4

Cubaynes, H. C., P. T. Fretwell, C. Bamford, L. Gerrish, and J. A. Jackson. 2019. Whales from space: four mysticete species described using new VHR satellite imagery. Marine Mammal Science. 35(2):466–491. https://doi.org/10.1111/mms.12544

Cusano, D. A., L. A. Conger, S. M. Van Parijs, and S. E. Parks. 2018. Implementing conservation measures for the North Atlantic right whale: considering the behavioral ontogeny of mother-calf pairs. Animal Conservation. 22(3):228–237. https://doi.org/10.1111/acv.12457

Cuyler, L. C., R. Wiulsrød, and N. A. Øritsland. 1992. Thermal infrared radiation from free living whales. Marine Mammal Science. 8(2):120–134. https://doi.org/10.1111/j.1748-7692.1992.tb00371.x

Dalgleish, F., B. Ouyang, A. Vuorenkoski, B. Ramos, G. Alsenas, B. Metzger, Z. Cao, and J. Principe. 2017. Undersea LIDAR imager for unobtrusive and eye safe marine wildlife detection and classification. OCEANS 2017–Aberdeen. https://doi.org/10.1109/OCEANSE.2017.8085029

Daly, J. N., and J. Harrison. 2012. The Marine Mammal Protection Act: A regulatory approach to identifying and minimizing acoustic–related impacts on marine mammals. *In* The effects of noise on aquatic life (A. N. Popper, and A. Hawkins, eds.), p. 537–539. Springer, New York, NY.

Davis, G. E., M. F. Baumgartner, J. M. Bonnell, J. Bell, C. Berchok, J. B. Thornton, S. Brault, G. Buchanan, R. A. Charif, D. Cholewiak, C. W. Clark, P. Corkeron, J. Delarue, K. Dudzinski, L. Hatch, J. Hildebrand, L. Hodge, H. Klinchk, S. Kraus, B. Martin, D. K. Mellinger, H. Moors-Murphy, S. Nieukirk, D. P. Nowacek, S. Parks, A. J. Read, A. N. Rice, D. Risch, A. Širović, M. Soldevilla, K. Stafford, J. E. Stanistreet, E. Summers, S. Todd, A. Warde, and S. M. Van Parijs. 2017. Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014. Scientific Reports. 7:13460. https://doi.org/10.1038/s41598-017-13359-3

Dawson, S. M., M. H. Bowman, E. Leunissen, and P. Sirguey. 2017. Inexpensive aerial photogrammetry for studies of whales and large marine animals. Frontiers in Marine Science. 4:366. https://doi.org/10.3389/fmars.2017.00366

Ditria, E. M., C. A. Buelow, M. Gonzalez-Rivero, and R. M. Connolly. 2022. Artificial intelligence and automated monitoring for assisting conservation of marine ecosystems: a perspective. Frontiers in Marine Science. 9:918104. https://doi.org/10.3389/fmars.2022.918104

Dombroski, J. R. G., S. E .Parks, and D. P. Nowacek. 2021. Dive behavior of North Atlantic right whales on the calving ground in the Southeast USA: implications for conservation. Endangered Species Research. 46:35–48. https://doi.org/10.3354/esr01141

Dreyfust, C., J. Kohut, L. Nazzaro, J. Brodie, M. Oliver, and M. Baumgartner. 2022. Aligning the seasonal migration of North Atlantic Right Whales with oceanic features. OCEANS 2022–Hampton Roads. 1–9. https://doi.org/10.1109/OCEANS47191.2022.9977171

Dugan, P. J., C. W. Clark, Y. A. LeCun, and S. M. Van Parijs. 2016. DCL system using deep Learning approaches for land–based or ship–based real–time recognition and localization of marine mammals. ONR Tech. Report. 15 p.

Fairfield, C. P., and S. A. Mizroch. 1990. Comparison of abundance estimation techniques for the western North Atlantic right whale (*Eubalaena glacialis*). Report of the International Whaling Commission. Special Issue(12):119–126.

Ferguson, M. C., R. P. Angliss, A. Kennedy, B. Lynch, A. Willoughby, V. Helker, A. A. Brower, and J. T. Clarke. 2018. Performance of manned and unmanned aerial surveys to collect visual data and imagery for estimating arctic cetacean density and associated uncertainty. Journal of Unmanned Vehicle Systems. 6(3):128–154. https://doi.org/10.1139/juvs-2018-0002

Fishbach, A. S., and D. C. Douglas. 2021. Evaluation of satellite imagery for monitoring Pacific walruses at a large coastal haul-out. Remote Sensing. 13(21):4266. https://doi.org/10.3390/rs13214266

Foote, A. D., P. F. Thomsen, S. Sveegaard, M. Wahlberg, J. Kielgast, L. A. Kyhn, A. B. Salling, A. Galatius, L. Orlando, and M. T. P. Gilbert. 2012. Investigating the potential use of environmental DNA (eDNA) for genetic monitoring of marine mammals. PloS ONE. 7(8):e41781. https://doi.org/10.1371/journal.pone.0041781

Forbes, R., B. Nakamoto, N. Lysiak, T. Wimmer, and B. Hayden. 2023. Stable isotope analysis of baleen from North Atlantic right whales *Eubalaena glacialis* reflects distribution shift to the Gulf of St. Lawrence. Marine Ecology Progress Series. 722:177–193. https://doi.org/10.3354/meps14428

Formel, N., I. C. Enochs, C. Sinigalliano, S. R. Anderson, and L. R. Thompson. 2021. Subsurface automated samplers for eDNA (SASe) for biological monitoring and research. HardwareX. 10:e00239. https://doi.org/10.1016/j.ohx.2021.e00239

Franklin, K. J. , T. V. N. Cole, D. M. Cholewiak, P. A. Duley, L. M. Crowe, P. K. Hamilton, A. R. Knowlton, C. T. Taggart, and H. D. Johnson. 2022. Using sonobuoys and visual surveys to characterize North Atlantic right whale (*Eubalaena glacialis*) calling behavior in the Gulf of St. Lawrence. Endangered Species Research. 49:159–174. https://doi.org/10.3354/esr01208

Fretwell, P. T., I. J. Staniland, and J. Forcada. 2014. Whales from space: counting southern right whales by satellite. PLoS ONE. 9(2):e88655. https://doi.org/10.1371/journal.pone.0088655 PMID: 24533131

Ganley, L. C., S. Brault, and C. A. Mayo. 2019. What we see is not what there is: estimating North Atlantic right whale *Eubalaena glacialis* local abundance. Endangered Species Research. 38:101–113. https://doi.org/10.3354/esr00938

Geoffroy, M., S. Rousseau, and C. Pyć. 2012. 2011 Beaufort Sea active acoustics survey for marine mammal and pelagic fish detection. Final Report, 54 p.

Geoffroy, M., S. Rousseau, F. R. Knudsen, and L. Fortier. 2016. Target strengths and echotraces of whales and seals in the Canadian Beaufort Sea. ICES Journal of Marine Science. 73(2):451–463. https://doi.org/10.1093/icesjms/fsv182

Gervaise, C., Y. Simard, F. Aulanier, and N. Roy. 2021. Optimizing passive acoustic systems for marine mammal detection and localization: application to real-time monitoring north Atlantic right whales in Gulf of St. Lawrence. Applied Acoustics. 178:107949. https://doi.org/10.1016/j.apacoust.2021.107949

Gillespie, D., and M. Caillat. 2008. Statistical classification of odontocete clicks. Canadian Acoustics. 36(1):20–26.

Gillespie, D., M. Caillat, J. Gordon, and P. White. 2013. Automatic detection and classification of odontocete whistles. Journal of the Acoustical Society of America. 134(3): 2427–2437. https://doi.org/10.1121/1.4816555

Gillespie, D., L. Palmer, J. Macaulay, C. Sparling, and G. Hastie. 2020. Passive acoustic methods for tracking the 3D movements of small cetaceans around marine structures. PLoS ONE 15(5): e0229058. https://doi.org/10.1371/journal.pone.0229058

Gonzalez, L. F., G. A. Montes, E. Puig, S. Johnson, K. Mengersen, and K. J. Gaston. 2016. Unmanned aerial vehicles (UAVs) and artificial intelligence revolutionizing wildlife monitoring and conservation. Sensors. 16(1):97. https://doi.org/10.3390/s16010097

Graber, J., J. Thomson, B. Polyagye, and A. Jessup. 2011. Land-based infrared imagery for marine mammal detection. Remote Sensing and Modeling of Ecosystems for Sustainability VIII. Proceedings 8156:81560B. https://doi.org/10.1117/12.892787

Griffiths, G., C. Jones, J. Ferguson, and N. Bose. 2007. Undersea gliders. Journal of Ocean Technology. 2(2):64–75.

Guzman, H. M, J. J. Capella, C. Valladares, J. Gibbons, and R. Condit. 2020. Humpback whale movements in a narrow and heavily-used shipping passage, Chile. Marine Policy. 118:103990. https://doi.org/10.1016/j.marpol.2020.103990

Hain, J. H. W., S. L. Ellis, R. D. Kenney, and C. K. Slay. 1999. Sightability of right whales in coastal waters of the southeastern United States with implications for the aerial monitoring program. *In* Marine Mammal Survey and Assessment Methods (G. W. Garner, S. C. Amstrup, J. L. Laake, B. F. J. Manly, L. L. McDonald, and D. G. Robertson, eds.), p. 191–208. CRC Press, London.

Hain, J. H. W., J. D. Hampp, S. A. McKenney, J. A. Albert, and R. D. Kenney. 2013. Swim Speed, Behavior, and Movement of North Atlantic Right Whales (*Eubalaena glacialis*) in Coastal Waters of Northeastern Florida, USA. PLoS ONE 8(1):e54340. https://doi.org/10.1371/journal.pone.0054340

Hamilton, P. K., K. R. Howe, A. R. Knowlton, D. J. Lockwood, K. D. McPherson, H. M. Pettis, A. M. Warren, S. L. Vance, and M. A. Zani. 2024. Maintenance of the North Atlantic Right Whale Catalog, Whale Scarring and Visual Health Databases, Anthropogenic Injury Case Studies and Near Real-Time Matching for Biopsy Efforts, Entangled, Injured, Sick or Dead Right Whales. Final Report to NMFS. Contract No. 1305M2–18–P–NFFM–0108.

Hammond, P., H. Benke, P. Berggren, A. Collet, M. P. Heide–Jørgensen, S. Heimlich–Boran, M. Leopold, and N. Øien. 1995. The distribution and abundance of harbour porpoises and other small cetaceans in the North Sea and adjacent waters. Final Report. European Commission Project LIFE 92–2/UK/027, 20 p.

Hammond, P. S., K. Macleod, P. Berggren, D. L. Borchers, L. Burt, A. Cañadas, G. Desportes, G. P. Donovan, A. Gilles, D. Gillespie, J. Gordon, L. Hiby, I. Kuklik, R. Leaper, K. Lehnert, M. Leopold, P. Lovell, N. Øien, C. G. M. Paxton, V. Ridoux, E. Rogan, F. Samarra, M. Scheidat, M. Sequeira, U. Siebert, H. Skov, R. Swift, M. L. Tasker, J. Teilmann, O. Van Canneyt, and J. A. Vázquez. 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation. 164:107–122. https://doi.org/10.1016/j.biocon.2013.04.010

Harcourt, R., J. van der Hoop, S. Kraus, and E. L. Carroll. 2019. Future directions in *Eubalaena* spp: comparative research to inform conservation. Frontiers in Marine Science. 5:530. https://doi.org/10.3389/fmars.2018.00530

Harland, E. J., and M. S. Armstrong. 2004. The real-time detection of the calls of cetacean species. Canadian Acoustics. 32(2):76–82.

Harris, R. E., G. W. Miller, and W. J. Richardson. 2001. Seal Responses to Airgun Sounds During Summer Seismic Surveys in the Alaskan Beaufort Sea. Marine Mammal Science. 17(4):795–812. https://doi.org/10.1111/j.1748-7692.2001.tb01299.x

Harwood, L. A., and A. Joynt. 2009. Factors influencing the effectiveness of marine mammal observers on seismic vessels, with examples from the Canadian Beaufort Sea. DFO Canadian Science Advisory Secretariat Res. Doc. Research Document 2009/048, 9 p.

Hastie, G. D., D. M. Gillespie, J. C. D. Gordon, J. D. J. Macaulay, B. J. McConnell, and C. E. Sparling. 2014. Tracking technologies for quantifying marine mammal interactions with tidal turbines: pitfalls and possibilities. *In* Marine Renewable Energy Technology and Environmental Interactions (M. A. Shields, and A. I. L. Payne, eds.), p. 127–139. Springer Dordrecht, London.

Hazen, E. L., D. M. Palacios, K. A. Forney, E. A. Howell, E. Becker, A. L. Hoover, L. Irvine, M. DeAngelis, S. J. Bograd, B. R. Mate, and H. Bailey. 2017. WhaleWatch: a dynamic management tool for predicting blue whale density in California Current. Journal of Applied Ecology. 54(5):1415–1428. https://doi.org/10.1111/1365-2664.12820

Heinemann, D., J. Gedamke, E. Oleson, J. Barlow, J. Crance, M. Holt, M. Soldevilla, and S. Van Parijs. 2016. Report of the Joint Marine Mammal Commission–National Marine Fisheries Service Passive Acoustic Surveying Workshop. NOAA Tech. Memo. NMFS–F/SPO–164, 107 p.

Hildebrand, J. A., K. E. Frasier, T. A. Helble, and M. A. Roch. 2022. Performance metrics for marine mammal signal detection and classification. Journal of the Acoustical Society of America. 151(1):414–427. https://doi.org/10.1121/10.0009270

Hoagland, P., A. G. Gaines, and M. E. Schumacher. 1999. AUV applications in Massachusetts Bay: an assessment of current and potential opportunities. MIT Sea Grant College Program Tech. Report. MITSG 01–10, 18 p.

Hodgson, A., D. Peel, and N. Kelly. 2017. Unmanned aerial vehicles for surveying marine fauna: assessing detection probability. Ecological Applications. 27(4):1253–1267. https://doi.org/10.1002/eap.1519

Hodul, M., A. Knudby, B. McKenna, A. James, C. Mayo, M. Brown, D. Durette–Morin, and S. Bird. 2022. Individual North Atlantic right whales identified from space. Marine Mammal Science. 39(1):220–231. https://doi.org/10.1111/mms.12971

Höschle, C., H. C. Cubaynes, P. J. Clarke, G. Humphries, and A. Borowicz. 2021. The potential of satellite imagery for surveying whales. Sensors. 21(3):963. https://doi.org/10.3390/s21030963

International Whaling Commission (IWC). 2020. Report of the Joint US Office of Naval Research, International Whaling Commission, and US National Oceanic and Atmospheric Administration Workshop on cetacean tag development, tag follow–up and tag best practices. Journal of Cetacean Research and Management. 21(Supplement):349–372. https://doi.org/10.25607/OBP-858

Irvine, L. M., M. H. Winsor, T. M. Follett, B. R. Mate, and D. M. Palacios. 2020. An at-sea assessment of Argos location accuracy for three species of large whales, and the effect of deep-diving behavior on location error. Animal Biotelemetry. 8:20. https://doi.org/10.1186/s40317-020-00207-x

Javaid, M. Y., M. Ovinis, T. Nagarajin, and F. B. Hashim. 2014. Underwater gliders: a review. MATEC Web of Conferences. 13:02020. https://doi.org/10.1051/matecconf/20141302020

Johnson, M. P., and P. L. Tyack. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. IEEE Journal of Oceanic Engineering. 28(1)3–12. https://doi.org/10.1109/JOE.2002.808212

Johnson, H. D., M. F. Baumgartner, and C. T. Taggart. 2020. Estimating North Atlantic right whale (*Eubalaena glacialis*) location uncertainty following visual or acoustic detection to inform dynamic management. Conservation Science and Practice. 2(10):e267. https://doi.org/10.1111/csp2.267

Johnson, H., D. Morrison, and C. Taggart. 2021. WhaleMap: a tool to collate and display whale survey results in near real-time. Journal of Open Source Software. 6(62):3094. https://doi.org/10.21105/joss.03094

Johnson, H. D., C. T. Taggart, A. E. Newhall, Y. Lin, and M. F. Baumgartner. 2022. Acoustic detection range of right whale upcalls identified in near-real time from a moored buoy and a Slocum glider. Journal of the Acoustical Society of America. 151(4):2558–2575. https://doi.org/10.1121/10.0010124

Kapoor, S., M. Kumar, and M. Kaushal. 2023. Deep learning based whale detection from satellite imagery. Sustainable Computing: Informatics and Systems. 38:100858. https://doi.org/10.1016/j.suscom.2023.100858

Kessel, R. T., and R. D. Hollett. 2006. Underwater intruder detection sonar for harbour protection: state of the art review and implications. *In* The Second IEEE International Conference on Technologies for Homeland Security and Safety; Istanbul, Turkey, 9–13 October. Institute of Electrical and Electronics Engineers (IEEE), Piscataway, NJ.

Khan, C., D. Blount, J. Parham, J. Holmberg, P. Hamilton, C. Charlton, F. Christiansen, D. Johnston, W. Rayment, S. Dawson, E. Vermeulen, V. Rowntree, K. Groch, J. J. Levenson, and R. Bogucki. 2022. Artificial intelligence for right whale photo identification: from data science competition to worldwide collaboration. Mammalian Biology. 102(3):1025–1042. https://doi.org/10.1007/s42991-022-00253-3

Knudsen, F. R., O. B. Gammelsaeter, P. H. Kvadsheim, and L. Nøttestad. 2008. Evaluation of fisheries sonar for whale detection in relation to seismic survey operations. Bioacoustics. 17(1–3):326–328. https://doi.org/10.1080/09524622.2008.9753864

Kowarski, K. A., B. J. Gaudet, A. J. Cole, E. E. Maxner, S. P. Turner, S. B. Martin, H. D. Johnson, and J. E. Moloney. 2020. Near real-time marine mammal monitoring from gliders: practical challenges, system development, and management implications. Journal of the Acoustical Society of America. 148(3):1215–1230. https://doi.org/10.1121/10.0001811

Laake, J. L., J. Calambokidis, S. D. Osmek, and D. J. Rugh. 1997. Probability of detecting harbor porpoise from aerial surveys: estimating g(0). Journal of Wildlife Management. 61(1), 63–75. https://doi.org/10.2307/3802415

LeCun, Y., Y. Bengio, and G. Hinton. 2015. Deep learning. Nature. 521:436–444. https://doi.org/10.1038/nature14539

Lewis, T., D. Gillespie, J. Gordon, and O. Chappell. 1999. Acoustic Cetacean Monitoring 1996 to 1999: Towards the Development of an Automated System Summary Report. Birmingham Research and Development LTD Report. Shell UK Ltd. Contract C10563.

Liu, Z., Y. Zhang, X. Yu, and C. Yuan. 2016. Unmanned surface vehicles: an overview of developments and challenges. Annual Reviews in Control. 41:71–93. https://doi.org/10.1016/j.arcontrol.2016.04.018

Lucifredi, I., and P. J. Stein. 2007. Gray whale target strength measurements and the analysis of the backscattered response. Journal of the Acoustical Society of America. 121(3):1383–1391. https://doi.org/10.1121/1.2436643

Lyu, H., Z. Shao, T. Cheng, Y. Yin, and X. Gao. 2023. Sea-surface object detection based on electro-optical sensors: a review. IEEE Intelligent Transportation Systems Magazine. 15(2):190–216. https://doi.org/10.1109/MITS.2022.3198334

Malde, K., N. O. Handegard, L. Eikvil, and A. Salberg. 2020. Machine intelligence and the data-driven future of marine science. ICES Journal of Marine Science. 77(4):1274–1285. https://doi.org/10.1093/icesjms/fsz057

Manley, J. E. 2006. NOAA's AUV vision: status and opportunities. OCEANS 2006. 1–5. https://doi.org/10.1109/OCEANS.2006.307061

Manley, J. E. 2008. Unmanned surface vehicles, 15 years of development. OCEANS 2008. 1–4. https://doi.org/10.1109/OCEANS.2008.5289429

Marine Mammal Commission (MMC). 2016. Development and use of UASs by the National Marine Fisheries Service for surveying marine mammals. MMC Report, 41 p.

Marine Mammal Commission (MMC). 2024. North Atlantic right whale tagging workshop report. MMC Report, 37 p.

Marques, T. A., L. Thomas, S. W. Martin, D. K. Mellinger, J. A. Ward, D. J. Moretti, D. Harris, and P. L. Tyack. 2013. Estimating animal population density using passive acoustics. Biological Reviews. 88(2):287–309. https://doi.org/10.1111/brv.12001

Mate, B., R. Mesecar, and B. Lagerquist. 2007. The evolution of satellite-monitored radio tags for large whales: one laboratory's experience. Deep Sea Research Part II: Topical Studies in Oceanography. 54(3–4):224–247. https://doi.org/10.1016/j.dsr2.2006.11.021

Matthews, L. P., and S. E. Parks. 2021. An overview of North Atlantic right whale acoustic behavior, hearing capabilities, and responses to sound. Marine Pollution Bulletin. 173(Part B):113043. https://doi.org/10.1016/j.marpolbul.2021.113043

McCann, D. L., and P. S. Bell. 2017. Observations and tracking of killer whales (*Orcinus orca*) with shore-based X-band marine radar at a marine energy test site. Marine Mammal Science. 33(3):904–912. https://doi.org/10.1111/mms.12395

McCordic, J. A., H. Root–Gutteridge, D. A. Cusano, S. L. Denes, and S. E. Parks. 2016. Calls of North Atlantic right whales *Eubalaena glacialis* contain information on individual identity and age class. Endangered Species Research. 30:157–169. https://doi.org/10.3354/ESR00735

Miller, B. S., S. Madhusudhana, M. G. Aulich, and N. Kelly. 2022. Deep learning algorithm outperformance experienced human observer at detection of blue whale D-calls: a double-observer analysis. Remote Sensing in Ecology and Conservation. 9(1):104–116. https://doi.org/10.1002/rse2.297

Miller, J. H., and D. C. Potter. 2001. Active high frequency phased-array sonar for whale shipstrike avoidance: target strength measurements. MTS/IEEE OCEANS 2001. 4:2104–2107 https://doi.org/10.1109/OCEANS.2001.968324

Mingozzi, M., F. Salvioli, and F. Serafino. 2020. X-band radar for cetacean detection (focus on *Tursiops truncatus*) and preliminary analysis of their behavior. Remote Sensing. 12(3):388. https://doi.org/10.3390/rs12030388

Mohri, M., A. Rostamizadeh, and A. Talwalkar. 2018. Foundations of machine learning, 2nd ed., 487 p. MIT Press, Cambridge, MA.

Monahan, E. C., and M. Lu. 1990. Acoustically relevant bubble assemblages and their dependence on meteorological parameters. IEEE Journal of Oceanic Engineering. 15(4):340–349. https://doi.org/10.1109/48.103530

Moreira, A., P. Prats–Iraola, M. Younis, G. Krieger, I. Hajnsek, and K. P. Papathanassiou. 2013. A tutorial on synthetic aperture radar. IEEE Geoscience and Remote Sensing Magazine. 1(1):6–43. https://doi.org/10.1109/MGRS.2013.2248301

Murname, E. C. 2021. Detection, classification and prediction of satellite tagged marine mammals for the U.S. Navy. Naval Research Laboratory Report. NRL/FR/8114–19–10,343, 79 p.

Newton, J. 2016. Stable isotopes as tools in ecological research. eLS. 1–8. https://doi.org/10.1002/9780470015902.a0021231.pub2

Nielsen, B. K., and B. Møhl. 2006. Hull-mounted hydrophones for passive acoustic detection and tracking of sperm whales (*Physeter macrocephalus*). Applied Acoustics. 67(11-12):1175–1186. https://doi.org/10.1016/j.apacoust.2006.05.008

Office of the Chief of Naval Operations, Submarine Warfare and Department of the Navy, Navy Research and Development. 2004. The Navy Unmanned Undersea Vehicle (UUV) Master Plan. Navy Research and Development Report. 97 p.

Oleson, E. M., J. Baker, J. Barlow, J. E. Moore, and P. Wade. 2020. North Atlantic right whale monitoring and surveillance: report and recommendations of the National Marine Fisheries Service's Expert Working Group. NOAA Tech. Memo. NMFS–OPR–64, 47 p.

Parente, C. L., and M. E. de Araújo. 2011. Effectiveness of Monitoring Marine Mammals during Marine Seismic Surveys off Northeast Brazil. Journal of Integrated Coastal Zone Management. 11(4):409–419. https://doi.org/10.5894/rgci251

Parks, S. E., and P. L. Tyack. 2005. Sound production by North Atlantic right whales (*Eubalaena glacialis*) in surface active groups. Journal of the Acoustical Society of America. 117(5):3297–3306. https://doi.org/10.1121/1.1882946

Parks, S. E., J. D. Warren, K. Stamieszkin, C. A. Mayo, and D. Wiley. 2012. Dangerous dining: surface foraging of North Atlantic right whales increases risk of vessel collisions. Biology Letters. 8(1): 57–60. https://doi.org/10.1098/rsbl.2011.0578

Perryman, W. L., M. A. Donahue, J. L. Laake, and T. E. Martin. 1999. Diel Variation in Migration Rates of Eastern Pacific Gray Whales Measured with Thermal Imaging Sensors. Marine Mammal Science. 15(2):426–445. https://doi.org/10.1111/j.1748-7692.1999.tb00811.x

Petit, M., J. Stretta, H. Farrugio, and A. Wadsworth. 1992. Synthetic aperture radar imaging of sea surface life and fishing activities. IEEE Transactions on Geoscience and Remote Sensing. 30(5):1085–1089. https://doi.org/10.1109/36.175346

Pimm, S. L., S. Alibhai, R. Bergl, A. Dehgan, C. Giri, Z. Jewell, L. Joppa, R. Kays, and S. Loarie. 2015. Emerging Technologies to Conserve Biodiversity. Trends in Ecology & Evolution. 30(11):685–696. https://doi.org/10.1016/j.tree.2015.08.008

Pineda, J., V. Starczak, J. C. B. da Silva, K. Helfrich, M. Thompson, and D. Wiley. 2015. Whales and waves: humpback whale foraging response and the shoaling of internal waves at Stellwagen Bank. Journal of Geophysical Research: Oceans. 120(4):2555–2570. https://doi.org/10.1002/2014JC010564

Prasad, D. K., D. Rajan, L. Rachmawati, E. Rajabally, and C. Quek. 2017. Video processing from electro-optical sensors for object detection and tracking in a maritime environment: a survey. IEEE Transactions on Intelligent Transportation Systems. 18(8):1993–2016. https://doi.org/10.48550/arXiv.1611.05842

Premus, V. E., P. A. Abbot, V. Kmelnitsky, C. J. Gedney, and T. A. Abbot. 2022. A wave glider-based, towed hydrophone array system for autonomous, real-time, passive acoustic marine mammal monitoring. Journal of the Acoustical Society of America. 152(3):1814–1828. https://doi.org/10.1121/10.0014169

Preston, C., K. Yamahara, D. Pargett, C. Weinstock, J. Birch, B. Roman, S. Jensen, B. Connon, R. Jenkins, J. Ryan, and C. Scholin. 2023. Autonomous eDNA collection using an uncrewed surface vessel over a 4200-km transect of the eastern Pacific Ocean. Environmental DNA. 6(1):e468. https://doi.org/10.1002/edn3.468

Rahman, S., A. B. Vattulainen, D. A. Robertson, and R. Milne. 2023. Radar signatures of sea lions at K–band and W–band. IET Radar, Sonar & Navigation. 18(1):147–157. https://doi.org/10.1049/rsn2.12498

Ramírez-Amaro, S., M. Bassitta, A. Picornell, C. Ramon, and B. Terrasa. 2022. Environmental DNA: state-of-the-art of its application for fisheries assessment in marine environments. Frontiers in Marine Science. 9:1004674. https://doi.org/10.3389/fmars.2022.1004674

Rasmussen, J. H., and A. Širović. 2021. Automatic detection and classification of baleen whale social calls using convolutional neural networks. Journal of the Acoustical Society of America. 149(5):3635–3644. https://doi.org/10.1121/10.0005047

Risch, D., U. Siebert, and S. M. Van Parijs. 2014. Individual calling behaviour and movements of North Atlantic minke whales (*Balaenoptera acutorostrata*). Behaviour. 151(9):1335–1360. https://doi.org/10.1163/1568539X-00003187

Roberts, J. J., B. D. Best, L. Mannocci, E. Fujioka, P. N. Halpin, D. L. Palka, L. P. Garrison, K. D. Mullin, T. V. N. Cole, C. B. Khan, W. A. McLellan, D. A. Pabst, and G. G. Lockhart. 2016. Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. Scientific Reports. 6:22615. https://doi.org/10.1038/srep22615

Rodofili, E. N., V. Lecours, and M. LaRue. 2022. Remote sensing techniques for automated marine mammals detection: a review of methods and current challenges. PeerJ. 10:e13540. https://doi.org/10.7717/peerj.13540

Roman, J., I. Altman, M. M. Dunphy–Daly, C. Campbell, M. Jasny, and A. J. Reed. 2013. The Marine Mammal Protection Act at 40: status, recovery, and future of U.S. marine mammals. Annals of the New York Academy of Sciences. 1286(1):29–49. https://doi.org/10.1111/nyas.12040

Rudnick, D. L. 2016. Ocean Research Enabled by Underwater Gliders. Annual Review of Marine Science. 8:519–541. https://doi.org/10.1146/annurev-marine-122414-033913

Rudnick, D. L., R. E. Davis, C. C. Eriksen, D. M. Fratantoni, and M. J. Perry. 2004. Underwater gliders for ocean research. Marine Technology Society Journal. 38(2):73–84. https://doi.org/10.4031/002533204787522703

Schall, E., I. I. Kaya, E. Debusschere, P. Devos, and C. Parcerisas. 2024. Deep learning in marine bioacoustics: a benchmark for baleen whale detection. Remote Sensing in Ecology and Conservation. https://doi.org/10.1002/rse2.392

Silber, G. K., S. Bettridge, and D. Cottingham. 2009. Report of a workshop to identify and assess technologies to reduce ship strikes of large whales. NOAA Tech. Memo. NMFS–OPR–42, 55 p.

Smith, H. R., D. P. Zitterbart, T. F. Norris, M. Flau, E. L. Ferguson, C. G. Jones, O. Boebel, and V. D. Moulton. 2020. A field comparison of marine mammal detections via visual, acoustic, and infrared

(IR) imaging methods offshore Atlantic Canada. Marine Pollution Bulletin. 154:111026. https://doi.org/10.1016/j.marpolbul.2020.111026

Stanistreet, J. E., D. Risch, and S. M. Van Parijs. 2013. Passive acoustic tracking of singing humpback whales (Megaptera novaeangliae) on a northwest Atlantic feeding ground. PLoS One. 8(4):e61263. https://doi.org/10.1371/journal.pone.0061263

Sullivan, K., M. Fennell, W. Perryman, and D. Weller. 2020. Automated detection, tracking, and counting of gray whales. Thermosense: Thermal Infrared Applications XLII. 11409:44–58. https://doi.org/10.1117/12.2567187

Takhtkeshha, N., G. Mandlburger, F. Remondino, and J. Hyyppä. 2024. Multispectral sight detection and ranging technology and applications: a review. Sensors. 24(5):1669. https://doi.org/10.3390/s24051669

Theriault, J. A., H. Yurk, and H. B. Moors–Murphy. 2020. Workshop report: review of near–real time whale detection technologies. Canada Department of Fisheries and Oceans Tech. Report. Canadian technical report of fisheries and aquatic sciences 3410, 37 p.

Thorpe, S. A. 2004. Langmuir circulation. Annual Review of Fluid Mechanics. 36:55–79. https://doi.org/10.1146/annurev.fluid.36.052203.071431

Tomisa, T., S. Krajcar, and D. Pinezic. 2008. Multipurpose marine buoy. 2008 50th International Symposium ELMAR. 401–405.

Tuia, D., B. Kellenberger, S. Beery, B. R. Costelloe, S. Zuffi, B. Risse, A. Mathis, M. W. Mathis, F. van Langevelde, T. Burghardt, R. Kays, H. Klinck, M. Wikelski, I. D. Couzin, G. van Horn, M. C. Crofoot, C. V. Stewart, and T. Berger–Wolf. 2022. Perspectives in machine learning for wildlife conservation. Nature Communications. 13:792. https://doi.org/10.1038/s41467-022-27980-y

Urick, R. J. 1975. Principles of underwater sound, 2nd ed., 408 p. McGraw–Hill, New York, NY.

Vagle, S., R. E. Burnham, C. O'Neill, and H. Yurk. 2021. Variability in anthropogenic underwater noise due to bathymetry and sound speed characteristics. Journal of Marine Science Engineering. 9:1047. https://doi.org/10.3390/jmse9101047

Van Parijs, S. M., C. W. Clark, R. S. Sousa–Lima, S. E. Parks, S. Rankin, D. Risch, and I. C. Van Opzeeland. 2009. Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Marine Ecology Progress Series. 395:21–36. https://doi.org/10.3354/meps08123

Van Parijs, S. M., M. Baumgartner, D. Cholewiak, G. Davis, J. Gedamke, D. Gerlach, S. Haver, J. Hatch, L. Hatch, C. Hotchkin, A. Izzi, H. Klinch, E. Matzen, D. Risch, G. K. Silber, and M. Thompson. 2015. NEPAN: A U.S. Northeast passive acoustic sensing network for monitoring, reducing threats and the conservation of marine animals. Marine Technology Society Journal. 49(2):70–86. https://doi.org/10.4031/MTSJ.49.2.16

Van Parijs, S. M., K. Baker, J. Carduner, J. Daly, G. E. Davis, C. Esch, S. Guan, A. Scholik–Schlomer, N. B. Sisson, and E. Staaterman. 2021. NOAA and BOEM minimum recommendations for use of passive acoustic listening systems in offshore wind energy development monitoring and mitigation programs. Frontiers in Marine Science. 8:760840. https://doi.org/10.3389/fmars.2021.760840

Verfuss, U. K., A. S. Aniceto, M. Biuw, S. Fielding, D. Gillespie, D. Harris, G. Jimenez, P. Johnston, R. Plunkett, A. Sivertsen, A. Solbø, R. Storvold, and R. Wyatt. 2016. Literature review: understanding the current state of autonomous technologies to improve/expand observation and detection of marine species. SMRU Consulting Report. SMRUC–OGP–2015–015, 247 p.

Verfuss, U. K., D. Gillespie, J. Gordon, T. A. Marques, B. Miller, R. Plunkett, J. A. Theriault, D. J. Tollit, D. P. Zitterbart, P. Hubert, and L. Thomas. 2018. Comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys. Marine Pollution Bulletin. 126:1–18. https://doi.org/10.1016/j.marpolbul.2017.10.034

Verfuss, U. K., A. S. Aniceto, D. V. Harris, D. Gillespie, S. Fielding, G. Jiménez, P. Johnston, R. R. Sinclair, A. Sivertsen, S. A. Solbø, R. Storvold, M. Biuw, and R. Wyatt. 2019. A review of unmanned vehicles for the detection and monitoring of marine fauna. Marine Pollution Bulletin. 140:17–29. https://doi.org/10.1016/j.marpolbul.2019.01.009

Vickers, W., B. Milner, D. Risch, and R. Lee. 2021. Robust North Atlantic right whale detection using deep learning models for denoising. Journal of the Acoustical Society of America. 149(6):3797–3812. https://doi.org/10.1121/10.0005128

Wandinger, U. 2005. Introduction to Lidar. *In* Lidar: Range–resolved optical remote sensing of the Atmosphere (C. Weitkamp, eds.), p. 1–18. Springer, New York, NY.

Weilgart, L. S. 2007. A brief review of known effects of noise on marine mammals. International Journal of Comparative Psychology. 20(2):159–168. https://doi.org/10.46867/ijcp.2007.20.02.09

Wiley, D. N., C. A. Mayo, E. M. Maloney, and M. J. Moore. 2016. Vessel strike mitigation lessons from direct observations involving two collisions between noncommercial vessels and North Atlantic right whales (*Eubalaena glacialis*). Marine Mammal Science. 32(4):1501–1509. https://doi.org/10.1111/mms.12326

Wiley, D. N., C. J. Zadra, A. S. Friedlaender, S. E. Parks, A. Pensarosa, A. Rogan, K. A. Shorter, J. Urbán, and I. Kerr. 2023. Deployment of biologging tags on free swimming large whales using uncrewed aerial systems. Royal Society Open Science. 10(4):221376. https://doi.org/10.1098/rsos.221376

Williams, S. H., S. M. Gende, P. M. Lukacs, and K. Webb. 2016. Factors affecting whale detection from large ships in Alaska with implications for whale avoidance. Endangered Species Research. 30:209–223. https://doi.org/10.3354/ESR00736

Wilcock, W. S. D., S. Abadi, and B. P. Lipovsky. 2023. Distributed acoustic sensing recordings of low-frequency whale calls and ship noise offshore Central Oregon. Journal of Acoustical Society of America: Express Letters. 3(2):026002. https://doi.org/10.1121/10.0017104

Winn, H. E., J. D. Goodyear, R. D. Kenney, and R. O. Petricig. 1995. Dive patterns of tagged right whales in the Great South Channel. Continental Shelf Research. 15(4–5):593–611. https://doi.org/10.1016/0278-4343(94)00061-Q

Xu, J., Z. D. Deng, T. J. Carlson, and B. Moore. 2012. Target strength of southern resident killer whales (*Orcinus orca*): measurement and modeling. Marine Technology Society Journal. 46(2):74–84. https://doi.org/10.4031/MTSJ.46.2.2

Yang, D., Y. Liu, Q. Chen, M. Chen, S. Zhan, N. Cheung, H. Chan, Z. Wang, and W. J. Li. 2023. Development of the high angular resolution 360° LiDAR based on scanning MEMS mirror. Scientific Reports. 13(1):1540. https://doi.org/10.1038/s41598-022-26394-6

Zeh, J. M., V. Perez–Marrufo, D. L. Adcock, F. H. Jensen, K. J. Knapp, J. Robbins, J. E. Tackaberry, M. Weinrich, A. S. Friedlaender, D. N. Wiley, and S. E. Parks. 2024. Caller identification and characterization of individual humpback whale acoustic behavior. Royal Society Open Science. 11(3):231608. https://doi.org/10.1098/rsos.231608

Zerbini, A. N., J. Robbins, F. M. Gulland, N. Gales, M. Double, and P. J. Clapham. 2023. Assessing the performance and effects of newly designed integrated implantable large whale satellite tags. Final Report. N00014–18–1–2749.

Zhixiang, L., Z. Youmin, Y. Chi, and L. Jun. 2015. An adaptive linear parameter varying fault tolerant control scheme for unmanned surface vehicle steering control. 2015 34th Chinese Control Conference. 6197–6202. https://doi.org/10.1109/ChiCC.2015.7260611

Zitterbart, D. P. 2023. Offshore thermal imaging whale detection test in Canadian waters. Final Research Performance Progress Report. ONR Tech. Report. N00014–20–1–4001, 20 p.

Zitterbart, D. P., L. Kindermann, E. Burkhardt, and O. Boebel. 2013. Automatic round-the-clock detection of whales for mitigation from underwater noise impacts. PLoS ONE 8(8):e71217. https://doi.org/10.1371/journal.pone.0071217

Zitterbart, D. P, H. R. Smith, M. Flau, S. Richter, E. Burkhardt, J. Beland, L. Bennett, A. Cammareri, A. Davis, M. Holst, C. Lanfredi, H. Michel, M. Noad, K. Owen, A. Pacini, and O. Boebel. 2020. Scaling the laws of thermal imaging-based whale detection. Journal of Atmospheric and Oceanic Technology. 37(5):807–824. https://doi.org/10.1175/JTECH-D-19-0054.1

Appendix 7: March 7th Federal Agency Meeting Summary

North Atlantic Right Whale Vessel Strike Risk Reduction Technology Workshop
Meeting for Representatives of the U.S. Government and Government of Canada
Thursday March 7, 2024

Executive Summary

Representatives of U.S. and Canadian Federal Agencies[44] met on March 7, 2024 following the two-day public session of the North Atlantic Right Whale Vessel Strike Risk Reduction Technology Workshop, held in Arlington, VA, March 5-6, 2024. The purpose of the meeting was, as informed by discussions at the workshop, to: (1) share perspectives on promising technologies; (2) identify any concerns or constraints associated with that technology; (3) consider the most pressing research needs regarding vessels, North Atlantic right whales (NARWs), and candidate technologies; and (4) identify potential actions for federal partners (U.S. and Canada) to build on promising opportunities. Participants were asked to explore different possibilities without an expectation of commitment but with the potential to identify shared interests and areas of engagement to build on the momentum surrounding the workshop.

Initial reflections from representatives of federal agencies who participated in the workshop included the importance of: matching vessel strike risk reduction technology to the capabilities and needs of specific vessel sectors; integrating whale information into an already complex stream of information being provided to mariners; considering the diversity of decisions being made by mariners and associated timescales; utilizing safety as a common unifying goal; coordination among Federal Agencies at multiple levels; communication between agencies and with mariners, technology developers and interested parties; and the efficient and effective use of federal authorities and incentives to improve compliance with existing measures. Meeting participants expressed a clear desire to collaborate and to build on the momentum from the workshop.

Federal agency meeting participants also discussed the appropriate roles for the government to advance vessel strike risk reduction technology within the risk chain components. Within the Detection and Classification component, possible federal roles include but are not limited to: funding technology research and development; establishing performance metrics; establishing an interagency technology committee; and development of an outreach and communication plan. Participants identified a clear federal role in developing and disseminating information on NARWs and associated management areas. Participants also identified the need for further discussions between Federal Agencies and entities currently providing whale information to mariners to decide whether an expanded federal role in the aggregation of whale information was appropriate. Participants also flagged the need to define, describe, and explain how government entities manage data and use models to inform vessel strike risk reduction efforts.

Meeting participants shared information about what types of work their agency had underway or was interested in conducting in the various vessel strike risk reduction components. Specific roles were discussed such as providing guidance, management oversight, research and development, testing, deployment, standard setting, and outreach and communication. Opportunities for enhanced coordination were identified in areas of mutual engagement, and a variety of options for collaboration, ranging from informal to formal, were discussed.

[44] Agencies represented were the Bureau of Ocean Energy Management (BOEM), Bureau of Safety and Environmental Enforcement (BSEE), Department of Fisheries and Oceans Canada (DFO), Marine Mammal Commission (MMC), National Oceanic and Atmospheric Administration (NOAA), Transport Canada (TC), U.S. Army Corps of Engineers (USACE), U.S. Coast Guard (USCG), and the U.S. Navy.

Appendix 8: Report of a [2008] Workshop to Identify and Assess Technologies to Reduce Ship Strikes of Large Whales

Silber, G.K., S. Bettridge, and D. Cottingham. 2009. Report of a workshop to identify and assess technologies to reduce ship strikes of large whales, 8-10 July, 2008, Providence, Rhode Island. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-OPR-42. 55 p.
https://repository.library.noaa.gov/view/noaa/23529