MELO Project
Workshop Report

2023

ClearSeas

October 2023

Executive Summary

Workshop Objectives:
The purpose of the two-day MELO Project Design Workshop was to bring experts from various backgrounds in ship design, oceanography and marine biology together to collaboratively develop solutions to reducing the impact of underwater noise on marine mammals.

Key Takeaways:

- Opportunities for interdisciplinary knowledge sharing like the one presented by this workshop are rare and so the exchanges between participants were particularly valuable and led to an increase in collective knowledge and understanding that will enhance innovation in the work that follows.
- The current level of knowledge about marine mammals and their noise sensitivity amongst ship designers is low. Further research and knowledge mobilization is needed to close this gap.
- There are still very large opportunities for noise reduction from ships through improved designs but the trade-offs like fuel consumption and GHG emissions will need to be carefully managed.
- An improved understanding is further required of the fundamental physical mechanisms related to turbulent vortex and cavitation dynamics which are instrumental in the generation of tonal and broadband propeller noise. Such understanding will lead to cost-effective technologies for passive and active control strategies as well as retrofits to balance the trade-off between the GHG emission and URN impact.
- The application of artificial intelligence (AI) and machine learning, especially generative AI to all aspects of the ship/ocean/marine mammal system in the full lifecycle is yielding major benefits by reducing processing time, thereby permitting near real-time completion of tasks that were previously thought to be too difficult.
- Centralization of data in accessible formats from all sources including acoustic data, bathymetry, ship data, marine mammal reactions is urgently needed to accelerate the pace of understanding and innovation.
- Finally, an optimal combination of technological measures with AI-driven slowdown and distancing can be a rewarding and effective way to manage the impact of ship noise on marine mammals.

Workshop Outcomes and Next Steps:

- Knowledge sharing and networking opportunities for participants from a diverse set of backgrounds
- The MELO project team will continue to develop the analysis toolbox and publish results
- The MELO project team will gather field data and publish results
- The MELO project team will continue to develop the smart adaptive ship system concept to build on the inputs from the workshop participants including:
    i. Concept of full area optimization for all vessels and mammals present; and
    ii. Identification of near-term measures which could include “quiet mode” and “transit mode” for existing vessels

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MELO Project Design Workshop Report 2023

1.0 Introduction

On June 1-2, 2023, the MELO Project Design Workshop was held in-person at the University of British Columbia on the traditional, ancestral, unceded territory of the xʷməθkʷəy̓əm (Musqueam) First Nation. The MELO Project is a multi-year academic research initiative that aims to develop an underwater noise prediction toolkit that will allow ships to adjust their noise signatures in real-time. The project is co-led by researchers at the University of British Columbia and Clear Seas, a Canadian non-profit organization that supports safe, sustainable and inclusive marine shipping. The workshop was convened by the MELO Project team.

The purpose of the MELO Project Design Workshop was to bring experts from various backgrounds together to collaboratively develop solutions to the impact of underwater noise on marine mammals. Summaries of the speaker presentations and highlights from the discussion periods and breakout groups are included in this report.

The workshop agenda is provided in Appendix A. Digital copies of the breakout group brainstorming posters are provided in Appendix B, and a list of workshop participants and their contact information is found in Appendix C. Finally, in Appendix D, there is a research project summary titled Uplifting Traditional Indigenous Knowledge in Solving Underwater Noise Pollution, prepared by Chanessa Perry, a research intern with Clear Seas' Indigenous Internship Program. Copies of the speaker's presentations are found on the Clear Seas website.

Funding for this workshop was provided in part by Transport Canada through the Quiet Vessel Initiative and Mitacs, with additional support from Clear Seas and the University of British Columbia.

1.1 Context and Objectives

Anthropogenic noise from marine shipping and other sources poses a serious threat to marine mammals and the ocean environment. Advances in naval architecture are revealing opportunities for noise mitigation through the design and operation of vessels, while concurrent research by marine biologists and oceanographers have made significant advances in understanding the sensitivities of different species to noise. Unfortunately, these are often very different efforts. Developing solutions to ship-source underwater noise will require extensive collaboration across disciplines and a holistic understanding of the existing systems.

The MELO Project attempts to link together the knowledge streams of ship design and marine ecology to create innovative solutions to the impacts of underwater noise on marine mammals, using a systems-based approach. The goal of the MELO Project is to develop a physics-based machine learning toolbox to predict noise from distributed sources and then, based on an understanding of the sensitivity of marine mammals to noise, to demonstrate its application as an adaptive vessel-based noise mitigation strategy for marine vessels in operation. By reimagining what ships could look like, results of the MELO Project could encourage the next generation of ship designers to consider whether vessels could become a truly sympathetic part of the marine environment.

Over two days of presentations, discussions, and breakout group collaboration, the MELO Project Design Workshop brought people together to share knowledge and discuss different pathways to solving issues related to underwater noise. Exchanging knowledge with other researchers is an essential part of the MELO Project's methodology, and hosting the design workshop is one way the team is engaging with experts across disciplines. The workshop was planned to provide opportunities for constructive dialogue and brainstorming on innovative topics, such as:

- Leveraging emerging technologies from different disciplines in order to develop new solutions to reduce marine mammal disturbance from underwater noise;
- Understanding how artificial intelligence in the form of machine learning can be used to process data more efficiently, for example in order to predict noise in real-time onboard vessels; and
- Exploring how to improve our understanding of the sensitivity and response of marine mammals to underwater noise using data gathered by ships, hydrophones and other observation methods.

1.2 Workshop Approach

As a key component of the MELO Project, the design workshop was planned to bring together experts across different fields and gain feedback on the MELO Project's methodology. Invitations to attend the workshop were sent out to people around the world whose work or research focused on ship design, marine biology, underwater acoustics, and other areas. Speakers were invited based on their expertise in specific fields or on recommendation from other experts. Efforts were taken by the team to ensure representation from different disciplines in speakers and participants. Approximately 40 people attended the workshop, with a mix of students, academics, public servants, industry representatives, and one person who worked for a First Nations community.

The first day of the workshop aimed to bring a shared understanding across disciplines of issues and opportunities related to underwater noise. Seven speakers, from both academia and industry, gave presentations on their research area of interest. The speakers intentionally focused on trying to deliver their ideas and presentation content in a way that was accessible to all workshop participants, regardless of one's expertise in the topic. Each presentation session included a discussion period where workshop participants could pose questions or prompt conversations among the group. As part of the first day, the MELO Project team presented the preliminary results of their work, including the results of a literature review on marine mammal responses to underwater noise and a session on advances in the computational modelling of ship noise.

The second day of the workshop included facilitated sessions which aimed to form connections with others, discuss opportunities for innovation, and identify knowledge gaps in different research areas. Participants were separated into smaller breakout groups of 10-12 people and guided through two exercises. The objective of these breakout sessions was to co-develop design systems to account for the different interactions occurring between ocean users and inhabitants. In addition to the breakout sessions, the MELO Project team demonstrated the initial functionality of the analysis toolkit.

2.0 Summary of Day 1 of the Design Workshop

2.1 Opening

Paul Blomerus, Executive Director of Clear Seas, opened the workshop by sharing a written welcome from Richard Sparrow, Councillor at Musqueam Indian Band and a member of the Board of Directors of Clear Seas:

"I would like to welcome you, especially those who have travelled a great distance, to the traditional, unceded, ancestral territory of the Musqueam people. We have stewarded the waters and lands in our territory for thousands of years, and as a coastal people, our well-being is closely tied to the health of the marine life that inhabits these waters. I hope that the conversations from this workshop will be applied to protect and preserve the marine environment for future generations."

A review of the agenda and workshop objectives, as well as logistical information about the meeting space were also provided.

Andrew Trites, Director of the Marine Mammal Research Unit at the University of British Columbia and one of the MELO Project research leads, provided opening remarks. He highlighted the importance of bringing people together to do multidisciplinary research and remarked that this was the first time the MELO Project team had the opportunity to meet each other in person after years of virtual meetings. Next, the workshop participants were invited to introduce themselves and say a few words about their area of interest in the topic of underwater noise and the impact on marine mammals. Afterwards, the remainder of the first day of the workshop consisted of presentations and discussion periods among workshop participants.

2.2 Workshop Presentation Summaries

Understanding the impacts of ship noise on marine mammals

Dave Rosen

Assistant Professor, Marine Mammal Research Unit, UBC

The presentation addressed the impact of underwater noise on marine mammals, exploring various methods to quantify this impact. It introduced the classification of marine mammals into different hearing groups with similar acoustic sensitivity, providing a brief overview of local mammals in the Salish Sea region.

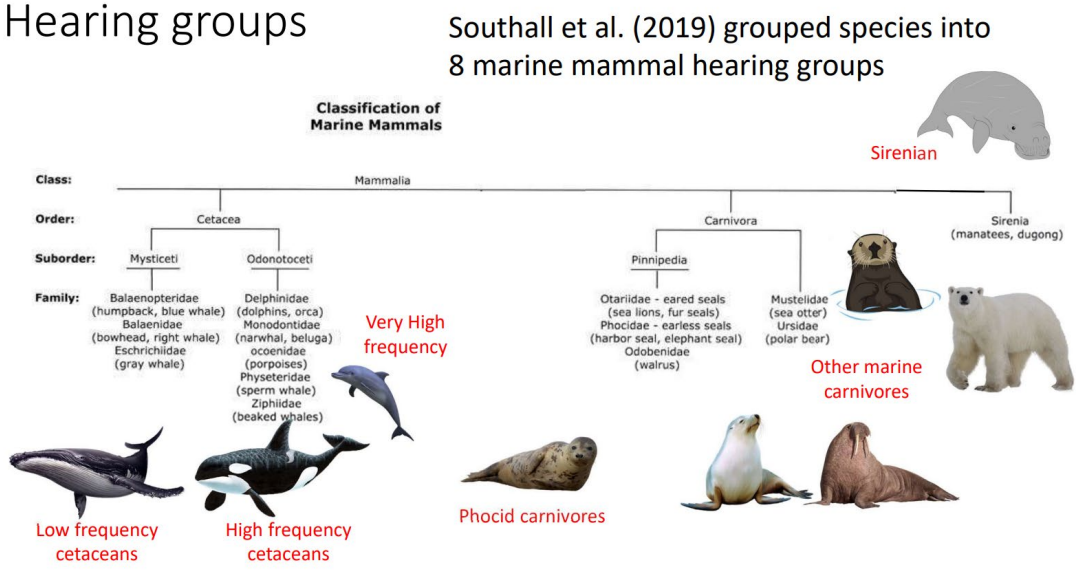


Figure 1. Slide from David Rosen's presentation showing marine mammal hearing groups.

The speaker highlighted the importance of targeting mitigation strategies at specific frequencies, prioritized based on factors such as biological effects, local species' interests, noise exposure functions, and audiograms. The limitations associated with using audiograms as a basis for prioritizing solutions were also discussed. An effective audiogram weighting function was presented to emphasize susceptibility to noise through frequency-specific filters. The presentation further explored the biological functions of marine mammals, categorizing them based on potential short-term and long-term impacts within specific frequency bands. Additionally, the concepts of masking phenomenon and noise exposure functions were briefly introduced as two effects with reasonably available data.

Highlights from the discussion period include:

- Interest in understanding the impact on marine mammals of multiple quieter ships rather than one noisier ship (e.g. longer term but lower intensity exposure versus shorter term but higher intensity exposure) and which one is worse? The answer is unclear.
- Discussed information and methods available for ways to assess impacts of noise on mammals. Audiograms have been done on very few species, on very few individuals, and often under human care (less reflective of true hearing).
    - Other types of monitoring (digital tags, other equipment to measure neurological response instead of behaviour).
    - Population Consequences of Acoustic Disturbance (PCAD) models can be useful to determine the ultimate cost of noise exposure to the marine mammal, but there is still work to be done in this field.
- Interest expressed to identify and understand noise levels that are not just neutral but positive for marine mammals.
    - Proposed idea of targeting troughs in audiograms, or
    - It could be argued that known sounds or predictable sounds are best.
    - Identified as a potential research opportunity.
- Thresholds are important to naval architects and engineers as they would provide a metric to define success in making ships quieter. However, acoustic thresholds are difficult to identify as they vary between species, populations, and individuals.
- Interest in the habituation of marine mammals to certain types of noise. Workshop participants posed the open question "Is it better to replace a noisy vessel with a new quieter vessel that produces less but different noise?"
- Concerns around increases in vessel strikes of marine mammals if noise is reduced too much.

Measuring and understanding underwater noise from ships (Project MARS)

Jean-Christophe Gauthier Marquis
Researcher, Innovation Maritime (IMAR)

The presentation focused on the Marine Acoustic Research Station (MARS) project. It provided an overview of the project's research activities, methodologies, and findings. The MARS station, located in the St. Lawrence Seaway, was highlighted as a site where more than 22 ships per day, including bulk carriers, cargo vessels, tankers, and container ships, are monitored. Two specific activities of the MARS project, on-board vibratory diagnostics, and URN (underwater radiated noise) signatures were discussed in detail. The presentation described the acoustic instruments employed in the project, specifically the I-shape and N-shape vertical arrays [insert picture from presentation here], explaining their design configurations, advantages, and disadvantages.

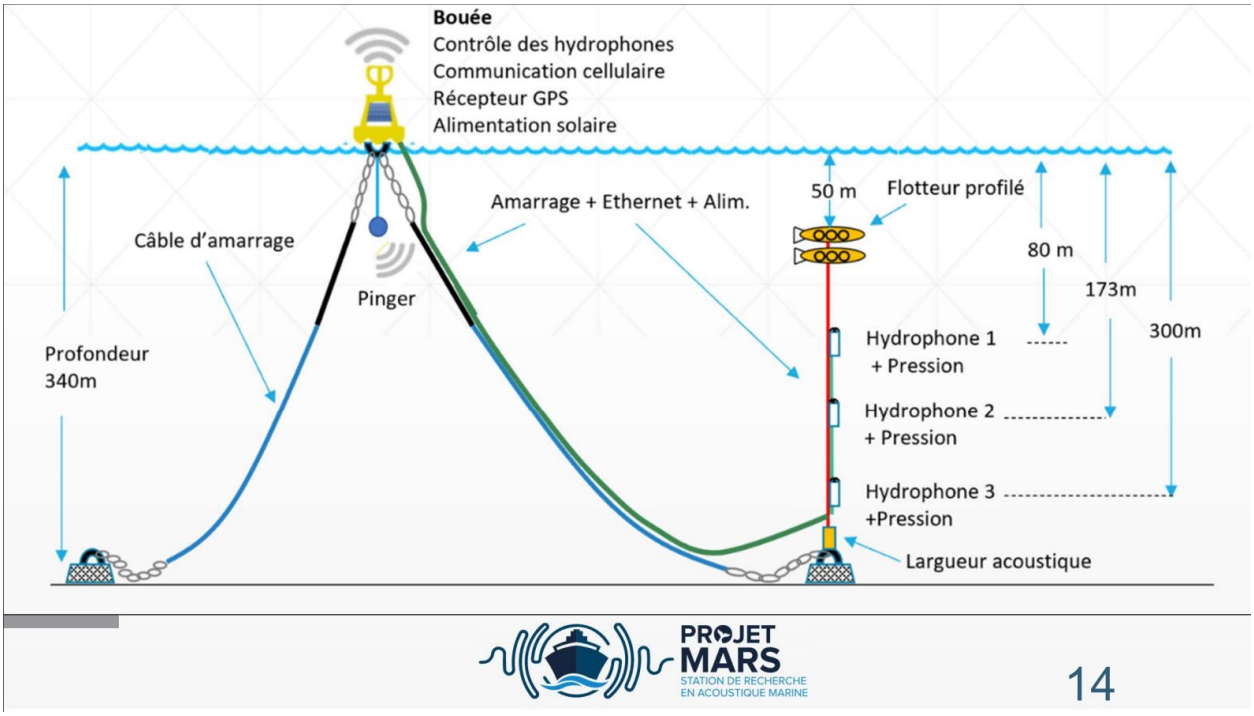


Figure 2. Slide from Jean-Christophe Gauthier Marquis' presentation showing N-shape hydrophone arrays.

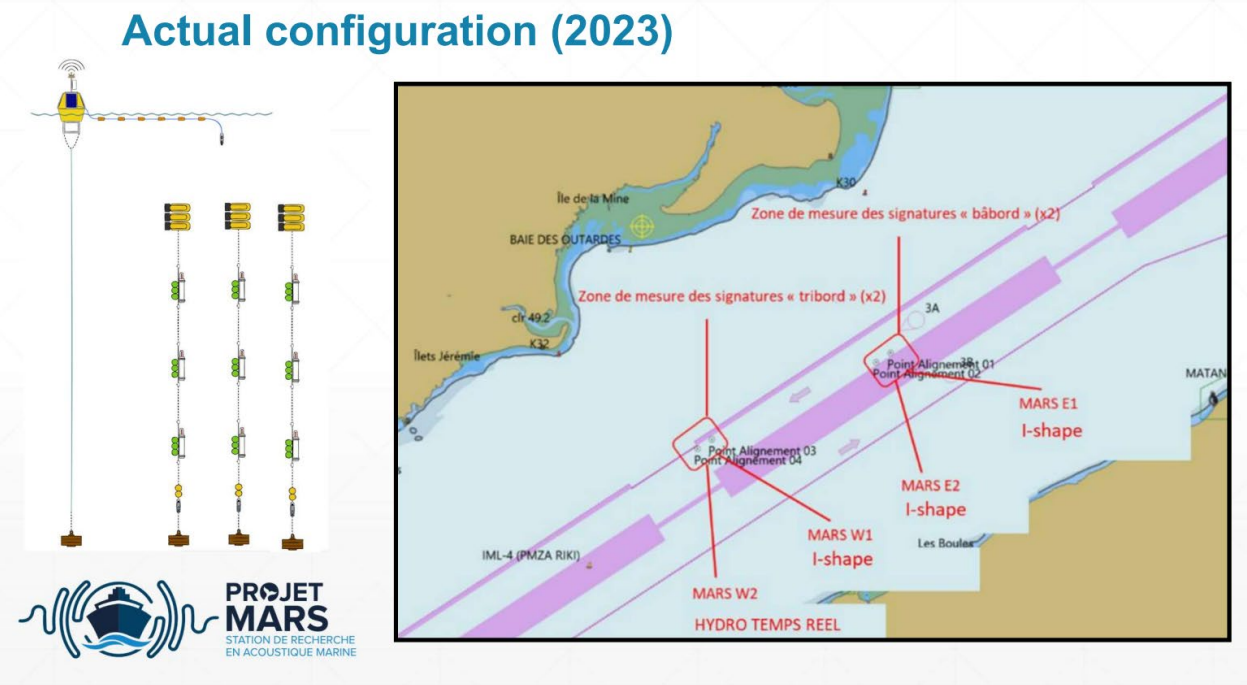


Figure 3. Slide from Jean-Christophe Gauthier Marquis' presentation showing I-shape hydrophone arrays in the actual configuration for the MARS Project.

The identification of machinery noise using on-board devices was explained, focusing on the installation locations of accelerometers and microphones on the ship, as well as the utilization of IoT (Internet of Things) technology. The noise spectrum of these diagnostics, which characterizes the noise and identifies cavitation effects of the ships, was presented as part of the research outcomes.

Highlights from the discussion period:

- Questions about how noise signatures differ between ships and voyages based on different factors (e.g., age of vessel, ballast vs loaded, speed, etc.).
- Complexities when comparing predicted vs measured URN,
    - Need the right accelerometers and a good hydrophone, and the placement of the equipment is critical.
    - Placing the accelerometer close to the ship frame leads to more variability in the collected data. There is a better signal to noise ratio when it is placed in the centre of the hull, away from the frame.
    - More studies are planned to better understand this topic. Planning a study to test this.

- The MARS Project has collected a lot of data over the course of the project and would consider data sharing agreements with other similar project teams. Enthusiasm from workshop participants about possible collaboration opportunities.
- Discussion about challenges of reliably measuring ship source noise using vertical array hydrophones.
- Question about how the data collected by the MARS Project is shared back to ship owners.
    - A report is provided to ship owners at the end of the year with information about the noise signatures from their ships based on the onboard measurements, but no raw data is provided. The report includes a comparison of the noise signatures from different ships in their fleet.
    - The objective is to share information from the acoustic station with shipowners within a few days of the vessel passage, but this is not currently happening.
- Considerations around calculating the contribution of URN from ships/fleets: sometimes the ships are so different that it is not possible to compare the signatures.

Spatial mapping of underwater noise

Vanessa Zobell

PhD Student, University of California San Diego

The presentation focused on the modeling of ship noise levels in the Channel Islands National Marine Sanctuary, considering both spatial and temporal aspects. The research presented utilized RAMGeo, a modeling tool, to estimate ship source levels in the area. The ship data obtained from the Automatic Identification System (AIS) and ship monopole source levels from JOMOPANS-ECHO were incorporated into the modeling process. In addition to ship-related data, oceanographic information such as water sediment properties, column characteristics, and wind speed were considered. The presentation introduced an empirical model to account for wind sound, which was overlaid onto the ship noise levels. The results demonstrated the temporal variation of Sound Pressure Level (SPL) at various resolutions, and validation with onsite measurements was provided to assess the accuracy of the modeling.

Highlights from the discussion period:

- Recurring discussion topic of comparing measurements and model outputs.
- Complexities around modeling ocean dynamics – taking an average of ocean conditions to input into a model can be drastically different than what is happening in the ocean at one location at one point in time.

    - Questions around what averaging time period is most effective to use to evaluate effects on marine mammals. Depends on the research question being asked.
    - Evaluating the impacts of noise on marine mammal diving behaviour might require an hourly time period of data, while measuring chronic physical stress might be better suited to a monthly average of data.
- Identified a gap in research on population level studies of blue whales, related to underwater noise impacts and other cumulative effects of human activity.
- Discussion on marine mammal behaviour when encountering a ship: blue whales will generally prioritize feeding rather than avoiding vessels or vessel noise. But it is important to understand that researchers are unsure how much of a "choice" this is, as whales may not assess situations in the same way humans do and it cannot be assumed that they do.

Modeling ocean acoustics and the accompanying sensing and prediction challenges

David Dowling
Professor, Naval Architecture & Marine Engineering, University of Michigan

The presentation focused on introducing a neural network model designed to efficiently predict the uncertainty of transmission loss (TL) as sound propagates through the ocean. The speaker began by providing an overview of the fundamentals of acoustics phenomenon and noise level determination. Various methods to estimate uncertainty, including Monte Carlo, Polynomial Chaos, Field Shifting, and Area Statistics, were briefly reviewed. Subsequently, a neural network model capable of predicting the Probability Density Functions (PDFs) of TL was presented. The model was trained using Monte Carlo PDF as a basis. The presentation concluded by highlighting the benefits of the neural network model, emphasizing its cost-effectiveness and accuracy in quantifying the uncertainty associated with TL.

Highlights from the discussion period:

- Request for clarification that the models are constructed for a single frequency and a discussion about how to consider multiple frequencies.
- Seafloor bathymetry has a major influence on model outputs. A 10cm difference can significantly affect the model results. Thermocline for shallow sources is also important, as shallow surface layer traps noise.

- Discussion around feasibility of real-time noise prediction where marine mammals might be. If all of the geometries of the marine environment were known, this would be possible. Difficult to accomplish because of the vast and dynamic nature of the ocean.

Current trends in ocean acoustic modeling

Jonathan Vallarta

Underwater Acoustics Business Lead, SLR Consulting

The presentation focused on the modeling of underwater noise levels in the Cook Inlet region of Alaska. The study specifically examined the noise levels produced by containerships at varying distances from two fixed sites.

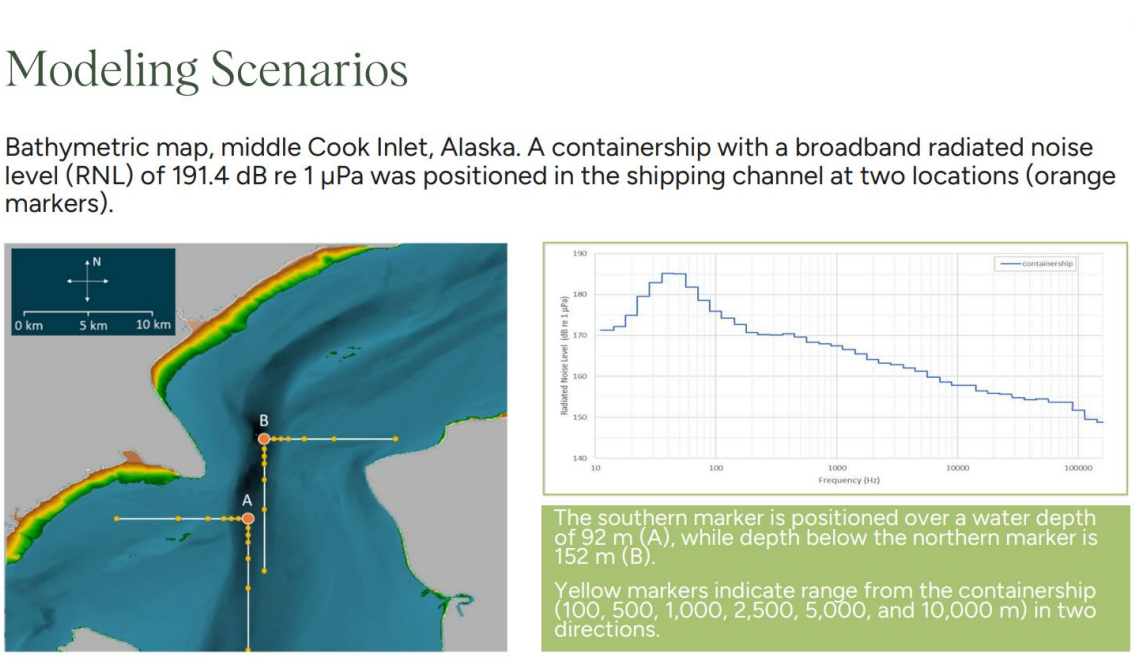


Figure 4. Slide from Jonathan Vallarta's presentation showing a modeling scenario for underwater noise from container ships in Cook Inlet, Alaska.

The research was conducted to investigate the masking effects in the communication and echolocation bands of Beluga whales. The findings revealed that auditory masking in Beluga whales was most significant within a range of 5km in the communication band and 2.5km in the echolocation band. This suggests that noise from large ships may have a notable impact on the whales' ability to effectively communicate and navigate within these specific frequency ranges.

Highlights from the discussion period:

- Conversations around how salinity affects propagation of noise in water – different salinity profiles may reduce or absorb more noise. This is an important consideration in areas where there is brackish water, such as Cook Inlet, because salinity levels change seasonally.
- Research gap: diets and distribution of marine mammal prey species and correlating their presence to noise, food sources, etc.
- In this case study, there are opportunities to consider other sorts of noise caused by ships, such as ships hitting and breaking ice.

Convolution recurrent autoencoder network for learning wave propagation: application to varying bathymetry

Rajeev Jaiman
University of British Columbia, Mechanical Engineering

This presentation provided an overview of the methodology for modeling oceanic environmental conditions and forecasting underwater acoustic noise using a combination of physics-based high-precision numerical simulations and data-driven machine-learning techniques. The speaker's team at UBC is testing how high-fidelity physics-based solvers can be used to study ship propeller noise due to cavitation and various other physical phenomena. Some highlights were provided on the best modeling practices, validation and the fundamental physical mechanisms related to turbulent vortex and cavitation dynamics which are instrumental in the generation of tonal and broadband propeller noise. The data-driven toolbox facilitates the creation of a solver that seamlessly interfaces with high-fidelity data to predict transmission loss for far-field noise propagation in real-time. Finally, a robust framework was built for the modeling and prediction of underwater noise for near-field transmission as well as far-field transmission for various ocean environments.

Highlights from the discussion period:

- The effect of hull wake flow will be considered in the modeling of propeller cavitation to realize the full-scale configurations. New propeller designs such as toroidal configuration need further investigation. To develop cost effective technologies, new passive and active control strategies as well as retrofits should be explored to manage the tradeoff between GHG emission and URN.
- From the mechanical engineering and naval architecture perspectives, Rajeev thinks vessels can be made 20 decibels quieter.
    - A quieter vessel may need to consume more fuel. This is a tradeoff that needs to be considered – more efficient vessels are not necessarily quieter, and quieter

vessels are not necessarily more efficient. Ideally, future ships will be both quieter and more fuel efficient. AI could be applied to consider the vessel's operating parameters and assess the tradeoff.

- When propeller noise is reduced, other machinery noise becomes more prominent, and may be more difficult to mitigate. A proper combination of technological measures with AI-driven slowdown and distancing can be an effective way to manage the impact of ship noise on marine mammals.

Boundary Pass Listening Station data acquisition for the MELO Project

David Hannay
Chief Science Officer, JASCO

The presentation focused on the Underwater Listening Station deployed in Boundary Pass, the site of a busy shipping lane. The project aimed to measure the noise emissions of thousands of commercial ships automatically and process them in real-time using the web-based PortListen application. The presentation highlighted the extensive measurement efforts conducted over a decade, including RNL (received noise level) and SL (source level) measurements of 32,259 vessel passes, which were stored as databases under the ECHO Program with the Port of Vancouver. The execution plan for the CCGS Sir John Franklin URN measurement for summer 2023 was also discussed, including the systematic sail tracks for the ship and the sensor locations. Additionally, preliminary work on marine mammal localization tracking of speed and movement was presented, showcasing ongoing efforts in this area.

Highlights from the discussion period:

- There are multiple studies that are ongoing in this region, including multivariate analyses (emission vs draft, speed, wind, etc.), identifying individual vessels through noise signatures, and others.
    - Large data library from hydrophone array in Boundary Pass.
- Opportunity: Quieter vessels could get a 'quiet' notation from class societies.
- A graphical representation of individual killer whale locations created by JASCO from Boundary Pass Listening Station data that identified the position of individuals within a pod was of key interest to several participants.

2.3 Key Takeaways from Day 1

The speaker presentations on the first day of the workshop prompted a variety of conversations, often spanning across disciplines. The collaborative discussion periods provided chances for people to connect with others working on related projects and identified synergies and opportunities for potential research collaborations. There was an agreement across disciplines that noise reduction targets are important for ship designers and further research and data are needed to develop these targets. Uncertainties exist in every discipline, and participants were encouraged to see that despite these uncertainties, advances are being made and research is moving forward.

There are many opportunities for further research into marine mammal responses to underwater noise, particularly since these responses are different between species, populations, and individuals. The new concept of altering ship-source noise to be beneficial, rather than negative or neutral, to marine mammals was of interest to multiple participants. The effect of depth on noise propagation was noted as a research area opportunity, particularly related to marine mammal species, which as diving mammals, use the surface and bottom of the ocean primarily. In general, there was agreement among participants that quieter vessels cause less stress to marine mammals, so designing as quiet of ships as possible is a valid goal. However, some frequencies are more harmful than others, so targets that only reduce average noise levels should be adopted with caution. A better understanding of habituation of marine mammals to noise is needed, to determine what the effect of new, but quieter, vessels will be.

Emerging technologies, such as non-invasive marine mammal observation, artificial intelligence (AI), and machine learning, are useful tools to leverage when developing solutions to the impacts of underwater noise on marine mammals. Gathering good quality data and creating accessible, interdisciplinary data sharing platforms is an essential component of these solutions, as data is needed from all disciplines to build comprehensive, powerful models.

The tradeoffs in fuel consumption and other efficiency metrics for quieter vessels were mentioned several times throughout the first day of the workshop. It will be important to assess and understand the impact of these tradeoffs at different time scales, while being able to rely on AI and other technologies to assess these tradeoffs during vessel operation in real-time. The parametrization of vessel operations was identified as a key step in this process.

Participants appreciated the presenters' abilities to share very detailed work on complex topics at a level where people from other research backgrounds could understand. Content related to the impacts of ship noise on marine mammals needs to be digestible for a broad audience, as

academic experts and naval architects are not the only players involved in creating the solutions. Traditional Knowledge from rightsholders should be incorporated as a valued form of information and data in the models and systems-mapping processes.

3.0 Summary of Day 2 of the Design Workshop

3.1 Workshop Presentation Summaries

To open the second day of the workshop, the MELO Project team demonstrated the initial functionality of the analysis toolkit.

Demonstration of MELO Project Toolkit - Akash Venkateshwaran, MSc Student, University of British Columbia

The presentation unveiled an optimization toolbox to mitigate URN from ships effectively. By optimizing ship velocity based on the voyage path and marine mammal's location along the path, ships become adaptable to their operating environment. Ship noises were modeled using empirical Ross's method, and the propagation of the noise levels was done using Bellhop models. The primary objective was to maintain noise levels below a specified threshold (defined by an audiogram) while ensuring the operational constraints such as the timely arrival of the ship at the destination. This innovative approach promotes more considerate ship operations, minimizing their impact on marine life. Moreover, the future prospects of the project were discussed, focusing on noise level estimation at the source by employing CFD to replace empirical models, as well as the use of machine learning models for noise propagation in the environment. These advancements are expected to enhance accuracy and reliability.

3.2 Day 2 Breakout Group Sessions

The second day of the workshop included facilitated breakout group sessions to promote more focused and in-depth discussions among participants. These guided sessions were intended to offer opportunities to participants to form connections with others, discuss opportunities for innovation, and identify knowledge gaps in different research areas. Participants were separated into smaller groups (named after species of interest - right whale, orca, and beluga) of 10-12 people and guided through two exercises.

In exercise 1, breakout groups were asked to discuss and report back on the following three questions:

1. Connections: Where is your main area of interest?
2. New developments: What are the most exciting new research or technology developments you are aware of in this domain?
3. Knowledge gaps: What new data, analysis capabilities, or improvements to understanding are needed?

For each of the questions, participants were asked to identify whether their response was focused mainly on the ship, the ocean, or marine mammals, and if their ideas were more situated in the digital or physical realm. With the help of a facilitator, groups discussed the questions and recorded their answers on a poster, which displayed a Venn diagram of overlapping circles, each with the title of either ship, ocean or marine mammal. Mapping responses on this poster template helped guide the conversation and easily identify common themes, as well as areas where more focus is needed. After the breakout sessions concluded, participants returned to the main session where each group's spokesperson shared the highlights of their discussion.

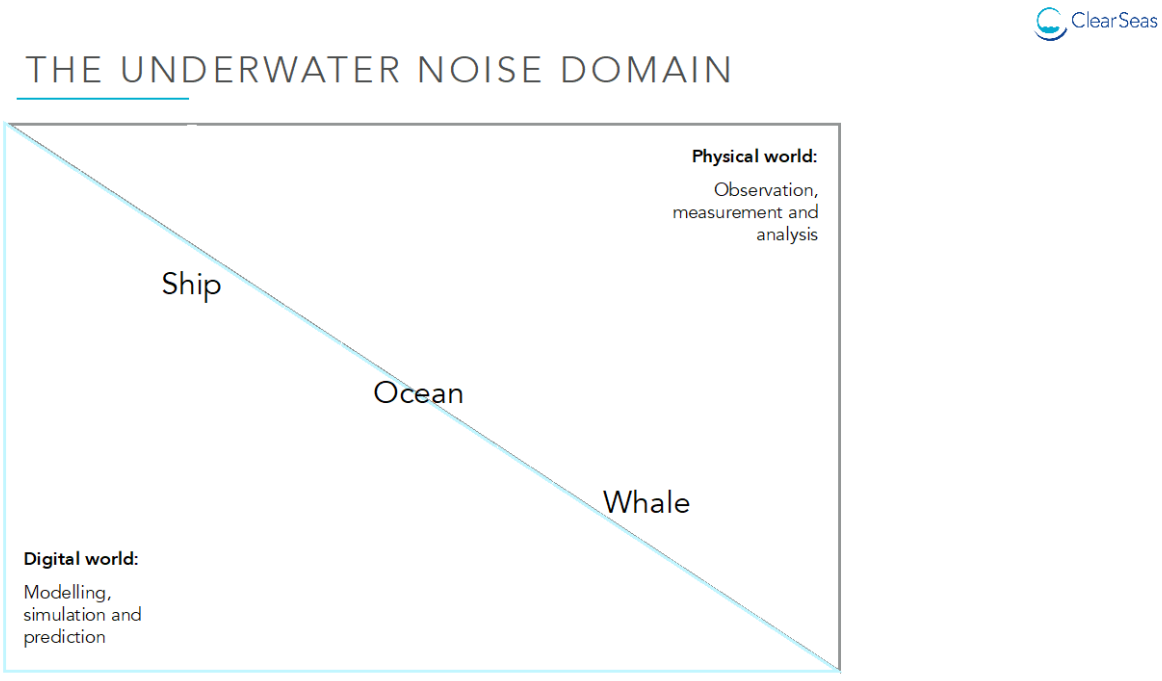


Figure 5. Poster template used in exercise 1.

The second exercise asked participants to co-develop design systems to account for the different interactions occurring between ocean users and inhabitants. A framework of an

interactive, looping ship-based system was printed on posters for each group. Participants collaboratively made edits and additions to the system to conceptualize its functionality as an option of mitigating the impacts of ship noise on marine mammals.

The discussions and results of these exercises are summarized by breakout group (right whale, orca, and beluga) in the following section. Copies of the posters from the second session were recreated after the workshop using PowerPoint, and can be found in Appendix B.

3.3 Exercise 1 – Assessing connections, new developments, and gaps in understanding

Breakout Group 1 – Right whale

1. Connections: Where is your main area of interest?

Name	Research Interest	Theme
Bruce Paterson	BC Ferries	Ship
Simone Philpot	UBC Institute for Resources, Environment and Sustainability	Ship/Ocean
Rajeev Jaiman	UBC Mechanical Engineering	Ship/Ocean
Sam Mansfield	Transport Canada	Ship/Ocean
Lorenzo Moro	Memorial University Newfoundland	Ship/Ocean
Vanessa ZoBell	Scripps UC San Diego	Ocean
Emma Gillies	DFO	Ocean/Whale
Jonathan Vallarta	SLR Consulting	Whale
Dave Rosen	UBC Marine Biology	Whale

2. New Developments: What are the most exciting new research or technology developments you are aware of in this domain?

Ship	Ocean	Whale
- New propulsion technology, such as vertical thrusters - Virtual reality for quick diagnosis and repairs on vessels - Active propeller control - Accessing community knowledge: fishermen, towboats - Systems theory-based decision support systems - Virtual reality for communication and empathy building - More efficient modeling techniques - Numerical modeling/computational fluid dynamics (CFD)	- Applying Indigenous Knowledge - Gliders - Marine protected areas - Acoustic monitoring for detection, localization of ships - Big Data - Real-time sound monitoring - Modular systems for onboard measurement: advisory tools - Use of AI to process large volumes of data to get insights	- Animal modeling - Modeling consequences of noise disturbance - eDNA - Satellite/aerial imagery - Infrared technology for nighttime observation - Digital tags and video tags - Habitat modeling/distribution modeling - Population recovery from whaling - New strike research in Gitga'at Territory (fin whales, humpback whales)

3. Gaps: What new data, analysis capability, or improvements to understanding are needed?

Ship	Ocean	Whale
- Time lag between current fleets and adopting new technology - Better technology for alternatively fueled vessels	- Better understanding of the URN contribution of small vessels - Universal database of ocean acoustics and marine mammal data	- Understand noise thresholds for different species - Understand abundance/foraging in

(i.e., electric vessels, hydrogen vessels) - Mitigation of URN and carbon dioxide (CO2) emissions - Accurate modelling and simulation of cavitation	- Understanding cumulative effects - More accurate modeling - Generative AI models for ship-whale interaction - Understanding how to manage, monitor and enforce URN mitigation in remote areas - More accurate source level models - Effect of Roberts Bank Terminal 2 on measurements	general, and in different seasons - Marine mammal species grouped by impact of URN, not hearing abilities - Quantitative indications about sound quality - Population level effects of noise - Masking noise - Digital models of whales' acoustic systems

Breakout Group 2 – Orca

1. Connections: Where is your main area of interest?

Name	Research Interest	Theme
Dimitrios Mylonas	VARD Marine Inc	Ship
Jean-Christophe Gauthier Marquis	IMAR & MARS Project	Ship/Ocean
Paul Blomerus	Clear Seas	Ship/Ocean
Vivian Mo	DFO	Ship
Indu Kant Deo	UBC Mechanical Engineering	Ship/Ocean
David Dowling	University of Michigan Naval Architecture	Ship/Ocean
Dominic Tollit	SMRU Consulting	Ocean/Whale
Catherine Maeve O'Connell	DFO	Ocean/Whale

2. New Developments: What are the most exciting new research or technology developments you are aware of in this domain?

Ship	Ocean	Whale
- New hull coatings being tested that may minimize noise (i.e., graphite hull coating) - Machine learning based noise source characterization and transmission loss prediction (JASA paper) - New propeller design - Hull form modelling - Retrofitting vessels - Traffic separation scheme to avoid southern resident killer whale (SRKW) habitat	- International Maritime Organization (IMO) work, European Union (EU) work (international progress)	- Citizen science - Whale Desk and Whale Report Alert System (WRAS) - New National Oceanic and Atmospheric Administration (NOAA) SRKW noise effect paper - Passive acoustic monitoring (PAM) - SRKW whale movement forecast model

3. Gaps: What new data, analysis capability, or improvements to understanding are needed?

- Propellers designed with a "quiet mode" - Use of tide to move vessels more efficiently with less noise - Advances in identifying noise design requirements - Full digital twin of vessels to predict noise - Supply chain arrival optimization	- Logistics: cost issues, dilemma of efficiency, procurement stage - Funding for propeller optimization - Onboard URN measurement and prediction - Open-source data and cross discipline data availability	- Better understanding of winter SRKW presence - Species identification in real time using machine learning - Species audiograms - Received noise level correlation with perceived noise level - Relation between wave form and perceived noise

- Retrofitting or improvements for existing vessels - Real-world testing of cavitation reduction methods - Clear noise target for ships and whales		- Robust disturbance threshold for SRKW
Ship	**Ocean**	**Whale**

Breakout Group 3 – Beluga

1. Connections: Where is your main area of interest?

Name	Research Interest	Theme
Dan McGreer	UBC Naval Architecture	Ship
Jasmin Jelovica	UBC Naval Architecture/ Mechanical Engineering	Ship
Saman Lak	UBC Mechanical Engineering	Ship
Chanwoo Bae	BC Ferries	Ship
Khaled Helal	Memorial University	Ship
Akash Venkateshwaran	UBC Mechanical Engineering	Ship
Josh van Berkel	DHI	Ship/Ocean/Whale (digital)
David Hannay	JASCO	Ocean
Andrew Trites	UBC Marine Biology	Whale
Vasiliki Karpouzi	DFO	Whale

2. New Developments: What are the most exciting new research or technology developments you are aware of in this domain?

Ship	Ocean	Whale
- Quiet mode for research vessels - Creating a particular noise model for each ship from several measurements - Ship multi-object optimization - Optimization and AI - New material systems - CFD for noise prediction - Meta-materials - Using underwater trains for shipping rather than surface vessels - New fuel/energy sources - Noise canceling ships - Machine learning: graphic neural networks - Noise mitigation systems - Noise limits in regulation/certification - Combining different technologies - Ship-source modelling	- Machine learning applied to the population consequences of disturbance (PCOD) model - Machine learning applied for calculating noise transmission - Mobile sensor network using ocean gliders	- Using machine learning for real time detection - New assessment methods: Listening space, echolocation space - New statistical models to process movement and behavioral data - Integrated modelling systems - Invisible fence to keep marine mammals out of shipping lanes - Sound data for whale tracking - Biologging: recording received sounds, remote sound sensing

3. Gaps: What new data, analysis capability, or improvements to understanding are needed?

Ship	Ocean	Whale
- Understanding the contribution of small (non-AIS) vessels to the ocean ambient noise - Developing lightweight structures effective in sound and vibration insulation for ships - Difficulty in sharing propeller geometry/ship designs (intellectual property (IP) issue) - Dual mode ships: quiet mode and transit mode, need to optimize each mode - Alternative propulsion technology - Better near field noise source models - Vessel source level models	- More mature AI related to ocean data - More testing of noise mitigation measures to understand their effectiveness - Better data sharing platforms available across disciplines	- Assessment methods for understanding biological effects of noise - Aversion research - Better understanding of the impact of noise on whales - Improved whale detection and tracking to ensure ships stay away from whales – real time tracking system - Need to forecast locations of species of concern and understand current habitat use patterns - Need to evaluate effectiveness of vessel modifications and agree on meaningful variables to measure - Need experimental controls to evaluate effects of noise and reductions of noise on whale behaviour - Better understanding of the ultimate consequence of noise on survival and reproductive rates of whales

Group Reflections from Exercise 1

New developments

The workshop group shared their excitement and hopefulness about new developments in various fields of research on addressing ship-source underwater noise. Firstly, there was a recognition of the importance of Indigenous Knowledge and community collaboration in understanding local impacts of shipping and URN on marine mammals. Opportunities to link Indigenous Knowledge with machine learning and AI were discussed, and the value of community knowledge, including anecdotal information, was highlighted as a key source of knowledge. The advancement of digital components was emphasized, with a focus on increasing ocean imaging and sensing and integrating AI for all components (ship, ocean, whale) of the interacting system.

The advancement of ship design and technologies onboard vessels, including alternative fuels, were discussed in several different contexts as key factors in the space of addressing impacts of underwater noise. Forecasting ship effects using probability models like PCOD and PCAD was also highlighted, along with integrative modeling that combines multiple approaches, including propeller and propagation mode modeling. Noise source characterization and noise transmission loss studies have also been advancing in recent years. The exploration of alternative propulsion systems like electric or wind power was considered as a potential exciting development, as well.

The use of gliders, buoys, and new monitoring stations for noise and animal presence monitoring was suggested, as well as the development of ship-based mitigation systems. Innovative monitoring methods for marine mammals, such as digital tagging, and effects assessment techniques like echo assessments and statistical assessments, were also highlighted as important areas of development to address the impact of ship-source underwater noise on marine mammals.

These cutting-edge advancements collectively represent a multi-faceted approach to addressing ship-source underwater noise impact on marine mammals. By integrating community engagement, modeling techniques, new technology, and decision support systems, these innovations have the potential to significantly contribute to the preservation of marine ecosystems and the well-being of marine mammal populations.

Gaps

Although advancements in ship noise mitigation have been made, there are still significant gaps in our understanding of the impact of ship-source underwater noise on marine mammals. Firstly, there is uncertainty about the full impact of noise on whales, emphasizing the need to confirm the negative effects of sound. To improve decision-making, harnessing generative AI for future predictions of both whales and ship noise will be a key component in these solutions. More data on the ocean, marine mammals, and noise need to be collected, and ensuring the quality of the data being collected is essential. Cumulative effects studies will help researchers understand the intertwining impacts of underwater noise on the marine environment. The assumption that animals rely on sound due to low light propagation environments was questioned for accuracy. Special attention is needed for SRKWs, particularly during winter, necessitating a revision of studies to understand their true distribution across seasons. Finally, it was noted by several workshop participants that it still needs to be determined whether reduced ship noise will matter to marine mammals, so studies must be established to measure this impact accurately.

Centralizing data is seen as crucial in addressing ship-source underwater noise impacts on marine mammals. Building digital twins of vessels to better understand noise signatures in different contexts is also an area of opportunity. Several ideas were posed related to data centralization, including the involvement of a government body or third-party organization who could maintain a system where ship owners are notified when they are about to encounter a whale. This system would involve tracking both ships and whales, using AIS data to locate vessels and other types of data (such as observations and digital tags) to track whales. The concept also suggests the use of forecasting models of marine mammal movements to predict whale locations. Additionally, the implementation of a Vessel Monitoring System (VMS) to notify ships and a decision support system to determine mitigation measures based on factors like marine mammal presence, safety, and speed was proposed. These ideas present some of the ways gaps in knowledge, data, and communication can be addressed to lessen the impact of noise on marine mammals and better connect the people who work with different elements of the interacting system of ships, whales, and the ocean.

Developing new models for habitat and animal interactions, alongside legal and regulatory certifications for quiet ships to incentivize ship owners, are essential steps. More real-world testing of noise mitigation technologies was deemed crucial. Considering ships with "quiet mode" and "transit mode" to balance noise reduction with fuel efficiency was recommended, especially since different locations are home to species with varying sensitivities, requiring

tailored vessel operations. Furthermore, optimizing supply chains and reducing the number of vessels on the water were additional strategies discussed to reduce ship noise levels.

3.4 Exercise 2 – Co-developing a framework for a smart adaptive ship noise system

For this exercise, breakout groups designed frameworks of an adaptive system that considers the dynamic relationships between ships, the ocean, and marine mammals and aims to reduce the impact from ship noise on the marine environment. Digital copies of these posters, recreated in PowerPoint, can be found in Appendix B.

Discussion summary: Right whale

In the discussions resulting from this exercise, the team identified a need to develop a scheme for organizing 'noise reaction groups' among marine mammals, prioritizing species at risk (like SRKWs) for the assessments. Also, it was noted that real-time notifications used to fine-tune vessel operations are essential for monitoring noise impacts. However, it was acknowledged that altering operations has its caveats involving financial, scheduling, and fuel trade-offs. While one solution suggested was producing quieter ships, there was also a call for long-term forecast planning to anticipate the future of ships and marine life in 5 to 10 years, especially for new fleets. It was also suggested that gathering data should be accomplished through various methods, including individual drones, satellite imaging, infrared technology, and citizen science. An area for growth that was identified was the consideration of the entire soundscape during different seasons in research. Understanding the noise impacts from all activities, not just AIS-tagged ships, and integrating seasonal and winter data will be important in future research.

Discussion summary: Orca

The conversations from this breakout group were focused primarily on data collection processes of marine mammals and the marine environment. The need to predict animal behaviour was identified, which requires comparing data in real-time, using innovative tools like rechargeable gliders and citizen science. Improvements in tracking technology, such as better digital tags and other tagging methods, are also essential for data collection. The importance of data quality and effective quality assurance processes was acknowledged. Furthermore, the adoption of these measures by ship operators depends on their selling points and cost implications, considering practicality and safety aspects, like the ability to accelerate and decelerate container ships. Additionally, the integration of tools like the MELO toolkit and

active noise cancellation should be designed into ships from the outset, recognizing the data and processing intensity of these approaches.

Discussion summary: Beluga

During this exercise, the group's discussion revolved around the concept of centralizing the entire system for managing ship noise impacts on marine mammals. Instead of individual "smart" ships, the proposal was to create a centralized system operated from the shore that collects data from all ships and generates decisions tailored for each ship. This system would involve feedback loops for real-time noise prediction and animal tracking, with validation of predictions. It was emphasized that this decision-support system should not only consider the impacts on marine mammals but also account for factors like fuel efficiency, emission control noise, and operational conditions of ships. However, there are acknowledged challenges, such as IP issues and data sharing concerns (particularly regarding sensitive ship designs) and the need for consensus on common threshold levels for noise management.

4.0 Closing Reflections

The reflection on the discussion periods during the workshop underscores the recognition that there is much work left to do in addressing the issue of ship-source noise in marine environments and the impact on marine mammals. There are knowledge and data gaps that need to be addressed and will require collaboration between different fields of research to be successfully resolved. The need for more proactive approaches to noise reduction is clear, and practicality is highlighted as a critical factor; any approach needs wide adoption to be effective in mitigating ship-source underwater noise impacts on marine mammals. However, there was a sense of encouragement and upliftment stemming from the diverse interdisciplinary contributions made during the workshop discussions.

List of figures

Appendices

APPENDIX A – WORKSHOP AGENDA
APPENDIX B – BREAKOUT GROUP SESSION VISUALS
APPENDIX C – WORKSHOP PARTICIPANTS CONTACT INFORMATION
APPENDIX D - *Uplifting Traditional Indigenous Knowledge in Solving Underwater Noise Pollution* by Chanessa Perry

MELO Project Design Workshop

Earth Sciences Building, Room 5104, 2207 Main Mall,
UBC Vancouver Campus, British Columbia, Canada

1-2 June 2023

AGENDA

Thursday, 1 June

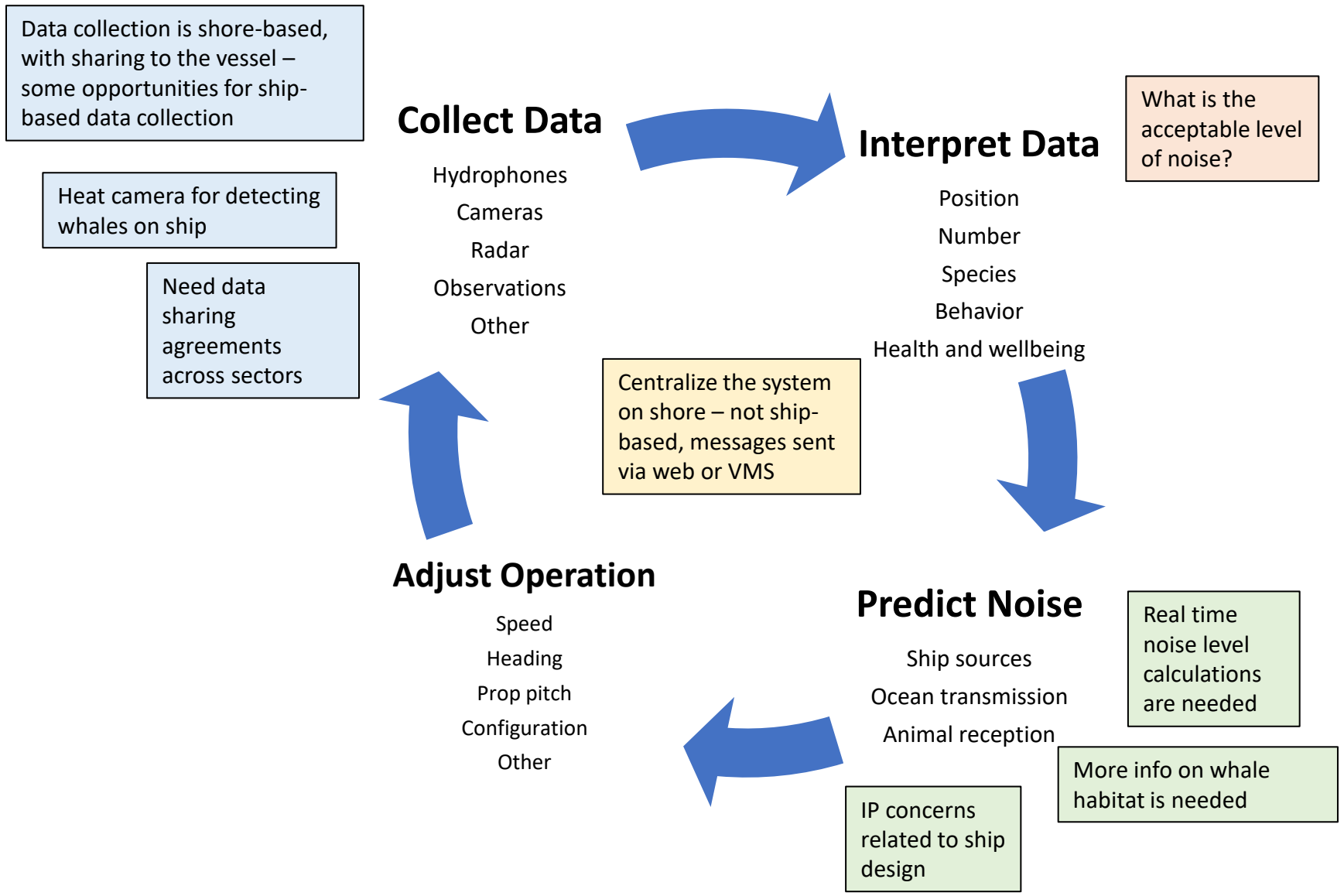
08.30-09.00 **Check-in**	Workshop participants can check-in during this time Coffee and tea will be provided
09.00-09.45 **Opening**	Welcome, opening remarks, and workshop details • Richard Sparrow, Councillor, Musqueam Indian Band • Andrew Trites, Director, Marine Mammal Research Unit, UBC • Paul Blomerus, Executive Director, Clear Seas
09.45-10.30 **Session 1**	Understanding the impacts of ship noise on marine mammals & real-time detection of marine mammals • Dave Rosen, Assistant Professor, Marine Mammal Research Unit, UBC
10.30-11.00	**Break**
11.00-12.00 **Session 2**	Measuring and understanding underwater noise from ships – Project MARS • Jean-Christophe Gauthier Marquis, Researcher, Innovation Maritime (IMAR)
12.00-13.00	**Lunch break**
13.00-14.30 **Session 3**	Panel of international experts on ocean acoustics and underwater noise: Spatial mapping of underwater noise • Vanessa Zobell, PhD Student, University of California San Diego Modeling ocean acoustics and the accompanying sensing and prediction challenges • David Dowling, Professor, Naval Architecture & Marine Engineering, University of Michigan

	Current trends in ocean acoustic modeling • Jonathan Vallarta, Underwater Acoustics Business Lead, SLR Consulting
14.30-15.00	**Break**
15.30-16.15 **Session 4**	Advances in computational modelling of ship noise – MELO Project • Rajeev Jaiman, Associate Professor, Department of Mechanical Engineering, UBC Boundary Pass Listening Station data acquisition for the MELO Project • David Hannay, Chief Science Officer, JASCO
16.15-17.00	Wrap up, reflections, and preview of Friday's session
17.00-19.00	**Cocktail reception**

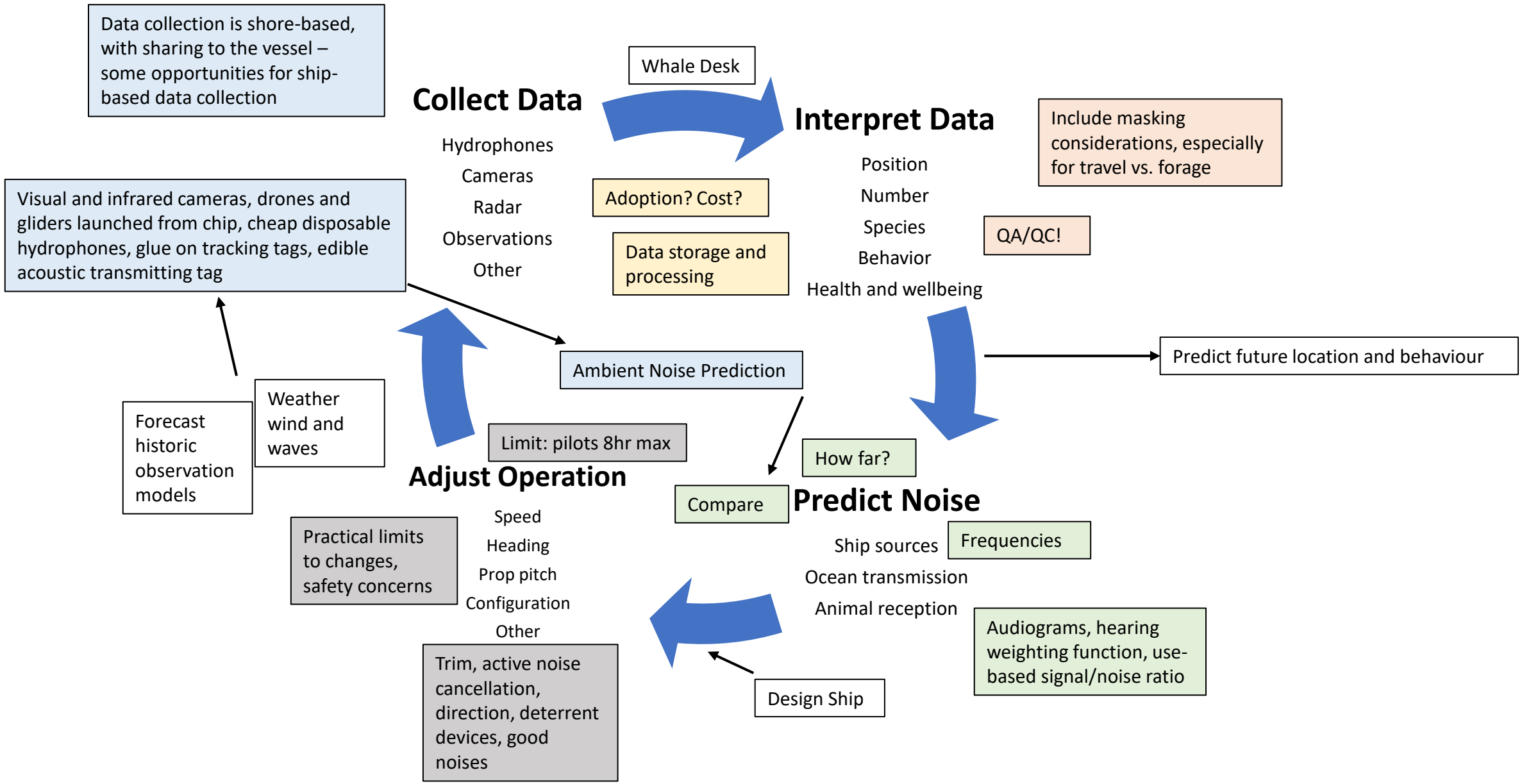
Friday, 2 June

09.00-9.30 **Welcome**	Objectives for the day
9.30-10.30 **Session 1**	Design Workshop – how does it all fit together?
10.30-11.00	**Break**
11.00-11.30	Demo of analysis toolkit from MELO Project team
11.30-12:30 **Session 2**	Design Workshop – what are the challenges we need to overcome?
12.30-13.00	**Wrap-up & closure of workshop**

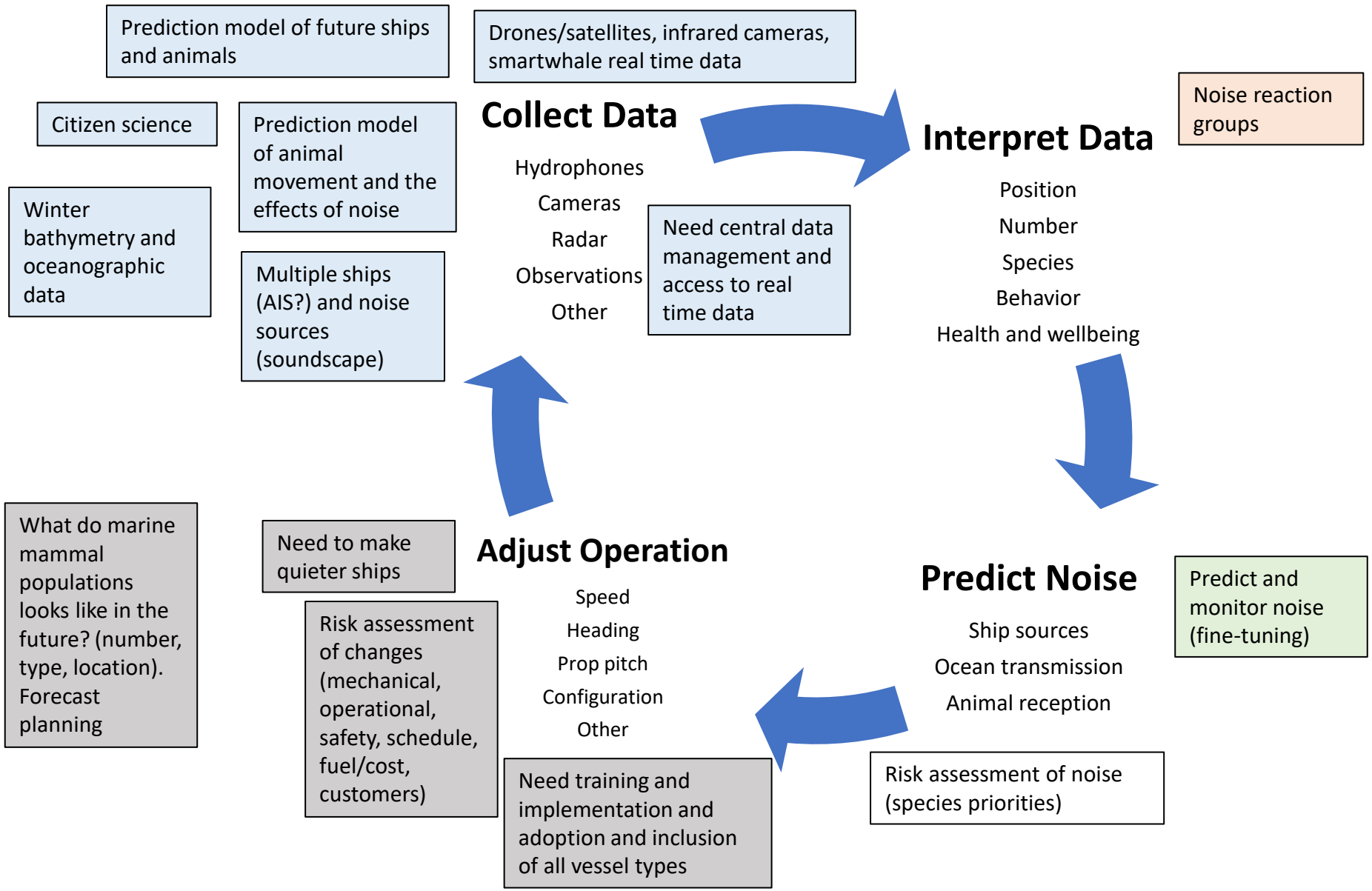
Smart Adaptive Ship Noise System – Beluga Group Ideas



Smart Adaptive Ship Noise System – Orca Group Ideas



Smart Adaptive Ship Noise System – Right Whale Group Ideas



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Uplifting Traditional Indigenous Knowledge in Solving Underwater Noise Pollution

To address the problem of underwater noise pollution and protect the marine mammal populations along the coast of British Columbia, Indigenous knowledge needs to be incorporated in the solution. Indigenous Peoples are deeply connected to the environment around them and have centuries of knowledge on migration patterns, the best hunting spots, and behavioral patterns of marine mammals. This knowledge is essential in developing comprehensive, effective solutions to the impacts of underwater noise on the marine environment.

Indigenous Stewardship of the Marine Environment

We can look to the Mahalat Nation as an example of strong stewardship of the marine environment. The Malahat Nation sought out to understand the interactions between vessels and the local marine mammals, so they invested in an underwater hydrophone station. The Malahat Nation set up hydrophones in order to listen to the underwater noises in their traditional territory. With help from marine scientists to better understand hydrophones, the Malahat has settled on 20 different locations to examine and record the underwater noises in those areas.

Another example of Indigenous-led research initiatives on underwater noise comes from the Gitga'at Nation. The Gitga'at Nation has taken initiative to solve underwater noise pollution through their involvement in the education system and conducting their own soundscape ecology research. The Gitga'at Peoples have been actively protecting their land, social structure, culture, and the marine life that has been a key part in sustaining their Nation for many years.

A Two-Eyed Seeing approach, taught by Mi'kmaw Elder Albert Marshall, could be beneficial in addressing this problem. This approach is explained as **"learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of mainstream knowledges and ways of knowing, and to use both these eyes together, for the benefit of all"**.

Case Study: Underwater Noise in the Arctic

The Inuit, meaning the people, originate from Canada 's Northwest Territories, Nunavut, Northern Quebec, and Labrador.

The underwater noise pollution issue is very important to the Inuit. The Inuit are dependent on the local marine mammals for food. This kind of noise may disrupt the marine mammals causing changes in hunting for the Inuit . There has been a significant increase in ship traffic in Tallurutiup Manga, a national conservation area at the North end of Baffin Island. With the use of Inuit Knowledge that was collected and combined with Western Science, as well as noise modeling, the Inuit and marine scientists were able to estimate the number of ships passing through the area. The Inuit had the knowledge and resources to contribute to this research in many different ways, including the ability and knowledge to identify and point out areas where marine mammals occupy.

Some Organizations Taking Action to Incorporate Indigenous Perspectives into Research on Underwater Noise

- Coastal First Nations
- Clear Seas
- Inuit Circumpolar Council
- Malahat Nation
- Raincoast Conservation Foundation
- International Maritime Organization
- Port of Vancouver
- Transport Canada

United Nations Declaration of Indigenous Rights

Article 29.1
Indigenous Peoples have the right to the conservation and protection of the environment and the productive capacity of their lands or territories and resources. States shall establish and implement assistance programmes for indigenous peoples for such conservation and protection, without discrimination.

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Chanessa is a citizen of the Nisga'a First Nation and is of mixed European and Nisga'a ancestry.