TECHNICAL PROJECT PROPOSAL DESCRIPTION

Objectives: Inuit Qaujisarnirmut Pilirijjutit on Arctic Shipping Risks in Inuit Nunangat (IQP-ASR) has been co-designed by representatives from Inuit organizations, Inuit communities, and universities in Canada and the UK. Our vision is to co-generate knowledge about risks associated with climate change-induced growth in Arctic marine shipping across Inuit Nunangat and to identify and evaluate potential management strategies that support Inuit self-determined shipping and oceans governance. The project's name and design are reflective of Inuit social values, Inuit Qaujisarnirmut (IQ), and the principle of Piliriqatigiingniq,[1] which is broadly defined as the process of respectful coming together and use of every resource, network, technology, and process available, in order to arrive at the best possible collaborative solution to a challenge. The geographic focus of the project is Inuit Nunangat, with specific case studies in two communities with historically low levels (Arviat, Nunavut) and historically high levels (Pond Inlet, Nunavut) of ship traffic. Building on previous research conducted by our team members through the Arctic Corridors and Northern Voices (ACNV) project (www.arcticcorridors.ca), the following project objectives were developed and include to:

1. Analyse historic ship traffic (since 1990) and project future trends (2050);
2. Model current and future (2050) ship source underwater noise nearby communities;
3. Conduct in-situ sampling of potential ship-sourced air and water pollution (black carbon, Heavy Fuel Oil residue, and ship derived plastic pollution (micro and macro-litter);
4. Evaluate potential for non-indigenous species introduction from ships, and;
5. Develop risk maps and recommendations for self-determined shipping governance.

Rationale: Climate change and related reductions in sea ice have increased open water areas and accessibility for ship traffic across Inuit Nunangat, where shipping activity has grown by >250% since 1990.[2] Regardless of mitigation efforts, it is expected that before mid-century the Arctic will be seasonally ice-free (defined as < 1 million km) for the first time in over 2.6 million years.[2,3,4] Profound shifts in ship season length are projected in the Beaufort region (increase of 100-200 days at 2 °C to 200–300 days at 4 °C warming), and the Northwest Passage, which could be 100% navigable for part of the year, regardless of vessel type, by 2 °C of warming above pre-industrial levels (expected to occur by mid-century[5]). Growth in shipping traffic will bring both risks and opportunities to Inuit Nunangat. The shipping industry supports 40% of the entire global economy, is responsible for the transport of 90% of all goods globally,[6,7] and plays a vital role in supporting the economy, environment and well-being of communities across Inuit Nunangat. Increased Arctic marine connectivity could enhance employment and economic development opportunities for Inuit, but could also increase risks related to environmental and cultural sustainability, safety and security, and present sovereignty tensions. It is vital that research, policy, and affected communities proactively plan, share knowledge, and provide evidence for decision-making for marine traffic in a rapidly changing and opening Arctic.

Methods: We will utilize two core approaches; 1) community-based research led by Inuit and northern youth in Arviat and Pond Inlet, Nunavut, and 2) sampling on board ships of opportunity (e.g., the *CCGS Amundsen*, *MS Ocean Endeavour*, and the *MS Fram*). We will opportunistically collect samples from on board ships transiting Nunavut waters from early July to early October in 2023 and 2024. Similarly, we will opportunistically collect samples at shore locations along cruise ship routes (where appropriate). Based on the ship itineraries for 2023, shore locations may include Pond Inlet, Arctic Bay, Dundas Harbour, Devon Island, Fort Ross, Gjoa Haven, Beechey Island, Prince Leopold Island, Resolute, Gjoa Haven, Fort Ross, and Cambridge Bay, but ultimately will be based on the route that the vessel takes and where it is able to stop. Shore locations that the vessels visited between 2015 and 2019 are presented in the attached map. We will also conduct community-based sampling of air, water, and sediment, led by Inuit in two communities with historically low (Arviat, Nunavut) and high levels (Pond Inlet, Nunavut) of ship traffic. Community-based sampling will be conducted from June – September in 2023 and 2024.

A variety of specific methods will be used, details of which are outlined below (note that activities 1 & 2 are desk-based and **activities 3 and 4 involve fieldwork that requires licensing**).

Activity 1 - Shipping Trends - past, present, and future (DESK-BASED): Our research team has created a geospatial database of ship tracks in Inuit Nunangat since 1990[2] and will use these data to analyse traffic patterns both temporally and spatially and to further identify local concerns about climate change and increased ship traffic in the region. For each ship, physical characteristics (e.g., width, length, draft, fuel type, and ice class) are being acquired by mining information available through public databases in order to fully understand the types of ships and resultant variation in risk profiles among the vessels that are operating in Inuit Nunangat. These data outputs will be used to understand potential environmental and cultural risks and as a basis to project future traffic patterns.

Activity 2 - Risks from ship-source Underwater Noise (DESK-BASED): We will use ship position data (Activity 1), and apply existing sound propagation models to predict shipping noise by vessel class and speed, and generate maps of traffic noise intensity within an approximate 100 km² radius around high traffic (Pond Inlet) and low traffic (Resolute Bay as a proxy for Arviat due to availability of data) regions. We will use these models to develop future scenarios for noise risk under different warming scenarios. We will also use existing year-long (2017-2018) passive acoustic data from Pond Inlet and Resolute Bay, collected using bottom-mounted High Frequency Acoustic Recording Packages (HARPs) to characterise seasonal variability in underwater sound levels and validate the noise models.[8,9] This data will also be used to estimate the exposure of different species of culturally important marine animals (e.g., narwhal, beluga and bowhead whales) to underwater noise from vessel traffic.

Activity 3 - Risks from Ship-based Pollution (air and water) (FIELDWORK): We will work with local youth and expert knowledge holders in Arviat and Pond Inlet to enable those communities to monitor and assess (even beyond the life of the project) the impact of particulate contaminants derived from ships in both the air and surface waters. Contaminants of interest are principally related to fuel emissions, grey water discharge, paint-derived microplastics from ship hulls, and plastic macro-litter. The project team will train Inuit youth and hunters as research associates to use air filtration units and depositional dust gauges to quantify the concentration and size distribution of air-borne particulates. Air sampling arrays will be deployed, two ashore in Pond Inlet and Arviat. To determine the composition of the particulates (e.g., mineral dust, black carbon), physical samples of air-borne particles will be collected on 37mm PTFE 2-micron pore size filters with a flow rate of 1 Lm^{-1} for multiple days to weeks. The rate with which depositional particles, of any size, are settling from the air will be calculated with a passive depositional dust gauge. Depositional dust will be collected over one-month intervals in both Pond Inlet and Arviat. Particles collected on the filters and depositional dust gauges will be analysed with scanning electron microscope (SEM), including energy dispersive X-ray (EDX) analysis, to determine the size distribution and elemental composition of the particles collected. A protocol, based on the optical filter analysis method[10] will be developed for this project to allow black carbon concentrations to be determined directly in the field and by Inuit youth research associates. Over the duration of the project, data collected will provide a time-series data that may be compared with environmental parameters (e.g., prevailing winds, precipitation etc.) and level of ship traffic (Activity 1) to determine what air pollution may be attributed directly to shipping activities.

We will train local Inuit youth and other local experts to conduct water sampling for microplastics using local boats around Arviat and Pond Inlet. Community-based water sampling will be conducted in surface waters relative to the main shipping corridors following validated methods[11] and in partnership with ECCC and an Inuk research technician already working in Pond Inlet. Community based sampling will be carried out using local boats that will deploy a 300um manta net. Samples will be taken in areas defined by community partners that are most likely to be exposed to varying levels of shipping traffic. Over the duration of the project, we will use community boats to map the concentration of anthropogenic particulates in the surface waters relative to the main shipping corridors and around important community shorelines. In addition to community-based sampling, we will use ships of opportunity. Four customised filtration systems, which sample a ship's uncontaminated sea water supply (ambient near-surface waters pumped through the hull) and do not interrupt ship operations will be deployed (following

[12]). The filtration system has an inline flow meter to record the volume of water filtered and three sequential filters (i.e., mesh size 300, 100, and 50 microns). Once the filtration system has clogged or the pre-determined transect has been completed, whichever happens first, the filtration system is disengaged and the three filters are retrieved, sealed and frozen for shore-based analysis. To better characterise the types and concentration of non-organic particulates that may be sourced from ships, we will periodically filter grey water discharged from the host vessels. All water samples will be processed in the lab following the guidance on microplastics monitoring as laid out recently by the Arctic Council's Litter and Microplastics Expert Group (LMEG) under the Arctic Monitoring and Assessment Programme (AMAP). Once the particles are sorted and separated from the water, SEM, EDX and Fourier Transform Infrared (FTIR) Spectroscopy will be used to identify and quantify the concentration of anthropogenic particulates and microplastics.

At shore locations along the vessel routes, we will take sediment samples (100g) in metal bottles to examine microplastics, and survey shorelines for macroplastic debris. For the sediment samples, we will use gravity filtration to remove plastic particles from the sediments. These samples will be used to explore how microplastics from hull coatings may be accumulating along vessel routes in relation to density of ship traffic. These methods will also follow the recent guidance from AMAP's LMEG. A combination of FTIR, Ramam spectroscopy and GC-Pyrolysis will be used to identify the hull coating particles through their known additives. This will be done through a custom polymer library that is currently being developed for ship based microplastics. For the shoreline surveys, we will use a previously developed protocol that aims to be rapidly deployed from ships transiting the Arctic. This will involve shoreline surveys from ships of opportunity and in communities through a combination of counting in the moment, and photographs along a 100m stretch of shoreline. This protocol specifically does not remove any litter from the shorelines, in compliance with Nunavut's policy regarding potential archaeological sites.

Activity 4 - Risks from Ship-source Introduction of Non-Indigenous Species (NIS) (FIELDWORK): To better understand the potential for non-Indigenous species (NIS) introduction in Arctic Canada, we will we will use results from Activity 1 to analyse ship histories and then evaluate higher and lower risk vectors based on known geographic species distribution[13,14]. This analysis will be complemented by in-situ ship-based and community-based approaches. Inuit research associates in Arviat and Pond Inlet, who were trained in water sampling (Activity 3), will also be trained to collect water samples for environmental DNA (eDNA) meta-barcoding. eDNA sampling is an emerging tool used to establish baseline biodiversity in marine coastal areas and to provide early indications of NIS in the Arctic without having to engage in expensive and invasive approaches such as bottom trawl or SCUBA diving[15,16]. Samples will be collected using local boats to establish local baseline temporal trends in coastal marine communities and identify any NIS. In addition, we will take surface water samples opportunistically while onboard ships of opportunity by using a small Remotely Operated Vehicle (ROV) equipped with a syringe sampler. When possible, organisms will also be collected from strainer baskets connected to water pipes in the ships, from sea chests/strainer baskets (located in the vessel engine room). Samples will be filtered and subsampled to obtain counts of viable organisms and a portion of each sample will be preserved for later taxonomic analysis and/or molecular genetic assessments to identify NIS.

The research team will use the underwater ROV to opportunistically (i.e., while in port in Quebec City or while visiting Arviat and Pond Inlet) photograph (video) each side of the hull and sample the hulls in strategic areas (i.e., anchor chains, propeller shaft) to determine extent of potential biofouling and to evaluate taxonomic composition within the samples. ROV photographs will be analysed using a 100-point grid over each photograph to estimate percent cover of each taxonomic group. To test fouling patterns on vessels, differences in percent cover (abundance) and taxa across underwater locations will be compared using analysis of variance and multivariate methods. We will also compare biofouling levels/patterns, densities of viable organisms and communities between locations, vessel type, and provenance of vessels to characterize factors contributing to risk.

Finally, the project will contribute to the co-creation of a Pan-Arctic Observing System of Systems (see https://arcticpassion.eu/), specifically contributing information to the creation of state-of-the-art short-term

satellite based WWIC products and forecasts. While on board ships of opportunity, we will engage ship captains to verify product needs.

Progress to date: We had four virtual team meetings including Inuit partners from Pond Inlet and Arviat, as well as three in-person team meetings held in the UK and Quebec City. In May, 2022, our full team participated in a virtual two and a half day training provided by our Inuit partner organization Aqqiumavvik Society. The training consisted of an overview of IQ, how to build trust, relationship and collaborative approaches, and an introduction to the Aajiiqatigiingniq Research Methodology. In December, several community researchers were shown our portable hydrophones while we were at the 2022 ArcticNet ASM and they were able to spend some time playing with the equipment and learning how it is used. In addition, we purchased two additional hydrophones for Arviat, NU for ongoing community use. In February, 2023, we held training in Ottawa for boat derived microplastics sampling. Three hunters from Pond Inlet and Arviat were able to participate in the training session, as well as team members from the UK and across Canada. These training opportunities provide new skills for community researchers and generate long-term capacity building benefits and access to sampling technology promotes self-determination in research.

We cleaned and updated our database of 1,311 ships that travelled within the Canadian, based on ship attributes and 'web-scraped' details. We now have a comprehensive spatial dataset of ship positions between 1990-2020. Community scale analysis for Arviat and Pond Inlet, and annual updates of traffic trends for those communities, has been completed up to 2020. We have completed base modeling for noise at Eclipse Sound and prepared passive acoustic data for validating model outputs at Eclipse Sound and Resolute. Opportunistic water sampling was conducted onboard the *MS Fram* (Hurtigruten) between August-September, 2022. Over 11,000 litres of uncontaminated seawater from the seawater inlet in the hull of the ship were filtered through 300, 100 and 50 micron meshes. 38 samples were collected between Baffin Bay and Cambridge Bay, and the return leg. Opportunistic sampling for eDNA was conducted onboard the *MS Ocean Endeavour* in September, 2022. We collected 44 water samples at 8 sites across Baffin Bay. Samples will be used for comparison of water from upstream and downstream of ship sterns to access differences in eDNA signatures between these two positions, and reference spatial sampling was also performed approximately 1km from the ship with the same protocol (mimic presence of a ship). Furthermore, in late 2021, the CCGS Amundsen was in drydock where we managed to sample the main haul all around the ship, including strategic areas such as the propeller, skeg, etc. The team did not find any freshwater or marine attached species on the ship. Note that sampling conducted in 2022 was authorized under an existing license (NRI Scientific Research License – 03 014 22R-M).

Data management: All data and samples are saved and/or stored in locked facilities and password protected computers/servers. The research team follows all procedures for data management and storage that is outlined in the Tri-Council protocols and that is also guided by the National Inuit Strategy on Research, that Inuit data-sovereignty project, and Tri-Council principles related to research with Indigenous peoples. Some specific details are provided below:

- The historic shipping database (Excel, ArcGIS) is managed by Dr. Jackie Dawson and is being stored on a password protected computer (and password protected cloud-based server).
- The noise modelling outputs (spatial data/raster) database is managed by Dr. William Halliday and is also being protected and stored on password protected computers and servers.
- Physical samples (water, sediment, air) are being stored at a locked facilities in Ottawa (ECCC) and in Cambridge (British Antarctic Survey).

Research outputs: Outputs from the activities described in the methods section will be combined and displayed graphically and spatially using risk mapping techniques, at both regional and local scales, using the multi-criterion datasets. Data analysis will be conducted using ESRI ArcGIS 10.8 to integrate the spatial datasets and identify

regions with high shipping risks and to identify areas and thematic issues of concern. All datasets will be standardized by weighting according to risk factor, and high-risk regions will be identified using spatial statistics tools such as zonal statistics, cluster analysis and optimized hot spot analysis using Getis-Ord Gi* statistic. The 'hot spot' risk maps as well as summarized findings from other activities will be shared through a youth-led and facilitated workshop (with simultaneous interpretation/translation) to be held in 2025 (final year of the project). The workshop will be used to 1) share project findings, 2) validate project results and conclusions, 3) and to identify and inventory self-determined governance approaches that may be developed and implemented to reduce identified shipping risks. Governance options identified in the workshop will be evaluated against existing regulatory mechanisms and evaluated for prioritization and feasibility. The workshop will also be used as an opportunity to provide communities with information on existing shipping regulation in order to increase local understanding of ongoing risk mitigation efforts which has been observed to be a challenge in previous research efforts. To date, the project has contributed 13 presentations (poster and oral), four published journal articles, and one submitted journal article. We plan to present annually at scientific conferences (e.g., ArcticNet ASM). We expect several publications and theses (n=~4).

References

[1] Ferrazzi, P. et al. (2019). Aajiiqatigiingniq: An Inuit Consensus Methodology in Qualitative Health Research. International Journal of Qualitative Methods.
[2] Dawson, J. et al. (2018). Temporal and Spatial Patterns of Ship Traffic in the Canadian Arctic from 1990 to 2015. Arctic, 71(1), 15-26.
[3] Serreze, M.C. & Stroeve, J. (2015). Arctic sea ice trends, variability and implications for seasonal ice forecasting. Philos Trans A Math Phys Eng Sci. 373(2045).
[4] Kwok, R. (2018). Arctic sea ice thickness, volume, and multiyear ice coverage: losses and coupled variability (1958–2018). Env. Res. Lett. 13, 105005.
[5] Mudryk, L.R. et al. (2021). Impact of 1, 2 and 4 °C of global warming on ship navigation in the Canadian Arctic. Nature Climate Change. 6
[6] World Economic Forum (2021). Our economy relies on shipping.
[7] World Bank, World Bank Open Data. (2020). Accessed March 2020. https://data/worldbank.org/
[8] Halliday, W.D. & Dawson, J. (2021). Ship-Source Noise Modeling from 2015-2018 in the Kitikmeot Region and Lancaster Sound (Northwest Passage), Nunavut.
[9] Kochanowicz, Z. et al. (2021). Using western science and Inuit knowledge to model ship-source noise exposure for cetaceans (marine mammals) in Tallurutiup Imanga (Lancaster Sound), Nunavut, Canada. Mar. Policy 130, 104557.
[10] Jeronimo, M. et al. (2020). Analysis of black carbon on filters by image-based reflectance, Atmospheric Environment, Volume 223,
[11] Provencher, J.F. et al. (2020). Polycyclic aromatic compounds (PACs) and trace elements in four marine bird species from northern Canada in a region of natural marine oil and gas seeps. Sci. Total Environ., 744, Article 140959, https://doi.org/10.1016/j.scitotenv.2020.140959
[12] Jones-Williams, K. et al. (2021). Remote but not isolated – microplastics and mesoplastics of the Canadian Arctic Archipelago. Frontiers Mar Sci, 8. 13 pp.
[13] Ruiz, G.M. et al. (2015). Invasion history and vector dynamics in coastal marine ecosystems: Ecosystem Health & Management, 18(3) 299-311
[14] Goldsmit, J. et al. (2019). Ecological risk assessment of predicted marine invasions in the Canadian Arctic. PLoS ONE 14(2): e0211815.
[15] Van den Heuvel-Greve, M.J. et al. (2021). Early detection of marine NIS on Svalbard by DNA metabarcoding of sediment. Polar Biol 44, 653–665
[16] Lacoursière-Roussel, A. et al. (2018). eDNA metabarcoding as a new surveillance approach for coastal Arctic biodiversity. Ecol Evol. 8: 7763–7777.