Long-term measurements of ambient sounds in Cambridge Bay (Canada), 2015–2024 – Implications for extending the MSFD to Arctic waters

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Abstract: *Climate change in the Arctic enables increased access to human activities, affecting underwater soundscapes. It is therefore important to have complete guidelines to monitor impacts on natural environments. The EU Marine Strategy Framework Directive is the most complete, strongly inspiring emerging guidelines in other countries. Primary descriptor D11C2 addresses continuous low-frequency sounds and makes extensive use of third-octave "shipping bands" at 63 and 125 Hz. To address the lack of measurements, models often use ship tracks recorded by their Automatic Identification Systems (AIS). But not all ships in the Arctic use AIS, and winter ice also allows human activities other than shipping. We use sound measurements by Ocean Networks Canada in Cambridge Bay (Nunavut) between 2015 and 2024, focusing on the months of May (full ice cover, no shipping) and August (little to no ice, shipping activity). We show impacts beyond the "shipping bands". Baseline soundscapes vary with ice cover and AIS underestimates impactful activities of all types. Our results show that future guidelines will need adapting to the Arctic environments to fully measure the range of human impacts.*

Keywords: *Marine Strategy Framework Directive, human impacts, Arctic, shipping*

1. RATIONALE

The Arctic regions have long been shielded from human activities, because of their remoteness, the challenging weather conditions and the predominant ice cover. This is all changing now and changing fast. Arctic amplification means polar regions are warming three times faster than the global average [1]. Between 1979 and 2019, the Arctic sea ice declined by up to 43% in all regions, with sea ice becoming younger and thinner over this period [2, 3]. Economic developments and geostrategic considerations are leading to the development of offshore structures, in particular near-shore extraction facilities, expected to develop, in particular in Nunavut (Canada), Russia and Greenland and to be associated with marine shipping of the resources. The gradual openings of the Northern Sea Route and the Northwest Passage are now associated with the distinct possibility of trans-Arctic routes in the near future [4]. Analyses of current shipping patterns show that the Northwest Passage in particular can decrease voyages by 7,000 km [5], The distances travelled by ships along the Northwest Passage already tripled between 1990 and 2015 [6] and the southern route is often preferred because of its relative shelter. Cambridge Bay (Ekaluktutiak) in Nunavut is the largest stop for passenger and research vessels along this route (Fig. 1), even though the number of ships passing in the outer Dease Strait is still relatively low [7]. It is therefore a good location to assess these changes over the years.

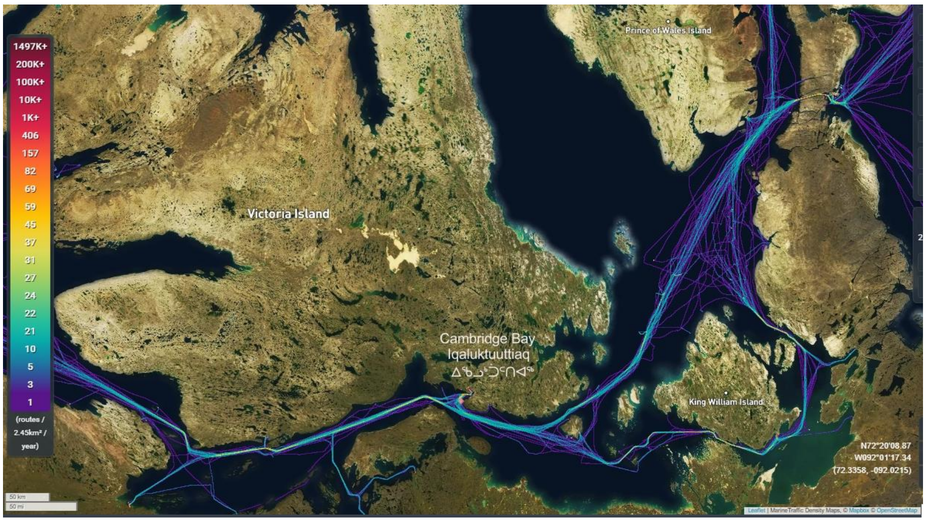

Fig.1: Cambridge Bay is on the southern route of the Northwest Passage. The most frequented shipping lanes show few vessels equipped with Automatic Identification Systems (2024 basemap from Marine Traffic, https://www.marinetraffic.com/).

The EU "Marine Strategy Framework Directive" (MSFD) is an important tool in the sustainable use of the oceans, providing a comprehensive series of metrics and contributing to addressing the UN Sustainable Development Goal SDG-14 "Life below water" (https://www.un.org/sustainabledevelopment/oceans/). It was augmented in 2022 by additional guidelines about setting threshold values for continuous underwater sounds [8], accounting for local conditions, acoustic baselines and marine life. The impact of human activities is measured along "shipping bands", third-octave frequency bands centred on 63 Hz and 125 Hz. This definition has been particularly useful to assess the impacts of marine traffic in different regions around Europe [9, 10] and in other oceans [11], including modelling the deep waters of the Arctic Ocean [12].

In the context of the shallow-water environment of Cambridge Bay, close to a harbour and town, ice-bound during winters, this article aims to address the following questions:

- What are the actual measurements of the "shipping bands"? How do they vary between seasons and between years?
- Are there other human activities that contribute to these bands? How do they compare with satellite monitoring of shipping activities?
- Beyond the MSFD "shipping bands", should other frequency bands be used to assess human impacts?

2. DATA AND METHOD

Ocean Networks Canada has been operating the Cambridge Bay Community Observatory for more than 10 years [13]. Soundscapes are measured continuously using an Ocean Sonics icListen HF hydrophone 8 m deep in shallow water (13 m). We use recordings from May and August, from 2015 to 2024. They are processed with PAMGuide [14], using the hydrophone sensitivity of -170 dB ref. 1 V/μPa and the frequency range of 10 Hz to 32 kHz. Time windows of 1 second, with a Hann filter and 50% overlap, were used to calculate broadband sound pressure levels (SPLs), power spectral densities (PSDs) and third-octave band levels (TOLs), aggregated every 5 minutes. There were occasional gaps in data coverage, due to hardware issues and the effects of COVID lockdowns on recovering data. Loud, continuous events are identified by their SPL exceeding the weekly average SPL by at least 10 dB for at least 1 minute (filtering out most ice-related processes, keeping most human-made sounds like shipping).

Regional ice information comes from weekly ice charts provided by the Canadian Ice Service, showing ice cover and ice types in Cambridge Bay and surrounding areas. These charts are based on analyses and combinations of satellite imagery, weather and oceanographic information and visual observations from ship and aircraft. Local ice thickness is provided by an ice profiler, operated by Ocean Networks Canada and located next to the hydrophone. Wind speeds and air temperatures were measured hourly at neighbouring weather station Cambridge Bay A, currently operated by NAV Canada. The average sound levels in each third-octave band were correlated with hourly wind speeds, in line with similar calculations by [15], as an indicator of Sea State. Hourly temperatures and their first derivatives were used to assess possible changes in ice dynamics.

Ship traffic information is coming from Automatic Identification Systems (AIS) collated by the Arctic Ship Traffic Database (ASTD) of the Arctic Council's working group on Protection of the Arctic Marine Environment (PAME). ASTD Level 3 data includes ship positions (every 6 minutes), ship type (e.g. cruise and passenger ships, general cargo, offshore supply and chemical tankers) and activity. The numbers of AIS entries for each month show the activity in Cambridge Bay and further out, even if the number of unique ships is small and some might be re-entering the area several times.

These strands of information have been used to focus on the contrasting months of May (maximum ice cover, no shipping) and August (smallest to no ice cover, higher shipping). An earlier study [16] had aurally identified different sounds (other than shipping) in May and August 2018, In later work [17], we had analysed the sound levels in the "shipping bands" of 63 Hz and 125 Hz for the months of May and August in 2015, 2016, 2018, 2019 and 2020. Here, we focus on <u>both loud and continuous sounds</u>, for a complete decade (2015 to 2024), with the added information of AIS to identify some ship types/activities but also to ascertain how much marine traffic is actually recorded with AIS (or not).

3. RESULTS

For the first four weeks of each month (to ensure statistical equivalence) and for all times where data was available, the variations of the third-octave levels for the 63-Hz “shipping band” (56.2–70.8 Hz) and its 125-Hz counterpart (112–141 Hz) are compared with those of the broadband (10 Hz – 32 kHz) Sound Pressure Levels between 2015 and 2024 (Fig. 2). The boxplots show the median values as central marks, and the 25th and 75th percentiles correspond to the edges of the boxes centred on the median values. Individual outliers are represented as crosses.

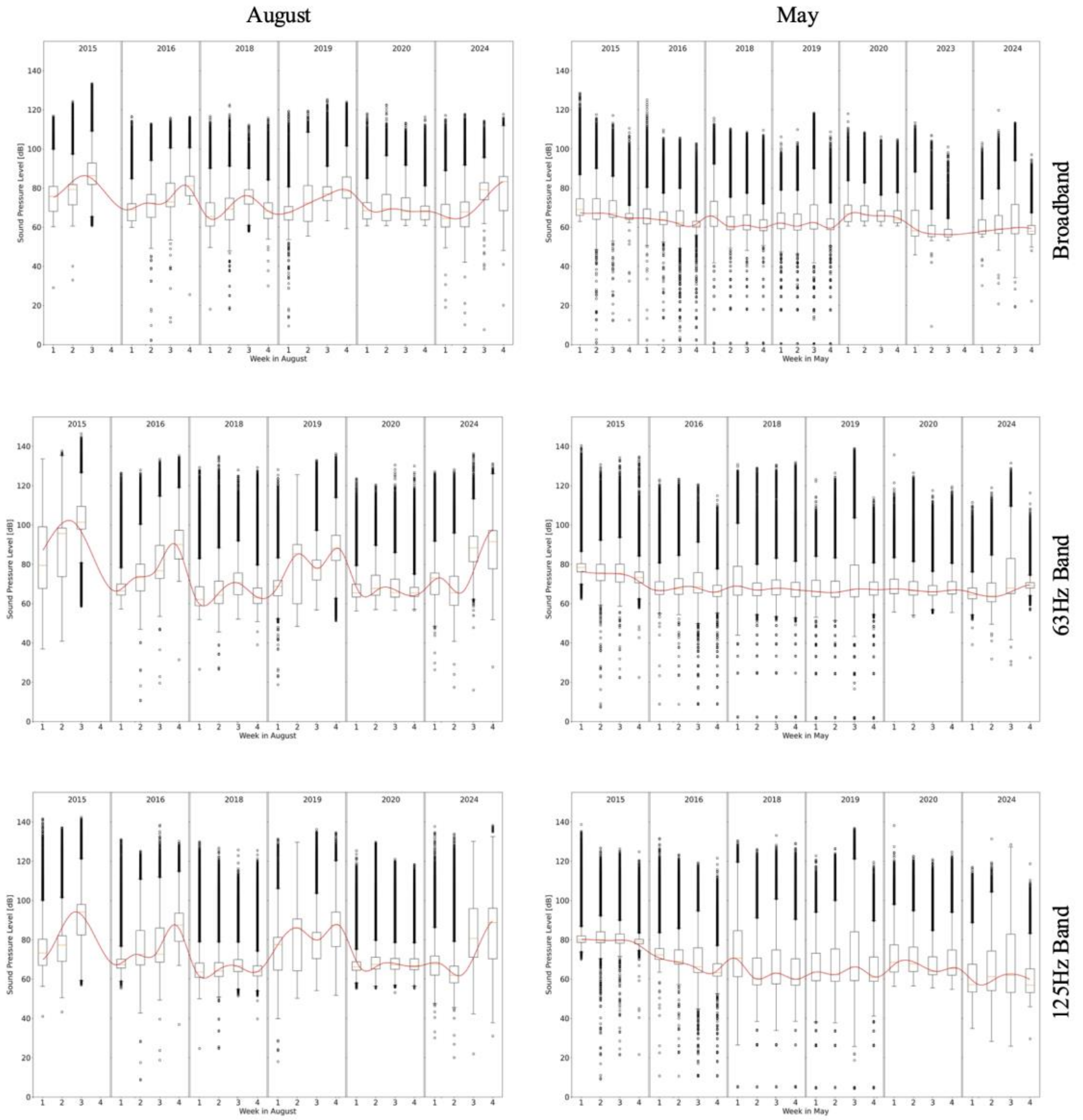

Fig.2: Boxplots showing the variation of Sound Pressure Levels, broadband (10 Hz – 32 kHz, top) and for the third-octave bands of 63 Hz (middle) and 125 (bottom) recommended by the MSFD, for the first 4 weeks of the months of August (left) and May (right), from 2015 to 2024. Months with not enough measurements are not represented. The red lines go through the mean values of each plot.

Broadband levels (Fig. 1, top) are generally louder by more than 10 dB in the summer months, with louder outliers present more than 10 times than the quieter ones. From week to week, the average levels generally increase as the month progresses and navigation becomes easier. Values for August 2020 are affected by the Covid lockdown, decreasing to levels generally seen in the months of May. Broadband sound levels in the months of May are generally similar and much lower than in August, with much less variation from year to year and from week to week.

In August (Fig. 2, left), the two shipping bands (Fig.2, middle and bottom) follow each other and the broadband SPLs. They have respective Pearson's correlation coefficients *r* of 0.87 (63-Hz band) and 0.90 (125-Hz band), with *p* values of 1.1×10^{-8} and 2.3×10^{-10} respectively. These very strong correlations show the main contributions to the broadband levels are indeed coming from these two bands. However, comparisons with AIS records do not correlate with the numbers of ships each week (or the time they spend in the area) with the variations in either shipping band.

In May (Fig. 2, right), the two shipping bands also show levels varying in line with the broadband levels, generally at similar levels to August averages and decreasing with the years. The quieter outliers (broadband and in the shipping bands) also drastically decrease in numbers from 2020 onwards. Values in the 63-Hz band have a lower correlation with the broadband levels ($r = 0.68$ and $p = 1.5 \times 10^{-5}$). Conversely, values in the 125-Hz band have correlations with broadband levels similar to those from the months of August ($r = 0.88$ and $p = 1.9 \times 10^{-11}$). Ice charts (and local measurements) show thick ice cover and AIS records confirm there is no shipping at these times.

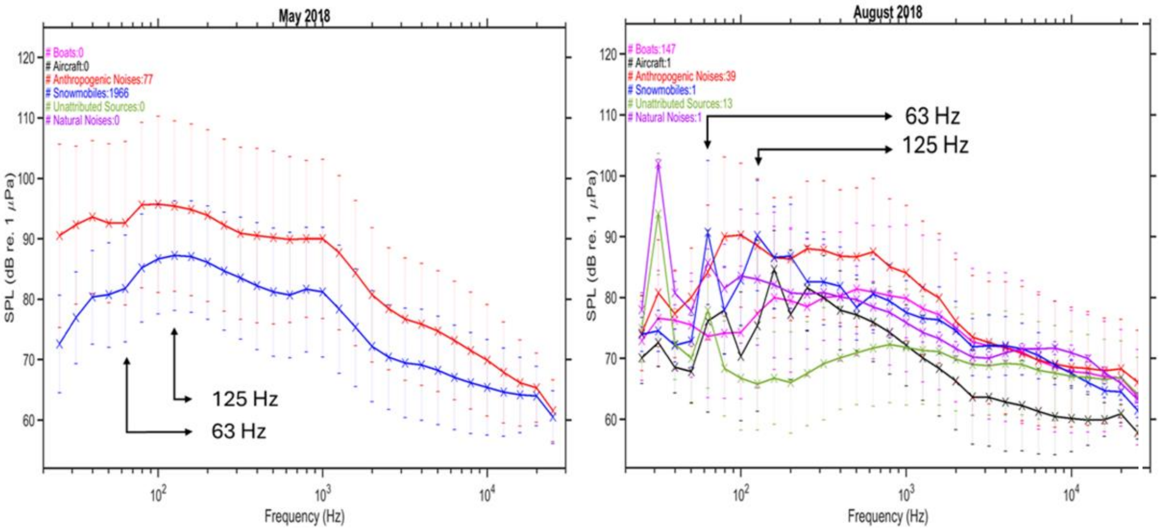

Fig.3: Aural classification of long, continuous sounds for the months of May and August 2018 (from [16]). They show that more ships are heard than are tracked with AIS and that other sound sources contribute to the MSFD bands.

Aural identification of recordings in 2018 showed there were many different sounds other than ships (Fig. 3; [16]), including aircraft (in summer) and snowmobiles (in winter). Aircraft sounds are similar to those presented in [18] and snowmobile sounds are similar to those presented in [19]. Other sounds were more difficult to identify with certainty and labelled "anthropogenic": they include machinery (onshore or on ships), sounds from repairs ("drilling" sounds) etc. Few ships are recorded using AIS, presumably because they are too small to legally need one, but hundreds of ships can still be heard in the data during the months of August, some for hours as they enter or leave Cambridge Bay [17] and the noise of machinery/lifting gear is also common. These ships create sounds generally at 125 Hz and below (including below 63 Hz) and extending into higher frequencies for shorter periods. Other sounds identified aurally as anthropogenic extend up to 700 Hz. Small vessels idling in the harbour are also a common occurrence. Because of the proximity to the Cambridge Bay Airport (2 km from the hydrophone) and the Cambridge Bay Water Aerodrome (less than 2 km away), aircraft can be heard too. The sounds primarily come from the propellers, with harmonics between ca. 80 Hz and 1 kHz, and PSD levels up to 100 dB. Less aircraft can be heard than expected from flight schedules, presumably based on variations in approach paths and aircraft types. In the months of May, no ships were heard (obviously) but there were a large number of snowmobiles and possibly All-Terrain Vehicles. Cambridge Bay is also famed for its Omingmak Frolics, a week-long spring festival featuring snowmobile races (and usually held in May). Snowmobiles create loud tonals (below a few hundred Hz), with PSD levels up to 80 dB between 40 Hz and 1 kHz, extending into higher frequencies as they pass above the hydrophone (as evidenced by Lloyd's Mirror Effects).

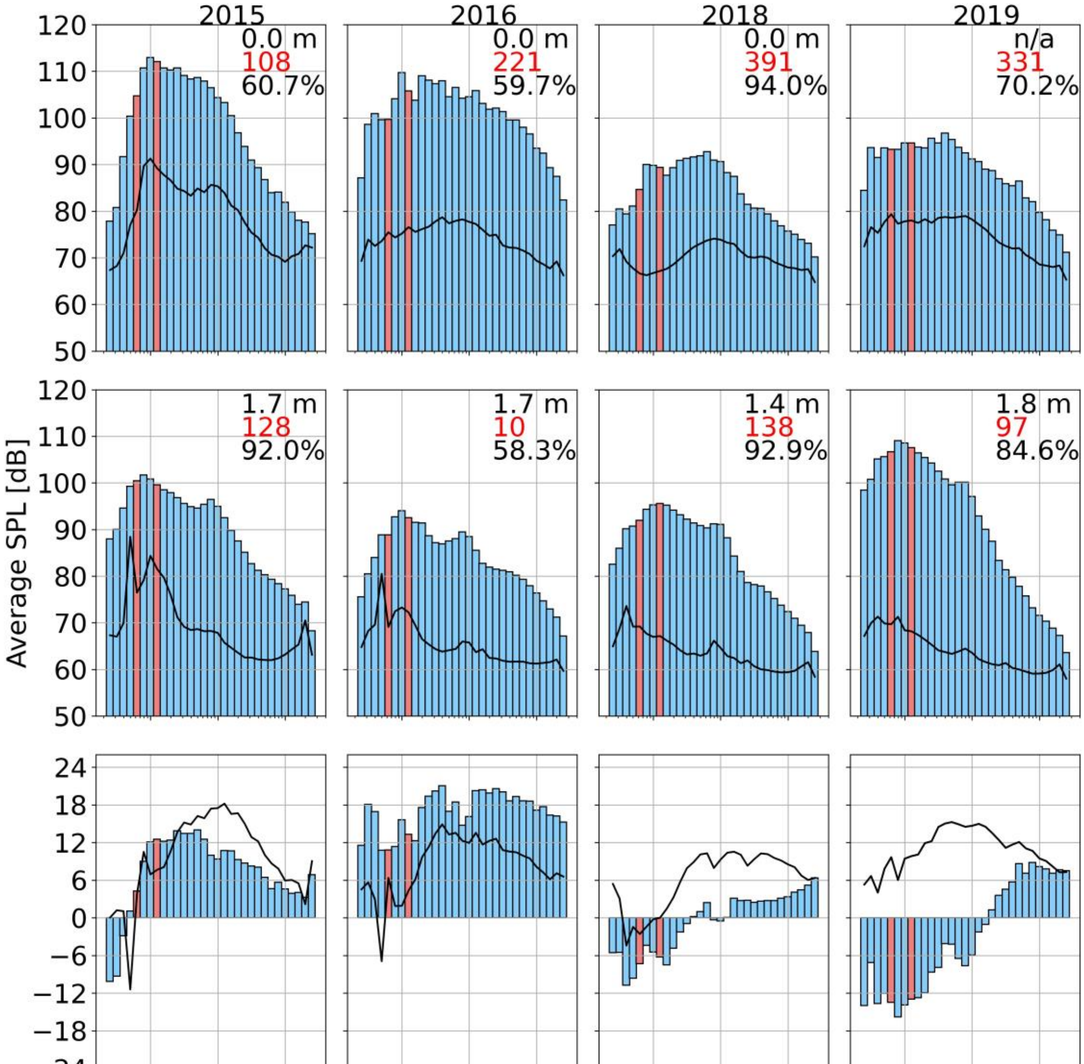

Fig.4: Frequency contributions of loud, continuous events for August (top) and May (middle) and their difference (bottom), with averages as black lines. MSFD bands are highlighted in red. Numbers show the ice draft, the number of continuous events identified and the record coverage for this month. For clarity, only some years are presented here.

Loud, continuous events extend well into the kHz range (Fig., 4) and the MSFD bands are not always the loudest. Sound levels in August are systematically louder in the 125-Hz band than in the 63-Hz band. This matches measurements by [10] in a similar bay, attributing it to the increased presence of smaller vessels (with no AIS) and the effects of acoustic propagation. Individual recordings of ships show their sounds often extend into the kHz range, especially when audibly closer. Other studies showed similar results, with sounds from small vessels centred on 200 Hz [20], louder between 350 Hz and 2 kHz [21] and extending up to 10 kHz [22], depending on the types of ships and their exact environments. Conversely, in May, the MSFD bands are loud (even if there are no ships) but the frequency distributions of loud events tail off steeply above 1 kHz. Sound levels are also different between August (louder in 2015+2016) and May (louder in 2018+2019).

4. CONCLUSIONS

Actual measurements of the MSFD "shipping bands" show they are not always louder in summer months (when there is shipping) than in winter months (when there is no shipping because of the full ice cover). Comparisons between these seasons show there are other contributors to the MSFD bands (and other frequencies), including small vessels (with no AIS), overflying aircraft, snowmobiles and ATVs (in winter) and machinery noise (in both seasons). Satellite monitoring of shipping is still helpful, but in coastal environments like this one, they do not provide a full picture of the varied activities taking place at different seasons. Models of acoustic impacts based solely on AIS data are consequently also of limited use for this type of area. Focusing on loud, continuous events, it is also clear that they contribute to frequency bands well into the kHz region (in the open-water season) and up to 1 kHz (in the fully ice-covered season). These measurements can be extended to include different levels of ice cover (e.g. during melting or break-up), related to different types of human impacts (more or less shipping, more or less on-ice activities like snowmobiles). Extensions of the MSFD to Arctic waters should therefore use different baselines depending on the ice cover. They should also recognise that the 63-Hz and 125-Hz bands are not the most representative of human impacts, from shipping or other activities, and that frequency bands up to the kHz region should be monitored.

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