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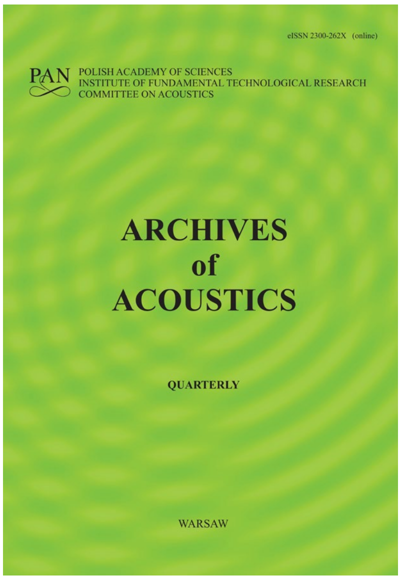

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Soundscape of Nansen Basin – Central Arctic Ocean

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ABSTRACT

This work mainly focuses on a deepwater soundscape study in the Nansen Basin, Central Arctic Ocean, by using Ambient Noise Measurement System (ANMS) data, which was deployed as part of the Nansen Environmental and Remote Sensing Center (NERSC-4) mooring from September 2019 to July 2020. The main objective of the work is to study the sources of underwater noise of the Central Arctic Ocean (CAO) along with their characteristic patterns. Also in this work, the seasonal variation of the sound pressure level of CAO is studied. The seasonal variation of the sound pressure level of the CAO is maximum in summer, and the minimum seasonal variation was observed during spring. The difference in seasonal variability in 1/3 octave band frequencies between summer and spring was 4.1 dB (re 1 μPa²/Hz). Shipping and marine species are the most dominant noise sources of the Central Arctic Ocean. Bowhead whales and bearded seals are the most common marine species observed in this location. The bearded seal vocalisation is more intense between 300 and 700 Hz. Bowhead whales produce two different types of simple calls i.e., sound patterns : one is S-moans, and the other is V-moans. The S-moan patterns are mainly dominated by low frequencies i.e., below 600 Hz. The V-moans patterns are dominated in the

frequency range of 300 to 1230 Hz. The killer whales are also observed in the study location, which represents a shifting Arctic environment. The soundscape generated by killer whales is observed between 160 Hz and 2 kHz.

Keywords: Bowhead whales, Nansen Basin, Central Arctic Ocean, Bearded seals, killer whales, Ice cracking

1. Introduction

Extremely cold temperatures, glaciers and sea ice cover define the Central Arctic Ocean (Bluhm *et al.* 2020; Ingvaldsen *et al.* 2021). It is one of the most vulnerable regions in the world to the effects of global warming. Global warming is accelerating the amount and rate at which glacier ice melts (Barnhart et al. 2016; Höglund et al. 2017), causing the sea level to rise and contributing to ambient noise. Climate change is also providing an opportunity to explore and exploit the natural resources present in this region to boost the economy (Haver et al., 2018; Klinck and Mellinger, et al., 2012). Because of these reasons, the polar region has gained importance over the last few decades.

The soundscape not only represents the current state of the environment but also how it has evolved over time. Therefore, soundscapes are not static features of the environment but vary spatially and temporally. The underwater soundscape consists of sound generated by biological, geophysical, and anthropogenic sources (Pijanowski and Villanueva-Rivera, 2013). Conditions of the changing abiotic environment are indicated by sounds produced by wind and ice (Halliday et al., 2020; Southall et al., 2020; Menze et al., 2017; Kinda et al., 2015). There is a very high likelihood that the habitat will be dominated by biological noise if the acoustic environment is untouched by human activity. The soundscape of the ocean has changed dramatically over the last half-century as a result of human activities (Hildebrand, 2009). Marine soundscapes are increasingly being impacted by shipping, seismic surveys, and sonar activities. The main dominating sources of soundscape are ice bubbling, calving, ice ramming, shipping, and rain (Mohanta et al., 2024; Madan et al., 2022, Pettit et al., 2015; Glowacki et al., 2018). The presence of soundscape also varies seasonally, with surface wind noise, ice activity, and shipping during the summer and ice and wind-wave activity during the winter (Sanjana et al., 2024).

The rising economic activity and rising ocean ambient noise levels are related. Between 1950 and 2007, there was an approximate 3.3 dB re 1 $\mu Pa^2/Hz$ rise in ambient noise levels in the open ocean every decade (Frisk, 2012). The consequences of noise pollution on terrestrial ecosystems are well known; the effects on marine ecosystems remain largely unexplored. (Duarte et al., 2021). A worldwide decrease in both commercial and private shipping traffic resulted in a notable variation in underwater ambient noise due to the COVID-19 pandemic. According to Robinson et al., 2023 there is a decrease in noise level between 1 and 3 dB below 100 Hz.

The global pandemic has given researchers the opportunity to examine how a sudden decrease in anthropogenic activities affects underwater sound levels. As far as marine mammals are concerned, increased noise pollution has a huge impact on them. Marine mammals rely on sounds for communication, social interaction, and navigation; however, noise from ships can interfere with their ability to hear these signals, causing auditory masking (Erbe et al., 2016a). Bowhead whales and bearded seals are the most common marine species observed in these locations. Numerous studies have explored bearded seal vocal behaviour, since their vocalisations can be easily identified (Frouin-Mouy et al., 2016; MacIntyre et al., 2013; Risch et al., 2007; Davis, Kovacs, Lydersen, and Van Parijs, 2006). Previous studies have demonstrated that during the mating season, call activity can increase and start earlier (Frouin-Mouy et al., 2016; Hannay et al., 2013; MacIntyre et al., 2013).

The Killer whales have traditionally been restricted from reaching many Arctic areas by seasonal sea ice. Sea ice is gradually disappearing from the Arctic Ocean, an area with a long history of sea ice cover. According to Higdon and Ferguson (2009) and Kovacs et al. (2011), the recent shift is giving killer whales more room to expand their range. This actually representing how rapidly the Arctic environment is shifting.

The deepwater soundscape study has been carried out in the Nansen Basin, Central Arctic Ocean, by using ANMS system data, which was deployed as part of the NERSC-4 (Nansen Environmental and Remote Sensing Center) mooring from September 2019 to July 2020. This study provides insights into the Central Arctic's acoustic environment and underwater noise patterns. It explores the sounds generated by marine species as well as the characteristics of the underwater soundscape of the Nansen Basin in the Central Arctic Ocean. This study also provides the seasonal variability of the underwater soundscape in the Central Arctic Ocean. The acoustic environment of the Arctic is expected to be better understood by continued measurements and characterisation of soundscape sources of ambient noise.

2. Materials and methods

The time series acoustic data were recorded by the autonomous Ambient Noise Measurement System (ANMS) of the National Institute of Ocean Technology, Chennai, which was deployed as part of the deep mooring system of NERSC (Nansen Environmental and Remote Sensing Center) under the INTAROS project. The goal of INTAROS is to build an integrated Arctic Observation System (iAOS), which will combine atmospheric, oceanic, cryosphere, and land observations. The NERSC-4 deep mooring was deployed at Lat: 81° 47' 094" N, Long: 22° 00'

280" E during 2019–20 where the ocean depth is 3458 m. The details of the mooring location and the study area are given below in Fig.1.

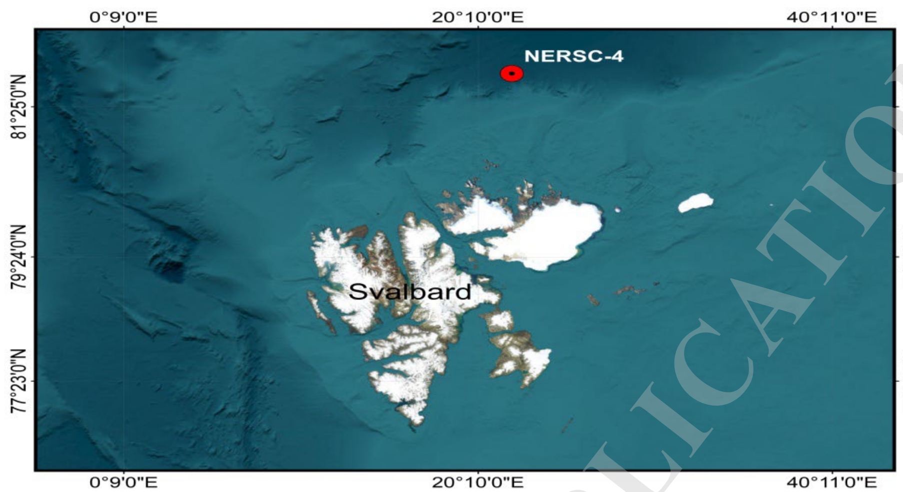

Fig.1. Ambient Noise Measurement System (ANMS) attached to NERSC-4 mooring deployed at Lat: 81° 47' 094" N, Long: 22° 00' 280" E in the Nansen Basin of Central Arctic Ocean.

In the multidisciplinary NERSC-4 deep mooring, instruments were incorporated to collect measurements of ocean sound, biogeochemical processes, and physical characteristics. The system consisted of hydrophones with associated data acquisition modules for the acquisition and storage of ocean ambient noise. The ANMS with cetacean C57 hydrophone was installed at a depth of 73 m below the ocean surface, the data recorded by this, have been used in this analysis. 11-month data sets (Sep-2019 to July-2020) have been used in this study. Data was sampled at 4kHz and recorded for a duration of one hour in every 36 hour interval, mainly to investigate low-frequency noise sources in the region. The frequency bandwidth of the hydrophone is 30 Hz to 100 kHz. This hydrophone's preamplifier has a gain of 20 dB and a sensitivity of -165 dB re 1 V/μPa. Tests and calibrations were performed at the underwater

Acoustic Test Facility (ATF) of National Institute of Ocean Technology (NIOT), which is accredited by the National Accreditation Board for Testing and Calibration Laboratories (NABL) in India.

The sea ice concentration data were collected from the website 'https://nsidc.org'. These sea ice data were collected with a temporal resolution of one day and a spatial resolution of 4 km x 4 km. AIS marine traffic data from https://www.vesselfinder.com/, helps to identify ship noise by providing details on vessel arrival and departure, ship name, IMO, MMSI, etc. The AIS marine traffic data were collected within a radius of 100 km from the study location. A preliminary observation of underwater ambient noise in the Central Arctic Ocean (CAO) has been carried out in order to evaluate the variation of sound pressure levels. Acoustic spectral analysis was performed on the Ambient Noise Measurement System (ANMS) time-series acoustic data. The hydrophone's receiving sensitivity was used in order to convert the voltage output into pressure. Sound pressure levels were estimated using Welch's Power Spectral Density (PSD) method (Welch, 1967). PSD estimations were calculated by using a 4096-point FFT with 50% overlap and a Hamming window.

Spectral analysis was carried out for each record, and the resulting PSD was used for identifying the presence of dominant sources such as ship noise, ice cracking noise, or biological activity. The Short-Time Fourier Transform (STFT) was used to generate a spectrogram, which showed how signal energy varies over both time and frequency. The identified source was further confirmed with audio recordings.

3. Results and discussion

In this study from September 2019 to July 2020, all three types of noise sources have been identified in the Nansen Basin of CAO.

3.1 Anthrophony

According to International Maritime Organisation (IMO) and United Nations Conference on Trade and Development (UNCTD, 2025) around 80% to 90% of all goods traded globally are transported by ship today". The rapid expansion of shipping is the leading source of ocean noise pollution worldwide (Kaplan et al., 2016). The shipping activity in the Central Arctic Region is less because of the presence of sea ice. Generally, the research and survey ships are observed in that area. The archipelago called Svalbard is located near the Nansen Basin. A distance of approximately 85 to 90 nautical miles separates Svalbard from the NERSC-4 mooring. Many Arctic research stations have been developed in Svalbard, Arctic, by countries like India, Norway, Poland, etc. Shipping activities are observed at the Ny-Alesund port, one of the busiest ports in Svalbard.

From the analysis of the acoustics data of CAO, it has been seen that the shipping noise spectrum was observed up to a frequency of 800 Hz. The shipping spectrum for the month of September was greater than 116 dB re 1 $\mu Pa^2/Hz$ in some records. The shipping noise frequency spectrum and spectrogram are shown in Fig. 2 (a and b).

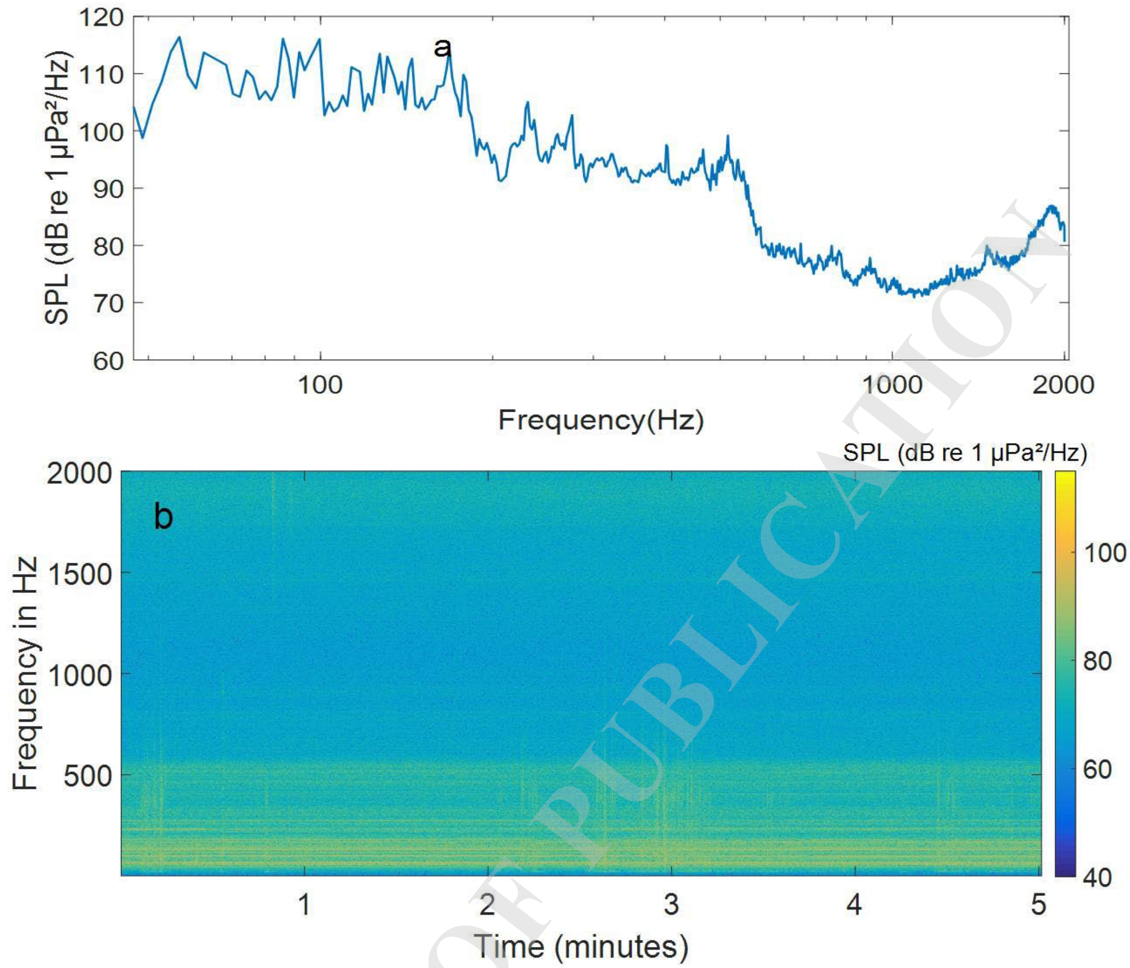

Fig.2.The frequency spectrum (a) and spectrogram (b) of shipping noise in the Central Arctic Ocean, respectively observed in the record on 4 September 2019 at 0000 UTC. The color bar indicates the noise level in dB re 1 μPa²/Hz.

Out of 11 months, most of the shipping records were observed in September, November, December and July. The shipping noise was confirmed by comparing the acoustics data having the shipping sound signature and the marine traffic data of the same time. The marine traffic data was collected from the website 'https://www.vesselfinder.com' of the central Arctic Ocean from September 2019 to July 2020. The latitude and longitude of every vessel are provided by the maritime traffic data. We have the ANMS latitude and longitude. Thus, the accurate distance between the mooring and vessel can be calculated by using the Haversine formula (Fig.3). In some data it has been seen that acoustic data has shipping noise, but at the same time, in marine traffic data, the ship details are not present. This is because the marine traffic data was collected over a distance of 50 nm in radius from the mooring position. So distance shipping details are not present in marine traffic data but are present in acoustic data. The majority of the vessels are present at a considerable distance from the study area, according to the distance computation between the ANMS location and the ship position Fig.3.

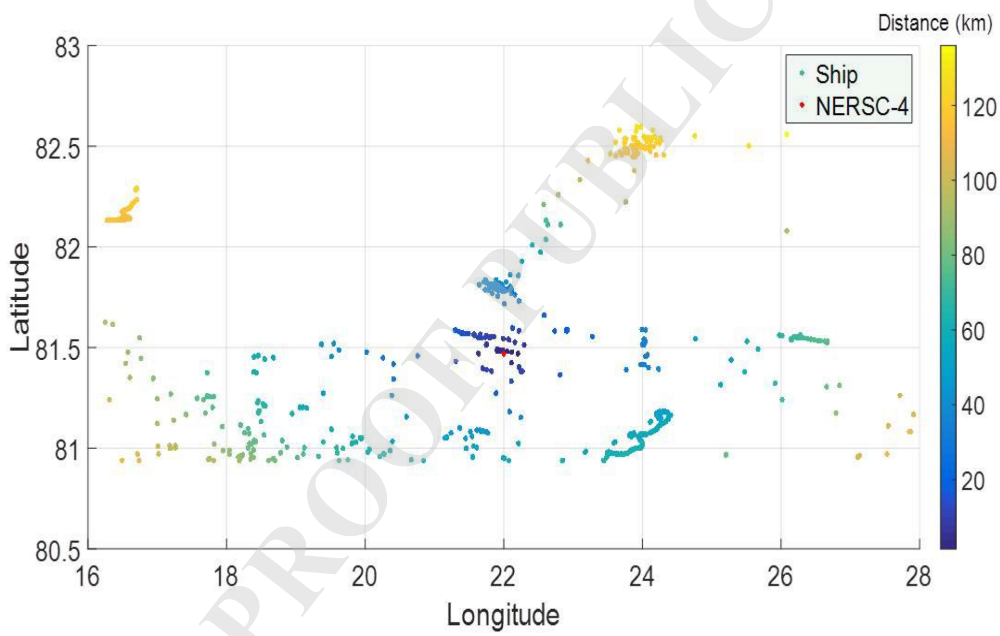

Fig. 3 shows the distance between each vessel and the NERSC-4 mooring of the Central Arctic Ocean from September 2019 to July 2020. The color bar indicates the distance in km.

3.2 Geophony

3.2.1 Ice cracking

The ice-cracking noise was observed in many records of Central Arctic Ocean data. The main mechanism of ice cracking depends on a combination of factors like wind, waves, icebergs, and the pressure exerted by sea ice. A number of factors, including the number and the kind of ice wedges being observed, the size of the area, and the duration of the observation, affect the frequency of ice cracking (Michael et al., 1994). The ice-cracking noise caused by thermal expansion contains a broad peak in its spectrum near 300-500 Hz (Milne, 1964; Milne, 1972; Pritchard, 1984; Farmer, 1989; Ganton, 1965).

From the analysis of acoustic data, it has been seen that the peak of the ice cracking noise was observed below 200 Hz in most of the data sets. Fig. 4(a) shows the three ice cracking events of 4th April, 5th April, and 8th April of 2020. The highest SPL of ice cracking noise was observed on 4th April 2020, which is around 116 dB re 1 $\mu Pa^2/Hz$. Fig. 4(b) shows the spectrogram of ice cracking noise of 4th April 2020. Out of these 11 months of data, it was observed that the months of September, November, February, March, April, and July were the months in which ice cracking sounds were detected. From the spectrogram it is clearly seen that the cracking events are very short duration events. The intensity of cracking events gradually decreases with increasing frequency. The details of ice-cracking noise are given in Fig. 4.

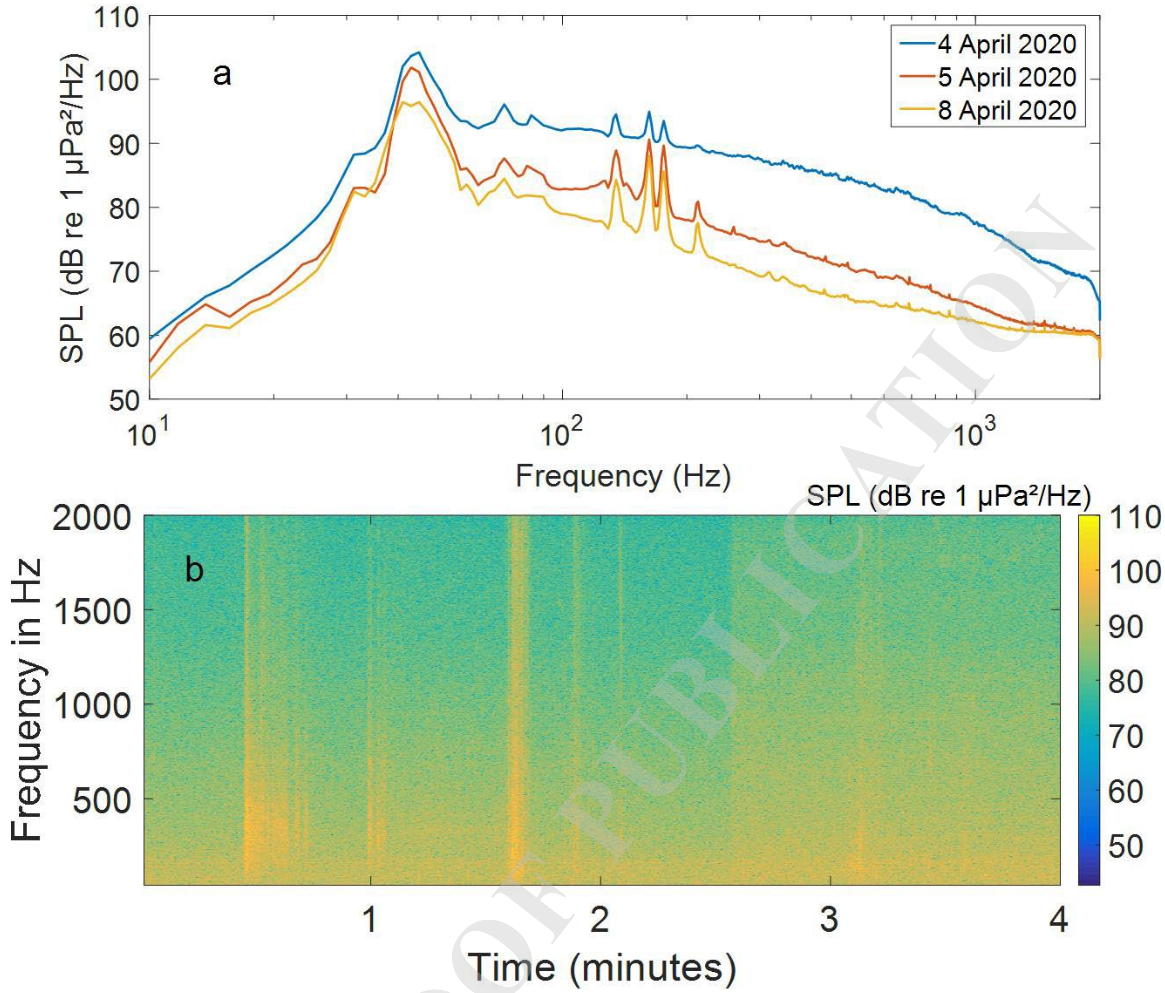

Fig.4.(a) The ice cracking noise spectra of 4th, 5th & 8th April 2020 and spectrogram (b) of ice cracking sound observed in the record on 4 April 2020 at 0000 UTC in Central Arctic Ocean respectively.

In the central Arctic, the sea ice concentration is almost constant throughout the year except in September. Here in Fig. 5. shows the seven-day average of sea ice concentration from Sep 2019 to July 2020. The minimum sea ice concentration has been observed in Sep 2019, whereas for all other months the sea ice concentration is almost constant. The details of the sea ice concentration is shown in Figure 5.

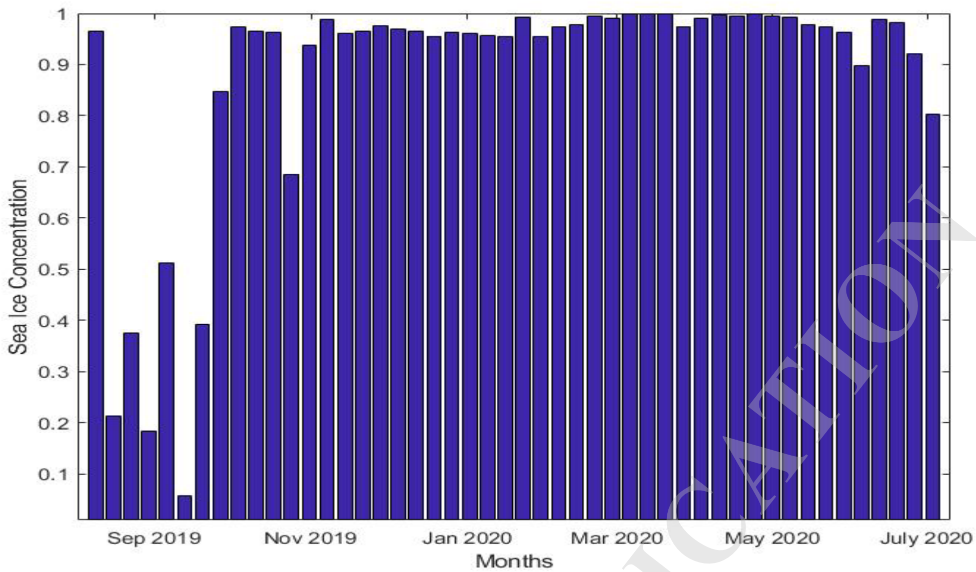

Fig.5. Seven days average of sea ice concentration data of the Central Arctic Ocean from September 2019 to July 2020.

3.3 BIOPHONY

Sea ice causes less trade and economic activity through the Arctic Ocean. There are various types of marine species that can be found in this region. From the spectrogram and audio file analysis of acoustics data of the Central Arctic Ocean, it has been seen that the bowhead whales, bearded seals and killer whales are most commonly seen in the study location of the Arctic Ocean.

3.3.1 Bearded Seal

The mooring is deployed at an approximate distance of 85-90 nm north from the mainland of Svalbard, i.e., Nordaustlandet, and approximately 65 nm from Nordkapp. The bearded seal vocalisation noise can be heard in the passive acoustic data. The bearded seal vocalisation noise was recorded between April and July 2020, although the data was gathered between September

2019 and July 2020. The bearded seal is the largest species of Arctic seal. Sea ice plays a crucial role in several activities, including reproduction and moulting (Burns 1970, 1981; Nelson et al. 1984; Moore and Huntington 2008). As the seasonal sea ice melts in the spring, many bearded seals migrate north, and as sea ice forms in the winter, they migrate south (Potelov 1969; Burns 1981; Simpkins et al. 2003; Frost et al. 2008). The bearded seal's mating period occurs from early April to mid-July. Cleator and Stirling (1990) found that vocalisations increase in duration as mating season approaches. For communication and feeding purposes, bearded seals use low-frequency sounds less than 1 kHz. Figure 6 (a and b) shows the details of the vocalisation of bearded seals.

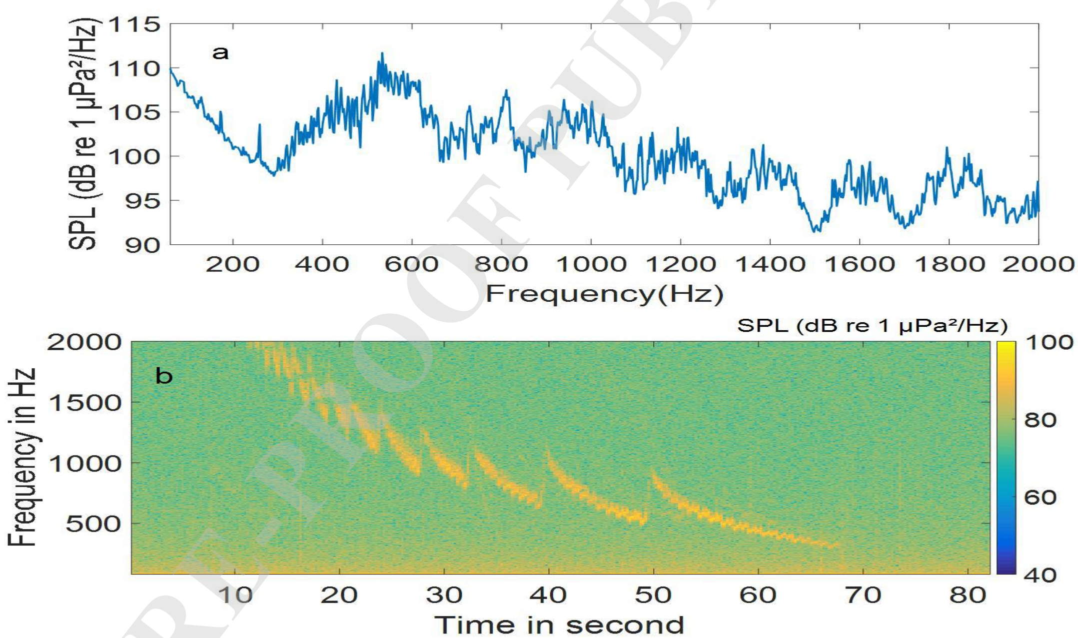

Fig.6. Vocalisation frequency spectrum (a) and spectrogram (b) of bearded seals respectively observed in the record on 16 May 2020 at 0000 UTC

The bearded seal vocalisation noise is more intense between the frequencies of 300 to 700 Hz, with a spectrum level of 110 dB re 1 μPa²/Hz. According to the acoustics data of the NERSC-4 mooring, bearded seals were most active during April and July 2020. There is an increase in the frequency of bearded seal vocalisations between the middle of April and the middle of July. There has been a presence of bearded seal vocalisation noise in almost every data set in these four months.

3.3.2 Bowhead Whale

Bowhead whales are mainly found in the Central Arctic Ocean throughout the year. The bowhead whales produce low frequency sounds when they communicate. Bowhead whales are highly vocal and produce different types of sounds that are simple calls, call sequences, and complex songs (Stafford *et al.* 2012; Ljungblad *et al.* 1982; Würsig & Clark, 1993). Simple calls are amplitude-modulated (AM) or frequency-modulated (FM), with the majority of their auditory energy observed below 500 Hz. Simple calls are observed throughout the year (Stafford *et al.* 2012). The call sequences are the repeated bouts of similar calls, normally in a bout of 3 to 25 calls (Ljungblad *et al.* 1982; Würsig & Clark, 1993; Stafford *et al.* 2008; Delarue *et al.* 2009). Songs are complex in nature. Songs are a combination of loud, raucous, and complex AM and FM, with a frequency 5 kHz (Stafford *et al.* 2012).

In this analysis, the simple calls are observed in most of the data sets. The simple calls are of two types: one is S-moans, and the other is V-moans. The S-moans patterns are mainly dominated by low frequency below, i.e., 600 Hz. The peak frequency of S–moans generated by bowhead whales is observed at 283 Hz with a SPL of 88 dB. V-moans patterns are dominated in the frequency range of 300 to 1230 Hz. The peak frequency of V–moans generated by bowhead whales is observed at 587 Hz with a SPL of 107 dB. The frequency spectrum and spectrogram of S-moans and V-moans are given below.

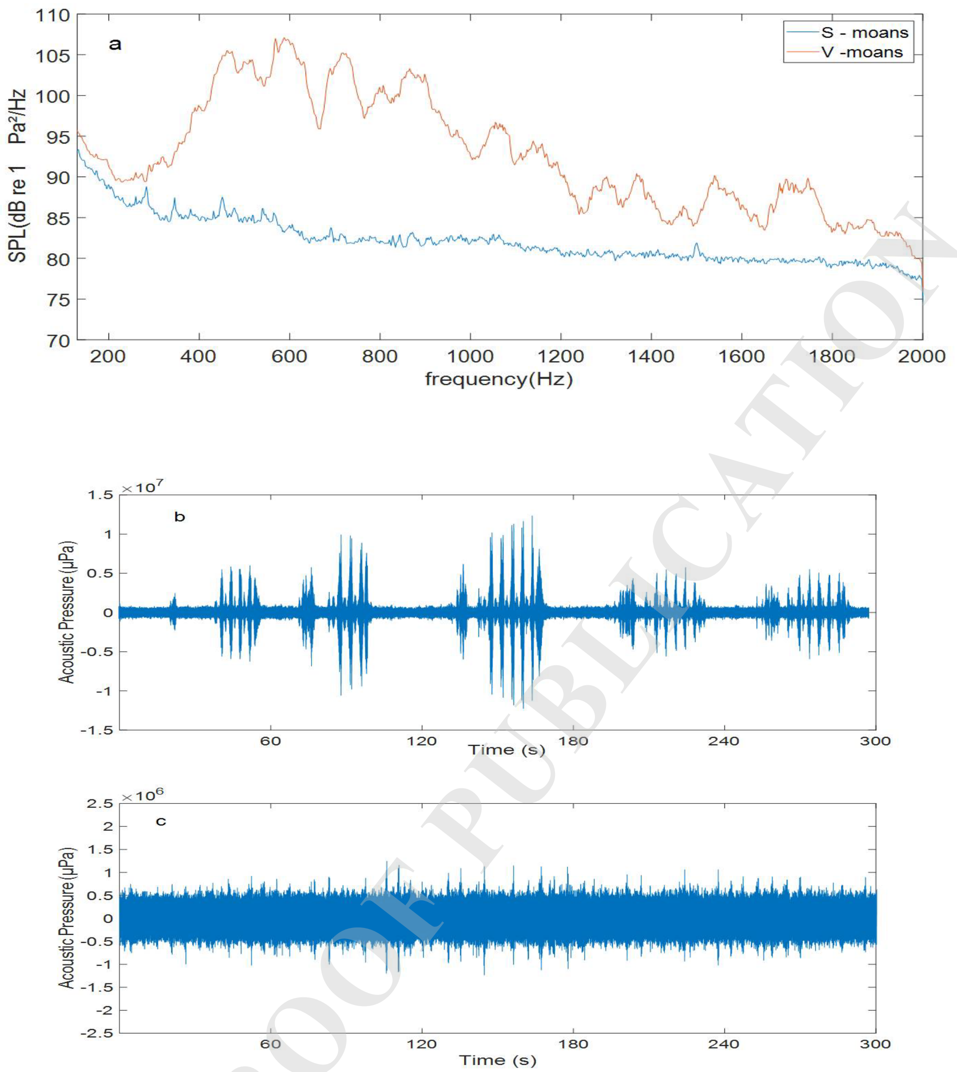

Fig. 7(a). Bowhead whale sound spectra of two different types S-moans, and V-moans. Each spectrum represents a mean of five individual calls for each call type. (b and c) are the time domain waveform of V-moans, and S-moans respectively observed in the record on 28 November 2019 at 1200 UTC and 13 April 2020 at 0000 UTC.

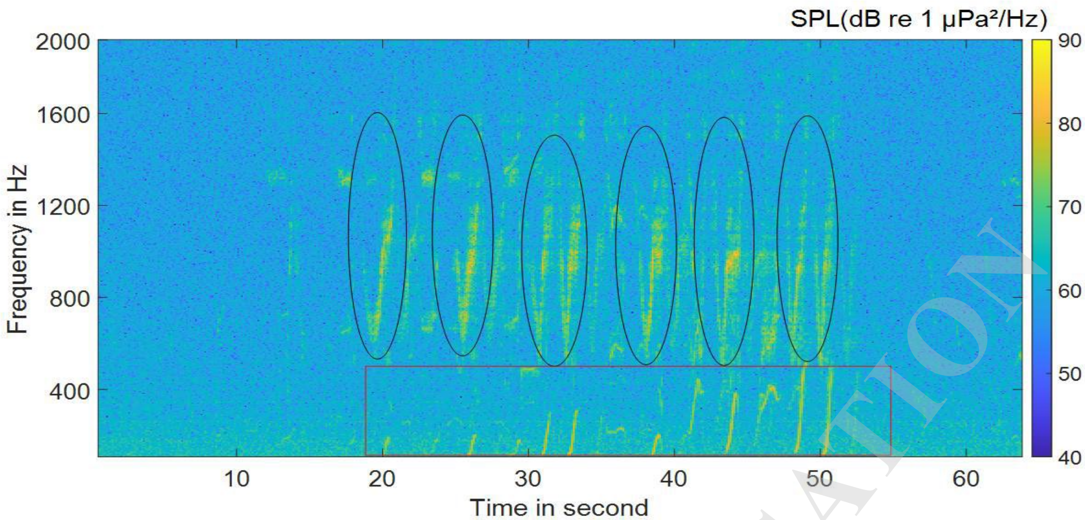

Fig. 8 Spectrogram of V–moans and S-moans sound patterns generated by bowhead whales observed in the record 11 April 2020 at 1200 UTC. The black circle shows the V–moans, and the red rectangle shows the S–moans sound patterns

3.3.3 Killer Whale, Orca

The killer whales are one of the top predators of open water. According to Inuit understanding, the arrival of killer whales in Arctic waters during the spring depends on sea ice conditions and happens only after the sea ice has cleared or started to break up (Higdon et al. 2014). It has been observed that killer whales in the Arctic are preying on other Arctic marine mammals, such as narwhals, beluga whales, and bowhead whales (Ferguson et al., 2010, 2012; Higdon et al., 2012; Breed et al., 2017). The Norwegian killer whales from the Barents Sea region move towards Novaya Zemlya Island, about 900 km from the Norwegian coast, approaching 77.0°N (Dietz, et al., 2020). A variety of distinct acoustic signatures were produced by killer whales. Sportelli et al., 2022) describe the 11 different noise patterns of killer whales, which are observed in the Canadian Arctic. There are some recent studies which represent the vocal patterns of killer whales (Selbmann et al., 2021). The pulsed calls of Norwegian killer whales were observed at frequencies ranging from 0.04 to 4.8 kHz and durations ranging from 0.11 to 2.2 seconds

(Strager, 1995). Similarly, the average fundamental frequency of Icelandic killer whale pulsed cries is between 0.16 and 3.28 kHz, and the average length is between 0.4 and 2.1 s (Moore et al., 1988).

From the analysis of Central Arctic Ocean data of the Nansen Basin, it has been observed that the killer whale pulse calls are observed between 160 Hz and 2 kHz. It has a peak at 208 Hz, having a Sound Pressure Level (SPL) of 108 dB re 1 μPa²/Hz. The details are shown in the figure 9 below.

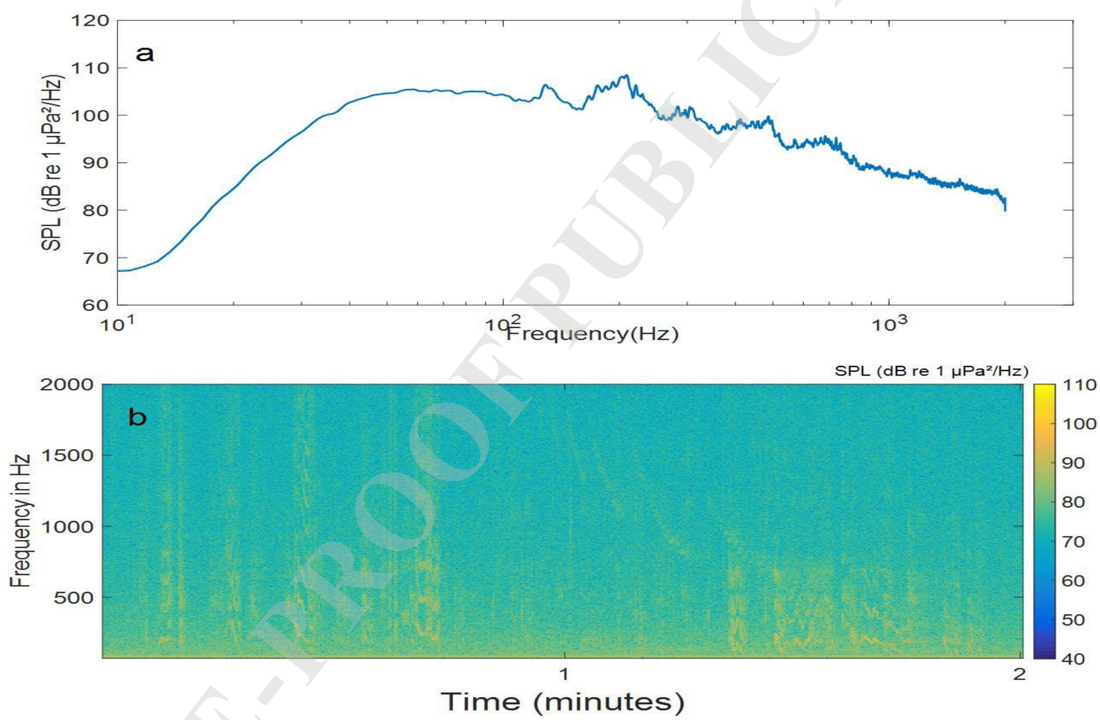

Fig. 9 (a and b). Frequency spectrum and spectrogram of killer whale pulse calls, respectively observed on 13 May 2020 at 1200 UTC.

From the spectrogram of killer whale pulse calls (Fig. 9(b)), we can clearly segregate the time duration of each call. As shown in Fig. 9(b), there are five pulse calls present in the first minute and four pulse calls present in the second minute. The average time duration of each call is between 3 sec to 6 sec. The study location data indicates that the occurrence of killer whales is predatory in nature and does not occur throughout the full observation period. Spring and summer are the seasons when killer whales are most likely to be observed. There are two data sets from the month of May, one data set from June and three data sets from September and October with killer whale signatures.

The presence of marine species like the killer whale, bowhead whales and the bearded seal near to the NERSC-4 mooring shows that the Arctic environment is undergoing ecological changes and is no longer the same. According to the recent study the killer whale, and bowhead whales shifted their presence from west of Spitsbergen to toward fjords and coastal areas (Bengtsson et. al., 2022). It has been documented that killer whales and bowhead whales were present around Svalbard, Norway, during 2005-2019 up to latitude 80.2°N (Bengtsson et. al., 2022). Historically, Arctic sea ice has been a natural barrier, restricting the movement and spread of killer whale migration (Higdon, and Ferguson, 2009). However, the ongoing loss of sea ice due to global climate change has given killer whales greater access to the ocean .The killer whale's presence at higher latitudes is a sign that sea ice levels are declining. (Stafford, 2019; Stafford, 2022; Kimber et. Al., 2025). There have been reports in the Greenland Sea, Baffin Bay, and Melville Bay regions showing bearded seal vocalisations during the months of January to July and Bowhead whale sounds were observed during winter and spring. (Ladegaard et al., 2021). The Pacific Arctic also has seen an increase in killer whale rake markings on bowhead whale flukes, similar to the eastern Canadian Arctic (George et al. 2017). Llobet et al., 2023 reported that bearded seals and bowhead whales were seen in the Kongsfjorden region and another eastern site, which is located in the northeastern part of the archipelago, 50 km south of Kvitøya. The NERSC-4 mooring data also shows that the killer whale, bowhead whales and the bearded seal are further approaching towards the CAO. The presence of these species clearly indicates that the Arctic environment is changing.

4. Variation in soundscape of Central Arctic Ocean

The acoustic data collected between September 2019 and July 2020 from the Central Arctic Ocean have been analysed. The soundscape of the central Arctic Ocean is influenced by all three types of sources, i.e., anthrophony, biophony and geophony. Anthropogenic sources such as shipping are major contributors to underwater noise. The biological noises are mostly from bowhead whales, bearded seals and killer whales. The geophysical sources, such as ice-cracking noise, are observed in the Nansen Basin of the central Arctic Ocean. Throughout the measurement period, bowhead whales have been observed mostly from September to the end of March. Bearded seals are most commonly observed between early April and mid-July (Fig. 10). September has the highest amount of shipping activities among these months, with a variety of vessel types, including patrol, cargo, and passenger ships. The most commonly observed type of vessel during the remaining months is the patrol vessel.

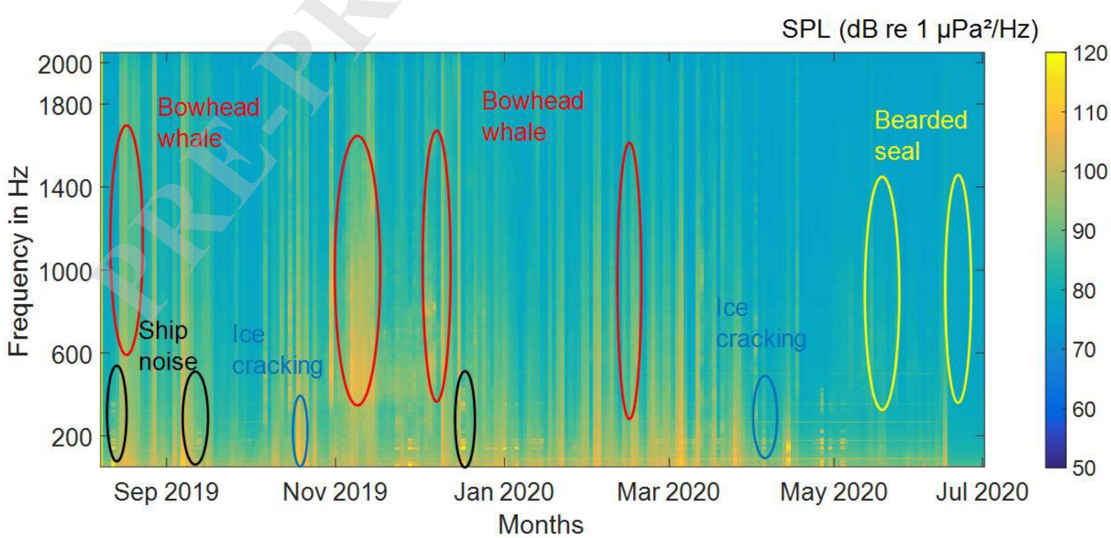

Fig. 10 Spectrogram of different types of sources present in the Nansen Basin of the central Arctic Ocean from Sep 2019 to July 2020. The color bar indicates the noise level in dB re 1 μPa²/Hz.

4.1 Monthly variation in soundscape of Central Arctic Ocean

After analysing the acoustic data on a monthly basis, it is observed that September 2019 and April 2020 have high average sound pressure levels as well as high standard deviations. A higher standard deviation indicates that the data has a wider variety of sources. Since the data were collected from the Central Arctic Ocean, the presence of marine species is obvious in most of the data sets. In September 2019, various types of noise sources were identified, including shipping activities, ice cracking, and marine species. So the standard deviation for September 2019 is higher (Fig. 11).

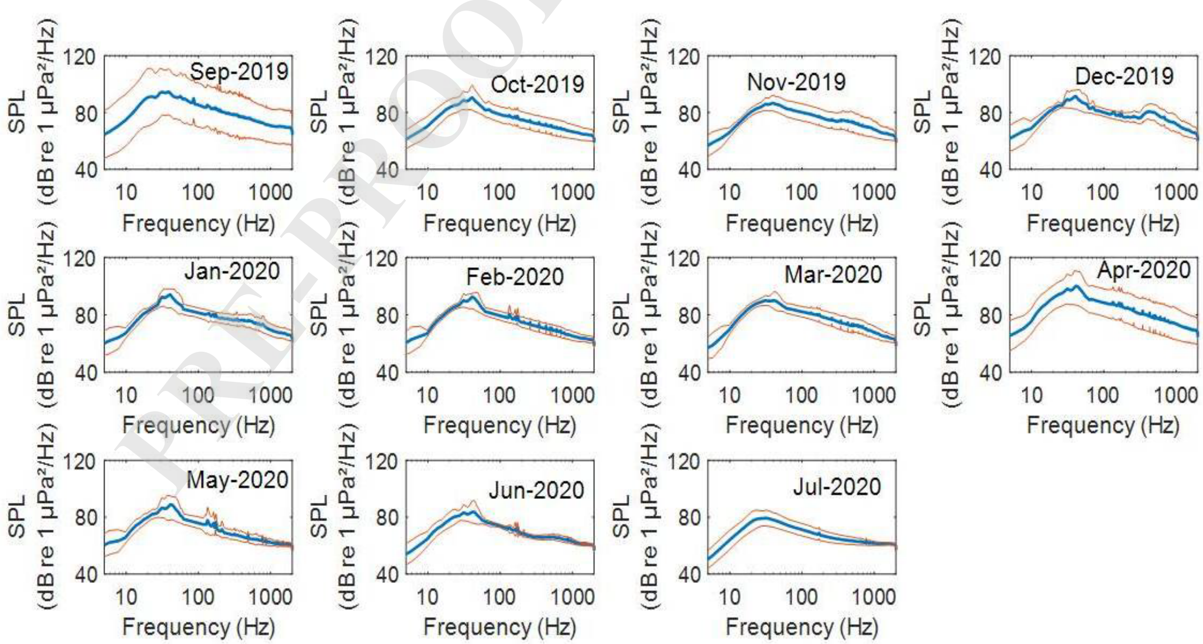

Fig.11. Spectrum level and the standard deviation of monthly data from September 2019 to July 2020.

There is also a higher standard deviation for April 2020 as well. There are more types of noise sources in the month of April, 2020, compared to the other months. Ice cracking and marine species sounds like bowhead whales and bearded seals were observed in April 2020. Almost all other months, except for September 2019 and April 2020, have a smaller standard deviation. These months are mainly dominated by marine species, which dominate the soundscape in the majority of the data. Therefore, it is possible to determine the surrounding ecological status by studying the soundscape.

4.2 The seasonal variability of the Central Arctic Ocean

In the Arctic region, there are mainly four seasons, i.e., winter (January–March), spring (April–June), summer (July–September), and autumn (October–December) (Yu and Zhong, 2021). The variation in sound pressure level is also investigated for all 4 seasons. To find out how the underwater acoustic environment differs depending on the season, the average Sound Pressure Level (SPL) was computed for each of the four seasons. The average SPL seasonal variation is shown in the Fig.12 below.

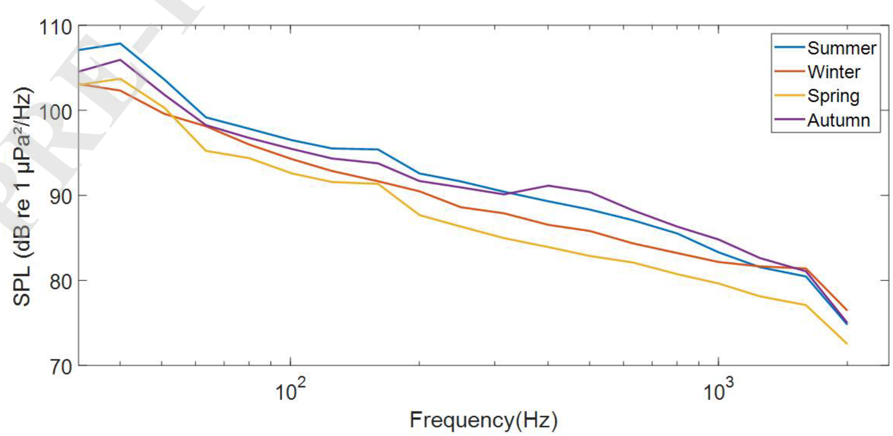

Fig. 12. Seasonal average of SPL with all noise sources of the Central Arctic Ocean. The seasonal average is calculated for winter (January–March), spring (April–June), summer (July–September), and autumn (October–December).

While considering the SPL variation, the maximum seasonal variability was observed during summer, and the minimum seasonal variability was observed during spring. The difference in seasonal variability in 1/3 octave band frequencies between summer and spring was 4.1 dB (re 1 μPa²/Hz). The sea ice concentration of CAO during summer (July–September), is less which supports the statement of sea ice decreases the underwater ambient noise level.

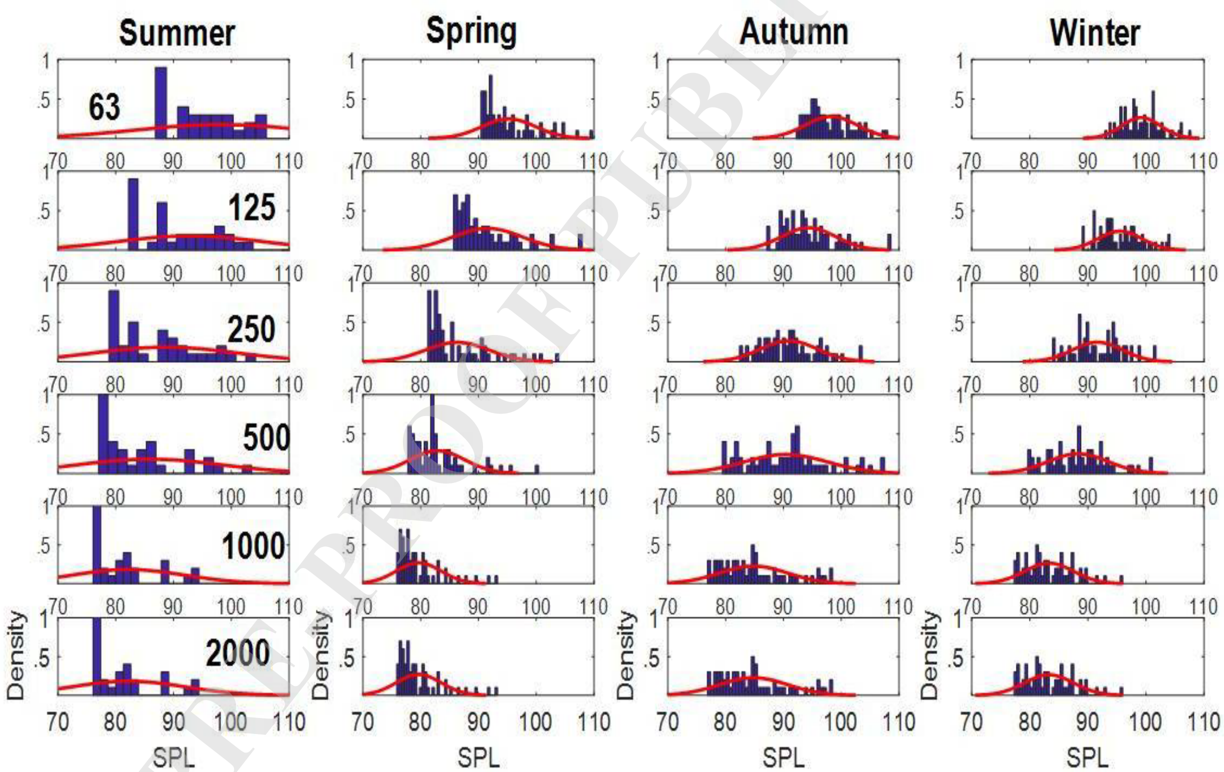

Figure 13. Empirical probability distribution for SPL of seasonal fluctuations (September 2019 to March 2020) from frequencies 63 Hz to 2 kHz at the 95% significance level.

The probability distribution function (PDF) is used to better understand seasonal variations. The PDF shows the distribution of noise in octave bands between 63 Hz and 2 kHz. According to the empirical probability distribution for the octave frequency band, a non-Gaussian distribution was fitted to the noise histograms at a level of significance of 95%, which indicates that the sound pressure levels (SPL) of each frequency were not symmetric for the majority of frequencies in all four seasons. The tail part contains information from sources such as shipping activities, marine species etc, as it moves toward a higher sound level. A PDF (Fig.13) of Seasonal variation clearly shows a gradual decline in sound pressure level with increased frequency. Low-frequency energy with significant seasonal variability dominates the soundscape.

5. CONCLUSIONS

The noise levels in the frequency band **< 2000** Hz have been analysed to study the soundscape of the Central Arctic Ocean. It is understood from the study of ambient noise data sets that the Central Arctic Ocean soundscape is influenced by distant shipping activities, ice cracking, and marine species such as bowhead whales, bearded seals and killer whales. It has been seen that the bearded seals are present during April to July. Bowhead whales are observed more frequently between September and April, but their presence is rare after April. The killer whales are observed between May and October. The killer whales presence to higher latitudes showing the decline in the sea ice content.

While considering the SPL variation, the maximum seasonal variability was observed during summer, and the minimum seasonal variability was observed during spring. The difference in seasonal variability between summer and spring was 4.1 dB (re 1 μPa²/Hz) in a 1/3 octave frequency band.

In conclusion, the analysis of SPL variation in the CAO indicates that reductions in anthropogenic activity when sea ice concentration is more and natural seasonal fluctuations are responsible for the observed changes. This result gives a primary understanding of the CAO habitat patterns as well as the variation in underwater noise levels. A more comprehensive understanding can be attained through extended monitoring and correlation with environmental and anthropogenic factors.

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