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THE MARINE SOUNDSCAPE OF KONGSFJORDEN, SVALBARD: TWO-YEAR STUDY ON SPECTRAL VARIABILITY AND ENVIRONMENTAL DRIVERS

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ABSTRACT

The accelerating effects of climate change and growing economic interests have significantly increased underwater noise in the Arctic, risking irreversible changes. To predict potential acoustic impacts, it is essential to comprehend the environmental, biological, and anthropogenic elements of the soundscape. This study investigates underwater noise levels and soundscape variations in Kongsfjorden (Svalbard archipelago) between September 2021 and July 2023, when an autonomous acoustic recorder was deployed on the Mooring Dirigibile Italia at 76 m depth, recording data on a 50% duty cycle. Measurements of noise levels, power spectral density, and sound pressure level were taken in one-third octave bands from 10 Hz to 10 kHz at varying time scales. Two primary frequency clusters were identified, outlining the noise levels' distribution and variability. The study revealed low levels of anthropogenic noise (<160 Hz), with environmental sources dominating the soundscape. Notable differences in noise levels were observed between the two years. Noise levels were thus correlated with possible environmental forcings, including meteorological and marine parameters, to evaluate their contributions to the soundscape. Our preliminary findings improve knowledge on the drivers and dynamics of underwater sound and lay the groundwork for long-term soundscape monitoring in Kongsfjorden.

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1. INTRODUCTION

The acoustic environment plays a critical role in marine habitats, exerting significant influence on ecosystem functionality. Within any given habitat, the marine soundscape is a complex combination of sounds originating from geophysical, biological, and anthropogenic sources. These elements interact to create distinctive acoustic patterns that fluctuate daily and seasonally [1]. Both biotic and abiotic factors shape the soundscape, contributing to the broader acoustic environment. Investigating the Arctic soundscape holds critical importance, as its variations provide indicators of dynamic processes and changes within the marine ecosystem, offering valuable insights into its health and sustainability [2]. Kongsfjorden, located within the Svalbard archipelago, is an open fjord influenced by a convergence of seawater from the Fram Strait and freshwater from glaciers. This unique interplay of environmental forces shapes its dynamic ecosystem [3]. The fjord serves as a key breeding habitat for ice-dependent marine pinnipeds such as walruses and bearded seals, which congregate in polynyas and on drifting ice throughout the seasons [4]. Nonetheless, the rapid retreat of Arctic sea ice, driven by global climate change, poses a serious threat to the region's marine ecology [5]. Furthermore, the growth of maritime activity endangers breeding grounds and may significantly alter the seasonal acoustic soundscape of Arctic fjords [6]. This study shows new insights from a passive acoustic monitoring (PAM) study conducted over two years (2021–2023) across various seasons to assess the acoustic environment of Kongsfjorden, Svalbard [7]. In

particular, this work aimed to enhance the understanding of spectral patterns observed in relation to environmental factors. To focus on this, the same month was compared over two different years, and noise levels were correlated to environmental variables including air temperature, wind speed, rain, water temperature and salinity, thereby providing novel insights into soundscape dynamics within the fjord's ecosystem.

2. METHODS

Acoustic and environmental data were collected at the MDI (Mooring Dirigibile Italia) site, located in the innermost part of Kongsfjorden, Svalbard. The mooring was first deployed in September 2010 at 103 m water depth, and it has been maintained annually since then [8,9]. Since 2021, an autonomous acoustic recorder model SYLENCE LP 440, equipped with a HTI-99_UHF omnidirectional hydrophone, was positioned at 76 m water depth on MDI. Acoustic data were collected with a duty cycle of 50% at a frequency rate of 64000 samples/sec. Recordings were saved in 30-min long, 16 bits, .WAV files. The data used in this study included a subsample from the datasets of two monitoring sessions: 2021-22 (Sept. to March) and 2022-23 (Sept. to July), hereafter Year 1 (Y1) and Year 2 (Y2), respectively. The Sound Pressure Level (SPL) was measured at 20 sec intervals over the 1/3 octave frequency bands from 16 Hz to 10 kHz (center frequencies), hereafter "FB". Median SPL values were averaged hourly and daily, to assess the potential occurrence of spectral trends at different temporal scales. The median SPLs were used to perform Long-Term Average Spectrograms (LTSA) and compare sound levels between the two years [10]. All analyses were performed in MATLAB (Mathworks v.2016b). To characterize temporal variations across a wide range of frequencies, a hierarchical cluster analysis revealed 2 main clusters [7]: a lower cluster, from 16 Hz to 125 Hz FBs, and a higher cluster, from 160 Hz to 10000 Hz FBs. In this work, we focused on the months of October across the two years, as the median SPL values during this month were significantly different in Year 1 compared to Year 2. Since no anthropogenic or biological sounds were detected that could account for the differences observed between the two years, we investigated the temporal variation of environmental components associated with meteorological disturbances and oceanographic variables. Hourly data of air temperature (°C) and wind speed (ms^{-1}) at 5 m, were obtained from the Italian scientific platform Amundsen-Nobile Climate Change Tower (CCT); daily precipitation amount (mm) from the Norwegian Meteorological Institute (https://www.met.no/en); hourly means of water temperature and salinity (S) were obtained from a CTD probe SeaCat-SBE37 deployed at 89.7 m on the mooring MDI. Correlations between the hourly median SPL values from the two months and each environmental parameter were ascertained by looking at the Spearman's rho correlation coefficient. ($p<0.01$).

3. RESULTS

In October 2021, the SPL values of the lower cluster FB (16 Hz to 125 Hz) were significatively and positively correlated to wind speed (WS) and water temperature (WT): noise levels below 160 Hz increased linearly with WS and WT. The higher cluster FB (160 Hz to 10000 Hz) was significantly correlated only to WT and with a negative trend, since noise levels at higher frequencies decreased at increasing WT.

In October 2022, both cluster FBs were positively correlated with WS, WT and salinity. Differently from October 2021, SPL increased even in the higher Cluster FBs with increasing WT. No significative correlation was found between SPL variation in the two cluster FBs, and air temperature or daily precipitation. Figure 1 shows the monthly variation of all data in October 2021 (Fig. 1 a – d) and in October 2022 (Fig. 1 e – h).

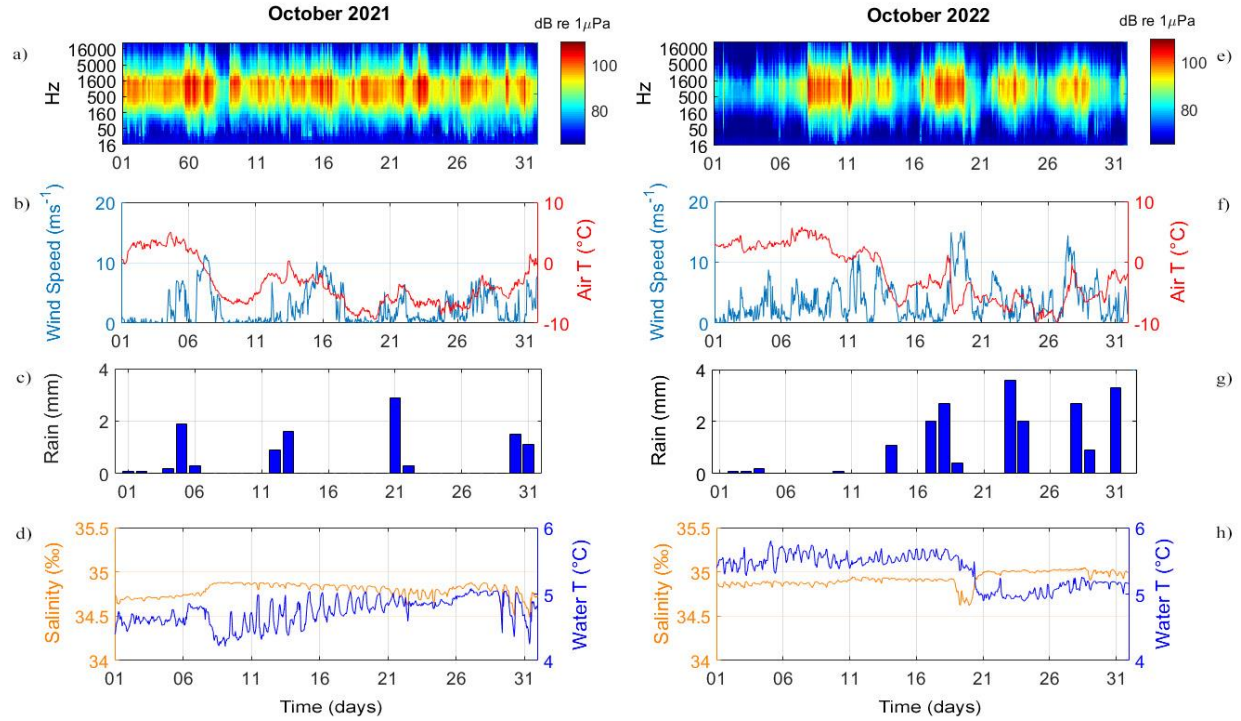

Figure 1. a) and e): Long-Term Spectral Average (LTSA) of the hourly median SPL values performed in the 1/3-octave frequency bands between 14,3 Hz and 11.225 Hz. b) and f): hourly measurements of wind speed (ms^{-1}) and air temperature (°C); c) and g): daily precipitation amount (mm); d) and h): hourly mean values of salinity (‰) and water temperature (°C) measured at 89 m depth on the same MDI mooring.

4. DISCUSSION

The results of this work improve our knowledge of the marine soundscape and ecosystem at a hot-spot location such as the Kongsfjorden. This is essential to reach a wider and more comprehensive understanding of the effects of climate change [11]. Median SPL noise levels, integrated over 1/3-octave frequency bands, along with their LTSA representations, were employed to analyze soundscape trends during the same month in two separate years. Applied methodologies such as the SPL metrics facilitate the comparison of the measurements between different locations [12]. Presented results of acoustic and environmental data analysis increase the understanding of marine soundscape dynamics. The analysis of SPL distributions across both years, as reported in [7], revealed significant differences between Y1 and Y2. Specifically, median SPL values were higher in October of Y1. Two distinct cluster frequency bands were identified, with results showing lower SPLs in the low-frequency cluster, indicative of minimal anthropogenic noise, especially from maritime vessels. Consequently, the observed trends may be attributed to environmental conditions, meteorological patterns, and ecological factors. Notably, no biological sounds were detected in October of Y1 or Y2 that could account for the substantial differences observed across the entire frequency range. In October of Y1, noise levels below 160 Hz showed a linear increase with wind speed and water temperature, while at higher frequencies, noise levels decreased as water temperature increased. In October of Y2, SPL levels rose in both cluster frequency bands with increasing wind speed, water temperature, and salinity. Furthermore, SPL variation in the two cluster frequency bands was not correlated with air temperature or daily precipitation in either of the years examined.

5. CONCLUSIONS

The most significant environmental changes between the months of the two years under consideration were observed in water temperature and salinity variations, as well as in the correlation between these variables and noise. While these factors cannot fully account for the observed noise level variations, they help refine the scope for future research. Subsequent studies will incorporate these and additional variables in a comprehensive multivariate statistical analysis. Among other aspects, variations in the sound field due to acoustic propagation will be explored, and the investigation will be expanded to encompass the entire dataset available.

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