Abstract: The Venice Lagoon and its major canals are an example of particularly high traffic of vessels from cargo and passenger ships to water busses (vaporetto) and fast recreational motorboats. In January and July 2018, we conducted underwater noise measurements in this area for three weeks in continous. We deployed near the island of Certosa in the San Nicolò channel at a depth of 4m a hydroacoustic buoy SM2M of the WildeLife Acoustics company, which recorded the ambient noise at the sampling frequency of 96 kHz. The maximum values of Averaged Noise Spectrum Level and Sound Pressure Level were in the frequency band between 500 Hz and 800 Hz corresponding to the underwater noise emitted by high-speed motor boats. For this frequency range, the average Sound Pressure Level was much higher than 110 dB re 1μPa². Recognition and quantification of noise events was carried out in the 1/3 octave frequency bands. In addition, wavelet analysis parameters of underwater noise were calculated as input data to the fuzzy logic clusters algorithm, which allowed for automatic detection of noise generated by ships and motor boats from underwater ambient noise.

Keywords: Anthropogenic underwater noise, Venice lagoon, nature conservation
1. INTRODUCTION

Underwater noise levels of anthropogenic origin have been increasing in the seas and oceans since the end of the World War II [1]. It has a very negative impact on the life of marine organisms, disturbing their functioning and, in extreme cases, can lead to their death. Noise pollution is particularly noticeable in sea straits, along shipping routes as well as in areas with heavy traffic.

This problem is discussed in a number of important international documents, such as the Marine Strategy Framework Directive (MSFD). Monitoring projects have been developed to implement the recommendations of Descriptor 11 of the MSFD of the European Union.

The Lagoon of Venice (Fig.1) is an example of an area with a particularly high intensity of shipping traffic and a specific, limited shape of the maritime area. The lagoon with an area of 550 km² is located in the north-western part of the Adriatic Sea. It is very shallow with an average depth of approximately 1 m, but the deepest areas are more than 30 m deep [2]. Only 5% of the lagoon is deeper than 5 m while shallower areas, less than 2 m deep, cover about 75% of the lagoon. The lagoon consists of a complex system of navigation channels, tidal channels, intertidal mudflats and intertidal salt marshes [3]. The depth of the navigation channels ranges from 2 to 20 m.

Due to its structure, location and strong urbanisation, the lagoon is particularly vulnerable to the risks posed by the enormous intensity of boat and ship traffic [4]. The transport in the lagoon and the city of Venice is carried out by waterways, hence a large number of motor boats, water taxis, water busses (vaporettos) and speedboats travel along the navigational channels. In addition, cargo ships, ferries and cruise liners navigate the main channels. At the same time, Venice and its lagoon are a UNESCO World Cultural and Natural Heritage Site and requires particular efforts be protected from hazards.

Fig.1: Map of the St. Nicola channel of the Venice Lagoon with localisation of hydroacoustic recorder deployment. Sources: Esri, DigitalGlobe, GeoEye, EarthStar Geographics, CNES/ Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.
2. DATA ACQUISITION AND SIGNAL PROCESSING

In 2018, we conducted a series of underwater noise measurements near the island of Certosa in the St. Nicola channel of the Venice Lagoon, placing a hydroacoustic buoy SM2M of the WildeLife Acoustics company at a depth of 4m (Fig.1). The hydrophone sensitivity was -165 dB re 1V/μPa and sampling rate of 96 kHz. Registration was conducted continuously in the periods from 19th to 30th of January and from 18th of July to 8th of August 2018.

Moreover, on January 21st, 2018, a HTI-96-Min hydrophone was immersed on the south east part of the Marina Santelena that lies on the island of Santa Elena opposite to the buoy deployment place. Underwater noise was recorded for one hour, synchronized with the video recording of passing vessels and motor boats to combine acoustic signatures with boat types that do not have the Automatic Identification System.

The Automatic Identification System (AIS) of vessel traffic information was used instead to identify bigger vessels traffic. However, it should be noted that most of the small motor boats and water trams operating in the lagoon are not equipped with AIS and could not be identified in this way.

The density of movement of vessels in the Venetian channels is very high, as evidenced by the exemplary and typical recording of underwater noise from the hydrophone submerged near Santa Elena place. During nine and a half minute registration, 6 vessels were observed, including 2 water busses, 1 motor boat, 1 speed boat and 2 water taxis (Fig.2.b)

![Fig.2: a) Example of 9 minutes and 30 seconds continuous underwater ambient noise registration at 21th of January 2018 at S. Elena location, b) Motor boat categories recorded during the measurement.](image)

Figure 2.a) shows the changes in sound pressure at the recording location. Vessels sailed at different distances from the hydrophone and with different speeds, hence, similar vessels made noise at different sound pressure levels. Because of the high speed of some boats and their small distance to the acoustic logger, as well as the geometry of sound propagation, the level of hydroacoustic pressure was very high, reaching 30 Pa. Spectrograms of underwater noise were also calculated, showing that the underwater noise frequencies emitted by all boats observed in Figure 2 reached 48kHz. Recorded underwater sounds were filtered in 1/3 octave
in subsequent bands from 5 Hz to 40 kHz centre frequencies and sound pressure levels have been calculated for these bands.

For data collected in the San Nicolò channel, the following procedure of underwater noise classification and boats detection is proposed: for each registered 10 second signal portion sampled with 96 kHz, the 8 wavelet transformation parameters were computed. The continuous wavelet transformation of 10 second signal portions computed for the 7-channel dyadic decomposition (scale $a=2^j$, $j=1,...,7$) and 3rd-order Coiflet wavelet is the base for determination of wavelet energies:

$$E_{j,\text{Coif3}} = \int_0^{b_{\text{max}}} C^2(a,b)db,$$

where $C(a,b)$ are the wavelet transformation coefficients, $b_{\text{min}}$ and $b_{\text{max}}$ are boundary values of scale $b$ (time). The additional wavelet transform parameter is the wavelet entropy $h_{\text{Coif3}}$ defined as [5]:

$$h_{\text{Coif3}} = \sum_{j=1}^{7} E_{j,\text{Coif3}} \cdot \ln E_{j,\text{Coif3}},$$

The above defined parameters formed 8-element vectors for each 10 second long part of the recorded signal. The vectors were the input to fuzzy c-means (FCM) segmentation procedure, which indicates main types of underwater noise registration as sounds coming from vessels, breaking surface waves and other underwater noise sources.

3. RESULTS

The averaged spectra of underwater noise recorded during measurements in the St. Nicola channel in winter and summer 2018 are shown in Figure 3. In the frequency range from 3 Hz to 48 kHz we observe differences in Noise Spectrum Levels between the two seasons.

![Underwater Noise Spectra](image)

*Fig.3: Underwater noise spectra recorded in winter and summer 2018 in the frequency range up to 48kHz.*
For most of the analysed frequencies the level of underwater noise is much higher in summer than in winter. In the frequency range from about 18 kHz to about 25 kHz, jumps in the summer spectrum are visible, which can be caused by organisms living in the lagoon. Much more detailed picture of the spectra is shown in Figure 4, where the data from Figure 3 are shown for the range limited to 2 kHz. In this case we observe a high level of spectra for frequencies up to 200 Hz related to ship traffic. On the other hand, the higher spectral levels for the frequency range from 500 Hz to 800 Hz are demonstrably related to motor boats and water trams traffic.

Figure 4: Underwater noise spectra recorded in winter and summer 2018 in the frequency range up to 2 kHz.

Figure 5 shows averaged Sound Pressure Levels recorded in winter and summer 2018 in the 1/3 octave bands. The SPL measured in summer achieves a level exceeding 110 dB for the frequency range from a few Hz to approximately 125 Hz and excides 115 dB for 20 Hz to 80 Hz range. This is typical for the underwater noise generated by ships in motion. Also, for the frequency range around 800 Hz, the SPL exceeds 110 dB for both seasons.

Figure 5: Sound Pressure Levels recorded in winter and summer 2018 in the 1/3 octave bands.
The noise classification result for the 24-hour noise record of January 20, 2018 is shown in Figure 6, which illustrates the spatial distribution of the values of wavelet energy $E_{5,\text{coif3}}$ and wavelet entropy $h_{\text{coif3}}$ with marked clusters corresponding to the noise generated by motor boats and ships. Each point in the graph shows a 10-second fragment of the noise signal, which was subject to wavelet analysis.

![Figure 6](image)

*Fig. 6: The spatial distribution of the values of wavelet energy $E_{5,\text{coif3}}$ and wavelet entropy $h_{\text{coif3}}$ with marked clusters corresponding to the noise generated by motor boats – red dots, ships – green dots and other ambient noise – blue dots.*

4. CONCLUSIONS

The preliminary results of underwater noise measurements in the Venice Lagoon channel indicate a large contribution to the anthropogenic noise field of motor boats often operating at high speed. A particularly high level of SPL was observed in the summer when boat traffic increases, noise exceeded 115 dB for frequency band of 500 Hz to 2000 Hz – high speed motor boats and from a 20 Hz to 80 Hz – ships. The underwater noise classification algorithm based on waveform transformation parameters as an input to the FCM procedure was also tested. The algorithm separated the noises coming from their main sources in the investigated channel.

The results presented here are preliminary to more extensive underwater noise research in the Venice lagoon, the knowledge of which is necessary for the proper protection of the environment against the acoustic pollution.

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REFERENCES


