Using semantic trajectories for spatio-temporal characterisation of underwater noise

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Abstract

Underwater noise pollution from human activities, particularly shipping, has been recognised as a serious threat to marine life. The sound generated by vessels can have various adverse effects on fish and aquatic ecosystems in general. In this setting, the estimation and analysis of the underwater noise produced by vessels is an important challenge for the preservation of the marine environment. In this paper, we propose a model for the spatio-temporal characterisation of the underwater noise generated by the fishing vessels in the Northern Adriatic Sea. The approach is based on the reconstruction of the vessels' trajectories from AIS data. Trajectories are enriched with semantic information like the acoustic characteristics of the vessels' engines or the activity performed by the vessels. This is then used to infer how noise propagates in the area of interest. The conceptual framework has been implemented using MobilityDB, an open source geospatial trajectory data management and analysis platform. We present some preliminary analyses obtained by applying the developed tool.

Keywords

Semantic trajectories, underwater noise, fisheries, spatio-temporal databases

1. Introduction

The Northern Adriatic Sea area is one of the most exploited areas of the Mediterranean Sea and the underwater noise pollution is certainly among the effects of the intensive fishery activity. Underwater noise produced by vessels has a significant short and long term impact on animal species. Among the adverse effects we can mention communication interference, behavioural changes, stranding and mortality [1, 2]. For this reason, the creation of underwater noise maps is of paramount importance to monitor the quality of aquatic life, assess potential risks and inform ecologists and policymakers, so that they can develop effective plans to ensure a productive and healthy ecosystem.

However, determining underwater noise maps is a complex and resource-intensive process. Gathering data about underwater noise requires the use of hydrophones (underwater microphones), which, in turn, requires a team of experts to be deployed and tuned. Once collected, data need to be processed and analysed to extract meaningful information. Computer simulation may be used to predict and estimate noise levels in areas where data collection is infeasible, or to cover a wider area than the one monitored by hydrophones. Complex models of sound propagation, taking into account the different kinds of seabed floor as well as environmental variables such as temperature, salinity, waves height, etc., allow the simulation to be very accurate. Still, covering a wide area, such that the one of the Northern Adriatic sea, is challenging and, in any case, the estimated noise values are not guaranteed to be correct.

In this paper we focus on the noise generated by fishing vessels and we propose an approach to provide a characterisation of underwater noise produced by such vessels. Instead of using hydrophones at physical listening points our proposal is based on a reconstruction of vessels' trajectories which, enriched with semantic information like the acoustic characteristics of the vessels' engine and the activities performed by the vessel along the trajectory, are used to deduce how the noise generated by the vessels spreads in the area of interest. We build on our previous work [3, 4] which describes and implements a spatio-temporal database of the fishing activities in the Northern Adriatic Sea. The trajectories of the fishing vessels are reconstructed starting from the terrestrial Automatic Identification System (AIS) data, sent by ships and received by ground stations on the Italian coast. The original database, spanning the years 2015-2018, is here extended to include also years 2019-2021. In order to determine the acoustic characteristics of the vessels' engines and fine tune the propagation model, we also take advantage of the direct acoustic measurements produced by the Interreg project SOUNDSCAPE [5] that carried out an acoustic monitoring in the North Adriatic Sea from March 2020 to June 2021.

We propose a model of underwater sound propagation and use it to infer the fishing vessels' noise in the

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Northern Adriatic Sea. Specifically, we associate each fishing vessel with its estimated Sound Pressure Level (SPL), computing the intensity of the produced underwater noise. Then, we use the spatio-temporal database of the fishing vessels' trajectories to evaluate the underwater noise generated along the trajectories themselves. We partition the Northern Adriatic Sea into a regular grid, each cell having a size of 1km×1km, to collect the noise intensities in space and time. Instead of using physical listening points (hydrophones) we consider the centroid of each cell as a *virtual* listening point where we calculate the perceived sound pressure level.

The proposal has been implemented in MobilityDB [6], an open source geospatial trajectory data management and analysis platform. This is used to perform some preliminary analyses. Specifically, we present the maps of the average and peaks of the underwater noise in January and April 2020. This choice permits to discuss the effects of the COVID-19 pandemic on the underwater noise pollution due to the fishing activities. In fact, in January 2020 there were regular fishing activities while in April 2020, during the lockdown period, the activities were greatly reduced.

The paper is organised as follows. Section 2 briefly presents the literature on underwater noise. Section 3 describes our model for the underwater sound propagation. Section 4 outlines the construction of the fishing vessels trajectories and the computation of the underwater noise. It also includes some preliminary analyses performed on January and April 2020, before and during the COVID-19 pandemic. Some closing remarks are in Section 5.

2. Related works

Underwater noise arising from human activities is known to have a number of adverse effects on aquatic life. These can range from acute effects such as permanent or temporary hearing impairment to chronic effects such as developmental deficiencies and physiological stress [1, 2]. In [7] the authors try to summarise the status regarding continuous underwater radiated noise from shipping in European waters to provide recommendations on possible future activities. The work is focused on four main topics: characteristics and quantification of noise sources from various ship types, impacts on marine fauna, existing policies, including guidelines, decisions, resolutions and regulations and mitigation measures for the abatement of ship noise and noise-related impact.

The work in [8] analyses the noise generated by fishing boats. In particular, authors find out that the noise emitted by fishing boats is influenced by the characteristics of the engine type they are equipped with. Moreover, they observe that noise intensity at a specific frequency can be detected at a certain distance with a decreasing pattern: the higher the frequency, the faster the disappearance of the intensity along with increasing distance.

Paper [9] presents a real-time low-cost Passive Acoustics Monitoring (PAM) system tailored to assess anthropogenic noise in marine environments. The system, which performs a real-time detection of the underwater noise, is an outcome of project CORMA (*COntrollo Rumore MArino*)[1].

In [10] the authors use an external database (available from the Canadian Guard Coast) containing the ships transits derived from AIS data and apply a sound propagation model to derive the cumulative large-scale noise map of the area of interest. The approach is similar to the one proposed in our paper. However, in [10] the focus is just on readily obtaining the noise map images thanks to data coming from an external database. In contrast, we aim at proposing a general framework for underwater noise characterisation, including the creation of a spatio-temporal database, that can be used to answer any question about underwater noise. For instance, a user may request to visualise the noise produced by a single vessel along its trajectory, considering also the increase of noise while fishing, or to show noise maps for a chosen area and time period, or to produce videos illustrating the underwater noise dynamics in timelapse.

Differently, the aim of [11] is to carry out a multi-site validation of a large-scale shipping noise map constructed using a generic shipping noise model. More recently, the Interreg project *SOUNDSCAPE* [5] carried out an acoustic monitoring of the Northern Adriatic sea and, in [12], the authors describe the spatial and temporal variations of the ambient sound pressure levels recorded over one year.

Summing up, many of the presented works use measures obtained via hydrophones to reconstruct underwater sound. We propose a complementary approach based on AIS data and on the construction of semantic trajectories. We use the information on the engine power the fishing vessels are equipped with to determine the source noise levels generated by the vessels and then exploit their trajectories to deduce how such noise propagates. Having semantic information allows us to distinguish between different behaviours of the fishing vessels, in particular when they are fishing, an activity which increases the generated noise.

3. Underwater noise model

In this section we describe a model for underwater sound propagation which is used in Section 4 to provide a spatio-temporal characterisation of underwater noise in the Northern Adriatic Sea. We present the theoretical laws governing the underwater sound propagation and we also describe how we obtain the estimation for source sound

[1]http://www.corma.info/

levels, propagation loss and ambient noise, necessary for the definition of the model.

The estimation is based on real measurements. We use the dataset delivered by the project SOUNDSCAPE, which carried out an acoustic monitoring in the North Adriatic Sea from March 2020 to June 2021. Nine monitoring stations were set up encompassing different environmental characteristics. Two datasets have been realised composed of 20 and 60 seconds averaged Sound Pressure Levels (SPLs) data in a wide range of frequencies recorded at the nine stations. These datasets are available on Zenodo (https://doi.org/10.5281/zenodo.7472152) and some analyses are in [12]. Noise levels can vary based on the frequency at which they are measured. The *European Marine Strategy Framework Directive* (MSFD) adopts 63 Hz and 125 Hz frequencies as standard. In this paper, we focus on the 63 Hz frequency for assessing vessel noise and the dataset containing the 20 seconds SPL in such a frequency. The 125 Hz frequency could be chosen as well without any structural change to the model.

3.1. Sound propagation model

The basic objective of noise modelling is to assess how much noise a particular activity will generate in the surrounding area [13]: the aim is to model the received noise level (RL) at a given point (or points), based on the sound source level (SL) of the noise source, and the amount of sound energy which is lost as the sound wave propagates from the source to the receiver (transmission loss or propagation loss, TL). The relation between these quantities is encapsulated in the classic sonar equation [14]:

$$RL = SL - TL \tag{1}$$

This straightforward expression is fundamental to modelling underwater noise, and its simplicity belies considerable complexity in the task of computing the transmission loss in order to estimate the received noise.

Sound propagation is profoundly affected by some factors such as the conditions of the surface and bottom boundaries of the sea as well as by the variation of sound speed within the ocean volume [15]. Air has a density 800 times lower than the density of water, therefore a sound that propagates inside the water has a higher propagation speed, equal to about 1500 m/s, against about 340 m/s of air. So, with a sampling period of 20 seconds it makes sense to neglect propagation time within the circle of influence and, within the sampling interval, consider the noise level distribution as stationary. When a boat switches the engine on, we consider the noise as instantaneously propagated in the area of influence within the sampling period, without actually propagating the wavefront in space-time.

Sound propagation speed is also influenced by various chemical-physical factors such as temperature, salinity and pressure [16], varying both during the day and with the seasons in the superficial part [17], and with depth.

The computation of the transmission loss considering all these parameters is not a simple task and for this reason various models have been introduced. Before discussing the transmission loss, however, we focus on how to evaluate the source level, that is, in our case, the noise generated by the fishing vessels.

3.2. Source level estimation

The principal sources of underwater noise are machinery, propellers, and cavitation. Our AIS dataset includes some data of the fishing boats, such as the length overall (LOA) of the boat, the horsepower of the engine and also the fishing gear used. However, the dataset does not include direct measurements of the sound pressure levels of the fishing vessels. So, we need to infer such values considering the general literature about underwater noise and the measurements provided by the SOUNDSCAPE project.

A first issue is how to evaluate the increase of noise when a trawler is in action. Measurements with research vessels have 10dB of additional noise when trawling, regardless of speed, which can be much lower with trawl [18]. We adopt the same increase in our model.

To recover the sound pressure level of a specific fishing vessel, we consider a clean set of measurements coming from the SOUNDSCAPE project. In particular, we use the measurements of a hydrophone located at $13^{\circ}15.720E$ $44^{\circ}46.953N$, in the middle of Adriatic Sea, with 42m-depth, terrigenous sandy seafloor, taken on March 31, 2021 between 17:40 and 17:55. Here, there is a unique fishing vessel crossing nearby the hydrophone. Thus, the recorded noise is associated to the trip 1001 of MMSI 24705198 (length=27.45m, engine power=835Hp), while trawling at about 3.9knots between 500m and 60m from the hydrophone. This allows us, by linear regression on SPL measurements, to assign a vessel of 835Hp engine an estimated source level of 143dB when not trawling.

Finally, in order to associate the source levels to all the other vessels, we need to relate the sound pressure level to the engine horsepower, the latter being available in our dataset. If we assume that a constant fraction of engine power gets converted into acoustic power (i.e. acoustic power scales linearly with horsepower), this means that 3dB are added per doubling in engine power. We adopt such a linear progression on logarithmic scale of engine power. For example, for engines between 100Hp and 835Hp we obtain a range between 134dB and 143dB.

3.3. Transmission loss

In the simplest scenario, transmission loss is modelled by a spherical spreading law, of the following form, where r is the distance from the noise source in meters [13].

$$TL = 20 \times log_{10}(r) \quad (2)$$

If we consider again the measurements for trip 1001 described in the previous section, a simple linear regression on $\log_2(r)$ gives, with multiple R-squared equal to 0.77, the estimated slope of -6.15dB, which is close to the theoretical -6dB per doubling of distance of spherical spreading [19] (inverse square law). In practice, given a reference reliable measurement in realistic condition, we can justify the adoption of simple spherical propagation.

Simple geometric spreading does not take into account the environmental characteristics that are needed for a more accurate estimation of transmission loss. Therefore, it can only be used in uncomplicated propagation scenarios, or at frequencies that are barely affected by environmental features. In more realistic models, what we want to consider are all the environmental aspects that influence the sound propagation underwater, by adding a term proportional to distance from the source [19]:

$$TL_{tot} = TL + \alpha \times r \quad (3)$$

In the literature there are several models for predicting the absorption of sound in sea water which retain the essential dependence on temperature, pressure, salinity, acidity and other environmental features. In the Francois and Garrison model [20] the general equation for the absorption of sound in sea water, at a given frequency f, is given as the sum of contributions from boric acid, magnesium sulfate, and pure water. At a frequency below 100Hz only the first contribution is relevant, although α is approximately of the order of $10^{-6} dB/m$ [19].

3.4. Ambient noise

The received noise level (RL) at a given point is computed starting from Equation 1. However, the formula does not consider the ambient (or background) noise, which is present in the marine environment. In fact, when the noise generated by a source is the same as that of the background, this noise is no longer distinguishable and, consequently, it is no longer perceived. The formula for calculating RL then becomes the following:

$$RL = SL - TL_{tot} - AN \quad (4)$$

where SL is the sound source level, TL_{tot} the transmission loss and AN the ambient noise.

We use the SOUNDSCAPE measurements [12, 21] also to estimate the ambient noise. Being the frequency-dependent noise levels very different at the nine different stations, for a general ambient noise of the Northern Adriatic Sea, we decided to consider the overall median noise level value at 63Hz, our reference frequency, which is 85dB according to their measurements (see Fig.2 in [12]).

3.5. Summing different received noise levels

At a measurement point that is equally distant from two equally-powerful sound sources, the two contributions would add up in magnitude and phase. However, distinct and independent sources, such as two boats, can be treated as incoherent sources. Even in a narrow frequency band, there will be a random phase difference between the two sources. Therefore, the noise in a 1/3 octave band around 63Hz (or in any other band) gets increased by 3dB if there are two equal contributions, by 6dB if there are four equal contribution, etc. [22]. More precisely, what does add are the intensities, after inversion of the logarithmic function that defines the decibel. Generally and precisely, if we have n sources reaching a cell with n different values of RL, the total noise level is:

$$RL_{total} = 10 \times log_{10}(10^{RL_1/10} + \ldots + 10^{RL_n/10}) \quad (5)$$

4. Model implementation and preliminary results

We develop a framework for the spatio-temporal characterisation of underwater noise. We partition the Northern Adriatic Sea into a regular grid composed of square spatial cells (1km$\times$1km) and we estimate the noise generated by the fishing vessels in any cell at regular time intervals (every 20 seconds).

First, as described in Section 4.1, starting from the AIS data, we create a set of semantic trajectories representing the behaviour of the fishing vessels. For this task, we build on our previous work [3, 4]. Then in Section 4.2 we proceed with the description of the algorithm computing the map of the underwater noise. Finally, in Section 4.3 we delve into the analyses and results, along with the presentation of underwater noise maps generated through our sound propagation model.

4.1. Creation and enrichment of the trajectories of fishing vessels

The first step consists in reconstructing the trajectories of the fishing vessels starting from terrestrial Automatic Identification System (AIS) data, i.e., the AIS data sent by ships and received by ground stations on the Italian coast of Northern Adriatic Sea. AIS data contains the identifier of the vessel, called MMSI, its position and the time instant of the bearing, together with other information, like speed and course. Since boat positions are recorded every 10-20 seconds, that correspond to a small spatial displacement of the boat, trajectories are reconstructed by linear interpolation of the AIS data. Next, in order to organise the data into distinct trajectories followed by the fishing vessels, also called trips, the continuous movement of a vessel is split according to several criteria (see [4] for more details).

A reconstructed trajectory consists of a sequence of segments obtained by connecting consecutive AIS points. The next step is to enrich such trajectories with different kinds of semantic information, called *aspects*, following the MASTER model [23]. The model distinguishes among *long-term* aspects, (associated with the full trajectory), *volatile* aspects (associated with the segments) and *permanent* aspects (associated with the fishing vessel, derived from the MMSI). A *long-term* aspect is the length and the duration of the trajectory whereas a *permanent* aspect, defined for this specific work, is the sound level associated with the engine horsepower of the vessel. This aspect is computed as specified in Section 3.2, and it is denoted by $mmsi.hpSL$. A crucial *volatile* aspect is the *activity* carried out by the fishing vessel. We consider the following activities: *in port*, *entering to* and *exiting from* the port, *navigation* and *fishing*. The *in port*, *entering to* port and *exiting from* port situations can be deduced from the position of the extremes of the segment w.r.t. the port area. If none of the previous cases applies, the *fishing* or *navigation* activities are established on the basis of the average speed of the boat. This aspect is of fundamental importance for the underwater sound propagation model, because when a boat is fishing it produces a much more intense sound. Given a spatio-temporal point $p = ((x, y), t)$ belonging to a segment s ($(x, y) \in s$) in a certain time interval I ($t \in I$), we set *p.fishing* to 1 if the activity associated to the segment s during I is *fishing*, and to 0 otherwise.

4.2. Construction of the noise map

In this section we describe the procedure for assigning a noise level induced by the fishing vessels to the cells of a regular grid, partitioning the Northern Adriatic Sea, every 20 seconds. We define $\mathbb{G} = \mathbb{S} \times \mathbb{T}$ as a set of spatio-temporal cells, where $\mathbb{S}$ is a regular grid consisting of 1km$\times$1km spatial cells, and $\mathbb{T}$ is a set of time instants, such that t_0 is a fixed time instant and $t_{i+1} = t_i + 20$. Hence each spatio-temporal cell $c \in \mathbb{G}$ consists of two components, (g_s, t), representing the spatial cell g_s at time instant t, and it has three annotations: (i) α stores the absorption of sound as defined in Section 3.3; (ii) *ctd* contains the coordinates of the centroid of g_s; (iii) *rl* records the total noise perceived in *c*, i.e., by the centroid of g_s at time instant t.

Let $\mathcal{TR}$ be the set of the trajectories of the fishing vessels, $\mathbb{G}$ be the spatio-temporal grid, and AN be the ambient noise for the Northern Adriatic Sea, equal to 85dB, as reported in Section 3.4. Algorithm 1 computes the total received noise level for every cell $c \in \mathbb{G}$. We use $p{\downarrow}1$ to denote the projection on the first component of the spatio-temporal point p, i.e., its coordinates, and d(z_1, z_2) for the Euclidean distance between two spatial points z_1 and z_2.

Algorithm 1 Given $\mathcal{TR}$, $\mathbb{T}$, $\mathbb{G}$ and AN, the algorithm computes the total received noise level for each $c \in \mathbb{G}$

```
1:  Let mp: map⟨cell, float⟩
2:  for each tr ∈ 𝒯ℛ do
3:      for each t ∈ 𝕋 do
4:          p = (tr(t), t)
5:          SL = tr.mmsi.hpSL + 10 · p.fishing
6:          r = 10^((SL−AN)/20)
7:          for each c = (g_s, t) ∈ 𝔾.  d(c.ctd, p↓1) < r do
8:              dist = d(c.ctd, p↓1)
9:              RL = SL − 20 · log_10(dist) − c.α · dist − AN
10:             mp[c] = mp[c] + 10^(RL/10)
11: for each c ∈ 𝔾 do
12:     c.rl = 10 · log_10(mp[c])
```

The noise is estimated every 20 seconds, i.e., in the time instants belonging to $\mathbb{T}$. The centroids of the grid cells are considered as listening points (we have $43,386$ of these points), and consequently the noise *perceived* by a centroid models the noise in all the points of the cell at a certain time instant.

In order to build the noise maps, we get the positions of all the fishing vessels at the same time instants, i.e. every 20 seconds. We use these points to calculate the noise generated by the fishing vessels (line 5) obtained by adding to the sound level associated with the boat (*mmsi.hpSL*) the noise due to the fishing activity (10dB as explained in Section 3.2) if it occurs in p. In line 6, the sound propagation radius r (expressed in meters), i.e. the distance at which the noise generated by the fishing vessel is no longer perceptible, is computed. This is obtained by using Equation 4 and setting the received noise (RL) to 0:

$$0 = SL - TL_{tot} - AN$$

In computing the radius we ignore the coefficient of absorption α in Equation 3 for TL_{tot} and with some simple mathematical steps we get $r = 10^{(SL-AN)/20}$. Note that since α is very small (on the order of $10^{-7}dB/m$) ignoring its contribution simplifies the calculation while producing a negligible approximation. Also observe that in this way we overestimate r hence the approximation is safe. Then, we propagate the noise in the cells that are within the radius r (lines 7-10), summing up the received noise levels. Finally, by using Equation 5, we combine all the received sound levels to obtain the total noise level to be associated with the cell.

Concerning the complexity, let $n = |\mathcal{TR}|$, $m = |\mathbb{T}|$, $k = |\mathbb{G}|$, a be the area of a grid cell and r the largest radius arising in line 7. Then the complexity is $O(n \cdot m \cdot r^2/a + k)$. The factor r^2/a is motivated by the fact

Table 1
No. of vessels, AIS data and trips for January and April 2020.

Period	Vessels	AIS data	Trips
January 2020	620	12, 415, 463	6, 761
April 2020	472	6, 305, 277	2, 381

that in line 7 we consider the cells in a neighbourhood of radius r. Note that r depends on the source level, which is bounded by the maximum engine power of the monitored fishing vessels (in our case $r \leq 3,548m$).

In order to process all this data and build our model, we used a machine that features 32 Intel(R) Xeon(R) CPU E5-4610 v2 processors running at 2.30GHz, offering multithread performance. It is equipped with 256GB of DDR4 ECC RAM and it utilises a 500GB RAID 5 storage configuration. We evaluated the time for constructing the model assuming a daily data processing and considering 7 days in January 2020. With an average of $400,499$ AIS data and $1,050,651$ timestamps ($|\mathbb{T}|$) per day, the construction of the model requires about 34 minutes.

4.3. Preliminary analyses and results

For the implementation, we used *MobilityDB* [6], a moving object database that extends the type system of PostgreSQL and PostGIS with abstract data types supporting temporal types and spatio-temporal operators to manage moving objects. The offered constructs perfectly suite the representation of trajectories, which can be reconstructed from a sequence of spatio-temporal data, and allow for semantic enrichment of trajectories. Moreover, it offers spatial and temporal indexes to improve the efficiency of the general procedure described in Algorithm 1.

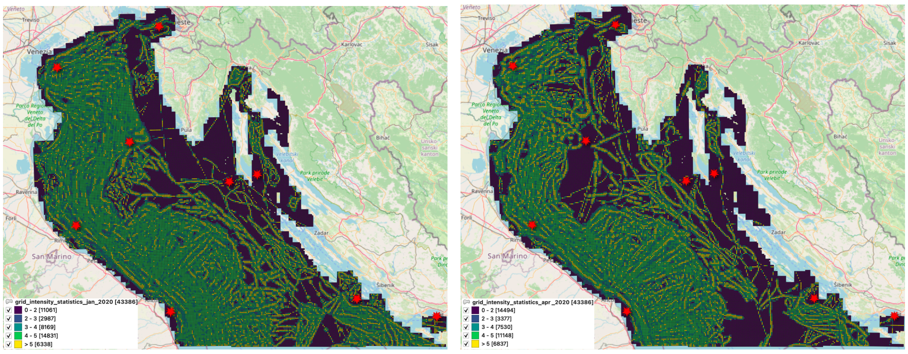
We next present some analyses performed by using our spatio-temporal characterization of the underwater noise. For our experiments we focus on two months, January and April 2020, with the aim of investigating the effect of the COVID-19 pandemic outbreak on underwater sound pressure levels due to the fishing activities in the Northern Adriatic Sea. January 2020 represents a pre-COVID-19 period with normal fishing activities while April 2020 is a month where several containment measures were adopted. In particular in Italy a lockdown was imposed from March 9, 2020 until May 18, 2020. Table 1 reports the number of vessels, AIS data and trips in these months. The first remark is that there is a clear drop in the number of boats during the pandemic period, leading to a dramatic reduction in AIS data and trips.

We generated two different maps to compare the underwater sound in these two periods. Figure 1 reports the average underwater noise value estimated in each cell for January and April. The average value for a cell is calculated by summing up the underwater noise computed every 20 seconds in the cell and dividing it by the number of values. Instead, Figure 2 reports the peak maps for each month: each cell is characterised by the maximum noise detected in that cell (the peak of the month in the cell). It is worth recalling that Equation 4 is employed for computing the received sound level in each cell. Thus, the sound depicted in the maps represents the noise exceeding the ambient noise *perceived* by each cell centroid.

Figure 1 shows that in April 2020 some zones in the central and in the central-southeast area are totally not explored compared to January 2020. In particular, there are more cells with a medium-low underwater sound (0-3dB on average) in April (3823 more). This perfectly reflects the reduction of boats and trips during the COVID-19 pandemic period. Instead, in April, there is a slight increase in cells characterised by a high average underwater sound value (>4dB), 499 additional cells with respect to January, located mainly near the coasts. This phenomenon could be explained by the fact that, during COVID-19, vessels reduced the navigation time, preferably staying near the coast, thus limiting the fuel consumption and the related costs. A consequence of this behaviour is the increase of the average sound level in coast areas which have seen a larger concentration of vessels.

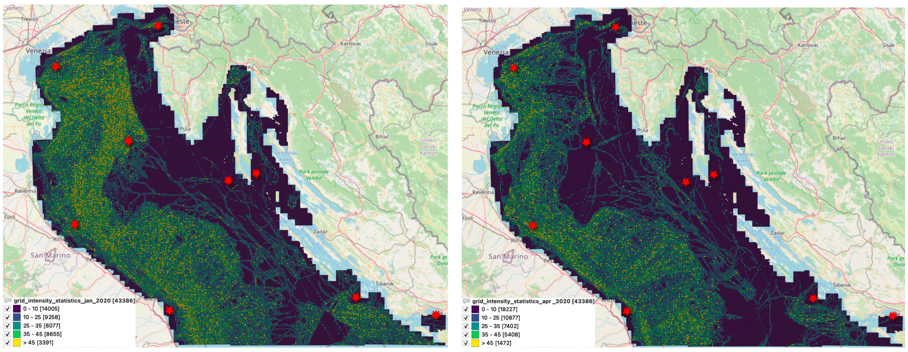
These phenomena are even more evident in the map of the noise peaks in Figure 2. In fact, we can observe that in April the number of cells characterised by high peaks is smaller than in January. In particular, the number of cells with peaks above 35dB in January exceeds that in April by 5166 and even in this case in April the areas with larger peaks are near the coast.

Finally, our implementation provides also the possibility of visualizing the spreading of underwater noise in time for a set of vessels. By using *QGIS TimeManager*, it is possible to generate animations which, for a selection of vessels, visualise the noise propagation determined by these vessels moving in the Northern Adriatic Sea. The user can choose the boats according to several criteria, such as the range of horsepower, the MMSI, the length overall, or the activity, and the time window of the analysis. In Figure 3 we can observe a different sound propagation depending on the engine power of the vessel and its activity. We focus on four vessels: A has engine power 959.4Hp (SL $146dB$), vessel B 246.4Hp and D 335Hp (having the same SL $140dB$) and vessel C 679.6Hp (SL $143dB$). Vessels A and B are navigating but not fishing (red dot) and, as expected, the sound propagation is limited and it is greater for vessel A which has a greater engine power. Vessels C and D are fishing (light blue dot): this increases the noise level and thus the propagation radius. It is worth noticing the difference between B and D having the same SL but D is fishing, and between A and C, with A having a greater engine power and C fishing. These comparisons highlight how



(a) January. (b) April.

Figure 1: Underwater noise average maps for January and April 2020. The red stars are the hydrophones of SOUNDSCAPE.



(a) January. (b) April.

Figure 2: Underwater noise peak maps for January and April 2020. The red stars are the hydrophones of SOUNDSCAPE.

a fishing vessel generates more substantial underwater noise than a boat merely sailing, even when the latter has higher horsepower.

5. Concluding remarks

In this work we proposed an approach for the characterisation of underwater noise in the Northern Adriatic Sea, based on the reconstruction of the fishing vessels' trajectories and on the propagation of their noise along the trajectories. The approach has many advantages. Since we reconstruct trajectories starting from AIS data, we can readily obtain noise maps at different time granularities, e.g., on a daily basis, or monthly (as shown in the paper) or seasonally. The framework can be used in absence of hydrophones, which can be expensive to install and maintain and cover a limited area. Besides, it allows for distinguishing contributions to the underwater noise from different ship types, not only fishing vessels but also tankers or cruise ships, provided that the AIS data are available. The noise propagation model used in our implementation, although very simple and calibrated on a single measured trajectory, is sufficient to demonstrate the advantages of semantic trajectories for a first and prompt characterisation of underwater noise. More complex calculations, relaxing some of the assumptions and exploiting the available geographic as well as boat-related information, may actually be introduced for a more accurate characterisation at different frequencies, without altering the algorithmic and information structure.

A drawback of our approach is that the boats without an AIS transceiver cannot be modelled. It is therefore not possible to estimate their contribution to the total noise, which, as a consequence, could be underestimated. This means that areas of the sea showing high values of underwater noise are surely risky for the underwater world, whereas areas that result to be quiet could hide some untracked noise.

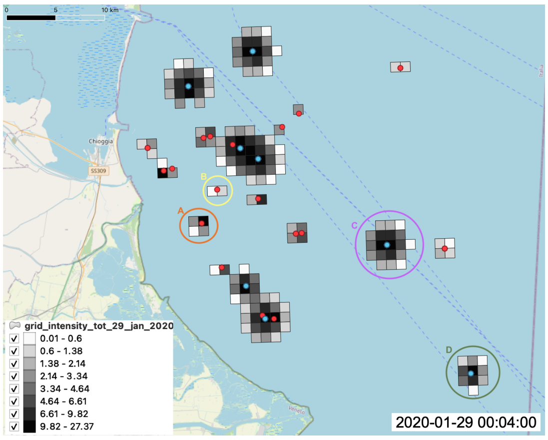


Figure 3: Propagation of underwater noise of fishing vessels in the Northern Adriatic Sea on January 29 2020 at 00:04. Vessels with a light blue dot are fishing, with a red dot are not fishing.

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