Assessment of the Distribution of Maritime Traffic and Anthropogenic Underwater Noise in Pelagos Sanctuary

Short Technical Report in support to STC16

Document identification	
Document reference	QO.20231012.01.RAP.01A
Contractor	Permanent Secretariat of the Pelagos Agreement
Customer	Permanent Secretariat of the Pelagos Agreement
Contract reference	Consultancy Service 2, Contract No. 2023-07
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PROJECT	DOC	CHRONO	VER	IND	CUSTOMER	ACRO	DATE	TYPE	CLASS
QO.20231012.01	RAP	001	01	A	Pelagos Secretariat	PEL	24.03.2024	PROD	DR

Quiet oceans

Ocean Noise Forecasting Monitoring & Mitigation

Document history							
Ver	Ind.	Responsible	Date	Verification	Validation	Date	Description
01	A	T. Folegot	22.03.2024	D. Clorennec	T. Folegot	22.03.2024	Initial version

Citation

Folegot, T. (2024), Assessment of the Distribution of Maritime Traffic and Anthropogenic Underwater Noise in Pelagos Sanctuary, Short Technical Report in support to STC16 , report number QO.20231012.01.RAP.001.01A, Quiet-Oceans, Brest, France.

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Definition of terms used in this report

Underwater acoustics is a scientific field of fluid mechanics. It uses its own vocabulary and its own units. A definition of the main terms used is presented in this glossary in order to facilitate the understanding of the document by the reader.

AIS

The Automated Identification System is a system on board ships that transmits their identification and location in near real time to an observation network. Various reception stations, set up by State services or private companies, thus make it possible to monitor maritime traffic in almost real time. Maximum coverage can reach 30 nautical miles from the coast depending on weather conditions.

Decibel

The decibel (dB) is a measure of sound pressure level, a quantity that is the basis of the perception of sound volume. It is a logarithmic scale that describes a multiple of a reference value. When the sound power doubles, the decibel value increases by 3 dB. In underwater acoustics, the reference level in decibels is 1 µPa (micro-Pascal).

Sound frequency

Frequency is the number of oscillations of sound pressure in one second. Bass sounds have a low frequency, treble sounds have a high frequency. The unit of frequency is Hertz (Hz). As an illustration, the human ear perceives only frequencies between 20 Hz and 20 kHz, although the upper limit generally decreases with age. Underwater species have a different auditory spectrum.

Source level

Sound pressure or energy level emitted by a source one meter away, described as a function of frequency.

Decidecade

A decidecade is a logarithmic unit of frequency ratio equal to one tenth of a decade (ISO 18405, 2017). The International Electrotechnical Commission (IEC, 1996) and the American Standard Institute (ANSI 2004) defines the center frequencies and the characteristics of the filters used to distinguish them.

Percentile or quantile

A percentile is the proportion of time and space for which noise exceeds a given level. In the case of this study, an N percentile therefore gives the minimum sound pressure level that would be measured with a probability of N% in the geographical area and the period of time considered.

This notion is very widespread, even in everyday life. As an example, the health records of each individual present curves of the distribution of the weight of the infant population as a function of age in percentiles: for example, we can see there, for each age, "the average weight of the last child. Percentile", that is to say the average weight of the 10% of the heaviest children, or the average weight of the 5% of the lightest children. The 50th percentile represents the median weight, i.e. the weight of 50% of children of the same age.

Sound speed

Celerity describes the speed at which sound waves travel in the marine environment, around an average value of 1500 m/s. It is a function of depth, temperature and salinity. Its variability is temporal (depending on the seasons, meteorological events, etc.) and spatial.

Chapter I. Introduction

I.1. International context

It is globally recognized that man-made underwater noise from shipping significantly modifies the natural soundscape in such way that **disturbance** and **masking** are likely to generate mid- and long-term effects on the marine biodiversity (Southall et al., 2019) (Tougaard et al., 2019) (Tougaard et al., 2021). Indeed, the International Marine Organization (IMO) has issued and approved in 2014 their "Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life" (IMO, 2014). Since then, a continuous collaborative work, led by Canada, including international workshops, has been performed to further clarify, improve and detail what steps would be likely to support a global reduction of this noise pollution (IMO, 2023).

At the European level the introduction of sound energy as one of the threats to the marine environment is identified to require a wide cooperative action and regulation. This is a driver for the Marine Strategy Framework Directive (MSFD), adopted by the European Union in July 2008 (Parlement Européen et Conseil de l'Union Européenne, 2008). The main goal of the Marine Directive is to achieve a Good Environmental Status (GES) of EU marine waters by 2020. With regards to underwater sound, Descriptor 11 of the MSFD states that GES is achieved when the introduction of energy, including sound, is at levels that do not adversely affect the marine environment. To implement this, EU Member States have to established a baseline of the current level and any trend of ambient noise in their national waters, and adopt management measures to contain or reduce the sound levels where needed (Sigray et al., 2023).

I.2. Pelagos sanctuary regional context

The Pelagos sanctuary, and the North-West Mediterranean as a whole, combine a high abundance of cetaceans, including the fin whale and the sperm whale, Bottlenose dolphins and Cuvier's beaked whales, and a very high intensity of maritime traffic. With the expected doubling of maritime traffic every 15 to 20 years, the noise in the Pelagos Sanctuary is likely to chronically increase if no measure is taken. The richness of the area in cetaceans and the impact of maritime traffic on these populations are identified in numerous conservation initiatives: the North-West Mediterranean has been identified as an area of ecological and biological interest under the Convention on Biological Diversity (CBD) and a Particularly Sensitive Sea Area (PSSA) by the International Marine Organization.

The Permanent Secretariat of the Pelagos Sanctuary and the regional Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS) both recognize underwater noise as a major threat for marine wildlife and the conservation of endangered species such as several species of cetaceans in the Sanctuary.

I.3. Scope of work

The Permanent Secretariat of the Pelagos Sanctuary has given the mandate to Quiet-Oceans to assess the distribution of maritime traffic and anthropogenic underwater noise in the Pelagos Sanctuary (Figure 1). The objectives of the project are:

- to provide an initial evaluation on the distribution and seasonality of maritime traffic
- to provide an initial evaluation on the distribution and seasonality of underwater noise
- to support the Secretariat and the coordinators of relevant WGs to draw a simple but structured plan for further improved analysis and approaches

In order of reach the objectives, the work is organized in 3 parts:

- The production of seasonal status maps of commercial and recreational maritime traffic based on Automated Identification System (AIS),
- The production of anthropogenic underwater noise statistical maps,

- A maritime traffic and noise risk assessment, taking into account "co-occurrence" and "species vulnerability".

This report describes the tools and methodology that will be applied in this project and provide a few preliminary results for illustration:

- OceanPlanner© platform will be used to provide the analysis of shipping for 2019 and 2023, to combine the sound maps with ecological data produced by consultancy service 1, and to host all data and maps produced during the consultancy service,
- Quonops© Online Services platform will be used to produce the statistical quarterly sound maps for 2019 and 2023.

Figure 1 : Area of the Pelagos Sanctuary

Chapter II. Analysis of shipping with OceanPlanner©

II.1. About the OceanPlanner Platform

OceanPlanner© (Folegot and Baudin, 2023) is designed to address the needs of governmental agencies, maritime authorities, marine protected area and Natura2000 managers, and harbor masters. The tool provides tangible assessment on the current status and on the key characteristics of the shipping. It also provides a ranking in terms of risk by extracting from the Automated information System (AIS) data that address the following two questions:

- which are the maritime activities that carries to high risk in terms of effect on the marine biodiversity,
- what are the places where regulation actions must be carried out in priority to inform the national and regional roadmaps relating to the preservation of the marine environment.

II.2. Characterization of shipping at regional level in the Pelagos Sanctuary

The assessment provided by the platform are in forms of maps that can be visualized on the graphical interface, and detailed reports that can be downloaded directly from the interface. The assessment is made globally and separately for groups of activities along 10 categories of vessels: Passenger, Roll-on Roll-off, Container ship, Cargo, Tankers, Cruise, Pleasure, Working Vessel, Fishing, and other vessels.

There are three key parameters relevant for getting the full understanding of the underwater noise issue related to shipping at regional level:

- the number of vessels sailing in the Pelagos Sanctuary, since each vessel is a source of noise,
- the travelled distance, since the more a vessel is navigating in the Pelagos Sanctuary, the more noise is introduced into the marine environment,
- the speeds at which the vessels are sailing, since a general rule establishes that the faster a vessel, the noisiest.

II.3. Analysis in the Pelagos Sanctuary for two seasons in 2019 and 2023

II.3.1. Structure of shipping in the Pelagos Sanctuary

The AIS data providers are Spire for the 2019 dataset, and CLS for the 2023 dataset. It is important to note that the change of provider and the rapidly evolving of the AIS network may introduce bias in the comparison between the two years. This may be particularly true for pleasure vessels, since the AIS device equipment rate is likely to increase rapidly as AIS transponder becomes more and more accessible and are perceived even by the general public as a safety equipment. This may also apply for fishing vessels to a lesser extend.

The spatial distribution of the maritime traffic in the Pelagos Sanctuary is shown Figure 2 for June 2023. The passengers and Roll-on Roll-off show very structured routes, mainly connecting at high speeds the harbours of the main lands of France, Monaco and Italy to the Toscana islands, Corsica and Sardinia (Figure 2, centre). The pleasure activity spreads all over the sanctuary at lower speeds without clear pattern (Figure 2, left). Finally, the commercial routes taken by cargo, container ships and tankers connect at medium speeds the major commercial harbors of the main lands of France and Italy within the Sanctuary together, and with destinations outside the Sanctuary.

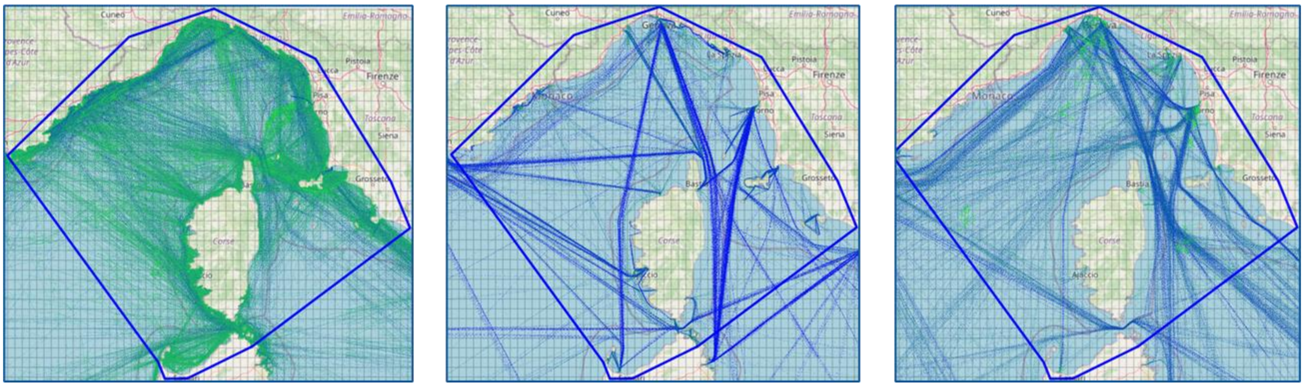


Figure 2: Maps of shipping in the Pelagos Sanctuary in June 2023 (raw AIS data). Left to the right: *Pleasure vessels, Passengers + Ro-Ro vessels, Cargo + tanker + container vessels.* The colors indicate speed from the lowest (green being below 10 knots) to the faster (dark blue being above 20 knots).

II.3.2. Behaviour of shipping in the Pelagos Sanctuary

The following tables and figures demonstrate that:

- The number of vessels is largely dominated by pleasure boats (Figure 3), but Roll-on Roll-off vessels travel almost equally than all the pleasure boats together (Figure 4),
- The seasonality in terms of number of vessels sailing in the Pelagos Sanctuary is largely due to the pleasure vessels which number of units increases as the spring/summer season approaches, and decreases after august, similarly in 2019 and in 2023 (Figure 3),
- Although the number of pleasure boats are approximatively 20 times larger than Roll-on Roll-off ships (Table 1 and Table 2), the cumulative distance sailed in the Sanctuary is the same order of magnitude. The average distance sailed by a pleasure boat is 19 times less than a Roll-on Roll-off vessel, identically in 2019 and in 2023.
- The average distance sailed by the Roll-on Roll-off ship (in km/vessel) has increased by 18% from 2019 to 2023.
- Cargo and tankers represent about 4,000 units in 2019 and in 2023, although the number of tankers has increased by 25% while the number of cargo vessels has decreased by 15% (Table 3). However, the travelled distance for tankers has increased by 36% while the travelled distance of cargo vessels has decreased by 25%. This leads to tankers navigating 8% more on average in 2023 than in 2019, while cargo vessels navigating 11% less in 2023 than in 2019.
- The container activity has increased significantly from 2019 to 2023, in number of vessels (+64%), an even more in travelled distances (+97%), leading to an increase by 20% of the average distance sailed by each container vessels.
- The number of cruise liners has increased by 40%, similarly to the travelled distance, indicating an increase of the economic sector by almost 10% per year between 2019 and 2023.
- The number of passenger vessels (ferries that only transport people) has largely increased from 2019 to 2023, but for an equivalent travelled distance, indicating more vessels navigating less.
- In terms of median speeds, there are no significant differences between 2019 and 2023, and between January and August. The behaviour of the vessels remains unchanged, with the Roll-on Roll-off, passenger and cruise liners being the fastest (Figure 5): Roll-on Roll-off vessels spend 80% of their navigation above 15 knots and 30% above 20knots, cruise and passenger vessels being in the same order of magnitude with more variability though (Figure 6). Tankers, fishing and working vessel are the slowest barely never exceeding 15 knots. Pleasure vessels spend about 15 to 20% of their navigation at speed above 15 knots.

Table 1: Annual number of vessels, travelled distance and averaged distance travelled per vessel sailing in the Pelagos Sanctuary in 2019 per category of vessel

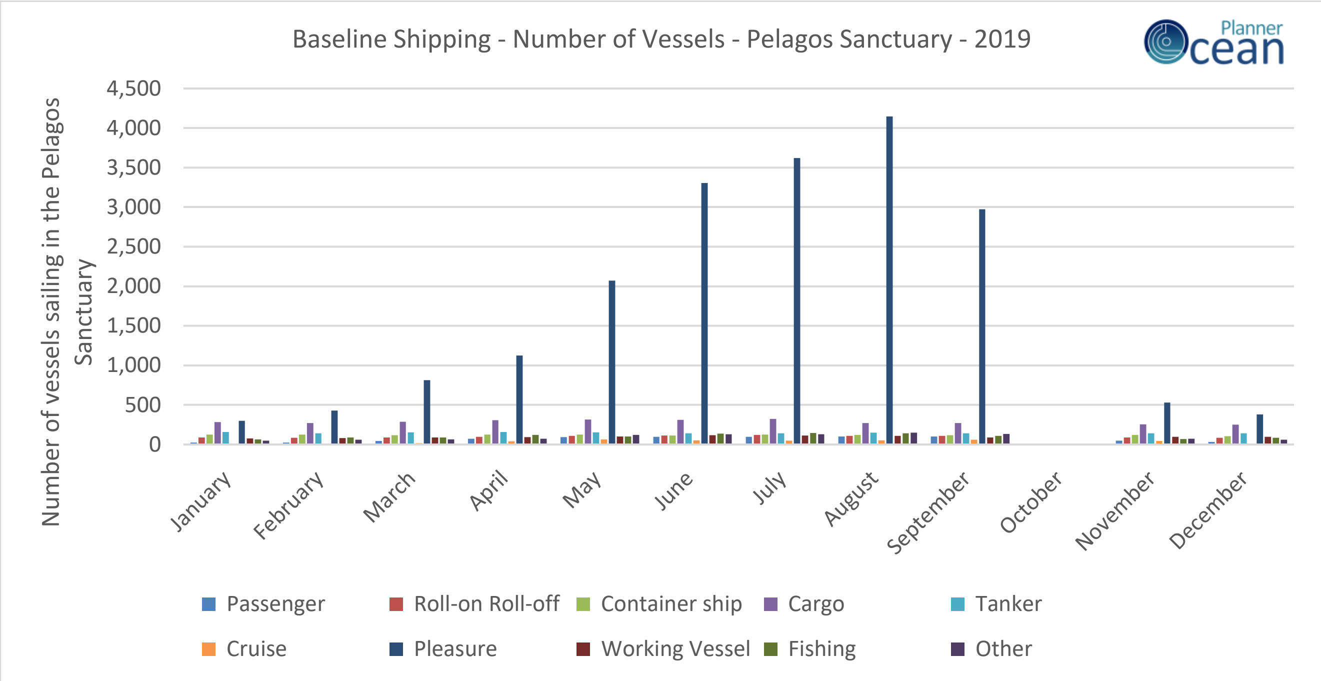
	Baseline Shipping - 2019										
	All vessels	Passenger	Roll-on Roll-off	Container ship	Cargo	Tanker	Cruise	Pleasure	Working Vessel	Fishing	Other
Number of vessels	**31,229**	724	1,090	1,322	3,140	1,619	400	19,683	1,062	1,145	1,044
Travelled distance (km)	**14,873,290**	970,874	4,081,550	830,260	1,797,625	904,762	578,239	3,944,339	489,275	1,034,366	242,000
Average travelled distance per vessel (km/vessel)	**476**	1,341	3,745	628	572	559	1,446	200	461	903	232

Table 2: Annual number of vessels, travelled distance and averaged distance travelled per vessel sailing in the Pelagos Sanctuary in 2023 per category of vessel

	Baseline Shipping - 2023										
	All vessels	Passenger	Roll-on Roll-off	Container ship	Cargo	Tanker	Cruise	Pleasure	Working Vessel	Fishing	Other
Number of vessels	**59,338**	1,216	1,491	2,170	2,673	2,027	560	42,912	1,783	2,773	1,733
Travelled distance (km)	**25,377,224**	937,454	6,577,566	1,634,847	1,356,385	1,228,147	842,268	9,929,738	835,589	1,647,255	387,975
Average travelled distance per vessel (km/vessel)	**428**	771	4,412	753	507	606	1,504	231	469	594	224

Table 3: Trend in the annual number of vessels, travelled distance and averaged distance travelled per vessel sailing in the Pelagos Sanctuary in 2023 per category of vessel

	Baseline Shipping - Trend Analysis 2023 vs 2019										
	All vessels	Passenger	Roll-on Roll-off	Container ship	Cargo	Tanker	Cruise	Pleasure	Working Vessel	Fishing	Other
Number of vessels	**+90%**	+68%	+37%	+64%	-15%	+25%	+40%	+118%	+68%	+142%	+66%
Travelled distance (km)	**+71%**	-3%	+61%	+97%	-25%	+36%	+46%	+152%	+71%	+59%	+60%
Average travelled distance per vessel (km/vessel)	**-10%**	-43%	+18%	+20%	-11%	+8%	+4%	+15%	+2%	-34%	-3%



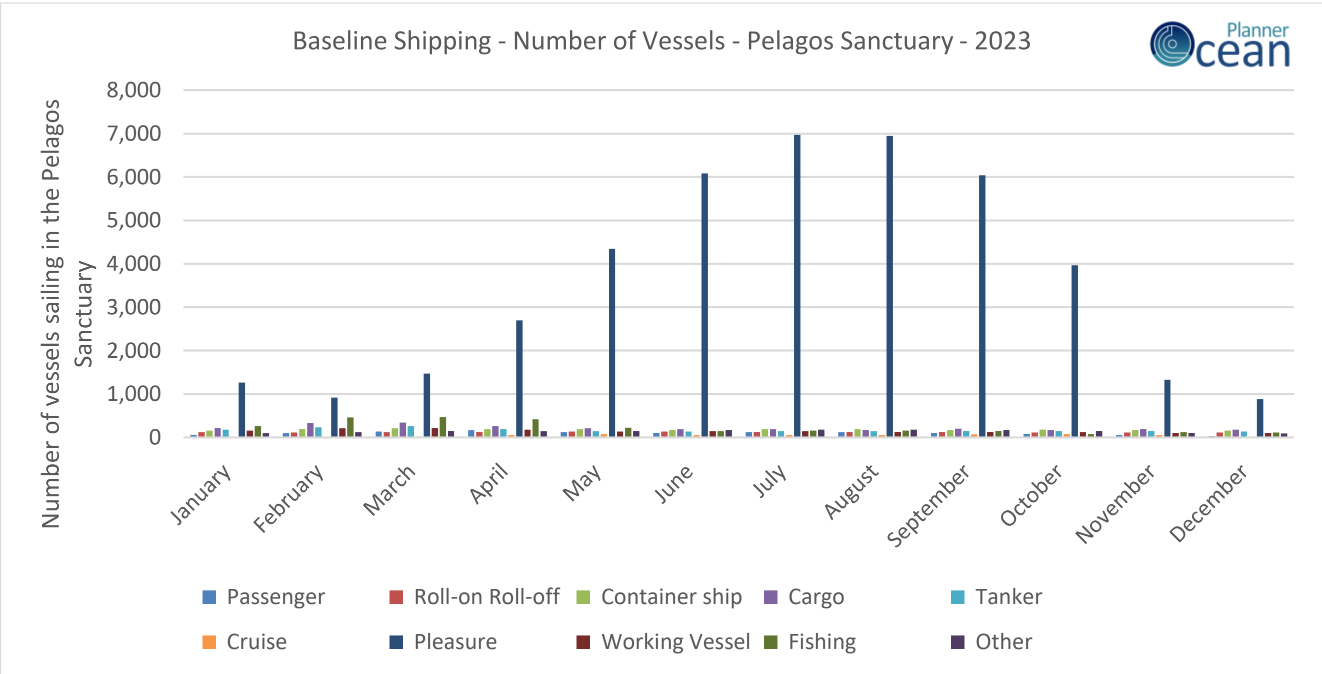
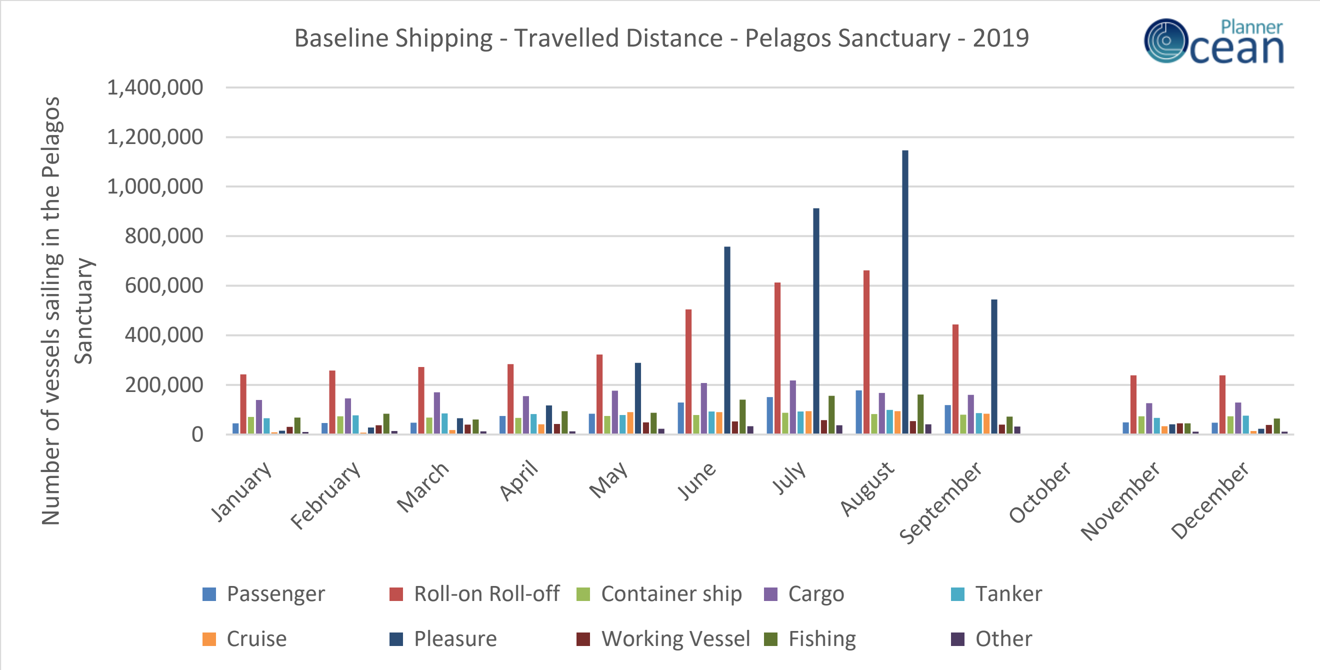


Figure 3: Monthly evolution of the number of vessels sailing in the Pelagos Sanctuary per category for 2019 and 2023. Attention is raised on the fact that the AIS provider for 2019 and for 2023 are not identical, and that the AIS coverage tends to improve with time which may lead to some bias.



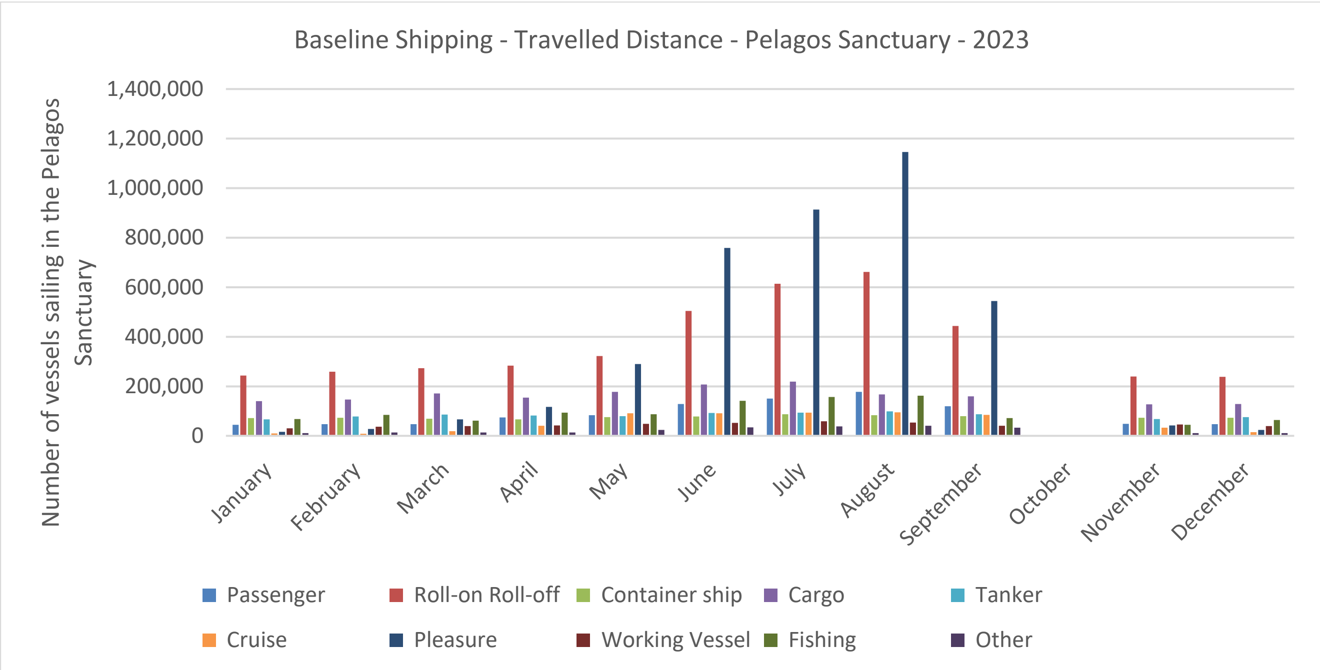


Figure 4: Monthly evolution of the travelled distances in the Pelagos Sanctuary per category for 2019 and 2023. Attention is raised on the fact that the AIS provider for 2019 and for 2023 are not identical, and that the AIS coverage tends to improve with time which may lead to some bias.

Figure 5: Comparison between travelled distance, median speed and number of vessels (size of the bubbles) in winter and summer, and in 2019 and 2023.

January | August

2019

2023

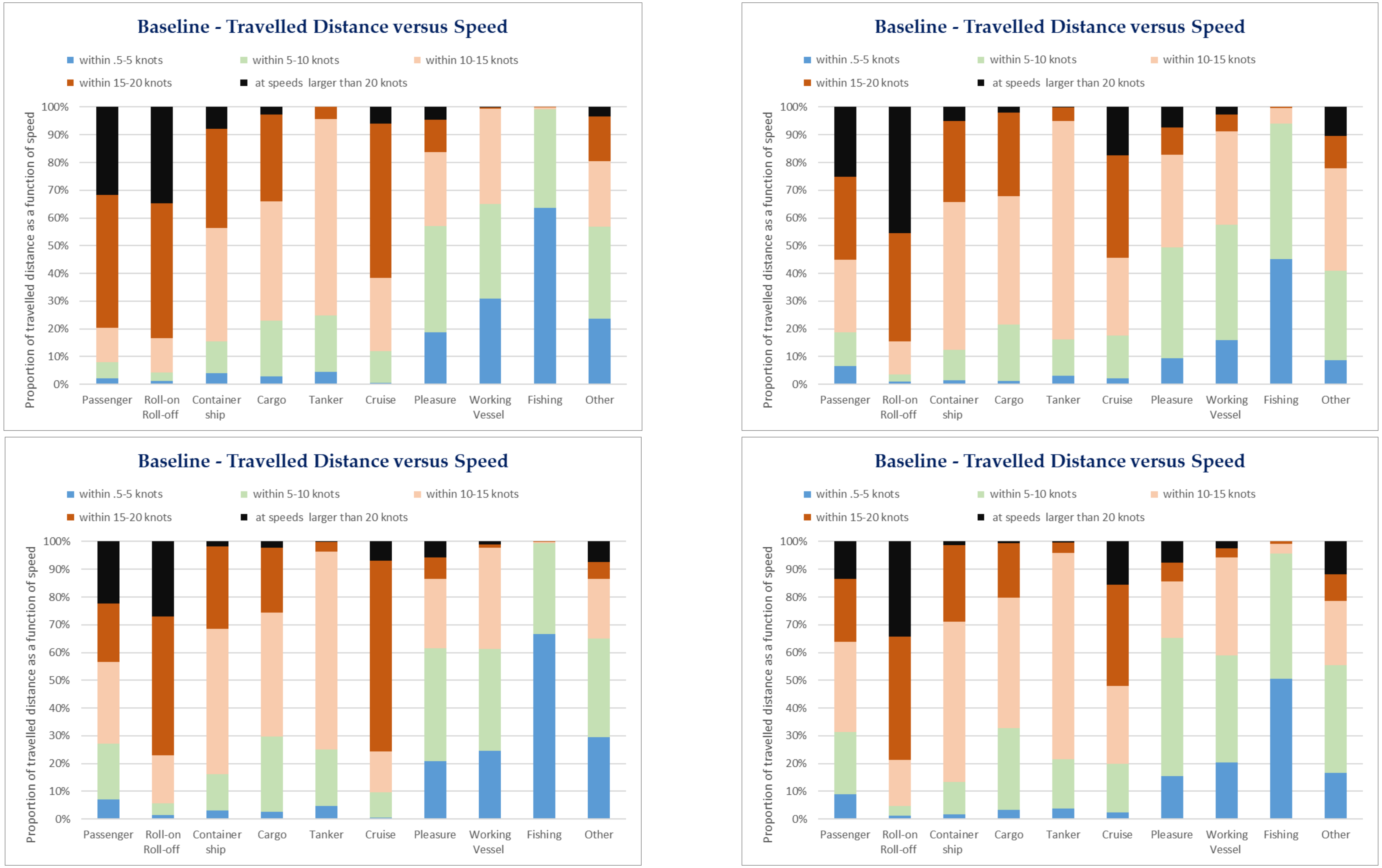


Figure 6: Analysis of speeds in 5 different ranges per category of vessels in winter and summer, and in 2019 and 2023.

Chapter III. Sound propagation modeling methodology

The objective of this chapter is to describe the sound modelling platform used to model the propagation of noise in the marine environment.

III.1.1. The noise mapping platform Quonops©

Quiet-Oceans develops and operates Quonops©, an operational system for monitoring and forecasting anthropogenic noise. Like weather forecasting systems, this platform produces an estimate of the spatio-temporal distribution of the noise levels generated by most of human activities at sea. The maritime activities covered are numerous, including shipping, construction and operation of offshore wind turbines, offshore drilling and blasting, etc. The data produced by Quonops© cover the needs as defined in national and international regulations, existing and emerging, concerning pollution levels and the preservation of habitats, marine ecosystems and the protection of marine species (Folegot, 2009)(Folegot, 2011)(Folegot et al., 2016).

Quonops integrates two types of propagation models: a parabolic equation solver (Porter and Reiss, 1984)(Collins 1991)(Collins 1994) and an energy distribution to Gaussian beams solver (Porter and Bucker, 1987), which both accurately reflect the geometric distribution of sound in the water column, while offering interesting computing performance for statistical analysis (Jensen, 2000).

Sound speed in water is proportional to the water temperature, salinity and pressure (or depth) and subject to large variability in space and time. The main effect of these inhomogeneities in the sound velocity distributions is to bend the rays spread and create propagation channels. These complex phenomena, however, are predictable by numerical simulation. The modeling of sound propagation is done by a succession of models in vertical planes interpolated cylindrically (Nx2D).

III.1.2. A platform meeting the highest international standards

The models implemented by Quonops© are largely validated through in-situ measurements since 2011. Within the framework of European project AQUO (Achieve QUieter Oceans), Quiet-Oceans organized and participated in an international initiative to compare eight acoustic models used in underwater acoustics, including those implemented in Quonops©. This work consisted in defining several theoretical and realistic propagation test scenarios and in evaluating / comparing the results of the different acoustic propagation models of the different research institutes. The results, made public in a joint scientific publication (Collin, et al., 2015), demonstrated that the models implemented by Quonops© are among the best of the international state of the art.

III.1.3. Which parameters are taken into account in the modeling?

The Quonops© modeling platform takes into account most of the data that condition the propagation of noise in the marine environment (Figure 7):

- environmental data, namely bathymetry, type of seabed, water temperature and salinity, tidal range and sea state (Table 4);
- anthropogenic data descriptive of shipping from the Automated Identification System (AIS).

The results obtained in the form of sound maps faithfully transcribe the specific characteristics of noise propagation and maritime uses specific to the study site.

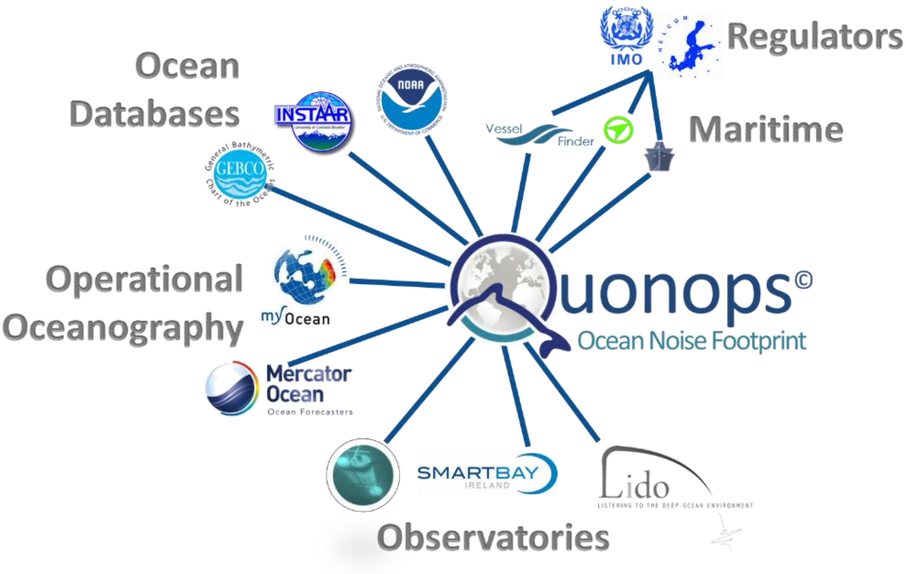


Figure 7 : Schematic description of the operational noise forecasting platform. Source: Quiet-Oceans

Table 4 : Sources of environmental data and their resolutions used in the Pelagos Sanctuary. CMEMS stands for Copernicus Marine Environmental Marine Service, and NCEP for National Centers for Environmental Prediction.

Type	Spatial resolution (Lon x Lat)	Temporal resolution	Source
Bathymetry	36m x 49m	-	EmodnetQO50m
Sediment	136m x 185m	-	Worldwide sedim from SHOM
Sound Speed	3km x 5km	1 hour	CMEMS
Wave height	3km x 5km	1 hour	CMEMS
Wind	41km x 56km	3 hours	wind from NCEP global forecast

III.1.4. Wind noise source

Natural ambient noise was modelled from wind data and derived into so called natural sound level (Mustonen et al. 2020). Wind data over the period is converted into noise level for each frequency using Ainslie's conversion formulas (Ainslie, 2010). Figure 8 illustrates the sound level induced by this environmental component as a function of its speed and frequency.

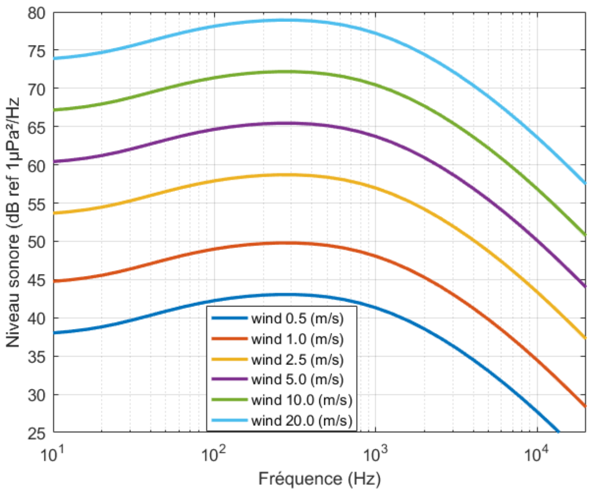


Figure 8 : Noise level induced by the wind as a function of its speed and frequency

III.1.5. Vessel noise

The noise generated by each individual vessel is estimated according to the RANDI model (Ross, 1976), which depends on the type of vessel, the speed and the length of the vessel. A variety of vessel source levels is shown as a function of frequency (Figure 9) (Wagstaff, 1973) (Breeding, 1996), and are corrected for the speed and length.

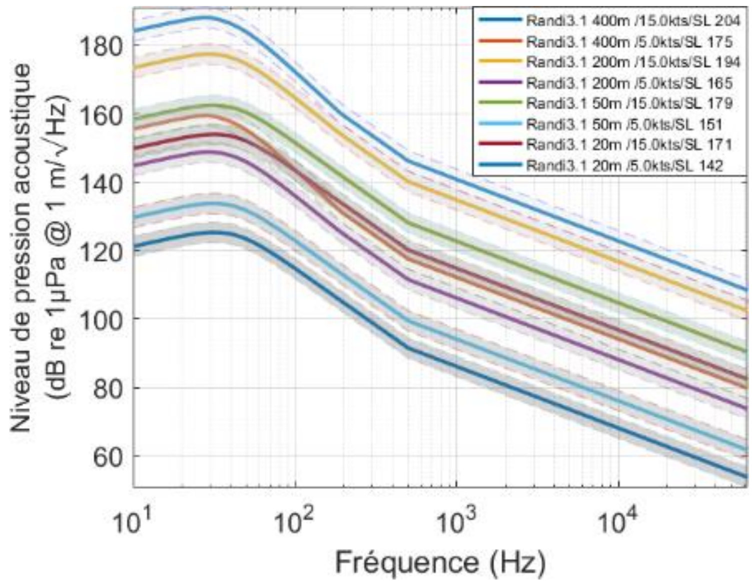


Figure 9 : Sound templates of ships as a function of vessel length, speed and frequency

III.1.6. Statistical mapping of underwater noise

Noise from individual ships is propagated into the surrounding environment with the range dependent parabolic equations algorithm (Collins, 1996), and added to all other ship sources. Modelling of instantaneous maps situations are computed once every hour across the surrounding tri-dimensional environment along a grid of 247m x 242 m resolution in latitude and longitude. Approximatively 720 steady-state noise fields per month are obtained, where vessels, tide, temperature, salinity, bathymetry, sediment, waves and wind are considered as constant for each situation. To calculate Sound Pressure Levels, sound originated by wind is added. At each geographical position of the grid, the distribution of the sound levels is calculated providing a statistical description of the variability of the sound in the form of percentiles along time through the month and depth from the surface to the sea-floor. The resulting distribution of sound pressure levels in each grid cell is then characterized by seven percentiles (L5, L10, L25, L50, L75, L90, L95). The lowest percentiles (L5, L10) are usually representative to the highest sounds occurring during short periods of time (respectively 5% and 10% of the period of analysis), while the largest percentiles (L95, L90, L75) describe lowers levels of sound but occurring during long periods of times (respectively 95%, 90% and 75% of the period of analysis).

III.1.7. Calibration of the sound maps

The development of the calibration methodology has been initiated during the BIAS project (Folegot et al. 2016). The methodology developed overcome the difficulty linked to the fact that the measurement and the modelling are not performed at similar time resolutions by defining a common robust metric. This metric used is the Cumulative Density Functions (CDF) that provide a description of the statistical content of the sound for the period considered similarly for both the measurement and the modelling regardless from the technical characteristics of the measurement nor the modelling. The CDF express the relationship between the sound level and the percentile, e.g., the proportion of time a given level occurs.

The calibration process consists of finding the best set of model parameters that minimize the difference between the CDF provided by the measurement and the CDF provided by the model at the position of the measurement and for the same period of time. It is acknowledged that the input data have uncertainties, and the calibration process aims at reducing these uncertainties thanks to the ground truth provided by the measured ambient sound. The calibration is performed by minimizing a cost function that considers the following major uncertainties:

- Wind: the wind distribution data is converted into a distribution of natural sound. The ground truth provided by the measured ambient sound enables to consider the local conditions that influence the natural sound generated by the wind.
- Sediment: the grain size data provides an a priori knowledge of the bottom. The grain size is converted onto the geo-acoustic parameters used in the model. However, a given grain size is equivalent to a range of values for the geo-acoustic parameters, source of uncertainties. During the calibration process, a range of geo-acoustic parameters are modelled, and the ground truth data enables to find the best set of geo-acoustic parameters that describes best the influence of the bottom on the sound propagation.
- Vessel source levels: it is acknowledged that the diversity of commercial vessel designs, propellers, sizes, and hulls introduce uncertainties in the estimation of the source levels of the vessels. The RANDI 3 source level model gives an a priori assessment. The calibration process accounts for this uncertainty and uses the measured ambient sound levels to adjust the source levels of the surrounding vessels.

Available in-situ measurement made by Quiet-Oceans in partnership with WWF France will be reviewed to evaluate whether the data can be used to calibrate the sound maps produced during the project.

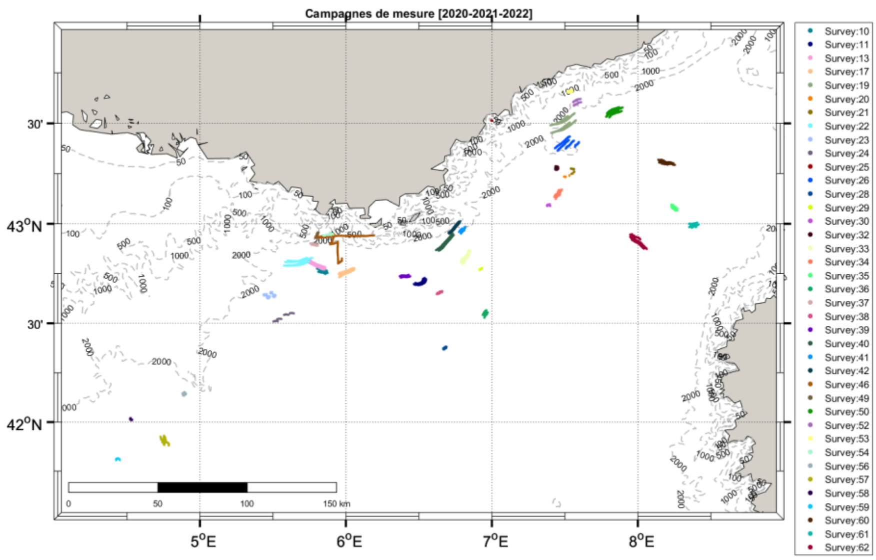


Figure 10 : In-situ acoustic measurement made by Quiet-Oceans in partnership with WWF France.

III.1.8. Metrics used

The metric used for modeling and rendering the results is the Sound Pressure Level (SPL) over a cumulative period of 24 hours. Use of this metric indicates that the forecast is the level of sound energy accumulated over a 24-hour period. This unit is particularly suitable for this study for the following reasons:

- the **Sound Pressure Level** metric is related to the absolute pressure level of a sound, and is suitable for describing the continuous nature of the noise, potentially leading to **disturbance** ().
- the difference between Sound Pressure Level and the natural ambient sound can also be computed to assess the **Excess Level** (Kinneging & Tougaard, 2021). It is a measure of how much the ship noise has elevated the total noise above the natural ambient level. It is measured in decibels (dB) and therefore has a lower bound of 0 dB (no ship noise, only natural ambient noise). The Excess Level describes the levels potentially leading to **masking and communication loss**.

III.1.9. Preliminary noise maps of the Pelagos Sanctuary

Figure 11 is an illustration of preliminary results of statistical sound maps of the Pelagos Sanctuary for the first quarter of 2023 at 63Hz decidecade band. Two metrics are displayed on the figure: on the right, the Sound Pressure Level containing the natural component of the sound derived from wind and shipping derived from the AIS data; on the right, Excess Levels which represent the amount of sound that is added to the natural sound by the shipping activities. An Excess Level of 12dB induces a reduction of the communication and echo-localization space by 75%.

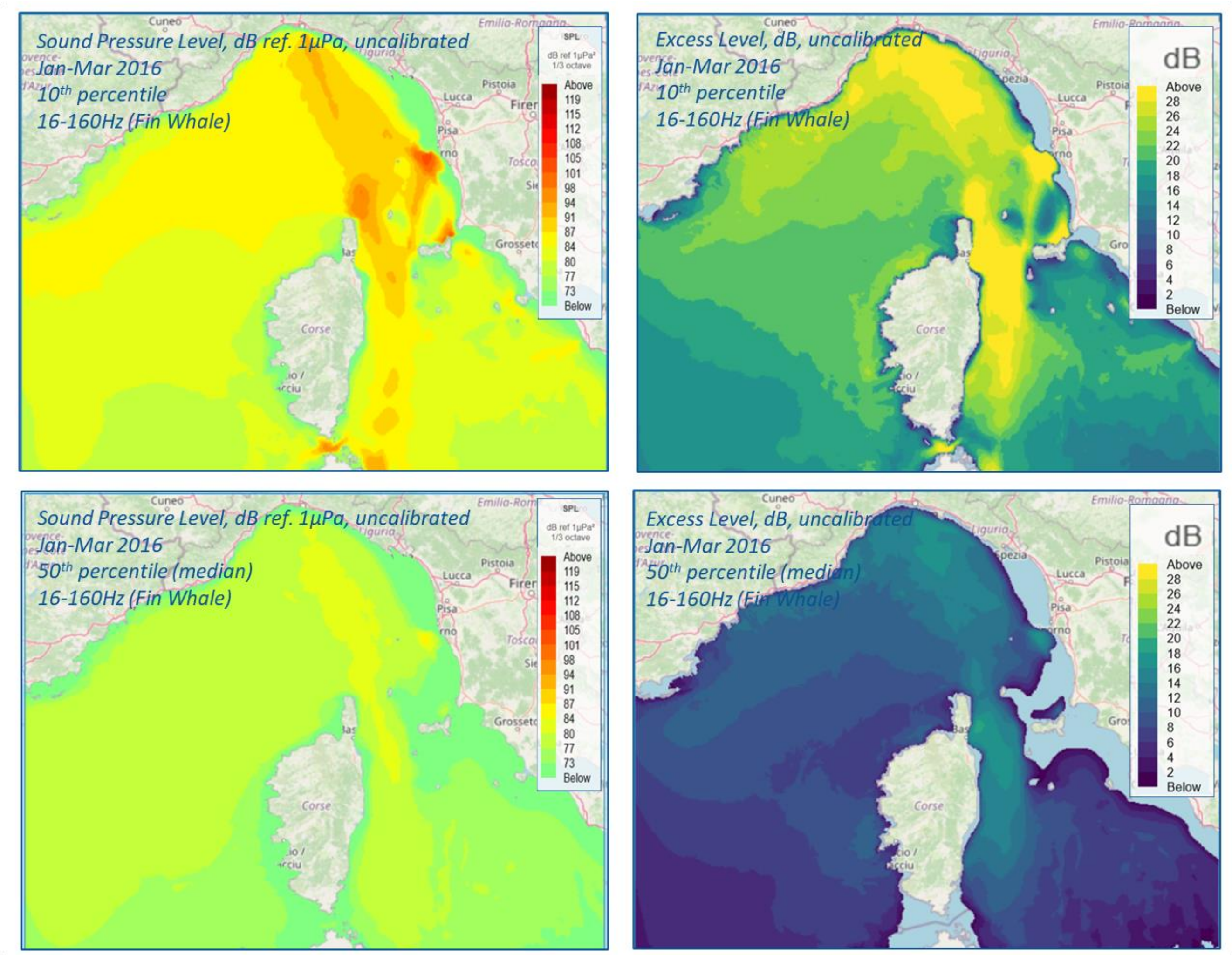


Figure 11 : Uncalibrated statistical sound maps in the Pelagos Sanctuary for the first quarter of 2023 in the 16-160Hz band (Fin Whales) and for the 10th (top) and 50th (bottom) percentiles (e.g. levels reached 10% and half of the time). Left: Sound Pressure Level. Right: Excess Level.

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