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Analysis of the influence of the marine traffic noise in whales trajectories

Photo: John Calambokidis, Cascadia Research.

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Summary

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Acronyms

AIS Automatic Identification System.

AMURE Aménagement des Usages des Ressources et des Espaces marins et littoraux.

ARTS Air Rocket Transmitter System^{TM}.

EMED Eastern Mediterranean.

IMO Internationnal Maritime Organization number.

LLI Loyd List Intelligence.

MMSI Maritime Mobile Service Identity.

NAO North Atlantic Ocean.

s-AIS Satellite Automatic Identification System.

SHOM Service Hydrographique et Océanographique de la Marine.

t-AIS Terrestrial Automatic Identification System.

WMED Western Mediterranean.

1 Introduction

Ambient noise in the ocean is the combination of sounds coming from natural and anthropogenic sources. Natural sources include geologic processes such as earthquakes, wind-driven waves, rainfall, and thermal agitation of seawater and biological activities such as mammal clicks, whistles and songs, or invertebrate and fish sounds. Anthropogenic noise is generated by a variety of activities, including commercial shipping; oil and gas exploration, development, and production, naval operations, fishing, research and other activities such as construction, icebreaking, and recreational boating [1]. In deep water settings, ambient traffic noise is mainly represented by low frequencies, between 10 and 1000 Hz [25] with dominant frequencies between 50 and 150 Hz.

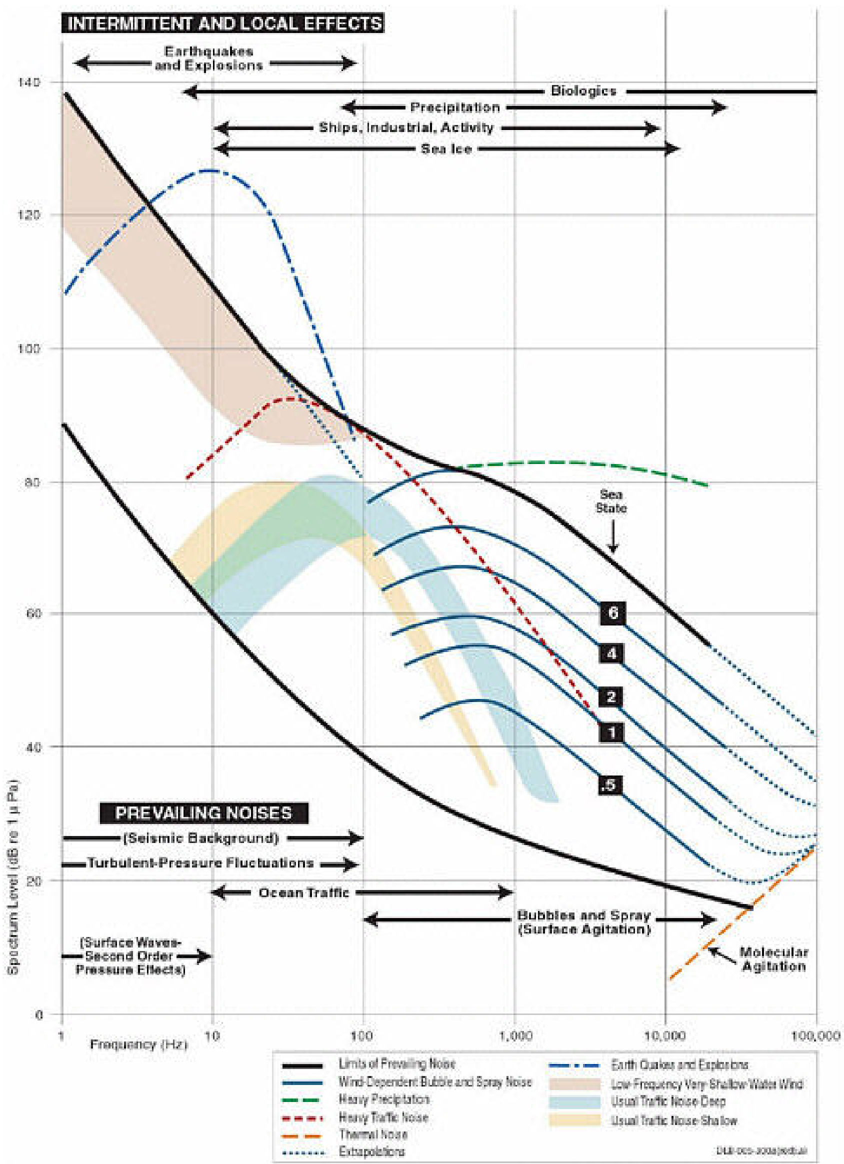

Figure 1: Spectral density levels of marine ambient noise from weather, wind, geological activity and commercial shipping in deep water environments (Adapted from Wenz, 1962. Source: [8]).

~~Actually,~~ it is not yet possible to establish long-term trends regarding ~~the evolution of~~ ambient noise in the oceans. In spite of this, it is possible to make well-funded comments between ship radiated noise and shipping traffic and their implications for the long-term ocean noise levels. ~~We can affirm that~~ ships generate noise and ~~that~~ the world fleet has increased substantially since 1950. Shipping has been identified as the major contributor to ocean noise [8, 1]. Over the last 50 years, several studies have shown an increase in the level of underwater noise in certain regions, as a consequence of the increase in world shipping and economic activity [8, 29, 26, 39]. However modern boats have increased ~~ship~~ size, propulsion power, and sophistication. New ship designs ~~usually include as a common feature that they~~ are less noisy [27].

~~Recent studies show that d~~ifferences in the design of ships~~,~~ result in variations in radiated noise. According to ship-type, ~~differences in~~ the dominant frequency of radiated noise ~~are found~~. These differences may be specific to each vessel type and relate to operational differences~~,~~ load of the ship, propeller type, or hull design. It has also be demonstrated how ~~certain~~ ship types~~,~~ with special designs influence ~~directly~~ the spectral characteristic of underwater acoustics. In addition variations in the power of the engine result in an increase in the radiated noise. This has been detected in studies where surface current was opposite to the direction of the boat as well as in rougher waters originated by waves. These situations implied an increase of engine power resulting in increased cavitation and ~~in the predicted~~ radiated noise levels.These studies are of great importance for more specific ship design recommendations in the future and for proper radiated noise estimation [27, 28].

Acoustics is used by most marine fauna, from invertebrates and fish to marine mammals, to accomplish vital functions such as acoustic sensing, communication, navigation and feeding [8, 25]. The anthropogenic sound sources constitute a pressure on marine mammals. [40, 6]; it is an important component of the total oceanic ambient noise and may interfere with the normal use of sounds by marine animals (i.e. masking of the communication) leading to a considerable impact ~~in~~ their habitats [8, 20].

Mysticetes, such as the fin whale Balaenoptera physalus, are mammals that emit at low frequencies~~,~~ are presumably more likely to be disturbed by low frequency shipping noise from marine traffic. Short-term responses of cetaceans to anthropogenic sound sources include sudden dives, ~~evade~~ from the sound source, changes in vocal behaviour, longer dive times, shorter surface intervals with increased breathing rate, attempts to protect pups [11, 33, 18]. However the responses to noise by changes in the behavior are complex and still little studied.

In marine environments, the underwater noise level is modelled from the source level, which corresponds to the sound pressure at one meter from the source, and from losses by propagation between source and receptor, which depend on the oceanographic environment, including bathymetry, speed of sound in the water, and sedimentology [16]. Noise levels are expressed in a logarithmic scale to approximate the perception of sound.

~~With the purpose of~~ increas~~ing~~ knowledge on the effect of noise on animal behavior and bridging the gap (Figure 2), both biological and non-biological components must be studied. This work focuses on the study of non-biological components of noise (such as source and propagation). The sources of noise coming from marine traffic data will be initially analyzed and ~~later on~~ the propagation of sounds will be studied to estimate, with the aid of a model of ambient noise, the noise level ~~in~~ whales positions. Finally noise levels will be related to whale positions. The study will focus on fin whale trajectory obtained by satellite tagging in the WMED.

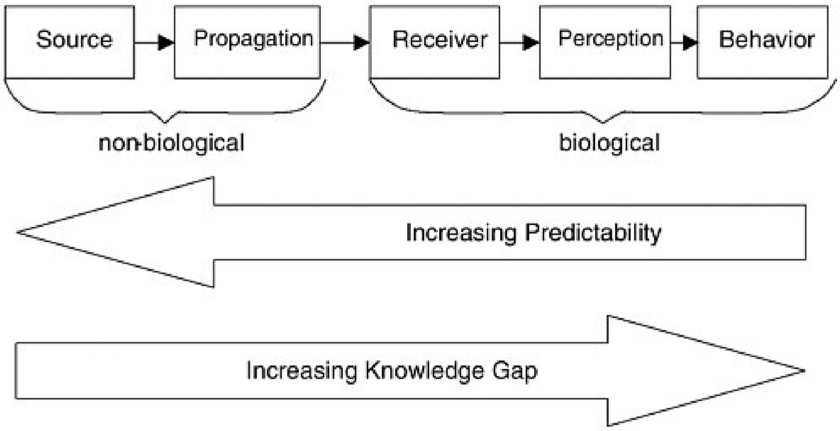

Figure 2: Theoretical framework to assess impact of noise on marine life (Source: [8].

The main purpose of this work is to develop a method to analyze the influence of ships on the trajectory of whales. Specifically, we want to :

- Develop a tool for predicting shipping noise from the number of boats present at any given time in the Mediterranean Sea, as well as their speed, length and category, through search of large databases.
- Represent whales trajectories and estimate of the noise level ~~in~~ each position using the tool developed.
- Relate the trajectory of one individual ~~and~~ noise levels.

2 Material and Methods

2.1 Study Site

The Mediterranean sea is a mid-latitude semi-enclosed sea, with a mean depth of 1500 meters [21]. The Mediterranean Sea exchanges water, salt, heat and other properties with the North Atlantic Ocean (NAO), through the Strait of Gibraltar. It is subdivided into two main basins, the Eastern Mediterranean (EMED) and the Western Mediterranean (WMED), communicat~~ed~~ through the Sicilian Channel.This study will focus on the WMED due to the marine traffic density and the whale's presence in this area.

Balaenoptera physalus is the only mysticete specie ~~regulatory~~ present in the Mediterranean Sea [12]. ~~Notarbartolo (2003), shows that t~~he Ligurian-Corsican-*Provençal* basin is by far the most important habitat for whales in the Mediterranean Sea. This area is the north-western portion of the Mediterranean sea, named "Pelagos Sanctuary for

Mediterranean Marine Mammals" (Figure 3). It is located between south-eastern France, Monaco, north-western Italy and northern Sardinia, and surrounding Corsica and the Tuscan Archipelago. Pelagos Sanctuary with a surface over 87,500 ~~square kilometres~~ km^2 is a high primary productivity area due to a permanent frontal structure [17]. This can be the reason for the high number of whales during summer, which is ~~known to be~~ the feeding season.The whales' presence in the Pelagos Sanctuary is continuous throughout the year but during autumn and winter the number of individuals decrease [22].

Figure 3: Study site, Western Mediterranean sea.(Source: SHOM)

~~With respect to the marine traffic, it is known that~~ the Mediterranean Sea (0.8 per cent of world ocean surface [12]) is one of the most navigated areas of the world[32]. ~~The~~ 30 per cent of the world's merchant shipping pass through the Mediterranean Sea [2]. In the central and western Mediterranean region ~~are located~~ almost 80 per cent of all the ports. Also in the WMED are present the most of the top ports, with only few exceptions. Over the past ten years vessel activity increased in the Mediterranean Sea.Based in current~~s~~ trends ~~it has been estimated that~~ an increase ~~by~~ 18 per cent in ~~the~~ vessel activity ~~will be present~~ in the next decade. ~~In the same way it is known that v~~essels size has increased by a 30 per cent since 1997 and will continue rising [32]. Due to the high percentage of marine traffic and the high presence of whales in the Pelagos Sanctuary this study will be carried out in the WMED.

2.2 Marine Traffic

2.2.1 Describing Automatic Identification System (AIS) data

~~With the aim of~~ estimat~~ing~~ the radiated noise levels it is necessary to know the properties of the source, in this case vessels properties [25, 38]. The AIS will be used to get the ship information. It is an automatic reporting system widely installed on ships initially for collision avoidance ~~by~~ report~~ing~~ their kinematic and identity information continuously [23].

AIS DATA
Internation~~n~~al Maritime Organization number (IMO)
Maritime Mobile Service Identity (MMSI)
Longitude
Latitude
Vessel type
Length
Speed over ground

Table 1: Data set information.

Each data set ~~AIS~~ includes all the information listed in Table 1. AIS data can be provided by land-based stations (Terrestrial Automatic Identification System (t-AIS)) and satellite sampling (Satellite Automatic Identification System (s-AIS)). In addition, AIS data can differ depending on the provider. AIS data have been obtained from OCTRAF [31] except for the speed and length of each vessel which have been tracked directly in the Loyd List Intelligence (LLI) databases.

2.2.2 Traffic modelling: OCTRAF software

OCTRAF is a tool to calculate maritime traffic density. OCTRAF is based on two complementary components: a database on the one hand, and the calculation and consultation software on the other.

Thanks to OCTRAF we can estimate the real-time situation of AIS, it also allows the selection of the database, in the present work data is provided by the LLI that has gathered maritime information for several years. From this provider we will use the two observation sources: t-AIS and s-AIS. Depending on AIS sampling method (station or satellite), temporal an spatial resolution differ~~s~~. Station are know to provide accurate spatial and temporal resolutions in their detection area (very high frequency electromagnetic wave range, approximately 40 miles), whereas satellite gathers large scale area, even off shore, but at a low frequency related to the rotation of the satellite. These constraints impact the definition of real-time situation of AIS~~,~~ it has to be performed over analysis period (time window) to take into account AIS data gathered by the satellites.

2.3 Underwater acoustic

2.3.1 Acoustic wave propagation

This part aims at computing the received noise level coming from ships. Figure ~~1~~ introduces the framework for one receiving whale at depth z_r and a ship at the distance r_e and the depth z_s. Both are supposed to be punctual. The propagation medium is defined by a first top half space of air, one layer of water and a half space of seabed. Air half space is characterized by the sound speed c_a in the air and the air density ρ_a. Water layer is characterized by its depth D, sound speed c_w and density ρ_w; all three depends on the range r; c_w and ρ_w depends as well on depth (z).

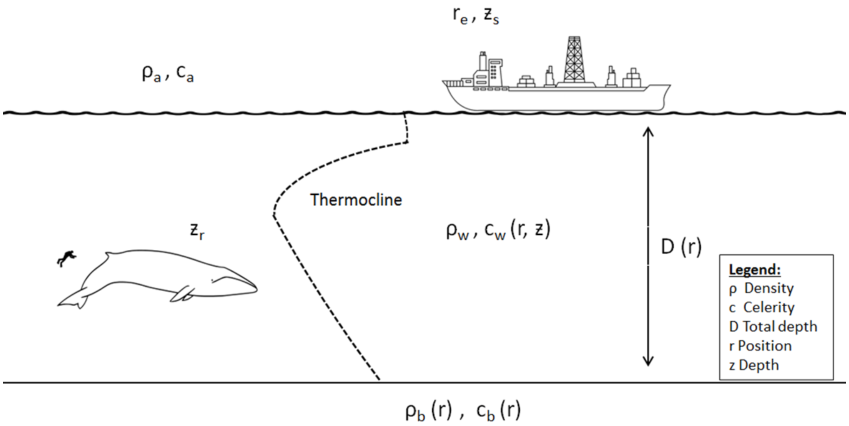

Figure 4: Ocean environment properties.

Therefore the speed of sound will vary depending on the oceanographic environment and it can be expressed as a function that relates these three variables (Equation 1) [19]. Variations in the speed of sound c in the ocean are relatively small but these variations in c would significantly affect the propagation of sound:

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016z \quad (1)$$

Seabed is characterized by its sound speed c_w, attenuation and density ρ_w; for rocky seabed, additional parameters for shear waves are added: shear wave speed and shear wave attenuation. Environmental data are provided by Shom. The acoustic pressure p at range r and depth z for the frequency f is computed by solving

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right) + \rho_w \frac{\partial}{\partial z}\left(\frac{1}{\rho_w}\frac{\partial p}{\partial z}\right) + \frac{\omega^2}{c^2(z,r)}p = -\frac{\delta(r)\delta(z - z_s)}{2\pi r} \quad (2)$$

with $\omega = 2\pi f$, and δ is the Dirac distribution.
Two boundary conditions have been established in this study: the sea surface and the seafloor. The sea surface is considered as a perfect reflector, ~~in the present work it has been assumed that no~~ energy is transmitted from water to air. Therefore at sea surface ($z = 0$) ~~it~~ is taken as zero value ~~(i.e. total reflexion of the sound wave)~~. On the other hand, seafloor is more complicated, except when $c_b > c_w$ ~~where~~ there is no propagation and it can be considered as a total reflection. The water-~~fond~~ interface will ~~vary the~~ reflectivity characteristics depending on the nature of the geographical location [16]. This is why ρ_b and c_b depends on r, the location.

Because environment changes in space (i.e. range dependant), the equation is solved using a parabolic equation approach, a numerical method which discretize the medium in range and depth [9].

2.3.2 Ambient noise modelling: CABRAIS2 software

The ambient noise is obtained from the modelling of the sources (AIS data) and their propagation in the oceanic environment [5]. CABRAIS2 [30] is a tool to compute the ambient noise from in situ data.

The received acoustic level RL at position r, depth z_r and for a frequency f and for a source is defined as [14]:

$$RL(f, r, z_r) = SL(f) - TL(f, r, z_s) \tag{3}$$

Where SL represents the source level and it is attenuated by the transmissions losses TL, due to the oceanic environment. RL, SL and TL are expressed in dB (ref 1μ Pa).[5] TL is computed from the logarithmic expression of (2) for unitary source. SL is computed using updated Ross model of ship noise. It depends on the speed v (in knot) and the length l (in meter) of the ship [10].

$$SL(f, v, l) = SL_{s0} + 60\log(\frac{v}{12}) + 20\log(\frac{l}{300}) + df \times dl + 3 \tag{4}$$

Where SL_{s0} is a basis spectrum in dB and dl and df are correction values depending on ship type. This formula was inferred from measurements but may need to be updated with recent ships [27]. Basically, it states that the larger and the quicker the ship, the noisier it is.

For several ships and one receiver, equation (3) is computed for each source, and levels are added in Pascal, then converted into dB. Then CABRAIS is able to estimate the contribution coming from a direction depending on the source distribution, their level and propagation properties.

RL are computed for a receiver depth of 5 meters because whales tend to remain in surface waters, and only occasionally fin whales dive below 50 meters [34]. In addition detection of tags happens when whales are near the surface. As fin whales audition is supposed to be more acute at low frequency, the RL are computed for frequenc~~y~~ between 30 and 500 Hz.

2.4 Whales tag data

To obtain whale position data, several adult individuals were tagged late summer 2012 at Pelagos Sanctuary [37]. These data have been obtained ~~in order~~ to expand the information about whale migration after the feeding season at the Pelagos Sanctuary [22]. Transdermal tag (Wildlife Computers molds 177 and 193) locators -Argos™ satellite tags [3, 35, 4]- placed on the dorsum or the dorsal fin of whales were deployed with a custom-modified pneumatic line thrower (Air Rocket Transmitter System™ (ARTS)). The location data is recorded by the satellite each time the whale comes to the surface. In order to record the data the whale must remain ~~a minimum time~~ on the surface.

The data retrieved in this study were previously analyzed with the Aménagement des Usages des Ressources et des Espaces marins et littoraux (AMURE) laboratory. In this work the signal received by the cetacean whose tag number corresponds to 112708 was studied. This fin whale was tagged on September 17^{th}, 2012 at Pelagos Sanctuary and the signal position was transmitted over 81 days. The month of November (2012) was selected because of the limitation on AIS data. November is by all means a good representative period of marine winter traffic. The results obtained are shown below.

3 Results

Results for the AIS data distribution and noise level due to shipping in the WMED are presented.

3.1 AIS data

The sound sources correspond to the ship location obtained from the AIS data. An average of around one thousand ships per day were identified throughout the month of November in the WMED. By using a half-day analysis window it is possible to obtain the position data closest to the coasts, collected by ground stations (t-AIS) as well as those present at sea captured by satellite (s-AIS) (Figure 5).

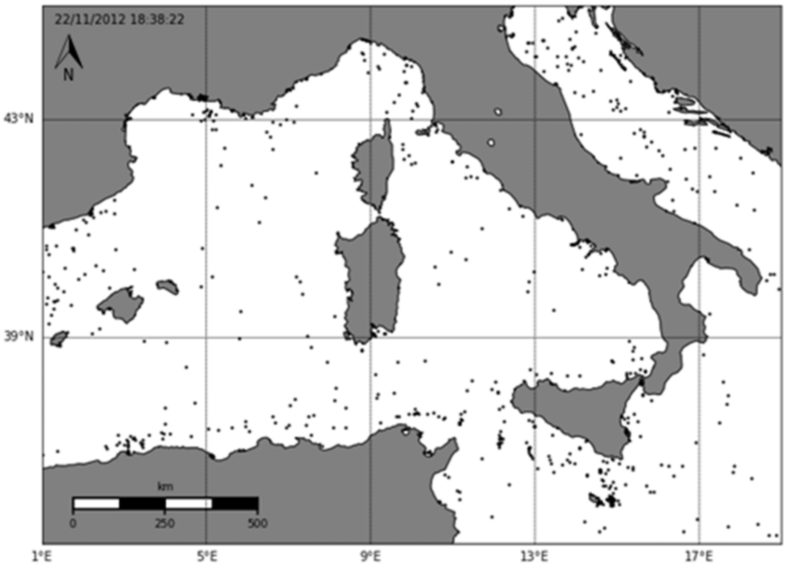

Figure 5: Snapshot of ship locations in the Western Mediterranean ~~the 22 of November~~ 2012 at 18:38:22 (0.5 day analysis window).

For greater accuracy in the position of the boats, several analysis windows were studied (Appendix I). Windows of more than one day were discarded due to the great variation of locations that ~~can have~~ a vessel in that period. On the other hand, smaller windows ~~not considered due to the fact that as the window decreases to reach a higher accuracy~~ the number of ship positions ~~also~~ decreased considerably. This was attributable to the absence of data collected by the satellite~~,~~ and in view of the paucity of data the window of one day was chosen. ~~Accordingly t~~he positions of the boats farthest from the coast were not lost due to the absence of the satellite.

~~In order~~ to estimate the ambient noise at a specific point of the Mediterranean, vessels present in a range of 500 km around the area of interest were evaluated. Some of the ships share the same MMSI number, so the IMO number was also used ~~for the identification of~~ each vessel. The ships were analyzed on a one by one basis to obtain their speed and length. Figure 6 shows the velocity and length distribution of the boats present in the

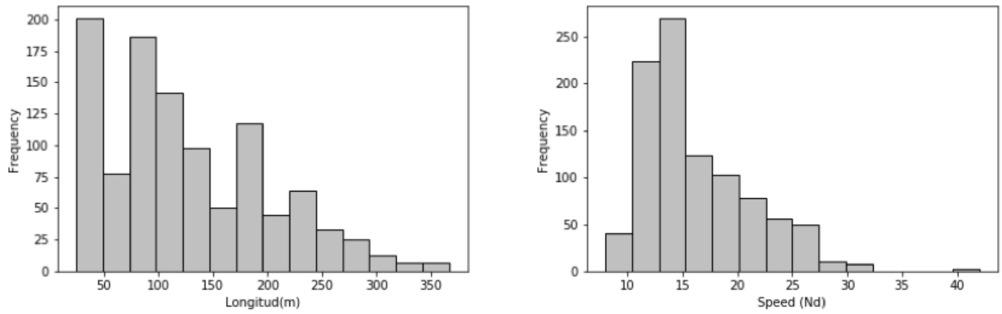

Figure 6: Velocities and lengths of the vessels analyzed around the study area.

study area. It is possible to observe a greater presence of small-medium size boats with average speeds around 25 knots. Values that were not included in the LLI database are not represented and are taken as null values throughout the study. The distance and the azimut between the source and the point of interest were estimated. All these data were collected in order to study the noise level and its propagation direction.

3.2 Ambient noise and whale trajectories

The whale selected for the study was tagged at the Pelagos Sanctuary in September. By the end of October the whale moved towards the Gulf of Lions and the Balearic Islands, remaining in this area throughout the month of November. In Figure 7 is represented the trajectory that the animal ~~made throughout the month of~~ November.

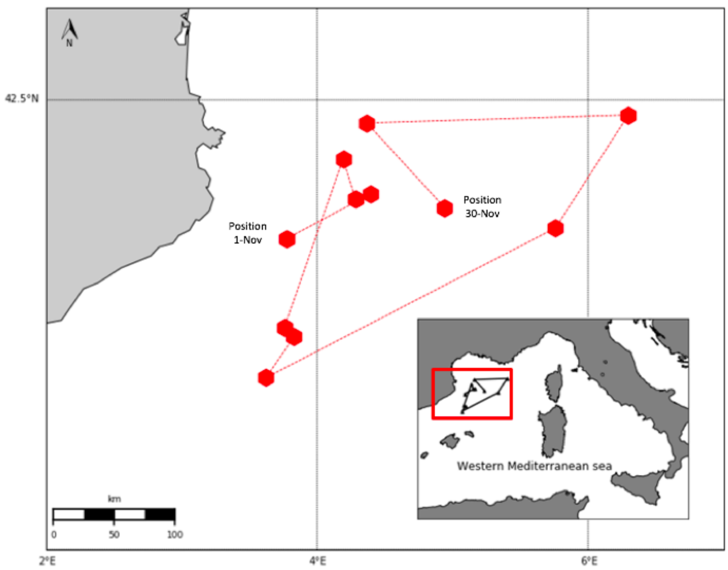

Figure 7: Fin whale trajectory in November 2012 (tag number 12708).

Applying the model proposed by Ross (1976), ship-radiated noise was determined [16]. Ambient noise was estimated at each of the points of the whale's trajectory (Figure 7).

Figure 8 shows the spectrum ~~in~~ four of these positions. These noise spectra are presented with centre frequencies of 30, 40, 50, 63, 80, 100, 125, 160, 200 and 500 Hz.

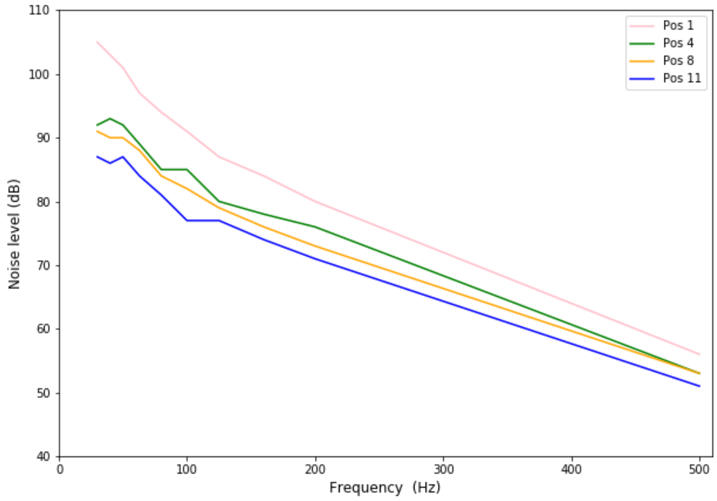

Figure 8: Power spectrum level (dB re 1 μPa) of shipping noise in the range 0-500 Hz in positions 1,4,8 and 11 of the whale trajectory.

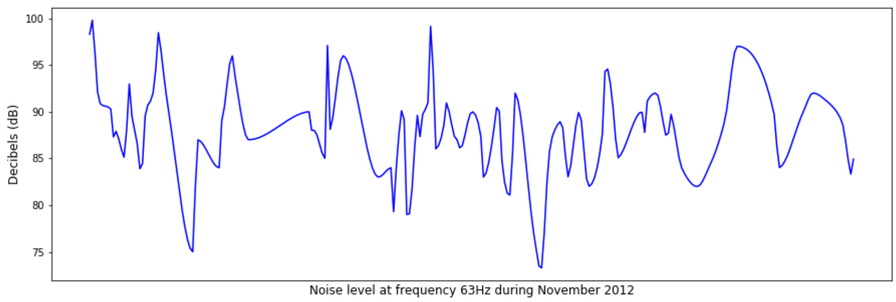

Figure 9: Energy received at frequency 63 Hz during November 2012.

It is possible to observe that the first position, the closest to the coast, is the one that presents a greater noise level, probably related to the greater abundance of ships ~~close to land~~.

The results show maximums of 104 dB while the minimum levels are around 65 dB, ~~but~~ these values were obtained at low frequencies. The marine traffic is the major contributor of noise at low frequencies in the ocean, as the results shown at lower frequencies we find greater variations in the noise level, and this can be due to number of vessels.

The total amount ~~the~~ energy received by the individual ~~during the month of~~ November was also calculated at frequency 63 Hz. For this purpose, the noise level in the 11 positions represented in figure 7 was estimated. These values were then interpolated in order to obtain daily values received by the whale. This frequency represents the anthropogenic pressure exerted on the cetacean~~.~~ (Figure 9).

4 Discussion

~~Throughout this study we~~ have investigated the impact of ships as a source of acoustic pollution and its relationship with the trajectory of whales in the WMED. The shipping noise prediction tool has been implemented and used in the present case study in the Mediterranean Sea over an area with whale presence. The prediction tool generates noise levels profiles at any desired point. Nevertheless, it has not yet been possible to prove that the trajectory of whales is affected by shipping noise.

Ambient noise from AIS data

Marine traffic is the main cause of noise pollution at low frequencies. Using AIS data for the estimation of maritime traffic density and/or calculation of ambient noise have previously been studied in previous investigations [14, 7, 23, 13]. The method employed in the present study obtained values close to reality. However, there are still a number of uncertainties with this method~~ology~~. In particular, the choice of the analysis window represents a problem when the accuracy of the position of the ship is considered. The t-AIS data are received at the ground station every 2-10 seconds depending on the ship and the distance, on the contrary, the s-AIS data are only collected with the passage of the satellite. This leads to a great uncertainty in areas far from the coast where the t-AIS cannot capture the signal because the frequency of the passage of the satellite is ~~much lower~~. The implementation of the s-AIS is of great importance because t-AIS datasets depend on the spatial coverage of the AIS land-based systems, and this propagation is limited to a range of 15-20 nautical miles around each station due to the earth's roundness, leading to a great loss of data. In studies of marine traffic density this problem is overcome~~d~~, but it is not so easily solved when you want to know the exact position of a ship at a given time.

~~On the other hand the speed of each boat~~ were obtained from the LLI database. These speeds depend on the activity-type and design of each boat. At the beginning of this study the speeds ere intended to be calculated manually using several real-time AIS positions. But it proved impossible to recall due to the fact that a large number of boats do not present successive position data over time. The use of average speed provided by the LLI gives us an appropriate value for noise estimation. But ~~as a matter of fact lack a certain degree of reliability, since~~ the value annotated is not measured at the exact moment the ambient noise is ~~desirably calculated~~. In spite of this, in numerous studies of noise estimation from AIS data the vessel speed values are recalled either from the LLI lists or from the AIS datasets.

Ambient Noise

The SL calculation using the Ross model has been ~~utilized~~ in many scientific investigations. But has been recently criticized by Wales and Heitmeyer because there is a negligible correlation between the source level and the ship speed and the source level and the ship length. These observations complicates ~~the determination of the possible correlation of ship parameters to~~ noise level estimation [8]. Comparing our simulations to measurements made in [15], in the WMED, it can be said that RL are of similar magnitudes, validating the methodology.

Whales trajectories

It would have desirable to correlate actual results from non-biological contribution regarding the source and propagation of sound, with biological data referring to the behaviour of the whales under the pressure of acoustic pollution from ships. From the data obtained in the present study it is not possible to establish a relationship, or a specific behaviour, as a response pattern from the fin whale. Nevertheless previous studies in this area ~~show~~ how this ~~impact~~ affects the behaviour of whales. In the study carried out by Rolland *et al.* (2012), traffic noise may cause stress to the whales [36]. In a different study Jahoda *et al.* (2003), investigated the reactions of fin whales to an approaching small inflatable device, and two different avoidance strategies were simultaneously performed by the whales *v.g.* escape at increased velocity and reduction of time spent at the surface [24].

Several other studies related to the anthropogenic acoustic pollution have been carried out in the last decades, but it is extremely important and desirable to continue applying the developed tool within this study to more whale trajectories and thus be able to identify and quantify the impact of shipping noises in their trajectories.

5 Conclusion

The physical-biological relation is very important in a multitude of oceanic processes. The ocean is a multidisciplinary area of study where everything is interconnected. This is why it is essential to combine the study of multiple disciplines. The objective of this study includes the physical-biological relationship as well as data analysis that can lead to address both disciplines. The fact of having accomplished both disciplines,in order to increase the knowledge of this topic for a correct management and conservation, is a motivation that has been present since the beginning of the work.

Also, the fact that marine traffic is considered the main contribution to ambient noise has awakened my interest in the anthropogenic acoustic impact on the oceans and its evolution over the last years. From this starting point I have been able to learn about the development of data analysis of AIS databases. In spite of the difficulties faced with regard to the low temporal resolution analysis when ships are far from the coast, it has helped me in the search for solutions when studying databases. I have also discovered the complexity in the propagation of sounds in an environment such as the ocean. This complexity motivates me to continue learning and deepening in the study of underwater acoustics.

When undertaking this study I have had the opportunity to develop a tool for the analysis of acoustic pollution from anthropogenic sources. This tool is useful as a good approximation ~~to~~ the noise generated by ship sources, and this could be an appropriate way to understand the risks of its impact. Finally, this study continues gaining insight in the present area of study in applying the above mentioned method in order to identify the impact as well as the response of these cetaceans concerning the pollution produced by shipping.

6 Future work

In this work, a tool has been developed to estimate the impact of ambient noise on whale trajectories. That is why over the next two months this method will be applied to multiple whale trajectories in the Mediterranean ~~trying~~ to identify the impact of this anthropogenic pollution on whales. The presence of chlorophyll will also be analyzed, to identify feeding areas, and the developed method will be applied to estimate the ambient noise in these areas.

Any research work carried out with a minimum of enthusiasm helps to clear up some unknowns about the subject but, in a simultaneous way, it generates new questions, new ideas and/or opens up new ways of working.

This is why it would be of great interest to study further the following aspects:

In relation to the AIS data it could be interesting to access directly to the large databases using MySQL to be able to calculate manually the speed of each one of them and to obtain with more accuracy the moment in which the ship sent its AIS position.

Regarding the propagation of sound a new line of research would be to study the propagation in the surface layer of the Mediterranean. This sea presents variations in the thermocline what can give rise to variations in the propagation. As we have seen before, sound propagation depends greatly on environmental variables and a variation in surface temperature can give rise to different forms of sound propagation.

An abstract of my work has been submitted for a poster presentation for the World Marine Mammal Conference 19 in Barcelona this December.

Nowadays, despite the large number of studies carried out over the last two decades in this area of research, there are still many uncertainties about the impact of noise on cetaceans. It is therefore necessary to continue the research with the purpose of a correct conservation of the species.

7 Limitations

At the end of this investigation, it is necessary to point out the presence of several limiting factors:

- The duration of the internship leads to the generation of many questions in the area of study. In spite of this, due to the short duration of the internship, it is not possible to go any deeper than what was previously established.

- Another limitation is based on the resolution of the AIS data.Vessels positions far from the coast will only be collected with the passage of the satellite. This results in a low temporal resolution for those ships whose position cannot be captured by the isolating earth stations.

- Also the model proposed by Ross neglects technical characteristics of each boat related to the design and the engine, which can modify the emitted noise.

- Estimating the impact on whales is limited at scientific level due to the absence of information about the individual's reception and perception of sound.

- Finally, it is important to emphasize the importance of research in this area for a better understanding the anthropogenic noise impact on our ecosystems.

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Appendix I

Analysis windows studied

The AIS data analysis window was chosen based on the results obtained from a study in which different windows were compared. The objective of this comparison is to obtain the most realistic values of ambient noise at a given time.

First of all, an increase in the analysis window is directly related to an increase in the number of vessels (Figure 10). It is also observed how the trends between the different analysis windows are very similar, (i.e. the days when the number of ships is high continue to have this high value when the window is changed). This is reflected in the high rates of positive correlation (r ≈ 0.7-0.9) between the different cases studied.

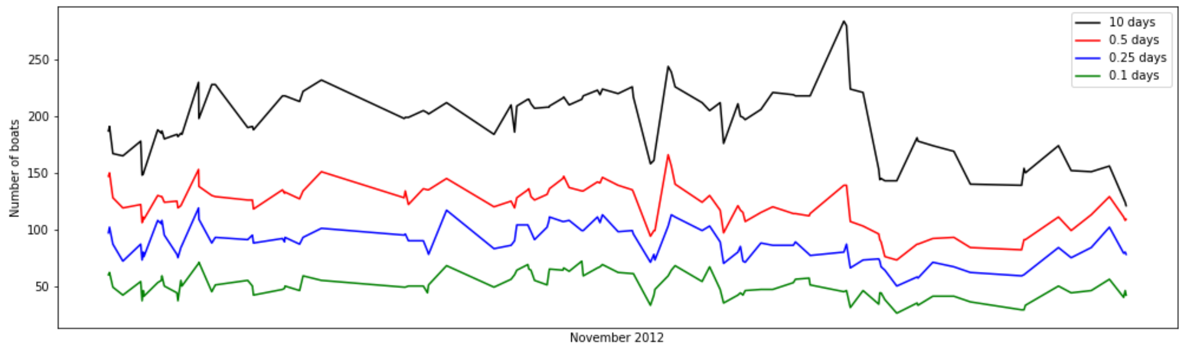

Figure 10: Number of boats taken into account for noise level estimation using different sizes of analysis window (10, 0.5, 0.25 and 0.1 days).

Secondly, it is analyze the ambient noise obtained using the different analysis windows (Figure 11). In the first place it is observed how the results are very with the exception of those obtained with the 0.1 days analysis window. This may be because the size of this analysis window is too small so that in many cases is not found any AIS position resulting in ambient noise zero. By using a window so small a problem is found when we analyze the farthest points of the coast where boat positions are not received by terrestrial stations (t-AIS). Therefore far from the coast, AIS data depends on the passage of the satellite (s-AIS), which forces to increase the analysis window due to the temporal resolution of the satellite. On the other hand there is a great correlation (r=0.94) between the ambient noise estimated for the window 0.5 days and 10 days. This similarity in the result is remarkable because of the difference in the number of boats taken into account to estimate the ambient noise it is much higher in the window of 10 days. This result may be due to the fact that by expanding the analysis window many of the ships detected are at a large distance which hardly contributes to the increase of the ambient noise or its speed is zero which would not contribute to an increase of the underwater noise.

Due to these results, a 0.5 days analysis window has been used in this study. This window allows to capture the AIS data collected by the satellite and presents ambient noise results very similar to a window reduced to half (0.25 days) and practically exact to larger analysis windows. In addition the AIS data are interpolated to obtain a greater precision of its position in an exact moment.

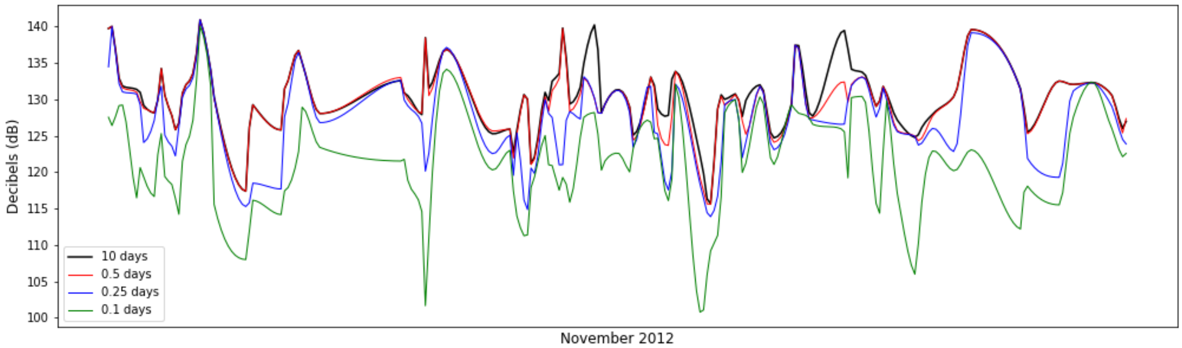

Figure 11: Estimated noise level using different window size (10, 0.5, 0.25 and 0.1 days).