Do fin whales avoid noisy area? ~~M~~ethod to analyse shipping noise in relation to trajectories.

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Western part of the Mediterranean Sea hosts populations of fin whales. Depending on the seasons, the animals are known to be located in the Pelagos Sanctuary (in the Ligurian Sea), and can migrate around Corsica and Balearic Islands. This area is also frequented by several shipping activities: regular ferry lanes, as well as tanker and super-containers of various sizes. These types of boat are major contributor to low frequency ambient noise in the Mediterranean. Such anthropogenic noise can cause masking of the communications of baleen whales, and may lead to the risk of impacts at the population scale.
In this study, we present a method where the relation between fin whales migration patterns and shipping noise levels is investigated. Positions of animals are retrieved using tagged data. Received levels are computed using Automatic Identification System (AIS) and propagation model.

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I. INTRODUCTION

Ambient noise in the ocean is the combination of sounds coming from natural and anthropogenic sources. 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[2] with dominant frequencies between 50 and 150 Hz.

~~It is possible to comment the~~ relation between ship radiated noise and shipping traffic and ~~their~~ implications for the long-term ocean noise levels. Ships generate noise and the world fleet has increased substantially since 1950. Shipping has been identified as the major contributor to ocean noise[1,3]. 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[3,4]. However, modern boats have increased size, propulsion power, and sophistication. New ship designs are less noisy[5]. Differences in the design of ships, result in variations in radiated noise. It has also be demonstrated how ship types with special designs influence directly the spectral characteristic of underwater acoustics. These studies are of great importance for more specific ship design recommendations in the future and for proper radiated noise estimation[6].

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[2,3]. The anthropogenic sound sources constitute a pressure on marine mammals.[7]; 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[3]. 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[8–10]. 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[11]. Noise levels are expressed in a

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logarithmic scale to approximate the perception of sound.

The main purpose of this work is to develop a method to analyze the influence of ships on the trajectory of whales. The method is for predicting shipping noise level and direction from the number of boats present at any given time at whales positions. The sources of noise coming from marine traffic data will be initially analyzed and then the propagation of sounds will be studied to estimate, with the aid of a model of ambient noise, the noise level and the noise direction at whales positions.

II. METHOD

This section describes the method based on two aspects: the AIS data input and the acoustic model used for field computations.

A. Source of noise

The AIS data will be used to get the ship information. To estimate the radiated noise levels, it is necessary to know the properties of the source, in this case vessels properties[2,12]. The AIS data provides for each ship in the selected ocean area the following parameters: ~~current~~ position, ground speed, ship type, Internationnal Maritime Organization number (IMO), ship length, etc. AIS data have been obtained from OCTRAF -tool to calculate maritime traffic density-[13] except for the speed and length of each vessel which have been tracked directly in the Lloyd List Intelligence (LLI) databases.

AIS data are provided by land-based stations (Terrestrial Automatic Identification System (t-AIS)) and satellite sampling (Satellite Automatic Identification System (s-AIS)). Stations 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.

B. Modeling shipping noise and their propagation

The ambient noise is obtained from the modelling of the sources (AIS data) and their propagation in the oceanic environment[14]. It is calculated using CABRAIS2[15], 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[16]:

$$RL(f,r,z_r) = SL(f) - TL(f,r,z_s) \tag{1}$$

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).[14] Equation (1) 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.

SL is computed using updated Ross model of ship noise. SL_{s0} is a basis spectrum in dB and dl and df are correction values depending on ship type. It also depends on the speed v (in knot) and the length l (in meter) of the ship[17].

$$SL(f,v,l) = SL_{s0} + 60\log(\frac{v}{12}) + 20\log(\frac{l}{300}) + df \times dl + 3 \tag{2}$$

To estimate TL the propagation medium has been 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 in the air and the air density. Water layer is characterized by its depth D, sound speed cw and density w; all three depends on the range r; cw and w depends as well on depth (z). Seabed is characterized by its sound speed cw, attenuation and density w; for rocky seabed, additional parameters for shear waves are added: shear wave speed and shear wave attenuation. The tool requires an environmental description including the bathymetry, the sound speed profile and the seabed composition. Environmental data are provided by SHOM database. TL is computed from the logarithmic expression of (3) for unitary source that is solved using a parabolic equation approach, a numerical method which discretize the medium in range and depth because environment changes in space (i.e. range dependant).[18].

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right) + \rho_w \frac{\partial}{\partial z}\left(\frac{1}{\rho_w}\frac{\partial p}{\partial z}\right) + \frac{\omega^2}{c^2(z,r)}p = -\frac{\delta(r)\delta(z-z_s)}{2\pi r} \tag{3}$$

The noise prediction tool compute RL for a receiver depth of 5 meters because fin whales tend to remain in surface waters, and only occasionally fin whales dive below 50 meters[19]. As fin whales audition is supposed to be more acute at low frequency, the RL are computed for frequency between 30 and 500 Hz.

C. Whale trajectories

Whale position data are necessary to apply our methodology. To obtain it, several adult individuals were tagged late summer 2012 at Pelagos Sanctuary[20]. These data have been obtained to expand the information about whale migration after the feeding season at the Pelagos Sanctuary[21]. Transdermal tag (Wildlife Computers molds 177 and 193) locators -Argos satellite tags[22–24]- placed on the dorsum or the dorsal fin of whales were deployed with a custom-modified pneumatic line thrower (Air Rocket Transmitter System^{TM} (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 on the surface.

III. EXPERIMENTAL RESULTS

This section reports on experimental results ~~on~~ shipping noise for a fin whale trajectory in the Western Mediterranean Sea during November 2012. November is ~~by all means~~ a good representative period of marine winter traffic. ~~The results obtained are shown below.~~

A. Ambient noise at whale position

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 1 ~~is represented~~ the trajectory that the animal followed in November.

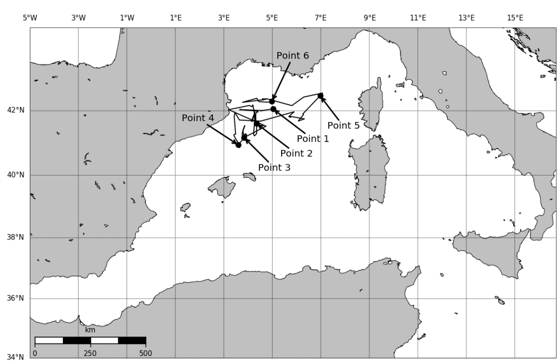

FIG. 1. Fin whale trajectory in November 2012 (tag number 12708) .

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 Western Mediterranean(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).

To estimate the ambient noise at a specific point of the Mediterranean Sea, vessels present in a range of 500 km around the area of interest were evaluated. 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.

~~Applying the model proposed by Ross (1976)~~, ship-radiated noise was determined[11]. Ambient noise was estimated at each of the points of the whale's trajectory (Figure 1). Figure 2 shows the spectrum at the six ~~points pointed of these~~ positions. These noise spectra are presented with centre frequencies of 30, 40, 50, 63, 80, 100, 125, 160, 200 and 500 Hz.

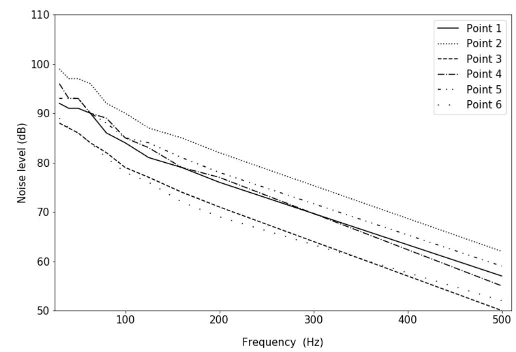

FIG. 2. Power spectrum level (dB re 1 μPa) of shipping noise in the range 0-500 Hz ~~in~~ six positions of the whale trajectory.

The total amount of energy received by the individual in November was also calculated at frequency 63 Hz. 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 3).

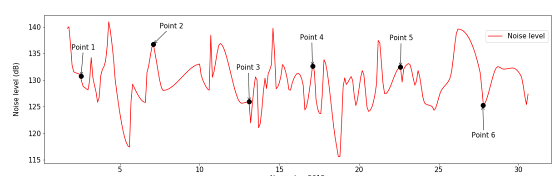

FIG. 3. Energy received at frequency 63 Hz during November 2012.

B. Ambient noise direction

We have also estimated the noise direction of arrival at whale positions. Applying the Ross model, the azimuth between the source and the whale position is estimated. With this data we are able to estimate the direction of noise reaching the desired point. Figure 4 shows the noise direction at the six ~~points pointed. Also,~~ we have represented the whale direction of depart. ~~This application of our method try~~ to understand if there is a relationship between the noise level ~~and the decision~~ and the decision made by an individual regarding his trajectory.

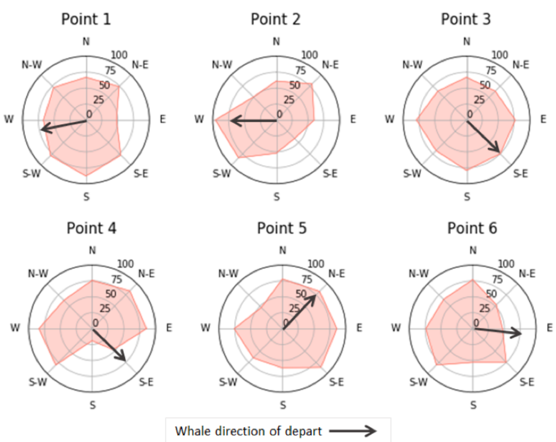

FIG. 4. Noise direction at whales positions and direction of depart of the position

IV. CONCLUSIONS

The method employed in the present study obtained noise level values close to reality[25]. However, there are still a number of uncertainties with this method. 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. 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. Boats speeds were obtained from the LLI database. The use of average speed gives us an appropriate value for noise estimation. But it is not reliable the value annotated is not measured at the exact moment the ambient noise is estimated.

The SL calculation using the Ross model has been used in many scientific investigations. But recently has been criticized by Wales and Heitmeyer, for them there is not a correlation between the ship length and speed and the source level, the two parameters that are taken into account to estimate marine traffic noise. These observations complicate noise level estimation from ships parameters[3]. The model proposed also neglects technical characteristics of each boat related to the design and the engine, which can modify the emitted noise.

The Mediterranean 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.

~~This method is useful as a good approximation of the noise generated by ship sources, and this could be an appropriate way to understand the risks of its impact. The objective of this study includes the physical-biological relationship as well as data analysis that can lead to address both disciplines.~~ From the data obtained in the present study it is not possible to establish a relationship, or a specific behavior, as a response pattern from the fin whale. Nevertheless, previous studies in this area have shown how this affects the behavior of whales.[26,27]

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.

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 method within this study to more whale trajectories and thus be able to identify and quantify the impact of shipping noises on their trajectories.

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