UNIVERSIDADE DO ALGARVE
UNIVERSITY OF ALGARVE

FACULDADE DE CIÊNCIAS E TECNOLOGIA
FACULTY OF SCIENCES AND TECHNOLOGY

"Modelling underwater acoustic noise as a tool for coastal management"

MESTRADO EM GESTÃO DA ÁGUA E DA COSTA
(CURSO EUROPEU)

ERASMUS MUNDUS EUROPEAN JOINT MASTER
IN WATER AND COASTAL MANAGEMENT
Documento Provisório

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FARO, 2009

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DATA / DATE: 31st August 2009

TÍTULO DA TESE / TITLE OF THESIS:

"Modelling underwater acoustic noise as a tool for coastal management"

JURI:

ACKNOWLEDGEMENTS

First of all, I am really thankful to the Erasmus Mundus Programme for allowing me to join it and giving me the possibility to widen my academic knowledge in an international atmosphere.

Special thanks have to be given to the Algarve University for accepting me in the developing period of my master thesis. Particular thanks go to all the people from the SiPLab for receiving me despite my rough knowledge in the area. Special attention for Sergio Jesus and Cristiano Soares for teaching me so much in a practically new area for me, and to Sofia Patricio from the Wave energy Centre for giving me the support and comprehension needed during all this time.

Finally, I have to mention all the people who came along with me since I arrived here. To my master colleagues, especially to Astrid, Bruna, Jeff and Marcia for giving me their support in every single moment both in academic and personal doubts and fears. Thanks to my flat mates here in Portugal, Michaela and Susana, for making life easier in the worst moments.

And most of all, I have to thank the most important people in my life, my family and my forever friends, which even being normally far away, are the most close to me every time. For you, most than anyone, for your corrections, opinions, encourage, advice, and in general for your unconditional love and for being always here for me. I cannot mention all of you, but you know who you are…

And thanks to all of you, whoever you are, interested in reading it.

RESUMO

A instalação de equipamentos off-shore para a produção de energia podem criar vários efeitos indesejados, entre os quais, o incremento do ruído acústico no meio marinho.

O objectivo principal deste trabalho é provar a viabilidade da modelização do ruído acústico submarino como ferramenta de gestão costeira na futura instalação dos equipamentos de energia das ondas.

A metodologia foi dividida em três passos. O primeiro consistiu numa caracterização do caso de estudo: caracterização ambiental, biológica e da fonte sonora, e a ilustração do esquema do marco DPSIR. Em segundo lugar, foi utilizado o programa MATLAB como interface para o modelo de propagação acústica de modos normais KRAKEN para a obtenção de mapas espaciais dos níveis do ruído acústico submarino. No terceiro passo, a validação do modelo foi feita, e as áreas onde o nível de ruído ficava acima dos limiares sonoros dos mamíferos marinhos foram obtidas.

Segundo os resultados do presente estudo, fica demonstrado que, mediante o uso da modelização do ruído acústico submarino, os valores da propagação podem ser preditos e a criação de mapas do impacto acústico facilita ao gestor a tomada de decisões. Tal poderá ser utilizado na minimização ou mitigação dos efeitos da introdução do ruído acústico submarino.

As acções de gestão costeira escolhidas para o caso do dispositivo Pelamis foram a criação de níveis de exposição segura, um maior estudo e monitorização das características tanto ambientais como do ruído, e a criação duma regulação apropriada para o ruído acústico submarino e a fixação de limiares sonoros fiáveis para a sua utilização.

Palavra-chaves: energia das ondas, limiares auditivos dos mamíferos marinhos, gestão costeira, acústica submarina, modelo de modo normal KRAKEN.

ABSTRACT

The installation of off-shore equipments for energy production may create undesirable effects, like an increase of acoustic noise on the marine environment.

The main objective of this work is to test the viability of modelling the underwater acoustic noise, as a tool for coastal management on future installation of wave-energy equipments.

Methodology was divided in three steps. The first step consisted on a characterization of the case-study: environmental, biological and noise source characterization, and the DPSIR framework scheme illustration. Within the second step, Matlab software was used for running KRAKEN normal mode model to obtain spatial underwater noise level maps. Within the third step, validation of the model was done, obtaining the areas where noise is over the hearing thresholds of marine mammals.

By the results of the current study, it remains demonstrated that, by the usage of modelling underwater acoustic noise, values of propagation can be predicted and the creation of maps of acoustic impacts facilitates manager decision-making. This will lead either to minimize or mitigate the effects of anthropogenic acoustic noise introduction.

Management actions chosen in the case of Pelamis device were mainly the creation of safe exposure levels, adjustment of noise source, further study and monitoring of either the environmental and noise characteristics, and the creation of appropriate regulation over marine acoustic noise and setting of reliable hearing thresholds to use.

Keywords: wave energy, marine mammals hearing threshold, coastal management, underwater acoustics, KRAKEN normal mode model.

“My interest is in the future because I am going to

spend the rest of my life there”.

Charles F Kettering.

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GLOSSARY OF TERMS

DPSIR Driver-Pressure-State-Impacts-Responses management framework.

EIA Environmental Impact Assessment

MPA Marine Protected Area

NOAA National Oceanic and Atmospheric Administration

ORED Off-shore Renewable Energy Device.

Rms root-mean-square

SPL Sound Pressure Level

TTS, PTS, SEL Temporary Threshold Shift, Permanent Threshold Shift, Sound Exposure Level

RELEVANT UNITS:

dB In underwater acoustics the most dominant unit is the decibel (dB), designating the ratio between two intensities or pressures expressed in terms of base 10 logarithm. The ratio r between two intensities or powers in decibels is given by 10log(r). The ratio r between two pressures or two voltages is given by 20log(r). Absolute intensities can therefore be expressed using reference intensity. Presently the accepted reference quantity is the intensity of plane wave having a root-mean square (rms) pressure of 1 micropascal (μPa).

TW, GW, MW, kW Terawatt, gigawatt, megawatt, kilowatt. Power multiple units for the Watt, International System of Units for Power. 1 W = 10^{-3} kW = 10^{-6} MW = 10^{-9} GW = 10^{-12} TW

Hz, kHz Hertz, kilohertz. Basic unit for frequency in the International System of Units, it is used for measuring any periodic event. 1 Hz = 1 cycle per second = 10^{-3} kHz.

1. INTRODUCTION

Dependence on energy is increasing constantly in current society. Almost every single action of our days depends on electricity. The energy requirements are getting higher, and the energy resources at present seem not to be sufficient to satisfy them. A severe diminishing of fossil fuel sources comes together with this increasing energy demand. Energy industries are forced to look for new energy sources capable to cover supply and need to resort to the harnessing of energies that were not really developed some few years ago.

Progressive concern about environment and the overexploitation of fossil energy resources, leads the industries to realize that these new energy sources need to be "clean and inexhaustible". Industries focus directly on renewable energies.

There are many renewal energies nowadays, but their implementation still requires numerous studies and development. Most of the available renewable energies by now, are more expensive than traditional fossil fuel reservoirs, but some of them will become economically feasible in the near future. Energies such as hydroelectric, solar, wind, geothermal, waste, marine energy and biofuels, could be presented as alternative sources to the traditional ones.

One of the major energy reservoirs is the ocean. No more than a quick view over the effects the ocean cause in marine dynamics is needed to realize the huge amount of energy hidden within the sea. Breakage and erosion of cliffs, coastal erosion processes, transformation of rocks into sand (accumulated in beaches afterwards) are evidences of this energetic and dynamic system.

Many projects related with harnessing marine energy are currently being under development or in investigation phase. Those projects include the creation, development and installation of mechanical systems which take advantage of the energy coming from tides, currents or waves. A number of these devices have been under study, and some of them have passed trial phases, and are already functioning.

A high quantity of shoreline, nearshore and offshore devices are currently appearing in our coasts. As technologies are improved, this quantity is growing very fast. All those devices have an inherent impact on the environment that needs to be deeply studied, due to the imminent requirements of a correct Environment Impact Assessment (EIA) involving directives, research, monitoring and management over renewal energy devices susceptible of being installed.

The following study will be focused on an Off-shore Renewal Energy Device (ORED) project which has been developed in Portugal by the Scottish firm Pelamis Wave Power. The goal of this device is to harness the energy from waves. The Pelamis device is an articulated system, and as such, it has an inherent noise that can propagate in the submarine medium. Underwater sound propagation can suffer different processes than those when propagating through the air. It is necessary to study the underwater noise propagation pattern to analyze the effects it can have in the marine environment.

Some marine organisms, such as marine mammals, use sound for many survival processes under the water. The introduction of external noise sources can interfere in those processes, and therefore cause effects on them. Those effects can range from light to severe, such as stranding and death.

It is important to determine the quantity and quality of impacts that the installation of an ORED in the coast can have over the marine mammals within the zone of implementation. In this direction, the following case study will try to determine whether the project proposed for the installation of Pelamis device is susceptible to cause determinant effects over the marine mammals in that zone. This will be done by the utilization of acoustic simulation tools to determine the underwater acoustic level distribution pattern.

The purpose of this project is to demonstrate the viability of simulation for its inclusion as a parameter for setting some references which are necessary for the decision-making process. As the study is performed, results are expected to give the manager the ability of presenting feasible guidelines for assessing the environmental impact of an ORED project.

2. RESEARCH/MANAGEMENT MOTIVATION AND OBJECTIVES:

The main objective of this study case is to determine the viability of using an underwater acoustic noise level modelling as a tool for coastal management, through series of questions:

Are the underwater acoustic noise levels produced by Pelamis, overpassing the thresholds set for the protection of marine mammals?

In order to demonstrate this viability we will follow three specific objectives:

1) Environment identification

2) Establishing an acoustic underwater noise level spatial distribution map.

3) Demonstration of the viability of modelling as a tool for coastal management, by the integration of this tool in a DPSIR framework scheme.

3. STATE OF THE ART:

3.1. Renewable energies. Introduction to wave energy.

Energy has traditionally been obtained by burning fossil fuels. Due to the current diminishing of fossil resources and the high prices reached as a consequence of this diminishing, together with the growing concern of society on environmental protection, energy industries were lead to look for new and more sustainable manners of obtaining energy.

An important event to take into consideration regarding the development of renewable energies is the carbon dioxide emission levels set by the Kyoto protocol. Countries all over the world are lead to establish directives and legislations for regulating emissions, and to the discovering of new and less polluting energies. According to a European Directive called Renewal Energy Directive (RED, 23 January 2008), utilization of renewal energies sources in energy consumption needs to increase up to 20% by 2020, which is also an important reason for the current interest in the development of renewable energies.

When these directives become effective, we will see the real peak of renewal energies development. The sun is presented as the main energy source, directly from sun rays, or its derived energy accumulated in wind and ocean. This way, solar energy and wind power are highly developed in a wide range of countries. However, marine energy remains a little bit at their rearguard because its development presents greater difficulty. Some other

Fig 1. Influence of waves over the coast. Boca do Inferno, Portugal.
(Source: www.picasaweb.com)

renewable energies appear at the same time, such as geothermal energy, or those related with biomass (biofuels, bioethanol, …).

The ocean is therefore, an obvious resource to take into account when looking for energy supplies. By simply looking at how waves can erode beaches, transform cliffs into simple rocks, or those rocks into sand, we perceive the power that is hidden in the ocean (Fig 1).

Ocean wave energy comes indirectly from the sun, as it is basically wind energy concentrated in marine surface. However, waves can also be produced by earthquakes or great objects crashing with sea surface (such as meteorites). Waves are defined as mechanical perturbations generated over the sea surface. These perturbations are produced by the mechanical stresses that are intervening in the ocean and altering its equilibrium. Waves generated by the wind are formed when it blows over the sea surface and a friction is produced. This friction over the surface lightly sweeps away the water, creating microwaves or wrinkles. These wrinkles offer a bigger surface for the wind to continue pushing them, and this allows the formation of waves. Power of waves increases with higher speeds, stability and duration of wind.

In high depths waves can travel almost without losing their energy. That is the reason why they can reach zones so far from their origin and the original atmospheric conditions in which they were formed. When approaching the coast, they start losing their energy due to interaction with the bottom. Although they lose energy with proximity of coasts, they generally reach coastal zones with still a high amount of energy. According to this idea, the energy carried by waves is sensitive to location and distance from shoreline. This has to be taken into account when setting the location of OREDs.

Wave energy is not homogeneously distributed in the planet, the most powerful waves are usually found at the eastern coast of continents and between 40 and 60 degrees latitude in both hemispheres, which could be the reason why United Kingdom and Portugal are perfect places for harnessing this energy (as shown in Fig 2).

Ocean wave energy is inexhaustible and has lower variation during diurnal and seasonal periods if compared with solar and wind power. It is more easily predicted. According to that, it is susceptible to be a constant and prolonged energy supply.

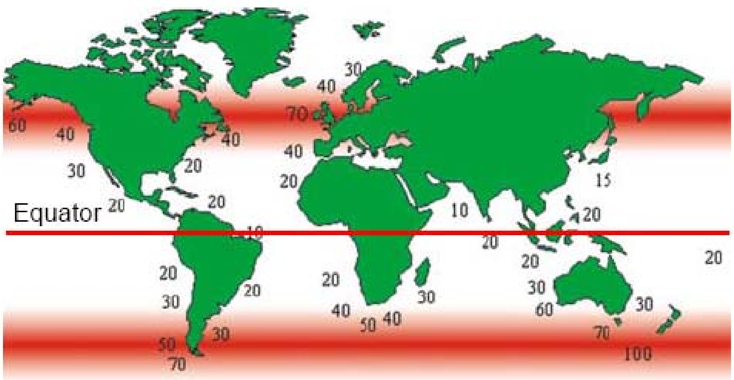


Fig 2. Worldwide distribution of wave intensities. Numbers show the intensity of coming waves in kW/m. (source: Leao Rodrigues) .

It is presented as a great enemy to climate change, in the way that it could be able to spare up to 1.2 billion tons of carbon dioxide per year, as claimed by the British Energy Association.

According to a study performed by Leao Rodrigues (supported by the department of electrical engineering of Universidade Nova de Lisboa), “the global theoretically energy from waves correspond to $8 \cdot 10^6$ TW/year, which is about 100 times the total hydroelectricity generation of the whole planet”. He says, “The global wave resource due to wave energy is roughly 2 TW and Europe represents about 320 GW, which is about 16% of the total resource. However, for various reasons, it is estimated that only 10 to 15 % can be converted into electrical energy, which is still a vast source of energy, able to feed the present all world”.

However, despite solar and wind power having been widely extended and deeply studied, and appearing as viable at present, marine energy has always stayed in their shadow, due to its difficulty of harnessing. Nevertheless, there are many studies which have been carried out in the last decades on marine energy sources and their feasibility, becoming a promising electricity source. Numerous marine energy harnessing devices have been widely presented either shoreline, nearshore and offshore, such as Oscillating Water column, Limpet, Aquabuoy, Oyster, Pelamis Wave Energy Converter, Wave dragon, to cite some of them (examples shown in figures 3, 4, 5).

Fig 3,4,5. Figures showing the Limpet, Wave dragon, and Oyster devices respectively. Source: Limpet uses power of marine waves on-shore, wave dragon is an off-shore device, and Oyster system is placed on the sea bottom. Sources: www.wavegen.co.uk , www.wavedragon.net, www.aquamarinepower.com.

Some of these devices appear finally just as theoretical ideas, but some others overpass all the trials and experimenting phases and are already implemented into the field. There have been many ideas for marine energy supply, but technical and practical problems normally arose when these devices were studied in greater depth. One of the main problems, for example, is the fact that those new energy harnessing offshore devices underestimate the power of the sea, and then present a lack of capacity to resist its force.

The current study focuses on OREDs, therefore offering the availability of a higher energy resource, as they are situated offshore. Waves on offshore zone, are supposed to be more energetic than those reaching the coastline. That is the reason why any device located offshore will be susceptible to harness more energy from waves than those located along the coastline.

Though they imply more difficult access, need of sophisticated technologies, the added difficulty of energy transmission to land, and although nowadays there are less environmental constraints, prototypes have still to be tested and research on them is being carried out.

Although firms and investors want to improve these projects, and higher development and studies are being carried out, installing the devices is also expensive, and this energy can not normally compete with the great oil companies' economic infrastructures. But as soon as extraction of marine energy becomes economically profitable, there is no doubt that it would become a great contribution for the worldwide energy supply, as the length of coasts susceptible of accommodating this kind of devices is very high. So there are some advantages of wave energy, as operation and maintenance is not so expensive, no waste is produced, the liquids used do not contain any pollutant and no toxic paints or treatments are used. But there are also main disadvantages: this energy depends totally on wave intensity and thus on installation location, and this can affect the environment by generating underwater acoustic hum, which can cause many harmful effects on environment. It is paramount to remember that the importance of wave power does not rely on the supply itself, but on an alternative to reach the energetic requirements at local and regional scale, combined with other energy sources.

3.2. General aspects of underwater acoustics.

Sound is a form of mechanical energy, a vibration that travels as a wave by causing pressure changes in a fluid. Sound propagation, as said in the previous sections, is not the same as in the air when the propagation channel is the ocean. The main importance of sound within the ocean resides in the fact that the ocean is transparent to acoustic waves, while practically opaque to electromagnetic radiations. It seems to be the only radiation that can be propagated through long distances within the sea, especially at lower frequencies.

The main variable affecting sound propagation in the ocean is sound speed. Sound celerity is normally related to density and compressibility. Sound celerity in the ocean is presented as an oceanographic variable, which is a function of three main parameters: depth, salinity and temperature. Sound speed increases both with temperature and pressure (Fig 6). This dependence can be seen in the empirical simplified expression for the determination of sound celerity (Jensen & Kuperman, 1994):

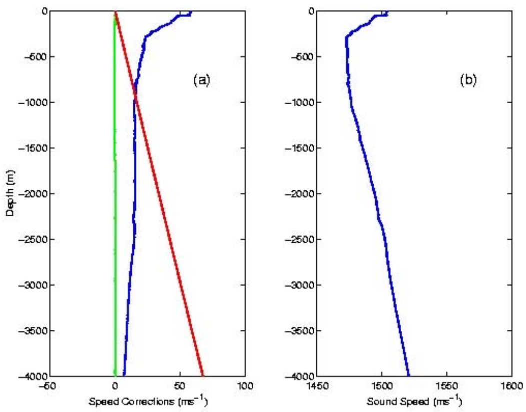


Fig 6. General variation of sound speed with salinity (green), pressure (red) and temperature (blue) in fig (a) and sound speed resultant in fig (b).

$$c = 1449.2 + 4.6\,T - 0.055\,T^2 + 0.0029\,T^3 + (1.34 - 0.01\,T)\,(S-35) + 0.016\,z; \quad \text{(Eq. 1)}$$

where temperature must be given in Celsius, salinity in parts per thousand and depth in meters.

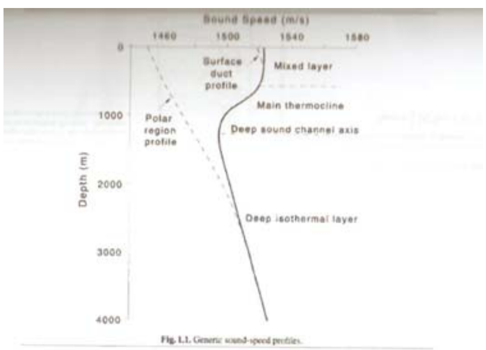


Fig 7. Generic sound speed profile within the ocean water column. (Source: Jensen & Kuperman, 1994)

Then it also varies with season, diurnal changes, geographical location, and time, as these parameters affect the oceanographic conditions of the water column (affecting indirectly the three parameters mentioned above: T, S, z).

Special attention has to be paid to the sound speed profile in the ocean, noting the high decrease on its values in the existence of thermocline, however increasing with depth since the deep sound channel axis. A typical value of 1500 m/s is normally given, even though sound speed varies with oceanographic parameters, and is not homogeneously presented within the ocean. A generic sound speed profile is shown in Fig 7. There is a decrease on the sound profile from surface to depth due to decreasing temperature (higher in surface because of sun heating, decreasing because of cooling with depth). When temperature becomes mainly constant, pressure is the main factor affecting sound speed, and as it increases linearly with depth, sound velocity also increases linearly. Salinity does not have a great impact in open ocean, where no significant changes occur, while it can be important in shallow waters, estuaries, or closed areas, in other words, in those parts of the ocean where an important halocline is occurring.

There is a region where the sound is trapped (regions of low sound speed), which is known as the Deep Sound Channel, whose axis is at the sound speed minimum. Sound travelling trough the ocean will suffer a transmission loss due to the sum of three processes:

Transmission loss is a standard measure for underwater acoustics of the change in signal strength with range, and is defined as the ratio in decibels between the acoustic intensity I(r,z) at a field point and the intensity I_0 at 1m distance from the source (Jensen & Kuperman, 1994):

$$TL = -10 \log (I(r,z)/I_0) = -20 \log (|p(r,z)| / |p_0|) \quad [\text{dB re 1 m}] \quad (\text{Eq. 2})$$

Where the intensities and pressures are measured at a field point (I(r,z);p(r,z)) or at 1 m distance from the source (I_0, p_0). For this equation the assumption of the proportional intensity to the square amplitude for pressure has been taken into account.

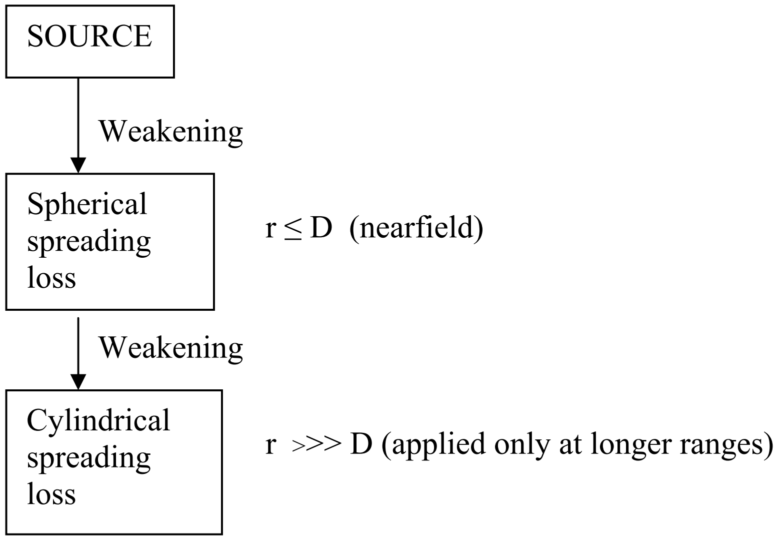


Fig.8. Scheme showing the type of spreading loss from the source depending on the range.

Spherical spreading loss: TL = 20 log r [dB re 1m] (Eq. 3)

Cylindrical spreading loss: TL = 10 log r [dB re 1m] (Eq. 4)

(Equations 3 and 4 taken from Jensen & Kuperman, 1994).

Total loss in the ocean will be higher due to both the attenuation of sound in the water, and to various reflection and scattering losses. The most important loss mechanisms are: Volume attenuation, bottom reflection loss; surface, bottom and volume scattering loss.

It is important to highlight that the unit of intensity in underwater sound is the intensity of a plane wave having an rms pressure equal to 1 micropascal. The decibel (dB) is the unit that gives us an idea of the logarithm of the comparison of two quantities of sound expressed by their intensities. It is also important to remind that standard reference pressures for water and air are not the same, and thus noise levels from both mediums cannot be compared directly. And as decibels are logarithmic values, it must be said that two noise levels cannot be simply summed.

There remains a big importance in treating the ocean bottom accurately in the numerical models. Numerical models depend on factors such as source-receiver separation source frequency, and ocean depth. Bottom interaction is in general unimportant for large ranges, high frequencies, and deep water, but crucial for short-range, low frequency or shallow-water propagation.

Table 1.General types of man-made sounds in the oceans

TRANSPORTATION	GEOPHYSICAL SURVEYS
· Aircraft(fixed-wing & helicopters)	· Airguns
· Vessels(ships & boats)	· Sleeve Exploders & Gas Guns
· Icebreakers	· Vibroseis
· Hovercraft and vehicles on ice	· Other techniques
DREDGING AND CONSTRUCTION	**SONARS**
· Dredging	
· Tunnel boring	
· Other Conbstruction Operations	**EXPLOSIONS**
OIL & GAS DRILLING & PRODUCTION	**OCEAN SCIENCE STUDIES e.g.**
· Drilling from islands and caissons	· Seismology
· Drilling from bottom-founded platforms	· Acoustic Propagation
· Drilling from vessels	· Acoustic Tomography
· Offshore oil and gas production	· Acoustic Thermometry
(Source：[2] p.102)	

Fig 9. General types of man-made sounds in the ocean. Source: Kakuta, 2004.

Sound will be naturally produced by other noise sources, and there will also be an introduction of noise into the environment derived from human activities.

Sounds which will naturally be produced within the ocean will create the existence of a constant ambient noise within it. As natural sound sources into the ocean we find: earthquakes, volcanic tremors, lightning to the sea surface, wind and waves, and the voices, calls, songs and other sounds made by marine life. All the noise produced by human activities introduced into the ocean environment is known as anthropogenic noise. As anthropogenic sources we have: vessels, resource exploration and exploitation activities, fishing operations, coastal development works, scientific surveys, military operations, and a wide variety of sources (Fig 9 and 10).

Table 2. Natural and human-made source noise comparisons.

Nosie Source	Maxiumum Source Level	Remarks	Reference
Undersea Earthquake	272 dB	Magnitude 4.0 on Richter scale (energy integrated over 50 Hz bandwidth)	Wenz, 1962.
Seafloor Volcano Eruption	255+ dB	Massive steam explosions	Deitz and Sheehy, 1954; Kibblewhite, 1965; Northrop, 1974; Shepard and Robson, 1967; Nishimura, NRL-DC, pers. comm., 1995.
Airgun Array (Seismic)	255 dB	Compressed air discharged into piston assembly	Johnston and Cain, 1981; Barger and Hamblen, 1980; Kramer et al., 1968.
Lightning Stike on Water Surface	250 dB	Random events during storms at sea	Hill, 1985; Nishimura, NRL-DC, pers. com., 1995.
Seismic Exploration Devices	212-230 dB	Includes vibroseis, sparker, gas sleeve, exploder, water gun and boomer seismic profiling methods.	Johnston and Cain, 1981; Holiday et al., 1984.
Container Ship	198 dB	Length 274 meters; Speed 23 knots	Buck and Chalfant, 1972; Ross, 1976; Brown, 1982b; Thiele and Ødegaard, 1983.
Supertanker	190 dB	Length 340 meters; Speed 20 knots	Buck and Chalfant, 1972; Ross, 1976; Brown, 1982b; Thiele and Ødegaard, 1983.
Blue Whale	190 dB (avg. 145-172)	Vocalizations: Low frequency moans	Cummings and Thompson, 1971a; Edds, 1982.
Fin Whale	*188 dB (avg. 155-186)*	*Vocalizations: Pulses, moans*	*Watkins, 1981b; Cummings et al., 1986; Edds, 1988.*
Offshore Drill Rig	185 dB	Motor Vessel KULLUK; oil/gas exploration	Greene, 1987b.
Offshore Dredge	185 dB	Motor Vessel AQUARIUS	Greene, 1987b.
Humpback Whale	180 dB (avg. 175-180)	Fluke and flipper slaps	Thompson et al., 1986.
Bowhead Whale	180 dB (avg. 152-180)	Vocalizations: Songs	Cummings and Holiday, 1987.
Right Whale	175 dB (avg. 172-175)	Vocalizations: Pulsive signal	Cummings et al., 1972; Clark 1983.
Gray Whale	175 dB (avg. 175)	Vocalizations: moans	Cummings et al., 1968; Fish et al., 1974; Swartz and Cummings, 1978.
Open Ocean Ambient Noise	74-100 dB (71-97 dB in deep sound channel)	Estimate for offshore central Calif. sea state 3-5; expected to be higher (= or > 120 dB) when vessels present.	Urick, 1983, 1986.

Note: Except where noted, all the above are nominal total broadband power levels in 20-1000 Hz band. These are the levels that would be measured by a single hydrophone (reference 1 μPa @ 1 m) in the water [7].

Fig.10. Natural and human-made source noise comparisons. Source: Kakuta, 2004

Shallow water

For the acoustical propagation of sound in shallow waters, the ocean appears as a channel, where the upper part is limited by the sea surface and the lower part by the sea-floor. Both limits present a roughness related with scattering and attenuation of sound. The current situation is that wavelength is comparable to water depth, and depending on the relation between them sound will be propagated in several different manners. This is related with the pathway followed by the sound transmission as it encounters both limits being either refracted, reflected or absorbed. Thus, surface, volume and bottom properties are all important. They vary spatially and generally are not well enough known for an accurate prediction. Many reflection and absorption processes are related with those boundaries in the case of sound propagation through shallow water.

Cylindrical spreading is improved at shorter ranges, and the increased boundary interaction degrades transmission at longer ranges (Jensen & Kuperman, 1994).

Sound speed profile varies with currents, heating and cooling, and tends to be irregular and unpredictable. Sound speed for shallow water is known to be range dependent, which means that it is not horizontally stratified, and it can not be considered in range and depth separately, which complicates the calculations.

Many bottom interactions occur in shallow water, which appears to be very important in the determination of sound propagation in this case. Bottom presents layering, with different densities and sound speeds, the porosity of materials affecting the density and thus propagation within the water column. Absorption from bottom increases with increasing frequency. Geo acoustic parameters are normally not particularly known for their inclusion in the sound propagation studies. All the characteristics mentioned above, converts the sound propagation in shallow waters, in a complex task for study.

3.3. Modelling processes

Measuring and researching acoustic signals in the ocean, normally requires extensive equipment. Measuring also present a high difficulty according to the properties (range dependence, complicated dependence on acoustic frequency) and inaccessibility of the means. That is the reason why modelling acoustic signals and being able to make predictions trough the utilization of modelling processes is so important.

Modelling the underwater acoustic propagation is made basically by solving either the wave equation or the Helmholtz equation (reduced wave equation). This procedure implies a high complexity due to the various acoustical environmental conditions described in the previous section. Some of those variables could be sound speed profile, depth and range variations, bottom characteristics related with the appearance of shear, presence of interface waves, and many others. Resolution of the wave equation would imply the determination of the sound field (intensity and phase). Thus, a variety of numerical techniques has been developed, even though none of them is capable to include all possible environmental conditions, frequencies and transmission ranges of interest. (Buckingham, 1992)

Most of the propagation models made until the present have been considering sound propagation in 2D. This means a limitation in shallow waters, where obliquely incident rays are reflected from the bottom into a different vertical plane. That is called "horizontal refraction", and requires a 3D modelling, where the sound field is given in depth and range, but also in azimuth. The so called 2 ½ D or Nx2D models are intermediate solutions which give the field in range and depth, but applied over a large number (N) of bearing angles. (Buckingham, 1992)

Five principal deterministic models can be mentioned for describing sound propagation within the sea (deterministic because they neglect the effect of fluctuations in the sound speed profile by small scale turbulences, internal waves, etc):

- Ray tracing.
- Normal mode techniques.
- Green's function solutions.
- Finite element methods.
- Parabolic equation models.

Their principal characteristics are described in Table 1, where advantages and disadvantages, and some examples of each model are shown.

Model name	Advantages	Disadvantages	Examples, codes
Ray models	- Advisable for deep water problems, where only a few rays are significant. - Fast to compute. - Pictorial representation through ray diagrams of the rays in the channel. - Easy to accommodate directionality of source and receiver. -Rays can be traced through range-dependent sound speed profiles and over complicated bathymetry.	- Difficulties in keeping track of phase at bottom reflections. - So many rays have to be traced. - Computations must be performed at all ranges out of the receiver. - Wave effects (diffraction and caustics) cannot be handled satisfactorily→ limitation for bottom interactions and low frequency propagation. - May generate false caustics and produce shadow zones. - Shear waves in an elastic bottom are beyond the capabilities of ray tracing models.	GRASS (Germinating Ray Acoustics simulation System), PLRAY (ray Propagation Loss), FACT (Fast Asymptotic Coherent Transmission), RAYMODE.
Normal mode techniques	- Mode functions do not have to be calculated at all intermediate ranges between source and receiver. (mode functions in deep, stable part of the water column are calculated and stored in advance, saving computation time). - It can be used either for range-independent environments (coupled model), or range-dependent environments (uncoupled models) if range dependence is low. - Suitable for low frequency or shallow water applications where the number of models is small.	- Most of them do not include branch line contribution, not handling shear in the bottom.	FFP (Fast field program) sometimes required Coupled model: COUPLE Uncoupled models: SNAP, SUPERSNAP, KRAKEN

Model name	Advantages	Disadvantages	Examples, codes
Green´s function solutions	-Give the full equation for the field in a horizontally stratified medium. -Fluid layers and extended to include homogeneous solid layers capable of supporting shear. - SAFARI provides an excact solution of the Helmholtz equation (except within a wavelength or so of the source)	- Need of a horizontally stratified medium.	FFP (Fast Field Program) SAFARI
Finite element methods	- Able to cope with variations of horizontal range dependence environments, even when range dependence is too Fast and incluyes shear → enables it to fluid sediments - Could be in principle extended to 3D	- At the operating frequencies appears to be extremely demanding of computer time and memory (limited to relative low frequencies and un realistically short ranges) - Mainly applicable to low frequency problems (blow 100 Hz) - Difficulties concerning the truncation of the finite element mesh somewhere below the sea floor.	FOAM, ISVRFEM
Parabolic equation models	- Codes whose starting point is a parabolic equeation →Alternative to “exact” numerical propagation models, with their heavy computational overhead. - Give the field over he entire water column with no additional effect and they can handle range-dependent environments.	- Lack of precision - No easy way to incorporate shear - Impractical in high frequency regimes, as run time increases rapidly with higher frequency. - Inability to cope with backscattered radiation. - Grazing angle limitation.	PAREQ, IFD (N), IFD (W)

Table 1. Principal characteristics of the various acoustic propagation models already existing. Source: Urick,1983.

3.4. Main effects of underwater acoustic noise over the environment.

As said in the previous section, marine environment is constantly exposed to an ambient noise. Marine organisms are used to this ambient noise caused by natural sources. The problem appears with the introduction into the environment of an additional man-made noise.

Any organism has the necessity of communicating with its environment, and in terrestrial animals, this communication can be done through the five senses. In the marine environment, light is attenuated in the first meters of depth, being practically inexistent reaching certain depths in the ocean. As a result, vision is a limited sense in the ocean. Nevertheless, sound, as seen in the previous section, is in comparison quite easily propagated within the medium, which in fact, leads it to be presented as the basic communication tool among some marine organisms and their environment. Therefore, there are numerous marine organisms, such as marine mammals which use sound as their principal sense for the so called "echolocation", inter and intraspecies communication, and detection of preys and predators.

Numerous studies have been carried out to determine the effect that anthropogenic underwater sound is capable to cause over marine mammals. By the middle of the 20th century seismic prospecting, marine transport by vessels, sonar, explosions and industrial activities are presented as the main anthropogenic underwater acoustic noise sources in the ocean, and are getting more and more frequently encountered in the medium. All those sources generate a noisy ocean with a high short-term acoustic pollution, which requires urgent monitoring. This noise appears to be interfering in communication, orientation and feeding of marine mammals. Conflict with evolutionarily-adapted sound-sensing marine mammals seems inevitable (Lopez et al, 2003). Also fish use sound for communicating, principally in the mating process, though there is much less research on the effects that introduction of noise can cause in this case.

A general description of the way marine mammals use sound will be given in this section. First of all, adaptations in marine mammals are not reduced to the use of sound as a hearing sense, but appear also in the morphology of their auditive system. In this sense, they present differences in their organs compared to terrestrial mammals. Their inner ear is similar, while their medium ear is largely modified and their external ear is almost inexistent.

Most of marine mammals studied use echolocation, which means they use sound for exploring their surrounding and for communicating. There is a wide range of frequencies in which marine mammals can produce and hear sounds, depending basically on the physical properties of the environment.

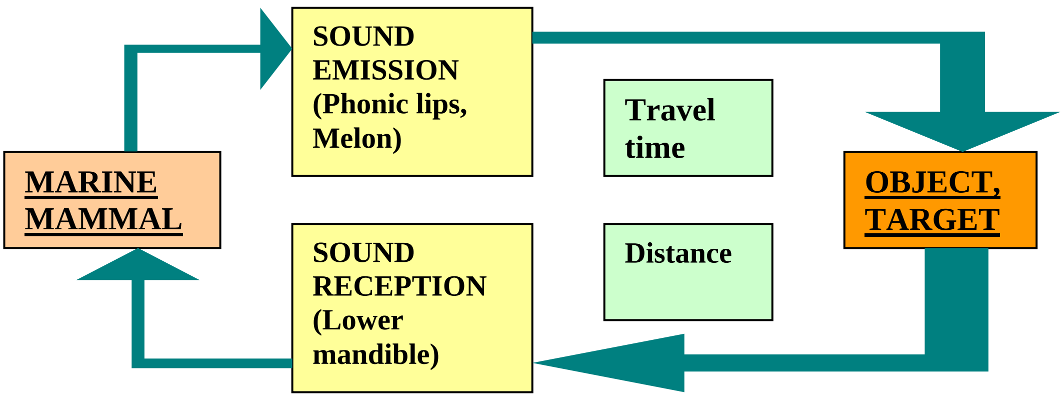


Fig 11. Easy scheme showing the functioning of echolocation. A certain acoustic signal is emitted by the marine mammal, and is reflected when encountering the target, returning to the animal and being perceived by it. Taken into account the travel time in between emission and reception, the distance can be obtained.

The functioning of the echolocation system is quite easy (simple scheme in Fig 11). The marine mammal creates a sound, which travels trough the ocean until it is reflected by an object and returns to the cetacean, which receives the signal. Depending on the time the sound takes to go and return, and depending on the properties of the sea the distance between source and object is known. Sounds are produced as pulses, originated in the nasal cavities, and transmitted to the water trough the melon. After encountering the object and coming back, the sound reflected is absorbed by the lower mandible, and transmitted this time to the medium ear by a continuous fat body. (Clarifying schemes in Fig 12, 13, 14).

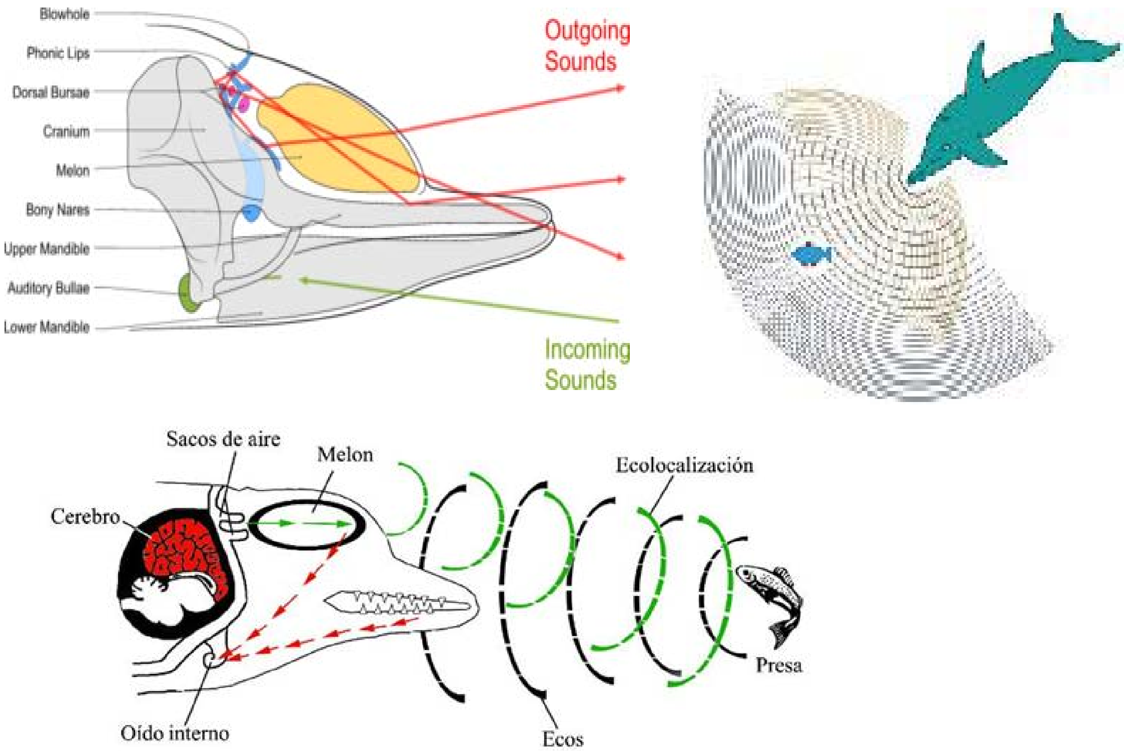


Fig 12, 13, 14. Pictures showing parts of morphology of marine mammals head, and examples of simple schemes of sound emitted and received by marine mammals. Modified from Castro P y Huber ME, *Marine Biology*, Mc Graw Hill Ed.

After several studies, carried out mainly by researches concerned about the protection of marine mammals, stranding events and injuries in the auditive systems of cetaceans have been correlated with the introduction of anthropogenic sounds from different sources. These effects range from mortality of cetaceans due to stranding on the coast caused by loss of direction, to injuries in the auditive system, which can range also from minor and temporally, to severe and permanent (Lopez et al, 2003). The threshold from effects proposed by those scientists, are based on these two types of injuries. Nevertheless, current scientific knowledge regarding the effects on marine mammals and their habitat is not enough to understand the relation between frequencies, intensities and duration of exposure and the cause of adverse consequences. All this implies that it is necessary to perform more exhaustive and deep research on the effects of underwater acoustic noise on cetaceans. This research will be used to develop and implement either mitigation methods, limits for activities causing noise in certain zones where cetaceans concentrate, and objective parameters for advising conservation of marine biodiversity design, needed for establishing international and European norms on acoustic marine pollution (Greenpeace and Spanish Cetaceans Society, 2003)

The principal impacts caused by the introduction of underwater acoustic noise into the environment can be divided mainly into three categories: 1) masking, 2) disturbance, 3) effects on sensitivity of hearing.

So, the main studies carried out on cetaceans were “focused primarily on understanding criteria and thresholds for physiological and behavioural effects, location and abundance of marine mammals, and sound source characteristics and propagation paths” (Hastings, 2008). Some standard reference levels were set after those studies, in relation to sound intensity and effects on marine animals. Those effects could be tissue damage, changes in hearing sensitivity and/or changes in behavioural aspects, which are related with age, sex, activity engaged in at the time of exposure. Subsequently to these bioacoustic experiments, some threshold values are fixed for the different species, depending on the duration of effects:

- Temporary threshold shift (TTS) → if hearing threshold returns to the pre-exposure level
- Permanent threshold shift (PTS)→ if threshold does not return to pre-exposure levels.

Both TTS and PTS, are correlated with the so called sound exposure level (SEL), measured for several different types of sound sources. (Hastings, 2008).

3.5. Acoustic noise policies and implications on management.

According to the 1982 United Nations convention on the Law of the Sea (UNCLOS), "States have the obligation to protect and preserve the marine environment", as cited in Article 192. This is the first time that this obligation is explicitly required in a global treaty.

By this convention marine pollution is defined as: "the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities". Noise is a form of energy, such as heat and radiation, which is introduced into the sea by different ways. Its deleterious effects on marine animals have been studied in several occasions, resulting in the ability of loud sounds to injure or kill marine mammals. For those reasons, noise can be considered a pollutant according to the convention. Heat and radiation were previously studied and regulated in other occasions, but noise has not been included as a pollutant in any convention till this point.

Noise must be treated as a transboundary pollutant, and the UNCLOS is also focusing its effort on this part, by Article 194: "States shall take all measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other states and their environment, and that pollution arising from incidents or activities under their jurisdiction or control does not spread beyond the areas where they exercise sovereign rights in accordance to this Convention". And referring to the cooperation between nations or regions cited in Article 197, "States shall cooperate on a global basis and, as appropriate, on a regional basis, directly or through competent international organizations, in formulating and elaborating international rules, standards and recommended practices and procedures consistent with this Convention, for the protection and preservation of the marine environment, taking into account characteristic regional features".

Article 204 on the UNCLOS refers to the need for monitoring and research. Article 206 refers to the necessity of previous environmental plans before the activities take place.

Although UNCLOS gives the perfect framework for pollution prevention and is susceptible to include new forms of pollutants such as noise (also because a part referred to marine mammals protection is included), it is still not specific about the requirements for States to deal with these pollutants. It does not treat the problem of underwater acoustic noise itself.

About the existing regulatory framework on underwater acoustic noise some facts are found which turns it regulation difficult: its transboundary nature, and the lack of knowledge regarding its effects. There are still no international agreements or international organizations responsible for that.

Nevertheless, an overview of the regulatory framework on underwater acoustic noise (McCarthy, 2004) will be done, through a brief view on the existing cooperative agreements and international bodies with an important role involved:

- United Nations Environmental Programme (UNEP), does not refer to underwater acoustic noise as a pollutant, but refers to it in its publication "Marine Mammals: Global Plan of Action".
- The international Maritime Organization (IMO), does not include underwater acoustic noise as a pollutant on its main Protocol of 1978 (MARPOL); but includes the creation of Particularly Sensitive Sea Areas (PSSAs), which include even noise among the possible pollutants within the marine area.
- The International Whaling Commission (IWC), which addresses the disturbance noise effects of vessels on marine mammals.
- The International Seabed Authority (ISBA) shows no legal standards with reference to noise and acoustic disturbances.
- The European Union, protects marine mammals by the Council Directive 92/43/ECC on the conservation of Natural Habitats and of Wild Fauna and Flora, but makes no explicit reference to noise. The European Union perceives the necessity of the development of international agreements for the regulation of noise in the ocean.

The latest news related to acoustic noise pollution from the European Commission Research (European Commission Research News, 2004) is presenting actions for the creation of a European normative related to the air noise pollution, but no reference to acoustic noise pollution is done. A European Directive related with sound (European Environmental Noise Directive, DIRECTIVE 2002/49/EC) was found to be related only with air noise pollution, with no reference to underwater acoustic noise pollution was made but only references to human impacts.

More information about research over acoustic noise and its impact on marine mammals has currently been done by USA, most of it related with specific sound systems, such as military sonar, Surtass LFA, and others. Committees on Sound and Marine Mammals have been established and produce reports on the state of knowledge and recommendations for changes in the regulatory process as well as facilitating tools and supporting the evaluation of effects of underwater noise. (Hastings, 2008). It is in the USA where most legislative development for underwater acoustic noise has been done; some important protection figures related with marine mammals and sound appears with the Marine Mammals Protection Act (MMPA), the Endangered Species Act (ESA). They have both joined the NOAA for running some programmes of research and protection which have been derived in some legislation forums and characters. There is a report by the NOAA symposium of 2004, “Shipping Noise and Marine Mammals”, which makes references to underwater acoustic noise, but only the one produced by maritime traffic.

Returning to the European case, the European Cetacean Society presents a statement on marine mammals and sound on its web site as follows:

1) Research on the effects of man-made noise on marine mammals is urgently needed, and must be conducted to the highest standards of science and public credibility, avoiding conflicts of interest.

2) Non-invasive mitigation measures must be developed and implemented as soon as possible

3) The use of underwater powerful noise sources should be limited until their short- and long-term effects on marine mammals are better understood, and they should not be used in areas of importance for cetaceans.

4) Legislative instruments that help to implement both national and European policies on marine noise pollution must be developed.

Underwater acoustic noise resulting from the installation of off-shore devices appears as a significant pollution source in the environment, but still not proper attention has been paid to the anticipated impact that man-made noise can produce. (Kakuta, 2004)

There has been a workshop in San Sebastian (SPAIN) in 2007 by the European cetacean society and the UNEP/ASCOBANS, where relation between wind farms and cetaceans has been deeply discussed, but still, not even the relation with other ORED (Off-shore Renewable Devices) has been studied.

"In the absence of data, scientists and government regulators have always been precautionary in recommending noise exposure criteria for marine animals" (Hastings, 2008)

As an example of some threshold criteria "NOAA Fisheries set a sound pressure limit of 180 db re 1µPa that could not be exceeded for mysticetes and sperm whales, and 190 db re 1µPa for most odontocetes and pinnipeds" (Hastings, 2008)

"Finally, in order to begin to understand "biologically significant" effects on behaviour as defined within the framework outlined in the latest NRC report (NRC, 2005), multi-disciplinary basic research is needed to understand the primary and synergistic effects of sound on marine ecosystems, including crustaceans, corals, sponges, sea grasses, and all other living things in the sea. Designing experiments to learn about potential changes in the marine ecosystem, including animal habitats, over long periods of time is a very difficult task. But changes in the behavior and habitats of marine animals over the long term could significantly affect their populations as well as the overall health and stability of the marine environment" (Hastings, 2008)

Even though there is a lack of concrete and reliable legislation over acoustical impacts on marine mammals, there are several protection figures related to them. Those legislative figures on marine mammals could also be used in management plans for industrial projects.

" One way to assess the impact of ocean noise is to consider whether it causes changes in animal behaviour that are "biologically significant", that is, those that affect an animal´s ability to grow, survive, and reproduce." (NRC, 2005)

In this direction, main protective figures over cetaceans will be named (Atlas of Cetacean, 2003):

- Bern Convention, implemented in 1982: common dolphin, bottlenose dolphin, harbour porpoise, blue whale, humpback whale, northern right whale and bowhead whale are under strict protection by Appendix II.
- Bonn Convention, implemented in 1983: blue whale, humpback whale, bowhead whale, and northern right whale, are under strict protection in Appendix I, on the Convention of Migratory Species.
- EU Habitats and Species Directive (1992): Annex 2 includes harbour porpoise and bottlenose dolphin as `animal and plant species whose conservation require designation of Special Areas of Conservation´
- OSPAR, Oslo-Paris Convention (1992): bowhead whale, northern right whale, blue whale and harbour porpoise are included in its first list of threatened and declining species.

- UNCLOS, United Nations Convention on the Law Of the Sea (1995): where "including the preservation and protection of the marine environment and the conservation of marine living resources both within and beyond national jurisdiction" appears as fundamental obligation.

After that, referring to the case of Portugal, the Ministério da qualidade de vida, on its "Decreto lei nº 263/81", makes a special regulation for the protection of marine mammals within the coastal and Economic Exclusive Zone, and publishes a list of cetaceans which are under special protection by this law.

3.6. The DPSIR framework for management.

The DPSIR framework has been adopted by the European Environment Agency (EEA), and is a causal framework used in Integrated Coastal Zone Management (ICZM) for the Environmental Impact Assessment (EIA). It is used to describe the interactions between ecological, economical and social aspects. It enables to create basic schemes for presenting all the information needed for policy makers and the decision-making process. DPSIR framework is useful to identify the dynamics between origin and consequence of environmental problems, by following the causal chain shown in figure 15. The main goal of this scheme is to give a structure for data and information on diverse environmental problems. This structure and the environmental indicators used on it will be useful for communicating environmental information to the policy makers and the public.

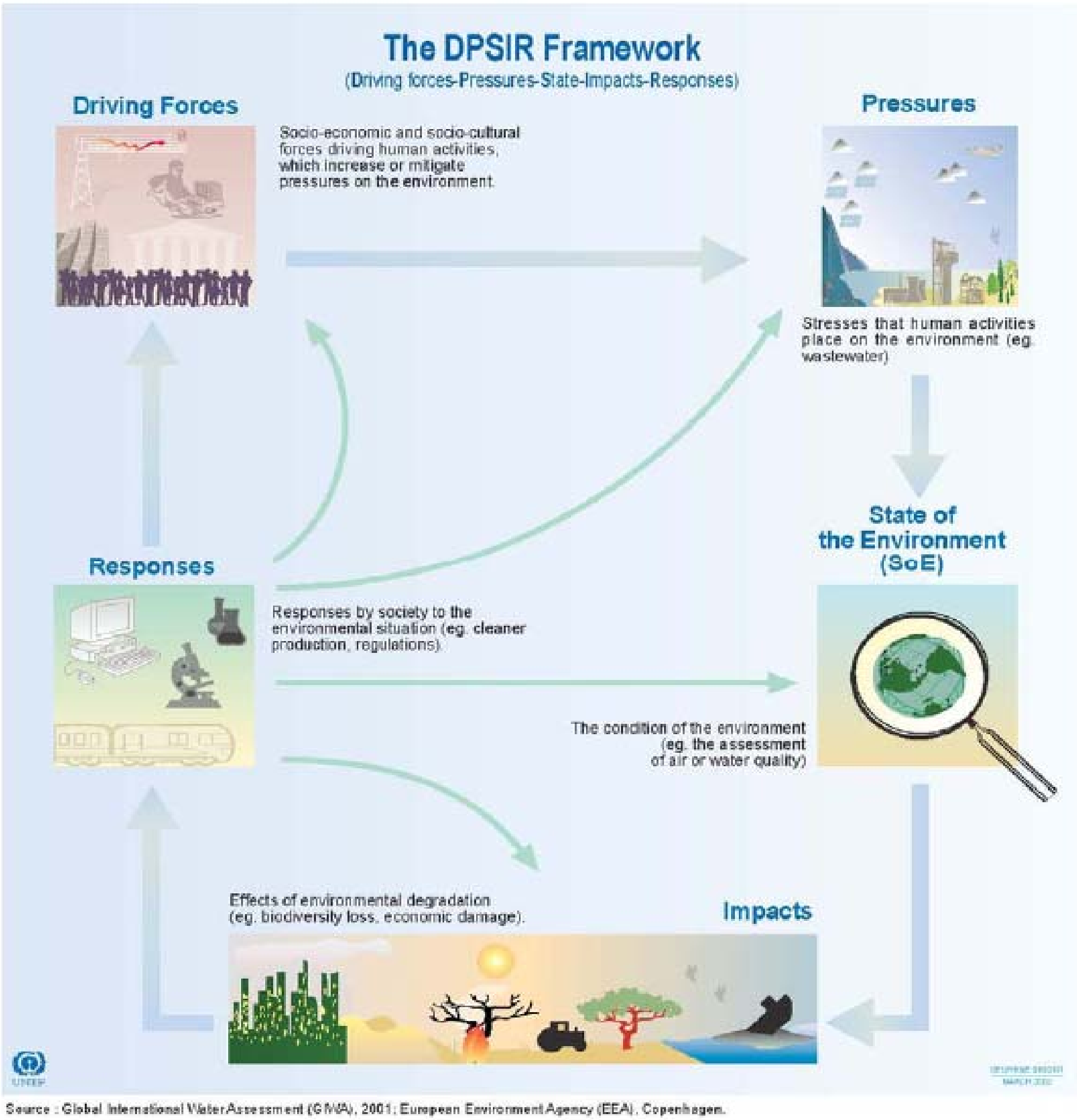


Fig 15. Basic elements susceptible of being found in a general DPSIR scheme. (Source: Global international Water assessment, 2001. http://maps.grida.no/go/graphic/the_dpsir_framework)

The basic components of the DPSIR framework (Martin Le Tissier) are mainly:

- DRIVING FORCES: they are the needs. It can be primary driving forces as shelter, food and water; and secondary driving forces such as mobility, entertainment and culture.
- PRESSURES: Human activities from driving forces, creates pressures in the environment. These pressures can be divided into excessive use of

environmental resources, changes in land use, and emissions (chemicals, waste, radiation, noise) to air water and soil.

- STATE OF THE ENVIRONMENT: Is the reaction of environment to the pressures.
- IMPACTS: They can be on population, economy and ecosystems. Changes in state may cause impacts derived from pressures.
- RESPONSES: they can be referred to as the responses by society, or policy makers to an undesired impact. Those responses can affect some or all the parts of the causal chain.

The process of determining the causal chain is complex and sometimes needs to be done by determining subgroups on the different parts of the scheme as well as the interaction between them. It is sometimes necessary to focus on some of these relationships for a proper understanding of the entire scheme.

4. STUDY PROCEDURE

Some specific objectives will be set for the completion of the main objective as shown in the table below:

SPECIFIC OBJECTIVES AT STUDY CASE	METHODOLOGY
I. CASE STUDY CHARACTERIZATION.	- Location and environmental characteristics determination. - Description of the offshore device. - Determination of marine mammal populations within the zone, the acoustic frequency bands they use, and acoustic thresholds set for noise effects. - Determination of DPSIR scheme to follow for management study.
II. MODELLING UNDERWATER NOISE LEVEL. OBTAINING SPATIAL DISTRIBUTION MAPS	- Use of matlab software for underwater acoustic noise level modelling, through the normal mode model KRAKEN. - Underwater acoustic noise level distribution map obtention.
III. VALIDATION OF THE MODEL.	- Comparison of sound levels with cetacean acoustic effect thresholds/acoustic bands. - Demonstration of viability of modelling as a tool for coastal management.

I. CASE STUDY CHARACTERIZATION:

Four main goals were supposed to be covered within this objective. First of all, location of ORED and environmental characteristic of the area should be done. Afterwards, knowledge of the device under study itself will be needed for the whole problem understanding. Determination of the aspects of marine mammals related to the zone under study, will be the next step. And finally, determination of the DPSIR scheme to follow for management study.

Within the first goal, description of the area where the device is located will be done. Referring to the environmental characteristics of the zone, mainly values for depth, salinity, temperature, and then sound celerity would be needed (using the sound celerity formula, Eq. 1). But also the sound characteristics of the noise source (the device itself in our case), would be needed for an appropriate and accurate modelling.

Acoustical research in the field normally requires at-sea platforms equipped with sound projectors, receiving arrays and sensors for measuring the environment. In our case study, sound is already made by the device, and what is needed are sound levels at certain points for making a matrix related to sound level, distance to the source and depth, so a number of hydrophones should be set in the area. In our case study, the main acoustic scheme would be shown in fig 22, where hydrophones should be in the primary phase of receiving, and for the modelling. Even though, the final receivers, which should be taken into account should be the marine mammals susceptible of being affected by the underwater acoustic noise emitted by the Pelamis device:

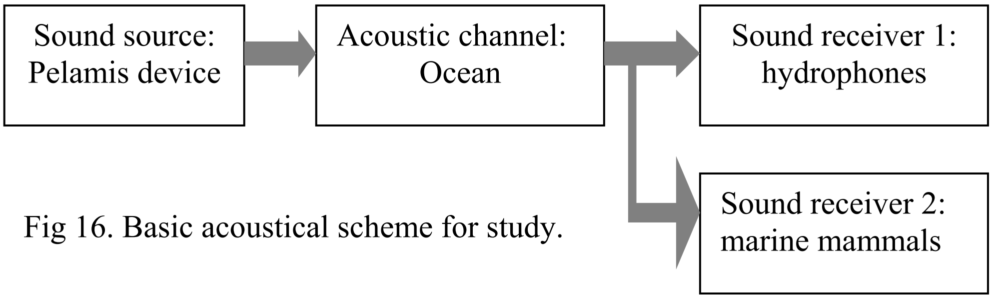


Fig 16. Basic acoustical scheme for study.

An introduction to our specific ORED will be made in the next step. It is important to know everything about our device in order to be able to determine whether some aspects of our case study are important or not. An explanation about what is the device and how it works is necessary for understanding the reasons for this case study.

In third step, determination of cetacean distribution within the zone would be needed. It would also be useful to determine the state of conservation of those marine mammal species present within the study area. Cetacean populations could be affected directly by the noise produced by the source itself, or by the noise propagation trough the ocean. Information about the frequency bands in which the marine mammals emit and receive sounds would be needed. Nevertheless, some references of thresholds and reaction levels would be desirable in order to compare our results with any values already set before starting. Information about species within the zone was obtained by interviewing some Portuguese experts in marine mammals (Marina Sequeira and Jose Vingada), and by seeking results in cetacean researches made in Portugal. About 80 species are described worldwide, 23 of them in Portugal, and seven of them within our study area. Results from three different sources agreed in species distribution, although published and real data is still not available, but is being studied under the SAFESEA project (reliable published data will be available in some years).

Data related with acoustic noise effect thresholds and sound references for cetaceans will be taken from various studies, where we can find references of sound levels emitted and received for each species under study, and in some cases the threshold levels set for them. (Annex 1).

The determination of the DPSIR framework scheme has to be accurately done in order to present the overall information in the most complete way for the manager comprehension.

II. ACOUSTIC UNDERWATER NOISE SPATIAL DISTRIBUTION MAP OBTENTION:

This part of the project will consist basically in the creation of a virtual scenario trough acoustic modelling, which will allow the user to predict the sound level at each point in the marine environment within the affected area.

Different types of models for solving the wave equation were reviewed in the underwater acoustics section, and a table showing their principal characteristics was given. As we assume to be in a shallow off-shore environment, which would not be horizontally stratified and would be range-dependent mean, we assume that the best type of model to use would be a normal mode model. Normal mode models give a numerical solution to the wave equation by the usage of branch integrals. They are suitable for low frequencies and shallow environments where the number of modes is reduced. They normally take into account layered environments (water column and bottom layer, at least). KRAKEN normal mode model is constituted by an algorithm. This algorithm includes the elastic properties of the ocean bottom which enables it to model ocean environments that are range-dependent, range-independent or even 3D (consisting in infinite 2D superposed to create a 3D scenario). KRAKEN appears to be a multilayered model, where roughness and elastic characteristics of layers can be included.

The program that will be used for the modelling part will be implemented in Matlab. Through the use of this program, KRAKEN normal mode model is supposed to be used for obtaining a simulated map, which would give the acoustic sound levels at each point from the marine environment within the study area.

After the completion of data compiling, the model will be ready to run, and after that, an acoustic underwater noise spatial distribution map would be obtained as a result.

III. DEMONSTRATION OF VIABILITY OF MODELLING AS A TOOL FOR COASTAL MANAGEMENT:

The question of the marine mammal's threshold will be tried to answer in this part of the project. Sound levels obtained by the simulation should not exceed the thresholds set in previous studies. If it is possible to compare those values obtained by the map with those within the studies done on cetaceans for setting thresholds, then a decision upon the viability of the renewal energy device implementation could be done. In this direction, if the sound levels obtained do not exceed the thresholds set before, the environmental acoustic study over the zone will be positive, and the project will carry on with its implementation and will remain active. If those sound levels exceed significantly the thresholds, then further studies over device must be done or mitigation measures taken into account. The following figure shows a simplified scheme of how the viability demonstration could be done, and the steps to follow from the planning of the device installation to the final decision-making (Fig 17).

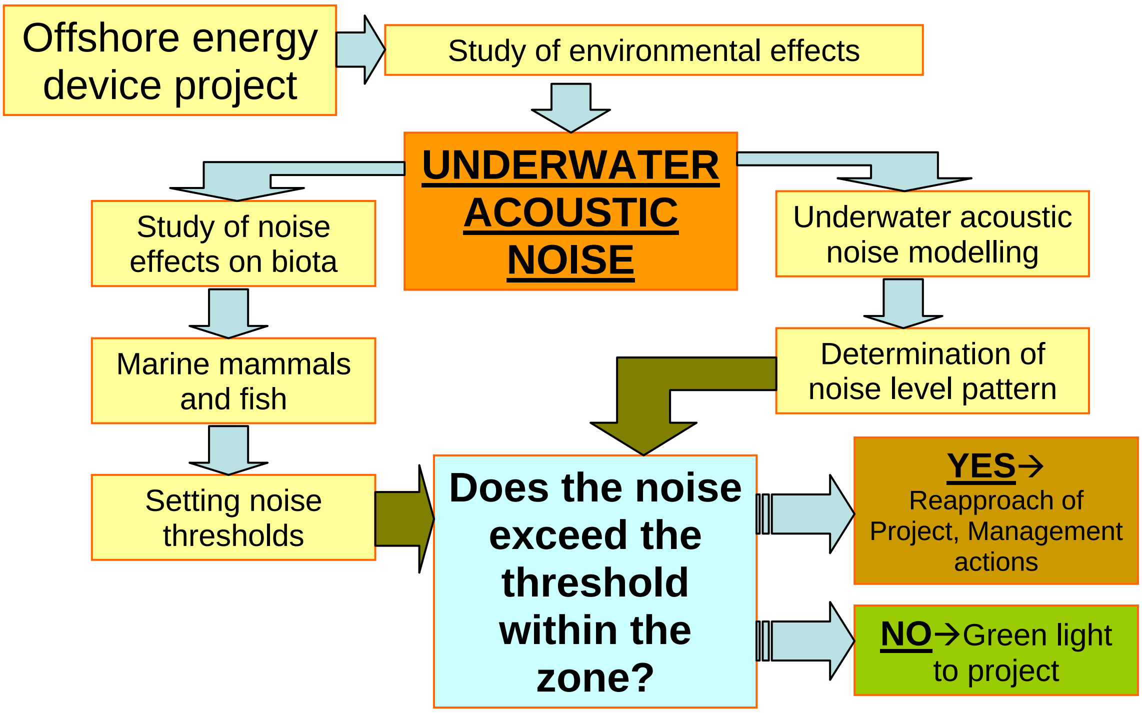


Fig 17. Basic scheme of the management procedure that will be used within this study.

5. CASE STUDY CHARACTERIZATION.

Our study will take place over the first commercial wave farm worldwide. It is located in Aguçadoura, a town in Povoa de Varzim, near the Portuguese city of Porto, in the north of Portugal. The entire Portuguese coast is known by the formation of waves coming from the Atlantic Ocean. Those waves are mostly permanent during the whole year, which makes it a perfect suitable place for installing wave energy devices (Fig 18).

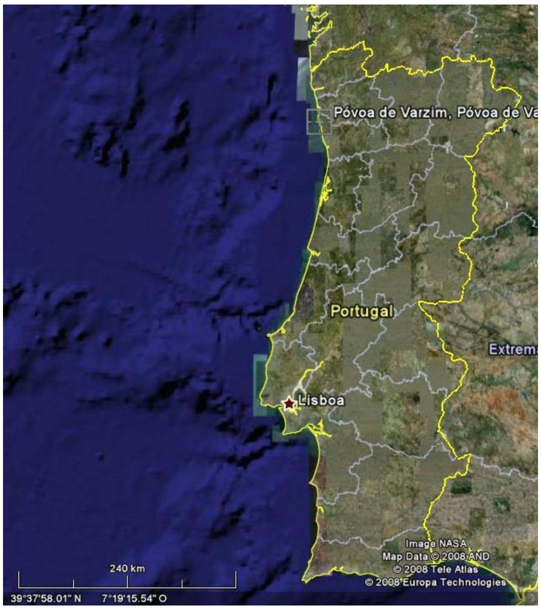


Fig 18. Map showing Povoa de Varzim, north of Portugal.
Source: Google Earth

There are two main reasons for the establishment of this wave farm in Portugal. First of all, Portugal is blessed with a good and strong wave energy climate. Secondly, it has a proactive government that is developing a favourable climate for wave energy demonstration projects and for further commercial development of the wave energy market. "This project benefits from a special feed in tariff established by the Portuguese Government to support the first wave energy installations. The tariff of 25 cent €/kWh is higher than the one provided to wind energy but lower than the one provided to solar energy. All of them are relatively mature technologies which have enjoyed significant cost reductions over time through volume production. The initial phase is also supported by the Demtec programme with a 1.25 million € grant from the Agencia de Inovaçao (www.adi.pt).

For the environmental characterization of Povoa the Varzim, some data will be required. First of all, temperatures within the water column through the year will be needed. Fig 19 shows data referring to temperature profiles corresponding to

April 2004, July 2007 and October 2000. There is no presence of a significant thermocline. April temperature profile appears to be so smooth varying only about 1º C within the first 120 meters, while bigger differences are shown for July and October.

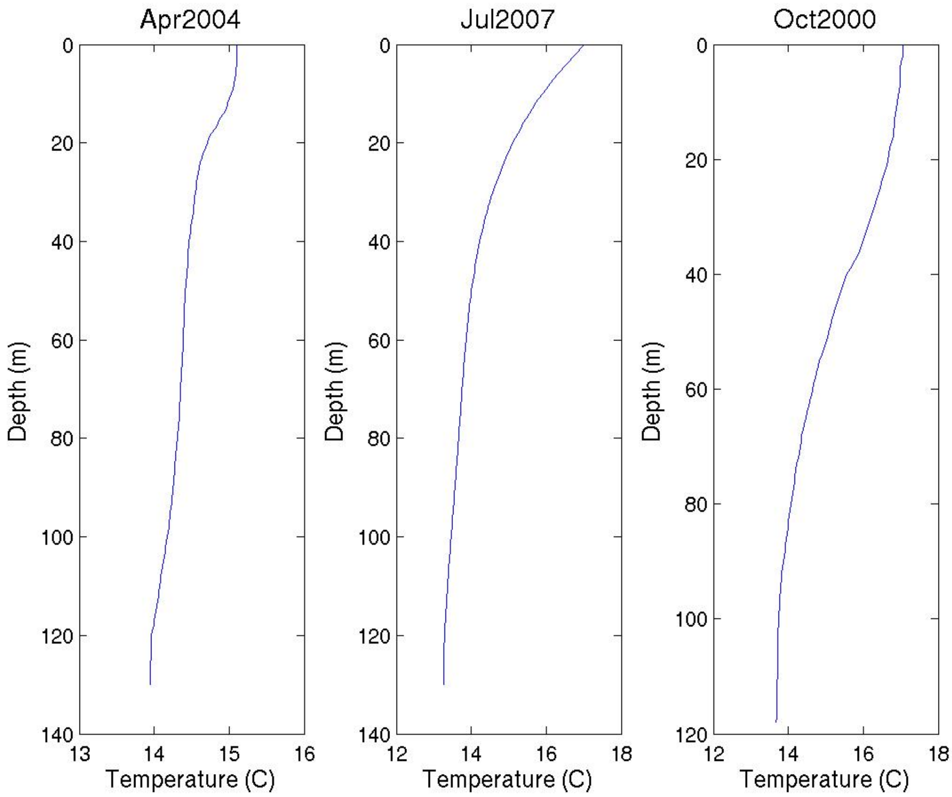


Fig 19. Temperature profiles for three different seasons. This plot was obtained with Matlab software, and shows the temperature variation within the water column for three different seasons.

A plot for the bathymetry is shown in Fig 20 where the coast is left on the right side of the figure, and the north is in the top of the figure. Depth has a general trend to grow with distance to the coast. Nevertheless, two zones with shallower depth can be seen in between 41.15º N and 41.1º N and 8.9º W and in between 41.20º N and 41.25º N and 8.98º W. Hot colours within the figure represent higher depths, while cold colours represent shallower depths as given by the bar on the right of the figure.

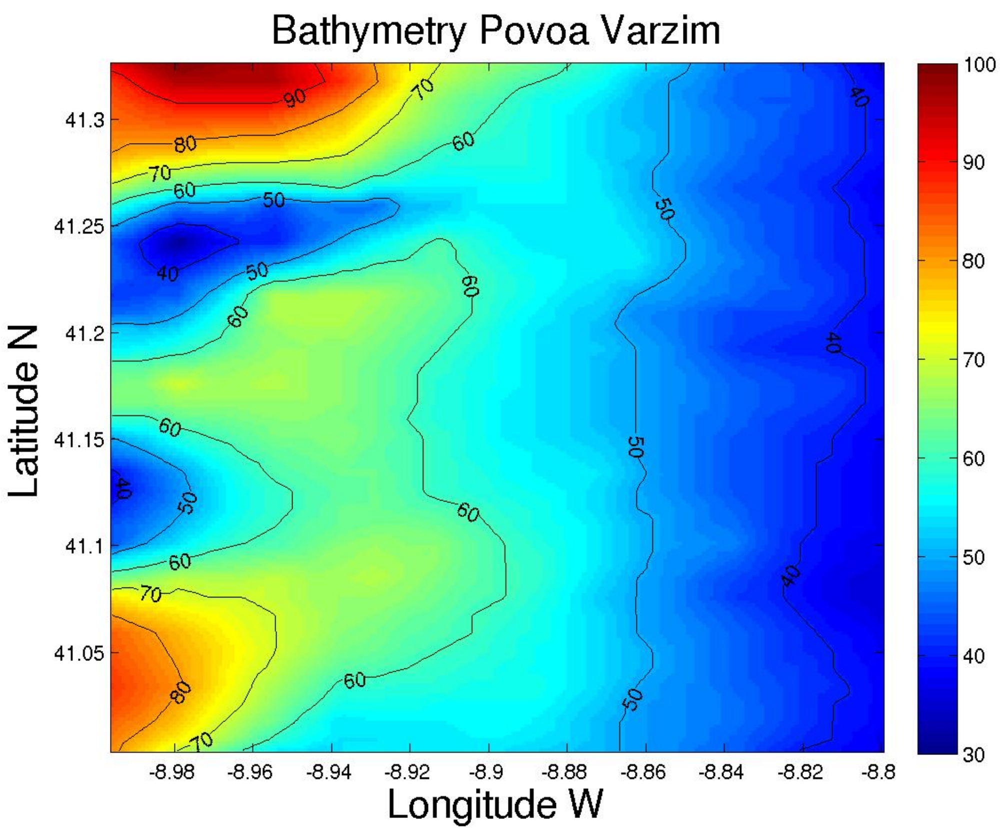


Fig 20. Bathymetry of Povoa de Varzim. This plot was obtained with Matlab software. The bar within the right indicates depth in meters, so hot colours are deeper and cold colours appear to be shallower depths.

Secondly, an introduction to the Pelamis device should be done: The station has been promoted by the Portuguese enterprise Enersis and planned and designed by the Scottish enterprise Ocean Power Delivery, worldwide leader on this technology. A number of Portuguese organisations are currently involved in the project. These include the AICEP-Portugal Global (www.investinportugal.pt), Instituto Hidrografico (www.hidrografico.pt), Wave Energy Centre (www.wave-energy-centre.org), INESC Porto (www.inescporto.pt) and INETI (www.ineti.pt).

The proposed device by the Scottish company Pelamis Wave Power is known as P-750, due to its power efficiency (750 kW). According to their description of the device, it is composed by cylindrical sections, made mainly by mild steel and washed sand for ballast, which are semi-submerged in the water. Each P-750 is about 120 m long and wit a diameter of 3.5 m, and has three conversion modules on it (each of them with a length of 5 m and the same diameter). Each of the conversion modules has a 250 kW electric generator, giving a total power of 750 kW for each Pelamis unit.

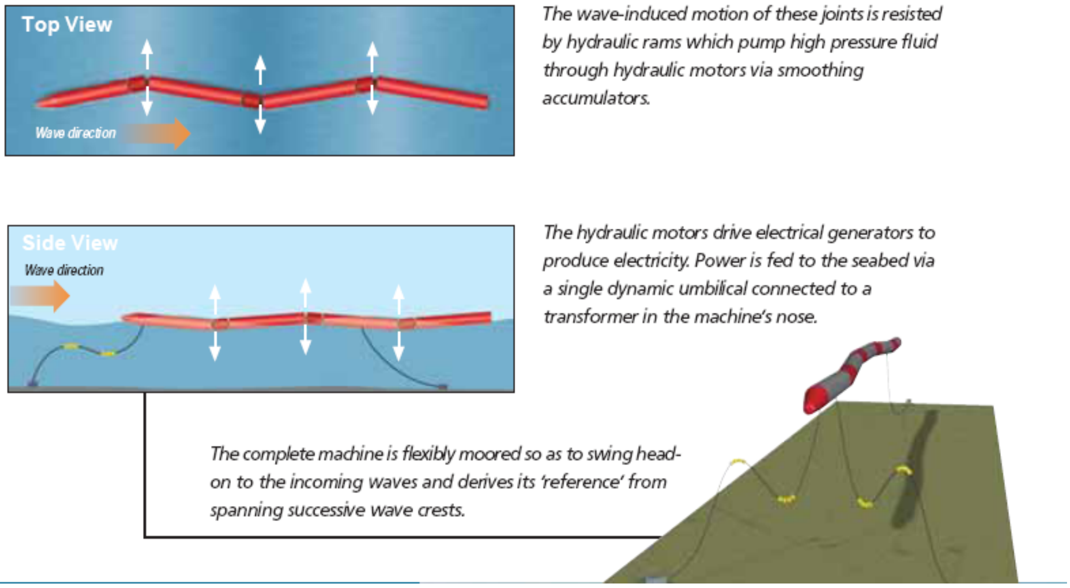


Fig 21. Basic movement made by Pelamis device.
(Source: www.pelamiswave.com)

Functioning of the Pelamis device consists basically in the use of wave motion to get movement of a hydraulic fluid (biodegradable in marine environment). It moves similarly as a sea snake, from where it receives its name (the word pelamis in Greek language means sea snake). As the wave comes, Pelamis device adjusts its movement to it as if it was a rope, and every cylindrical section gets moved up and down. This up-down movement allows the hydraulic fluid contained in the conversion modules (in Fig 21) of Pelamis to activate

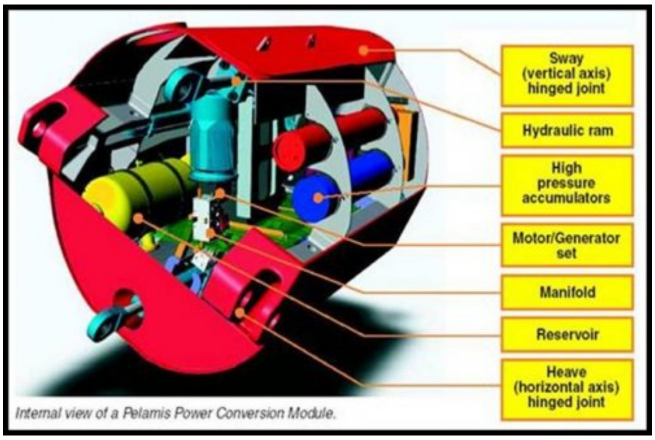


Fig 22. Scheme of a conversion module from Pelamis. (Source: www.pelamiswave.com/)

electrical generators driven by hydraulic motors, which leads to the production of electricity (Fig 22).

As a result of the state of marine conditions waves will be variable, and so "depending on the wave resource, machines will on average produce 25-40% of the full rated output over the course of a year. Each machine can provide sufficient power to meet the annual electricity demand of approximately 500 homes" (Pelamis web site)

Before the installation of the Pelamis device in Portugal, a series of trials in the North Sea were previously performed in 2004 with a large scale commercial prototype (Fig 23) which had the ability of supplying energy to the UK grid. It took 18 months to check design with one of the leading consultants in offshore structures called Atkins, before building the machine, which had initially a design life of 15 years. Critical test objectives were run over the machine during an extensive phase of testing. Success in this checking made it possible to plan the installation in Portuguese waters for the first commercial wave farm in 2006.

Fig 23. Pelamis prototype device. (Source: www.pelamiswave.com/)

It was ten years before that Pelamis Wave Power started developing Pelamis technology (Fig 24). After completing the development process, Pelamis Wave Power is still running studies that will improve those technological and economical aspects, including the reduction in costs of installation, maintenance and decommissioning.

Fig 24. Pelamis device in off-shore location. (Source: www.pelamiswave.com/)

Pelamis Wave Power does not mention any impacts susceptible to be caused by the device, neither the studies carried on in the testing phase. That leads to no information about acoustic characteristics of devices for the moment.

In comparison with other wave energy converters, Pelamis wave energy devices offer several technological, economical and environmental advantages of implementation:

- Tuneable response allows power capture to be maximised in small seas while limiting loads and motions in extreme conditions,
- The head on aspect to severe waves presents the minimum resistance to the high velocities in extreme wave crests,
- The finite length of the device is optimised to extract power from shorter wavelengths and is unable to reference against the long waves associated with storm conditions,
- The small diameter leads to local submergence or emergence in large waves limiting the forces and moments in the structure,
- The flexible mooring system has a range of motions able to accommodate the largest waves,

The Project proposed for Povoa de Varzim consists, at present, of three devices located at 5 - 6 km from the coast (in a location of about 50 meters of depth). It is supposed to be able to give energy supply to up to 1500 Portuguese homes, with an average power supply of 2,25 MW. Nevertheless, a second phase of the project is now planned to install up to 25 devices, with 750 kW each, which would mean obtaining nearly 21 MW. The complete project would be able to supply to more than 15.000 Portuguese families and save 60.000 tonnes of CO_2 emissions per year, as said by "companhia da energia oceanica". In fact, this would be a huge energy supply added to the electricity network for Povoa de Varzim.

Fig 25. Pelamis wave farm. The upper side of image shows the current wave farm project (3 devices), and the lower shows the planned wave farm (21 devices). (Source: www.pelamiswave.com/)

Pelamis wave energy converter appears as the first off-shore viable energy harnessing system, and it is the first one that reaches the commercial phase. This project is run with an investment of 9 million € under the influence of different groups, which made up a joint venture, where 77% is owned by Babcock and Brown, Energias de Portugal and Efacec (forming the Ondas de Portugal Consortium), and Pelamis Wave power limited holds the remaining 23%. This group is preparing more activities in wave energy projects.

The installation of the pilot wave farm in Portugal, does not only allow the testing phase in the real environment of the device, but also the study of the different effects that wave energy can cause over the environment and thus, the viability of the project.

FREQUENTLY OBSERVED	**NOT THAT COMMON**
Order “Cetacea” Suborder “odontoceti” Family “Delphinidae”: -Short beaked common dolphin (*Delphinus delphis)* - Common bottlenose dolphin (*Tursiops truncatus)* - Harbour porpoise (*Phocoena phocoena*). VULNERABLE. - Stripped dolphin (*Stenella coeruleoalba*)	**Order “Cetacea” Suborder “Mysticeti” Family “Balaenopteridae”:** -Minke whale (*Balaenoptera acurostrata*). VULNERABLE. **Order “Cetacea” Suborder “odontoceti” Family “Delphinidae”:** - Pilot whale (*Globicephala malaena*) - Risso´s dolphin (*Grampus griseus*)

Table 2. Cetacean distribution in Povoa de Varzim. Seven species are found within the zone, four of them are frequently observed. Two of the species found have a vulnerable figure of protection.

As said by experts, seven species of marine mammals have been observed in our study area, which is shown in the Table 2, as well as their conservation states. As frequently observed, four dolphins are shown in the table, and not that frequently two dolphins and a mysticet whale. Even though, not reliable data have been published yet, studies and stock lists are being currently done. While all of them carry an ecological importance and protection as they are marine mammals, two of them are included in the Red List of Endangered Species in Portugal (Harbour Porpoise and Minke Whale). Information about the species within the zone included in this list is available in Annex 3 and Annex 4, where characteristics of each species and conservation status are available.

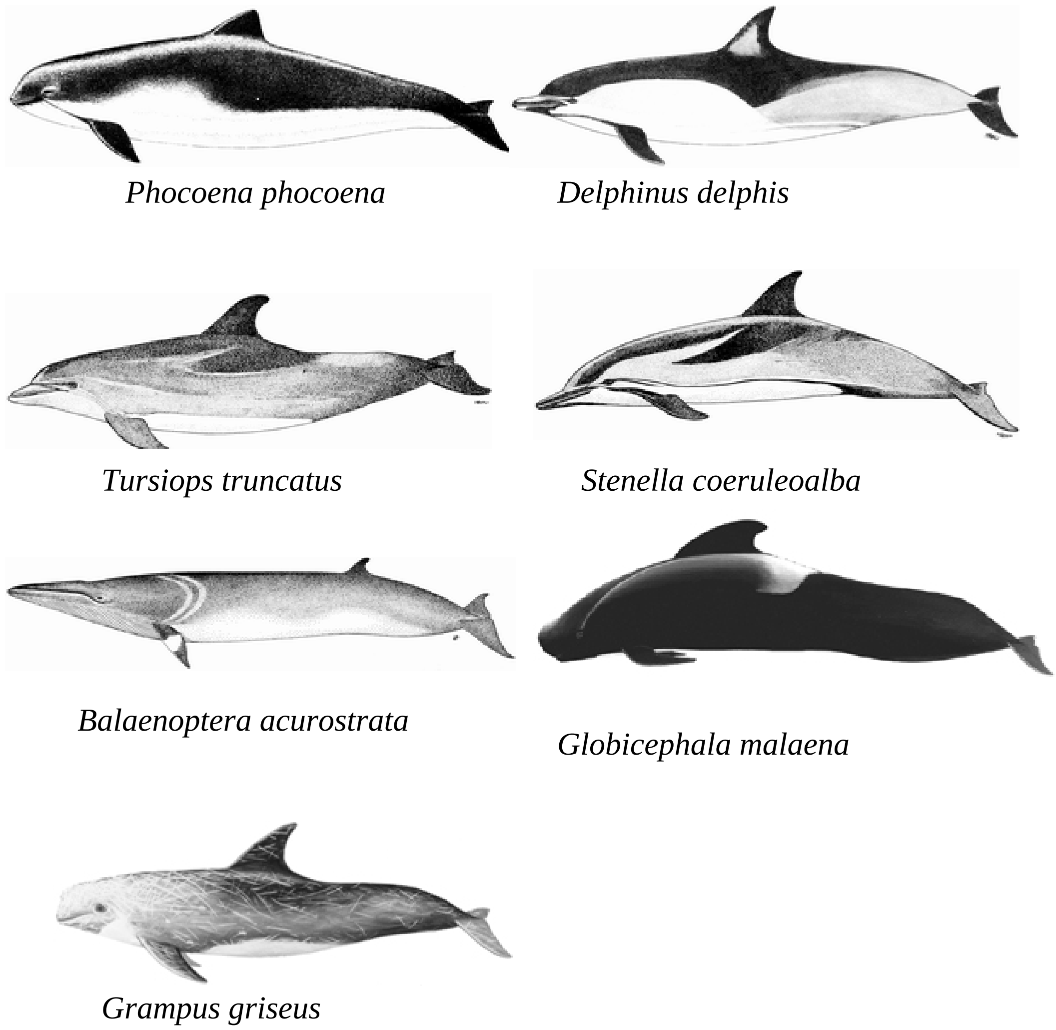


Fig 26. Pictures of the main marine mammal species found within Povoa de Varzim. (Source: www.fao.org)

All these data related with the acoustic characteristics of these marine mammal species are shown in a table taken from various publications on marine mammals which is shown in the Annex 2. Those thresholds and frequency bands are the ones which will be used for the determination of acoustic impacts on the environment, and therefore as the main tool for the Environmental Impact Assessment over the zone under study.

A plot will be made (Fig 27) in which the audiograms selected for different species will be shown. The red line will be of the main importance, due to the conservation status of the harbour porpoise (vulnerable).

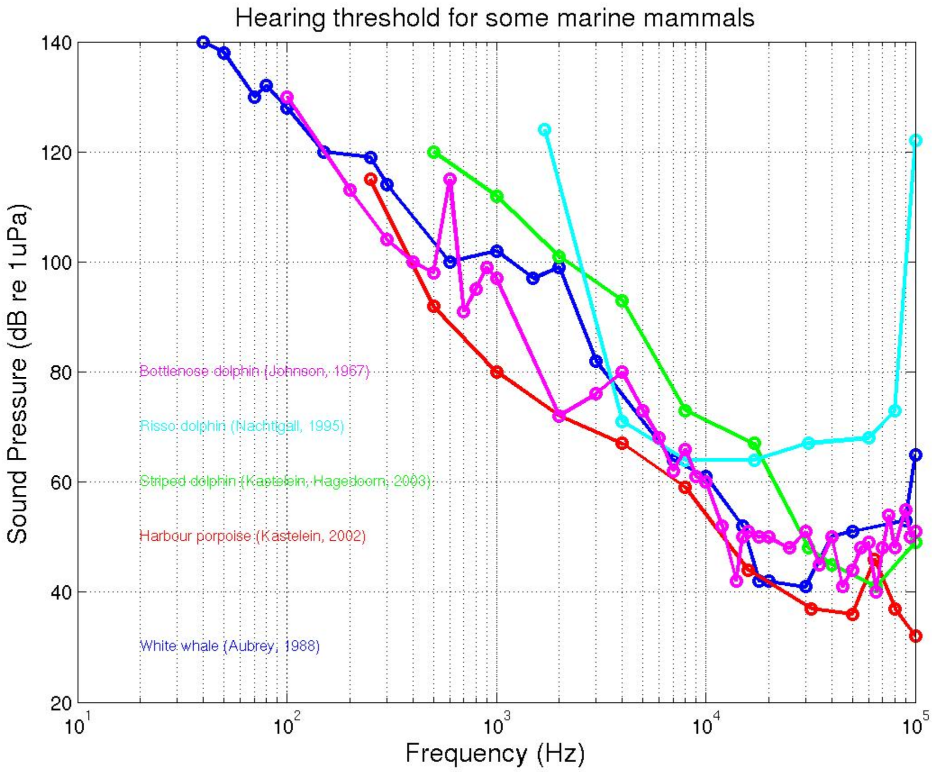


Fig 27. Audiograms from different cetaceans made with Matlab. Different lines represent the hearing threshold at a bandwith frequency for different marine mammals: bottlenose dolphin, striped dolphin, risso´s dolphin, harbour porpoise and white whale. Values of Sound Pressure level above these lines could be harmful for the species.

A reference for determining different zones of effect over marine mammal would be useful. As referred in Fig 28 (Richardson et al, 1995), zones with different effects can be found in the surrounding of a noise source. This scheme follows the theory: "The closest to the noise source the area, the heavier impacts on the animal".

- Audibility zone: the zone where the animal is able to hear the noise.

- Masking zone: the zone where the noise produced could have the ability to interfere with other sounds produced for echolocation or detection of preys.

- Responsiveness zone: the zone where the animal is susceptible of reacting physiological or physically.

- The hearing loss, injury or discomfort zone: the zone where sounds are too loud that they can cause injuries as tissue damage, or discomfort. The effects on marine mammals auditory systems, as said before can range from temporary (TTS) to permanent (PTS).

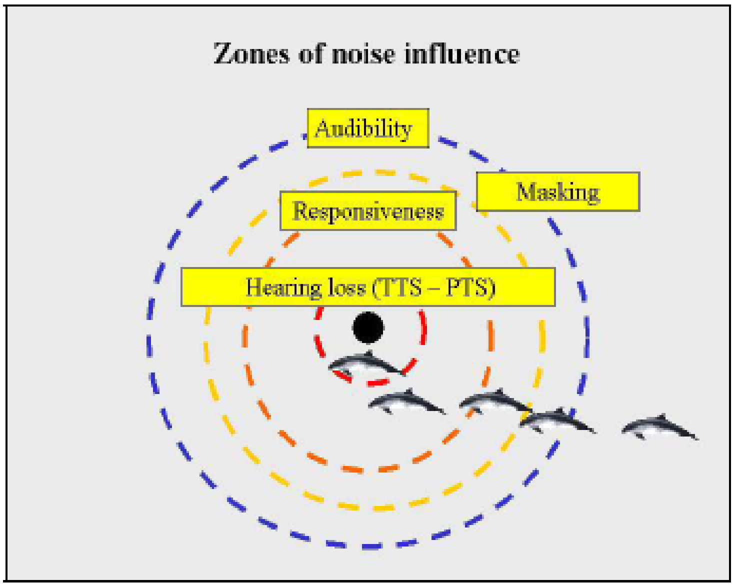


Fig 28. Zones of noise influence. Zones closer to the noise source would be more harmful than those on the outside part. (Source: Richardson et al, 1995)

And finally, the DPSIR found for the study would be as the one following, in which Drivers, Pressures, State, Impacts and Responses are shown, and which clarifies the relations in between them. This figure makes it much simpler to determine the main aspects to be considered when applying the management plan for the case study.

As referred in chapter 2.6, it is sometimes needed to focus not on the whole scheme but on some relationship between elements of the DPSIR framework. We will focus our study in the relationship IMPACTS-RESPONSES, with the acoustical impact estimation tools. These tools will be modelling the underwater acoustic noise levels, and determining the acoustic levels susceptible of being harmful to cetaceans.

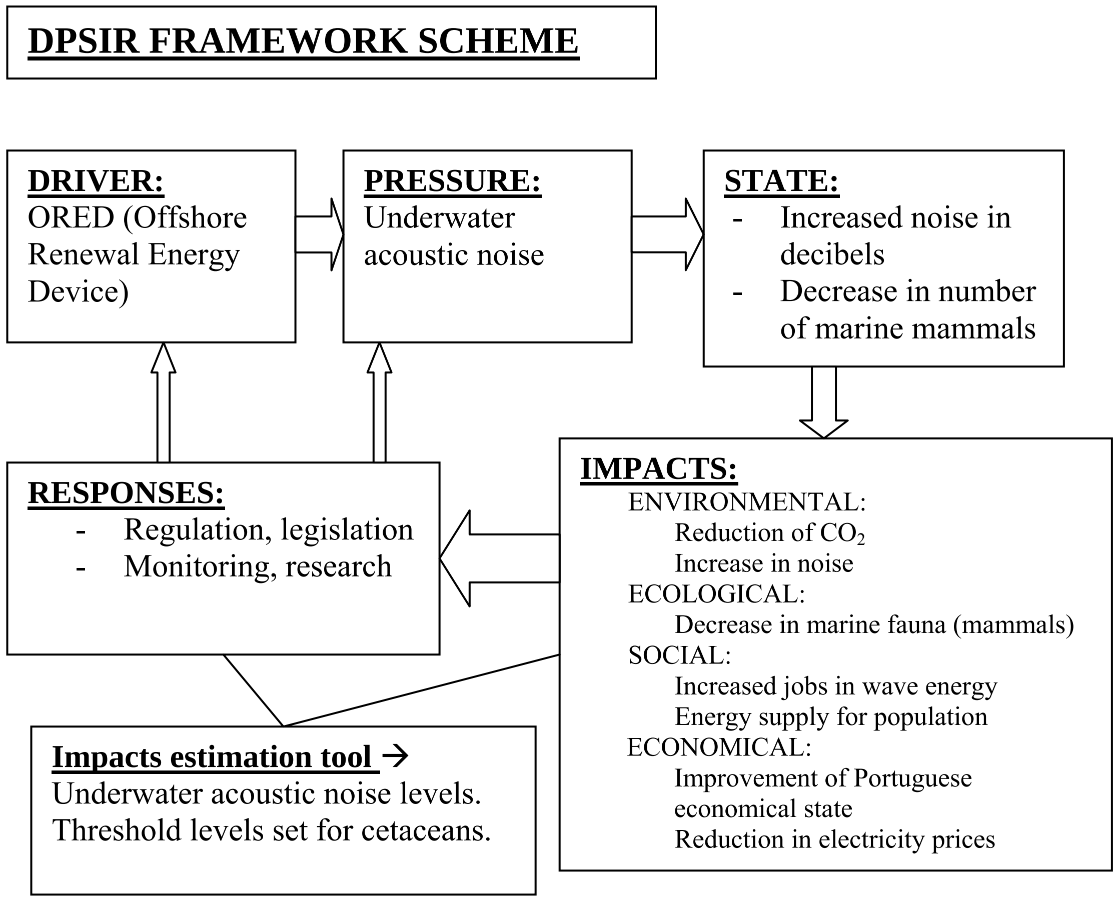


Fig 29. Basic DPSIR framework scheme for the study site. There is an added element on this scheme, that functions as a link in between tha main elements, Impact estimation tools appears as a tool for facilitating the whole DPSIR framework comprehension.

The acoustic data required for the model, could be obtained by the location of hydrophones in strategic sites within the study area, in order to obtain a matrix with different sound level values for running the model. In this case, these acoustic data matrix will be randomly generated by the model as the real acoustical data from the environment measured with hydrophones is still not available. A rms SPL for the source will be selected and also the frequency band in which the source is supposed to be emitting.

6. MODELLING UNDERWATER NOISE LEVEL. OBTAINING SPATIAL DISTRIBUTION MAPS.

Acoustic modelling will be carried out for cases combining three temperature profiles during the year, considering several receiver depths, and a range of frequencies located in the lower part of the waveband. As the noise generated by the real source is still unknown, we used computer generated signal for carrying out acoustic modelling.

Three sources will be taken into account for the simplest case of study, one for each Pelamis device. Wave front is supposed to come orthogonally to the line of devices. This is the case that will be considered in this study, a more complicated case will consist in the assumption of nine sources (corresponding to each converter of the three devices in the plan) and wave front coming from any angle. The basic scheme for both cases is shown in Fig 30.

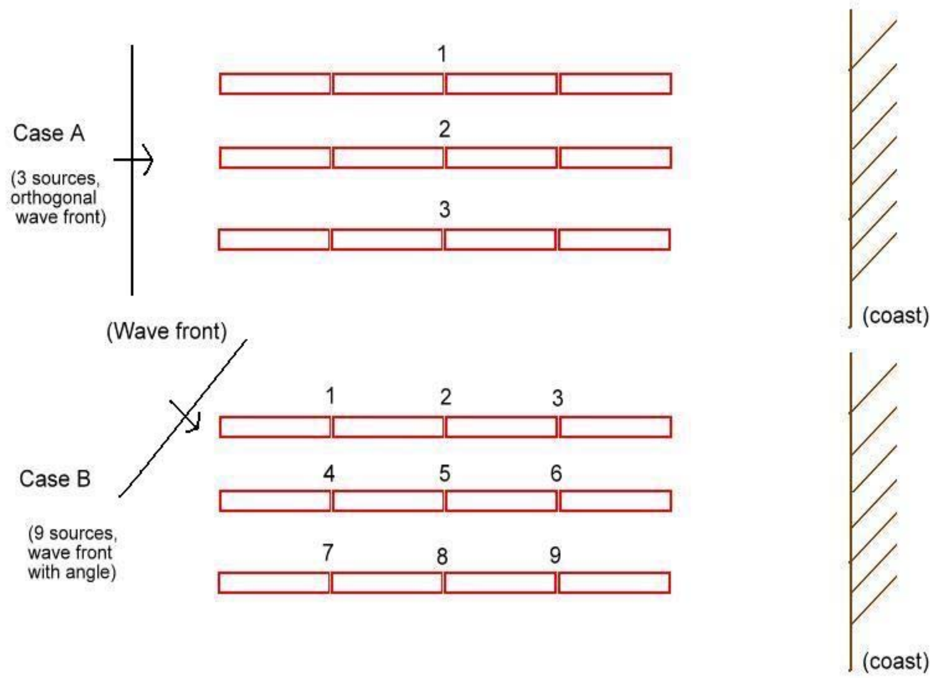


Fig 30. Scheme of possible study cases. Case A is the most simple one, while case B is more complicated. Case A is including each device as a noise source, while B assumes each converter as a noise source. Wave front in case a comes at the same time to devices, creating a simultaneous signal from every noise source, while B has an angle, making the signals created to differ in time.

The three sources will be located at about 8.88º W and 41.15º N. The three noise sources will be supposed to emitting in the range of frequencies going from 200-1000 Hz and an rms SPL of 170 dB. Signal will consist of discrete frequencies: 200, 400, 800, 1000 Hz, and also of a continuous broadband of frequencies in the range from 200 Hz to 1000 Hz. A plot showing the frequency band used and the signal generated by the programme can be shown in Fig 31. As the wave front is orthogonal to the coast, and also to the line of devices, they are supposed to be activated and moving at the same time, making a simultaneous signal the three of them.

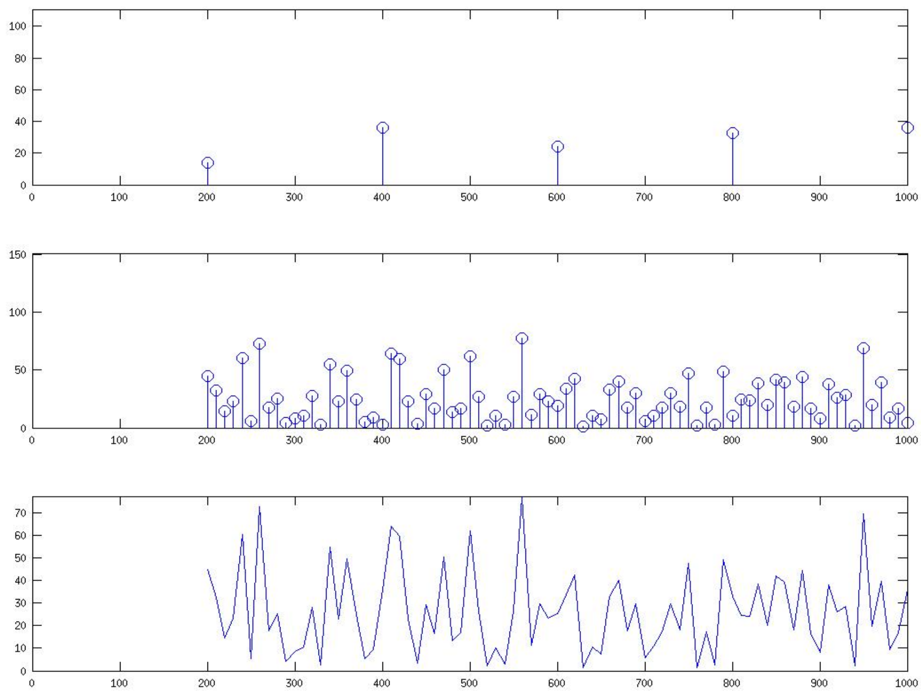


Fig 31. Plot for the signal obtained randomly with Matlab software for the signal created for the case study. First plot shows the discrete frequencies, second one shows the continuous frequency, and the last one shows the resulting of summation of them.

The KRAKEN normal mode model will be run, considering noise sources respecting to three wave energy converters activated simultaneously, combining calculations of transmission loss along four depths (2,5 m,15 m, 30m and 45m) with sound speed profiles respecting to the three seasons mentioned above (see Fig 24). For the purpose of relating the calculated sound pressure levels to a marine mammal example, an audiogram of the species harbour porpoise (*Phocoena phocoena*) will be used.

Plots corresponding to "Sound Pressure Level (SPL)" and "Sound Pressure Level over hearing threshold (SPL over ht)" will be obtained for the different depths. First of all for 2.5 m, being the same depth as the source, and for 15, 30 and 45 m or determining the trend on sound propagation with depth. The same process will be repeated for the three season periods (April, July and October) to also determine whether there is an existing trend on sound propagation with changes in the thermocline. (Fig 32 - 52)

The figure of SPL refers to the Sound Pressure Level within the area, which is the sound level found in every location in dB. Figure of SPL above ht, represents the Sound Pressure Level above the hearing threshold of the marine mammal in dB, this hearing threshold will be determined by the audiogram of the species (shown in Fig 27). A range of frequencies was used for generating the noise source signal, so it can be confusing to find only one value of dB for each location. The programme makes some integration methods for this goal. That can be resumed within two formulas one for the determination on SPL values, and the other one for the determination of SPL over hearing threshold values.

The broadband SPL e is the level of the acoustic waveform taking into account all the spectral components it carries:

$$SPL = 20\log_{10}\left(\sqrt{\sum_{k=1}^{k} P_{YY}(f_k)}\right) \qquad \text{(Eq 5)}$$

where $P_{YY}(f_k)$ is the spectral density of waveform Y at frequency f_k.

The SPL referenced by the animals auditivity system is given as

$$SPL_{ht}(species) = 20\log_{10}\left(\sqrt{\sum_{k=1}^{k} \frac{P_{YY}(f_k)}{HT^2(f_k)}}\right) \qquad \text{(Eq 6)}$$

where $HT(f_k)$ is the hearing threshold of the animal as a function of frequency.

(As all these variables are in linear scale we have to use the logarithmic transformation to give results in dB).

Fig 32. SPL, April 2.5 m, Harbour porpoise

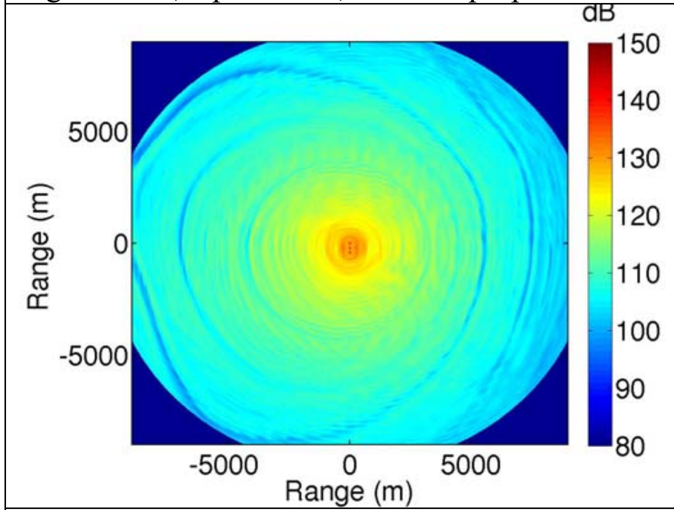


Fig 33. SPL, April 15 m, Harbour porpoise

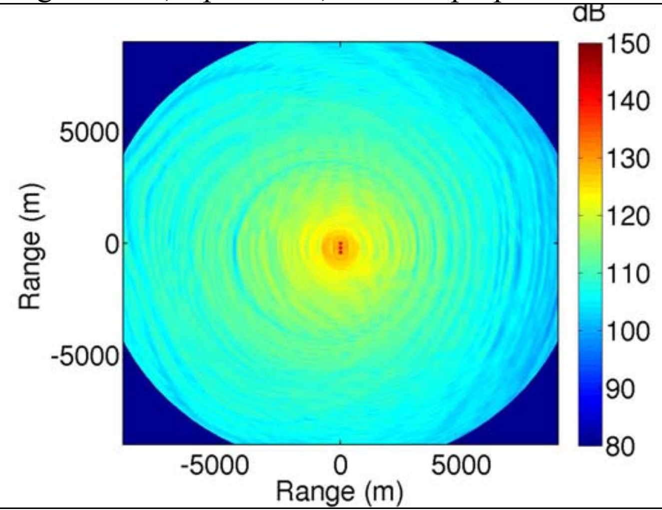


Fig 34. SPL, April 30 m, Harbour porpoise

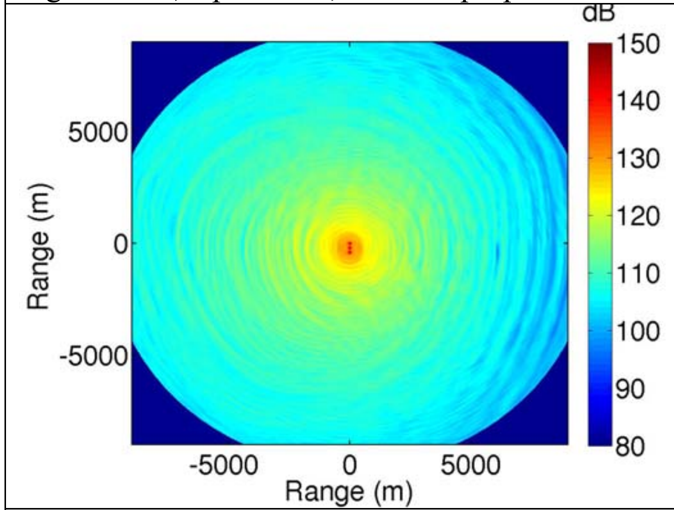


Fig 35. SPL, April 45 m, Harbour porpoise

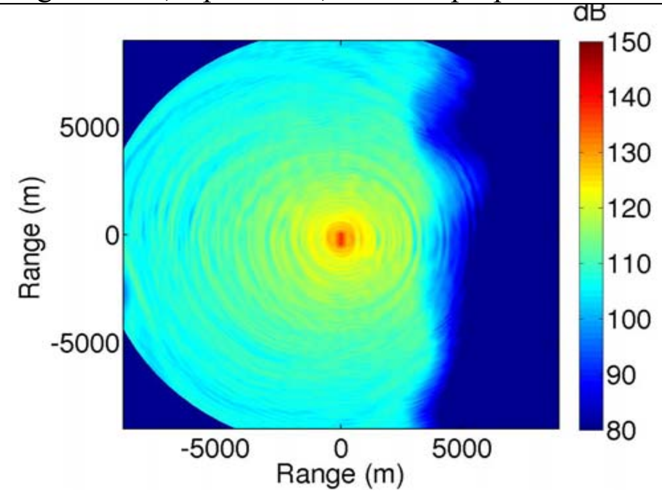


Fig 36. SPL above ht, April 2.5 m, Harbour porpoise

Fig 37. SPL above ht, April 15 m, Harbour porpoise

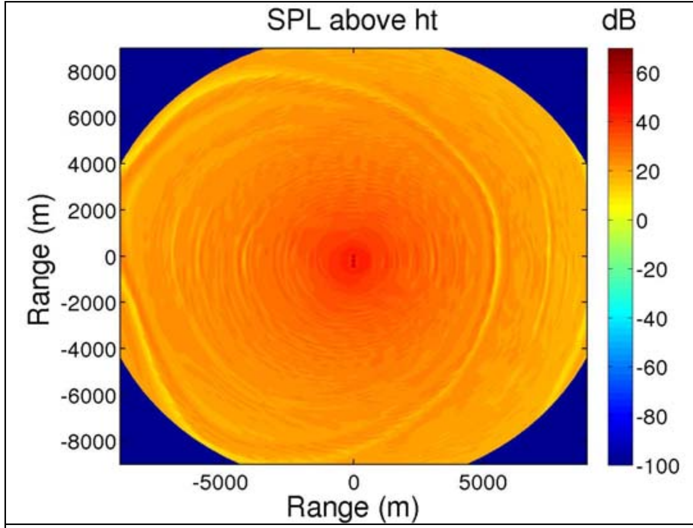


Fig 38. SPL above ht, April 30 m, Harbour porpoise

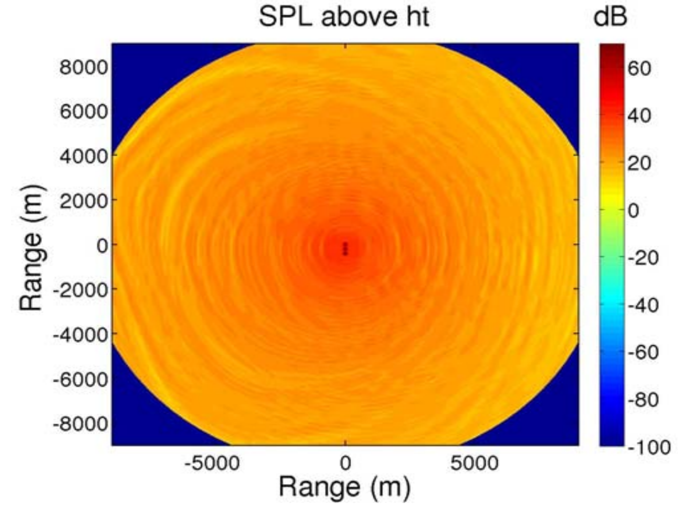
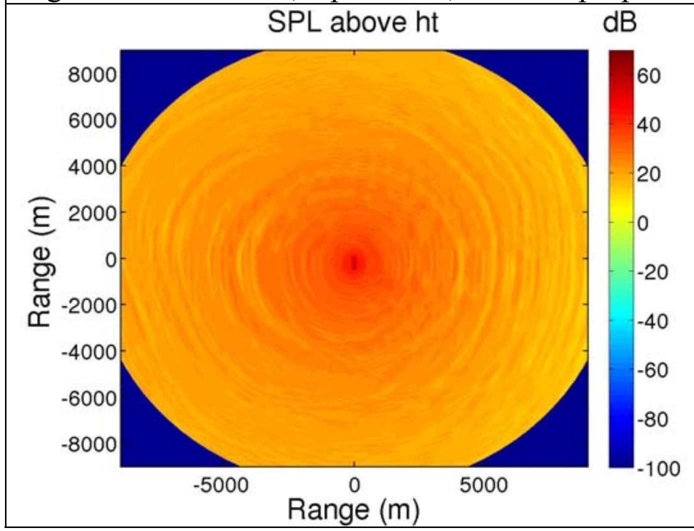


Fig 39. SPL above ht, April 45 m, Harbour porpoise



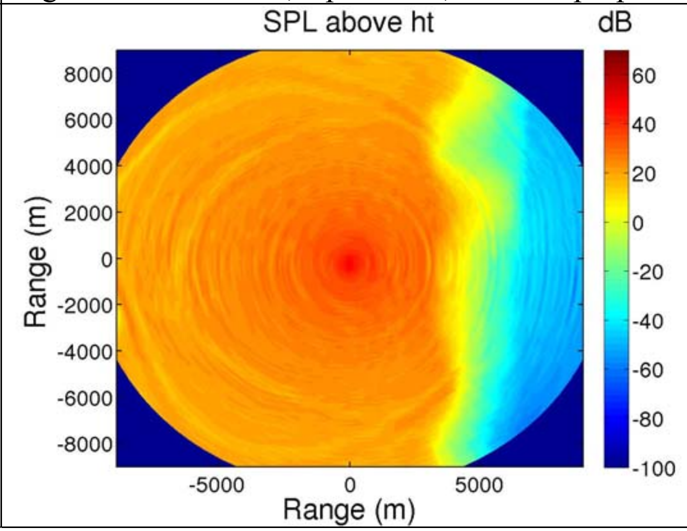


Fig 40. SPL, July 2.5 m, Harbour porpoise

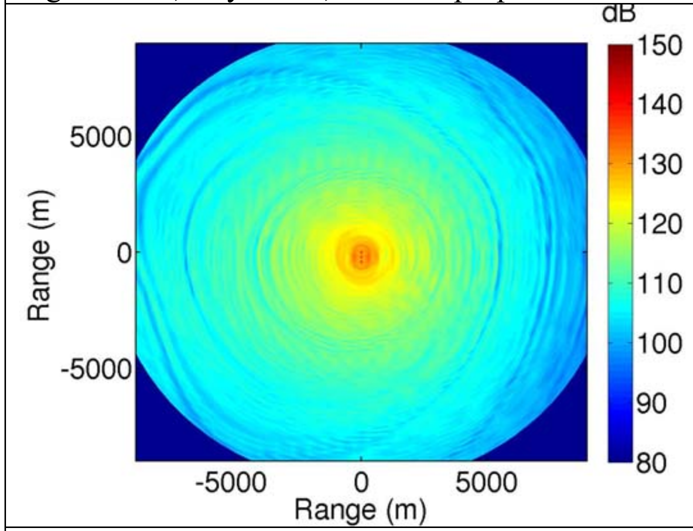


Fig 41. SPL, July 15 m, Harbour porpoise

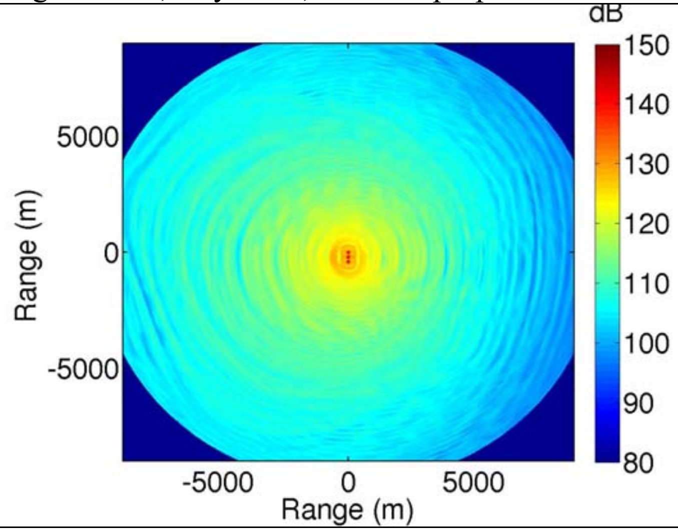


Fig 42. SPL, July 30 m, Harbour porpoise

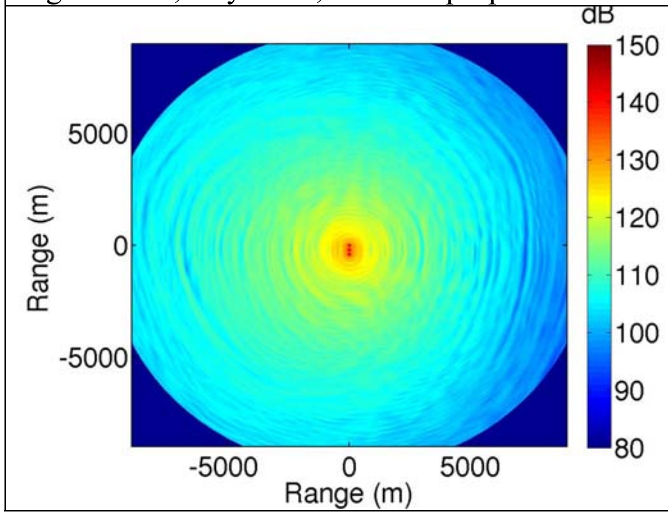


Fig 43. SPL, July 45 m, Harbour porpoise

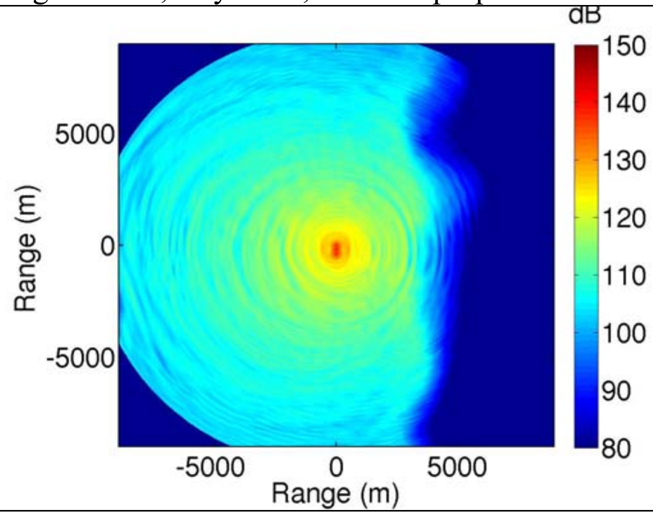


Fig 44. SPL above ht, July 2.5 m, Harbour porpoise

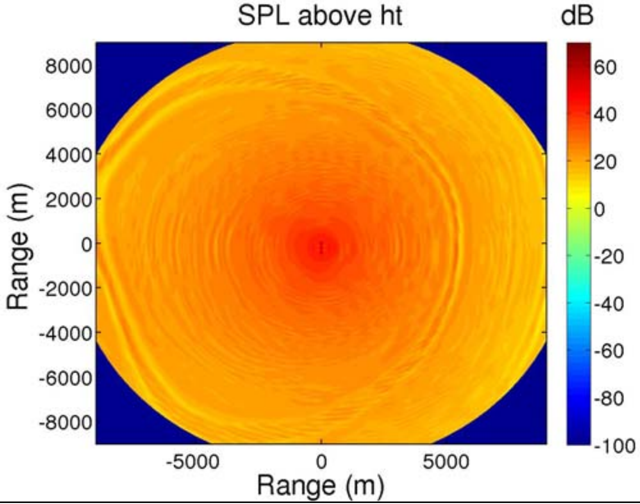


Fig 45. SPL above ht, July 15 m, Harbour porpoise

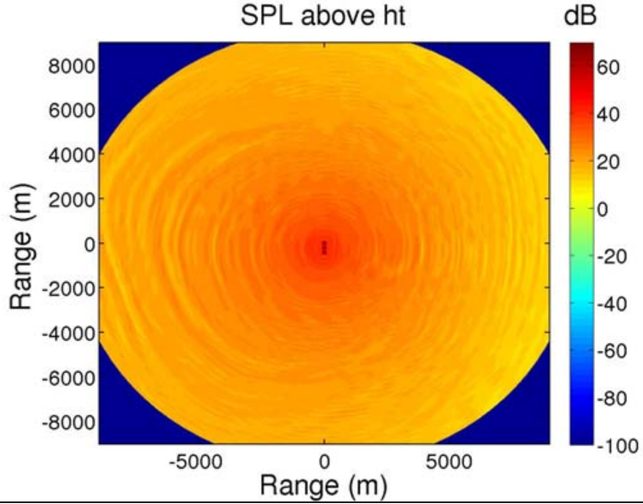


Fig 46. SPL above ht, July 30 m, Harbour porpoise

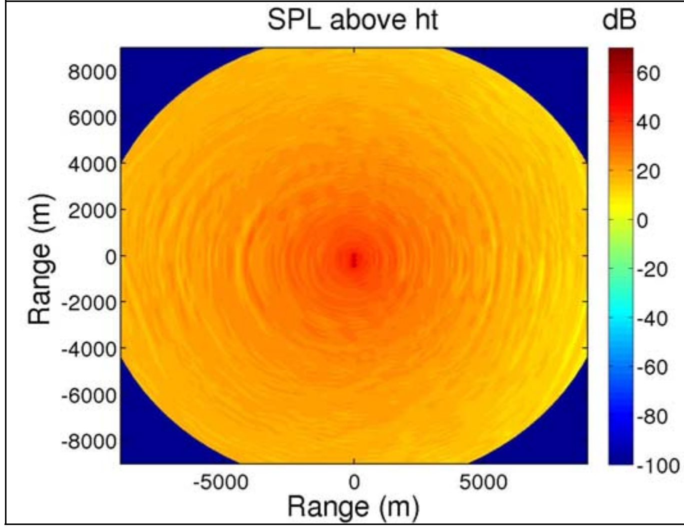


Fig 47. SPL above ht, July 45 m, Harbour porpoise

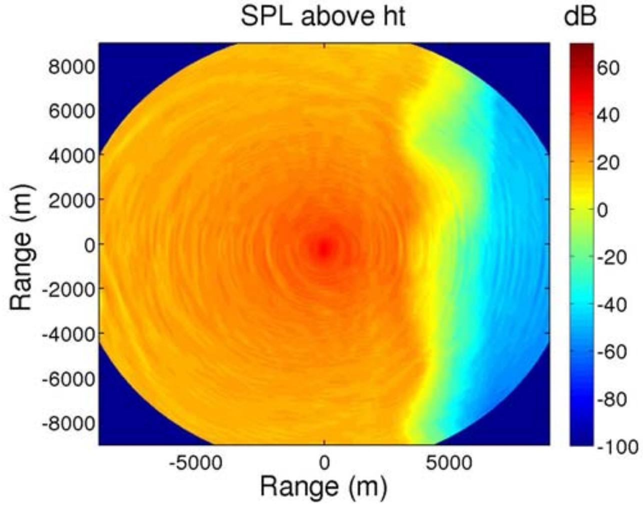


Fig 48. SPL, October 2.5 m, Harbour porpoise

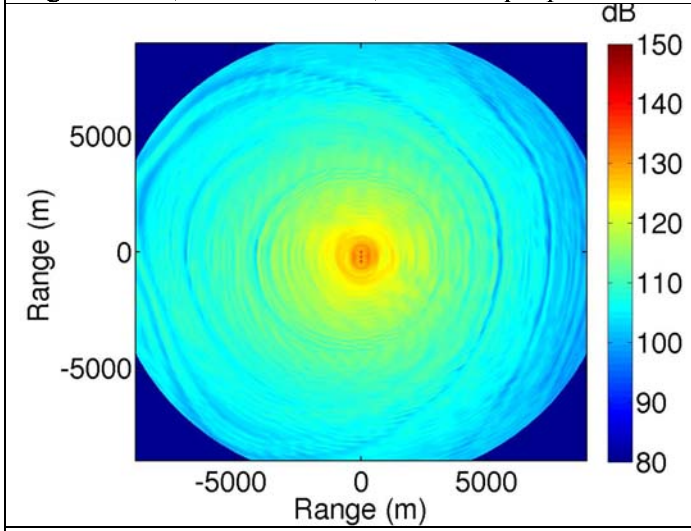


Fig 49. SPL, October 15 m, Harbour porpoise

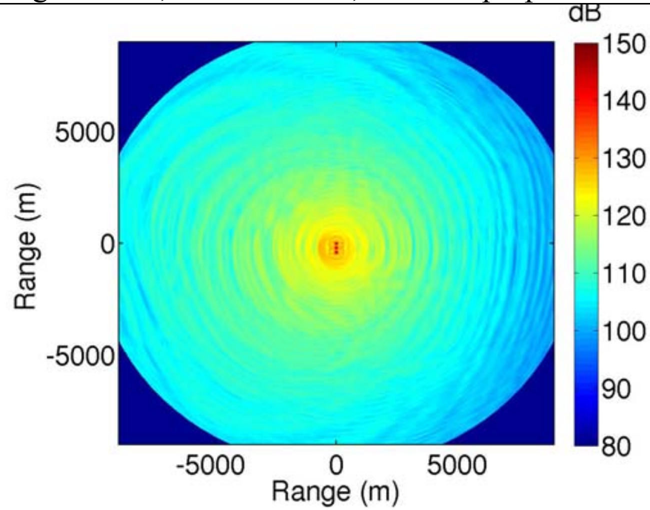


Fig 50. SPL, October 30 m, Harbour porpoise

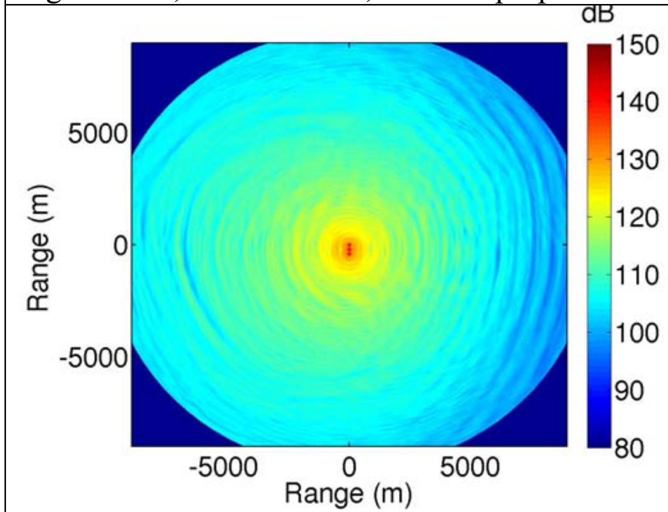


Fig 51. SPL, October 45 m, Harbour porpoise

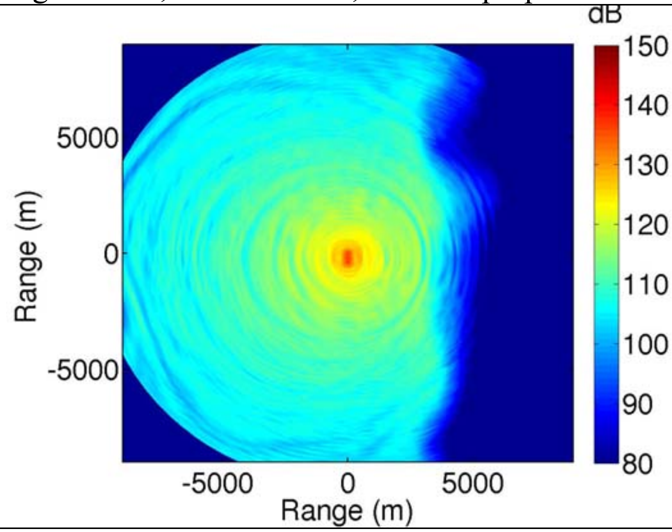


Fig 52. SPL above ht, October 2.5 m, Harbour porpoise

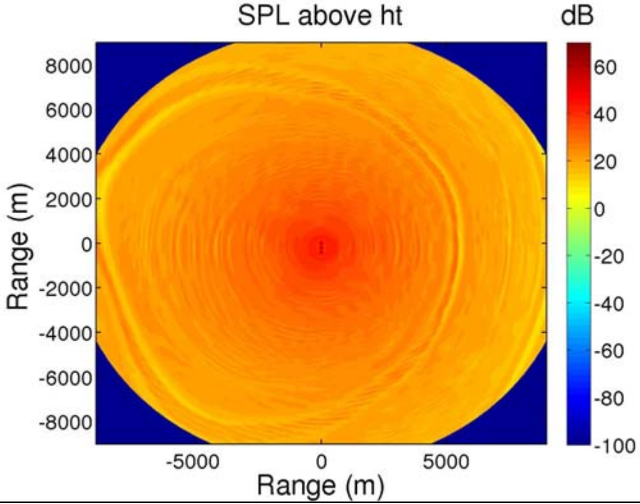


Fig 53. SPL above ht, October 15 m, Harbour porpoise

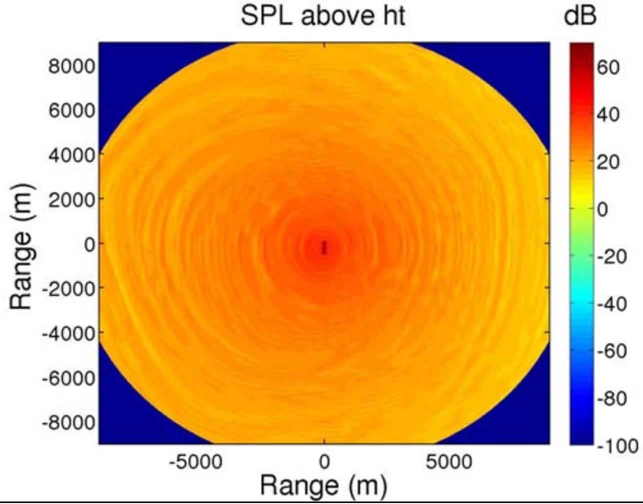


Fig 54. SPL above ht, October 30 m, Harbour porpoise

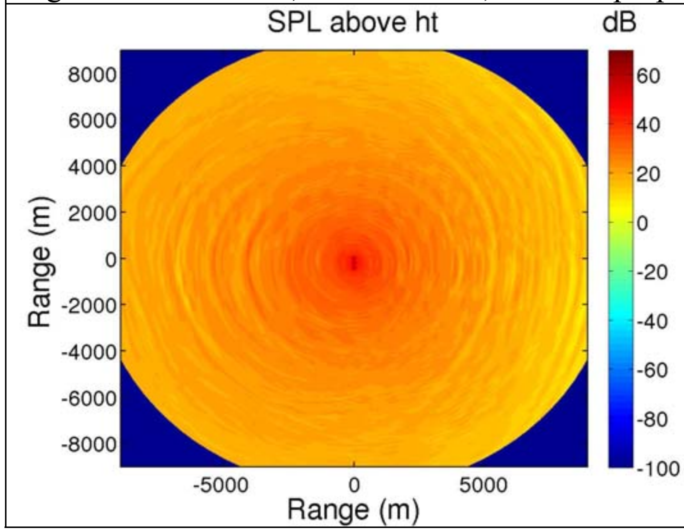
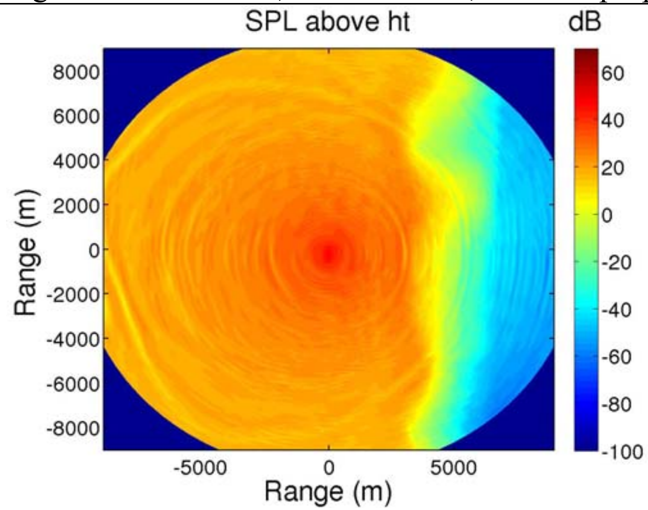


Fig 55. SPL above ht, October 45 m, Harbour porpoise



As a result of comparing the plots obtained for different depths some comments can be done. Apparently, no significant differences in noise levels are found in between the three seasons, according to these plots, even if they seem to be a little bit lower values during July. It is seen that the SPL remains similar at different seasons, which could be either related to the fact that temperature does not create an exaggerated thermocline that affects strongly the sound propagation within the zone. SPL appears to be above 120 dB at around 1250 m from the source, above 110 dB to 5000 m from noise sources and less than this level for areas further away from noise sources. Nevertheless, according to spherical spreading loss, values found within the same depth as the noise source appears to be more than 15 dB lower. A weak trend on SPL to be lower with depth can be seen through these plots, appearing lower values for SPL in 30 and 45 m. It can also be noticed the effect of bathymetry in the right side of the plot of 45 meters, where the sound encounters the bottom and is supposed to be lost by the absorption of it (thus this model does not take into account the processes occurring within the bottom according to its characteristics).

SPL above hearing threshold seem to have a similar behaviour than plots from SPL, which is reasonable taking into account that they should have a direct proportional relation. The higher the SPL within the area, the higher the difference with the hearing threshold from the audiogram could be. Similar comments can be done for the plots with SPL above ht. It seems to have similar behaviour during the three seasons, even if it seems to be lower values in July. Now it is easier to see where we had higher values for SPL. Values above 60 dB above hearing threshold set in 120 dB can be found just in the three points corresponding to our noise sources, while values ranging from 40 to 60 dB above hearing threshold are found in the areas nearer 1.250 m from noise sources. Further from that, lower values are found. In plots for 45 m depth, where bottom is supposed to be found, the right side of the plots show again the interaction with the bottom, and then show values below zero, as no sound is found for the programme within the bottom sea floor.

There is a little trend in higher values (either in SPL and SPL above ht) to be dislocated to the left, which could be related to the presence of higher depth to propagate. That could mean that sound propagates better in higher depths, according to the absence of bottom loss.

7. VALIDATION OF THE MODEL.

Plots for facilitating this part are obtained for the validation of the model. Behavioural effects are difficult to model, while effects based on the hearing range of marine mammals are so much easier predictable. Thus, plots for “disturbance”, “audibility”, and “4-6 dB TTS”, and “4-6 dB TTS + 10 dB”. The figure of audibility shows those points where the marine mammal is susceptible of perceiving noise. For the obtaining of this plot, values of 20 dB above the audiogram will be taken into account. The figure of disturbance (for any cetacean considered) takes the main value of 120 dB instead, and all the values over this one will be considered for the obtaining of the plot. Finally, a temporary injury zone will be determined by the obtaining of the 4-6 dB TTS plot. This plot is obtained by assuming a noise source emitting 30 dB louder and considering the cetacean audiogram (Fig 27). The last plot obtained, would be an extreme case in which the sources are added even 10 dB more, and is calculated the same way as the previous plot.

In the previous plots for SPL and SPL above hearing threshold it was quite difficult to distinguish the areas where effects over marine mammals where susceptible to be found. All these plots make it easier to determine which is the extension of the area susceptible of being affected by the different effects defined for its calculation. The plots obtained show basically the areas where the cetaceans would be affected by the noise level existing. They show the distances from the sources where cetacean are susceptible of suffering because of noise propagation.

Fig 56. Disturbance, April 2.5 m, Harbour porpoise	Fig 57. Disturbance, April 15 m, Harbour porpoise

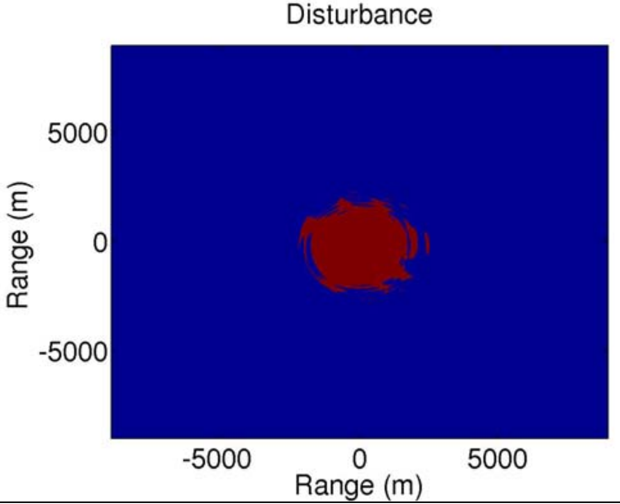
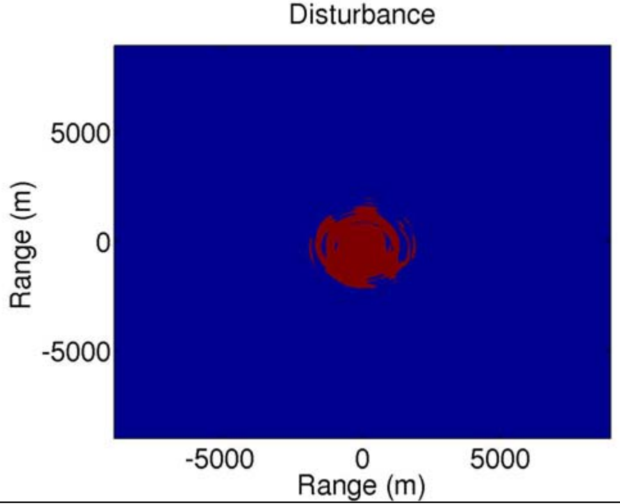

	

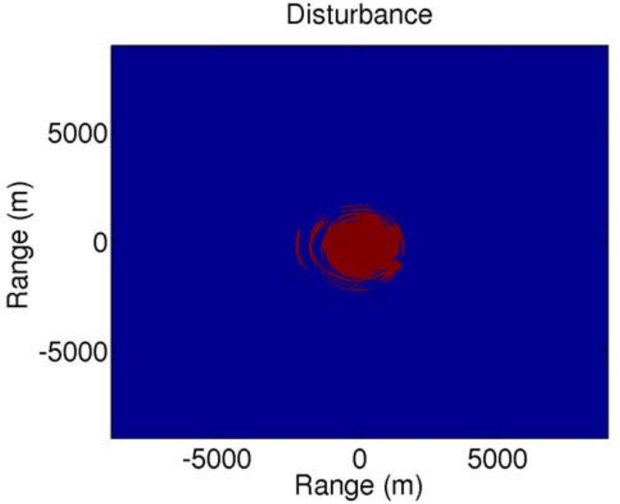
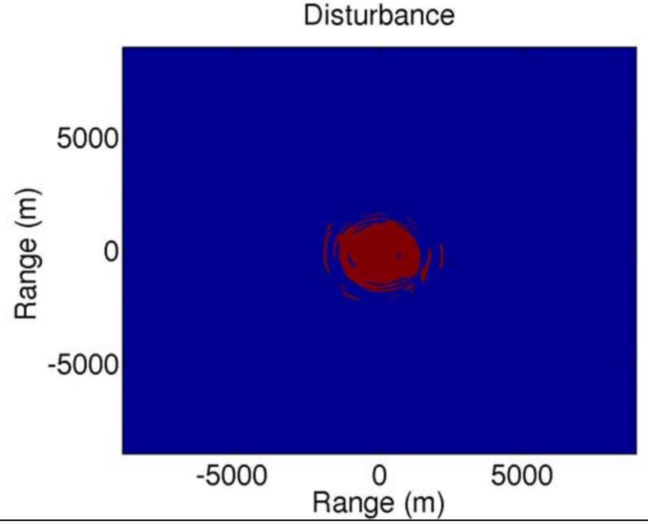
Fig 58. Disturbance, April 30 m, Harbour porpoise	Fig 59. Disturbance, April 45 m, Harbour porpoise
	

Fig 60. Audibility, April 2.5 m, Harbour porpoise

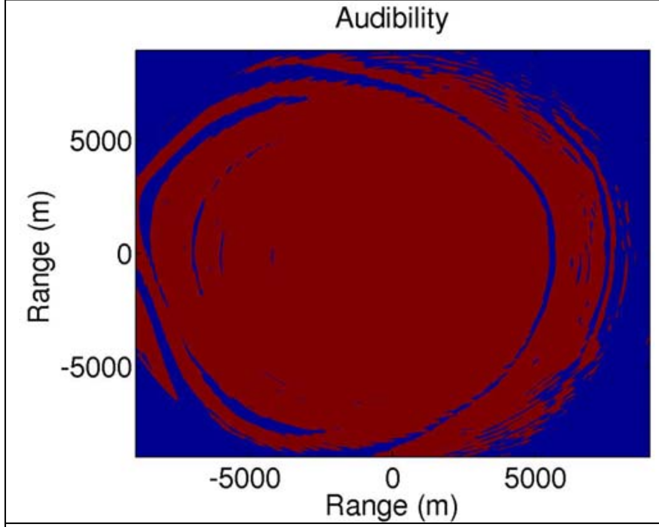


Fig 61. Audibility, April 15 m, Harbour porpoise

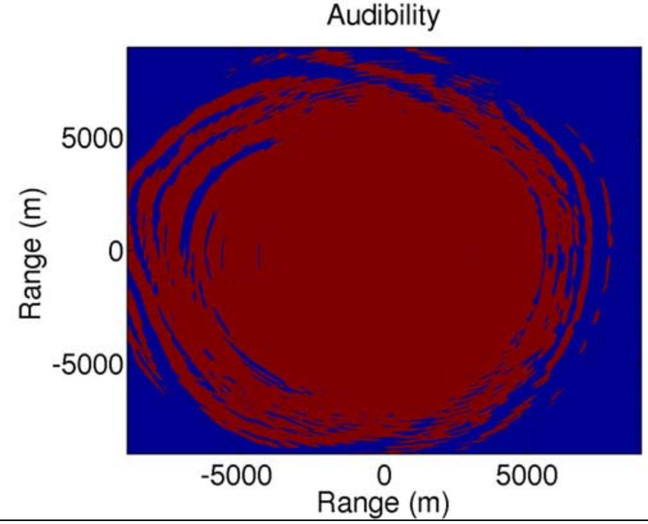


Fig 62. Audibility, April 30 m, Harbour porpoise

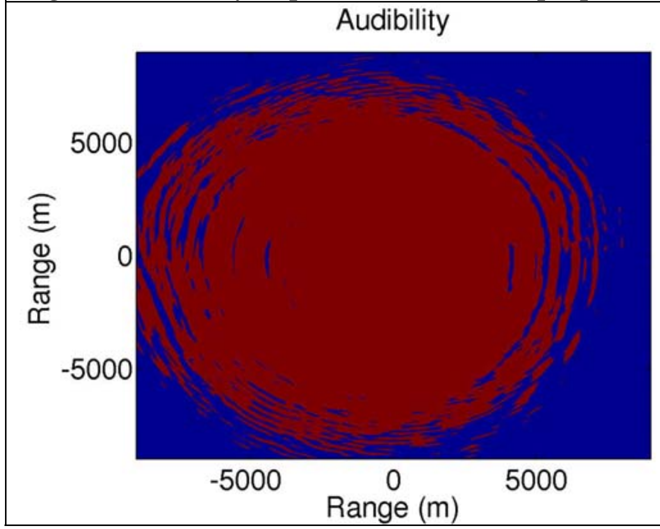


Fig 63. Audibility, April 45 m, Harbour porpoise

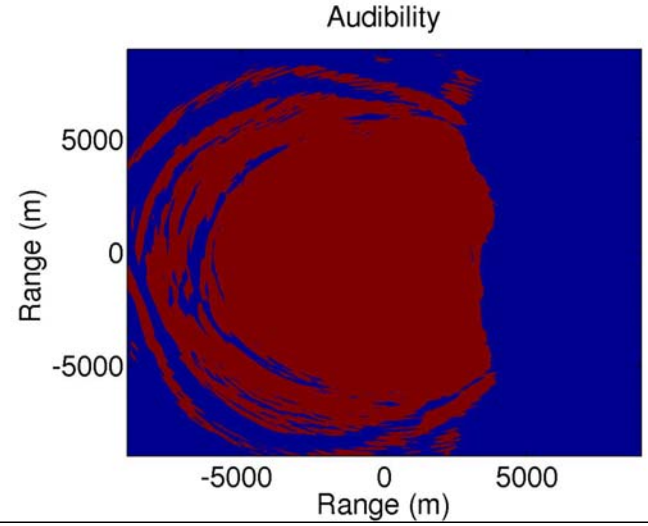


Fig 64. 4-6 dB TTS, April 2.5 m, Harbour porpoise

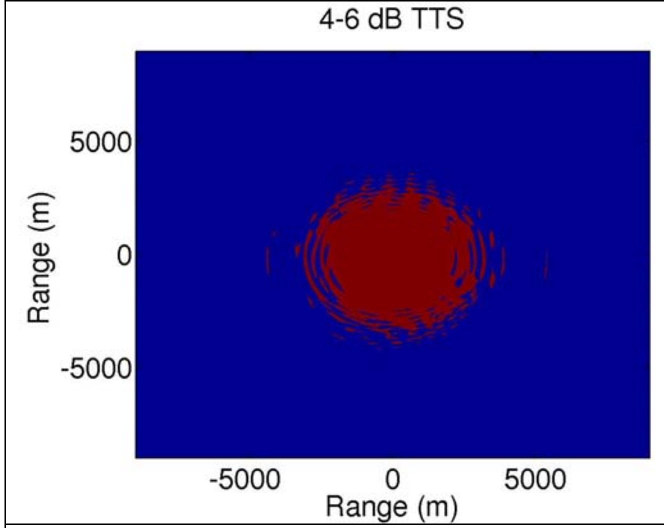


Fig 65. 4-6 dB TTS, April 15 m, Harbour porpoise

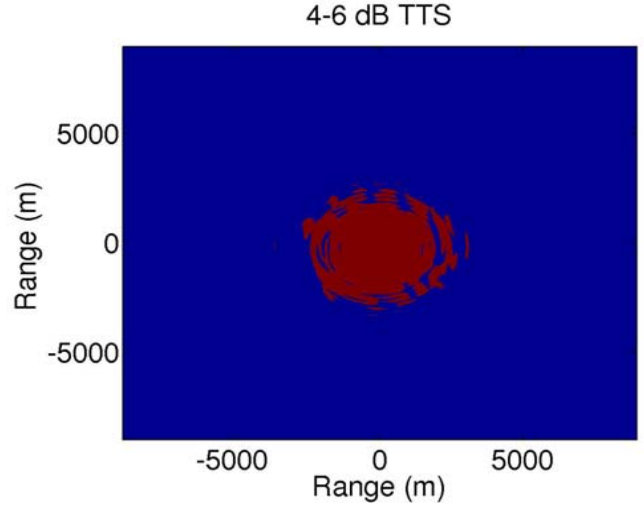


Fig 66. 4-6 dB TTS, April 30 m, Harbour porpoise

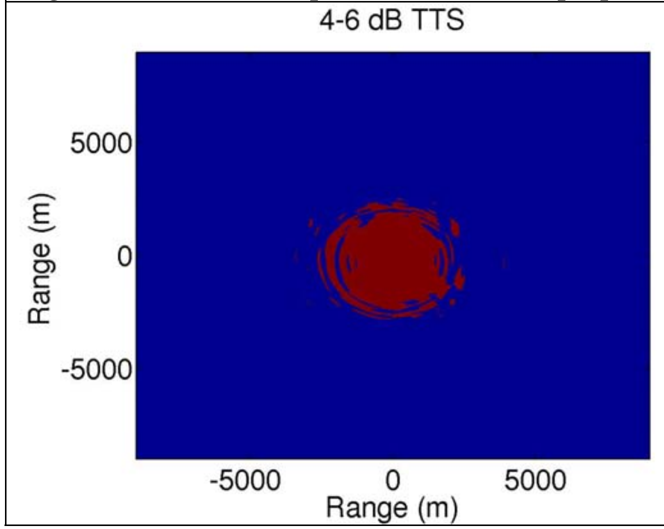


Fig 67. 4-6 dB TTS, April 45 m, Harbour porpoise

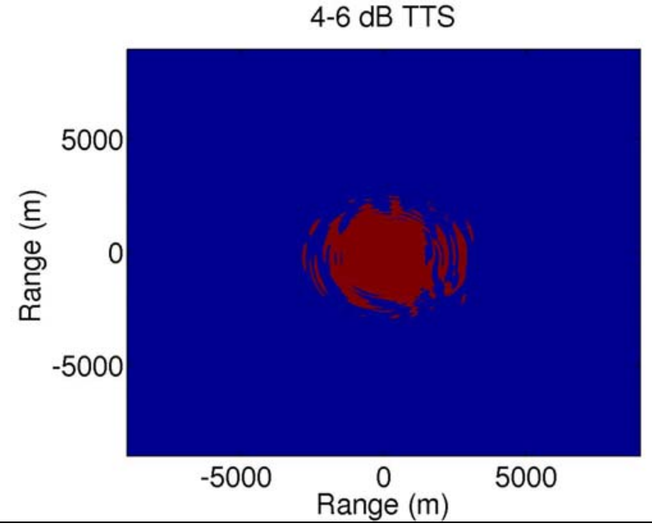


Fig 68. 4-6 dB TTS + 10 dB, April 2.5 m, Harbour porpoise

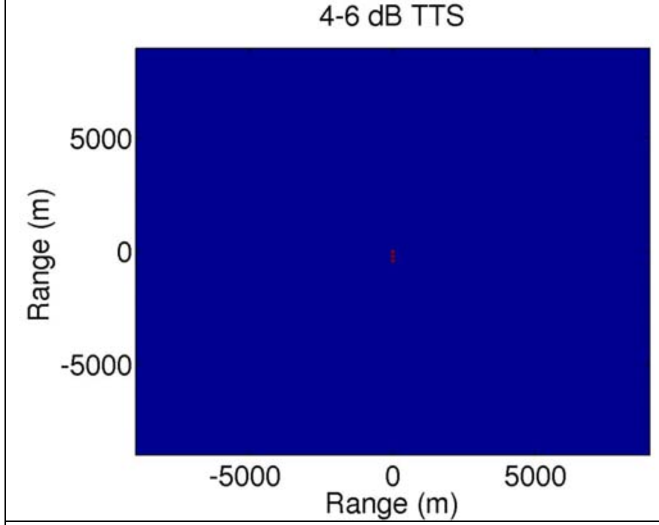


Fig 69. 4-6 dB TTS + 10 dB, April 15 m, Harbour porpoise

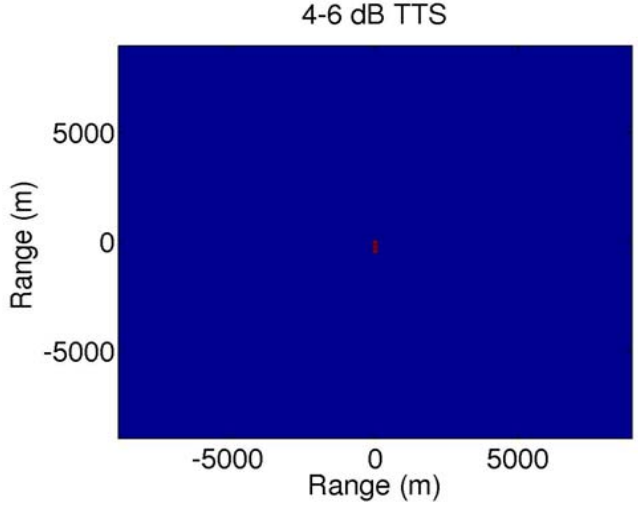


Fig 70. 4-6 dB TTS + 10 dB, April 30 m, Harbour porpoise

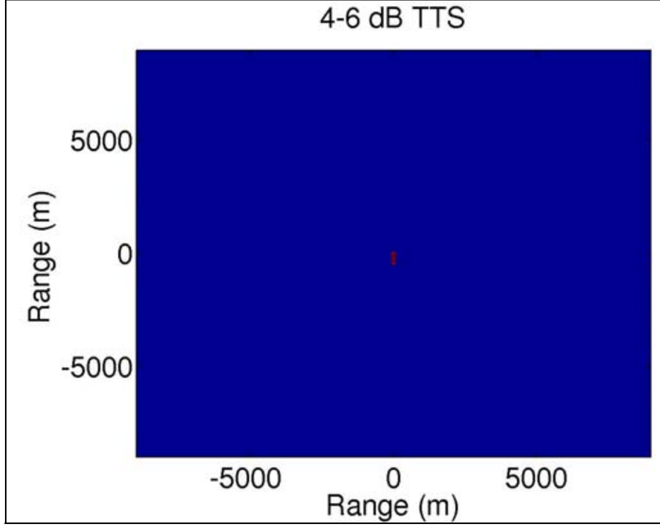


Fig 71. 4-6 dB TTS + 10 dB, April 45 m, Harbour porpoise

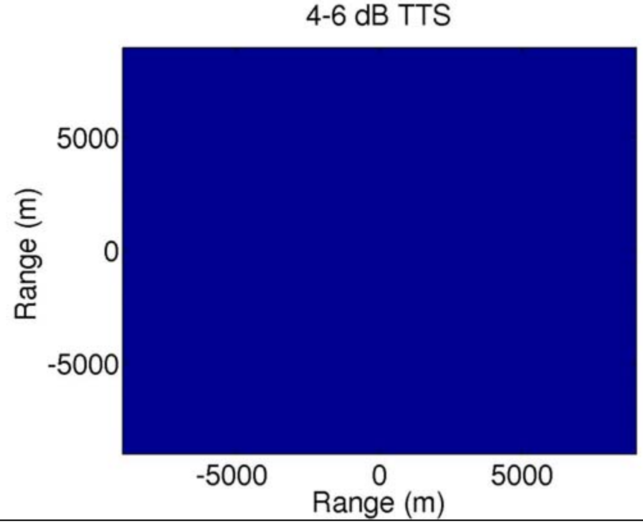


Fig 72. Disturbance, July 2.5 m, Harbour porpoise

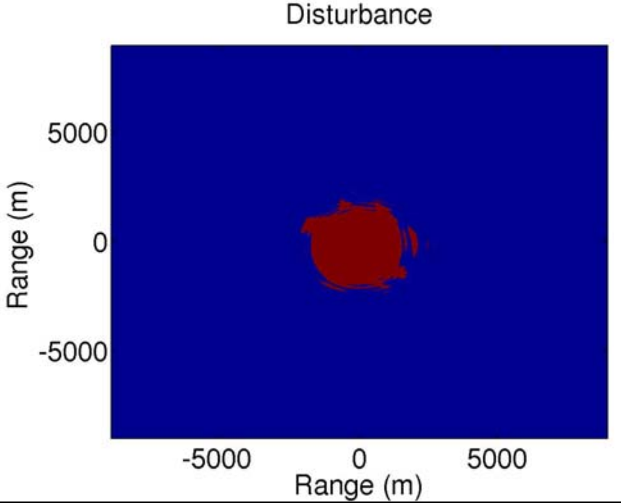


Fig 73. Disturbance, July 15 m, Harbour porpoise

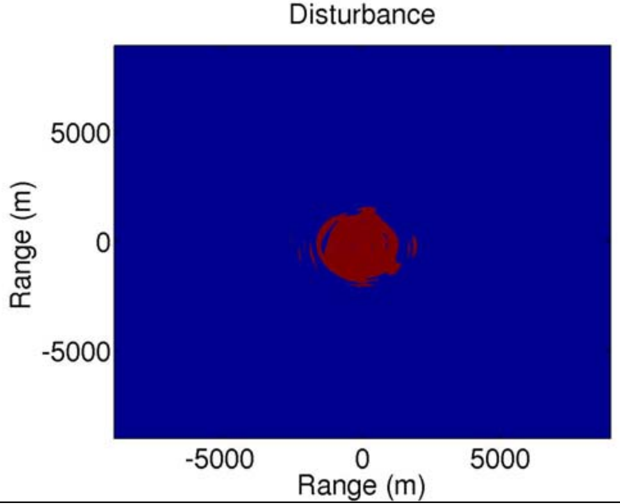


Fig 74. Disturbance, July 30 m, Harbour porpoise

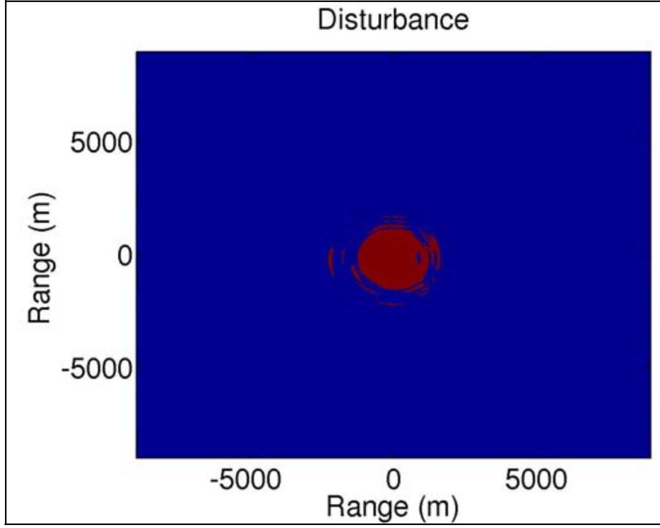


Fig 75. Disturbance, July 45 m, Harbour porpoise

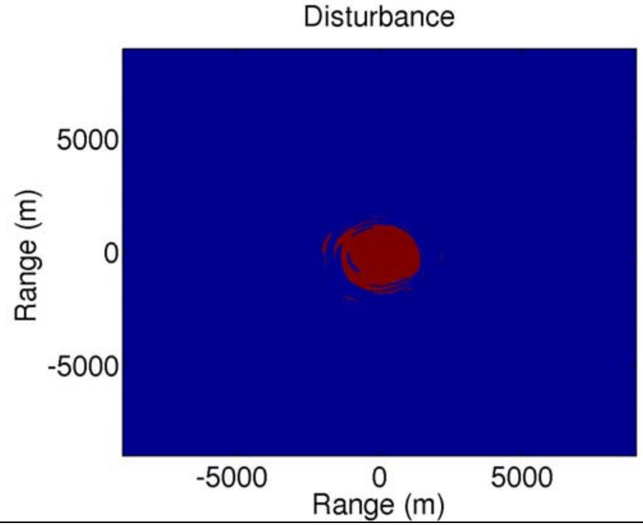


Fig 76. Audibility, July 2.5 m, Harbour porpoise

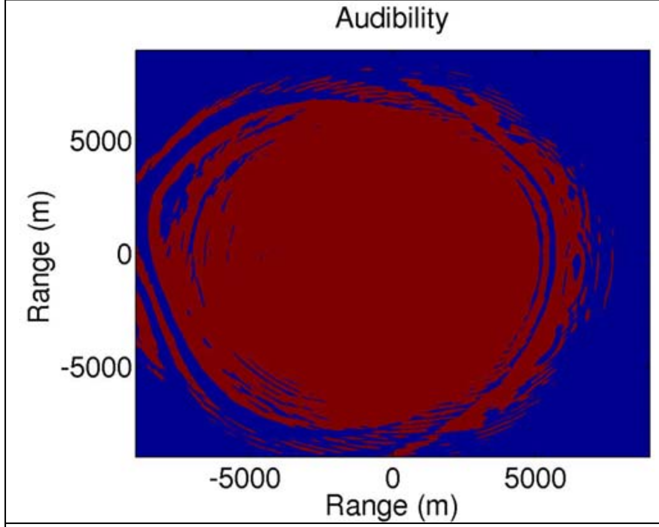


Fig 77. Audibility, July 15 m, Harbour porpoise

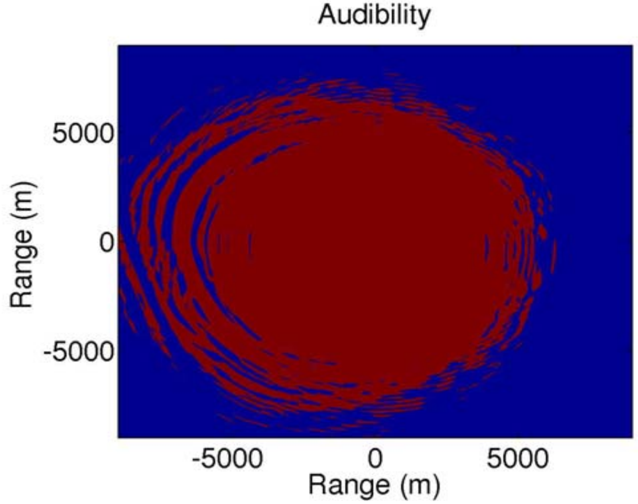


Fig 78. Audibility, July 30 m, Harbour porpoise

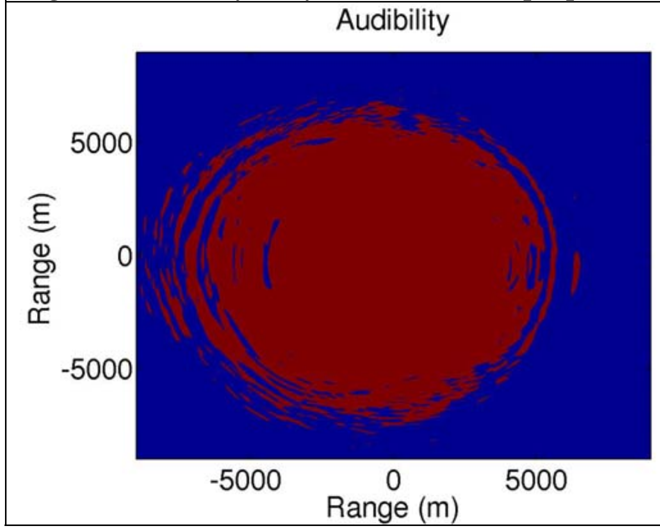


Fig 79. Audibility, July 45 m, Harbour porpoise

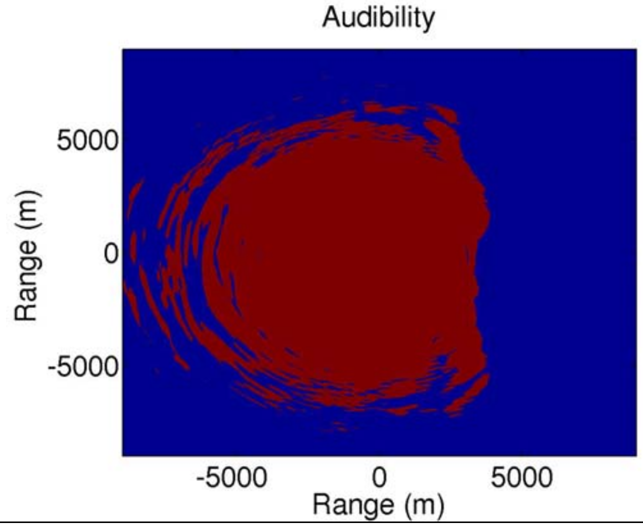


Fig 80. 4-6 dB TTS, July 2.5 m, Harbour porpoise	Fig 81. 4-6 dB TTS, July 15 m, Harbour porpoise

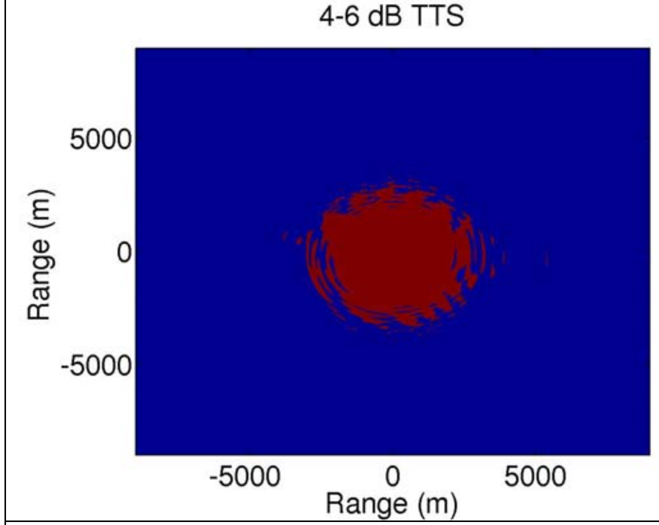
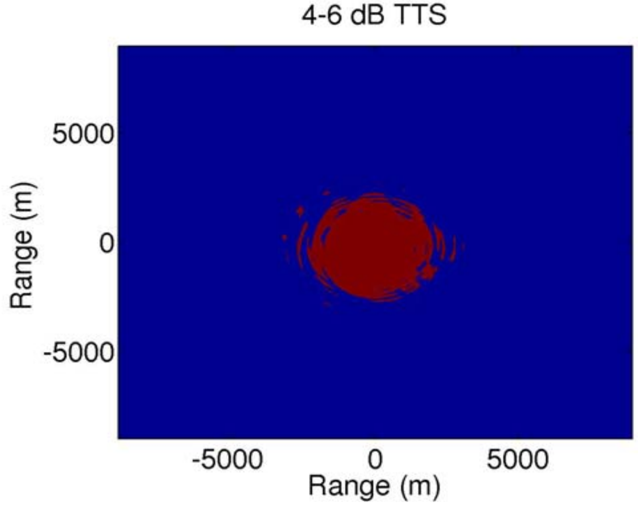
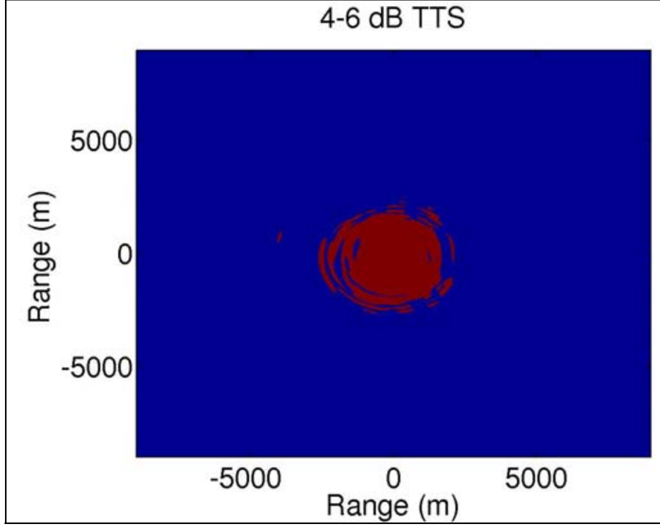
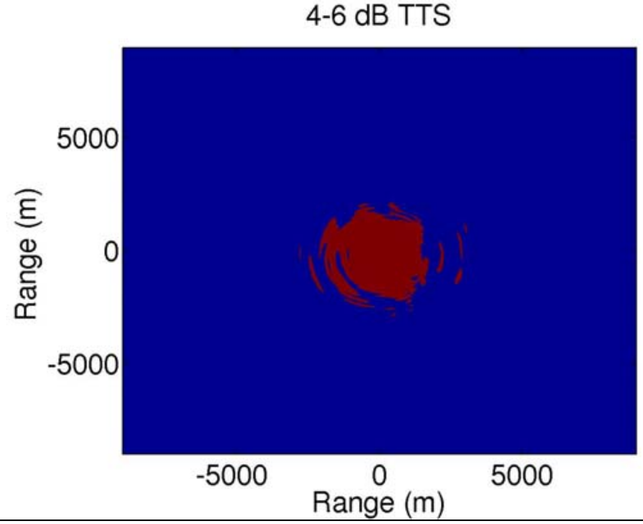

	

Fig 82. 4-6 dB TTS, July 30 m, Harbour porpoise	Fig 83. 4-6 dB TTS, July 45 m, Harbour porpoise
	

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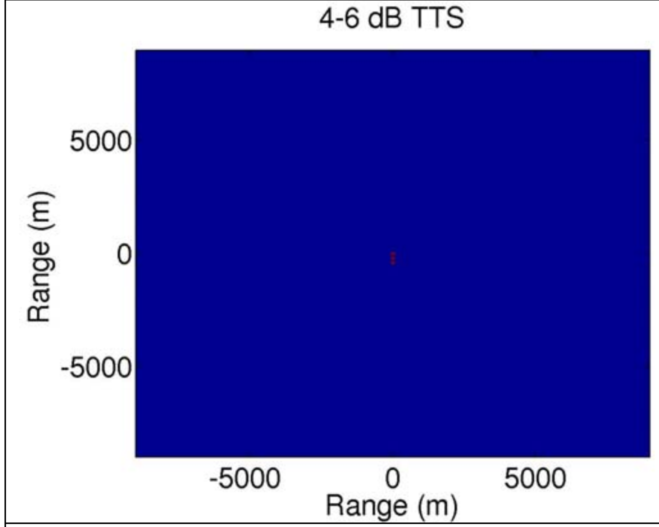
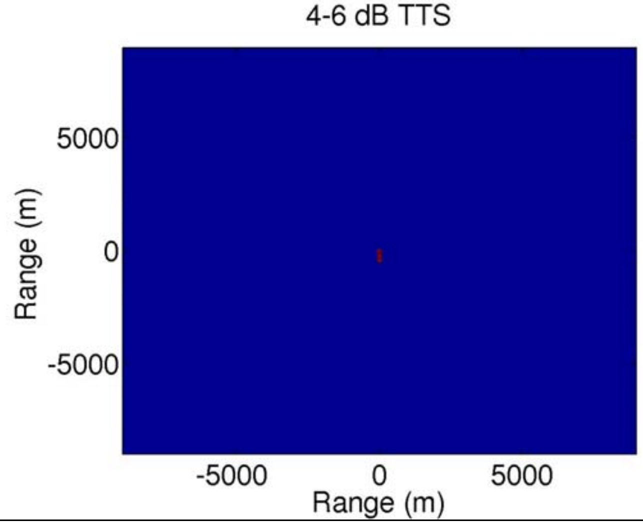
<tr><td>Fig 84. 4-6 dB TTS + 10 dB, July 2.5 m, Harbour porpoise</td><td>Fig 85. 4-6 dB TTS + 10 dB, July 15 m, Harbour porpoise</td></tr>
<tr><td>
</td><td>
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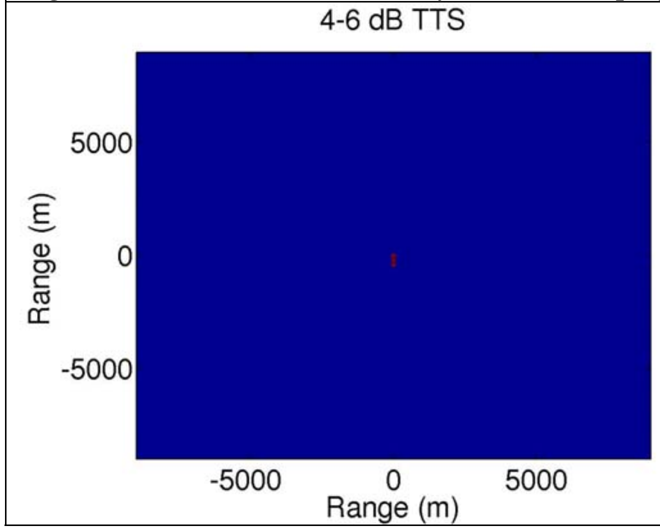
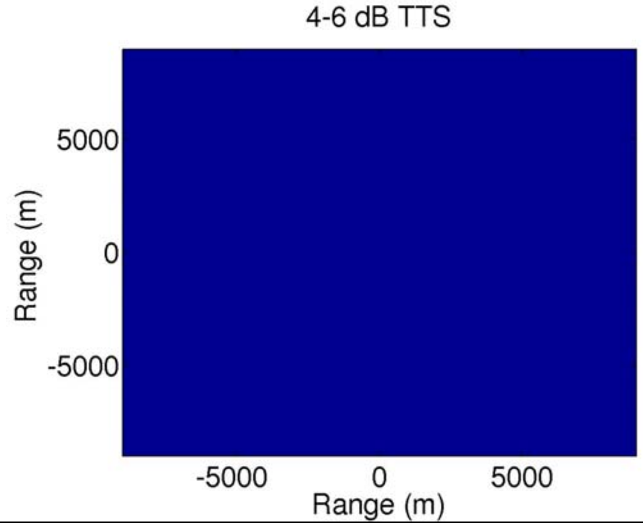
<tr><td>Fig 86. 4-6 dB TTS + 10 dB, July m, Harbour porpoise</td><td>Fig 87. 4-6 dB TTS + 10 dB, July 45 m, Harbour porpoise</td></tr>
<tr><td>
</td><td>
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Fig 88. Disturbance, October 2.5 m, Harbour porpoise

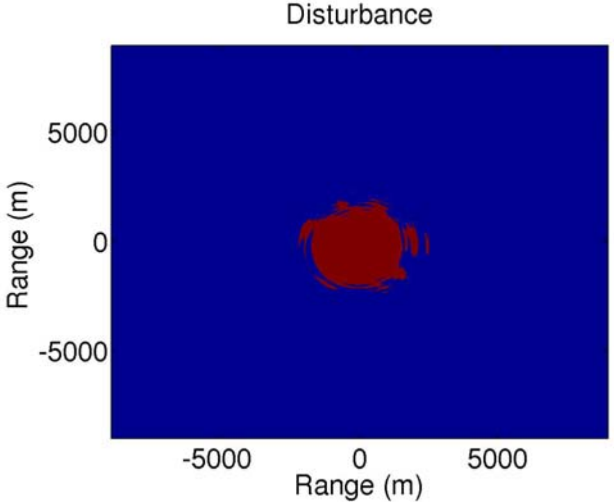


Fig 89. Disturbance, October 15 m, Harbour porpoise

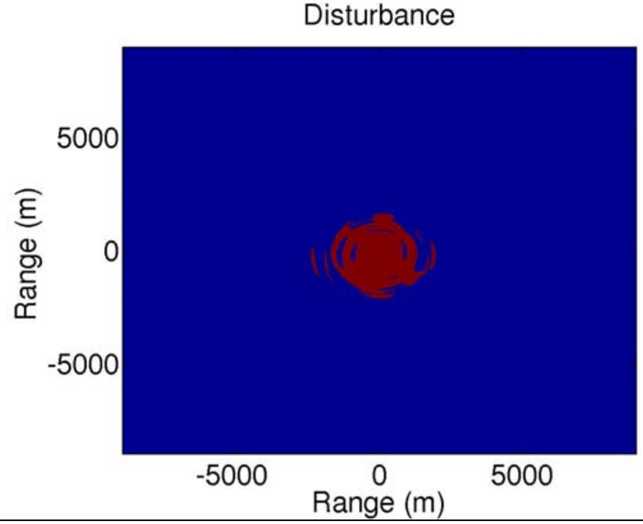


Fig 90. Disturbance, October 30 m, Harbour porpoise

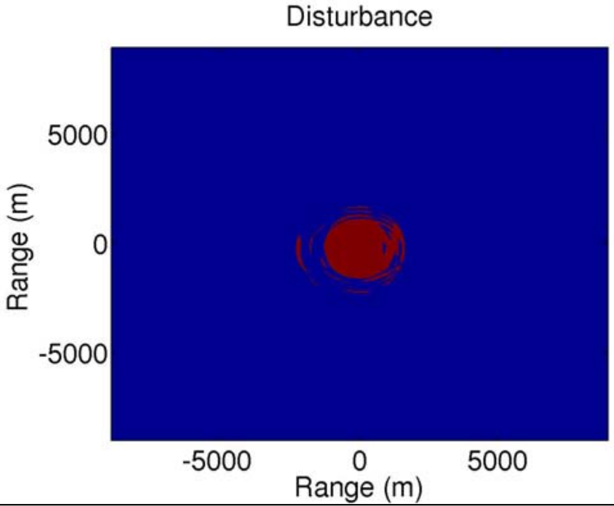


Fig 91. Disturbance, October 45 m, Harbour porpoise

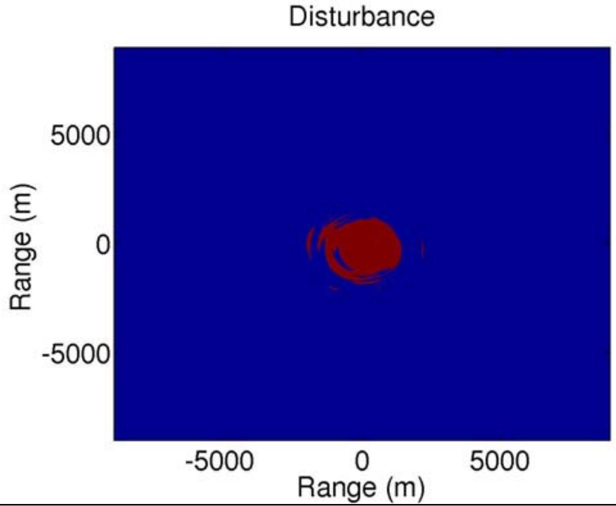


Fig 92. Audibility, October 2.5 m, Harbour porpoise

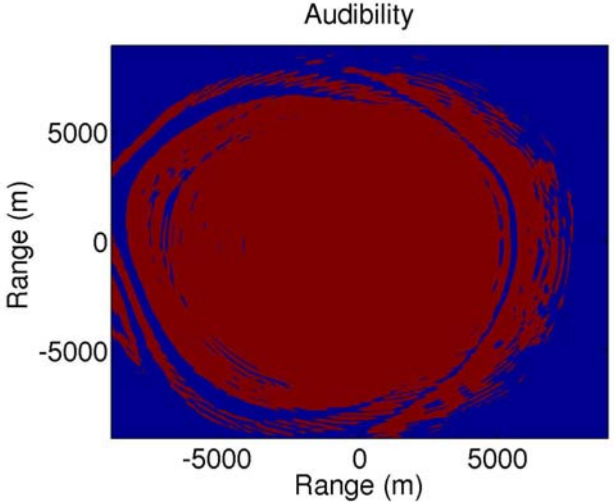


Fig 93. Audibility, October 15 m, Harbour porpoise

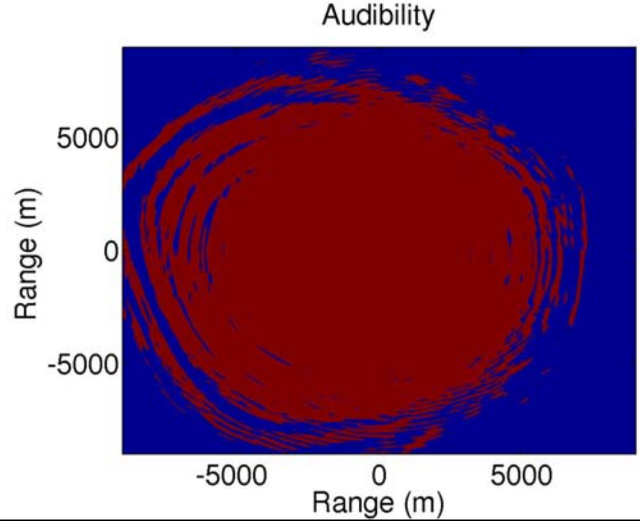


Fig 94. Audibility, October 30 m, Harbour porpoise

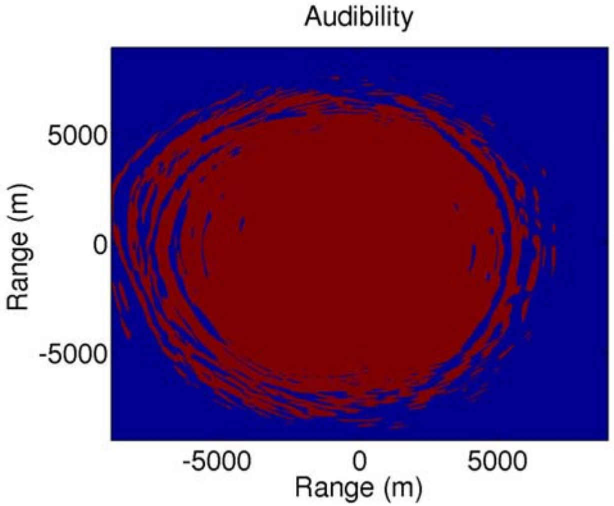


Fig 95. Audibility, October 45 m, Harbour porpoise

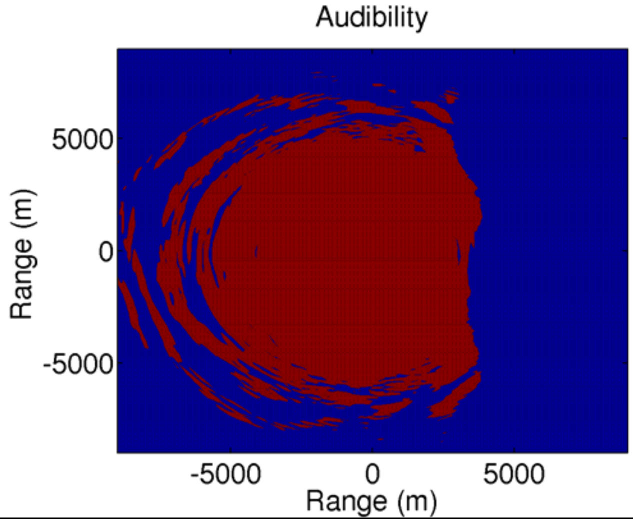


Fig 96. 4-6 dB TTS, October 2.5 m, Harbour porpoise

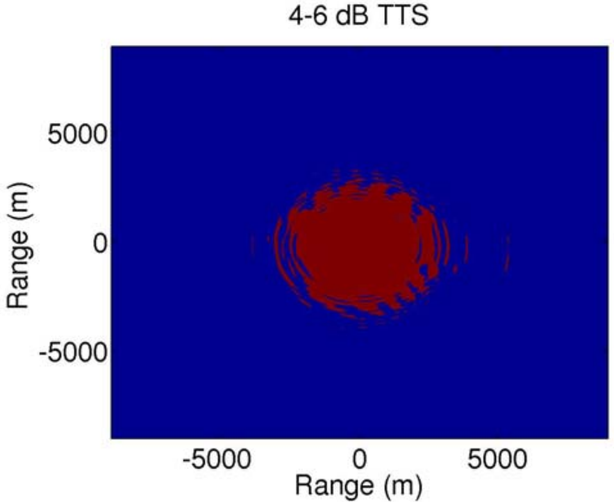


Fig 97. 4-6 dB TTS, October 15 m, Harbour porpoise

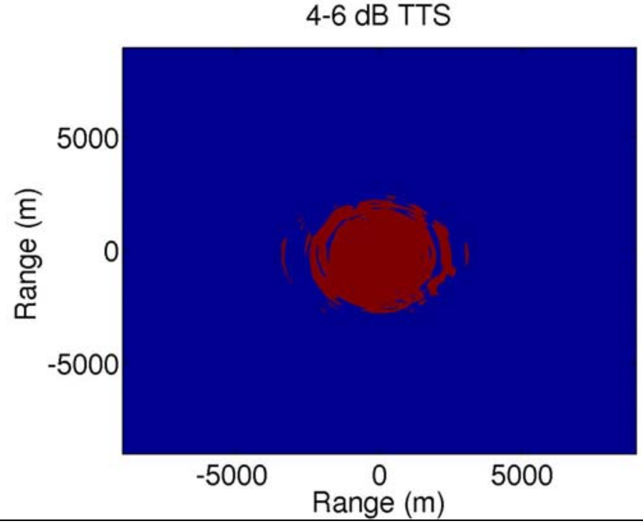


Fig 98. 4-6 dB TTS, October 30 m, Harbour porpoise

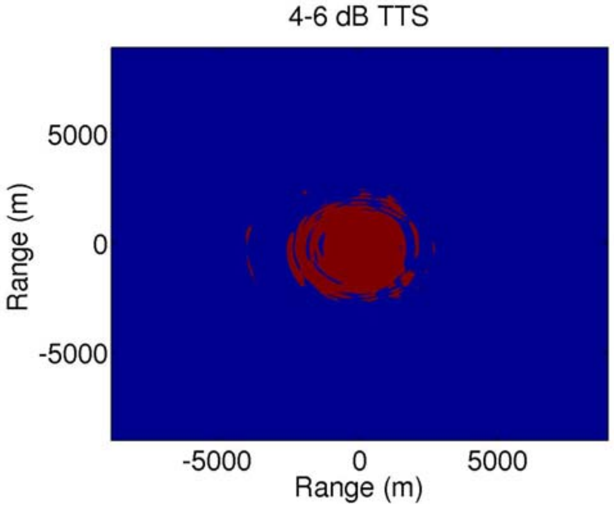


Fig 99. 4-6 dB TTS, October 45 m, Harbour porpoise

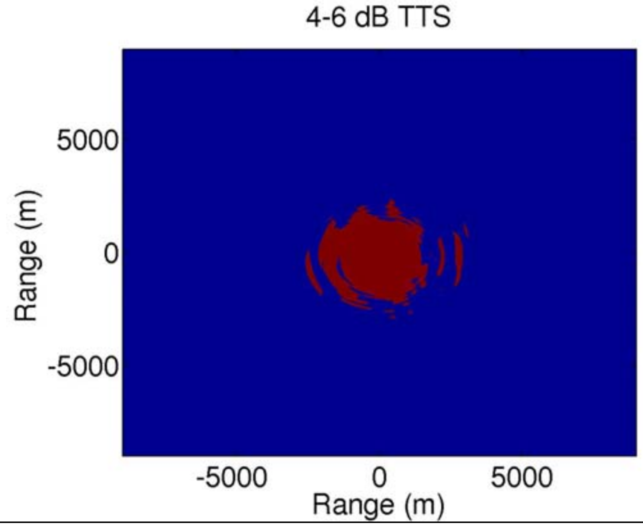


Fig 100. 4-6 dB TTS + 10 dB, October 2.5 m, Harbour porpoise	Fig 101. 4-6 dB TTS + 10 dB, October 15 m, Harbour porpoise

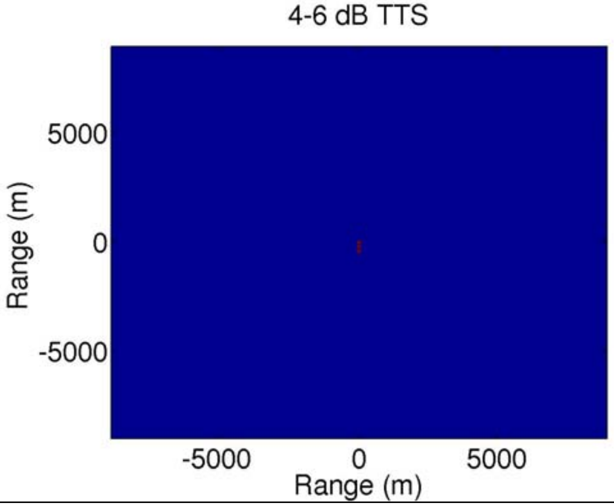
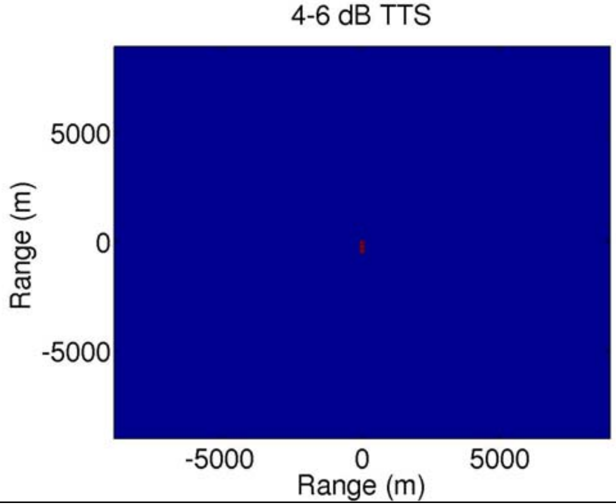
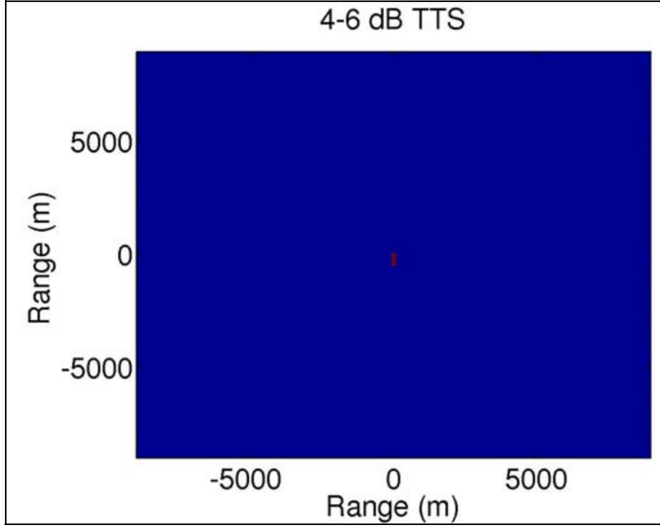
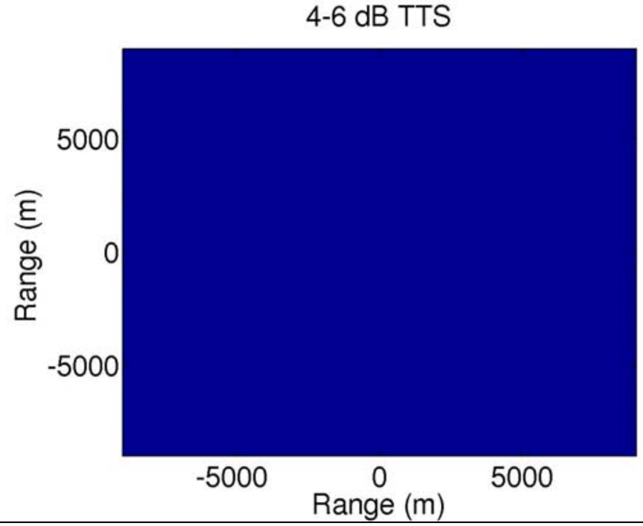

	

Fig 102. 4-6 dB TTS + 10 dB, October 30 m, Harbour porpoise	Fig 103. 4-6 dB TTS + 10 dB, October 45 m, Harbour porpoise
	

There is always a general trend in the plots obtained to have reducing areas with depth. The plots obtained do not seem to have a significant variation along the year, having similar shapes for every same plot at the same depth.

Disturbance plots show an area of about 1,5 km ratio from the source, which gets a little smaller with depth.

The areas found for audibility appear to be much wider, reaching the ratio of 5 km from the noise source.

Areas for the effects of up to 6 dB TTS, seem to reach the 2,5 km ratio, which is a bigger ratio than the one found for the disturbance area. That means, that if the source where louder, it would mean a real extension in the area where actually injuries could be affecting the marine mammals.

For the extreme situations simulation, it appears to be only significant in the noise source points.

All this plots represent the values over the reference set, that would mean that they represent those areas where the answer to the question "**Does the noise exceed the threshold within the zone?"** is positive, and so, a reapproachment of the project should be carried on, or some management actions has to be applied.

8. DISCUSSION:

Every developing plan occurring within the coast affects many social, economical and ecological variables that have to be taken into account while managing any of these programmes. A correct EIA and management are required for the evaluation of any plan.

New reliable tools need to be found to give the manager the ability of predicting impacts and facilitate how to measure and manage these environmental impacts. For the case of appearing of underwater acoustic noise impact onto the ocean, it converts the objective of managing into a real problem. As it is difficult to measure and evaluate the damages that it could cause over the environment as well as the propagation paths and transmission loss that noise suffers within the ocean. Modelling the underwater acoustic noise would be a useful tool for determining whether management actions should be applied within the zone, and how to implement them.

The main reason why sound requires a further study within the ocean is because its attenuation can be so weak that it can travel along long distances, with the added fact of being the most important sense for some marine animals as cetaceans.

The introduction of noise into the ocean by installation of OREDs is clearly a serious issue for marine mammals, and it needs to be correctly analysed and evaluated, taking into account that even installing is already taking place.

Modelling the underwater acoustic noise will firstly give the manager the ability of predicting expected noise values in every point of the water column, and thus giving him the opportunity of creating noise level maps. These noise level maps will give an intuitive idea of how the sound is transmitted within the study area. This would be a complex end expensive task if we had to make them with experimental data, because of the technology required and the inaccessibility of the mean. Afterwards, maps showing the areas susceptible of having any effect on marine mammals are easy to obtain, by comparison of sound level values with audiograms giving hearing thresholds for marine mammals. They facilitate a lot the determination of impact areas. After determining the spatial distribution of underwater acoustic noise and comparison of sound level values with thresholds set for marine mammals, it could also be appropriate to make a gradation map with distance, where zones of maximum, medium and minimum effects can be shown. This could be a good tool for determining the areas where more or less protection or management is needed.

For the determination of the impacts on marine mammals, behavioural and physiological effects can be studied such as hearing loss. Predicting hearing loss appears to be a complex task. Nevertheless, studies are being carried on in order to give more and more precise information about hearing loss in marine mammals. Values for temporary hearing loss (TTS – Temporary Threshold Shift) and (PTS – Permanent Threshold Shift) are given for different species on marine mammals. Exposure for long periods to TTS is susceptible to convert those levels into PTS. Thus, it is important to know the duration of the noise, which in this case is not possible as no real information about the noise source is still available.

The results obtained by the model determine whether the sound pressure levels obtained are loud enough to make any disturbance to the marine mammals existing in the zone. After running the model, the results have shown that they are able to give precise predicted areas with different effects over marine mammals. These simulated scenarios give also the possibility of experimenting possible effects and determining effect areas if the source is louder or quieter, for example, as we are allowed to change any source or environmental characteristic within the model. Also, it can be run plenty of times to study the best way of implementing any plan

<u>PROPOSED STRATEGIES ON OCEAN NOISE MANAGEMENT.</u>	
A. SAFE EXPOSURE LEVELS	- Establishment of a particular noise level, such as TTS, PTS or others.
B. MITIGATION MEASURES AND THEIR SHORTCOMINGS.	- SAFETY ZONES: establishment of visual safety zones, where observers determine the presence of cetaceans and temporarily can shut down or reduce the power of noise source. - "RAMP-UP" or "SOFT-START": Consisting in the gradually introduction of noise into the environment, assuming the possibility of the animal to move away without any significant impacts. (still not proven)
C. PRECAUTION IN MANAGEMENT.	- Setting of precautionary steps for preventing the effects and helping protection. First by increasing the protection before irreversible damage is done. Secondly, by distancing noise events from biologically important areas or concentrations of cetaceans.
D. SOURCE MODIFICATION.	- Changing the noise source characteristics, and building quieter noise sources.
E. SEASONAL AND GEOGRAPHIC EXCLUSIONS.	- Distancing noise events from important biological areas, or either manage seasonal functioning.

PROPOSED STRATEGIES ON OCEAN NOISE MANAGEMENT.	
F. MARINE PROTECTED AREAS (MPAs)	- Creation of zones, that if well-managed, offer the most effective means to protect cetaceans and their habitat (regulation over the entire ecosystem), from noise and any other anthropogenic stressors.
G. REDUCTION IN NOISE PRODUCING ACTIVITIES.	- Reducing noise-production activities by maximizing the results obtained for every trip or exploration, and by sharing data and results obtained in order to minimize the noise sources entering the ocean.
H. MONITORING	- MONITORING AND REPORTING: essential parts of management actions. Further studies on cetacean strandings and mortalities for appropriate thresholds/impacts determination. Usage of Passive Acoustic Monitoring (PAM) to detect presence of cetaceans, and to assess sources and levels of anthropogenic noise → Detection on how noise affects distribution and vocalization of cetaceans.

Table 3. Proposed strategies on ocean noise management. Table created from Weilgart, 2007.

Some strategies for ocean noise management were described by Weilgart, which are shown in Table 3. It will be discussed which of them are applicable in this case. Safe exposure levels (TTS, PTS, disturbance, audibility), were already used for the determination of the areas susceptible of causing any damage to cetaceans. Concerning the mitigation measures, it is unexpected that the power of the noise source could be gradually introduced or reduced in some moments, as it is activated by the wave motion and it starts functioning at the rms SPL at the moment when it is installed and activated by the waves, and can not be externally regulated or gradually increased. Precaution management could be done, trying to create legislations and protection figures that include the effects of noise before the installation of all these kind of devices. Source modification could be done by the engineering enterprise in order to minimize the impacts made by the noise, maximizing the energy provided. Seasonal and geographic exclusions could be a possible action if cetacean and their behaviour within the zone were further studied to determine if there is a period where their presence is concentrated. In this case, the device could be retired within this period. Even though, economically aspects of device transport and reinstallation should be taken into account in order to study the profitability of this action. The creation of MPAs should be done before the installation of the device, because in this case it can not be assumed. Reduction of noise producing activities could be done by maximizing the relation energy obtained/noise produced. Finally, monitoring will always be important during the planning, installing or even decommissioning phase of the plan, in order to make a reliable report on the species within the zone and their behaviour in the presence of noise.

It is important for the manager to use modelling only as a tool and not forget the rest of the DPSIR framework scheme. It is important to integrate the results obtained with this study but give the appropriate weight to each of the elements within the scheme before the whole plan decision-making.

There are many uncertainties involving this study:

- Lack of in-situ measurements to give information about noise source real characteristics (rms SPL, frequencies, duration of signals)
- Data for hearing thresholds in marine mammals has still to be studied further to reassure the limits over which real effects can be generated. It still exist much uncertainty about cetacean hearing and the ways to measure it.
- Data for hearing thresholds were not found for every species existing within the study area.
- There are no concrete existing laws on underwater acoustic noise produced by off-shore devices. Management over these plans have to be done then by the usage of policies implying protective figures over some of the marine mammals existing within the zone. It is important to consider underwater acoustic noise as a pollutant, with no boundaries, and to highlight the necessity of promoting its prevention, reduction and control.
- The case considered has some limitations as the wave front is orthogonal to the coast and we are only assuming three noise sources in order to simplify the example.
- Effects of natural underwater acoustic noise were not added to the noise levels obtained, also can not be forgotten.

9. CONCLUSIONS AND RECOMMENDATIONS:

It appears to be demonstrated that the viability of modelling underwater acoustic noise and the procedure followed as a tool for coastal management can answer the question **"Does the noise exceed the threshold within the zone?"** It allows the manager to determine the areas susceptible of having negative impacts to the animals, and thus, be able to decision-making.

Results obtained from this study give evidence that the use of tools, such as modelling physical properties related with some projects, need to be integrated into management for improving decision-making processes over renewal energy projects. Also the same needs to be done for setting guidelines, which can be used for future creation of directives and legislation, as they give a reliable simulated scenario which can allow the manager to have information that, without modelling would be practically inaccessible. This study made a simple example of the way modelling can help in determining the damaging effects that a project in a hostile medium such as the ocean can have into marine organisms.

Nevertheless, the case study is still very new that reliable information was still not available, and it is shown as a reference/example of what can be done in the future research for management. We only intended to show an example of how the current existing tools can be applied to perform a correct management process of the increasing use of off-shore devices.

As recommendations after the carrying out of this study:

- Study over the zones where OREDs are planned to be installed should be done in order to place them. If possible, it should be placed in those places where less marine life and impacts exist. However, this should be done even before installing the device, which is not possible in this study case as the device is already installed.

- Further study over marine mammals and their behavioural and hearing responses to different types of noise should be done, and data should be put in together for determining reliable thresholds within the scientific community.
- There is a need of a correct DPSIR framework scheme in order to use it as a guide for coastal management decision-making. This importance resides in the fact that sometimes there is a lack in between the different elements of the scheme and difficulties appear during the decision making process. That is the reason why it is important to determine the appropriate tools for relating the elements and making the links in between them more comprehensible.
- Introduction of available advanced technology tools should be facilitated to clarify as many of the DPSIR framework schemes as possible.
- Real data should be obtained for noise source and environment to determine the real effects of ORED installation within the study area. Also the complete case study should be taken into account for the determination of effects under every possible situation.
- Transboundary and international policies should be created for underwater acoustic noise introduction into the ocean, as well as for ORED installation. That is of an imminent necessity as ORED are already being installed along the worldwide coasts.

- Even though the model has been demonstrated to have reliable results, the collection of real in-situ data by hydrophones would always be recommended to validate the model.
- This study is considering the operating phase underwater acoustic noise, though it would be recommended to consider the noise produced during the installation and decommissioning phases.
- It would also be interesting to determine the cumulative effects of the underwater acoustic noise introduced by OREDs, as their number is increasing.
- Wide-ranging perspective, adaptable monitoring and research based on our best understanding of coastal environment would be needed, for the installation and remaining of every ORED located into the coast.

Different types of OREDs have been already set into our coasts, but creating a correct management procedure before their installation is a complete necessity, as there is an evidence that they are actually necessary for current energetic society requirements.

Bibliography

- BUCKINGHAM, M.J. "Ocean-acoustic propagation models" Journal acoustique (1992) 223-287.
- DELPHIS. 2004. Informe sobre Varamientos de Cetáceos y Tortugas Marinas en la Provincia de Cádiz. Ecologistas en Acción. Septiembre. 21 pp.
- ENS. "Noisy, acid oceans increasingly harmful to whales". Press release, issued December 3rd 2008.
- EUROPEAN COMMISSION RESEARCH NEWS, 2004. "`Calming´influence-European noise pollution network". 26 October 2004. (http://ec.europa.eu/research/transport/news/article_1608_en.html)
- GILL, A.B. "Offshore renewable energy: ecological implications of generating electricity in the coastal zone" Journal of applied Ecology, 2005. 42, 605-615.
- HASTINGS, M.C. 2008. "Coming to terms with the effects of ocean noise on marine animals". Acoustics today, volume 4, issue 2. April 2008. pp 22-33.
- JACOBSON, S., JOHNSON, A. "The diffusion of renewable energy technology: an analytical framework and key issues for research". Elsevier, Energy Policy 28 (2000) 625-640.
- JENSEN, F., KUPERMAN, W., PORTER, M. and SCHMIDT. "Computational Ocean Acoustics". American institute of Physics, New Cork, 1994.
- KAKUTA et al. "Review of Underwater Acoustic Sources and Evolution of Environmental Policy on Marine Artificial Sounds" IEEE, 2004. pp 1706-1709.
- KELLY, C., GLEGG, G.A., SPEEDIE, C.D. "Management of marine wildlife disturbance" ELSEVIER, 2004. Ocean and coastal management 47 (2009) 1 19.
- KRISTENSEN, P. "The DPSIR Framework" UNEP headquarters, Nairobi, Kenya. September 2004.

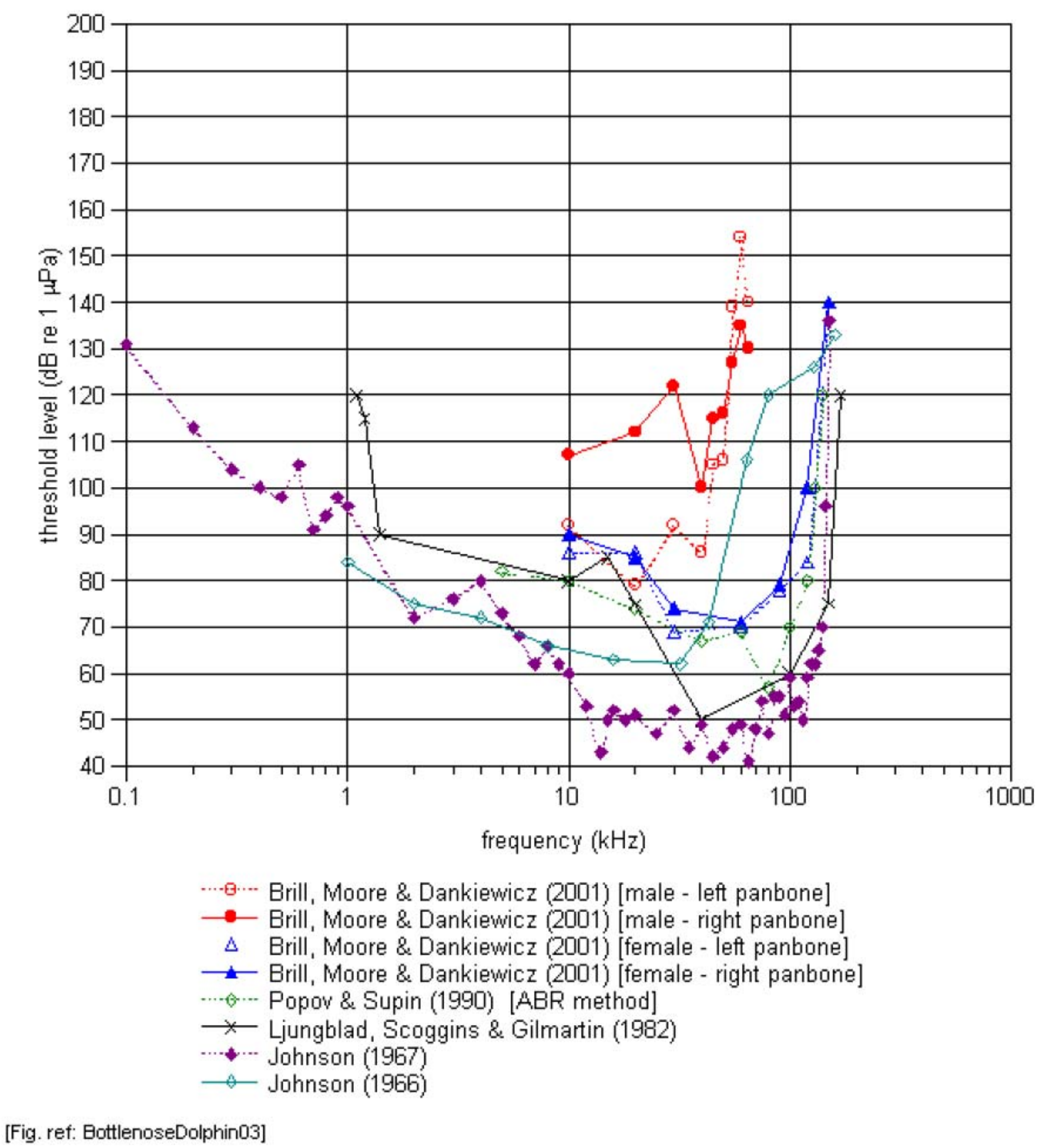
- LOPEZ, A., SAGARMINAGA R. y LOSADA S. 2003. "Cetáceos en un Océano Degradado: el Caso Español". Greenpeace y Sociedad Española de Cetáceos. Madrid – España. Mayo. 32 pp.
- MALDONADO, D., ALCALÁ, V. "Bioacústica en Cetáceos". Facultad de Ciencias del Mar de la Universidad de Cádiz. Fundación Bitácora. 1996 Disponible en http://www.terra.es/personal/fbitacora/Bio.htm (Consulted in December 2004).
- MANGHI, M., PAVAN, G. "Taking a picture of underwater sounds" Accobams kit for Field Cetacean Research, September 2002.
- MMPA 1997. Marine Mammal Commission Annual Report to Congress.
- NATIONAL RESEARCH SOUNCIL. 2005. "Marine Mammal Populations and Ocean Noise: determining When Noise Causes Biologically Significant Effects". Free executive summary at http://www.nap.edu/catalog/11147.html
- NATIONAL RESEARCH COUNCIL. 2003. "Ocean Noise and Marine Mammals". The National Academies Press. Washington D.C. – E.E.U.U.
- NEDWELL, J.R., EDWARDS, B. TURNPENNY, A.W.H, GORDON, J. "Fish and marine mammal audiograms: a summary of available information". Subacoustec report ref. 534R0214, submitted to Chevron Texaco Ltd, 278 pp.
- PREISIG, J. "Acoustic Propagation Considerations for Underwater Acoustic Comunications Network Development". Proceedings of the 1st ACM international Workshop on Underwater Networks. September, 2006. Los Angeles, California.
- REID, J.B, EVANS, P. and NORTHRIDGE, S.P "Atlas of Cetacean distribution in north-west european waters" Joint Nature Conservation Comitee, 2003.

- RICHARDSON et al. 1995. "Marine Mammals and Noise". Academic Press. San Diego – E.E.U.U.
- RODRIGUES, L. "Wave power conversion systems for electrical energy production". Nova university of Lisbon.
- THE ECONOMIST TECHNOLOGY QUARTERLY. 2008. "The coming wave". Press release, issued June 7th 2008.
- THOMSEN, F. , LÜDEMAN, K. , KAFEMAN, R. And PIPER, W. "Effects of offshore wind farm noise on marine mammals and fish" COWRIE ltd, July, 2006.
- URICK, R.J. "Principles of underwater sound" Ed McGrawHill, New York, 1983.
- WEILGART, L.S. "The impacts of anthropogenic ocean noise on cetaceans and implications for management" NRC Research Press Canada, 2007. 85: 1091-1116.
- WILHELMSSON, D., MALM, T., AND ÖHMAN, M.C. "The influence of off-shore windpower on demersal fish". ICES Journal of Marine Science, 63:775-784, 2006.

ANNEX 1

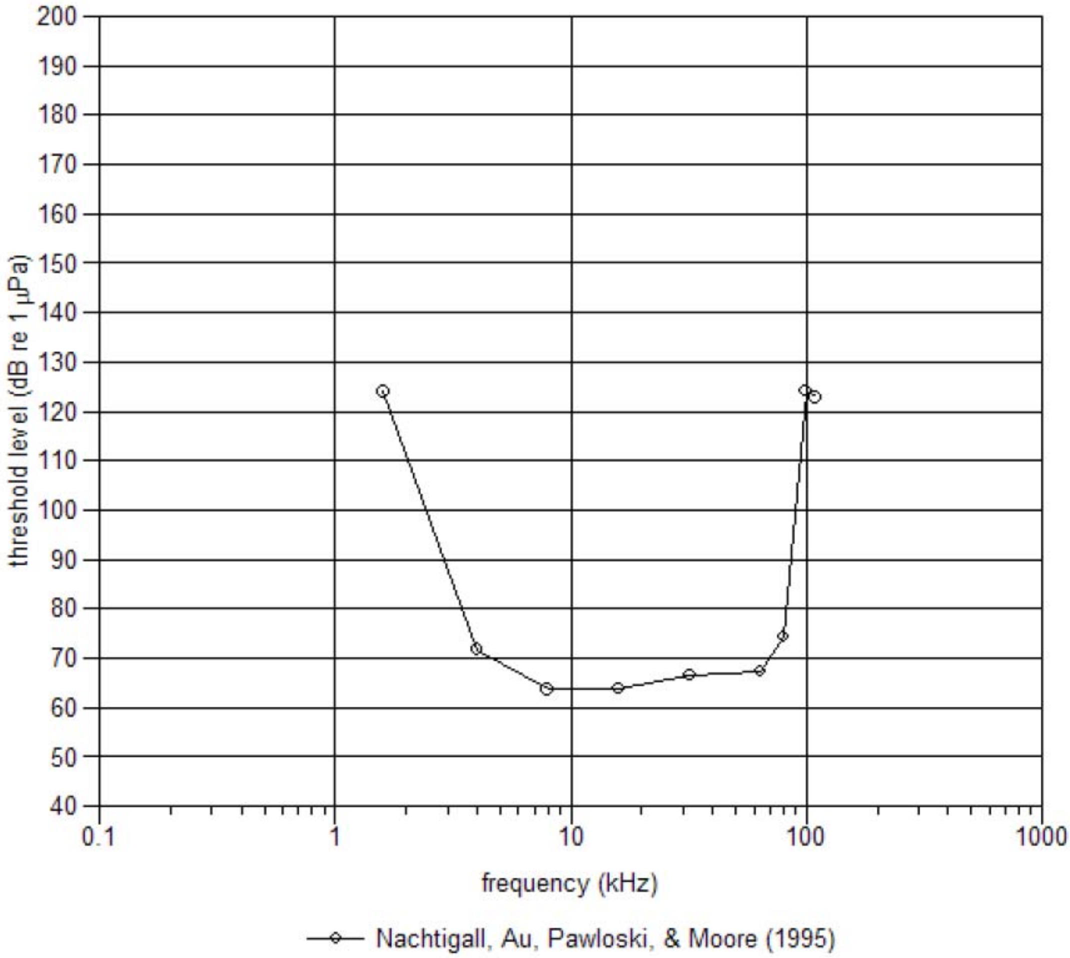
The following graphs shows the different audiograms found for the marine mammals existing in the zone under study. Source: Nedwell et al 2004, "Fish and marine mammals audiograms".

<u>Bottlenose dolphin</u> (*Tursioups truncatus*)



Audiogram for Bottlenose dolphin.

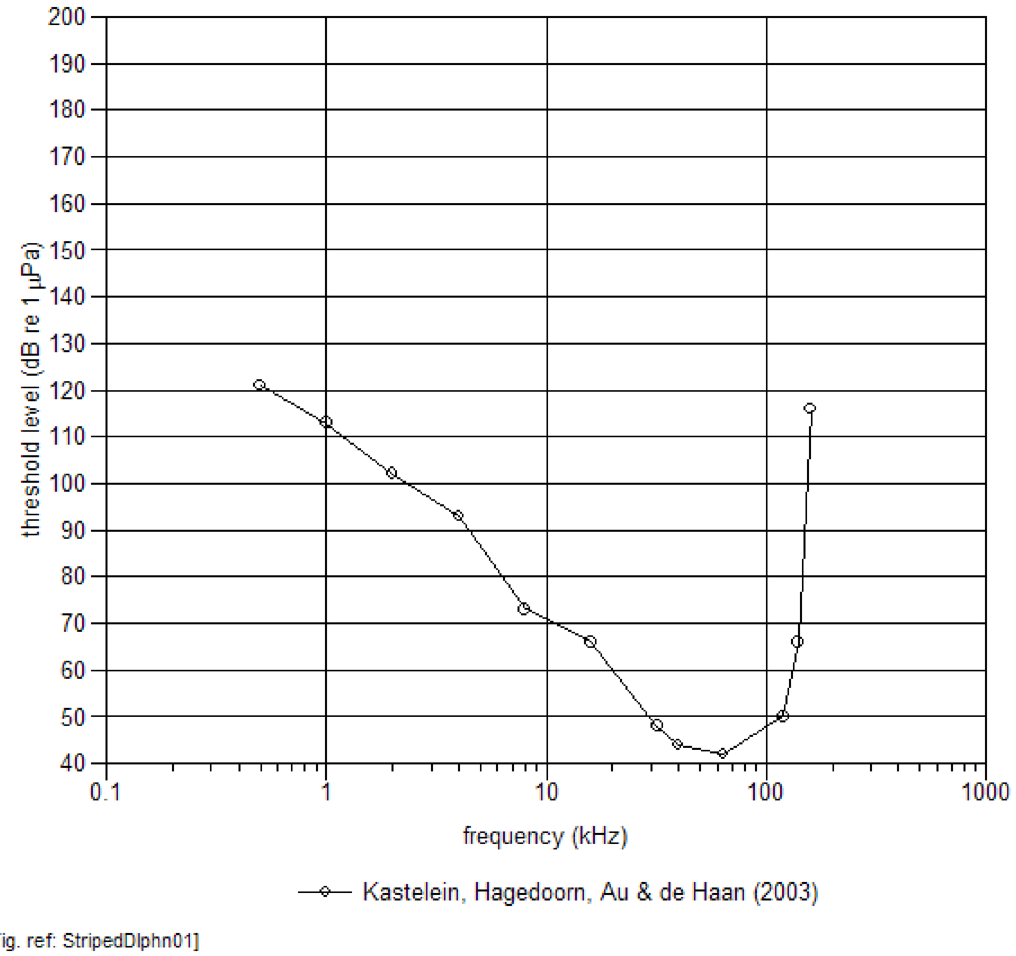
Risso’s dolphin (*Grampus griseus*)



[Fig. ref: RissoDlphn01]

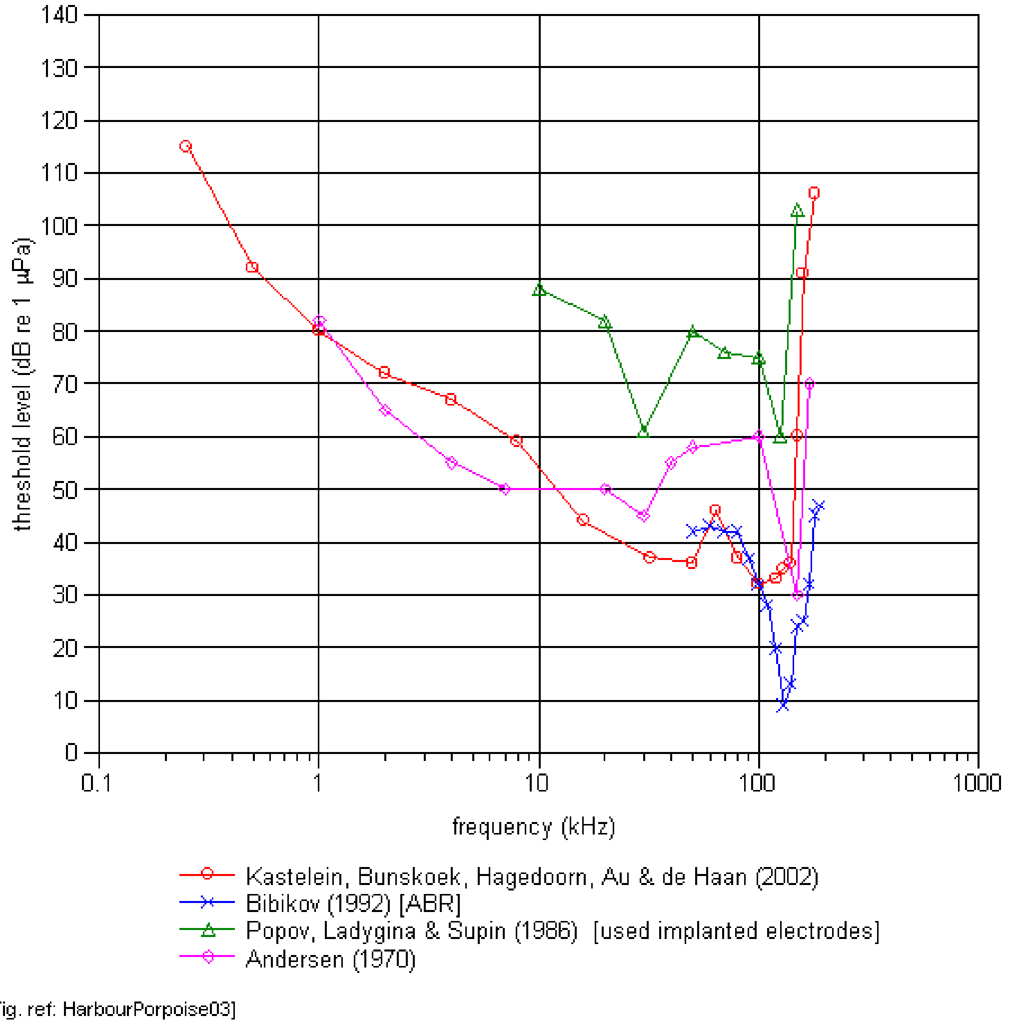
Audiogram for Risso’s dolphin.

Striped dolphin (*Stenella coeruleoalba*)



Audiogram for Striped dolphin.

Harbour porpoise (*Phocoena phocoena*)



Audiogram for Harbour porpoise.

ANNEX 2. **Acoustic characteristics and bandfrequencies of marine mammals**

SPECIE	STUDY	FIELD, LAB MODELLING	SOUND SOURCE	SIGNAL CHARACTERISTICS	RLs (Db re 1 microPascal)	DEPLOYMENT DETAILS	GENERAL RESULTS
Tursiops truncatus	Buckstaff (2004)	Field	Recreational boats		115-138 (planing boats); 114-121 (plowing boats); and 113-116 (idling boats)	Boats maintained 20m from local dolphin	Higher whistle rate at onset of noise than during or after exposure
Tursiops truncatus	Finnerman et al (2000)	Laboratory	Simulations of distant underwater eplosions		196/209 (disturbance threshold)**peak-peak		Behavioural alterations at these RLs; no TTS > 6 dB re 1 micropascal peak-peak
Tursiops truncatus	Cox et al (2004)	Field	Dukane netmark	10 KHz pulses every 4 seconds; 132 dB	120 dB at approximately 100m	Deployed during sea trials in active fishery	No differences in COA (closest observed approach) for active and inactive devices
Delphinus delphis	Goold (1996)	Field	Seismic survey air guns	a. 250 Hz, b. 2 KHz, c. 10 KHz, d. 20 KHz	a. 170, b. 140, c. 115, d. 90 ***re 1 micropascal/sgrt (Hz)	80-100 m depth, 5 km from source	Greater number of vocalizations per hour before than during seismic surveys

SPECIE	STUDY	FIELD, LAB MODELLING	SOUND SOURCE	SIGNAL CHARACTERISTICS	RLs (Db re 1 microPascal)	DEPLOYMENT DETAILS	GENERAL RESULTS
Grampus griseus	Au et al (1997)	Laboratory	ATOC, pure tone /Acoustic Thermometry of the Ocean Climate)	75 Hz (centre frequency)	141+- 1 (pure tone) and 139+-1 (ATOC; hearing thresholds)		Sound would only be audible directly above source at 400 m depth
Stenella Coeruleoalba + Phocoena phocoena	Kastelein et al (2006)	Laboratory	Dukane XP-10	16 tones (constant pulse width and interval) between 9 and 15 KHz; 145 dB	< o = 138 at 33 kHz	Deployed in tank with harbour porpoise and striped dolphin	Sound source avoided by P.phocoena, no reaction from S.coeruleoalba
Phocoena phocoena	Kastelein et al (2005)	Laboratory	ACME underwater communications	8-16 kHz chirps, spreadspectrum blocks, frequency sweeps and modulated frequency shifts, 116-130 dB	Discomfort at ≤116	Deployed in enclosure with two male harbour porpoises	Avoidance of sound source as source levels increased
Phocoena phocoena	Kraus et al (1997)	Field	Dukane netmark	10 kHz pulses every 4 seconds; 132 dB	≥98 at the net*	ADDsdeployed on actively fishing gillnets	Reduced by-catch, reduced catch of Atlantic herring (Clupea harengus)
Phocoena phocoena	Kastelein et al (19997)	Laboratory	Loughborough signal generator	Clicks, sweeps and tones 17.5-140 kHz	≤107	Deployed in tank with single female harbour porpoise	Avoidance of sound source

SPECIE	STUDY	FIELD, LAB MODELLING	SOUND SOURCE	SIGNAL CHARACTERISTICS	RLs (Db re 1 microPascal)	DEPLOYMENT DETAILS	GENERAL RESULTS
Phocoena phocoena	Kastelein et al (1997)	Laboratory	Memorial University ADD (MUN)	Tones, 2.5 kHz; 110-131 dB	≤107	Deployed in tank with single female harbour porpoise	Avoidance of sound source
Phocoena phocoena	Kastelein et al (1997)	Laboratory	Scannar netminder	110 kHz; 158 dB	≤107	Deployed in tank with single female harbour porpoise	Avoidance of sound source
Phocoena phocoena	Kastelein et al (1997)	Laboratory	Tri-tech ROV scanning sonar	325 kHz; 179 dB	≤107	Deploye in tank with single female harbour porpoise. 24º horizontal beam angle, 4.5º vertical beam angle; sonar scanned across the pool at various angles	Avoidance of sound source
Phocoena phocoena	Kastelein et al (2000)	Laboratory	Dukane netmark 1000	10 kHz pulses every 4 seconds; 132 dB	≤124	Deployed in tank with harbour porpoises	Avoidance of sound source
Phocoena phocoena	Kastelein et al (2000)	Laboratory	Dukane prototype	10 kHz pulses randomized production; 132 dB	≤124	Deployed in tank with harbour porpoises	Avoidance of sound source
Phocoena phocoena	Kastelein et al (2000)	Laboratory	Bird alarm	Sweeps between 2 and 3.5 kHz; 100 dB	≤90 at 3.5 kHz	Deployed in tank with harbour porpoises	Avoidance of sound source

SPECIE	STUDY	FIELD, LAB MODELLING	SOUND SOURCE	SIGNAL CHARACTERISTICS	RLs (Db re 1 microPascal)	DEPLOYMENT DETAILS	GENERAL RESULTS
Phocoena phocoena	Kastelein et al (2001)	Laboratory	Dukane XP-10	16 tones (constant pulse width and interval-6% duty cycle) between 9 and 15 kHz; 145 dB	≤138 at 33 kHz	Deployed in tank with harbour porpoises	Avoidance of sound, increased respiration rates
Phocoena phocoena	Kastelein et al (2001)	Laboratory	Dukane 2MP	16 tones (constant pulse width and interval-8% duty cycle) between 9 and 15 kHz; 145 dB	≤140 at 12 kHz	Deployed in tank with harbour porpoises	Avoidance of sound source, increased respiration rates
Phocoena phocoena	Kastelein et al (2001)	Laboratory	HS20-80	0.1 second unsweep and 0.2 second downsweep; 20-80 kHz; 96-118 dB; 4.6 % duty cycle	≤ 90 at 65 kHz	Deployed in tank with harbour porpoises	Avoidance of sound source, increased repiration rates
Phocoena phocoena	Culik et al (2001)	Field	PICE Pinger	Sweeps between 20 nd 169 kHz; 145 dB	102 at COA	Deployed on experimental net and during sea trials in active fishery	Avoidance of sound source, COA to active device =130 m
Phocoena phocoena	Koschinski and Culik (1997)	Field	MUN	Tones, 2.5 kHz; 115 dB	72 at COA	Deployed during sea trials in active fishery	Avoidance ofsound source, COA to active device 130 m
Phocoena phocoena	Gearing et al (2000)	Field	Custom pinger	Broadband with peaks at 3 and 20 kHz; 122-125 dB	≥90 at the net*	Deployed during sea trials in active fishery	Reduced by-catch

SPECIE	STUDY	FIELD, LAB MODELLING	SOUND SOURCE	SIGNAL CHARACTERISTICS	RLs (Db re 1 microPascal)	DEPLOYMENT DETAILS	GENERAL RESULTS
Phocoena phocoena	Trippel et al (1999)	Field	Dukane netmark 1000	10 kHz pulses every 4 seconds; 132 dB	Detection range of 0.1-0.6 km for 80-90 dB RL	Deployed during sea trials in active fishery	Reduced by-catch
Phocoena phocoena	Carlstrom et al (2002)	Field	Dukane netmark 1000	10 kHz pulses every 4 seconds; 132 dB	≥ 98 at the net	Deployed during sea trials in active fishery	No by-catch recorded
Phocoena phocoena	Cox et al (2001)	Field	Dukane netmark 1000	10 kHz pulses every 4 seconds; 132 dB	118-122 dB (ambient noise levels) at 125m	Deployed individually on mooring	Exclusion distance decreased by 50 % after 4 days
Phocoena phocoena	Johnston & Woodley (1998)	Field	Various	180-200 dB	122 at max range of influence*	Assessed extent of AHD use on salmon farms in lower Bay of Fundy	Large percxentage of sites using AHDs. Possible habitat exclusion
Phocoena phocoena	Terhune et al (2002)	Field	Airmar, Ferranti Thompson 4X special	195 and 166 dB respectively, 10-19 kHz	95 dB at 2.92 km for Airmar; 94 dB at 1.3 for Ferranti Thompson	AHDs deployed experimentally from small boat or on active salmon farms	Not Available
Phocoena phocoena	Jacobs & Terhune (2002)	Field	Airmar	172 dB	158-164 dB at approximately 45 m	AHDs deployed on active salmon farms	Seals avoided sound source, COA= 45 m

SPECIE	STUDY	FIELD, LAB MODELLING	SOUND SOURCE	SIGNAL CHARACTERISTICS	RLs (Db re 1 microPascal)	DEPLOYMENT DETAILS	GENERAL RESULTS
Phocoena phocoena	Olesiuk et al (2002)	Field		180 dB	≤134 at 200 m exclusion zone*	AHDs deployed on active salmon farms	Porpoises avoided sound source- none observed within 200m
Phocoena phocoena	Johnston (2002)	Field	Airmar	180 dB	125 dB at mean COA 991 m*	AHD deployed on mooring	Porpoise avoided sound source, COA to active AHD =645 m
Phocoena phocoena	Taylor et al (1997)	Modelling	Various	180-200 dB	> 130 dB at 1km for 200 dB source	Modelled various zones of acoustic influence	AHDs may exclude non-terget species from important habits

ANNEX 3.

Index cards for the species recorded on the "Livro vermelho das especies" (Red list of endangered species) of Portugal.

	CONTINENTE	AÇORES	MADEIRA
ocorrência	Res	Vis	Oc
categoria	VU	DD	NA

Balaenoptera acutorostrata Lacépède, 1804 mamíferos

Baleia-anã

Taxonomia
Mammalia, Cetacea, Misticeti, Balaenopteridae.

Tipo de ocorrência
Continente: Residente.
Açores: Visitante.

Classificação
Continente: VULNERÁVEL – VU (C2a(ii))
Fundamentação: A espécie tem uma população pequena (inferior a 10.000 indivíduos maturos); admite-se um declínio continuado no número de indivíduos maduros, e todos os indivíduos estão na mesma subpopulação.

Açores: INFORMAÇÃO INSUFICIENTE – DD
Fundamentação: Não existe informação adequada para avaliar o risco de extinção nomeadamente quanto ao tamanho da população e tendências de declínio.

Distribuição
A baleia-anã está amplamente distribuída em ambos os hemisférios, desde as regiões polares até às regiões subtropicais (Evans 1987, Leatherwood & Reeves 1983). Em anos recentes, o conhecimento da distribuição desta espécie no Atlântico Nordeste tem sido actualizado à medida que novos projectos vão sendo desenvolvidos em áreas a sul da Península Ibérica. Com efeito, alguns autores (Waerebeek *et al.* 1999) referem a possibilidade de a área de ocorrência na costa Noroeste de África se estender, pelo menos, até à Gâmbia.

No Continente, a espécie tem sido regularmente assinalada ao longo de todo o ano. Nos Açores, a sua presença está confirmada durante a Primavera e o Verão (dados não publicados, DOP – Univ. Açores).

População
A nível mundial, há três populações isoladas: a do Pacífico, a do Atlântico Norte e a do Hemisfério Sul (Evans 1987). Entre 1987 e 1995, a estimativa populacional para o Atlântico Norte (excluindo a costa do Canadá) foi de 149.000 indivíduos (IWC 2003) desconhecendo-se, no entanto, a tendência populacional.

Habitat
A baleia-anã encontra-se numa grande variedade de habitats marinhos, desde áreas costeiras a zonas pelágicas bastante afastadas da costa (Leatherwood & Reeves 1983). Nos Açores, tem sido avistada perto da costa ou em associação com montes submarinos (dados não publicados, DOP – Univ. Açores). No Continente, tem sido detectada próximo da orla costeira, chegando por vezes a entrar em portos e outras zonas relativamente confinadas.

Factores de Ameaça
No Atlântico Norte, a espécie ainda é caçada por alguns países, mas o facto de ser bastante abundante e de terem sido estabelecidas quotas anuais de captura não faz prever uma diminuição dos efectivos populacionais a médio-longo prazo. A sua dieta inclui várias espécies de valor comercial, pelo que a competição com pescadores e sobre-exploração de recursos piscícolas poderá ter impacto negativo ao nível populacional (Bogstad *et al.* 1997, Haug & Nilssen 1997, Skaug *et al.*

LIVRO VERMELHO DOS VERTEBRADOS DE PORTUGAL 507

mamíferos

Balaenoptera acutorostrata Lacépède, 1804

Baleia-anã

1997, Stefánsson *et al.* 1997). Capturas acidentais em redes de pesca e colisões com navios poderão causar algum impacto populacional, mas a amplitude destas ameaças é desconhecida (Clapham *et al.* 1999).

Na costa portuguesa, a baleia-anã está frequentemente envolvida em acidentes com artes de pesca utilizadas próximo da costa. Com efeito, e apesar de ser espécie de misticeto mais comum em Portugal Continental, a grande maioria dos animais arrojados ao longo da orla costeira mostram sinais de interacções com redes de emalhar ou cabos de covos ou alcatruzes. Apesar de não se conhecerem os efectivos populacionais, os actuais índices de mortalidade poderão, a longo prazo, contribuir para uma redução importante da população da baleia-anã presente na costa continental portuguesa.

Nos Açores, as actividades de observação de cetáceos poderão causar alguma alteração comportamental, mas não deverão constituir uma fonte de ameaça à conservação da espécie.

Medidas de Conservação

No Continente está em vigor legislação específica nacional de protecção de mamíferos marinhos, bem como transposição e regulamentação de legislação internacional. O "Guia de Identificação de Cetáceos" (Sequeira & Farinha 1998) foi produzido como material de divulgação.

Nos Açores, para além da legislação internacional em vigor, foi criada regulamentação para a actividade recreativa e comercial de observação de cetáceos. Estão ainda a ser realizadas campanhas de educação e sensibilização ambiental, no âmbito de projectos de investigação diversos.

Outra bibliografia consultada

Stewart & Leatherwood (1985).

	CONTINENTE	AÇORES	MADEIRA
ocorrência	?	-	Oc
categoria	DD	-	NA

Globicephala melaena (Traill, 1809)

mamíferos

Baleia-piloto

Taxonomia
Mammalia, Cetacea, Odontoceti, Delphinidae.

Tipo de ocorrência
Continente: Desconhece-se se é residente ou visitante.

Classificação
Continente: INFORMAÇÃO INSUFICIENTE – DD
Fundamentação: Não existe informação adequada para avaliar o risco de extinção nomeadamente quanto à redução do tamanho da população.

Distribuição
A baleia-piloto está amplamente distribuída nas águas temperadas e frias do Atlântico Norte e no Hemisfério Sul. As populações dos dois hemisférios estão separadas geograficamente, constituindo grupos distintos que são, por vezes, identificados como subespécies (*edwardsi* no hemisfério Sul e *melas* no Norte) (Mitchell 1975, Leatherwwod & Reeves 1983). A população do Hemisfério Norte estende-se desde a Gronelândia, a Islândia e o Mar de Barents, a norte, até ao Cabo Haterras no Atlântico Oeste, e o Noroeste de África (incluindo o Mediterrâneo) no Atlântico Este. No Atlântico Nordeste, a baleia-piloto é bastante comum no Golfo da Biscaia, onde se pensa que exista uma zona de invernada (Duguy & Aloncle 1975).

População
Apesar de ter uma presença regular, desconhece-se o número de efectivos presentes na costa portuguesa, bem como a sua tendência populacional.

Habitat
A baleia-piloto é considerada uma espécie pelágica, sendo-lhe atribuída a isobática dos 200m como limite de distribuição costeira. No entanto, a presença regular desta espécie em zonas de batimetria inferior pode estar ligada a factores tróficos.

Factores de Ameaça
A captura acidental em artes de pesca e a poluição por organoclorados e metais pesados constituem factores de ameaça para esta espécie.

Medidas de Conservação
No Continente está em vigor legislação específica nacional de protecção de mamíferos marinhos, bem como a transposição e regulamentação de legislação internacional. O "Guia de Identificação de Cetáceos" (Sequeira & Farinha 1998) foi produzido como material de divulgação.

Outra bibliografia consultada
Desportes (1983); Martin & Rothery (1993); Bloch (1994).

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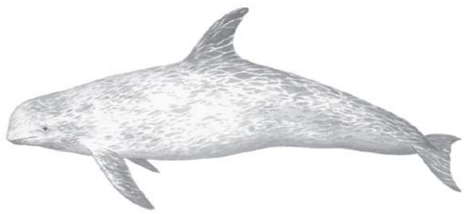
	CONTINENTE	AÇORES	MADEIRA
ocorrência	Res	Res	?
categoria	DD	DD	DD

Grampus griseus (Cuvier, 1812)

mamíferos

Grampo,
Moleiro (Açores)



Taxonomia
Mammalia, Cetacea, Odontoceti, Delphinidae.

Tipo de ocorrência
Continente: Residente.
Açores: Residente.
Madeira: Desconhece-se se é migrador ou visitante.

Classificação
Continente: INFORMAÇÃO INSUFICIENTE – DD
Açores: INFORMAÇÃO INSUFICIENTE – DD
Madeira: INFORMAÇÃO INSUFICIENTE – DD
Fundamentação: Não existe informação adequada para avaliar o risco de extinção nomeadamente quanto ao tamanho da população e tendências de declínio.

Distribuição
O grampo tem uma vasta área de distribuição, abrangendo as águas quentes e temperadas de todos os oceanos. No Atlântico Norte, distribui-se entre a Terra Nova e a Suécia, a norte, e o Mediterrâneo e as Ilhas Antilhas, a sul (Leatherwood & Reeves 1983). É uma espécie cosmopolita, associada a águas profundas, estando ausente em águas polares.

No Continente, ocorre ao longo de toda a plataforma continental podendo, ocasionalmente, ser avistado em zonas costeiras de menor profundidade.

Pode utilizar toda a área das Zonas Económicas Exclusivas dos Açores e da Madeira, especialmente junto às ilhas e bancos submarinos que, normalmente, constituem zonas de maior produtividade relativa.

População
Apesar de não haver informação disponível que permita estimar a dimensão e a tendência populacional, não há evidências que sustentem a possibilidade de existência de várias subpopulações.

Habitat
O grampo é uma espécie pelágica que ocorre em zonas de mar aberto. Na maior parte da sua área de distribuição, as observações efectuadas próximo da orla costeira são justificadas pela reduzida largura local da plataforma continental (Martin 1990).

Factores de Ameaça
Os principais factores de ameaça são a captura acidental em artes de pesca e a poluição por organoclorados e metais pesados. Nos Açores e na Madeira, as actividades de observação de cetáceos são consideradas um factor de perturbação para a espécie.

Medidas de Conservação
No Continente, está em vigor legislação específica nacional de protecção de mamíferos marinhos, bem como transposição e regulamentação de legislação internacional. O "Guia de Identificação de Cetáceos" (Sequeira & Farinha 1998) foi produzido como material de divulgação.

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mamíferos

Grampus griseus (Cuvier, 1812)

Grampo,
Moleiro (Açores)

Nos Açores, para além da legislação internacional em vigor, foi criada regulamentação para a actividade recreativa e comercial de observação de cetáceos. Estão a ser realizadas campanhas de educação e sensibilização ambiental, no âmbito de projectos de investigação diversos.

Na Madeira, para além da legislação internacional em vigor, foi implementada legislação regional de protecção. O Museu da Baleia dinamiza a investigação, a divulgação e a sensibilização para a conservação dos cetáceos neste Arquipélago. No âmbito do "Projecto para a Conservação dos Cetáceos no Arquipélago da Madeira", promove-se a avaliação dos efectivos populacionais, estudos de biologia e ecologia, bem como a avaliação das principais ameaças no sentido de apresentar às entidades competentes propostas de novas medidas de conservação e campanhas de educação e sensibilização ambiental. Uma das medidas de conservação actualmente em processo de implementação é o regulamento de adesão voluntária para as embarcações comerciais de observação de cetáceos no sentido de minimizar o impacto desta actividade na Região Autónoma da Madeira. Igualmente no âmbito daquele projecto, está a ser preparado um plano de monitorização das populações de cetáceos a longo prazo.

Outra bibliografia consultada

Sarmento (1948); Perrin & Reilly (1984); Kruse *et al.* (1999); Freitas *et al.* (2002).

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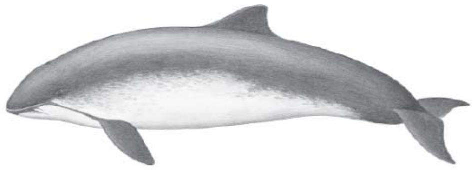
	CONTINENTE	AÇORES	MADEIRA
ocorrência	Res	-	-
categoria	VU	-	-

Phocoena phocoena (Linnaeus, 1758)

mamíferos

Boto



Taxonomia
Mammalia, Cetacea, Odontoceti, Phocoenidae.

Tipo de ocorrência
Residente.

Classificação
VULNERÁVEL – VU (C2a(ii))
Fundamentação: A espécie tem uma população pequena (inferior a 10.000 indivíduos maturos); admite-se um declínio continuado do número de indivíduos maduros, e todos os indivíduos estão na mesma subpopulação.

Distribuição
A área de distribuição do boto abrange unicamente as águas frias da região temperada e sub-ártica do Hemisfério Norte, estendendo-se desde a Islândia, Mar de Barents e Mar Branco (limite norte) até às costas da Mauritânia, com uma população isolada no Mar Negro (Duguy & Robineau 1982, Leatherwood & Reeves 1983).

Em Portugal, distribui-se ao longo de toda a orla costeira, com densidades mais elevadas na zona Norte. Conhecem-se núcleos populacionais com carácter relativamente permanente nos sectores litorais de Aveiro-Figueira da Foz, Arrábida e Costa da Galé.

População
Em finais do século XIX e princípios do século XX, a espécie era considerada como muito abundante ao longo da costa portuguesa, observada em baías e estuários, havendo registos de animais que subiam o curso dos rios até distâncias consideráveis do estuário (Bocage 1893, Nobre 1895, 1935).

Porém, a partir de meados do século XX, começou a registar-se um decréscimo populacional acentuado a nível europeu, mas a ausência de dados mais concretos não permite contabilizar com exactidão o valor dessa redução. Actualmente, as observações efectuadas ao longo da costa portuguesa referem-se a grupos muito reduzidos (1 a 3 indivíduos), e não há registos recentes da sua presença em estuários.

Habitat
O boto pode ser encontrado em baías, estuários e zonas costeiras de profundidade inferior a 200 metros.

Factores de Ameaça
Os principais factores de ameaça são: captura acidental em artes de pesca, particularmente em redes de emalhar e xávegas (com especial destaque para as que operam na região norte da costa portuguesa); poluição por organoclorados e metais pesados; turismo, especialmente provocado por embarcações de recreio, em algumas áreas da costa.

Medidas de Conservação
No Continente está em vigor legislação específica nacional de protecção de mamíferos marinhos, bem como transposição e regulamentação de legislação

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Phocoena phocoena (Linnaeus, 1758)

Boto

internacional. O "Guia de Identificação de Cetáceos" (Sequeira & Farinha 1998) foi produzido como material de divulgação.

Estão em curso ou previstas as seguintes medidas: i) avaliação do efectivo e distribuição populacional na região da Figueira da Foz; ii) estudo da biologia e ecologia do mesmo núcleo populacional; iii) avaliação dos factores de ameaças, em particular da mortalidade provocada por artes de pesca; iv) propostas de medidas de conservação; v) monitorização da população; vi) produção de material de educação e sensibilização ambiental.

Outra bibliografia consultada

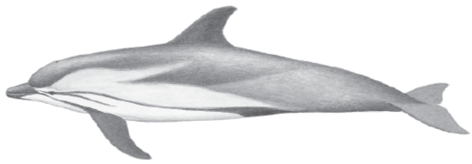
Lockyer (1995); Read *et al.* (1997).

	CONTINENTE	AÇORES	MADEIRA
ocorrência	Res	Vis	?
categoria	LC	LC	DD

mamíferos

Stenella coeruleoalba (Meyen, 1833)

Golfinho-riscado



Taxonomia
Mammalia, Cetacea, Odontoceti, Delphinidae.

Tipo de ocorrência
Madeira: Desconhece-se se é migrador ou visitante.

Classificação
Madeira: INFORMAÇÃO INSUFICIENTE – DD
Fundamentação: Não existe informação adequada para avaliar o risco de extinção nomeadamente quanto ao tamanho da população.

Distribuição
O golfinho-riscado está amplamente distribuído em regiões temperadas, subtropicais e tropicais; habita águas profundas onde ocorram grandes variações sazonais de temperatura.

A sua presença é regular nas águas do Arquipélago da Madeira.

População
O número relativamente pequeno de observações de animais desta espécie na Madeira, muitas vezes associados com golfinhos-comuns *Delphinus delphis*, não permite efectuar qualquer inferência relativamente ao tamanho da população e à sua tendência.

Habitat
O golfinho-riscado ocorre em zonas de mar aberto onde ingere, essencialmente, cefalópodes, peixes mesopelágicos e camarões (Leatherwood & Reeves 1983).

Factores de Ameaça
Não são conhecidas ameaças significativas para esta espécie nas águas da Zona Económica Exclusiva da Madeira. No entanto, considera-se que as actividades de observação de cetáceos poderão vir a ter impacto significativo a longo prazo, se a actividade se desenvolver descontroladamente e sem regulamentação adequada.

Medidas de Conservação
Na Madeira, para além da legislação internacional em vigor, foi implementada legislação regional de protecção. O Museu da Baleia dinamiza a investigação, a divulgação e sensibilização para a conservação dos cetáceos neste Arquipélago. No âmbito do "Projecto para a Conservação dos Cetáceos no Arquipélago da Madeira", promove-se a avaliação dos efectivos populacionais, estudos de biologia e ecologia, bem como a avaliação das principais ameaças no sentido de apresentar às entidades competentes propostas de novas medidas de conservação e campanhas de educação e sensibilização ambiental. Uma das medidas de conservação actualmente em processo de implementação é o regulamento de adesão voluntária para as embarcações comerciais de observação de cetáceos no sentido de minimizar o impacto desta actividade na Região Autónoma da Madeira. Igualmente no âmbito daquele projecto, está a ser preparado um plano de monitorização das populações de cetáceos a longo prazo.

Outra bibliografia consultada
Miyazaki (1984); Perrin *et al.* (1994); Freitas *et al.* (1998); Freitas *et al.* (2002).

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ANNEX 4.

Tables with the conservation information in the “Livro vermelho das especies” of Portugal, taken from the ICNB (Instituto da conservaçao da natureza e a biodiversidade). http://portal.icnb.pt/ICNPortal/vPT2007/Homepage.htm

Mamíferos	Categoria					Tipo de Ocorrência			% da pop. reg. / global	Instrumentos Legais					Livros Vermelhos 1990, 1991 e 1993		
Espécie / Nome Vulgar	Continente	Açores	Madeira	IUCN	Espanha	Continente	Açores	Madeira		Berna	Bona	CITES	Directiva Aves / Habitats	Outra legislação	Continente	Açores	Madeira
Microtus duodecimcostatus (de Sélys-Longchamps, 1839) Rato-cego-mediterrânico	LC			LR/lc[1]	NAm[3]	Res			5-24						NT		
Apodemus sylvaticus (Linnaeus, 1758) Rato-do-campo	LC			LC[2]	NAm[3]	Res			5-24						NT		
Rattus rattus (Linnaeus, 1758) Rato-preto	LC	NA	NA	LR/lc[1]	NAm[3]	Res	NInd	NInd	0-4					10/I	NT	NT	NT
Rattus norvegicus (Berkenhout, 1796) Ratazana	NA	NA	NA	LR/lc[1]	NAm[3]	NInd	NInd	NInd	0-4					10/I	NT	NT	NT
Mus domesticus (Schwartz & Schwartz,1943) Rato-caseiro	LC	NA	NA	LR/lc[1]	NAm[3]	Res	NInd	NInd	5-24						NT[$]	NT[$]	NT[$]
Mus spretus Lataste, 1883 Rato-das-hortas	LC	NA		LC[2]	NAm[3]	Res	NInd		25-49						NT		
Gliridae																	
Eliomys quercinus (Linnaeus, 1766) Leirão	DD			VU[1]	NAm[3]	Res			0-4	III					NT		
Cetacea																	
Delphinidae																	
Steno bredanensis (Lesson, 1828) Caldeirão		NA	DD	DD[1]			Oc	?	?	II	[$]	II A	B-IV	5, 7		K	
Tursiops truncatus (Montagu, 1821) Roaz	LC	LC	LC	DD[1]	K[3]	Res	Res	Res	?	II	[$]	II A	B-II B-IV	5, 6, 7, 8	NT	NT	NT
Stenella coeruleoalba (Meyen, 1833) Golfinho-riscado	LC	LC	DD	LR/cd[1]	K[3]	Res	Vis	?	?	II	[$]	II A	B-IV	5, 6, 7, 8	NT	NT	NT
Stenella frontalis (G Cuvier, 1829) Golfinho-pintado (A); Golfinho-malhado (M)		LC	LC	DD[1]	NAm[3]		Res	Res	?	II		II A	B-IV	5, 7, 8		NT	
Delphinus delphis Linnaeus, 1758 Golfinho-comum	LC	LC	LC	LR/lc[1]	K[3]	Res	Res	Res	?	II	[$]	II A	B-IV	5, 6, 7, 8	NT	NT	NT
Grampus griseus (Cuvier, 1812) Grampo; Moleiro (A)	DD	DD	DD	DD[1]	NAm[3]	Res	Res	?	?	II	[$]	II A	B-IV	5, 6, 7, 8	NT	NT	
Pseudorca crassidens (Owen, 1846) Falsa-orca	NA	DD	NA	LR/lc[1]	NAm[3]	Oc	Vis	Oc	?	II	[$]	II A	B-IV	5, 7, 8	NT	NT	
Globicephala melaena (Traill, 1809) Baleia-piloto	DD		NA	LR/lc[1]	K[3]	?		Oc	?	II	[$]	II A	B-IV	5, 7	NT	NT	

Mamíferos	Categoria					Tipo de Ocorrência			% da pop. reg. / global	Instrumentos Legais					Livros Vermelhos 1990, 1991 e 1993		
Espécie / Nome Vulgar	Continente	Açores	Madeira	IUCN	Espanha	Continente	Açores	Madeira		Berna	Bona	CITES	Directiva Aves / Habitats	Outra legislação	Continente	Açores	Madeira
Globicephala macrorhynchus Gray,1846 Baleia-piloto-tropical (A); Boca-de-panela (M)		LC	LC	LR/cd[1]	NAm[3]		Res	Res	?	II		II A	B-IV	5, 7, 8		NT	NT
Orcinus orca (Linnaeus, 1758) Orca; Roaz-da-bandeira (M)	DD	DD	DD	LR/cd[1]	K[3]	?	Vis	?	?	II	II[5]	II A	B-IV	5, 7, 8	R	R	R
Phocoenidae																	
Phocoena phocoena (Linnaeus, 1758) Bôto	VU			VU[1]	V[3]	Res			?	II	[5]	II A	B-II B-IV	5	I	I	
Ziphiidae																	
Ziphius cavirostris G Cuvier, 1823 Zífio	DD	DD	DD	DD[1]	NAm[3]	?	?	?	?	II	[5]	II A	B-IV	5, 7, 8	NT		
Hyperoodon ampullatus (Forster, 1770) Botinhoso		DD		LR/cd[1]			?		?	II	II	I A	B-IV	5, 7, 8		K	
Mesoplodon mirus True, 1913 Baleia-de-bico de True		NA	NA	DD[1]	R[3]		Oc	Oc		II		II A	B-IV	5, 7, 8			
Mesoplodon europaeus Gervais, 1855 Baleia-de-bico de Gervais		NA	NA	DD[1]	R[3]		Oc	Oc		III		II A	B-IV	5, 7, 8	K		
Mesoplodon bidens (Sowerby, 1804) Baleia-de-bico de Sowerby		NA	NA	DD[1]	R[3]		Oc	Oc		II		II A	B-IV	5, 7, 8		K	K
Mesoplodon densirostris (de Blainville, 1817) Baleia-de-bico de Blainville		NA	NA	DD[1]	R[3]		Oc	Oc		III	[5]	II A	B-IV	5, 7, 8	K	K	K
Physeteridae																	
Kogia breviceps (de Blainville, 1838) Cachalote-pigmeu	DD	NA	DD	LR/lc[1]	R[3]	?	Oc	?	?	II		II A	B-IV	5, 7, 8	K	K	K
Physeter macrocephalus Linnaeus, 1758 Cachalote	NA	VU		VU[1]	V[3]	Oc	Res / MigRep	Res / MigRep	?	III	I[5]/II[5]	I A	B-IV	5, 7, 8	NT	NT	NT
Balaenopteridae																	
Balaenoptera acutorostrata Lacépède, 1804 Baleia-anã	VU	DD	NA	LR/nt[1]	V[3]	Res	Vis	Oc	?	III	[5]	I A	B-IV	5, 7, 8	R	R	
Balaenoptera borealis Lesson, 1828 Baleia-sardinheira	NA	EN	NA	EN[1]	V[3]	Oc	Vis	Oc	?	III	I[5]/II[5]	I A	B-IV	5, 7, 8	I	I	
Balaenoptera physalus (Linnaeus, 1758) Baleia-comum		EN		EN[1]	V[3]		Vis		?	II	I[5]/II[5]	I A	B-IV	5, 7, 8	V	V	V

Mamíferos	Categoria					Tipo de Ocorrência			% da pop. reg. / global	Instrumentos Legais					Livros Vermelhos 1990, 1991 e 1993		
Espécie / Nome Vulgar	Continente	Açores	Madeira	IUCN	Espanha	Continente	Açores	Madeira		Berna	Bona	CITES	Directiva Aves / Habitats	Outra legislação	Continente	Açores	Madeira
Balaenoptera musculus (Linnaeus, 1758) Baleia-azul	NA	EN	NA	EN[1]	E[3]	Oc	Vis	Oc	?	II	I	I A	B-IV	5, 7, 8	E		
Megaptera novaeangliae (Borowski, 1781) Baleia-de-bossa	NA	VU	NA	VU[1]	E[3]	Oc	Vis	Oc	?	II	I[5]	I A	B-IV	5, 7, 8	I	I	
Balaenidae																	
Eubalaena glacialis (Müller, 1776) Baleia-basca	NA	NA	NA	EN[1]	Ex?[3]	Oc	Oc	Oc		II	I[5]	I A	B-IV	5, 7, 8	I	I	I
Carnivora																	
Canidae																	
Vulpes vulpes (Linnaeus, 1758) Raposa	LC			LC[2]	NAm[3]	Res			0-4			D		1	NT		
Canis lupus Linneaus, 1758 Lobo	EN			LC[2]	V[3]	Res			0-4	II		II A	B-II* B-IV	4	E		
Ursidae																	
Ursus arctos Linnaeus, 1758 Urso-pardo	RE			LR/lc[1]	E[3]					II		II A	B-II* B-IV				
Mustelidae																	
Mustela erminea Linnaeus, 1758 Arminho	DD			LR/lc[1]	NAm[3]	Res			0-4	III					K		
Mustela nivalis Linnaeus, 1766 Doninha	LC	NA		LR/lc[1]	NAm[3]	Res	NInd		0-4	III					NT	NT	
Mustela vison Schreber, 1777 Visão-americano	NA			LR/lc[1]	NAm[3]	NInd								10/III			
Mustela putorius Linnaeus, 1758 Toirão	DD			LR/lc[1]	K[3]	Res			0-4	III			B-V		K		
Martes foina (Erxleben, 1777) Fuinha	LC			LR/lc[1]	NAm[3]	Res			0-4	III					NT		
Martes martes (Linnaeus, 1758) Marta	DD			LR/lc[1]	NAm[3]	Res			0-4	III			B-V		I		
Meles meles (Linnaeus, 1758) Texugo	LC			LR/lc[1]	K[3]	Res			0-4	III					NT		