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Acoustics for the 21st Century…

Guidelines for prediction and evaluation of acoustic impact on underwater fauna

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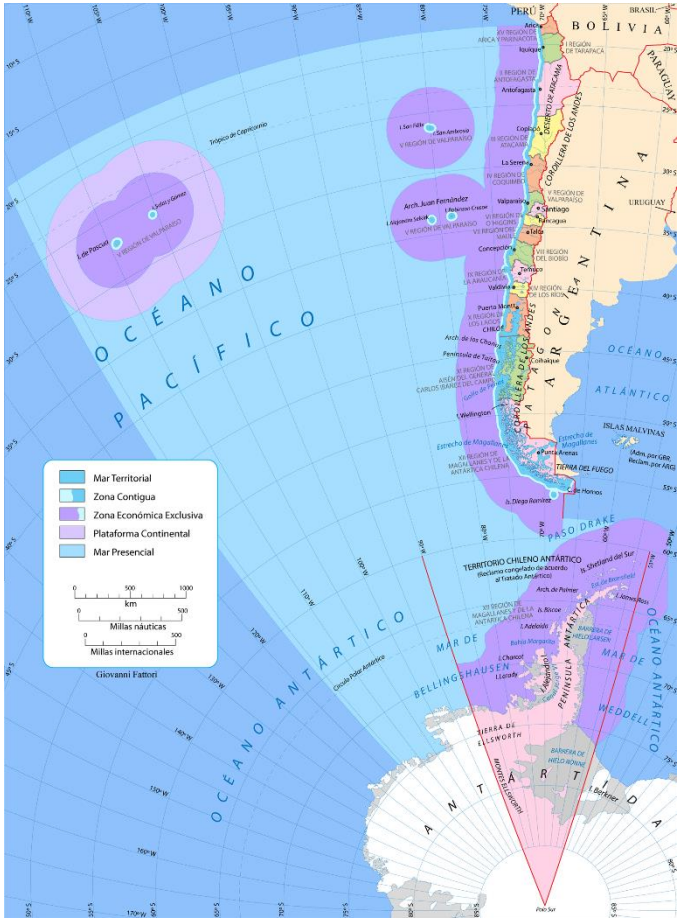
Topics

- **Introduction**
- Acoustic descriptors
- Noise sources
  - Natural
  - Anthropogenic
- Underwater sound propagation
- Underwater propagation recommendations
- Effects of noise on marine fauna
- Regulation approaches

Introduction

- In recent years, noise pollution has been recognized as the biggest threat to cetaceans.
- Chilean west coast extends for 6400 kilometers of the Pacific Ocean.
- This coast has 51 species of marine mammals, 36% of the world's diversity, including subjects of three groups: Whales, otters and pinnipeds (seals and sea lions).



Introduction

- Many marine mammals rely on sound for their basic needs:
  - Food,
  - Communication,
  - Protection,
  - Reproduction and
  - Navigation.

- One of the biggest concerns is the background noise
  - This species are capable to listen to each other?

Introduction

- Considering the great length of Chilean coast and the lack of any legal protection law in Chile, this topic is considered of high interest.

Ballena franca austral (Eubalaena australis) image ref

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Acoustic descriptors

- The unit of measurement is the Pascal (Pa)
- Is measured in Sound Pressure Level (SPL) expressed in decibels (dB) with a reference value of 1 μPa.
- The levels range from 50 to 250 $dB_{ref\ 1\ \mu Pa}$
- Linear decibel are used. This attributed to the wide audible frequency range of marine mammals and the different hearing sensitivity between species.

Acoustic descriptors

- (A) Sound pressure level (SPL)
  - Continuous sources are commonly described in terms of SPL.
- (B) Sound exposure level (SEL)
  - Commonly used for impulsive sources, allowing a comparison between signals of different duration or level.
- (C) Peak level
  - Maximum noise level recorded during the measurement period. Commonly used for impulsive sources.
- (D) Peak-to-peak level
  - Difference between the maximum and minimum noise level recorded during the measurement period. Also used as a descriptor for impulsive sources.

Acoustic descriptors

- No standard metric associated with the characteristics of the noise source. But there are two types of sounds:
  - Pulse:
    - Single Pulse,
    - Multiple Pulses.
  - Non-pulses.
- In practice, the distinction is unclear. It depends on:
  - (a) The source type.
  - (b) The propagation characteristic where the sound is generated.
  - (c) The distance between the sound source and the receiver.

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Noise sources - Natural

- Ambient noise have several components
  - turbulent pressure fluctuations,
  - surface agitation (wind dependent),
  - marine life,
  - seismic activities.
- Espectral Range
  - Waves or Wind (100 Hz to 50 KHz)
  - Volcanic activities (Below 100 Hz)
  - Rain, snow and hails (100 to 500 Hz)
- Duration
  - Short duration,
  - Repetitive,
  - A variety types of sound (cries, moans, grunts, chirps, etc.)

Noise sources - Natural

- Three orders for marines mammals
  - Cetacea (many species in Chile)
    - Odontocete
      - Many use echolocation (20 to 150 KHz)
    - Mysticete
      - Don't have echolocation (12 Hz to 8 KHz)
  - Sirenia
  - Carnivora
- Another biological sources
  - Fish and invertebrates.

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Noise sources - Anthropogenic

- (A) Commercial navigation
  - The greatest contribution of acoustic energy (5 to 5000 Hz)
  - Propeller, drive motor and the water flow under the boat
- (B) Sonar
  - Creates acoustic energy and listen (below 20 KHz)
  - Military: surveillance, submarine detection and defense systems
  - Commercial: fishing, probing deep, profiling water column.
  - Civil: Deep waters measurement, seabed mapping, location of fish banks.

Portable Fish Finder

Noise sources - Anthropogenic

- (C) Seismic exploration
  - Analyze the composition of the seabed, as well as being the main technique for locating oil reserves and natural gas.
  - It generates high sound pressure levels, at low frequency and short duration.
- (D) Exploration and production of gas
  - Mainly associated with drilling activities.
  - Historically the biggest source of acoustic activity of surface water (<200m).
  - In recent years these activities are moving to deep water (up to 3000 m).

Noise sources - Anthropogenic

- (E) Industrial activities and construction.
  - (E1) Dredging
    - To extend seaward land or harvest marine resources
  - (E2) Drilling
    - For construction of maritime infrastructure
  - (E3) Pile driving
    - Construction in coastal areas. Multiple pulses.
  - (E4) Blasting
    - Low frequency pulse. High sound pressure levels.

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Underwater sound propagation

- The ocean is an extremely complex medium due its inhomogeneous nature.
- The main effect of propagation is to decrease the signal amplitude, by geometrical spreading and absorption.
- For convenience, in this study are listed only the most relevant aspects related to wildlife impact assessment.
- There are other underwater phenomena and additional variables that can influence the underwater acoustic propagation.

Underwater sound propagation

- Transmission Loss by geometrical spreading (TLS)

$$TL_S = X \cdot log(R)\ [dB]$$

  - R: Range, the distance in meters.
  - X: factor depending on the type of propagation.
    - X=20 Spherical propagation. Near the source. Even in all directions.
    - X=10 Cylindrical propagation. Shallow water. Limited by the seabed and the surface.
    - X=15 for a mixed model.
    - Or a combination consider first a spherical propagation to a distance R = H (depth), and then a cylindrical propagation.

Underwater sound propagation

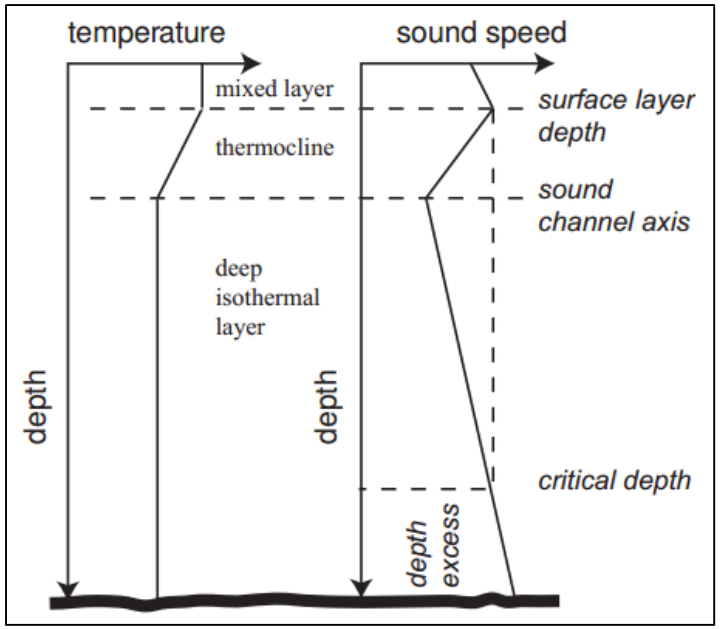
- Transmission Loss by absorption (TLA)
  - Mainly due viscosity, which is frequency dependent and also depends on some chemical reaction.
  - Thorp (1976)

$$\alpha(f) = 1.0936 \left[\frac{0.1 f^2}{1+f^2} + \frac{40 f^2}{4100+f^2} \right] \text{ [dB/Km]}$$

  - Ainslie and McColm (AM) (1998) simplified a version of the Francois–Garrison (FG)
    - Explicit the relationships among acoustic frequency, depth, sea-water absorption, pH, temperature, and salinity

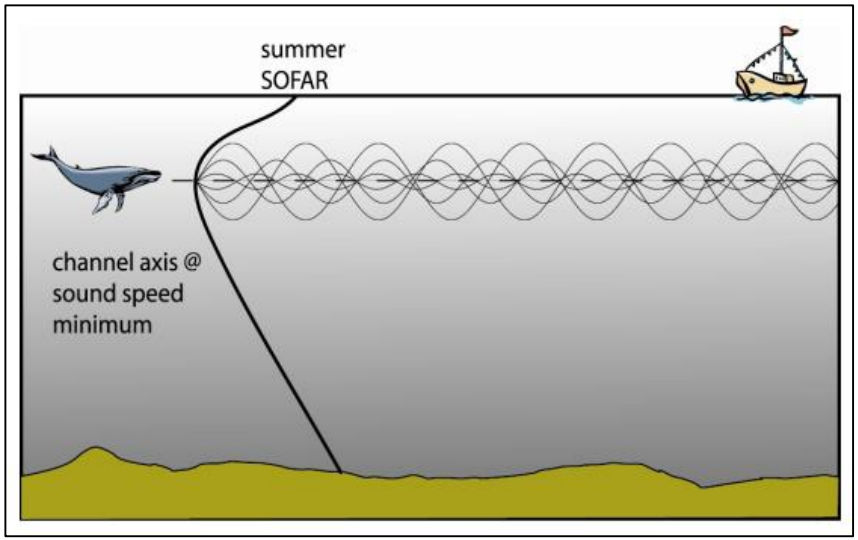
Underwater sound propagation

- The speed of sound (c) varies spatially in the ocean, mostly with depth (z), because of temperature and pressure constraints.
- The form (profile) of curve of c(z) and the distribution of the sound velocity gradient with depth, are important for the propagation of sound in the ocean.



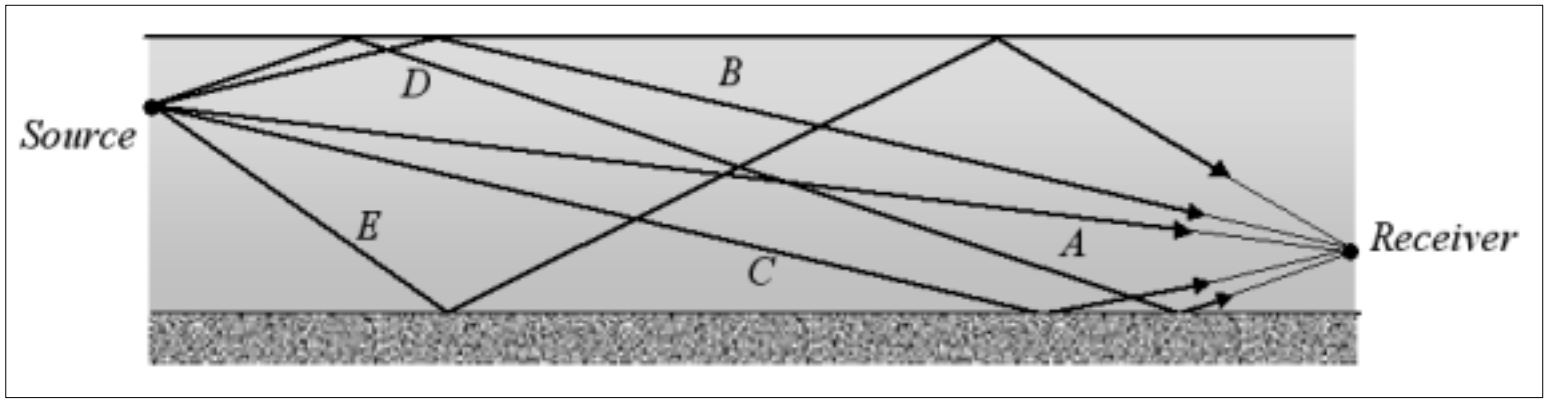
Underwater sound propagation

- For a negative gradient of velocity, the sound is refracted downward, while for the positive gradient of velocity, the sound is refracted upward, in both cases according to the Snell-Descartes law.
- Because of this phenomenon, a wave can travel long distances with minimal attenuation.



Underwater sound propagation

- In addition, the transmission path is not only the direct path between the source and receiver.
- Multiple transmission paths can occur due to reflections from the surface and seafloor.
- Also, some surfaces causes scattering and others produce absorption.



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Underwater propagation recommendations

- Calculation of TL in this context (impact on wildlife) should simplify the phenomenon and take into account a conservative approach.
- It is suggested to apply the mixed model for TL_S, either directly using a value of X = 15, or the combined model (spherical – cylindrical) in which the depth is known.
- For the absorption it is recommended to apply the basic formulation of Thorp. Change it only if need another spectrum.
- Taken into account the worst case for the spread (no interference patterns cancellations).

$$TL(R,f) = TL_S + TL_A = X \cdot log(R) + \alpha(f) \cdot R \cdot 1000 \text{ [dB]}$$

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Effects of noise on marine fauna

- Threats on marine life can include physiological and behavioral effects.
- The powerful noise can cause rupture or hemorrhage on ear, body parts.
- Also high levels of noise can trigger hearing loss, and interfere with the echolocation abilities.
- In the *Islote Lobería* of Cobquecura, Chile, has been observed that sea lions (*Otaria flavescens*) cease vocalization in the presence of fireworks during New Year celebrations.
- Disturbance can force whales to dive deeply, causing decompression sickness on rising.

Effects of noise on marine fauna

- Most of this studies are short-term behavioral observations, and a few-long term studies have been conducted.
- Marine mammals are very adaptable and tolerant to noise, but the limits of this tolerance are unidentified.
- The effects of masking important sounds, such as predators, and the adaptability to adjust the frequency or strength of their signals, are mainly unknown.

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Regulation approaches

General approaches to regulations include:

- (A) Noise source selection:
  - Minimum power source must be used or foundation alternative techniques.
- (B) Location and timing:
  - Spatial or temporal Vedas.
- (C) Operational procedures:
  - (C1) Soft start/ramp: gradual increase to full power.
  - (C2) Using vibrating ramming instead of pile driving.

Regulation approaches

- (D) Mitigation measures
  - Bubble screens. Almost all European countries require bubble curtains.
- (E) Mitigation procedures
  - (E1) Safety Zones.
  - (E2) Marine Mammal Observers (MMO).
  - (E3) Study before the start of operations.
  - (E4) Low Power and Off: If animals entering the areas. The operations have to switch to low power or off.
  - (E5) Passive acoustic monitoring (PAM). In addition to the MMO, the PAM is recommended for operations in low visibility conditions.

Thank you for your attention.

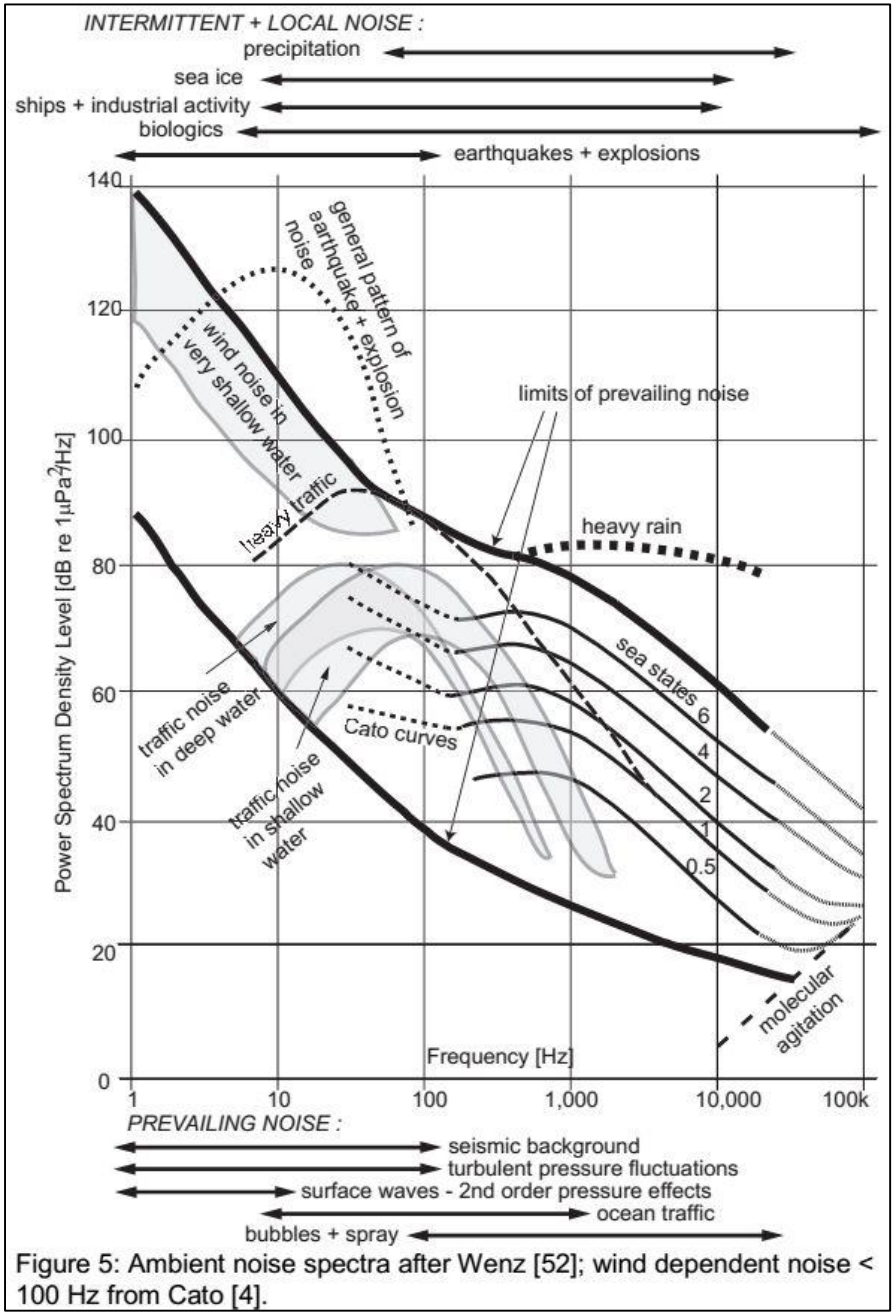

Figure 5: Ambient noise spectra after Wenz [52]; wind dependent noise < 100 Hz from Cato [4].