Probing the fin whale song evolution

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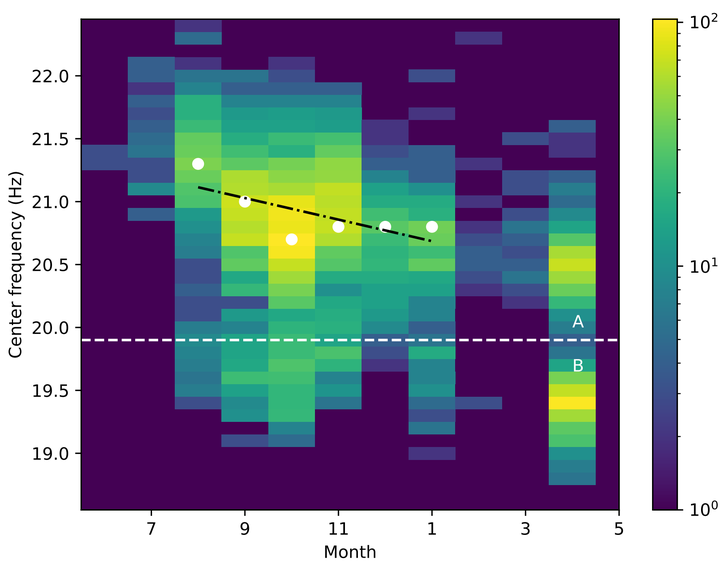
Introduction

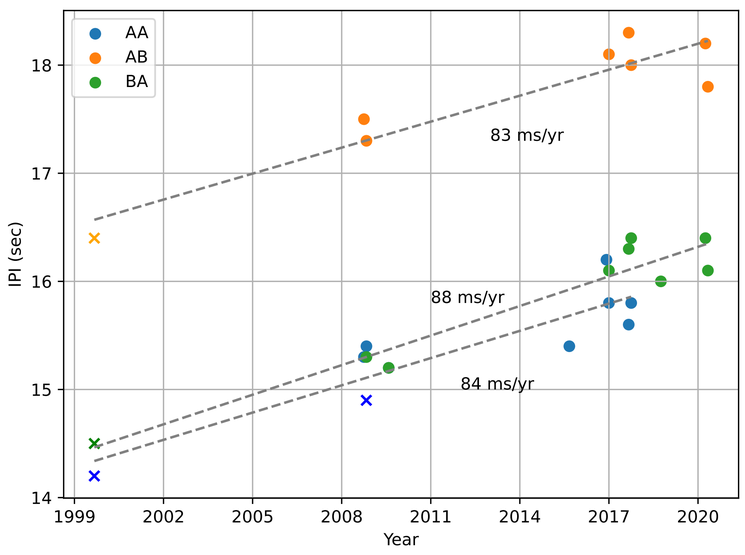
The fin whale (*Balaenoptera physalus*) is the second largest animal on earth, roaming all oceans including the Mediterranean Sea. Their songs are rhythmic sequences composed of pulse like vocalisations around 20Hz. Each fin whale population has its own song dialect which defines a pulse frequency and a rhythmic pattern (inter-pulse intervals). Automatic detection systems applied on long term recordings of the Ligurian Sea have allowed to characterise the Mediterranean fin whale song, as well as its evolution through the last 20 years.

Med. Sea seasonal trend



Pulse frequencies decrease each winter (-0.1Hz/month, $R^2 = 0.73$).

Med. Sea inter-annual trend

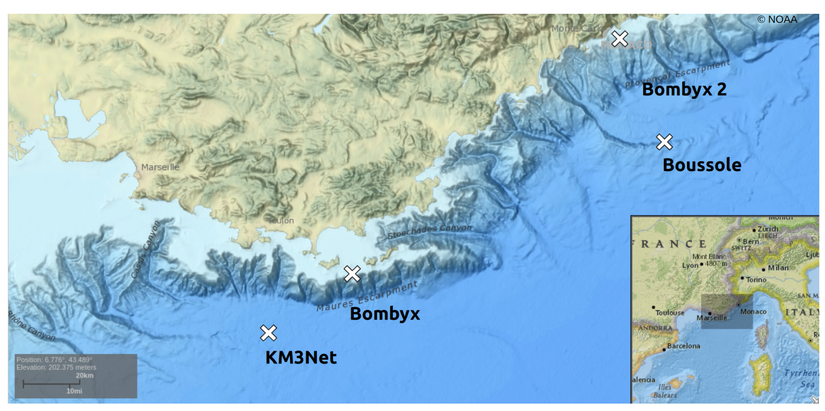


IPI increase across years ($R^2 > 0.86$)

Deep Leaning-based detection and song analysis

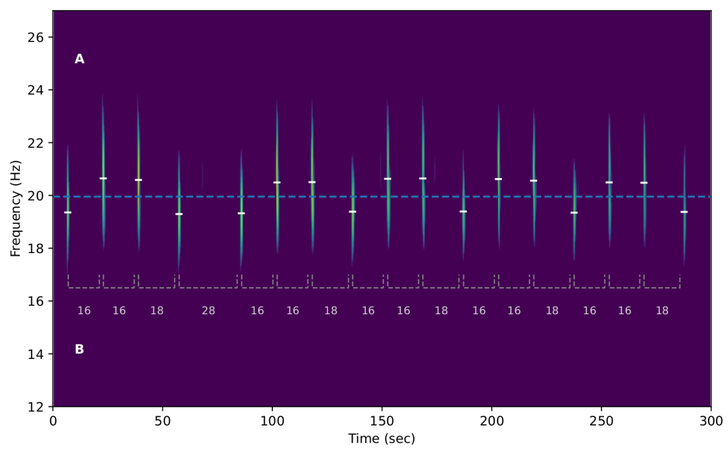
1. Using a CNN to detect 20Hz pulses :

Long term passive acoustic recordings from the Ligurian Sea allowed to gather numerous fin whale songs through the years. For their automated analysis, we trained a CNN to detect 20Hz pulses on spectrograms. This 3 layer lightweight CNN achieves 0.99 of AUC when tested on antennas unseen in training.



2. Song analysis:

Given the CNN detections, we extracted the timestamp and center frequency of each pulse. Pulse frequencies allowed to classify them by type (A and B, with A the higher pitched one). Grouping close pulse together in sequences allowed to estimate Inter-Pulse Intervals (IPI) which are characteristic of each bi-gram.



3. Summary of fin whale song trends worldwide:

		Inter-annual		Intra-annual	
Study	**Location**	**Frequency**	**IPI**	**Frequency**	**IPI**
Weirathmueller et al. 2017	N.E. Pacific	-0.17 Hz/yr	0.5-0.9 sec/yr	-	-
Oleson et al. 2014	N. Pacific	-	-	-	+7.5 sec
Leroy et al. 2018	Indian	-0.21 Hz/yr	-	$\sim$ -0.1 Hz/mth	-
Helble et al. 2020	N. Pacific	-	0.6-1.3 sec/yr	-	-
morano2012seasonal	N.W. Atlantic	-	* 0.5 sec/yr	-	+5.5 sec
Watkins et al. 1987	N.W. Atlantic	-	-	-	+6 sec
Širović et al. 2017	Gulf of California	-	$\sim$ 1 sec/yr	-	$\sim$ +8 sec
Furumaki et al. 2021	Chukchi sea	-	$\sim$ 0.5 sec/yr	-	$\sim$ +1 sec
Wood and Širović 2022	W. Antarctic	-0.2 Hz/yr	0.1 sec/yr	-	-
Ours	**W. Mediterranean**	-	**0.1 sec/yr**	**-0.1 Hz/mth**	-

Singing depth and water temperature

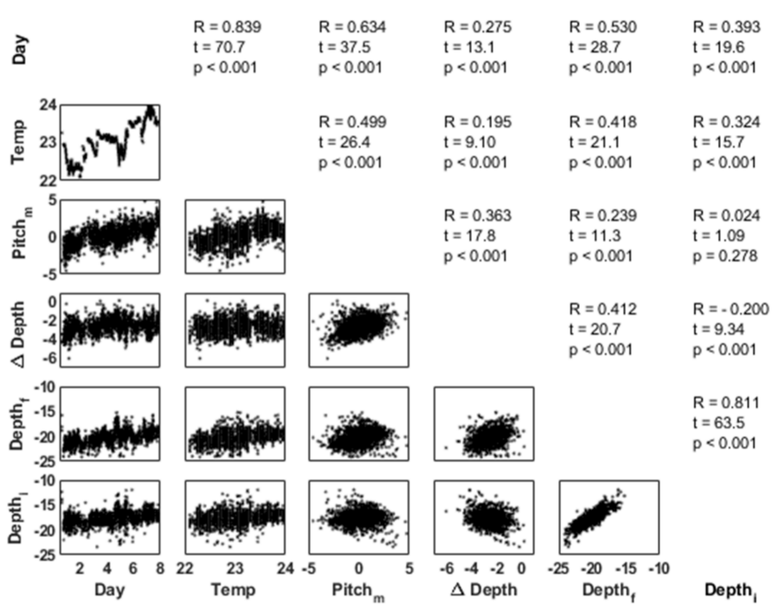
- A decrease of vocalisation frequencies is observed worldwide in 4 mysticete species

- The observation of seasonal trends has led the hypothesis of a temperature related phenomenon

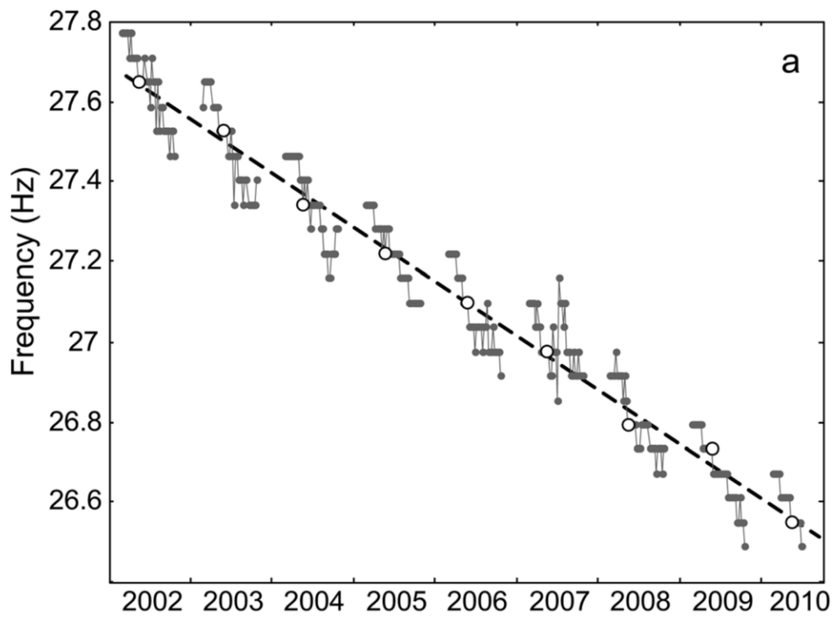
- A preferred singing depth could be motivated by the whale's buoyancy, which is related to water temperature and body condition

- The global sea surface temperature has been increasing linearly since 1960

- Singing depth could impact vocalisation frequencies (optimal propagation or pressure on the vocal apparatus)



Correlation matrix of a diving & singing pygmy blue whale *Davenport et al. 2022*



Inter and intra annual decrease of Antarctic blue whales *Gavrilov et al. 2012*

Conclusions and Future Work

Blue whales, pygmy blue whales, bowhead whales and fin whales demonstrate **long term variations in their vocalisation frequencies**. Numerous **hypothesis are being tested** such as a post whaling increase in population density or body size, increasing ambient noise levels and water characteristic evolution (warming, acidification), with **no current consensus**.

The **KM3Net acoustic recorders** could contribute to probing this phenomenon, by jointly estimating **vocalisation frequency and calling depth** across seasons and years.

Additionally, alongside the **Bombyx 2 network**, the KM3Net observatory could allow to alert on **cetacean presence in real time** and protect them from **fatal ship strikes**.

References

Davenport et al. "Pygmy Blue Whale Diving Behaviour Reflects Song Structure." Journal of Marine Science and Engineering (2022)

Gavrilov et al. "Steady inter and intra-annual decrease in the vocalization frequency of Antarctic blue whales." JASA (2012)

McDonald et al. "Worldwide decline in tonal frequencies of blue whale songs." Endangered species research (2009)

Best et al. "Temporal evolution of the Mediterranean fin whale song." Scientific reports (2022)