BOMBYX network : from Pelagos to PSSA
Intelligent real-time listening sonobuoys for whale-ship collision mitigation & environmental awareness

Chair IA intelligent listening AID DGA ANR http://bioacoustics.lis-lab.fr

GIAS MARITTIMO FEDER - Région Sud

Glotin Hervé, CNRS LIS Univ Toulon, & DYNI team
glotin@univ-tln.fr

Historic of BOMBYX : 2015-2018

The first long term stereo Monitoring of Sperm Whales

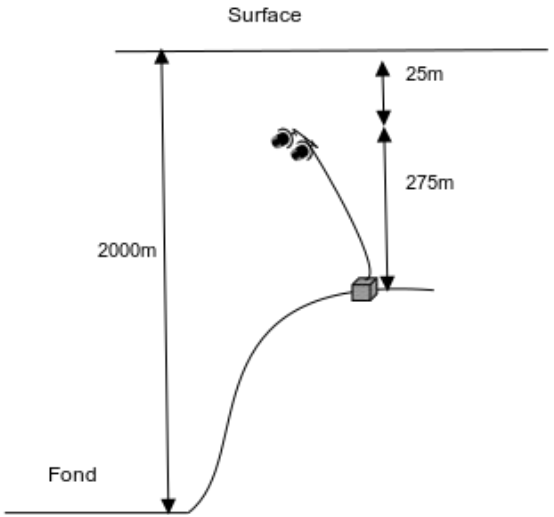
DYNI LIS CNRS in coll. with MIO and PNPC, Glotin 2012-2019

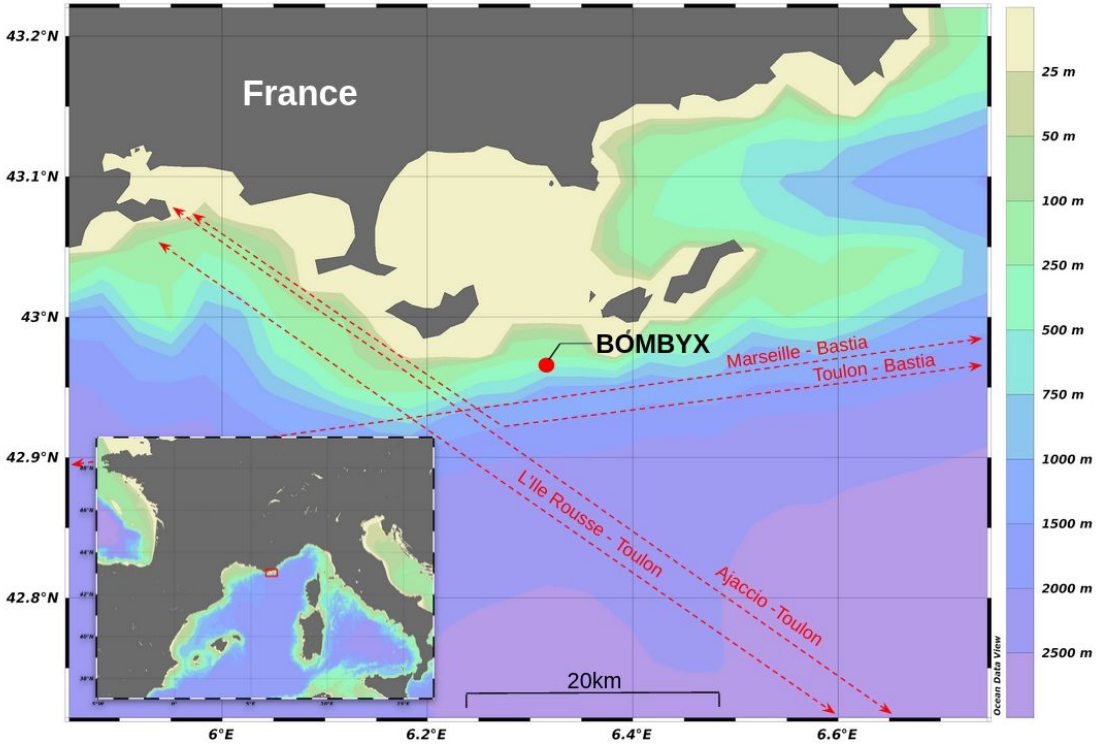
http://sabiod.lis-lab.fr/pub/BOMBYX/

http://glotin.univ-tln.fr/BOMBYX/

The BOMBYX 2015-2018

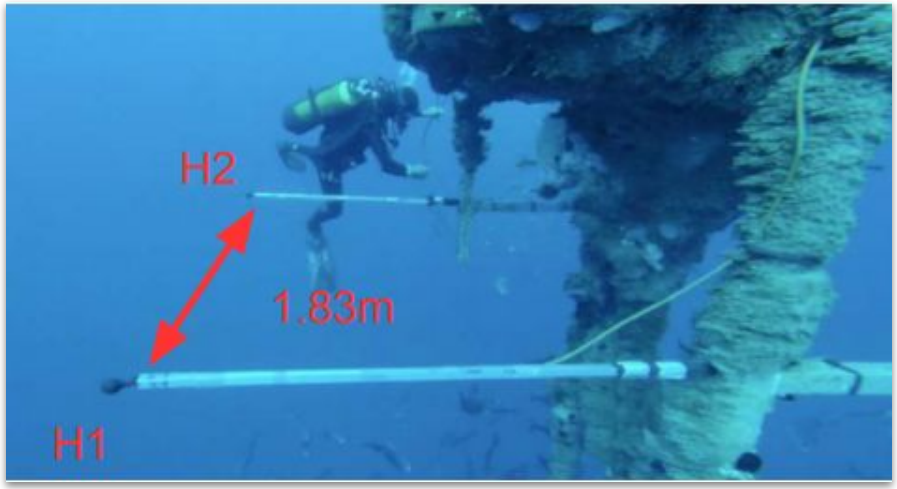
- Bombyx station, stereophonic
- 25 of depth
- Env 2700 hours of recordings, stereo
- Detection of sperm whales clics on Bombyx
- Data for future training





accepted in Nature, Scientific Report, Poupard,... Glotin, 2021

Bombyx 1



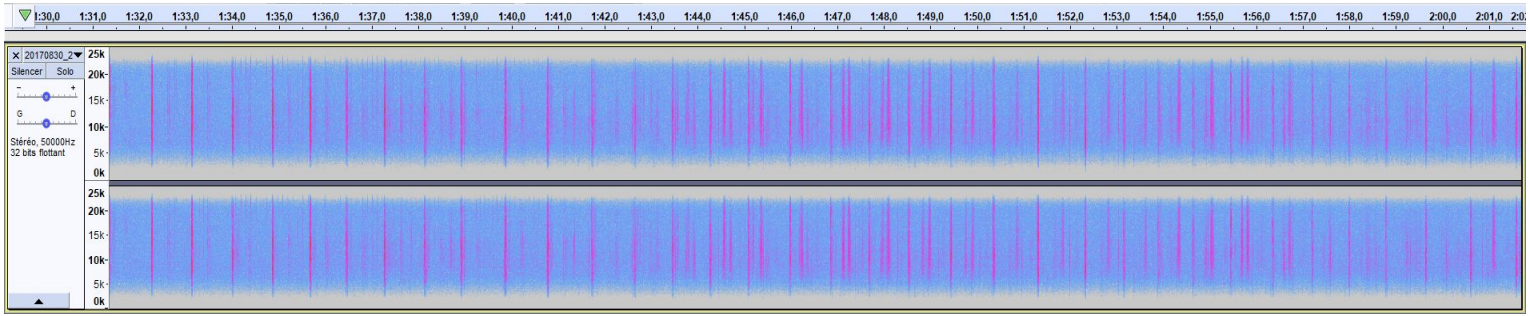
Data :

- Sparse recording from 2014 to 2018
- 2 channels (2 meters wide)
- 50kHz
- 25m deep hydrophones
- No annotation

Objective :

- Noise robust sperm whale and fin whale detections

1) STEREO CHANNEL ALLOW robust detection and counting of individual Physeters m.



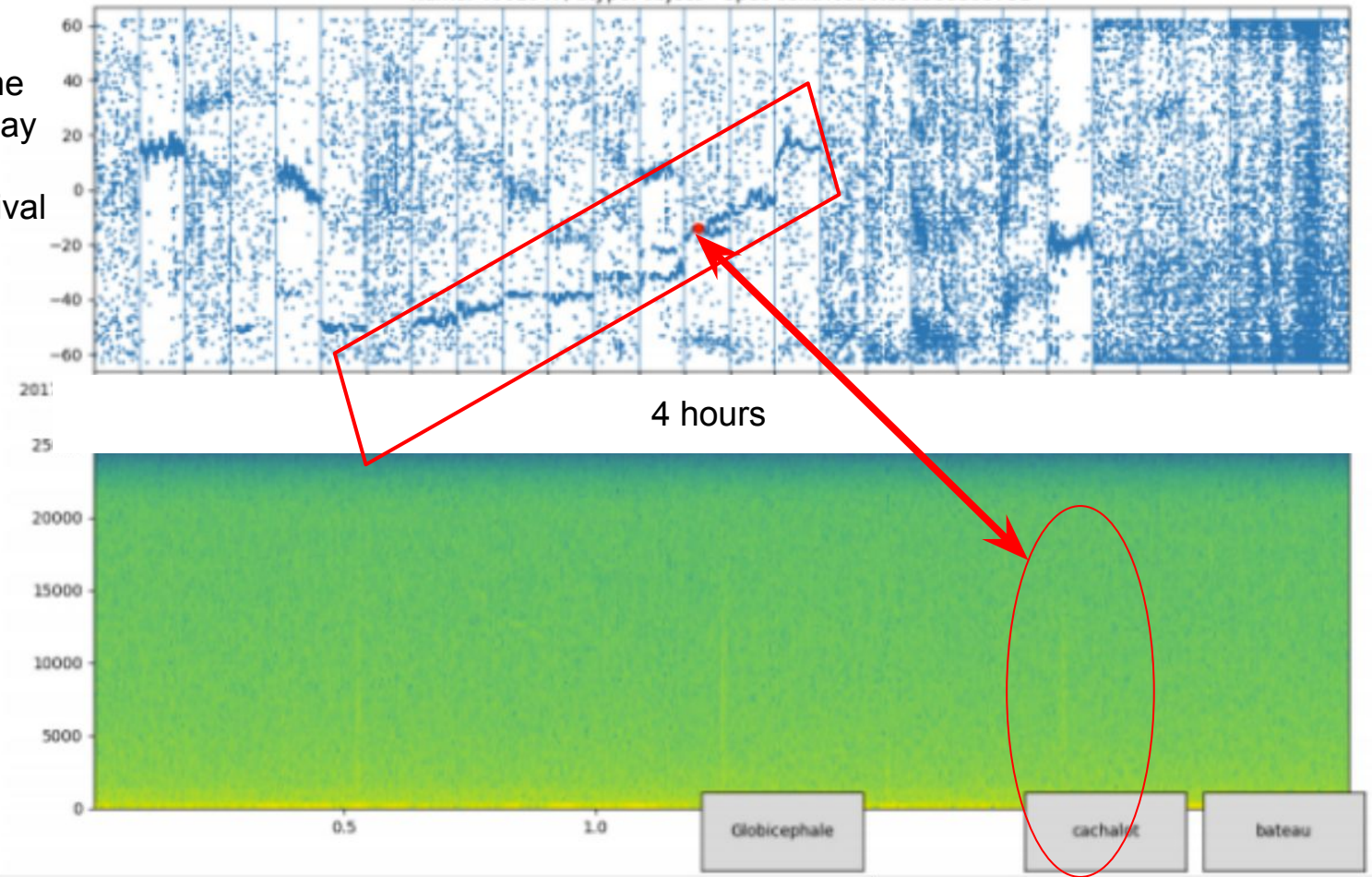
Example of Cachalot track from Bombyx1

folder_final /home/glotinh/Documents/bombyx/dist3/Bombyx4/B...
duration 300
abs_click_time 65056.9
labels None
Name: 4661647, dtype: object> Spec centr:6596.856933593751

Time Delay of Arrival

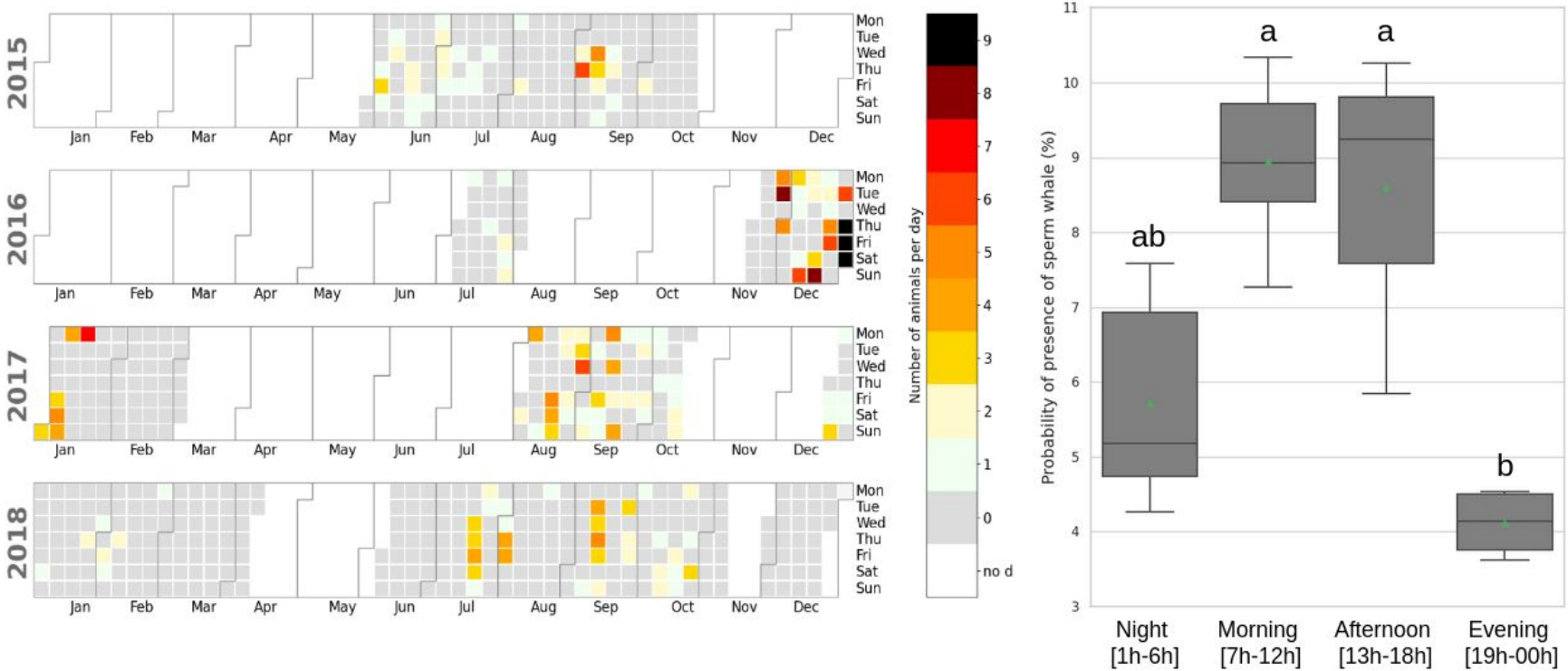
Multichannel = Big range detection (up to 30 km)

4 hours



Count of Sperm whales on BOMBYX 2015-2018

Sperm whale acoustic detection and background noise

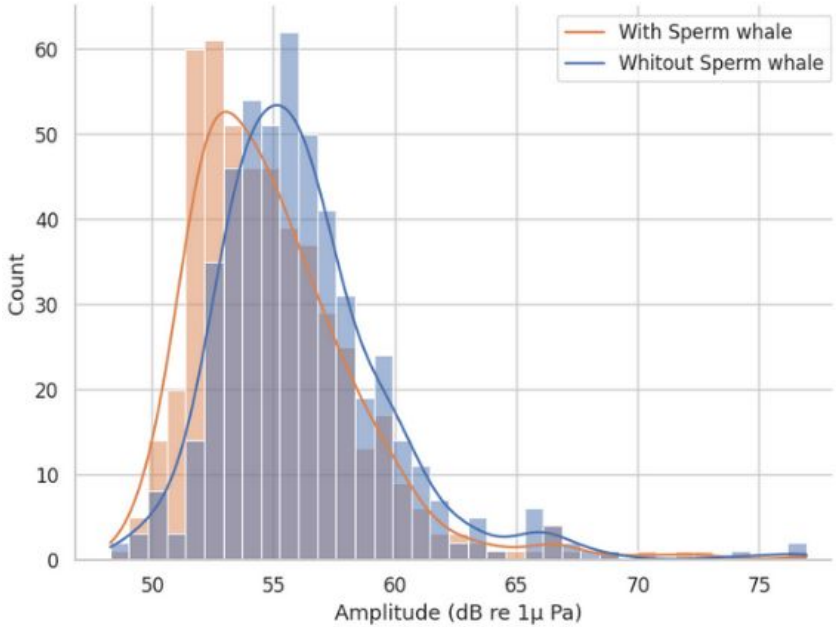


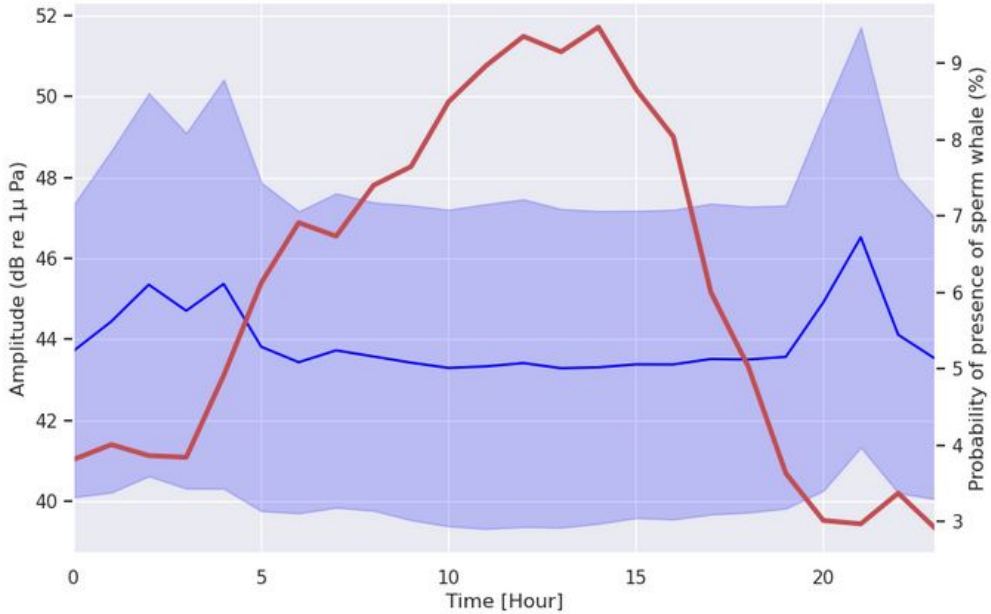
Left: Number of detected sperm whales per day during the 4 years of recordings (white region: no recording).Right: Mean of the probability of presence for each period of the day.

Accepted in Nature, Scientific Report, Poupard et al 2022

The BOMBYX 2015-2018

Sperm whale acoustic detection and background noise



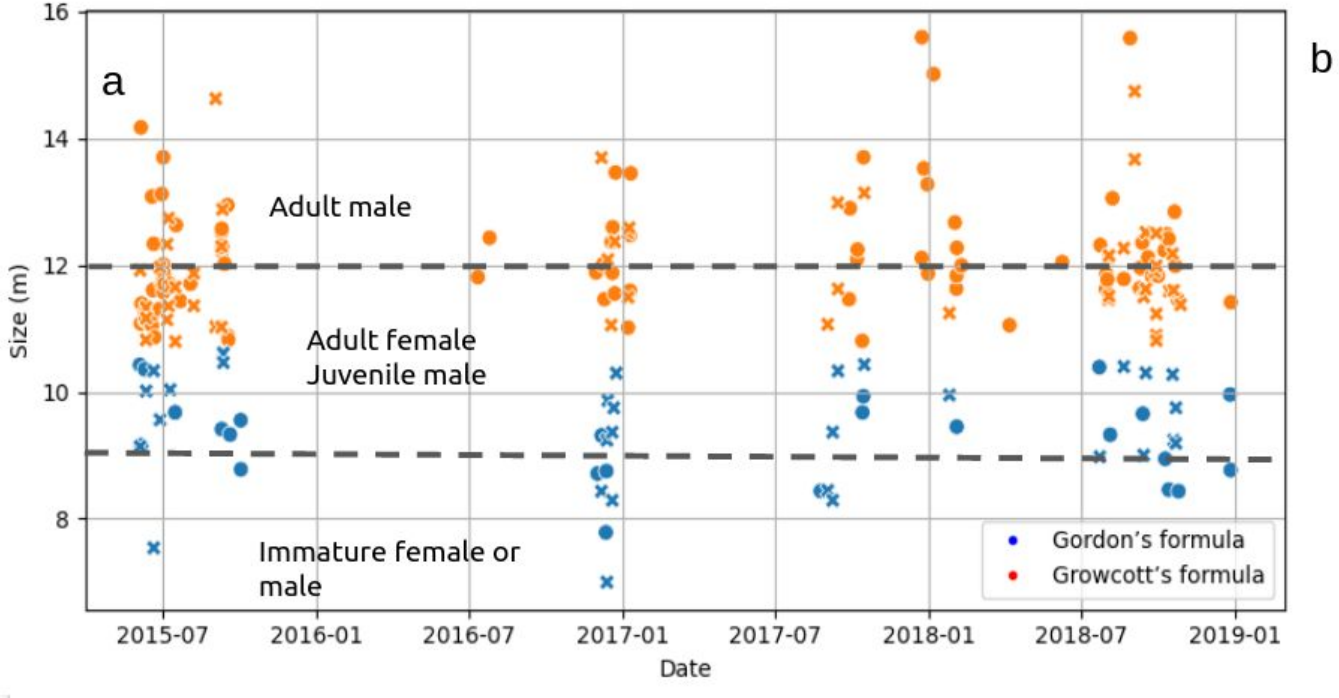


(Left) Distribution of the amplitude for the octave 12800 Hz according to presence/absence of sperm whales.
(Right) Superposition of dial pattern of amplitudes for the octave 12800 Hz and probability of presence of sperm whales.

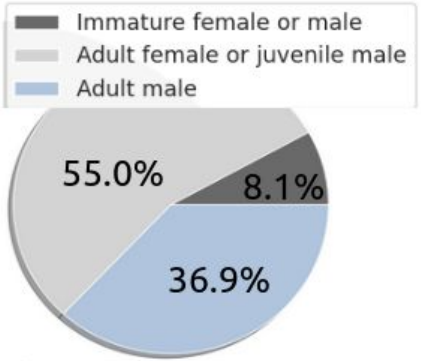
in Nature, Scientific Report, Poupard Ferrari Best, Glotin 2022

The BOMBYX 2015-2018

Sperm whale Interpulse Interval (IPI) and size measurement



b

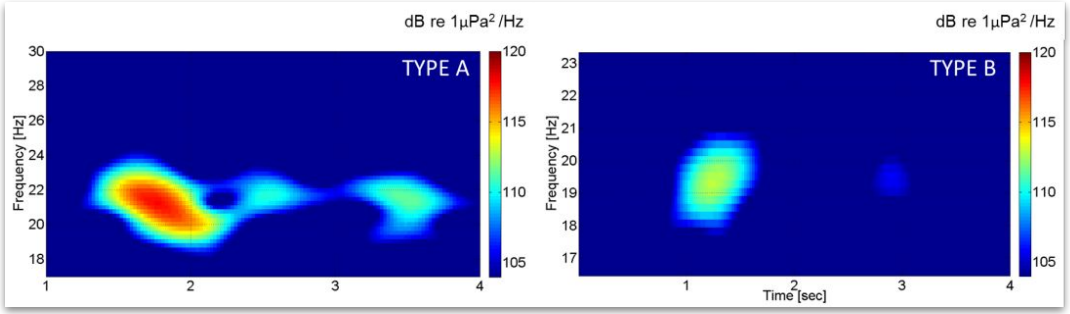


Composition of the group

Sperm whales density: density of sperm whales in the area was 1.69 whales/1,000 km2

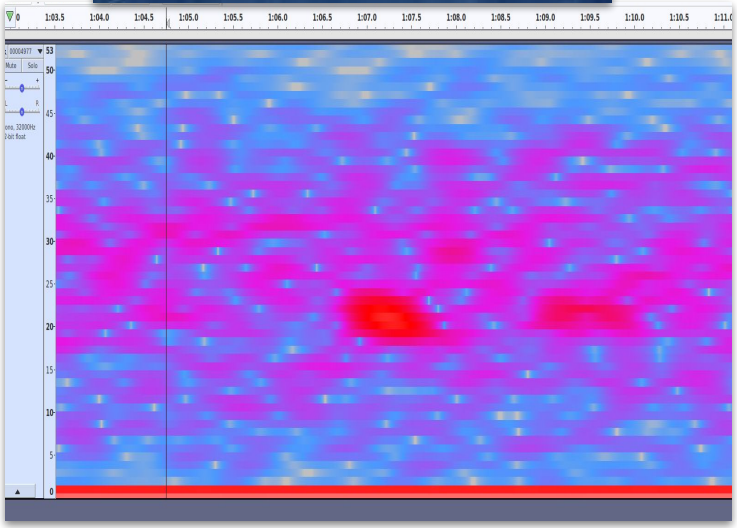
Accepted in Nature, Scientific Report, Poupard et al 2022

2) Fin whale pulse detection (low frequency)



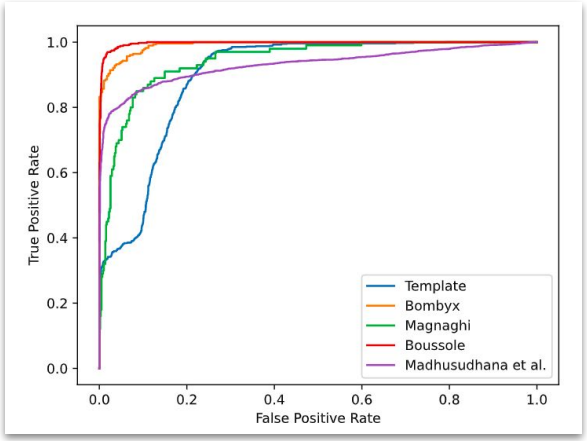
Monitoring fin whale (Balaenoptera physalus) acoustic presence by means of a low frequency seismic hydrophone in Western Ionian Sea - EMSO site. Gianni Pavan

- Low centroid frequency
- Bandwidth : 5-7Hz
- Length : 1sec
- Periodicity : 15-40sec



Sample from sonobuoy Boussole 2009 dataset

Low Frequency event classification : Deep learning Fin whale pulse detection

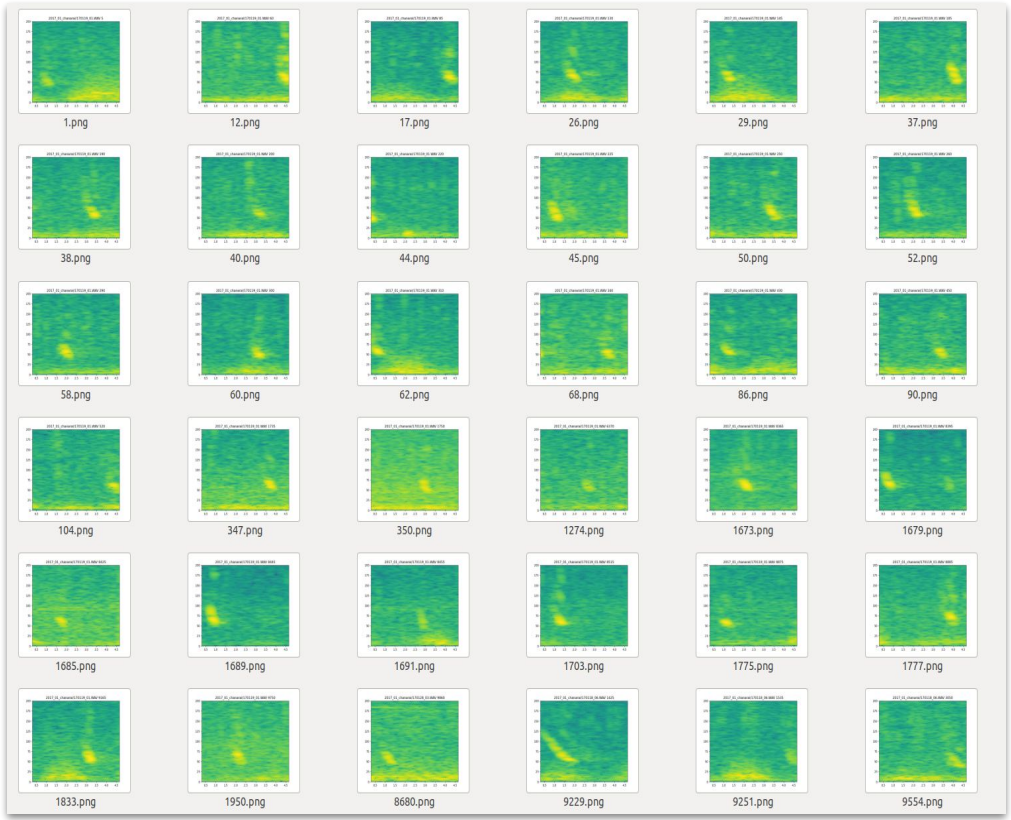


- Sampling frequency = 200Hz
- STFT (winsize=256, hopsize=16)
- Mel (128 features from 0 to 100Hz)
- Log
- Conv 128 - 512
- Conv 512 - 512
- Conv 512 - 1
- MaxPool

Conv = batch norm, depthwise conv, dropout, Relu

Best et al 2021

Sample of high predictions over Chilian dataset
(rec. Patris, Malige, Glotin 2017, Chanaral, Humbold loop…)



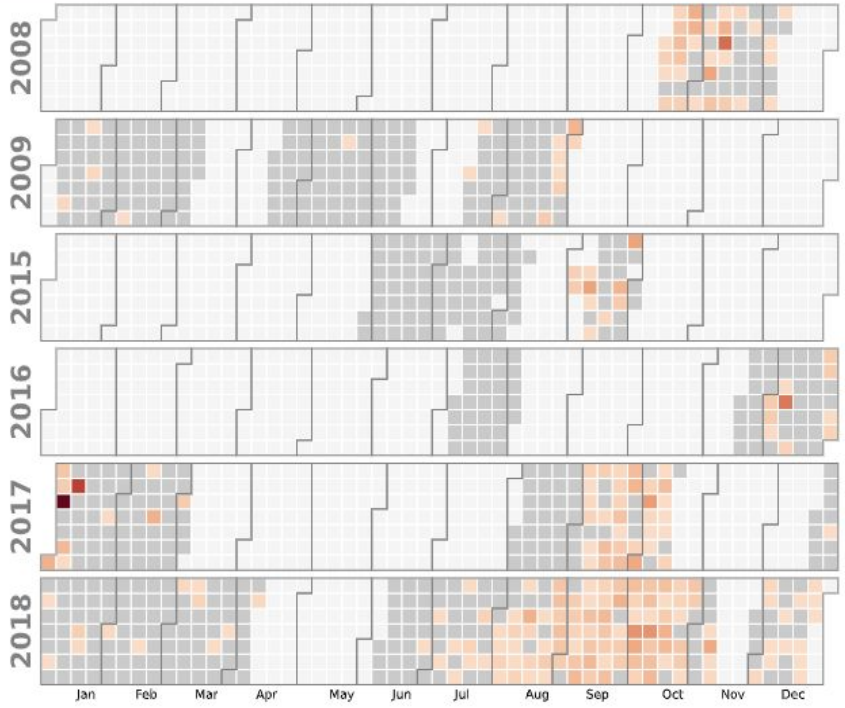


Figure 2. Calendar of the recorded days (grey cells). Shades of red denote the number of detected sequences normalized by the number of recorded hours (ranging from 0 to 8).

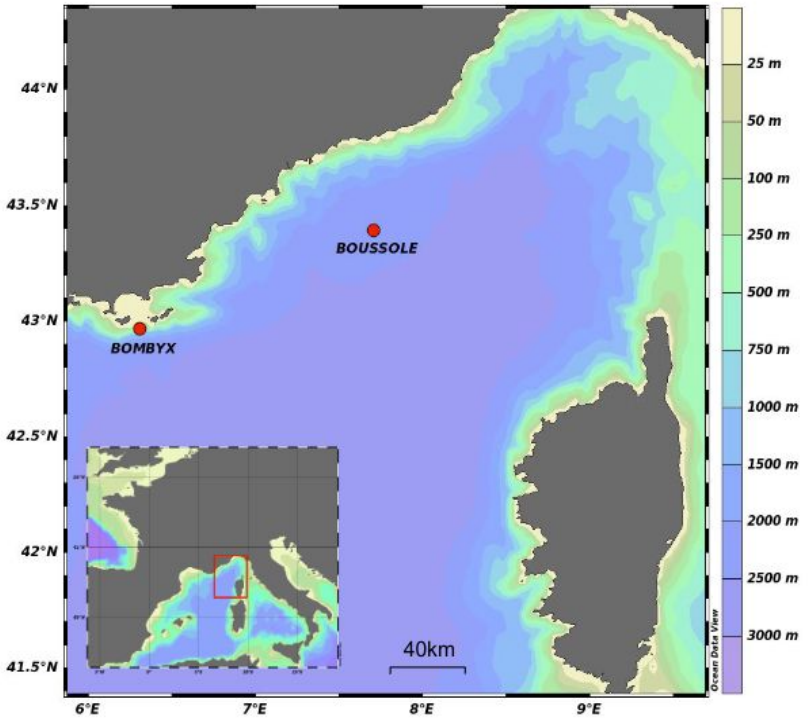


Figure 3. Map showing the two recording stations used in the analysis. This map was made using Ocean Data View[29].

Temporal evolution of the Mediterranean fin whale songs on BOMBYX1

Compilation of CNN detections into songs
Discrimination of pulse types (GMM on centroid freq)

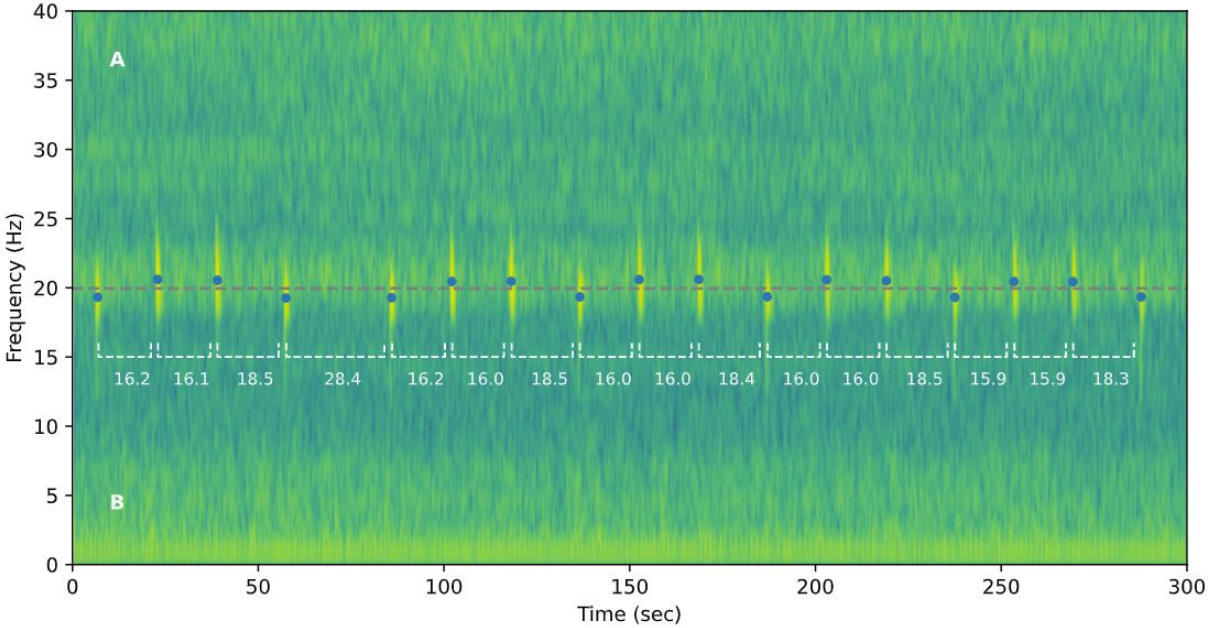
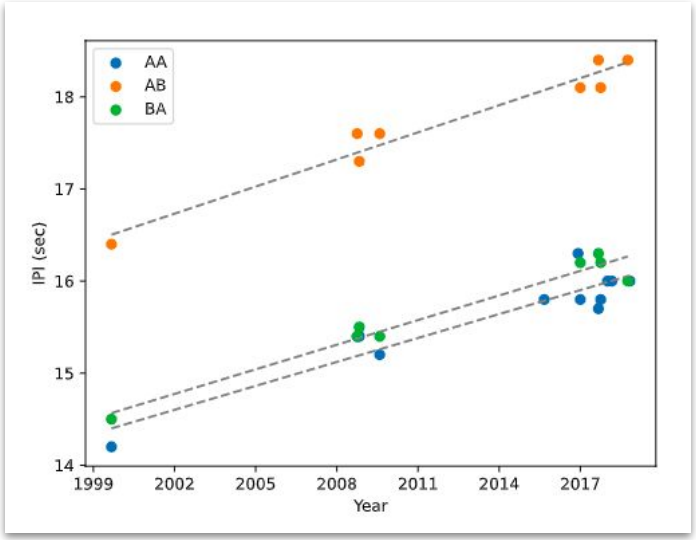


Figure 1. Spectrogram of a fin whale pulse sequence recorded by the Bombyx buoy in October 2018. Spectrogram parameters are described in section 2.7. Dots show the centroid frequencies of the detected pulses, with white dashed lines showing the IPIs. The grey dashed line denotes the discrimination threshold between type A and B pulses, at 19.9Hz.

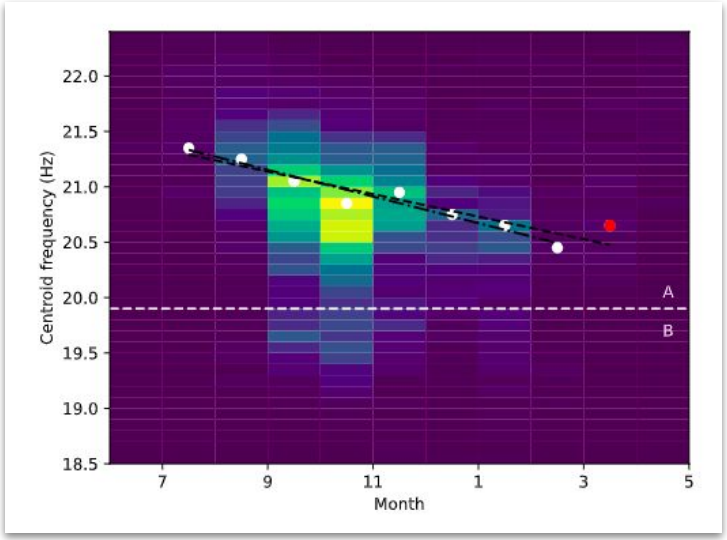
[submitted Scientific Report Best et al.]

Temporal evolution of Mediterranean fin whale pulses

Result of Fin whale on **Bombyx1 from 2015 to 2018**, IPI and frequency analyses



Yearly increase of the stereotypical IPIs
by 0.1sec/year



Seasonal decrease of the centroid frequency
by 0.1Hz/month

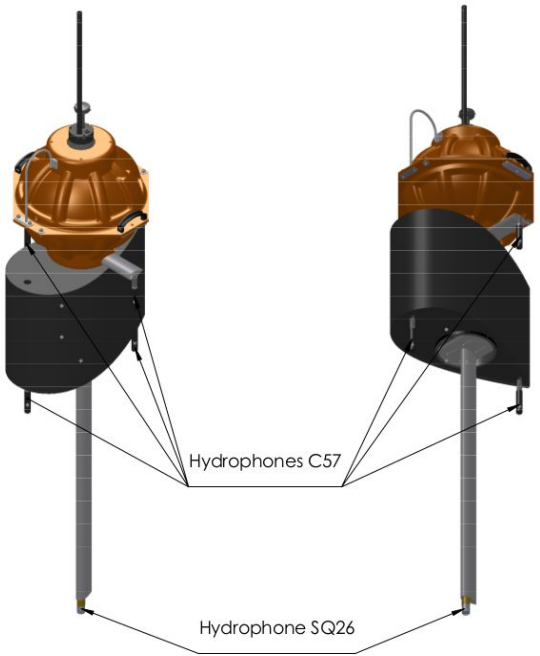
Putting all together =

BOMBYX 2

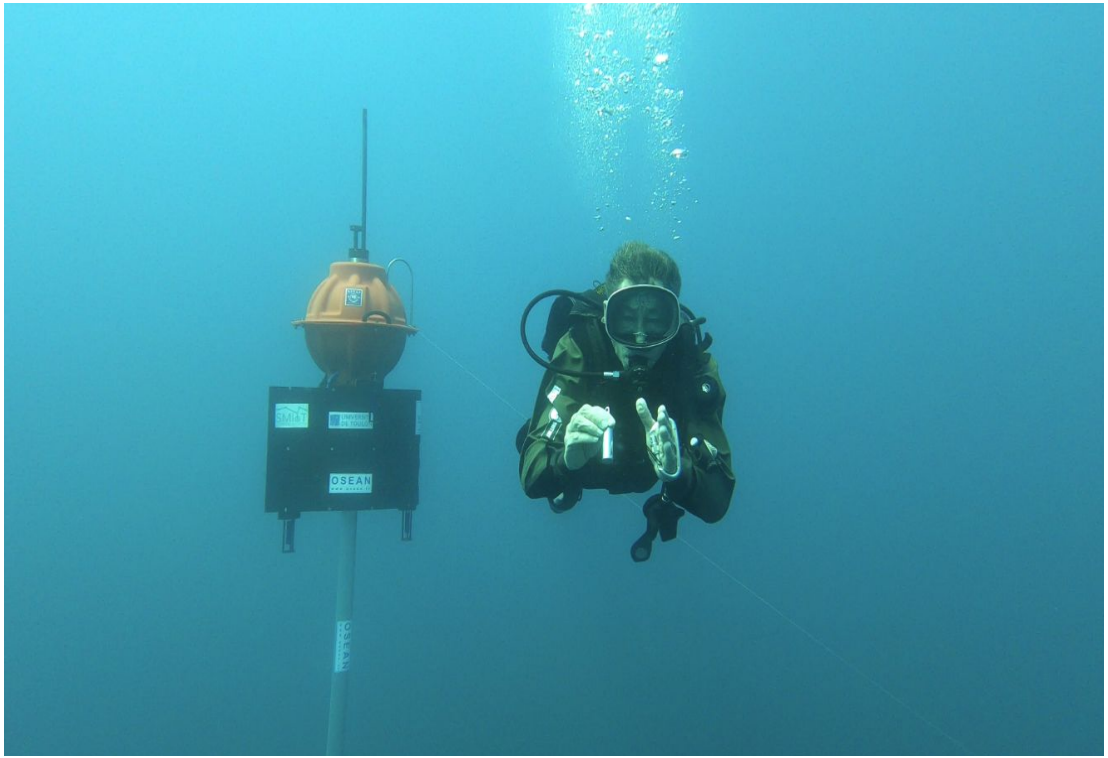
low power AI real-time alert
for Pm and Bp protection

BOMBYX2

4G or IRIDIUM transmission



5 hydrophones intelligent listening

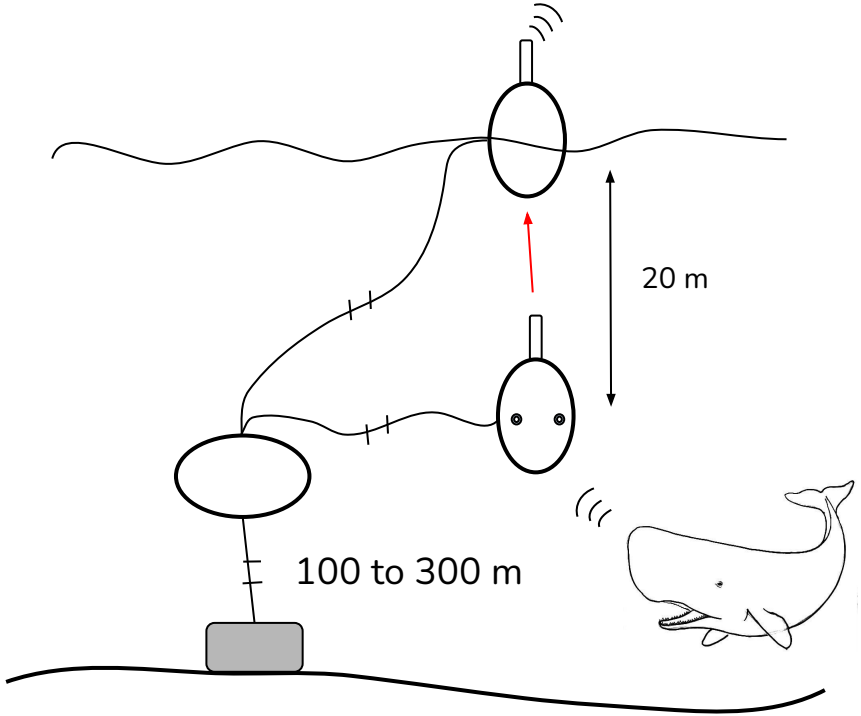


GIAS MARITTIMO Glotin et al 2018-2021, coll OSEAN, SMIoT

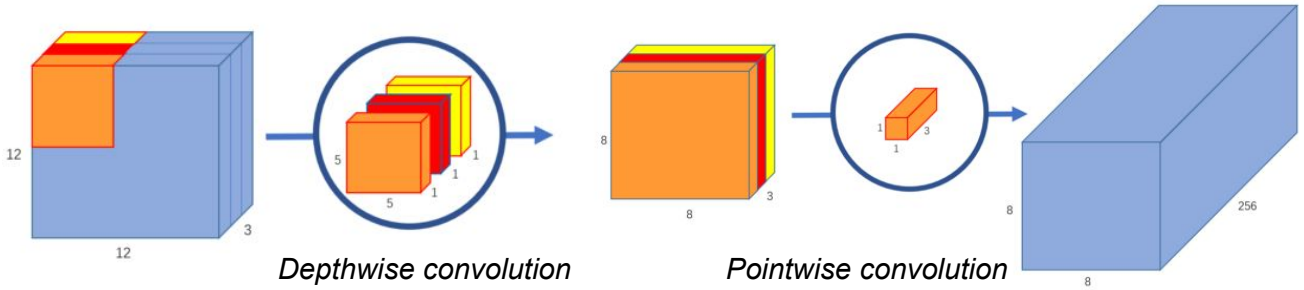
Application to Online AI Bombyx 2

4G emission to LIS, PELAGOS, PREMAR, REPCET

- To be placed in 2022
  - South of Port-Cros Island and Cape Corsica
- Floatability variation system
  - 20m deep recording and surface 4G communications
- Alert system for sperm whale and fin whale presence
  - Mitigate ship strikes risk
- 5 hydrophones
  - Azimuth and distance estimation
- Battery powered (approx. 6 month)
- PIC32-Mz microprocessor



Embedded AI
Depthwise separable convolution, decimated CNN



Conv : 5 x 5 x 3 x 256
DW Conv : 5 x 5 x 3 + 3 x 256

	# parameters	# mutliplications
Traditional	272 x10^3	309 x10^6
Depthwise	11 x10^3	13 x10^6

- Conv 64 - 512
- Conv 512 - 512
- Conv 512 - 1

L. Bai, Y. Zhao and X. Huang, "A CNN Accelerator on FPGA Using Depthwise Separable Convolution," in *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 65, no. 10, pp. 1415-1419, Oct. 2018, doi: 10.1109/TCSII.2018.2865896.

Embeded AI
Into Low power micro-processor (PIC)

Analyse pour 5 secondes de signal

	Fin Whale	Sperm Whale
Sampling rate	200 Hz	50 kHz
Spectrogram size	128 x 46	64 x 974
Spectrogram computation time	0.2 sec	4.5 sec
Forward pass time	0.5 sec	2.1 sec

PIC 32MZ by Microchip

Best et al 2020

Bombyx 2

Low complexity CNNs

	params type	# params	poids params	# mutliplications
Depthwise	float32	11K	54Ko	13 M
Quantized	int8	272K	1.1Mo	309 M

- Sampling frequency = 50kHz
- STFT (winsize=512, hopsize=256)
- Mel (64 features from 2 to 25kHz)
- Log
- Conv 64 - 64
- Conv 64 - 64
- Conv 64 - 1
- MaxPool

Conv = batch norm, depthwise conv, dropout, Relu
Valid AUC = 93 %

Sperm whale binary classifier

- Sampling frequency = 200Hz
- STFT (winsize=256, hopsize=16)
- Mel (128 features from 0 to 100Hz)
- Log
- Conv 128 - 512
- Conv 512 - 512
- Conv 512 - 1
- MaxPool

Conv = batch norm, depthwise conv, dropout, Relu
Valid AUC = 90 %

Fin whale binary classifier

Embeded AI
Bombyx2 - Analog wake-up

- Background noise estimation
- >8kHz Energy thresholding
- State Machine consistency validation
- 75% AUC on Bombyx 1
- Ultra low power **12.5µA**

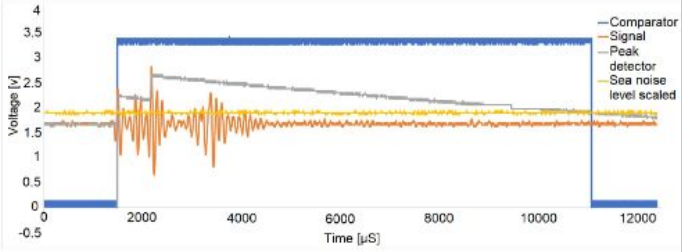


Fig. 7. Clicks of cetacean (Pm) with ULP processing, acquired on real signals (High-pass filtered input signal (orange), V_{Ref} (yellow), click envelope (grey), output of the comparator (blue)).

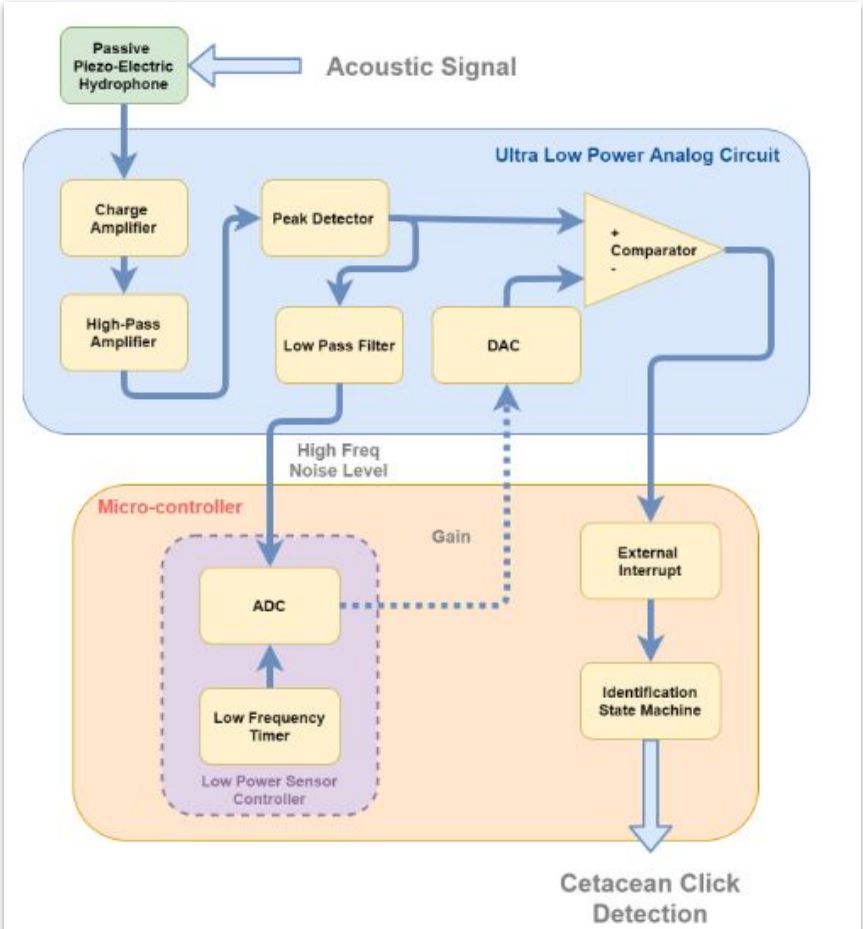


Fig. 4. Block diagram of the detector of a train of pulses of a Sperm Whale.

S. Marzetti, V. Gies, V Barchasz, P. Best, S. Paris, H. Barthelemy, H. Glotin (2020), Ultra-Low Power Wake-Up for Long-Term Biodiversity Monitoring, in proc. IEEE IoTAIS

Validation o Bombyx 2

Accomplished :

- Hyper-parameter search / optimization for the **low power analog detector**
- Training of low complexity (11k params) **CNN for sperm whale detection** (0.92 valid AUC), using data from Bombyx 1
- **Gathering of a multi-source dataset** of fin whale calls Iteratively
- Training of low complexity **CNN for fin whale detection**
- Implementation of the forward pass in C embedded in the buoy

VIDEOS available at http://sabiod.lis-lab.fr/pub/BOMBYX2/videos/

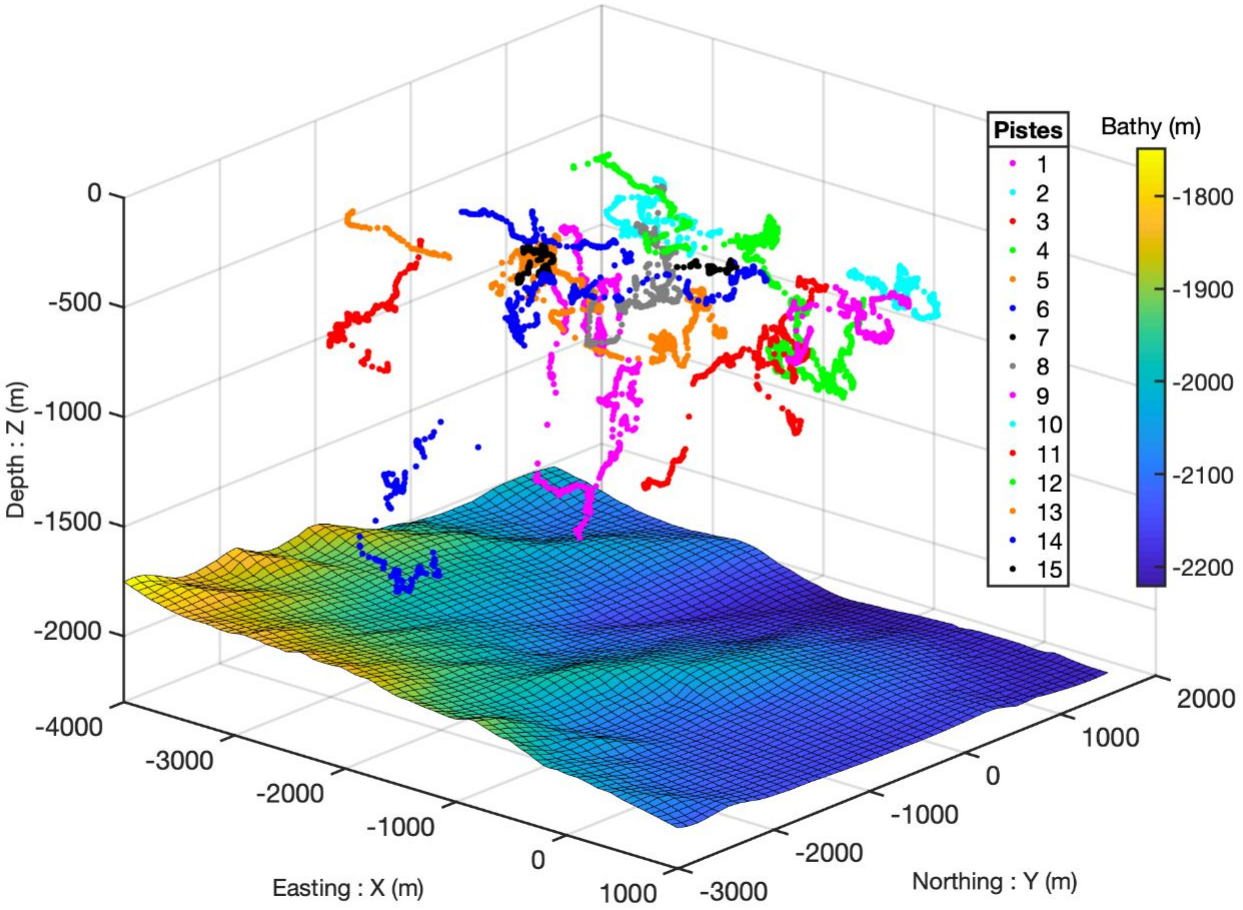
images at http://sabiod.lis-lab.fr/pub/BOMBYX2/

Movie at http://sabiod.lis-lab.fr/media/13h15.le.samedi.Fr2.20210619.mp4

BOMBYX2 allows 3D tracking at large scale

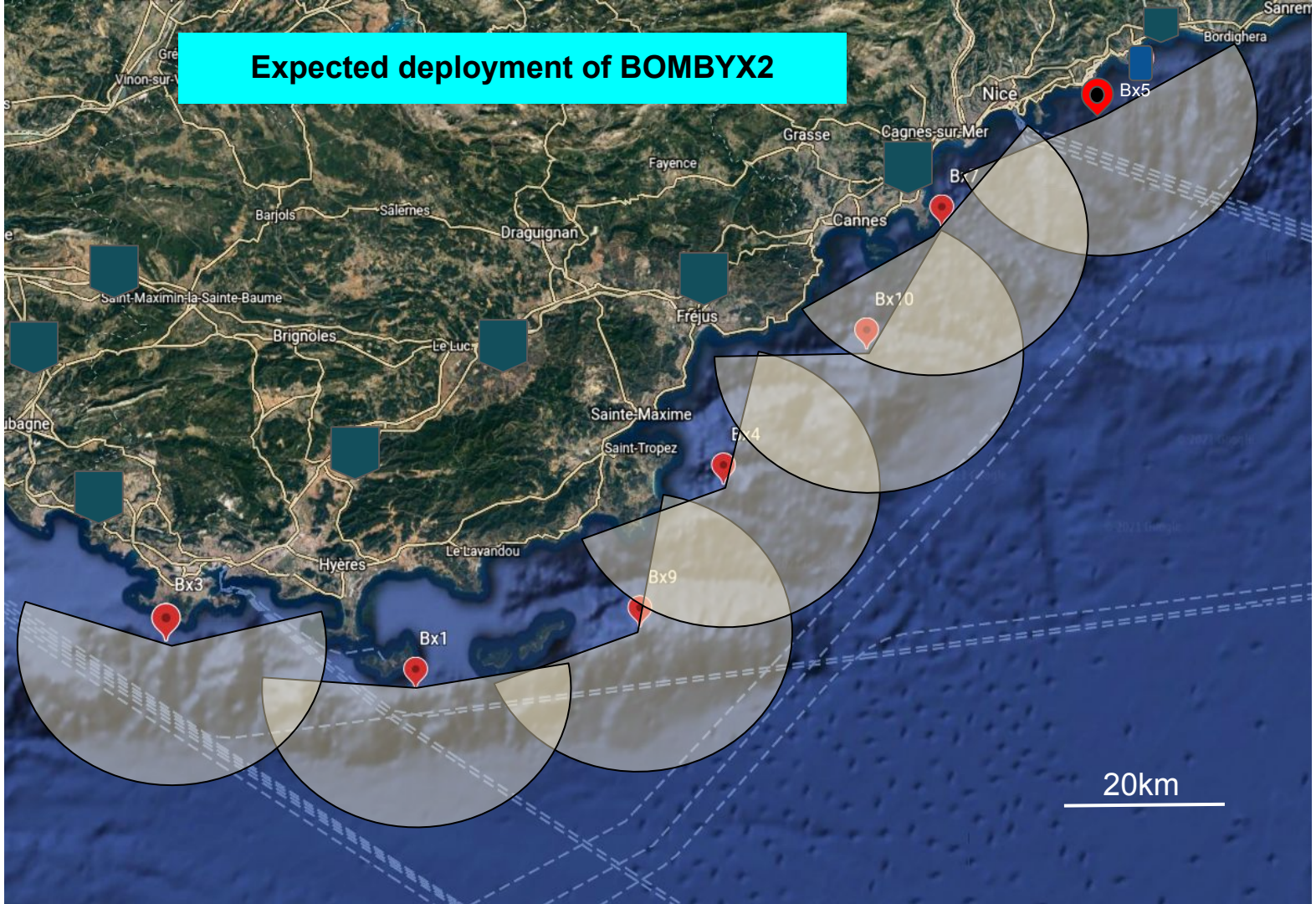
Figure : using the same antenna,
fixed on Sphyrna
result of a collaborative hunting of 6 Sperm Whales South of Monaco, 3 km away during 5 hours

[Glotin et al 2021, Sphyrna report, Monaco Explorations, FPA2, CNRS]

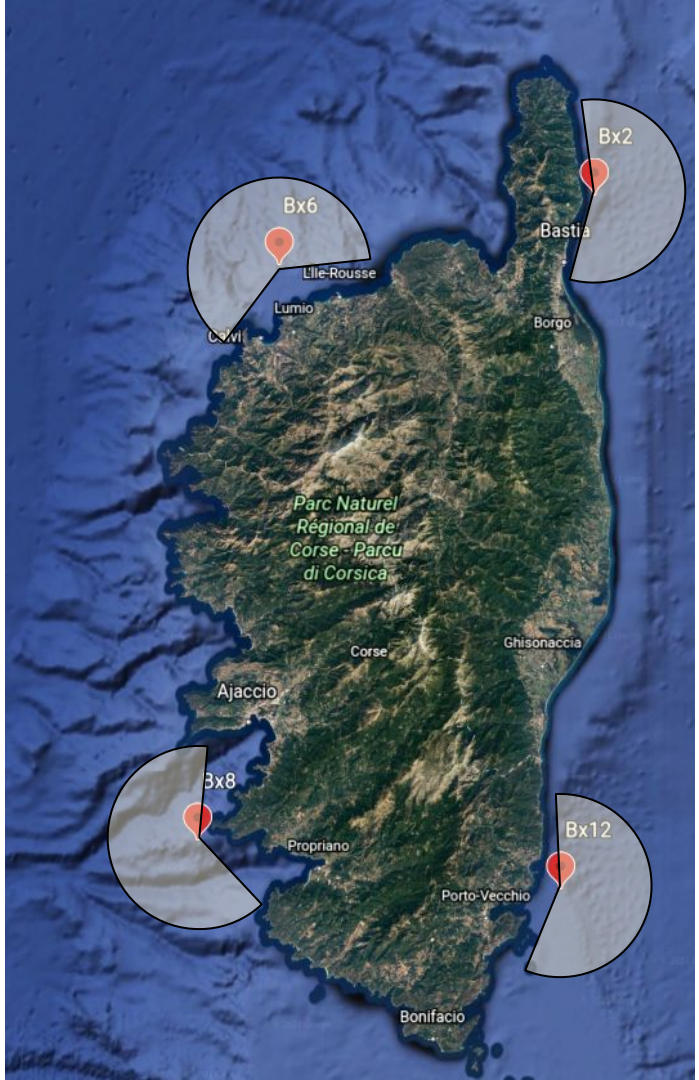


BOMBYX

FEDER
GIAS
+
Extension

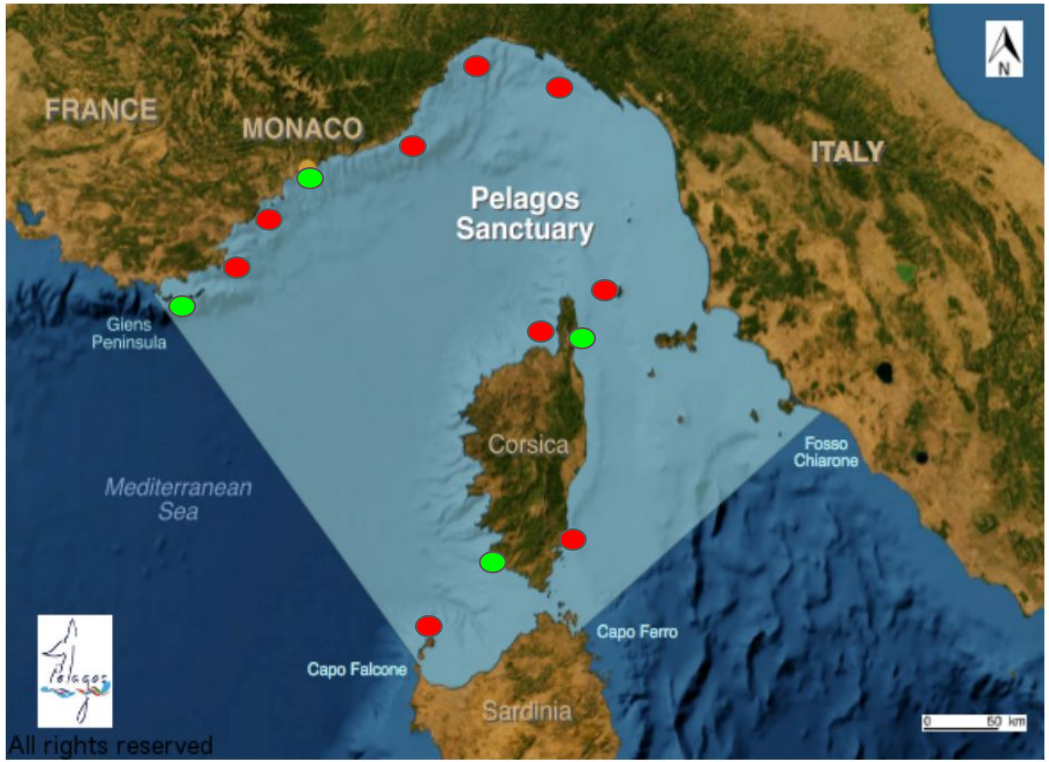


GIAS + extensions



Proposed Bombyx deployment in Pelagos in end 2024

- GIAS FEDER + UTLN in deployment 2021-2022
- Other deploy. 2023-2024 (4 IT + 3 FR)

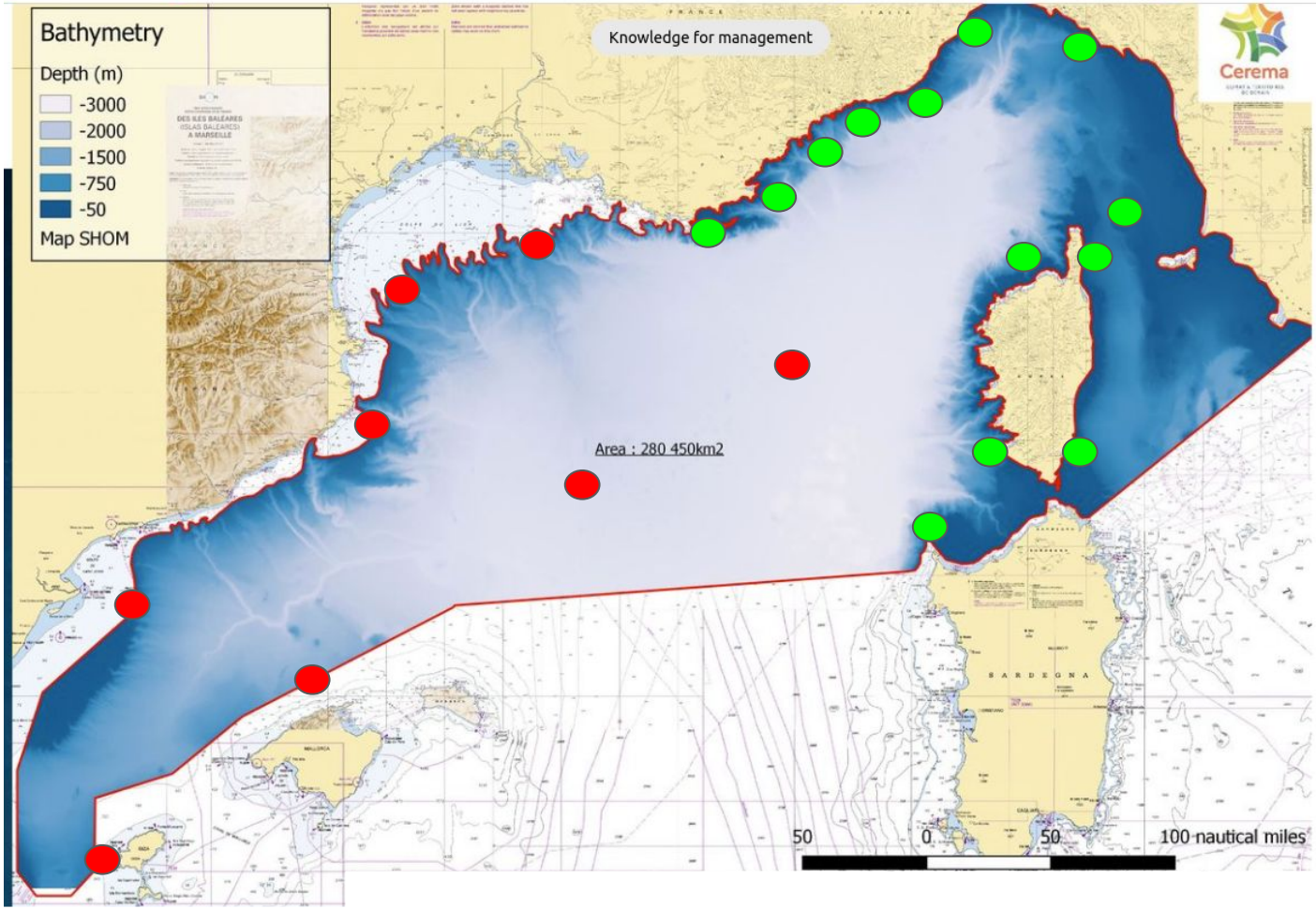


Perspectives : Bombyx deployment in Pelagos (2022-24) and PSSA ?

5 years RT listening in PSSA ZMPV

budget ~ 600 K€

Open to collaborations



Contact :

glotin@univ-tln.fr
PI Chair Artificial Intelligence for SubSea Listening

Estimation of the budget / projects

cost : 10 BOMBYX sonobuoys including 6 years of run is ~= 650 K€

2 are already paid via GIAS FEDER MARITIMO (UTLN, LAMLA IT) 2017-2022, coPi Glotin

2 are already paid via PACA APOG ETHAC 2022-2024

1 is requested in LIFE BIODIVERSA (in review) (UTLN and Norway)

2 requested by CPER UTLN, some others into PIA4 UTLN (in review)

We ask a budget to place 10 others in 2023-2025 = 650 K€ to complete

Partners

DYNI LIS CNRS

- Bombyx equipment
- IA algorithms for acoustic data recognition and 3D animal location estimates to feed an alerting system
- System management
- data analysis and interpretation

CIBRA Univ Pavia

- data analysis to join acoustic and visual data, scientific publications in cooperation with Tethys
- studies on whale spatial distribution and size across Italy / France boundaries
- data validation
- education and training
- data dissemination
- connection with the strandings data bank

Partners

Deployment, usage, maintenance of the LIFE BOMBYX observatory =

Coast Guard IT

- institutional support (permits, interface with local authorities, interface with ministry of environment, public communication)

- logistic support with boats and divers, access to forbidden areas

- interface with gov. institutions and NGOs for cetacean protection

- distribution of anti-collision alerts

- eventually - to be discussed - aerial support with drones

National Park of Cap Corse FR

- logistic support with boats and divers, access to restricted areas

- interface with gov. institutions and NGOs for cetacean protection

- distribution of anti-collision alerts around Corsica, center of PELAGOS

Tethys ONG IT

- local surveys in and outside the BOMBYX range for data validation and for integrating acoustic data with photo-id and eco/behavioural data

- logistic support with Tethys boat

- data processing and distribution

- public awareness and data dissemination

Centre d'Études et de Recherche sur les Contentieux - CERC Toulon

Legislation, laws on noise at sea