EUROPAM bioacoustics explorations in Arctic fjord - Mid term report

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Cover photo credit
Orca during our mission to Haudoya in 2022 (Left, credit Marion Poupard), and in competition with Humpback Whale in 2021 during OPALE protocol (Right, credit Stéphane Barnier).

Summary

1 Introduction

This report gives a summary of material, experiments and first models we built in the first years of EUROPAM project, with missions in 2023 and 2024 in the Arctic area of EUROPAM.

Many studies focus on the cold water ecosystems of the Greenland, Norwegian and Barents seas. They are of particular importance for the management of fishery resources, due to climate change likely to lead to the displacement of the habitat of certain species. These studies also show that for 10 years, the presence of humpback whales (*Megaptera novaeangliae*) and fin whales (*Balaenoptera physalus*) was marked by a northward shift in their feeding areas (Loviknes et al. 2021). This change is conditioned by the availability of prey, notably herring (*Clupea harengus*) (Jourdain et al. 2017). In the north of Norway, humpback whales have a feeding strategy, in competition with orcas (*Orcinus Orca*), usual predators of herring populations. Very recently, sperm whales (*Physeter macrocephalus*) were also observed and recorded. The presence of this species, usually found at depths of at least 1000m, is relatively surprising inside a fjord. This project is the first to study the presence and competition of these species by long-term passive acoustics, while noting the photographic identity of the animals, the hydrophysical quality of the environment and the quality of the prey by omics analyses.

Killer whales use an original hunting strategy, called carousel (Similä and Ugarte, 1993) based on the formation of herring balls and accompanied by sound signals (Simon et al. 2007; Van Opzeeland et al., 2005), a strategy that they are likely to modify today to avoid competition with humpback whales. Their vocalizations could change in number and quality, particularly when humpback whales are on the same herring ball. Several hypotheses are put forward, such as the adaptation of the vocal register of killer whales and their strategy of constructing smaller herring balls to dissuade humpback whales from taking advantage of them. It is this rapid inter-specific herring-orca-humpback whale evolution linked to marine pollution which constitutes the subject of our research.

This EUROPAM reports the real complementarity of the teams involved. Biologists therefore need the know-how of bioacousticians to identify hunting on herring schools and thus be able to make relevant measurements and sampling. Photo-Id, biological and chemical analyzes will then make it possible to give weight to the acoustic data recorded and thus facilitate the interpretation and understanding of the new behaviors of these super-predators. The description of hunting shared by killer, humpback and fin whales for herring has, in part, been described (Jourdain et al., 2017). To date, drones have been able to monitor these behaviors from the sky (Aniceto et al., 2018) and the thesis work of Theresia Ramm (2020) has made it possible to track humpback whales by photo ID. But, to our knowledge, there is no precise, long-term monitoring of the vocal activities of apex predators which makes it possible to describe their detailed interactions with their environment and therefore their adaptation.

The objective of EUROPAM here is to observe and provide hypotheses on the evolution of the adaptations of apex predators which have, for ten years, been competing in the Skjervoy area north of Tromsö. The target species are on the one hand herring, on the other hand humpback whale, fin whale, killer whale and sperm whale which feed on the same resource. In addition, anthropogenic pressure, both chemical and acoustic, is continually increasing, potentially impacting these populations, beyond the very strong fishing pressure. The expedition's assessment will focus on the state and evolution of the populations of these super-predators, as well as the description of their communication and hunting collaboration strategies, via localization algorithms developed by the AI ADSIL chair at the University of Toulon.

To do so, we will take stock of the acoustic, physico-chemical pollution and warming of the Troms Arctic Fjords, unique ecosystems. The omics protocol will make it possible to define the contamination rate and correlate it with the size of the herring population in the area. Thus our mission proposes to describe the interactions of 4 species of cetaceans by passive acoustics, while assessing the quality of the prey by chemical and omic analyzes (variation in the expression of mRNAs specific to key genes involved in reproduction and/or the well-being of the individual).
We will establish the feeding zones of the megafauna, in order to measure the communication and hunting coordination strategies of the super predators using bioacoustic indices. We will study the phonotactic evolution of the 4 species competing on these hunts and which must nevertheless coordinate at a distance, by acoustics, without informing the other species of the position of their herring balls. We will establish, in collaboration with Norwegian fisheries, the herring stocks associated with the hunts studied and their state of health (pollutant density).

This project was initiated in 2021 with tracking and acoustic measurements by portable antenna during near-field swimming with predators near Seglvik and Skjervoy, Norway, by H. Glotin and M. Poupard, with QHB advanced scientific instrumentation. Then this project was planned over 5 to 10 years, with a mission in 2022 and 2023, and the installation of an observatory of fixed stations in addition to nearby observations for the study of variations in the vocalizations of orcas and other cetaceans interacting in the area.

Figure 1.2: The expedition ship, “Isbjorn II”, during the mission (photo credit Gies)

This report thus jointly takes stock of the missions as well as an analysis of data from the 2021 and 2022 missions and from the fixed station over the winter of 2022-2023. For three weeks in total, we traveled the fjords, 100 km north of the Arctic Circle, on the ship Isbjorn II for 21 days. We characterized the water column over a height of 400 m, at a few points, revealing particular layers at -150m. We installed 2 long-term stereophonic listening systems, and short-term 3D listening systems to characterize the 3D acoustic activity of megafauna: humpback whales, orcas and rorquals, as well as their interactions. We continued this near-field study with our Opal antennas for identification of vocalizations during the 2 weeks in November 2022 (see examples on http://sabiod.org/orcas/).

2. The interdisciplinary expedition team

Title/NAME/First name of the project leader		Glotin Hervé, Pr
Section of the national scientific research committee		07
Attached establishment (CNRS, University of Nantes, CEA, etc.)		University of Toulon
Unit Code (UMR, UPR, etc.)		UMR 7020
Name of laboratory and/or team		PUMPKIN, FOX LAB Toulon
For units attached to the CNRS	Institut principal	IN2SI
	Regional delegation	DR12

Identification of the teams who worked on the project in 2024

Etablis.	CNRS Unit Code	Lab/team name	For units attached to the CNRS		Title/NAME/First name of the people involved
			Institut principal	Long time ago.	
Toulon University	UMR 7020	LIS	IN2SI, AI ADSIL underwater bioac Chair AID and DGA	DR12	Dr Pr Hervé Glotin (scientific director), Phd Student J. Girardet, G Patenotre Dr Biology Giraudet Pascale, Sebastien Paris
Longitude 181	NGO	Longitude 181	oceanology	-	Dr Véronique Sarano (observation & ethology protocol)
Toulon University	EA	MAPIEM			Pauline Vannier and Claudine Baraquet
Toulon University	UMR7334	IM2NP	IN2SI, SMIoT techno platform	DR12	Dr Gies Valentin (electronic protocols), Barchasz and Marzetti
Ocean Polar					
DGA reservists					
Valhalla	Norwegian SME	Valhallab	-	Norway	Julie and Rodolphe

Figure 2.1: the SAM 2024 scientific team

3. Physico-chemical characterization of the environment

3.1 By CTD measurement

Materials and methods

In-situ measurements of temperature, salinity and water column density were carried out to characterize the water masses. A CTD (Conductivity-Temperature-Depth) probe was used to determine the variations of these parameters as a function of depth (Fig. 3.1). The total number of distinct stations covering the entire fjord is 13 between 1^{is} and November 13, 2023 (Fig 3.2). Among the 13 stations, 10 stations aimed to create a grid of the entire fjord (station 1bis to 10) and 3 opportunity stations were sampled just after an orca hunt (stations FEED 1 and FEED 3 on herring, FEED 2 opportunistic hunting on a fishing boat). In addition, it was possible to revisit 2 stations (station 7bis and 10 bis) several days apart before and after a strong southerly gale which occurred on November 4-5, 2023 in order to estimate the potential effect of this gale on the mixing of the water column..

Figure 3.1 : CTD SAIV Akvaplan level https://saiv.no/sd204-ctd-profiler

The positions of the sampling stations were chosen in order to understand the potential variations in water masses from the northern entrance to the study area (Arctic Ocean – Barents Sea) through which orcas and whales enter the Fjord system, and the flow towards the South at the level of the fjords. In particular, 3 sampling stations were positioned in the North in a “channel” oriented towards the South (station 1bis, 2 and 9), 3 stations were positioned near the mooring of the buoy placed north of the island Haudoya, at the junction between the western and eastern parts of the fjord of Skjervøy (stations 3, 4 and 5), two stations to the south-west and east of the Fjord (stations 6 and 7), one station on the western edge (station 8) and one station on the outlet of the waters of the Fjord to the north-east (station 10) (Fig. 3.2).

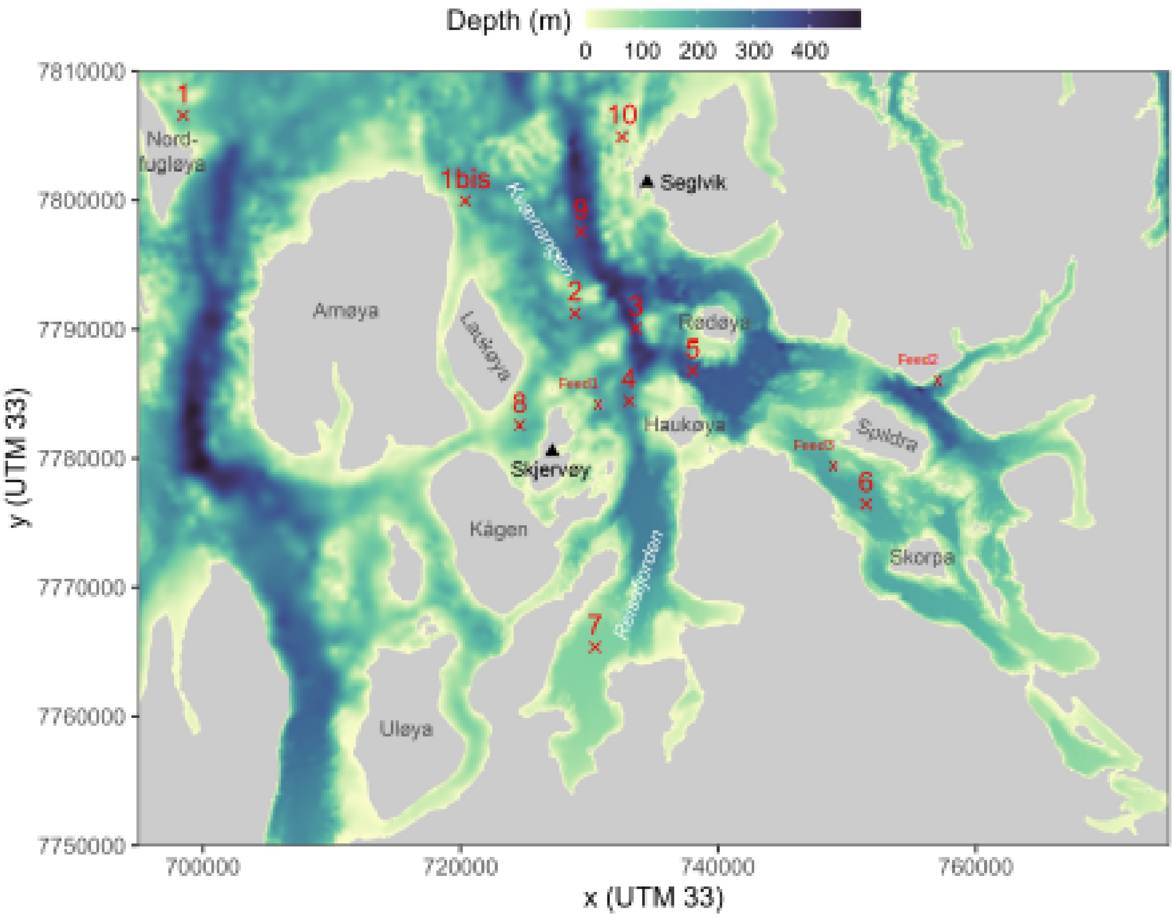


Figure 3.2 : Bathymetric map of the sampling stations of CTD measurements carried out in the period of 1^{is} as of November 13, 2023 (red cross).

The CTD measurements will also make it possible to complement the average surface current data modeled by Akvaplan-niva (Fig. 3.3).

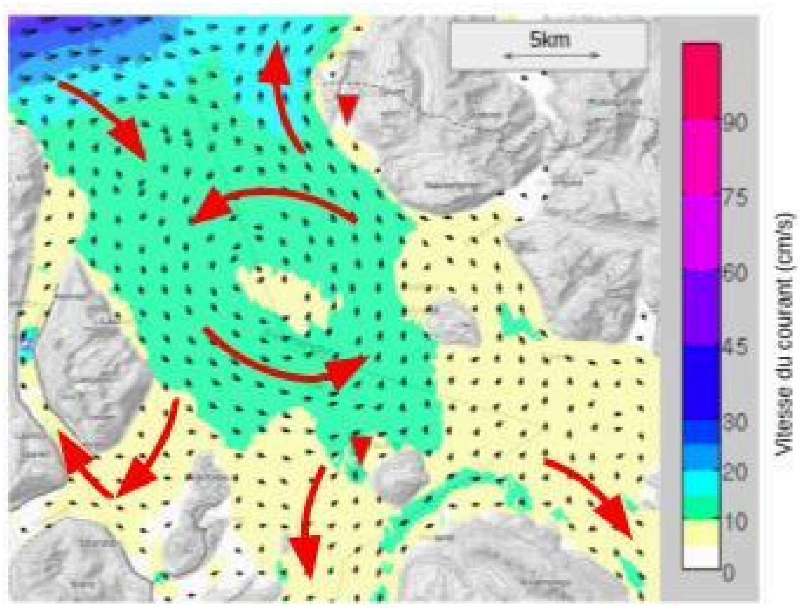
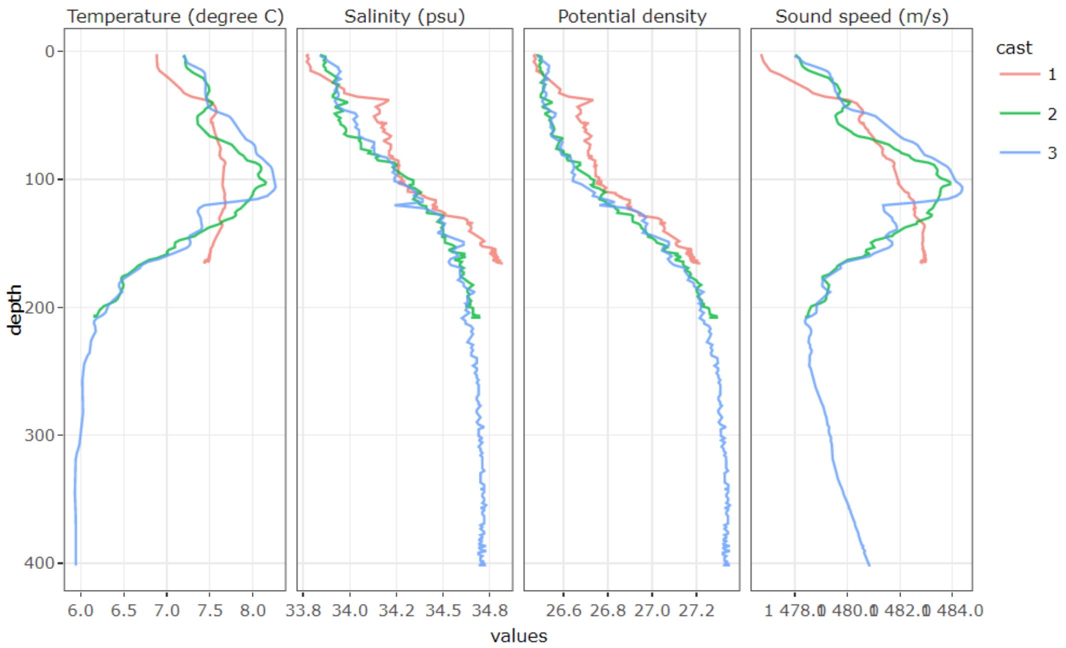
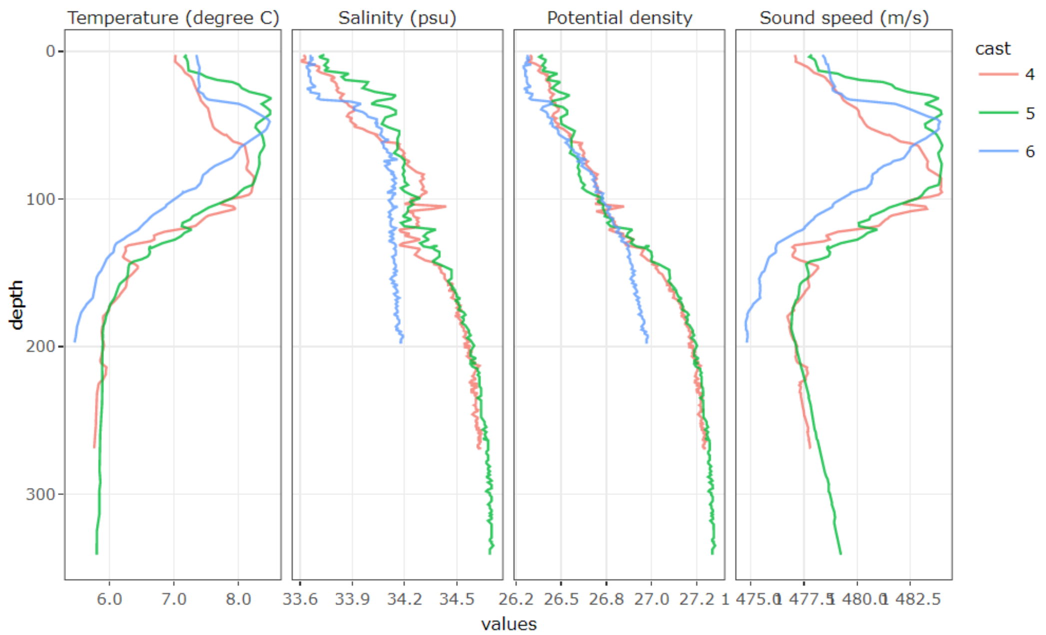


Figure 3.3 : Zoom on the nature of the average currents off Seglvik (red triangle to the North) and location of the 2 long-term acoustic stations installed by our mission, for 3 months of recording with our systems (▲). The distance between the two antennas is approximately 18 km.

CTD 2023 results:

The results of the vertical profiles produced have the following orders of magnitude for the hydro-physical parameters: a surface salinity around 33.5 PSU, a surface temperature which varied from 6.5°C to 7.5°C over the entire period of the experiment and a surface density around 26.2 with a mass of bottom water of density 27 (which is consistent with the density of bottom water at the polar regions). A warmer water mass (+ 0.5° relative to the surface) was observed around 80 m -110 m, with a thickness of approximately 30 m for a majority of stations (e.g., stations 2, 3, 8 9) (Fig. 3.4). The warmer water mass could correspond to the water mass of the North Atlantic drift (Northeast extension of the Gulf Stream in the Norwegian Sea) and rising towards the poles. Its initial thickness and depth varied in space and time. For example, the depth from which temperature increases decreased from 80 m to 30 m between stations 7 and 9.





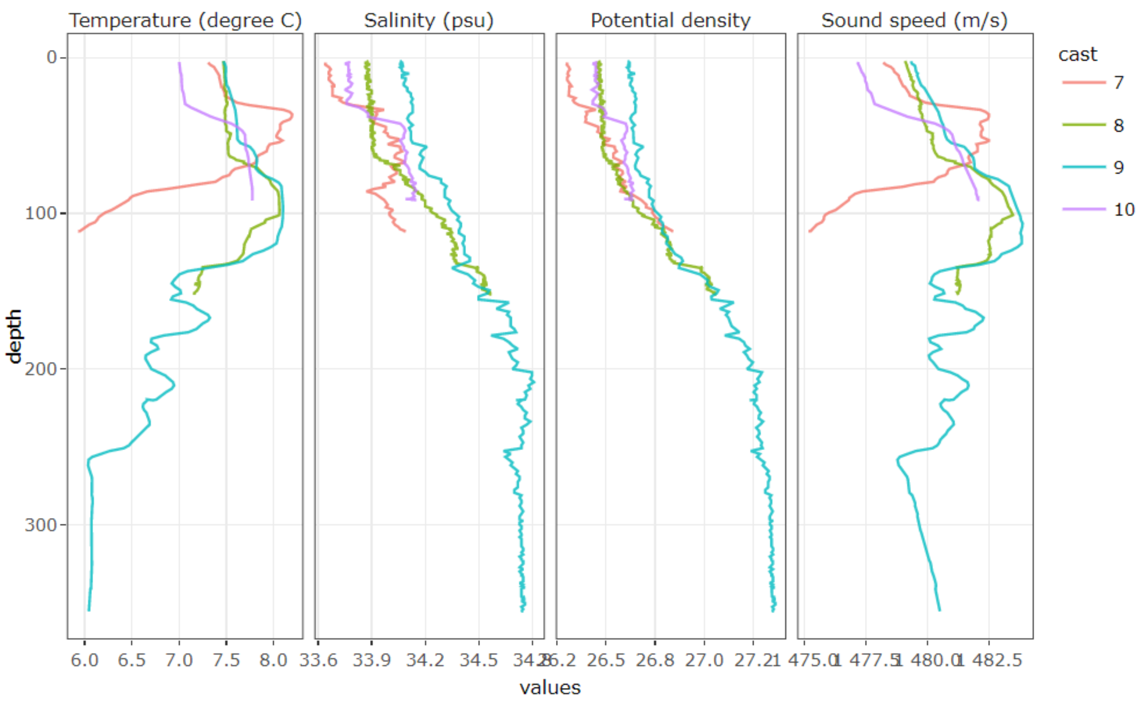


Fig 3.4 : Vertical profiles for measuring temperature, salinity and density (CTD probe) carried out in November 2023 for all stations.

The temperature profiles as a function of salinity revealed two or three water masses depending on the stations (two for station CTD10, three for all the other stations) (Fig. 3.5). These correspond to surface water, intermediate water (warmer than the surface) and bottom water. For the stations presenting these three water masses, a lack of mixing between the intermediate water and the other water masses is notable. This intermediate water probably comes from the North Atlantic drift current and is interesting to emphasize that it is present throughout the fjord. Station 4, which corresponds to the location of the Bombyx antenna, has a stronger temperature gradient than the other stations between the intermediate water and the bottom water.

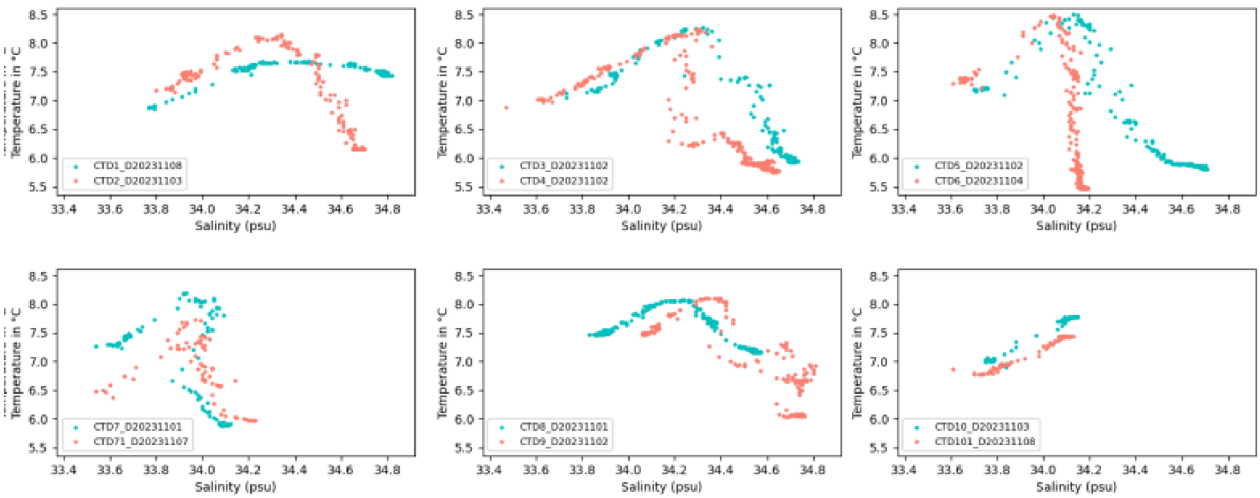


Fig 3.5 : Temperature diagrams versus salinity for all stations sampled in November 2023.

A strong gale (80 km/h) of southerly wind occurred on November 4 and 5, 2023 and a second gale (50 km/h) of northerly wind occurred on November 10, 2023. The gale of November 4-5, 2023 involved a significant cooling of the entire water column with a decrease in surface water temperature of around 1°C for station 7 (Fig. 3.5) and a decrease in the temperature of the "hot" water mass of approximately 0.5°C (stations 7 and 7bis, stations 10 and 10bis, Fig. 3.6). However, the gale was not long and constant enough over time to induce homogenization of the entire water column in most stations (as represented by station 7 and 10 Fig. 3.6 where measurements were taken before and after the gale). The "warm" water mass remains observable everywhere.

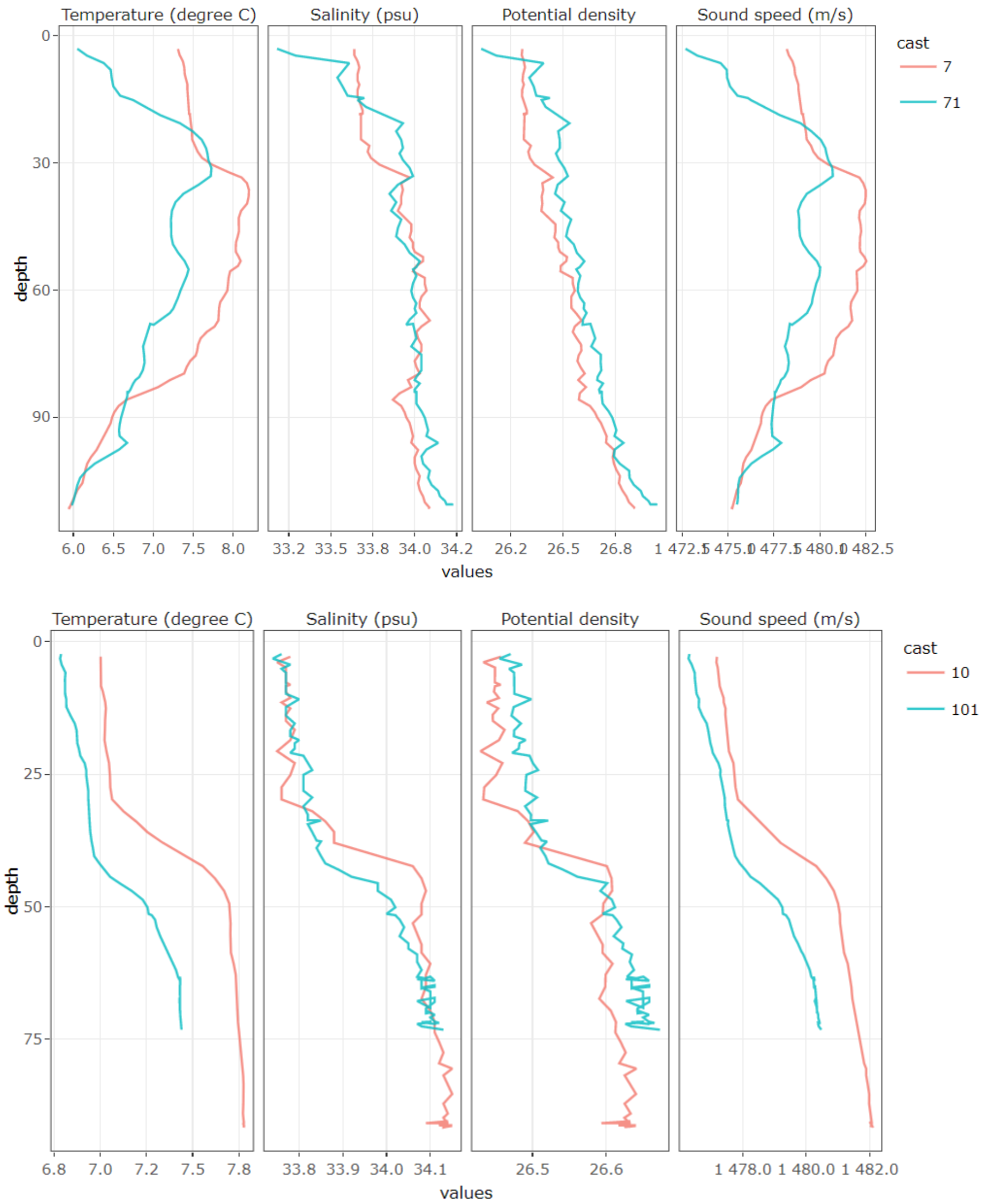


Fig. 3.6 : Comparison of CTD measurements before and after the gale of November 4-5, 2023: station 7 (before the gale) and 7bis noted "71" on the graph (after the gale), station 10 (before) and 10bis (noted 101 on the graph) (after the gale).

The configuration of the stations where orca hunts took place (FEED 1, 2 and 3) is similar to the other stations with three water masses and an absence of intermediate water mixing (Fig. 3.7). The comparison of these three stations shows a similarity in the temperature, salinity and density profiles between FEED2 and FEED3 as well as a similarity in the Temperature-Salinity diagrams. The two profiles show a cold surface temperature of up to 6°C, as well as a warm water mass and a halocline which begins around 35 m. On the other hand, the FEED3 station presents a different profile: the depth of the warm water mass is 70 m, the surface temperature is 7°C and the salinity is higher (+0.2). It is therefore difficult to conclude on any influence of the physical properties of the water mass with orca hunts at this stage of the study. However, it seems that surface water temperatures < 7°C, salinity < 34, as well as an intermediate warm water mass could be favorable to the location of herring and the resulting orca hunting zones. This hypothesis could be consolidated from other ancillary measurements such as systematic measurements made by an echo sounder during a hunt which would provide the depth of the herring balls. It would also be necessary to have additional measurements carried out systematically after each hunt and in sufficient number (> 10).

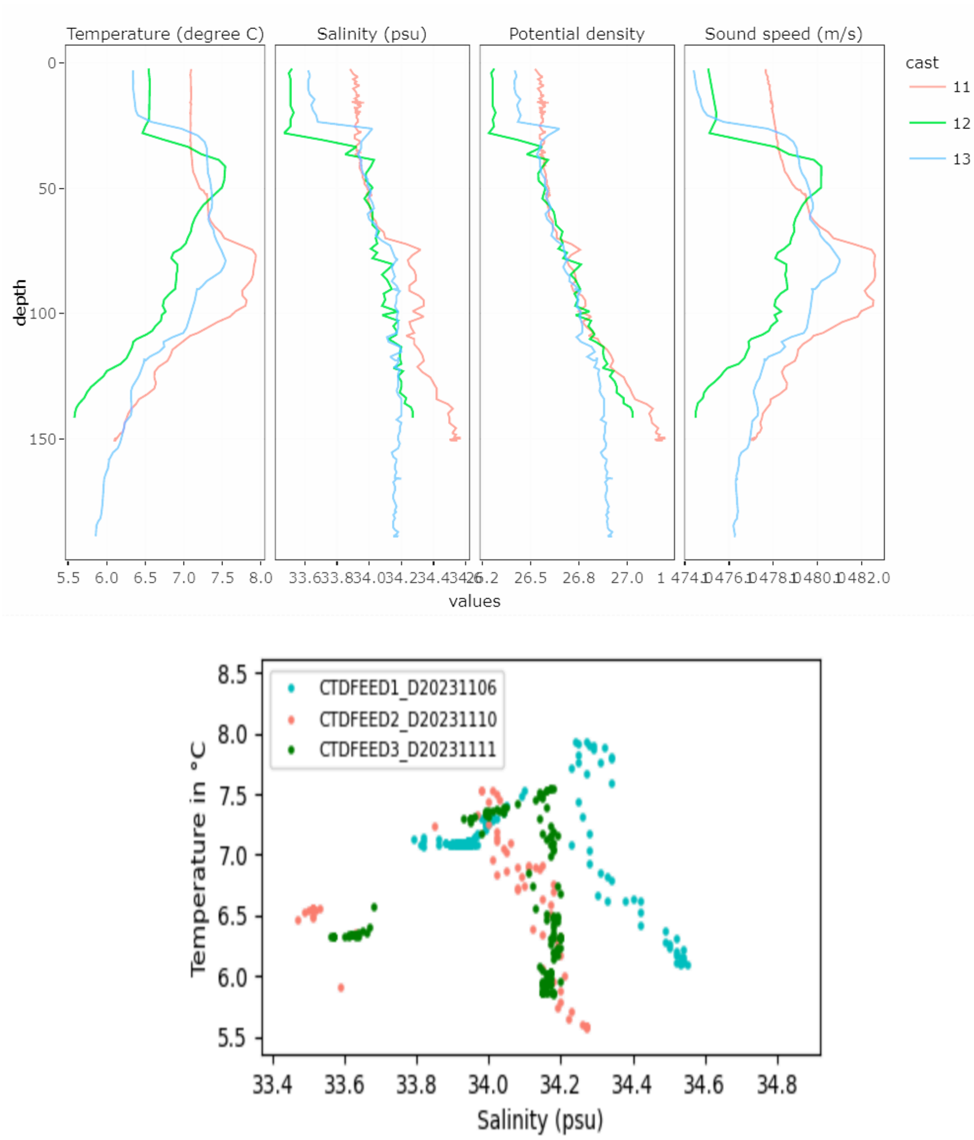


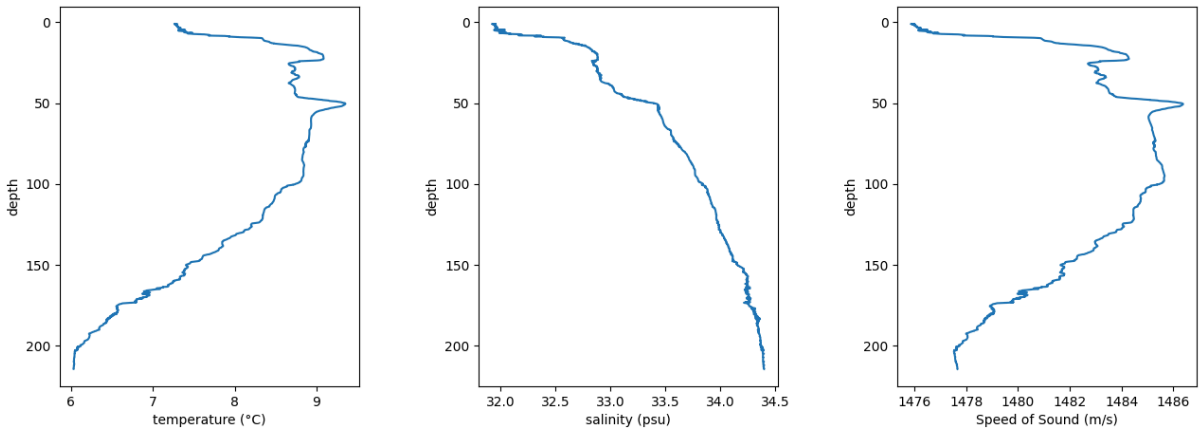
Figure 3.7 : (a) Comparison of profiles of stations “FEED” where have an orca/herring hunt took place (up), (b) inTemperature-Salinity agram (bottom). es The FEED1 station East rated 11 in Figure 7a, la station FEED 2 is noted 12 et FEED 3 East rated 13.

CTD results 2024

The graphs below were generated from the data acquired by the CTD probe during its descent and are currently analysed to determine possible climate changes in this arctic area.

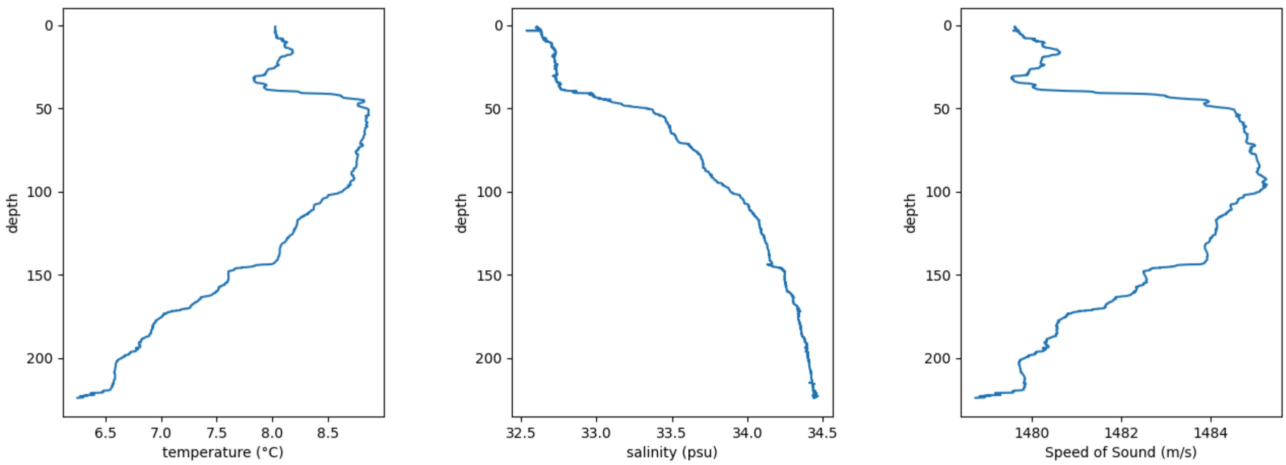
CTD 1 (19/11/2024)

6:16 p.m. 69°59.95 21°08.24 CTD carried out. 320 m extended end, 60/70° inclination. Max depth 214 m.
6:32 p.m. End CTD at 70°00.33 21°07.87



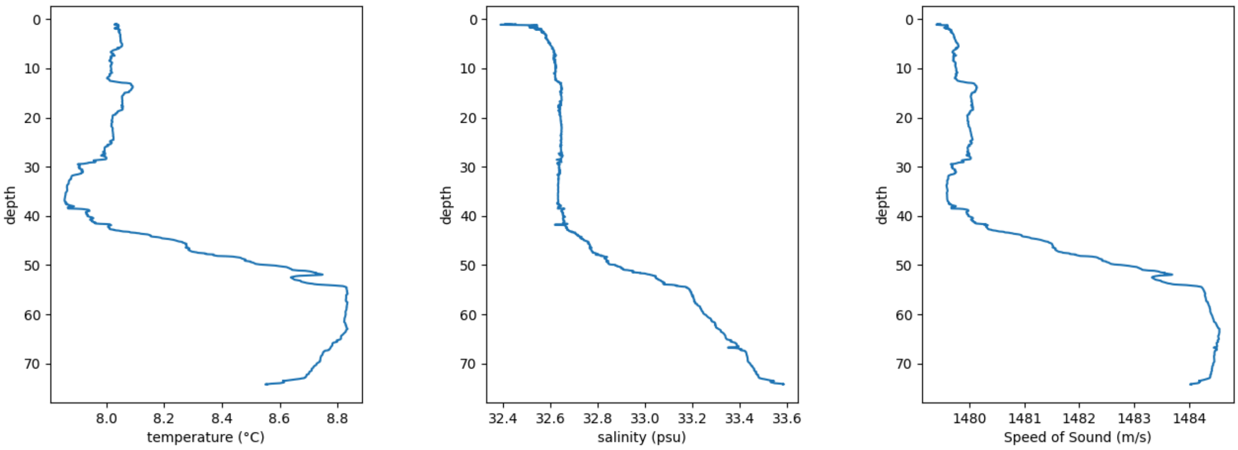
CTD 2 (20/11/2024)

11:21 a.m. CTD in the water (70°03.799 21°06.423)
11:26 a.m. CTD at the bottom (soft line), 230m (70°03.861 21°06.385), max depth 223m
11:31 a.m. CTD ascent (70°03.713 21°06.391)

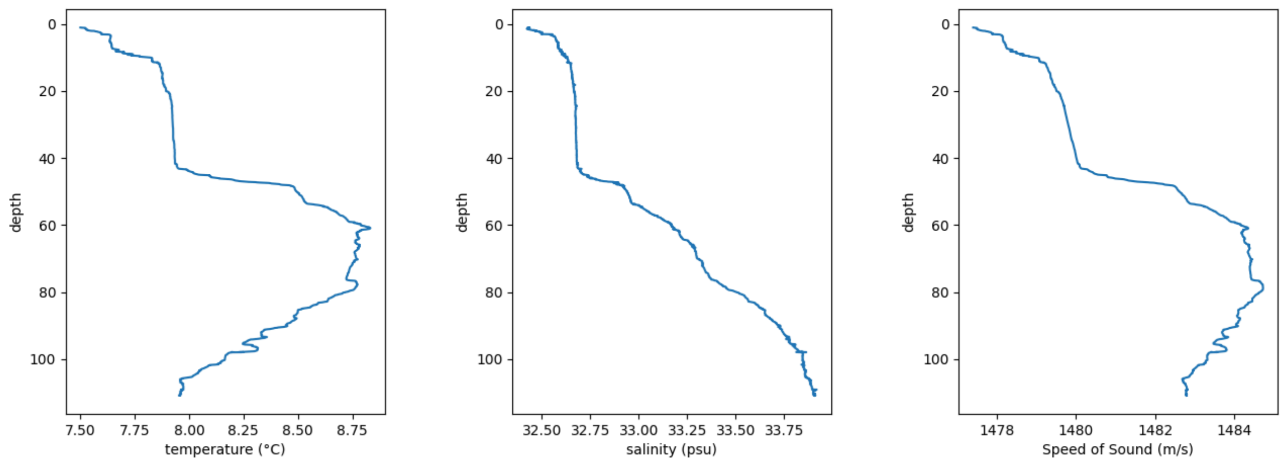


CTD 3 (23/11/2024)

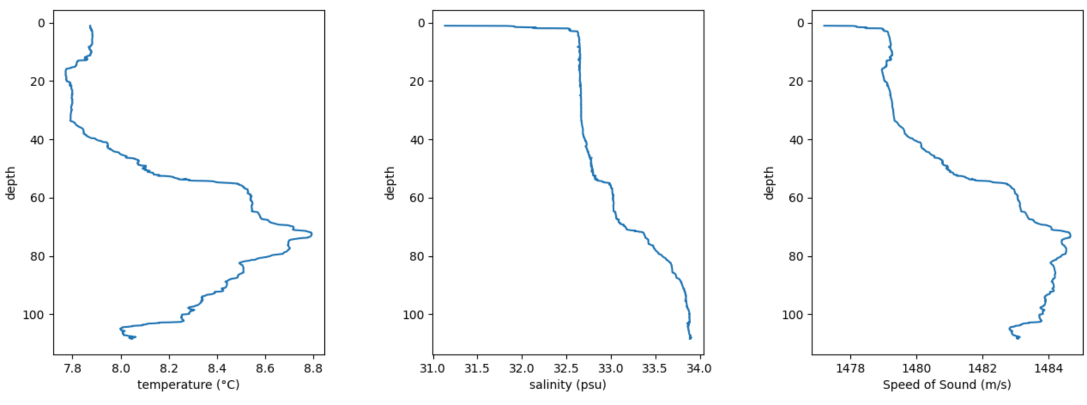
CTD carried out on 11/23/24 at 2:37 p.m.
Position : 69°59,24 22°01,09



CTD 4 (24/11/2024)
CTD carried out on 11/24/24 at 10:39 a.m.
Position : 70°03 21°95
Tilt of approximately 60°



CTD 6 (24/11/2024)
CTD carried out on 11/24/24 at 3:07 p.m.
Position: 69°58.17 21°35.08 (point 6 of 2023)
Tilt of approximately 70/80°



3.2 Satellite measurements

Materials and methods

To complement the CTD measurements, satellite data on surface temperature and chlorophyll levels in the fjord were sought in order to monitor the evolution of the environment. The data produced by the European Space Agency's Sentinel 3 satellite series were acquired from the Copernicus site. Satellite images were searched for several dates of the EUROPAM 2023 mission, those best covering the study area were selected (namely November 2, 8 and 11). For chlorophyll, level 1 and level 2 WRR (water full resolution) images were searched. For temperature, level 2 WST images were downloaded for the study area. The WST product corresponds to the atmospheric homogenization of surface temperatures to obtain the best product for local conditions. The resolution is one measurement per kilometer. Each image was then edited using SNAP and QGIS software.

Results

During the mission period, no chlorophyll product was not available. For temperature, the images acquired showed a large variation in surface temperature around and inside the Seglvik Fjord in just one week. At the beginning of November, relatively warm currents (around 10°C) were present in the fjord then followed by slight warming with surface water masses reaching 13°C. A general cooling of the water surface could then be observed with temperatures around 5°C inside the fjord.

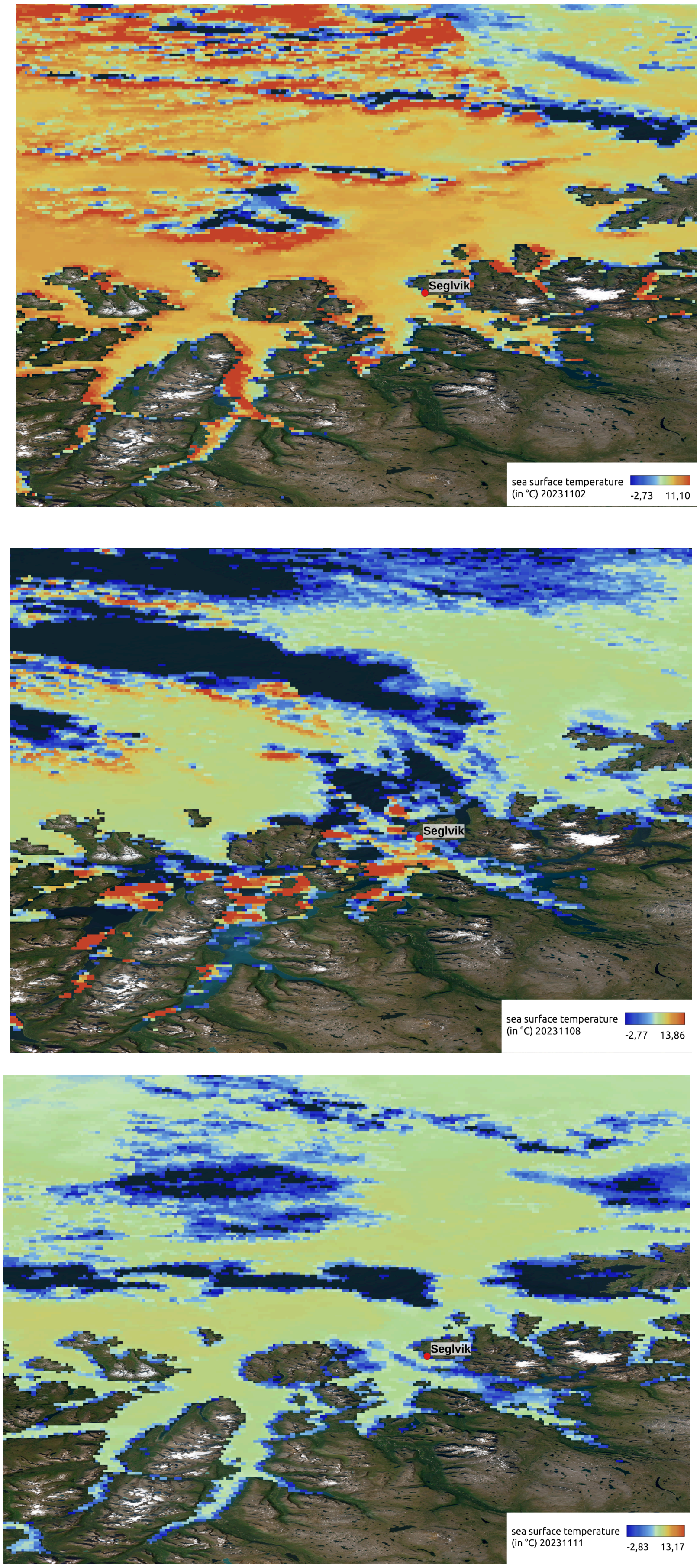


Fig 3.7 : satellite images of surface temperature in northern Norway and particularly in the fjord from Seglvik (indicated by the red dot) on 3 days of the November 2023 mission: November 2, 8 and 11

4. Acoustic protocol

4.1 QHB ultra-speed recorder

The main acoustic recorder found in several of the experiments carried out on Isbjorn is the Qualilife HighBlue (QHB) recorder Fig. 4.1.

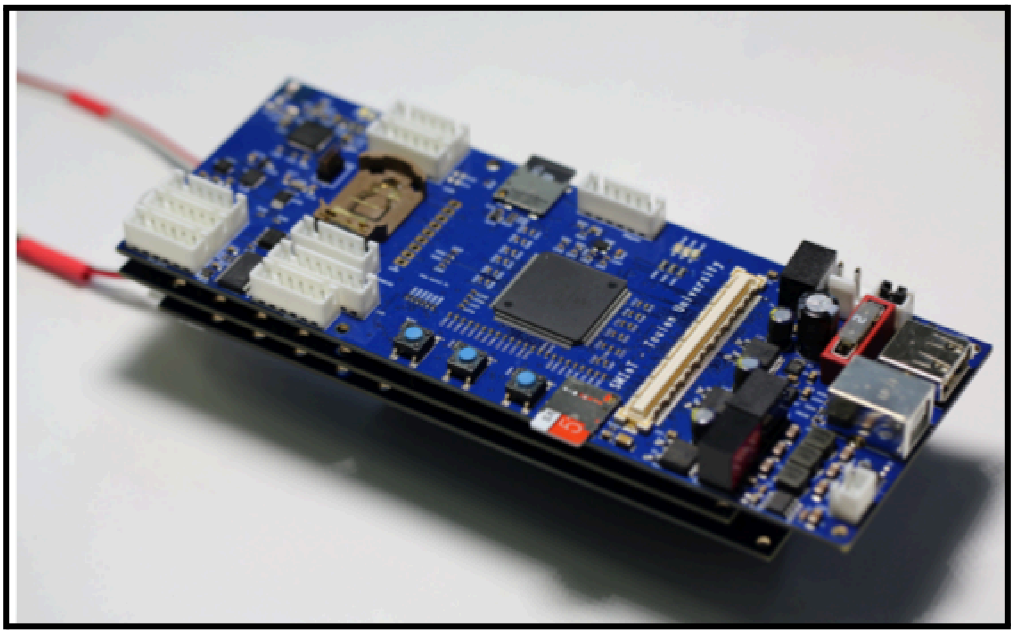


Figure 4.1 : Qualilife HighBlue (QHB) SMIoT UTLN logger (photo credit Gies)

Its original functional diagram (Fig 4.2) offers the following characteristics (Barchasz et al. 2020):

- Acquisition sampling rate up to 512 Ksps (Kilo samples per second) corresponding to a frequency range up to 256 kHz.
- Recording can be scheduled according to user needs.
- Up to 6 synchronous recording channels, with microsecond-accurate timing and timestamping.
- The signal sampling depth can be adjusted between 8, 16 or 24 bits. In this last mode, the noise specific to the recorder is limited to the 2 least significant bits, which means that 22 bits are actually significant for recording. This increases signal quality and potential detection distance compared to standard recorders, especially in quiet environments.
- Differential acquisition front-end with a maximum input level of ±2.5V to significantly reduce recording noise. Each recording channel has an adjustable differential gain: X1, X10, X20, X100.
- Anti-aliasing filtering automatically adjusted according to the acquisition sampling frequency. Signals with frequencies exceeding 0.55 x sample rate are attenuated by more than 120 dB.
- Sensor aggregation capability: The QHB includes a 9-axis IMU sensor (accelerometer, magnetometer and gyroscope) and several additional sensors can be added according to user needs, using the following protocols UART, SPI and I2C expansion bus.

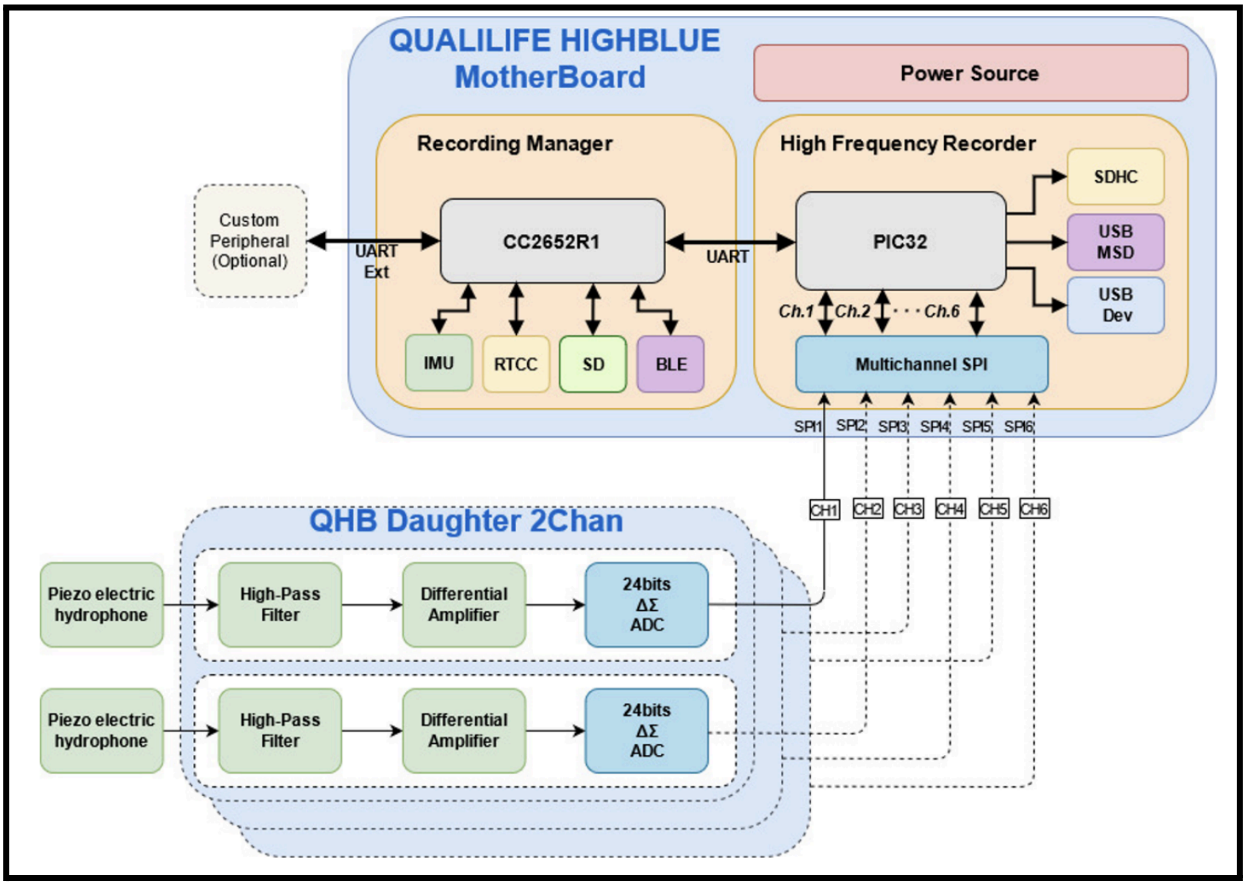


Figure 4.2 : QHB diagram

The QHB recorder was installed in a waterproof case to withstand pressure up to 100 m depth, the adaptation of different types of hydrophone such as the C75 from Cetacean Research, calibrated with a flat response ± 3 dB up to 250 kHz (calibration carried out at the Laboratory of Mechanics and Acoustics, Marseille), and a set of 21 D alkaline batteries (Barchasz et al 2021).

4.2 Isbjorn Transect

Two missions were carried out, totaling 21 days of experimentation aboard the Isbjorn (7 in 2022 and 14 in 2023). These are **616 km et 855 km** Who were traveled in search of orcas and humpback whales hunting on herrings. Our strategy was opportunistic, with the help of Whale watchers in the area, we had information concerning the position of the animals. Once confirmed, we went to the area concerned, and we implemented the 3 acoustic protocols and the visual protocol (photo and video) while remaining at a reasonable distance from the animals.

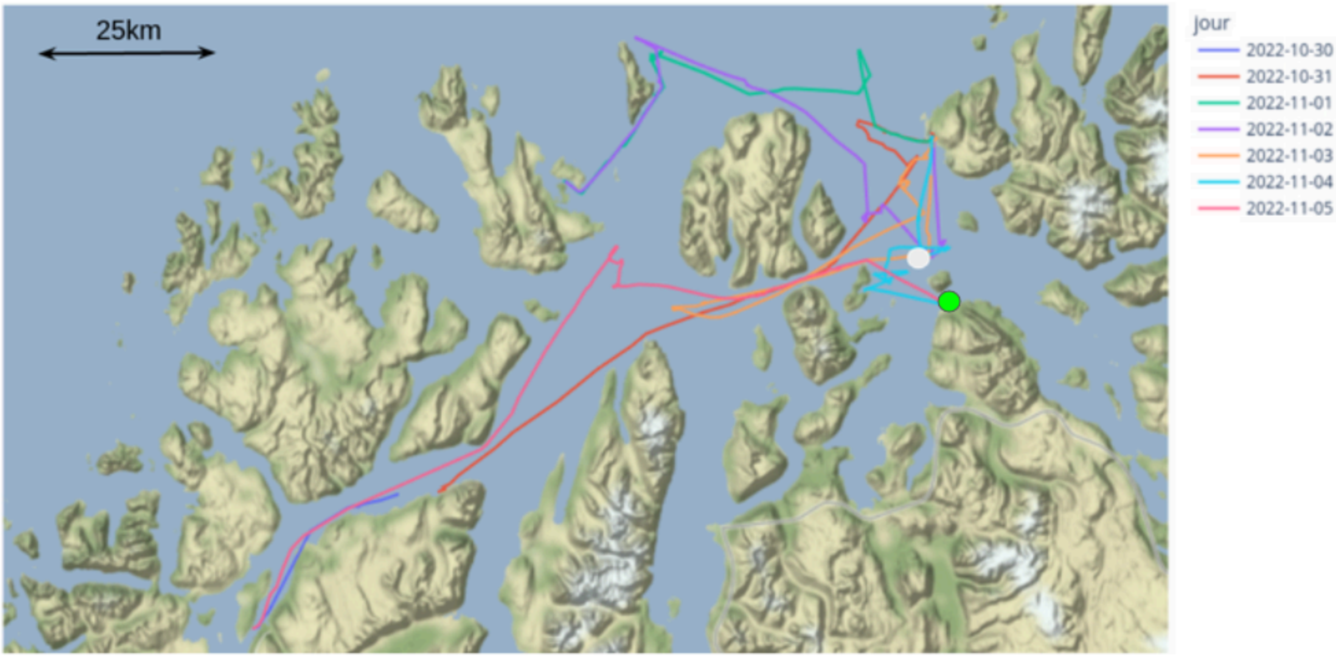


Figure 4.3 : General view of the transect carried out by our expedition in November 2022, over one week. The white circle corresponds to the water sampling and dB measurement from the evening of November 3. The dB measurement of the 4th and 5th in the evening was made at the green point.

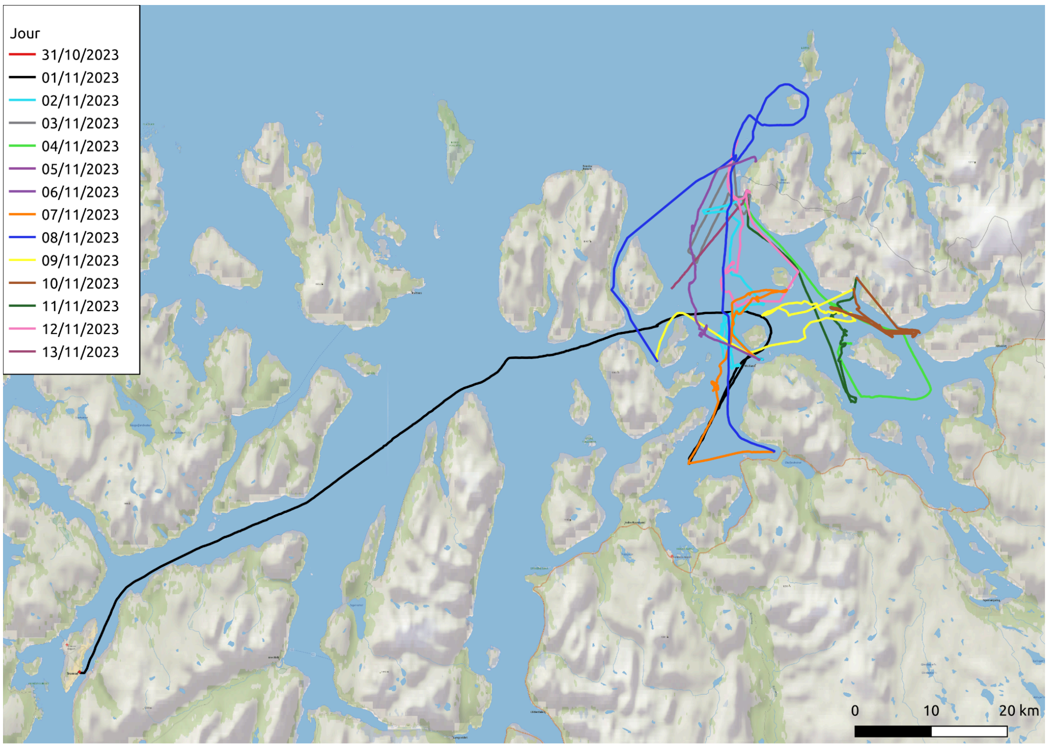


Figure 4.4 : General view of the transect carried out during the expedition in November 2023, over 14 days, total of 855 km.

4.3 Acoustic protocols deployed from Isbjorn

We have 3 acoustic antennas deployed from the expedition ship. The first is a tetrahedral antenna using QHB recorders and composed of 4 SQ26 hydrophones from Cetacean Research placed at the 4 corners of a regular tetrahedron, side length 70 cm (Fig. 4.4), with a tube containing batteries, and a High Blue card (Fe: 256 kHz). The next two are monophone antennas respectively composed of a C75, 20m of cable, and connected to a High Blue card (Fe: 512 kHz) and an SQ26, 10m of cable, connected to a recorder (Tascam) (Fe: 96 kHz).

Figure 4.4 : (Left) Launching from Isbjorn II (photo credit Gies) of the tetrahedral antenna, equipped with its sound card and four hydrophones, designed by SMIoT LIS IM2NP UTLN (Right).

4.4 Near field protocol (2021 / 2022)

The objective of this protocol was to film and record the animals during hunting periods. Two acquisition campaigns of two weeks each were carried out, one in November 2021 and the other in November 2022 following the week on Isbjorn. Two acoustic antennas were built by DYNI LIS UTLN for this protocol, each consisting of 4 hydrophones (2021) and 5 hydrophones in 2022 (Fig. 4.5). In 2022, launches were carried out for 9 days for the first antenna (Fig.4.6), and 7 days for the second antenna.
During these scenes, a cacophony of acoustic emissions is present: hisses, clicks, boat noises and it is impossible to identify the source of the sound emitted. Thanks to our two acoustic antennas made up of several hydrophones, we can separate clicks from background noise, follow an acoustic track over time and arrival times, or even attribute a vocalization or click to a specific individual.
We will then be able to study the true multi-individual, multi-specific acoustic structure which constructs this real cocktail party that is these hunting scenes. Know if there is a leader who leads the group, or if all animals participate in the hunt equally.
What are the changes from one year to the next, or within the season, in the behavior of orcas towards whales? Can we look for individual signatures in orcas or humpback whales, like those known from *Tursiops t*. (Janik et al 2006)?

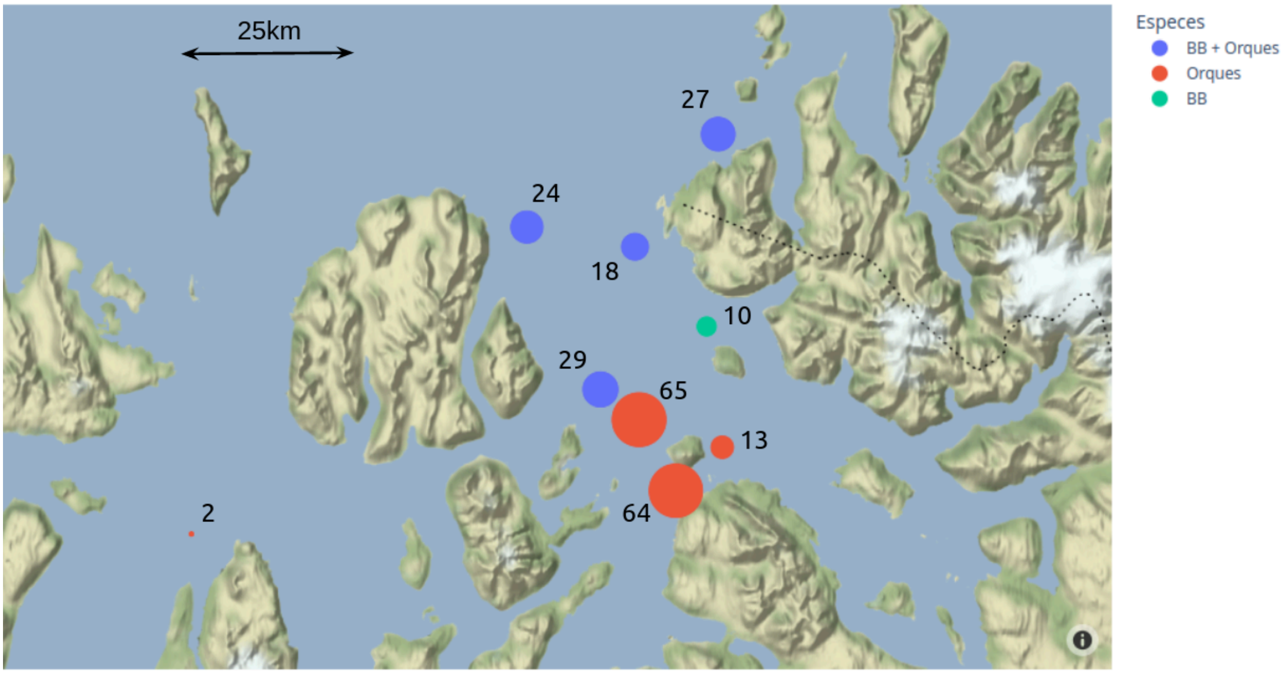


Figure 4.6 : Position of the launches for antenna 1 in 2022. The width of the points and the associated number represent the duration of the session in minutes. The colors represent the species present.

Examples of these video shots with our antennas or by simple Go-pro which are effective are available at http://sabiod.org/orcas, like the example Fig 4.7 showing an orca building a herring ball.

Figure 4.7 : An orca building a herring ball, shot by GoPro by OPALE

4.5 Installation of a fixed listening station over 2 years (Nov. 2022-2024)

In collaboration with our partner Valhalla, we were able to install a stereophonic wire station (SQ26) in Seglvik from the edge with 100m of cable. This buoy rests on the bottom at -7m depth at a distance of approximately 70m from the shore recording at 192kHz x 2 x 16 bits. It is powered by mains from the station *Valhallab*, allowing continuous recording backed up via hard drives connected to a PC. In 2022, the acquisition began on November 2 and was completed in February 2023 (storm and destruction). In 2023 it began in mid-November and was stopped without problems, still in operation, in February 2024. This antenna allows us to evaluate the density of animals entering or leaving (thanks to stereophony we have the measurement of the direction of movement) of this fjord during the year, as well as the anthropophonic levels.

4.6 Installation of a stereophonic buoy over 2x2 months (Nov. 2022 and Nov 2023)

We were able to lay a stereo buoy with the expedition ship to the north of the island of Haukøya. The first was destroyed when recovered by our partners (caught in their propellant), the second was recovered by our partners Akvaplan-Niva en février 2024. It characterizes the entrances and exits of animals at the end of the Fjord, highlighting the four superpredators: whale, sperm whale, ball. humpback and orcas vocalizing simultaneously which is a first

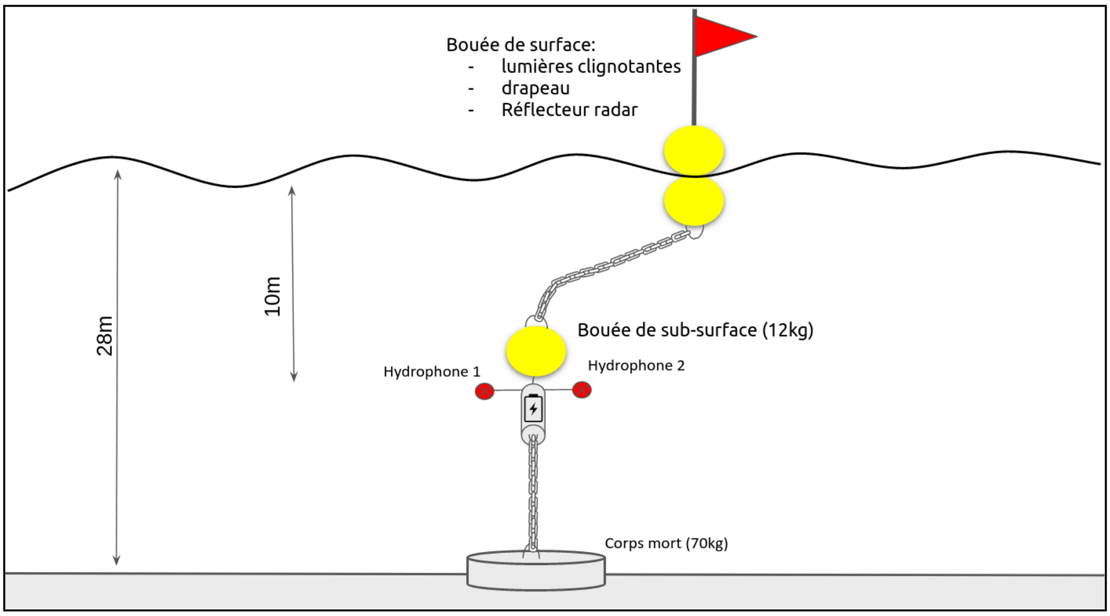


***Figure 4.8** : Diagram representing the stereophonic buoy placed north of Haukoya. The mooring was designed by Dyni and Akvaplan-niva, the buoy instrumented by Dyni.*

5. Acoustic results

5.1 Volume of recorded acoustic data

We deployed our acoustic antennas after or without visual observations. In the case of hunts, they were deployed as close as possible to orca hunts, to measure vocalizations and clicks emitted during the hunt, with and without humpback whales. We have about 12 hours of hunting of this nature. The tables below combine times and volumes.

Table 5.1: Summary table of acquisition efforts over the 7 days of expedition in 2022 and the following days by fixed stations or portable OPALE swimming antennas

Day	Distance traveled (km)	Temps record tetra (h:min:sec) (Goct)	Record time sq26 alone (h:min:sec) (Go)	Record time c75 alone (h:min:sec) (Go)
data type		**256 kHz Fe 16 bits 4 channels**	**96 kHz Fe 16 bits 1 channel**	**512 kHz Fe 16 bits, 1 channel**
30-10-22	27			
31-10-22	104	00:34:00 4,12 Go	00:31:52 1,1Go	00:29:20 2,71 Go

01-11-22	80	01:12:00 8,74 Go	00:32:50 1,1Go	00:32:00 2,96 Go
02-11-22	105	01:26:03 5,82 Go	01:01:51 2,1Go	01:41:20 9,230 Go
03-11-22	104	00:37:00 3,41 Go	00:22:00 0,8 Go	01:42:20 10,25 Go
04-11-22	69	01:19:04 9,88 Go	00:47:23 1,7 Go	03:42:34 20,50 Go
05-11-22	124			04:48:04 26,68 Go
TOTAL	**616 km**	**31,98 Go**	**6,8 Go**	**72,34 Go**

Table 5.1 shows the recording efforts with the 3 antennas concerned. On the last day (Nov. 5, 2022), the C75 was placed overnight and recorded approximately 5 hours.

Table 5.2: Summary table of acquisition efforts for stations installed during the mission and swims in 2021 and 2022 with OPALEs portable antennas

	station Seglvik nov 2021 - fev 2023	**station Seglvik nov 202 - fev 2023**	**Bombyx Haudoya buoy**	**OPAL antennas 1**	**OPAL antennas 2**
Type	128 kHz Fe 16-bit continuous stereo, on Scarlet card and 2 SQ26	256 kHz Fe 16-bit continuous stereo, on QHB card UTLN and 2 SQ26	256 kHz Fe 16-bit continuous stereo	4 or 5 channels, 256 kHz Fe 16 bit, near-field pinpoint	4 or 5 channels, 256 kHz Fe 16 bit, near-field pinpoint
Beginning	poses on November 20, 2021	poses on November 20, 2021	November 14, 2023	2 weeks in November 2021	2 weeks in November 2021
END	Destruction by storm	Stop before storm	Dec 26, 2023 (drums)	2 weeks in Nov 2022	2 weeks in Nov 2022
Data volume / duration	**1.5 To over 2.5 months**	**~ 2 To over 4 months**	**0.3 To over 2 months**	**0.2 To at 5pm**	**0.2 To at 5pm**

The total volume of recordings to date is approximately 5 TB from the Seglvik station continuously recorded in March 2024, making it possible to compare the acoustic landscape before and during the polar night. Our UTLN Valhallab station model could be duplicated at another point south of the fjord, currently being defined. Data from the Bombyx buoy is approximately 0.5 TB currently being recovered by Akvaplan. The buoy is still in place after the first passage in January by Akvaplan, confirming the good performance of the mooring, an interesting point for a reinstallation in 2025.

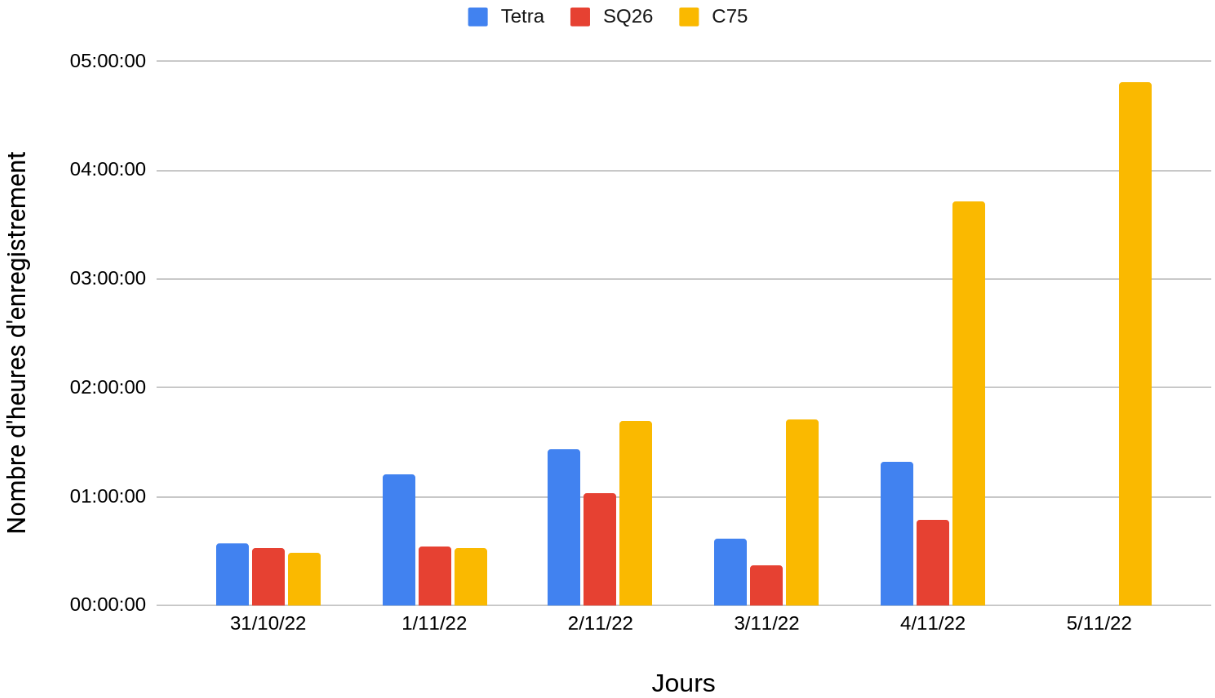


Figure 5.1: Graph representing the acoustic acquisition effort (number of hours) for the 3 antennas deployed from the IsbjornII, per day following the three types of measurements: antenna of 4 SQ26 hydrophones (Tetra), or single SQ26 hydrophone at 60 kHz bandwidth or C55 broadband alone.

5.2 AI automatic detectors

In order to analyze the acoustic presence of orcas and humpback whales within the recordings acquired during the missions, a convolutional network developed by the DYNI team (P. Best, 2022) was used. This model makes it possible to automatically detect the vocalizations of the two species and calculates a probability of presence at each millisecond of the signal. Using this model, we were able to detect the vocalizations (with a high signal to noise ratio) of humpback whales and orcas. Figure 5.2 represents the evolution of the model's predictions over 20 seconds of signal, containing orca vocalizations. Each red dot represents a detection.

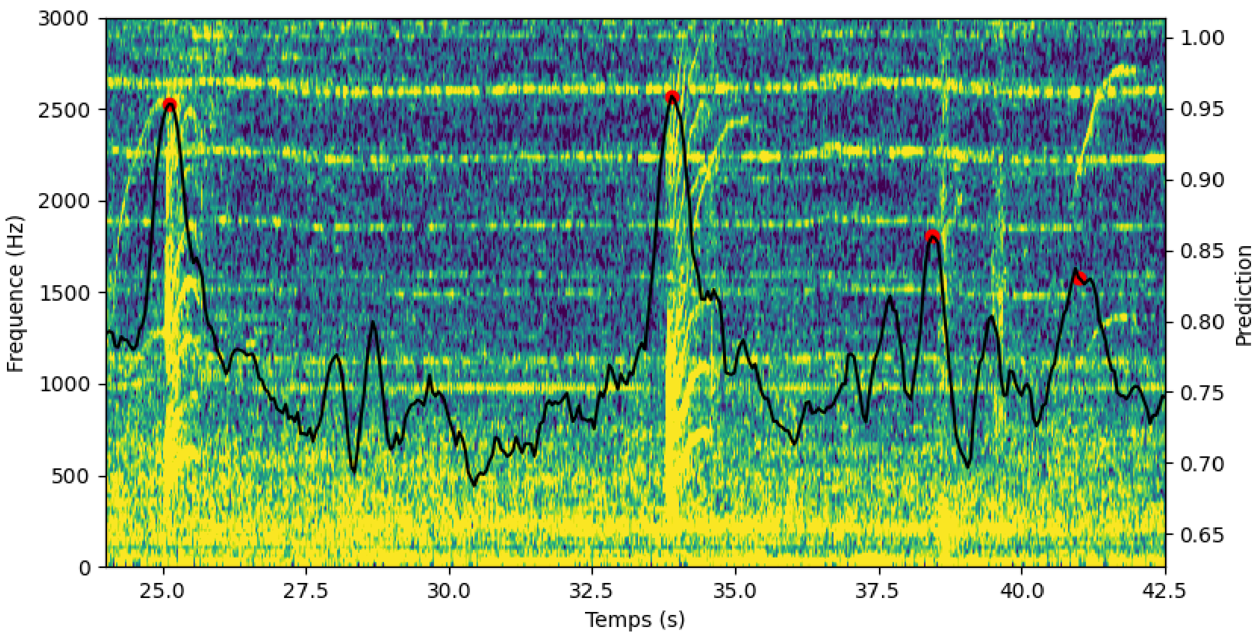


Figure 5.2: Example of predictions from the AI DYNI model on 20 seconds of signal. Each red dot represents a detected vocalization.

To automatically detect orca and humpback whale vocalizations and rorqual pulses in the fixed station recordings, the ready-to-use object detection program called “You Only Look Once” (YOLO-v5), developed for object detection in images and videos (Redmon, J., et al., 2016) on the basis of a convolutional neural network (CNN) was used. The acoustic recordings are represented as spectrogram images and these images are provided as input to the model. By processing audio recordings and providing the model with spectrograms spanning a few seconds, as well as annotations of vocalizations or pulses, the network is able to learn to recognize and then detect these objects in new recordings. For the detection of vocalizations of humpback whales, orcas and pulses of fin whales, two YOLOv5 models were trained: YOLO1 and YOLO2. The YOLO1 model was trained to detect humpback whale vocalizations between 0.1 and 6 kHz and orca vocalizations below 12 kHz. The YOLO2 was trained to detect the low frequency pulses of fin whales (around 15Hz and 130Hz) (Fig. 5.3).

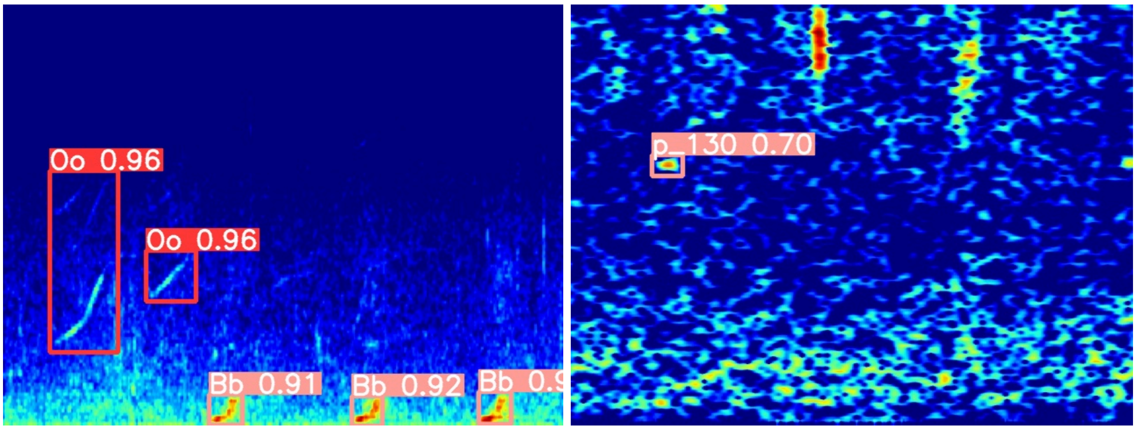


Figure 5.3 : (Left) Example of detections of YOLO1 (Oo=orca; Bb=humpback whale), (right) YOLO2 (p_130=fin whale pulse at 130Hz).

5.3 Acoustic detections of orca signals

In total, **764** Orca vocalizations were detected by the model, distributed over the 6 days of experimentation in November 2022 (Fig. 5.4). It was during the day of November 4 that the greatest number of vocalizations was detected (271).

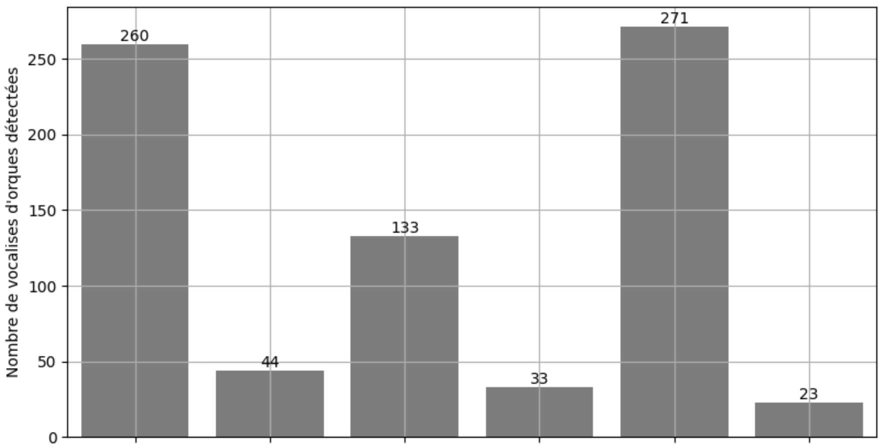


Figure 5.4: Number of orca vocalizations detected per day by the CNN

The analysis of these recordings made it possible to identify probable codas, never observed or published before according to our knowledge. These rhythmic codas of click trains, which are known in sperm whales, could code clans or individuals, which will be studied by EUROPAM (Fig. 5.5).

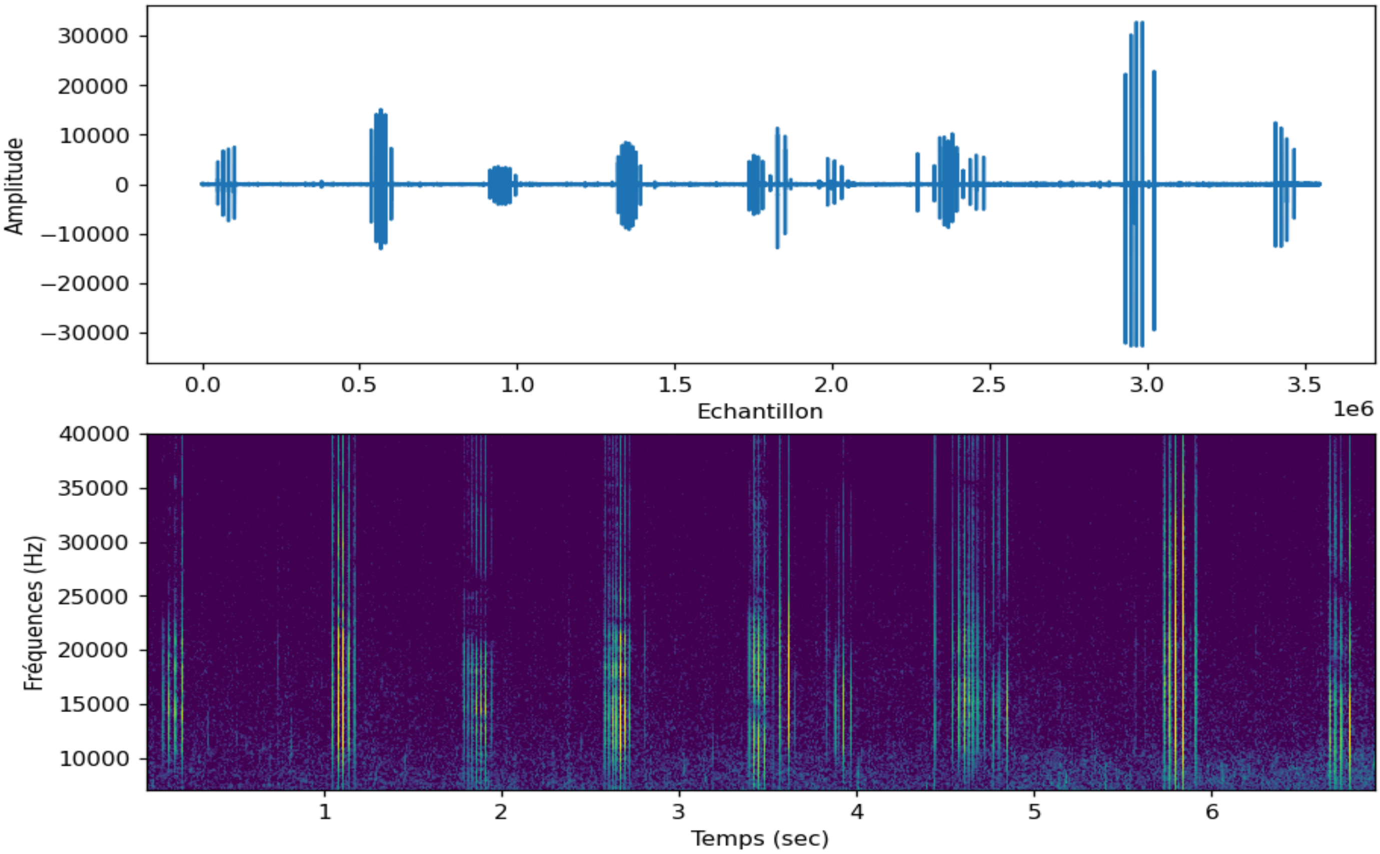


Figure 5.5: Several trains of orca clicks (waveform and spectrogram) (the orca is filmed during this broadcast) of the socialization type (not a hunt). Each little train of clicks is emitted at rhythms a+b, of a few units and of the same dB, like the 4+1 just before second 6.

Figure 5.6 represents the number of vocalizations per file distributed over the search area. Most meetings take place opposite and to the north of Skjervøy, up to Seglvik.

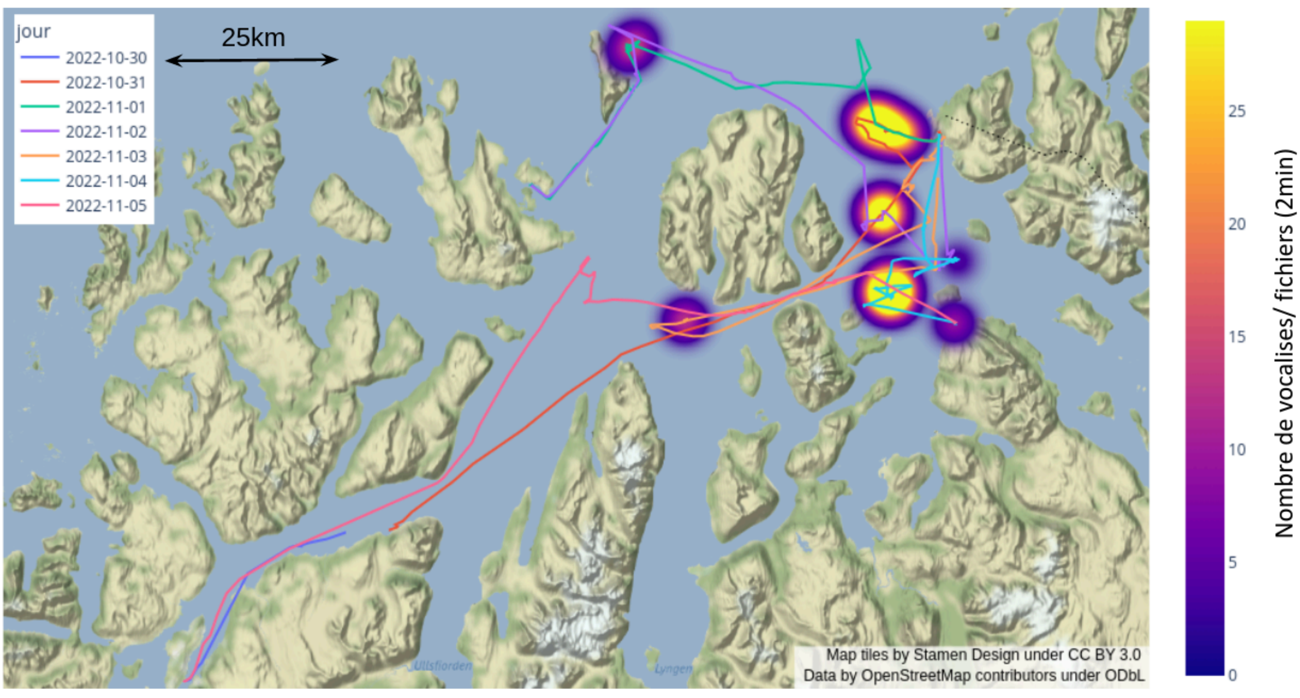


Figure 5.6: Map representing the routes of the Isbjorn and the number of orca vocalizations detected per two-minute recording

5.4 AI acoustic detections of humpback whales

The same protocol as for the detection of orca vocalizations was applied for humpback whales and made it possible to detect 422 vocalizations. The majority of vocalizations were detected during the night of November 4 to 5, with a total of 288 vocalizations (Fig. 5.7, example of vocalizations Fig 5.8). The peak in the number of vocalizations during that night is around 3 a.m. (Fig. 5.9).

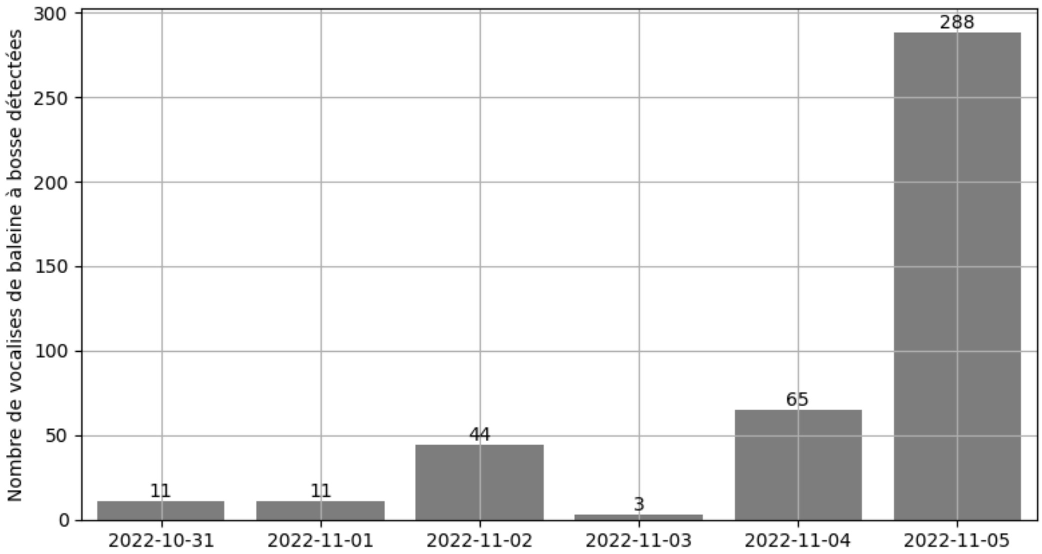


Figure 5.7: Number of humpback whale vocalizations detected per day by the CNN

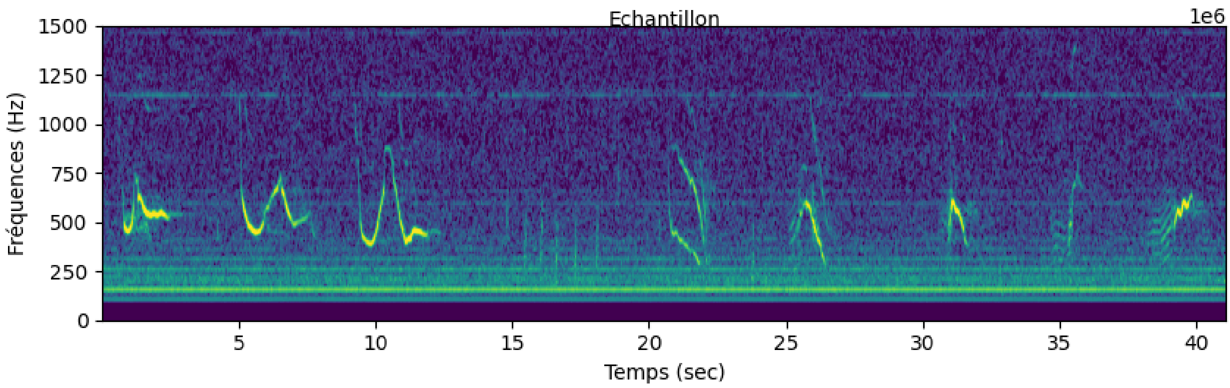


Figure 5.8: Example of recording of humpback whale vocalizations (05/11/22) at 2:53 a.m., near Skjervoy

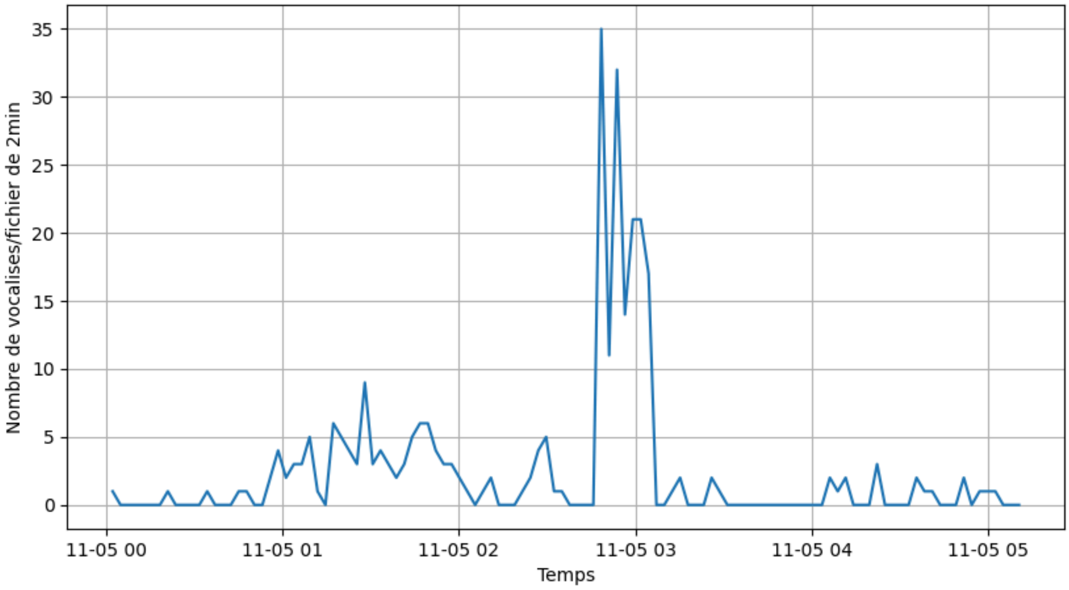


Figure 5.9 : Evolution of the number of vocalizations per 2-minute file during the night of November 4 to 5, 2022.

We also highlighted pulse trains from humpback whales compatible with the BF biosonar hypothesis of Au et al.
The majority of humpback whale vocalizations were recorded inside the fjord, to the south and opposite it. Skjervøy (Fig. 5.10).

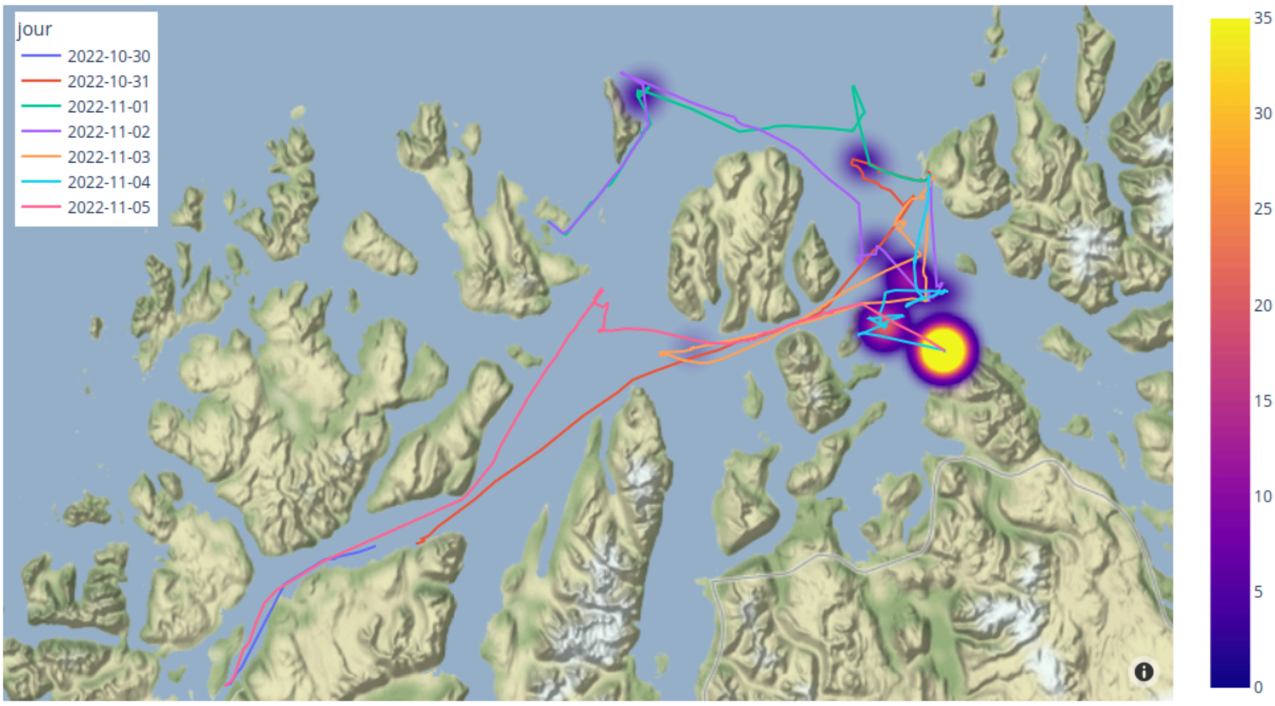


Figure 5.10: Map representing the routes of the Isbjorn and the number of humpback whale vocalizations detected at two-minute intervals.

5.5 Comparative analysis of the vocal repertoires of humpback whales from the Arctic to the tropics

Among all the vocalizations detected, a repertoire of at least 14 types was identified (Fig. 7.11).

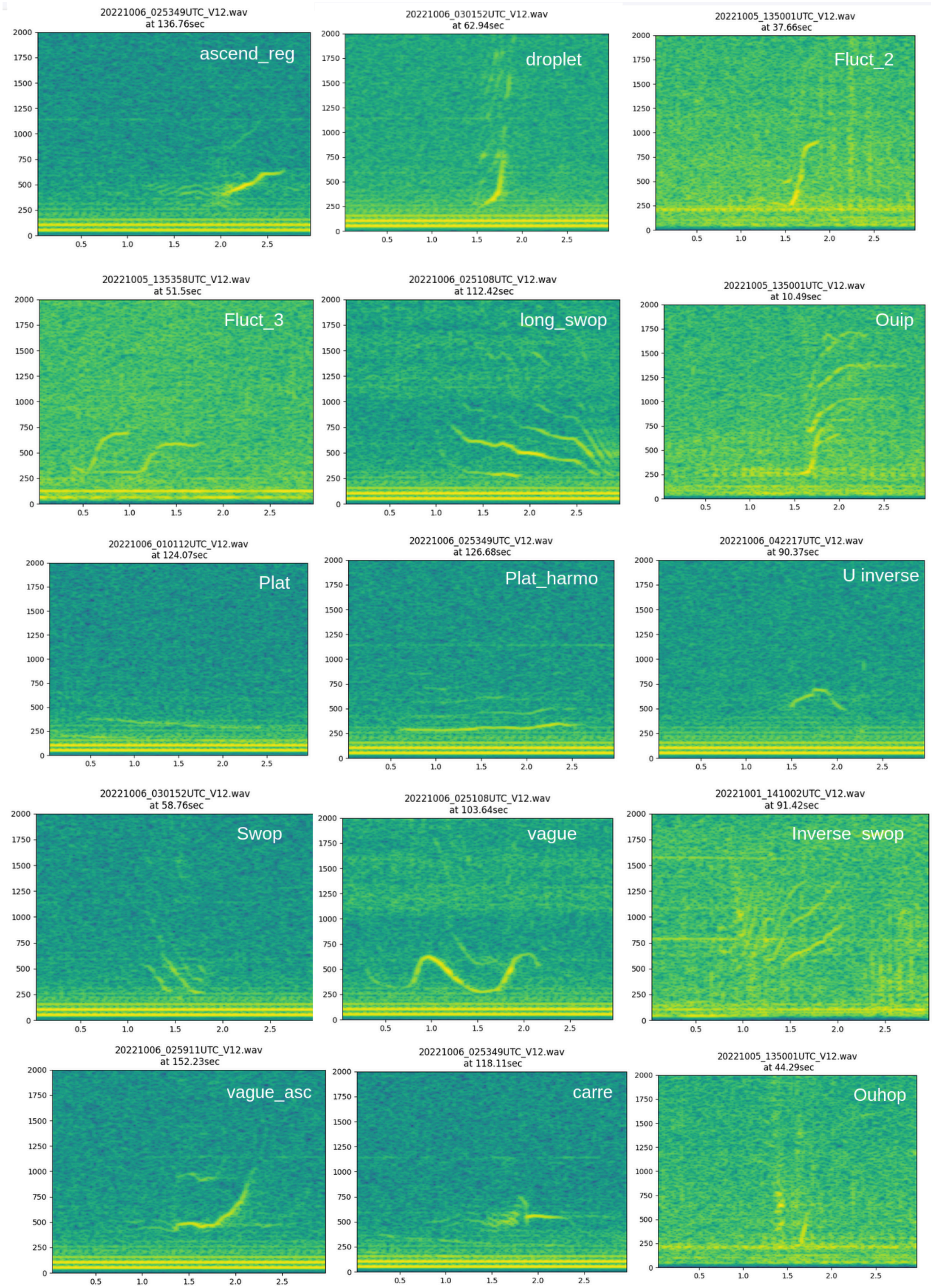


Figure 5.11 : the different types of humpback whale vocalizations identified in the mission

The DYNI team has built and is conducting a passive acoustics protocol in the Caribbean (CARIMAM, Glotin et al 2020), and has a large dataset of humpback whales during the breeding season. Twelve types have been identified in this area (Chavin et al 2022), the occurrence of each type of which is presented in Figure 7.12. Among these 12 types, 4 are also present in the acoustic repertoire identified in Norway (Fluct_2, Fluct_3, Plat_harmo and Droplet). This result confirms that the humpback whales present in Northern Norway come from the Caribbean area. This result shows that humpback whales are indeed acoustically active in feeding areas (shown in 2021 by Tyarks et al, discussed in Bouchar et al 2019), and that moreover, they can produce identical types of calls from breeding areas.
The presence of songs on a subarctic feeding ground probably facilitates the inter-individual transmission of the culture of the population of humpback whales of the North Atlantic which lives from the equator to the edge of the North Pole. Crop movements (repertoires and songs) are interesting biopopulation markers (Malige et al 2019) for monitoring the adaptation of populations to climatic upheavals and population movements.

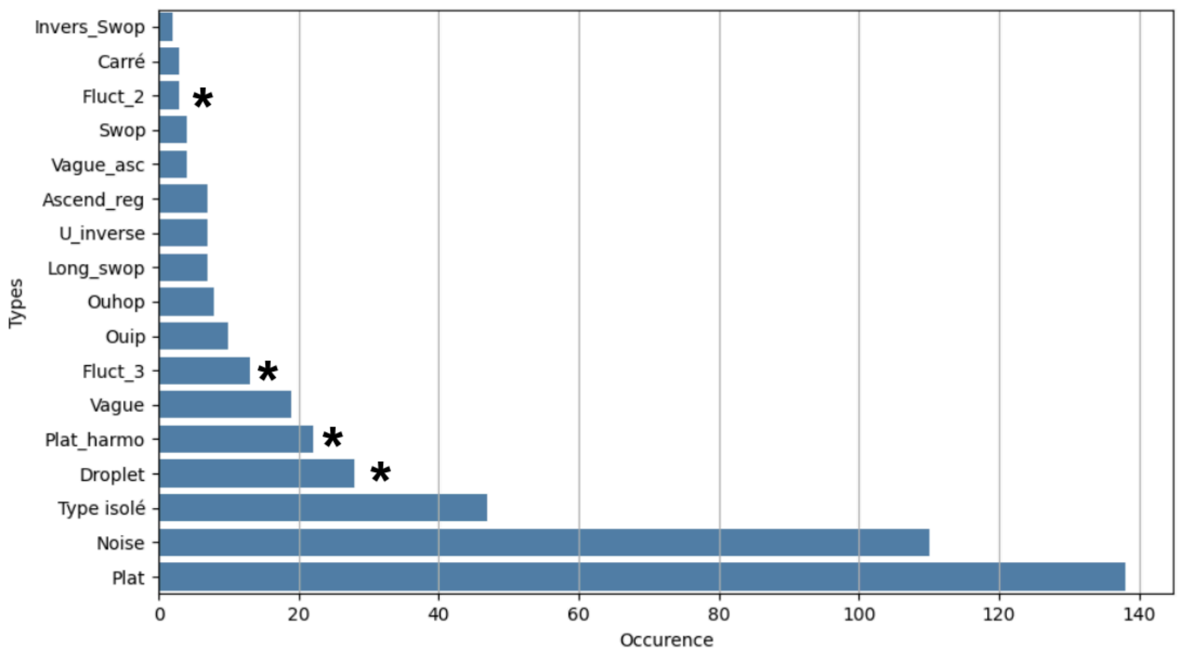


Figure 5.12 : Occurrence of the identified types. Isolated types = vocalizations present only once in the database. Noise=SNR too low for identification. (*)=types present in the Caribbean

5.6 Interspecific acoustic analysis (orcas & humpback whales)

The day of November 4 was particularly interesting. A pod of orcas was spotted in the morning. From 1 p.m., the orcas moved south, and all the individuals followed the same course. Then at **13h40**, a first feeding took place. The first feeding lasted approximately 10 minutes (from 1:44 p.m. to 1:55 p.m.) and no humpback whales were spotted in the feeding. At 1:54 p.m., the orcas moved south again, until 2:18 p.m., when the second feeding began. At 2:08 p.m., a humpback whale was spotted 15 miles from the hunt at Cape 40, approaching the feeding site. At 2:20 p.m., the whale was only 1 mile from the feeding and at 2:26 p.m., the whale arrived on the feeding. At 2:35 p.m., the feeding ended and the orcas returned to the South West. At 2:47 p.m. a new feeding begins with orcas but without humpback whales, until 3:10 p.m.

We were able to calculate the calling rate (number of vocalizations per minute) for the two species (orcas and humpback whales) for the three feedings (Fig.5.13). During the first feeding, only orcas were present, but vocalizations of both species were recorded. The vocalizations of the whale joining the feeding were therefore heard during the first feeding. During the second feeding, both species were present, and when the whale arrived in the feeding (2:26 p.m.), it no longer made any vocalizations.

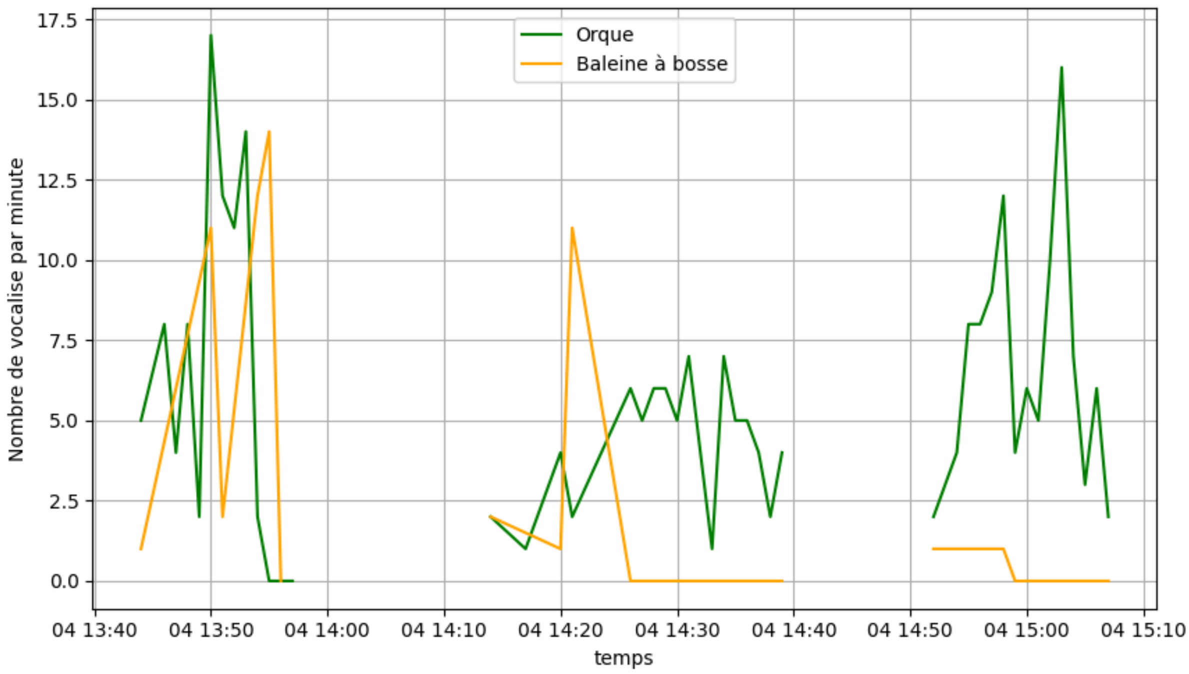


Figure 5.13: Calculation of the Call Rate (number of vocalizations/minute) during the 3 successive feedings of 04/11/22

The number of humpback whale vocalizations decreases during different feedings. Indeed, during the first feeding, the average call rate was > 6/min, then dropping to 3 vocalizations per minute, then less than 1/minute. Conversely, the average call rates for orcas remain rather constant (Fig. 5.14).

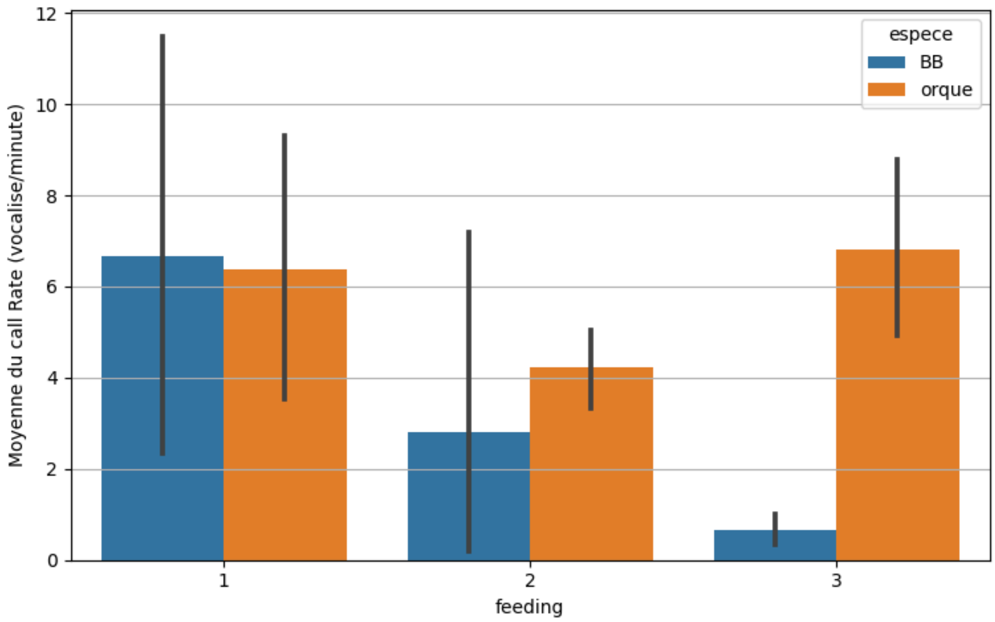


Figure 5.14: Average call rate (number of vocalizations/minute) during the 3 successive feedings on 04/11/22 for the two species

We can conclude for this feeding that humpback whales are acoustically active before arriving in the feeding, and once in the feeding, they emit few vocalizations.

5.7 Near-field tracking of orca tracks

Click detection was carried out on some recordings from the Opales 2022 antennas (5 channels), followed by a calculation of delay times of arrival (TDoAs) between the hydrophones of the antenna. An example (Fig 5.15) shows the TDoAs calculated after AI automatic detection. We are currently calculating the position of the transmitting individual in relation to the antenna and its camera using our processes (Ferrari et al 2020ab, Glotin et al 2008). This protocol will allow us to follow the evolution over the seasons and years of the acoustic emissions of the two species within a hunt but also to attempt the search for individual acoustic signatures, important for monitoring populations.

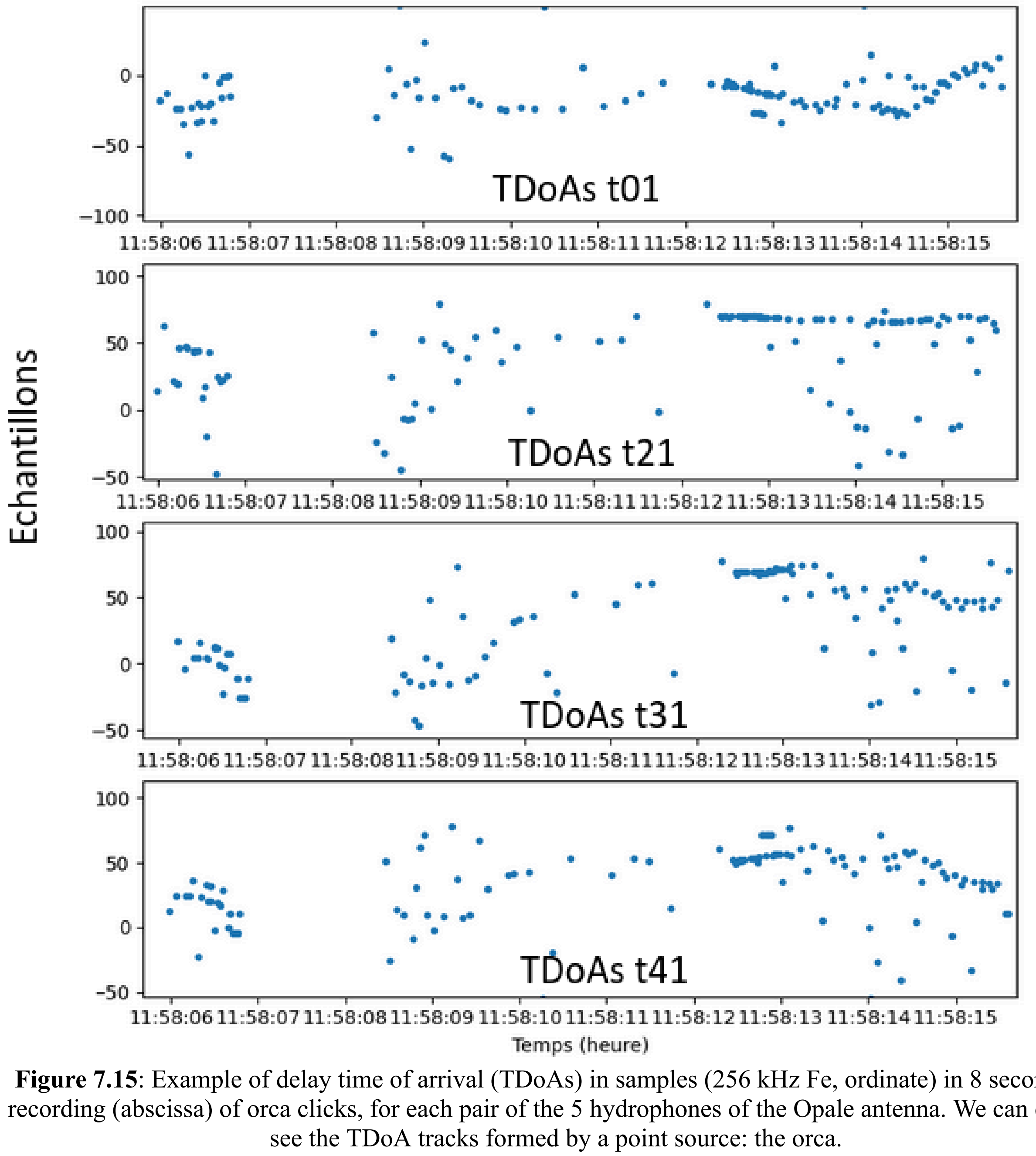


Figure 7.15: Example of delay time of arrival (TDoAs) in samples (256 kHz Fe, ordinate) in 8 seconds of recording (abscissa) of orca clicks, for each pair of the 5 hydrophones of the Opale antenna. We can clearly see the TDoA tracks formed by a point source: the orca.

5.8 tracking orca tracks in far fields

Track separation and therefore the analysis of vocalization forms by individual is also carried out by the Tetra antenna, an example of which is presented in Figure 7.16. There is therefore only one individual vocalizing at a time in this scene, probably the same one given the segments of the same color which follow one another.

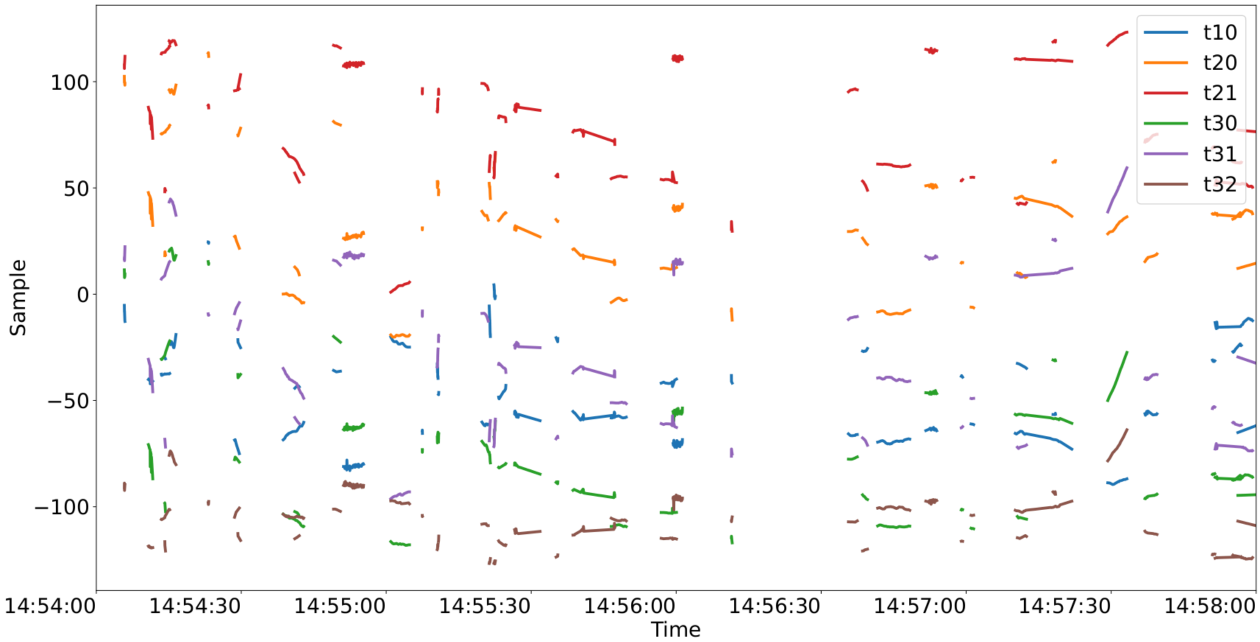


Figure 5.16: Example of delay time of arrival (TDoAs) in samples (Samples, 256 kHz Fe, ordinate) in 4 minutes of recording (abscissa) of orca clicks, for each pair of the 4 hydrophones of the Tetra antenna (t10, t20..). We can clearly see the TDoA tracks formed by a point source: the orca.

5.9 Study of vocalization rhythms of species (humpback whale, orcas, rorquals)

Presence of species

During the 80 days of recording, a total of 121,247 humpback whale vocalizations, 104,785 orca vocalizations, and 602,688 fin whale pulses were automatically detected by the trained YOLO models. Based on these detections, a timeline illustrating the detection rate (TD) (number of detections/recording time) and the presence rate (TP) (number of positive recordings/total number of recordings) was created to provide an overview of the acoustic activity patterns (Fig.5.19). The results highlight the almost continuous presence of all three species throughout the two-month recording period, with similar PR and DR for each species. However, the timing of peaks varies from species to species. Orcas were the first to appear, displaying TP above 0.5 and high TD (up to an average of 330 vocalizations per hour), between 18 November and 3 December. Fin whales were the most consistently present species, maintaining a TP rarely below 0.2 and reaching peak presence and vocal activity between 14 and 24 December. Finally, humpback whales were mainly detected in early January, reaching a peak detection rate of 325 vocalizations per hour. However, their presence was recorded as early as November 20, although detections were rare during this period.

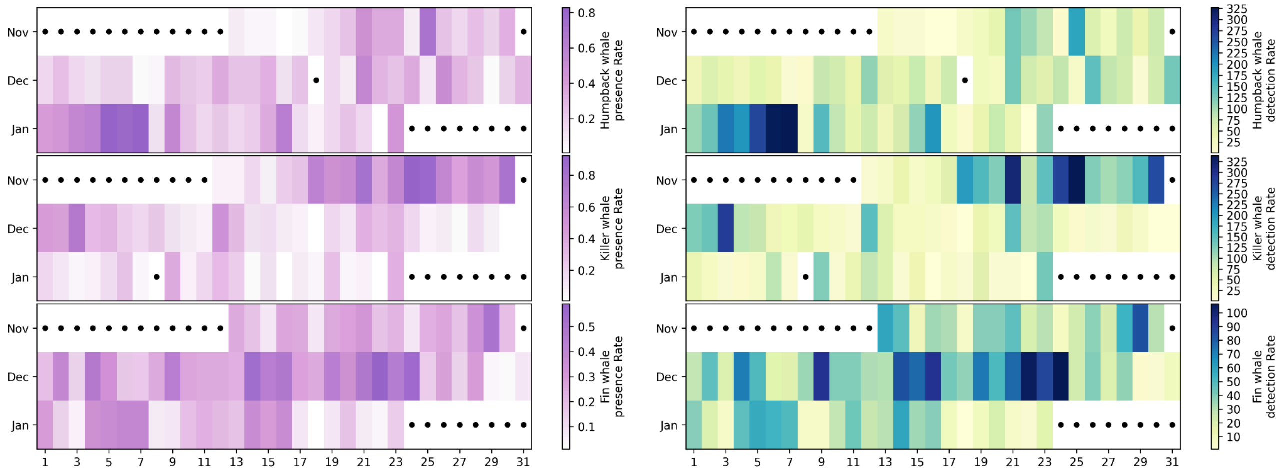


Figure 5.19 : calendar of presence rate (left) and detection rate (right) per day for the humpback whale (top), the orca (middle) and the rorqual (bottom) over the two months of recordings.

Daily attendance rate

Since the TP and TD profiles are similar, only the TD is presented here. Acoustic activity of humpback whales remained relatively high throughout the day, particularly during the afternoon and night, with a minimum of 50 vocalizations/hour at 6 and 7 a.m. Similarly, fin whales exhibited high acoustic activity during the night, with peaks between 10 p.m. and 5 a.m. and a minimum at 8 a.m. and 8 p.m. In contrast, orcas showed distinct peaks of acoustic activity at 7 a.m. and 6-7 a.m.

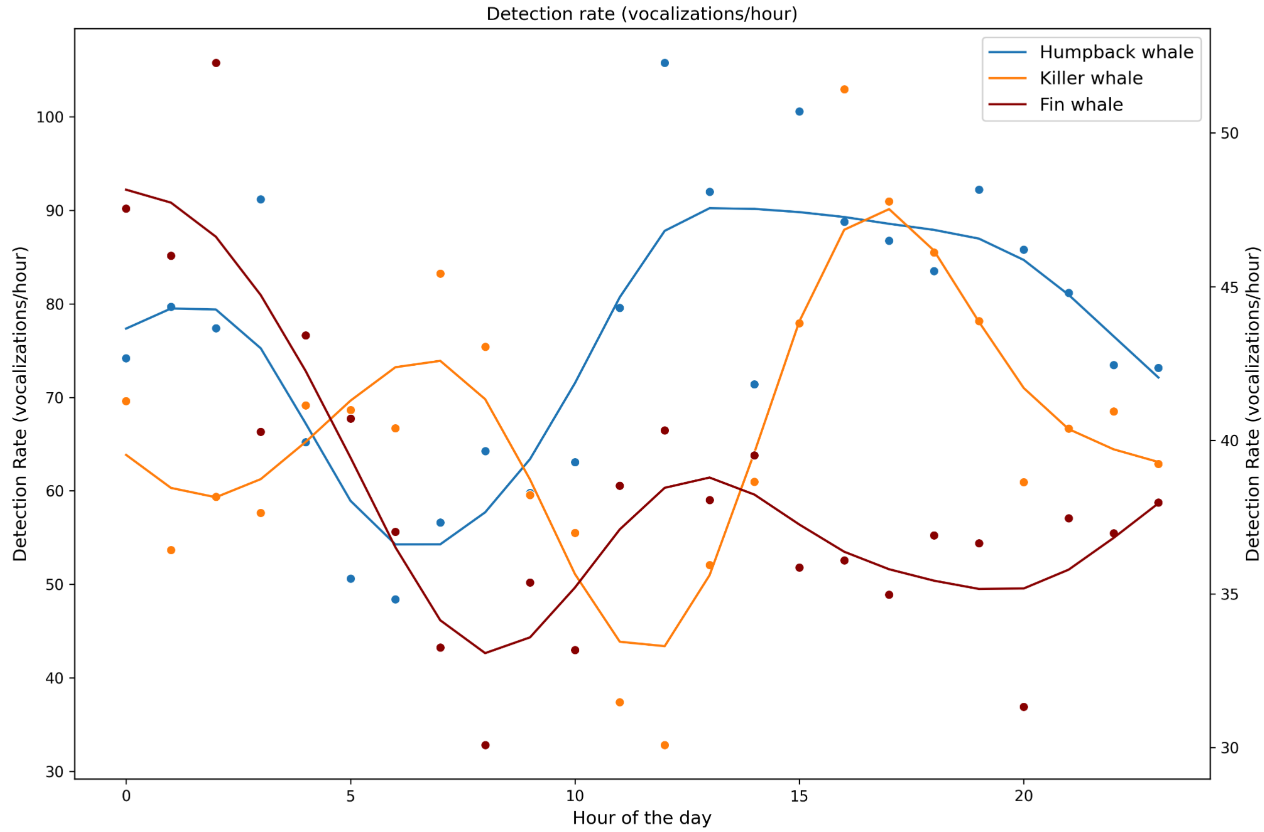


***Figure 5.20** : Detection rate depending on the time of day for the 3 species.*

During the winter months, there was a notable decline in daylight hours ranging from 4 hours on November 13 (09:12 to 1:26 p.m.), to polar night starting on November 25.

The orientation of the sun relative to the horizon was used to define periods of light, darkness and night. The detection rate of the 3 species was therefore compared between these 3 light periods. Orcas are more acoustically active during darkness and night, while rorquals are more active at night while humpback whales are mostly active during the day.

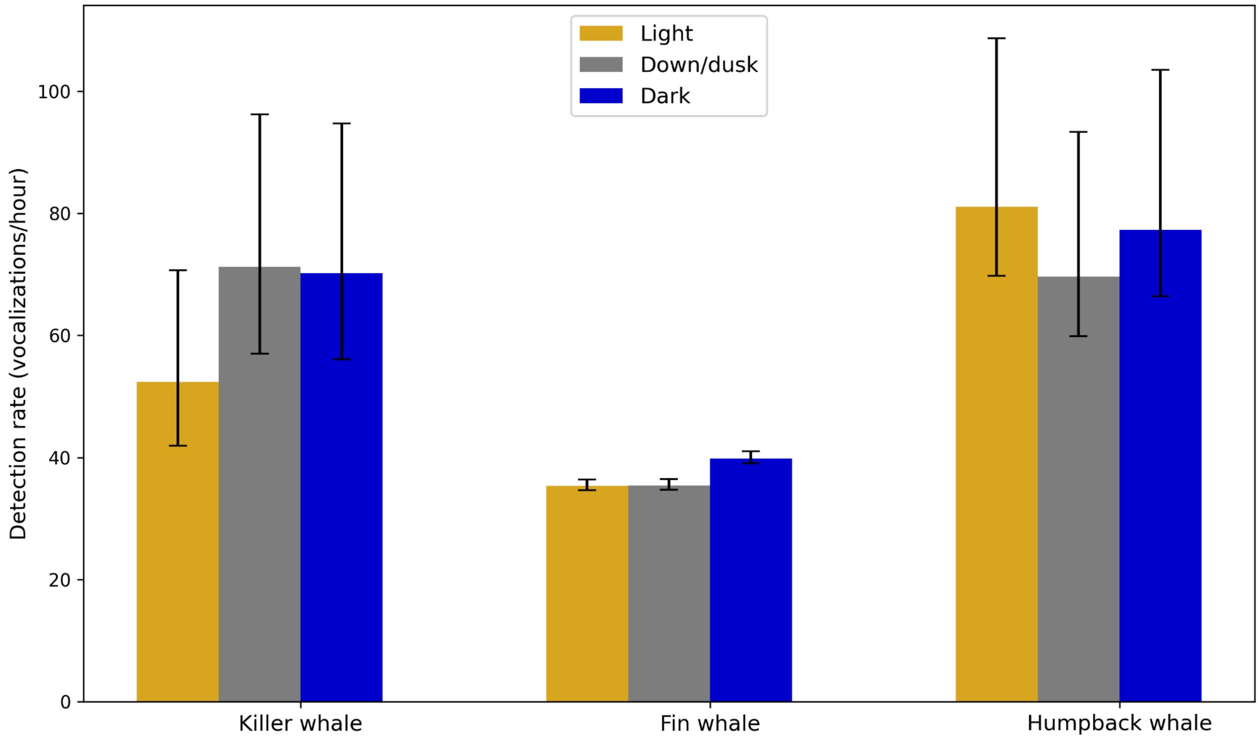


Figure 5.21 : Detection rate of the three species in the 3 defined light conditions.

6. Visual observation and identification protocol

To be able to evaluate a change in hunting strategy among orcas, do we still have to regularly find the same pods and the same individuals from one year to the next (recapture). This recapture is done both acoustically, but more conveniently visually. For this we have implemented a visual identification protocol: photo-identification.

6.1 Material and method

A visual observation protocol was put in place, from dawn to dusk, in shifts of 4 people, traveling over 2 hours, with binocular searches. In total, 41h35 of observation, or an average of 7h/day. Every day, navigation information, cetacean sightings and remarkable events were noted on a roadmap, with time and GPS point. Each orca sighting was documented in detail: behavior, time of diving and return to the surface, maximum number of individuals on the surface, number of males, presence of whales, acoustic recording sequences, photo and video numbers, as well as any information that can help the analysis of acoustic data and enable an ethological study to be carried out.

The visual estimation of the number of individuals is based on the maximum number of individuals from the same group, seen at the same time on the surface at the time of breathing. This number is obviously lower than the total number of individuals, because not all of them breathe at the same time. This estimate is advantageously supplemented by the analysis of videos which make it possible to distinguish individuals not breathing synchronously.

Figure 6.1 : Examples of typical orca sightings in November 2022 in the study area (photo credit Sarano)

The photo-identification of the orcas was carried out with a Canon EOS R5 photo/video camera, equipped with a 100-500mm lens. As only the left side of individuals is used in existing catalogs (Jourdain 2021), we only retained photographs of the left side – unless a remarkable injury cutting the dorsal fin allowed unambiguous identification. We also used the photos of the right flank to count the large males of Pod 1 because, the entire group having presented itself on the right flank, we were able to distinguish the individuals from each other. Humpback whales are identified using photos of the ventral side of the caudal fin.

The light conditions (darkness) and the distance to be respected so as not to disturb the cetaceans did not favor identification, because there are few orcas whose dorsal is clearly cut and whose details (scratches, difference in color) of the saddle are very legible. Particularly in 2024 (2^{th} half of November with only 3 hours of low light per day, without sun). Also, many photos were rejected because of insufficient quality (too far, too dark, backlight, wrong shooting axis, wrong side = right side).

6.2 Results

6.2.1 Delimitation of orca pods:
The analysis of the photos initially focused on the large males which characterize each pod, even if we noted that some males temporarily change pods. Over 2022-2023, it highlights 75 different large males, divided into 14 pods:

20221031-13h56-**POD 3** : 5 large male orcas
20221101-14h12-**POD 4** : 7 large male orcas
20221103-13h34-**POD 6 :** 5 large male orcas
20221104-13h26-**POD 5** : 8 large male orcas
20221105-12h05-**POD 1** : 6 large male orcas
20221105-13h00-**POD 2** : 4 large male orcas
20231105-**POD 8** : 14 large male orcas
20231106-**POD 9** : 3 large male orcas
20231107-**POD 10** : 8 large male orcas
20231109-**POD 11** : 2 large male orcas
20231110-**POD 12** : 3 large male orcas
20231111-**POD 13** : 9 large male orcas
20231112-**POD 14** : 1 large male orca

See an example (Fig. 6.2): identification catalog of males from pod 8.

A few females were also identified, because their dorsal fin was cut and their saddle clearly scratched:

20221031-13h56-**POD 3** : 7 females
20221101-14h12-**POD 4** : 1 female
20221103-13h34-**POD 6 :** none
20221104-13h26-**POD 5** : 5 females
20221105-12h05-**POD 1** : 3 females
20221105-13h00-**POD 2** : none

Analysis of photo-identifications from the 2024 mission is underway, with around ten new large males

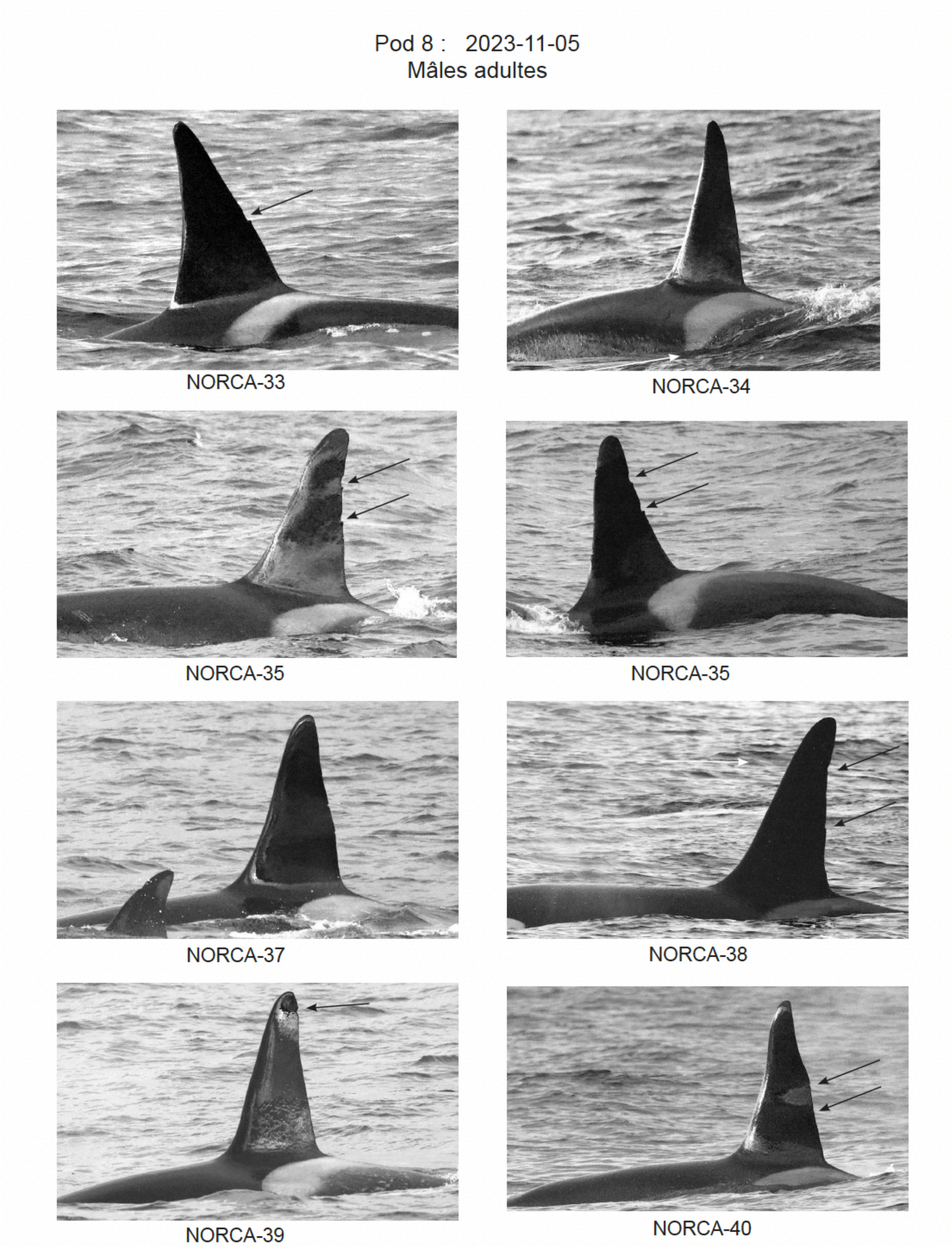


Figure 6.2 : Photo-identification of 7 males from pod 8, observed on 5/11/2023. The identification criteria are: the position of the front of the saddle in relation to the axis of the back protector, the slight indentations on the trailing edge of the back protector (pointed by the arrows) and the presence of scratches on the saddle.

6.2.2 Re-captures of male orcas

The search for re-captures (new observations of the same individual during our 3 missions or observations by other teams) shows the regularity of the return of certain pods in the Kvaenangen fjord and allows us to assess how long they have been returning (Tab. 6.1). It is based on the photo-identification catalog by Jourdain and Karoliussel (2021). 6 large males were re-captured, notably NORCA-51 (nicknamed “Graff”, for the characteristic marks on his saddle) which was **revised for 3th consecutive year in 2024.** This large male, identified by E. Jourdain (number NKW-1082) in 2018, was then classified among the “visitor individuals” of the Kvaenangen fjord. In view of these 3 re-captures, we can now classify it among the “regularly observed”, with pod 10 to which it belongs.

JOURDAIN et al 2021	ADAPREDAT-1 2022	ADAPREDAT-2 2023	ADAPREDAT-3 2024
NKW-1082 / 2018	NORCA-51 (GM2-POD6) / 2022-11-03	NORCA-51 Graff / 2023-11-07	NORCA-51 Graff / 2024-11-21
NKW-0171 / 2006	NORCA-20 (GM5-POD4) / 2022-11-01	NORCA-20 / 2023-11-03	
NKW-0491 Ziggy / 1992		NORCA-65 / 2023-11-11	
NKW-0167 / 2014.		NORCA-57 / 2023-11-10	
		NORCA-44 / 2023-11-06.	NORCA-44 / 2024-11-22
NKW-0102 / 2016			NORCA-82 / 2024-11-22

Table 6.1 Summary of male orcas re-captured on the 3 missions 2022 to 2024

Catalogue Jourdain et Karoliussel 2021	Recaptures ADAPREDAT-1 2022	Recaptures ADAPREDAT-2 2023	Recaptures ADAPREDAT-3 2024
			
NKW1082 2018	NORCA-51 Graff 2022-11-03	NORCA-51 Graff 2023-11-07	NORCA-51 Graff 2024-11-21
			
		NORCA-44 2023-11-06	NORCA 44 2024-11-22
			
NKW-0102 2016			NORCA-82 2024-11-22

Table 6.2: Photograph of individuals re-captured in 2024, notably NORCA-51 Graff

The analysis of the videos (taken when the light and proximity conditions were met) often reinforced the identification when there was doubt about certain photos. The videos also made it easier to count the individuals in certain well-grouped pods.

These video counts, which were compared to estimates made in the field, are essential because the visual estimate, based on the number of individuals present at the same time on the surface to breathe, is extremely delicate. The slow motion playback of the video leaves no room for doubt.

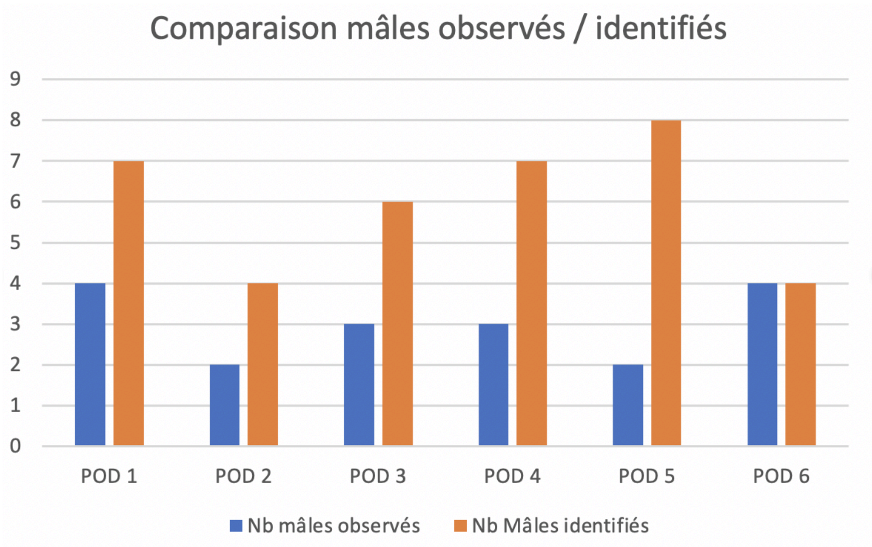


Figure 6.3 : Number of males counted at sea and number of males identified according to photos/videos, for each orca pod.

We note (Fig.6.3) that it is difficult to distinguish the different males upon observation (systematic underestimation). Photo-identification is therefore essential for counting the males encountered.

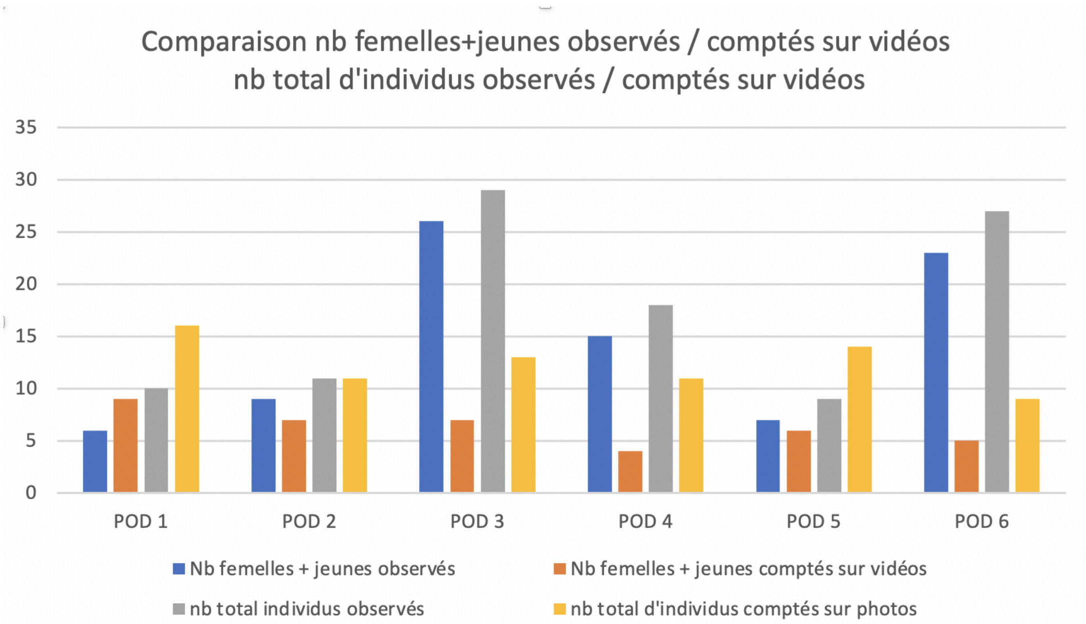


Figure 6.4 : For the 6 Pods studied, comparison between the numbers observed and counted on photos/videos, on the one hand for females + young people, on the other hand for the total number of individuals

Note (Fig. 6.4) that video is only really effective for counting when the orcas in the pod are well grouped together. When they are dispersed or when there are several small groups, video counting is not very effective (case of Pod 3, 4, 6) with a single camera.

The videos will also provide some elements to follow the evolution of the hunts. As part of a more in-depth ethological and social study underway, these videos will make it possible to unambiguously note the females followed, the affinities between individuals, the diving and surface breathing times, the hunting and playing behaviors. No large males were identified in 2 different pods. It therefore seems that we can use them to characterize each of the pods.

6.2.3. Identification and re-capture of humpback whales

As with the orcas, we seek to identify and re-capture the humpback whales observed during the 3 missions. Analysis of hundreds of photos taken made it possible to identify 25 individuals. Compared to the Happy Whale online catalog (https://happywhale.com/home), 15 had already been seen, including 6 from 2019 (date of start of the catalog) and 10 are new: our missions are the first to identify them (see tab. 6.2).

Saison	2019 2020	2021 2022	2022 2023	2023 2024	2024 2025	Total recaptures	oct	nov	dec	janv	fev	mars	avril	aout
HW-MN0102611	1			1		2		2						
HW-MN0102615	1		1	1		3		3						
HW-MN0102627	1	1		1		3		2	1					
HW-MN0102650	1	1	1	1	1 + 1	6		4	1		1	1		
HW-MN0200055	1	1	1	1	1	5		4	2	1				
HW-MN0200074		1		1		2		1					1	
HW-MN0200171			1	1		2		1						1
HW-MN0200237			1	1		2								
HW-MN0200258			1	1		2		2						
HW-MN0200245			1	1		2		2						
HW-MN0200423			1	1	1	3		3						
HW-MN0200424				1		1		1	et 1					
HW-MN0200425				1		1		1						
HW-MN0200426				1		1		1						
HW-MN0200427				1		1		1						
HW-MN0200428				1		1		1	et 1				1	
HW-MN0200430			1	1		2		1						
HW-MN0200434				1		1		1						
HW-MN0200437				1	1	2		2						
HW-MN0200444				1		1		1						
HW-MN0200445				1		1		1						
HW-MN0200471			1			1		1						

Tab. 6.2 : List of humpback whales identified (missions 2022-2024), years and months of recaptures of these whales over the period 2019-2025, according to the Happy Whale online catalog. Figures in black: observations made in Norway; in red: observations in Cape Verde or the Azores; in blue: 1 observation in Svalbard.

PHOTO-IDENTIFICATION des BALEINES A BOSSE

33 baleines à bosse (numérotées NBOSSE 1 à 33) ont été identifiées au cours de la mission. Les photos de leur nageoire caudale ont été comparées au catalogue mondial « Happy-Whale ».

Au 1er novembre 2024, la comparaison montre que :

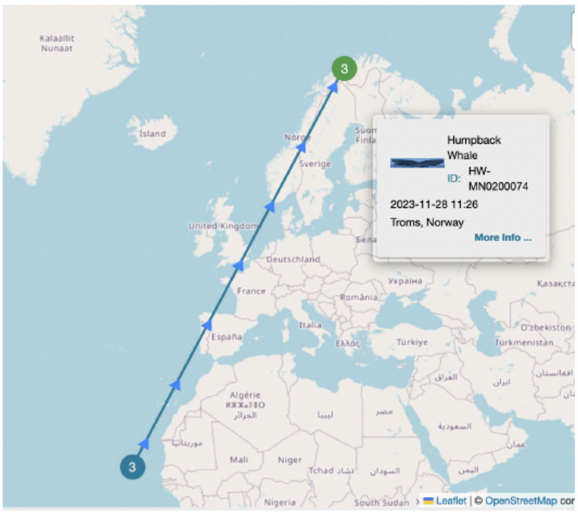
- 10 baleines n'ont jamais été répertoriées.
- 11 baleines sont déjà connues, les observations les plus anciennes remontant à 2019.
- 12 baleines sont toujours en cours d'analyse.

Recaptures dans d'autres zones géographiques

Parmi les baleines déjà connues, l'une d'elles (NBOSSE-1-2023_11_02_SVF_9999_531-blanche-A) a été déjà observée dans les eaux tropicales du Cap Vert, le 5 avril 2021, avec le nom : HW-MN0200074, ci-dessous :

La baleine à bosseNBOSSE-1-2023_11_02_SVF_9999_531-blanche-A a été déjà vue le 5 avril 2021 au Cap Vert, avec le nom HW-MN0200074

Ci-dessous
La baleine HW-MN0200248 a été vue en avril 2021 au Cap Vert et en novembre 2023 en Norvège



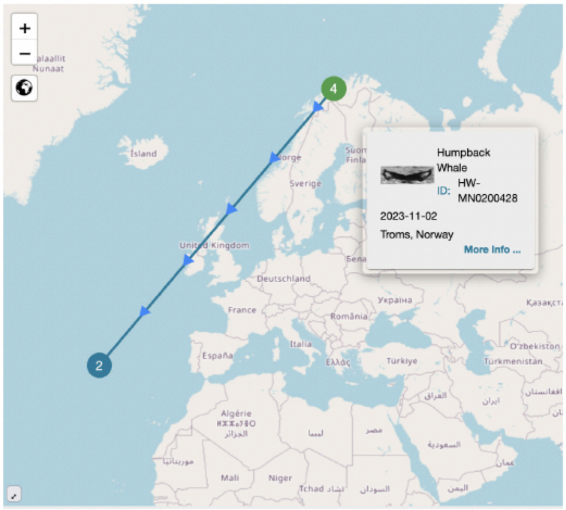
Une 2ème baleine (NBOSSE-12-2023_11_02SVF_9999_546-Noire-B) a été revue 5 mois plus tard, le 29 avril 2024, aux Açores. Elle porte le nom HW-MN0200428

La baleine à bosse NBOSSE-12-2023_11_02_SVF_9999_546-Noire-B a été revue le 29 avril 2024 aux Açores, avec le nom HW-MN0200428

La troisième baleine recapturée (NBOSSE-15-2023_11_02_SVF_9999_543-noiremedian-G) a été déjà vue dans les eaux polaires du Svalbard, le 5 août 2022. Elle porte le nom : HW-MN0200171, ci dessous :

La baleine à bosse NBOSSE-15-2023_11_02_SVF_9999 543-noiremedian-G a déjà été identifié en 2022 au Svalbard, avec le nom HW-MN0200171

Ci-dessous
Trajet suivi par la baleine HW-MN0200248 entre la Norvège (dec 2023) et les Açores (avril 2024)



Suivi dans le temps grâce aux recaptures

La recherche des baleines que nous avons observées en 2023 dans le catalogue Happy Whale révèle que :

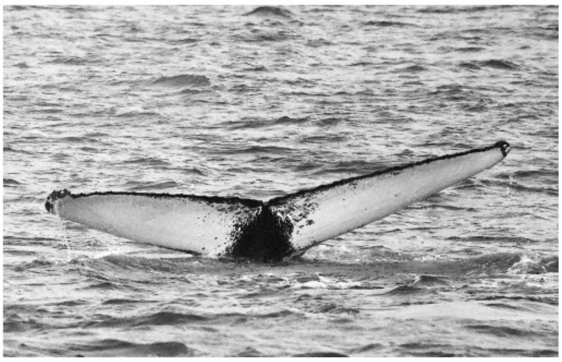
- 4 ont déjà été vues depuis 2019
- 7 ont été observées à partir de 2022

10 baleines ont été recapturées plusieurs fois après notre mission jusqu'à la fin novembre, et la HW-MN0200424 jusqu'au 30 décembre 2023.

Mieux, les 2 baleines répertoriées HW-MN0102615 et HW-MN0200424, que nous avions vues ensemble le 2 nov 2023, ont été revues ensemble le 30 déc 2023.

Plus intéressant encore, la recapture de ces baleines fin décembre, soit 2 mois après nos observations, montre l'importance de la durée du séjour dans les fjords norvégiens. La longueur de ce séjour modifie par conséquent fortement la date de départ de la migration annuelle vers le sud et les eaux tropicales. Ces 2 baleines font partie des 15% qui séjournent plus de 8 semaines en Norvège (Kettermer et al 2023).

L'ensemble du catalogue ADAPREDAT-2023 est consultable sur : https://happywhale.com/home.



La baleine à bosse identifié HW-MN0102615
photographiée le 2 novembre 2023
a été revue le 30 décembre 2023
dans le même fjord de Norvège

La baleine à bosse identifié HW-MN0200424
photographiée le 2 novembre 2023
a été revue le 30 décembre 2023
dans le même fjord de Norvège

The whale HW-MN0102650 was the most recaptured, 4 years in Norway + 2 in Cape Verde. Generally speaking, the humpback whales we observed in Norway seem to follow the eastern coast of the Atlantic, with migrations towards Cape Verde and the Azores.

7. Acoustic landscape, well of silence versus anthropophony pollution

7.1 Material and method

The fixed station and the stereo buoy, coupled with measurements in the center or offshore of the Fjord by the Isbjorn, allow an unprecedented qualification of the acoustic quality of an Arctic fjord. The approximately 2 TB of archive received in mid-January 2023 is currently being analyzed. However, we already have an overview of the level of the silence wells inside the fjord.

The AIS data (archives of boat trajectories in the area) that we are currently purchasing for the period end of 2022 and 2023 will make it possible to correlate the nature of the boats (tonnage), as well as their speed and distance to the hydrophone, to the dB per ⅓ octave as we analyze them for the SHOM (Ferrari et al. 2022). This will make it possible to qualify the anthropophony, as well as the quality of acoustic propagation in the Fjord.
We can imagine the acoustic qualities of a fjord like those of a cathedral with different naves and crypts, offering as many acoustic refuges by baffling. This can provide resting areas for the auditory system of predators sheltered from the acoustic radiation of rail tanker traffic in the Far North, which is increasingly dense due to warming. Animals may suffer less from such disturbances if the fjord itself is not sonicated by boats traveling the fjord. These wells of silence would then form

sanctuaries at certain times, conducive to optimal hunting and quality 'cultural' communications, internal to orca pods and humpback whales.
The estimation of dB levels is either made by DSP (Spectral Power Density) (Ferrari et al. 2022 SHOM study), or measured by frequency band. For the latter, the signals were divided into octave bands. The frequency bands treated here for the fixed station are the bands 10 to 400 Hz and 6500 to 12500 HZ. As a reminder, the sampling frequency of the fixed station was 96 hHz from November 13 to 17 then 192 kHz. Absolute dB was calculated with a sensitivity of -170, a gain of 10 and a voltage of 5.

7.2 Nighttime soundscape

An analysis of dB measurements taken on site (Fig. 6.3) reveals the presence of several distinct peaks in the data (Fig. 9.1). The first of these peaks, observed at 50 Hz, is probably due to the ship's power supply. This is a common frequency in noise generated by boat equipment and can be caused by a variety of sources such as generators, air compressors, and propulsion systems. Additionally, a peak observed between 5 kHz and 10 kHz is consistent with the inherent noise of the sound card used. This peak is usually caused by noise generated by the sound card's electronic components and can be reduced with proper calibration. The Bombyx stations and the Seglvik fixed station do not have these inherent phenomena due to the rolling of the boat.

In addition, a series of peaks observed around 50 kHz during the night of the 4th to the 5th are of anthropogenic origin, probably due to the use of a boat sonar system. These peaks are commonly associated with the use of active sonar systems and can be found at different frequencies depending on the type of sonar system and operating conditions. These anthropogenic noise sources are known to have a significant impact on marine life and can lead to physical injuries and behavioral changes in marine animals (Best et al 2019). It is important to note that sonar is not the only source of anthropogenic noise in this region, other sources such as shipping and oil and gas exploration also contribute to the underwater acoustic level in northern Norway. We compare Fig.9.1 the minima and medians, between 500 Hz and 5 kHz. The medians are reliable, and if close to the minima, they characterize a stable zone. They demonstrate, for the night of the 4th to the 5th, that the dB level is very low and stable behind Haudoya that night. It is a measurement inside the fjord which is baffled from the north by the mass of Haudoya. On the other hand, on Thursday, November 3 from 10 p.m. to 11:59 p.m., in North Haudoya, the minimum level is +3dB and the median level is +6dB (double the energy in this frequency interval), which is in favor of a demonstration of baffling and the existence of silence wells in the fjord.

In conclusion, this study on system measurements at Seglvik highlights the complexity of the underwater acoustic environment of a fjord, and the multiple sources of noise pollution that must be taken into account, to assess its impact on marine life and surrounding communities. Additional research is needed to better understand the interactions between these different noise sources and develop effective mitigation strategies to reduce the negative impacts of noise pollution on the marine environment. Long-term statistics at different points of the fjord will have to be established to show the effects of baffling and silence wells.

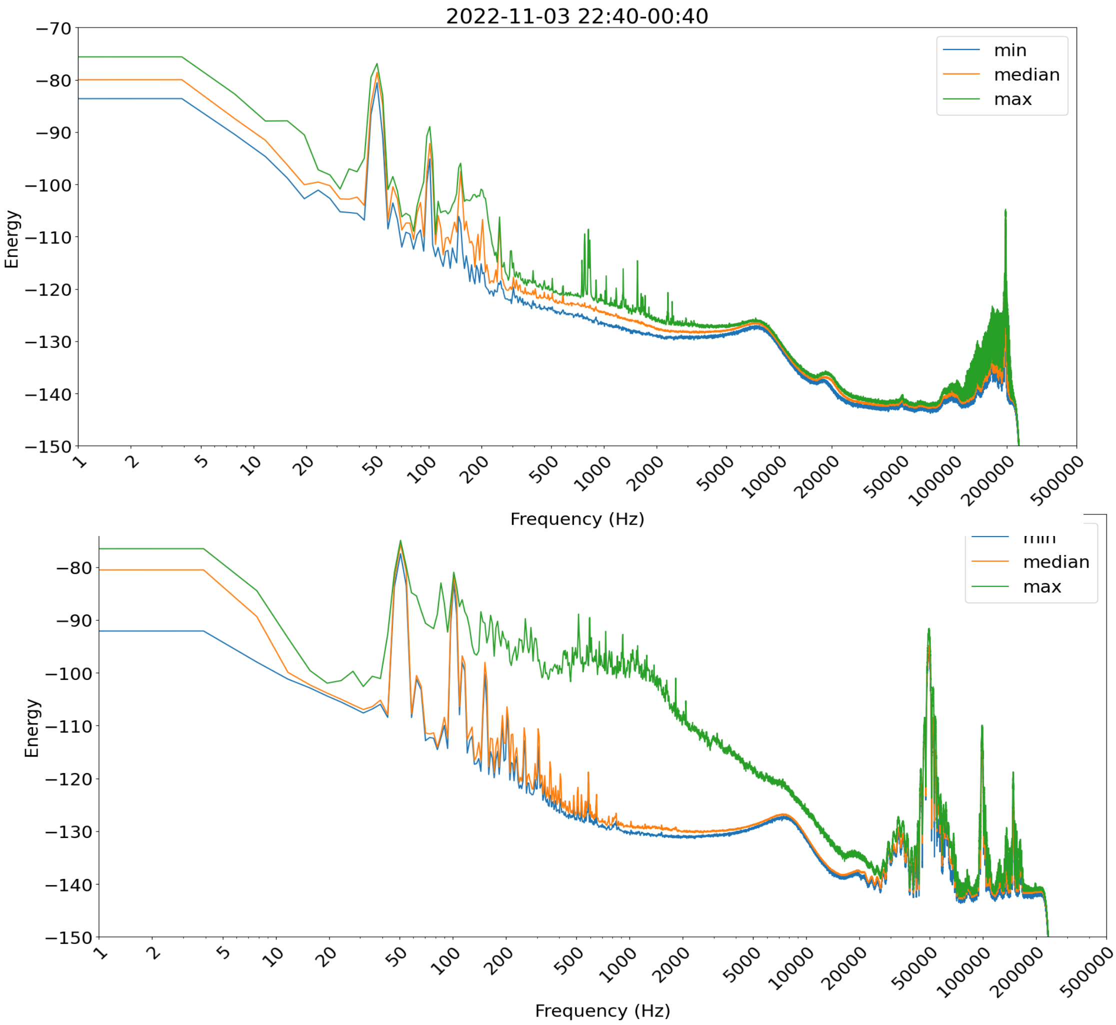


Figure 7.1 : dB measurements on 2 sites during the night of November 3 and 4, 2022, (Top) in the fjord north of Haudoya (White point on map 6.3), (Bottom) behind Haudoya green point on map 6.3). The energies before 300 Hz and after 5 kHz are partly observer artifacts (boat noise).

7.3 Soundscape of the Kvaenangen fjord

Thanks to the fixed antenna placed in the fjord, the soundscape over the entire winter period could be studied. Median dB levels were calculated in the low and mid frequencies (Figs 7.2 and 7.3). At low frequencies, ambient noise is around 70 dB. A noise dome centered at noon is visible (between 9 a.m. and 3 p.m.). This corresponds to a greater extent to the period of day, or of greater light during the polar night and therefore most certainly to the activity of the boats. Occasional very noisy events with +20 dB compared to the rest of the period can be noted, for example on December 8 and 9. The noise level observed corresponds, according to the Wenz chart (1962), to the noise usually observed with maritime traffic in shallow water. In the high frequencies, the background noise is around 50 dB and is relatively stable on a daily basis. Some events are notable with +20 dB, for example December 8 and 9 as well.

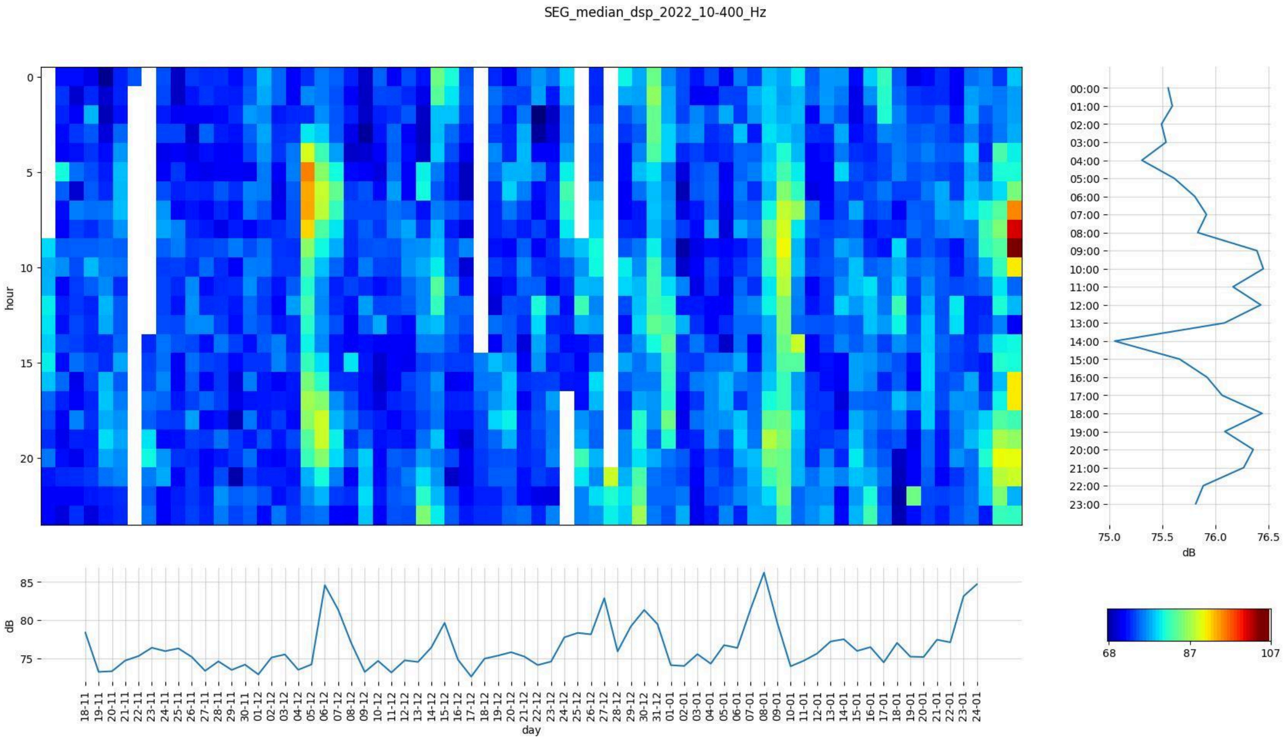


Fig 7.2 : Median dB level per day (abscissa) and per hour (online, in UTC) between frequencies 10 Hz to 400 Hz.

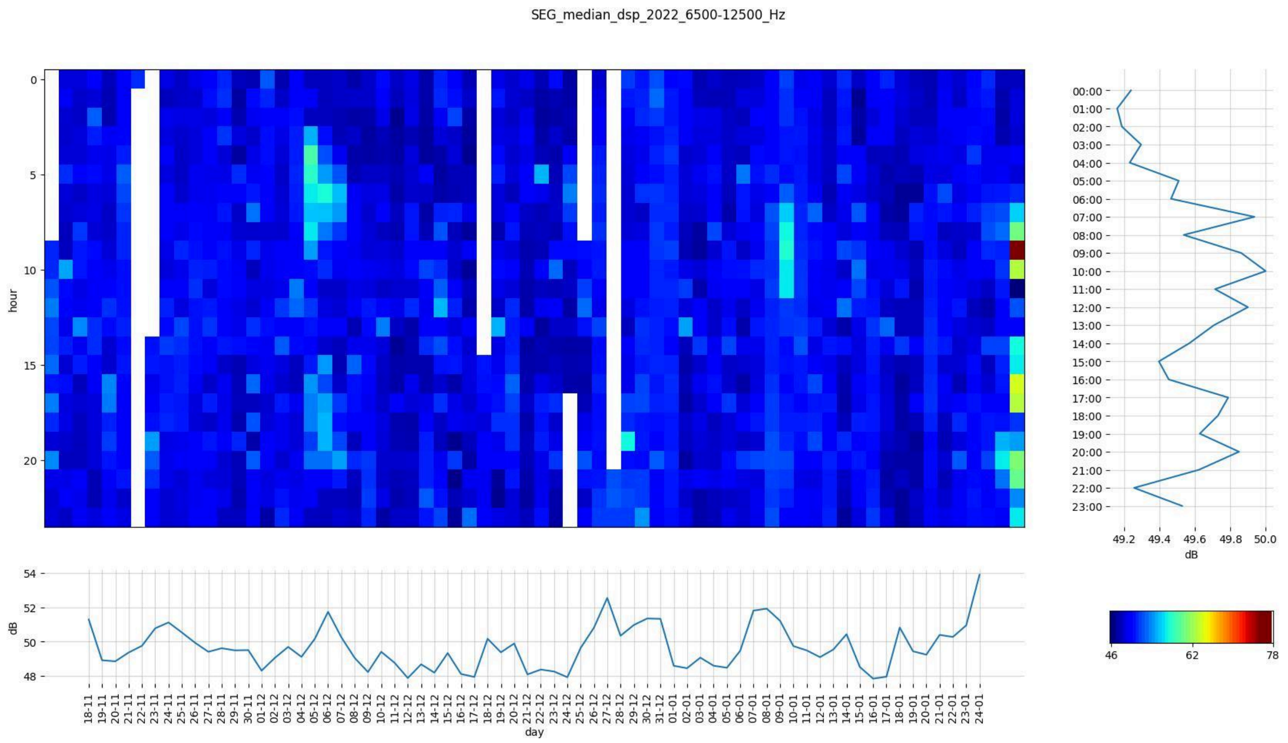


Fig 7.3 : Median dB levels per day (abscissa) and per hour (online, in UTC) from 6500 Hz to 12500 Hz. This PSD level in dB/Hz corresponds to sea force 3 (personal communication S. Jespers), which is on average the case in the Fjord.

7.4 Soundscape and acoustic presence of cetaceans

Anthropogenic noise has a negative influence on marine mammals. They could affect their behavior and many vital processes (orientation, communication). This influence depends on numerous acoustic characteristics including intensity, bandwidth or duration of exposure. We compared the evolution of the median sound level per day and per hour in low (10:400 Hz), medium (400:4000 Hz) and high frequencies (6500:12500 Hz) to the acoustic presence of cetaceans.

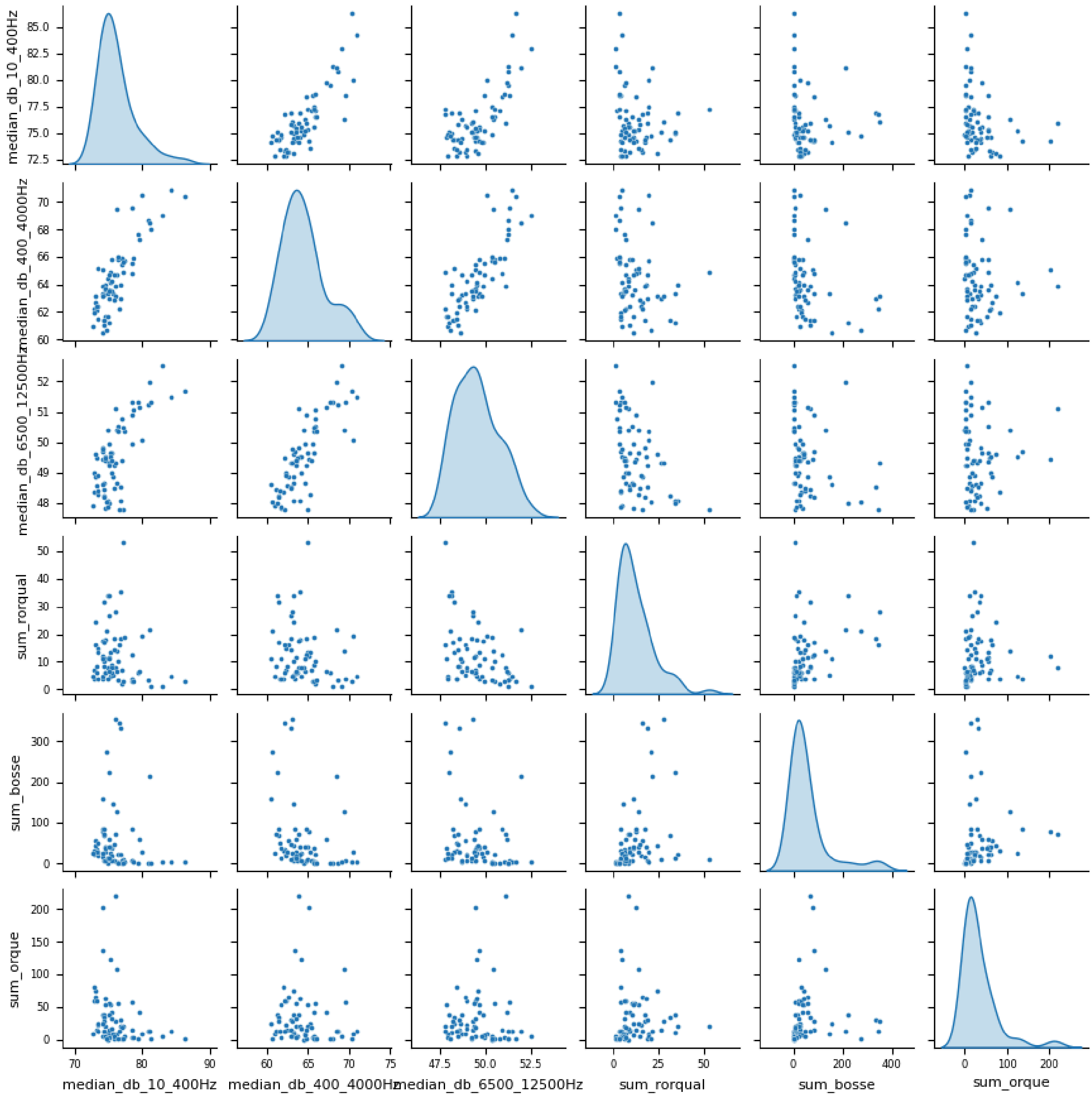


Fig 7.4 : Median number of detections per day for the three species studied from November 13, 2022 to January 22, 2023 and median noise level for low and medium frequencies.

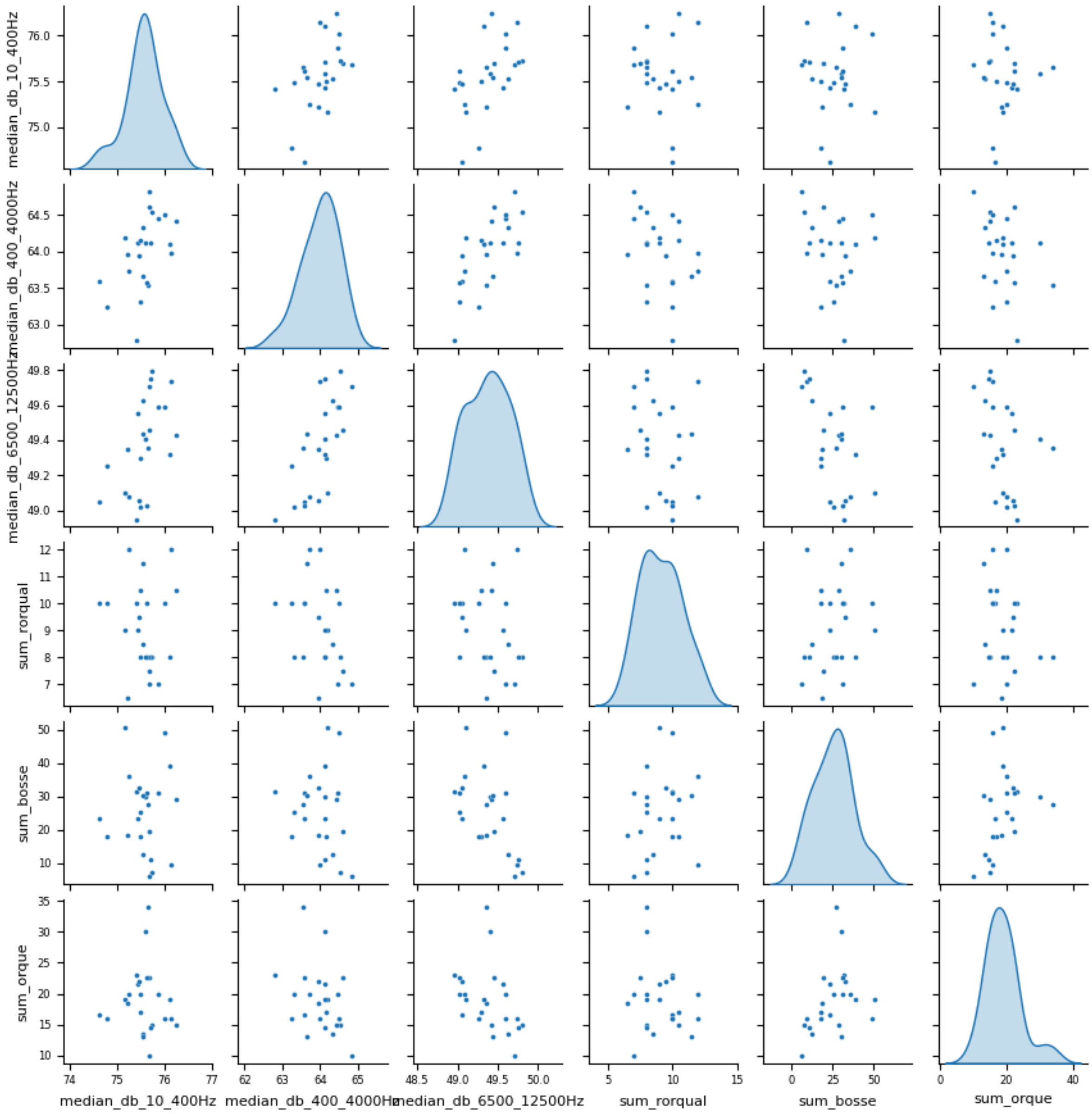


Fig 7.5 : Median number of detections per hour for the three species studied from November 13, 2022 to January 22, 2023 and median noise level for low and medium frequencies.

An anti-correlation is observed between the median noise level per day in high frequencies and the number of whale detections (r = -0.43, p-value = 0.0003). At the hour level (Fig 7.5), an anti-correlation was also found between median high-frequency noise and the number of humpback whale detections (r = -0.52, p-value = 0.009). These species emitting in frequency bands distinct from those with which they present anti-correlations, show that this is not a detection bias.

Humpback whales and rorquals could therefore adapt their acoustic behavior and be active at lower ambient noise. However, it is important to note that their acoustic activity also depends on their feeding behavior. In the previous section, we saw that humpback whales are vocally active during hunts but gradually decrease their activity during them. Whales, for their part, are quieter when feeding (Aulich et al. 2023). They could then be quieter at this time of the day because they are feeding. It is also important to remember that the median number of detections per hour for rorquals is relatively low.

The acoustic activity of orcas is not influenced by ambient noise, although a trend seems to indicate that these are less present (or less detected) when high frequency noise is higher (r = -0.36, p-value

= 0.08). Orcas need to communicate to socialize but above all to hunt and form herring balls in order to feed. As feeding is a priority, orcas feed even in a context of high ambient noise. It now remains to be determined whether the success of these hunts is impacted by ambient noise.

8. SeGaMas: acoustic modeling of the fjord and interaction models through serious games

The study of cetaceans is complex due to the inaccessibility of the marine environment and its low visibility. Passive acoustics is the most promising solution for studying them in a non-invasive way. Today, the detection and classification of recorded species is carried out automatically with good precision, in particular thanks to AI methods. However, using such methods to locate animals is still imprecise, due to the lack of data on their actual movements, and the small size of our antennas/buoys.

To overcome this, we are working on the creation of a complete model of acoustic scenes, called SeGaMas (Serious Game for Marine (mammals) Survey). This model includes the generation of realistic cetacean trajectories, the regular emission of a sound signal, the modeling of the propagation and the attenuation of this signal in a real environment until its reception by a sensor. As input, the model will receive bathymetric, oceanographic data and average ambient noise, as well as parameters linked to the scenario to be defined. As an output, it will provide the trajectories of the animals, the signal received and the path traveled by this signal (Fig. 10.1).

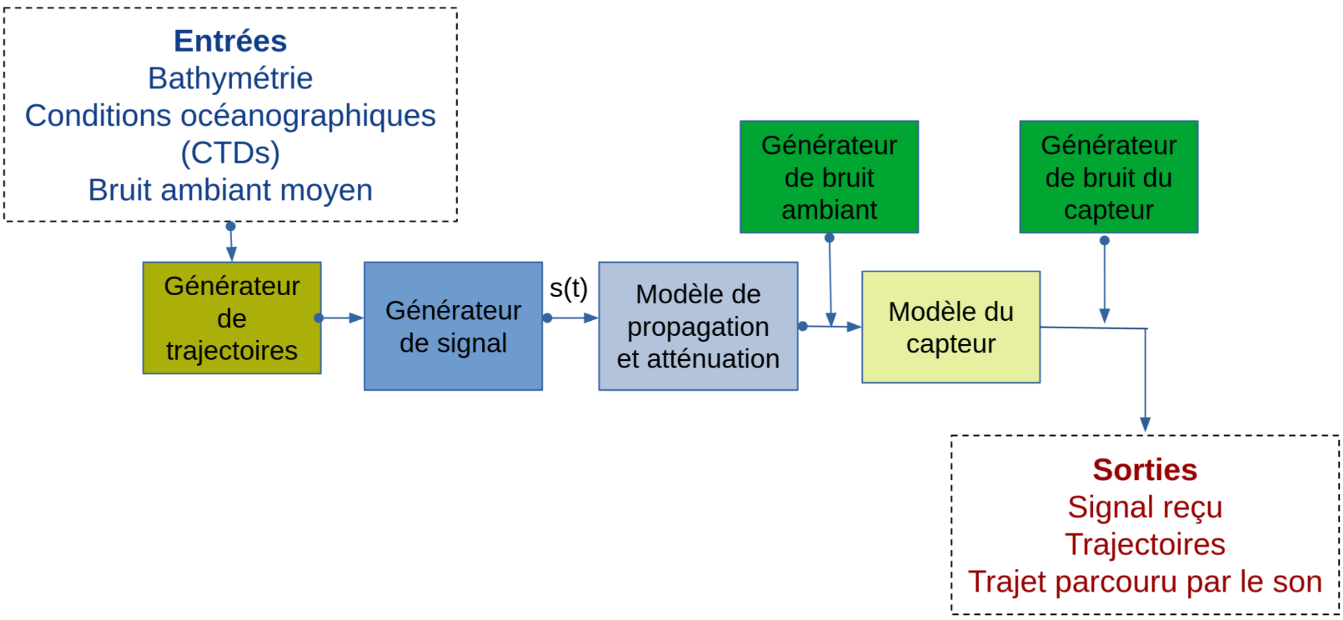


Fig 8.1 : Structure of the SeGaMas model

We first focus on a ray tracing sound propagation model, valid only for high frequencies. This model should soon operate in 2 dimensions in a real environment, with the assumption of a horizontally uniform ocean, without interference or diffraction phenomena. The model will take into account the refraction of sound due to differences in oceanographic conditions depending on depth, as well as reflections on the surface and at the bottom of the water. Throughout its trajectory, the signal will undergo modifications due to the physical and chemical properties of the water, and an attenuated signal will be received. The first models are tested in the fjord of Kvaenangen on 2 species of odontocetes (orcas and sperm whales) during the EUROPAM mission.

To date, we are able to emit sounds in an area of the fjord (Fig. 10.2 10.3), and to trace the propagation of several rays to a receiver. However, we still observe some bathymetry traversal artifacts that we are trying to correct.

Once the model is reliable in 2 dimensions, we plan to move on to 3-dimensional simulations. An intermediate step towards 3D will be N*2D, that is to say the extraction of several bathymetries following planes rotating around a point (a hydrophone), followed by the simulation of the propagation and attenuation of sound in each of the planes (Fig. 10.3). This part of the model is already operational.

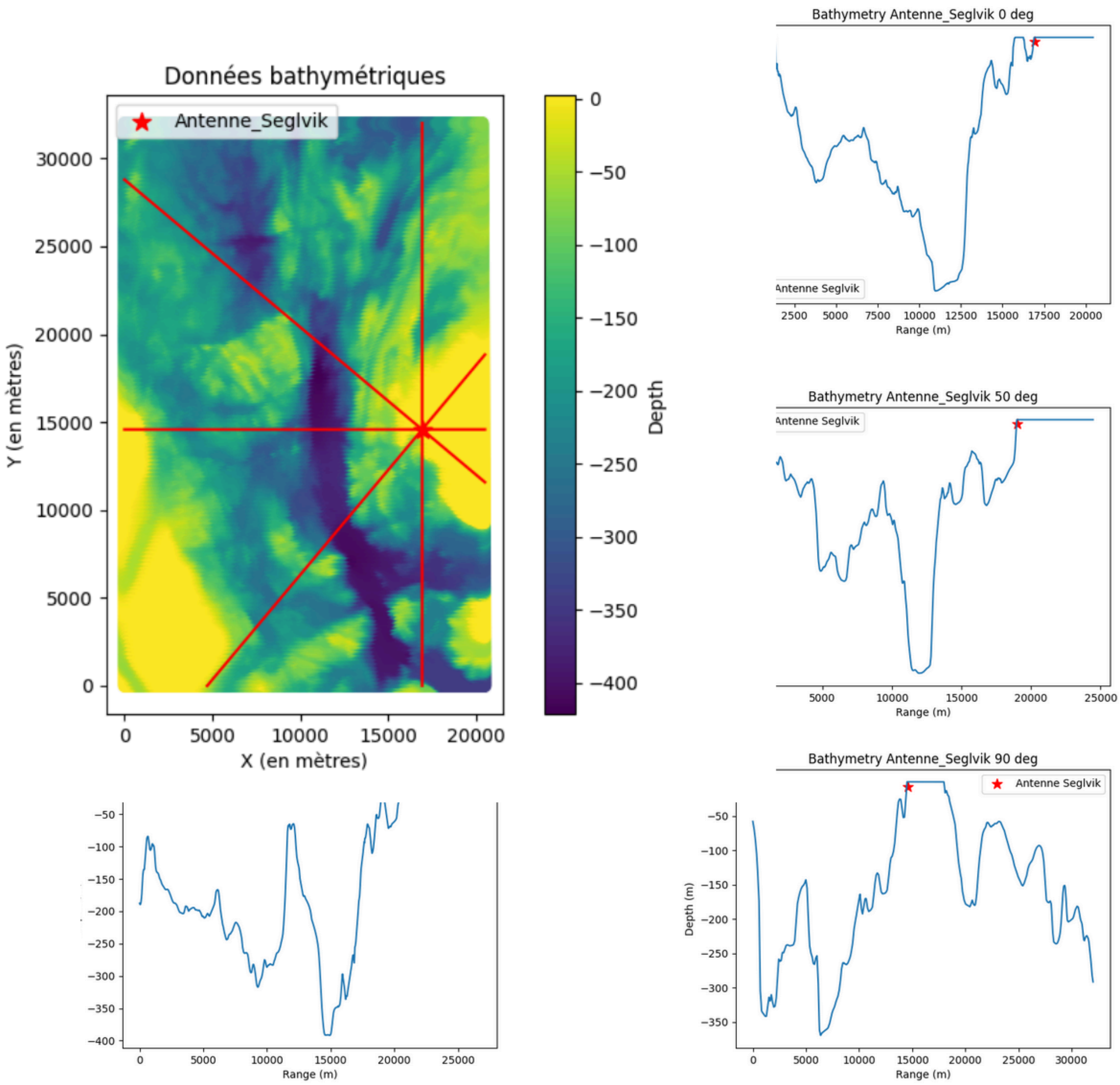


Fig 8.2 : Extractions of several 2D bathymetries from the 3D bathymetric map of the fjord. The user can choose the angles of interest for the extraction (0°, 50°, 90° and 140° in this example)

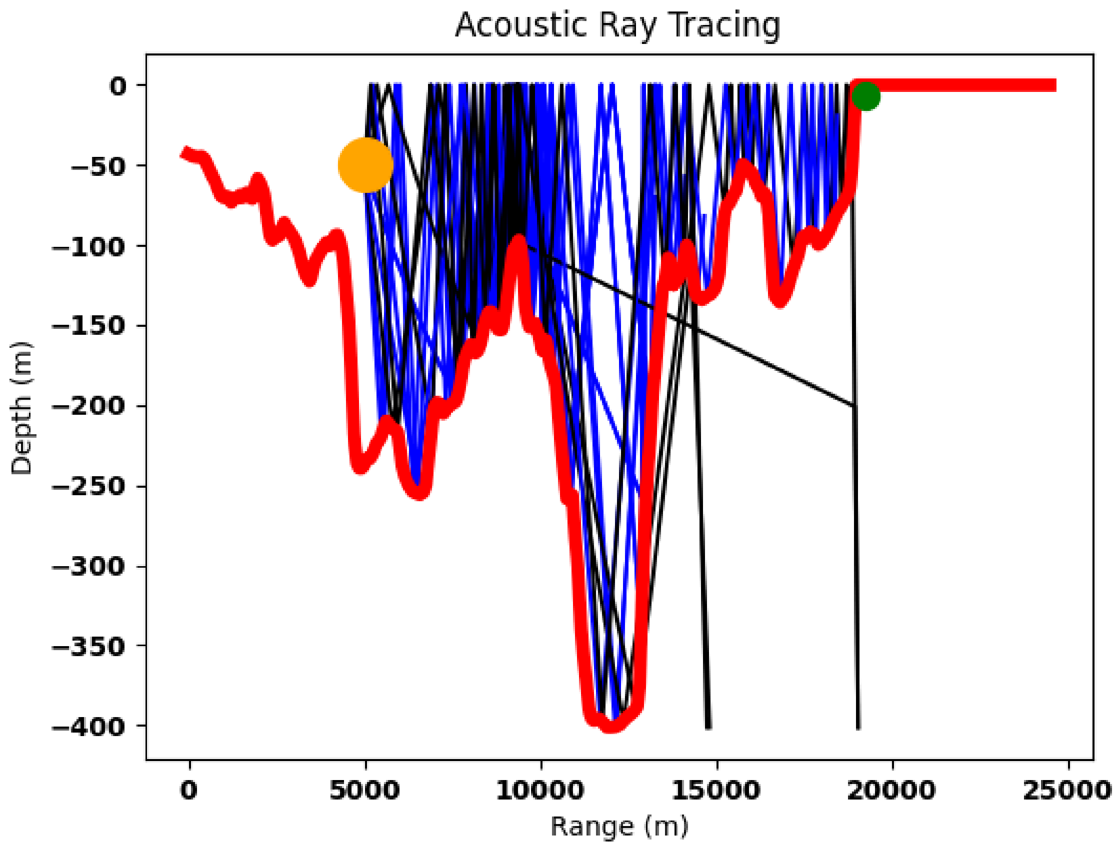


Fig 8.3 : Tracing of the ray tracing in this Kvaenangen fjord on the 50° section. The rays are emitted at the transmitter (in orange), propagate in the fjord, bouncing on the surface and at the bottom, until they arrive at a receiver (in green). The black rays are those which touch the receiver, and the blue those which do not reach it. Some aberrant rays are visible and will need to be corrected in future versions of the model.

The generation of realistic trajectories will take into account the kinematic constraints, head angle, animal behavior and their areas of interest, bathymetry, etc. Ultimately, we hope to be able to recreate scenes from animal life, simulating the trajectory of several individuals simultaneously, where each emits regular sounds.

The data simulated by SeGaMas will then be used to improve our TDoA and emission angle estimators, then to create position and trajectory estimators using Machine Learning. We also want to use SeGaMas to optimally position our sensors, in order to ensure maximum detections in a known area. Finally, this model will provide us with a better understanding of what cetaceans can say and hear, thanks to the possibility of reversing the transmitter-receiver roles. We will in fact be able to simulate the passage of a boat (here the transmitter) and the path of the sound emitted by this boat to a cetacean (here the receiver), and thus better understand the perceptions of these animals.

9. Discussion

This study is one of the first to describe a new behavior, which has appeared over the past ten years, in a population of humpback whales which is changing its migratory strategy to spend the winter in the Arctic, instead of migrating directly to the tropics like the others. These individuals, in addition to their usual feeding strategy, profit opportunistically from the herring balls gathered by the orcas, and are therefore in competition with the usual predators of these herring balls: the orcas.
The number of humpback whales has increased exponentially since hunting stopped 40 years ago (approximately 5 generations). This is reflected everywhere in the world where we see populations of whales "appearing" where there were none before", for example in Reunion. This impression of seeing whales arriving in new regions simply reflects our ecological amnesia which ignores the original situation before the hunt. We are studying a species in reconstruction. The more numerous whales today are reconquering the territories they occupied before being decimated by hunting and are rediscovering all the behaviors before the hunt. So, before the hunt, not all the whales migrated at the same time. In particular, pregnant females stayed in winter to eat herring before embarking on their journey to tropical waters to give birth. Analysis of the captures of humpback whales by whalers 100 years ago shows the capture of whales at the end of gestation in winter beyond the Arctic Circle, which is today confirmed by molecular sexing and hormonal analyzes (Kettemer et al. 2023).

The change observed over the past 10 years in the fjords simply reflects the better health of humpback whale populations and shows the effectiveness of the moratorium on hunting. On the other hand, current orcas, who did not experience the situation before the hunt, are faced with new competition from whales to which they must adapt. We therefore observe an incongruous cohabitation of two generations who rub shoulders again, with what this implies in terms of the superposition of their sounds.

These two species show a certain degree of vocalic interaction, with a modulation of the Call Rate, or still unknown productions: orca codas, and on the other hand biosonar clicks of a humpback whale as it approaches the herring ball. This is to probably locate it and swoop on it while minimizing interactions with the orcs. These phenomena resemble strategies of stealth and effective target detection, and perhaps minimize interference from the two species.

The fixed station, thanks to which we had continuous recording during the winter of 2022-2023, allowed us to highlight the co-occurrence of 3 species, soon four with the sperm whale in the 2024 records currently being analyzed. The current analyzes are studying the variation of the sequences and their interdependence, to test the hypothesis of their co-adaptation. This would notably provide knowledge on the plasticity of the acoustic sensorimotor systems of marine mammals. These models are expected in particular with regard to their possible adaptation to anthropophonic pollution.
The behaviour of parents and their offspring during feeding is influenced by one another. Parents feed depending on how much their offspring begs, while the offspring begs depending on how hungry it is. This would normally lead to a conflict of interest between parent and offspring, as the offspring will want to be fed as much as possible, whereas the parent can only invest a limited amount of energy into parental care. As such, selection would occur for the combination of begging and feeding behaviours that leads to the highest fitness, resulting in co-adaptation.[10] Parent-offspring co-adaption can be further influenced by information asymmetry, such as female blue tits being exposed more to begging behaviour in nature, resulting in them responding more than males to similar levels of stimuli.[11]

At the middle level, the CTD 1 measurement in the North is strongly influenced by the coastal currents (Norwegian Coastal Current) as shown by its comparison to stations inside Skjervøy. There are also differences between stations 2 to 5. These gradients could modify the structure of the herring schools that the echo sounder could reveal. The echo soundings carried out in 2022, after the hunts so as not to disturb them, are only to the east of Skjervøy at 15 min intervals, therefore in similar hydrographic conditions. More measurements are required for this hydrophysical study as well as school structures and predator behaviors. This hypothesis will be worked on with the corpora of the following mission in 2023. This hydrophysical characteristic could be a cause of the convergence point of humpback whales demonstrated by Tag since 2018 (Fig 11.1) and further confirmed by our bioacoustic pre-results.

In addition to tags, Bérubé's 2004 study genetically identified the same individuals in Norway and the Caribbean. We complete this work by showing the acoustic similarity between these individuals. We also show that humpback whale songs recorded in Norway have similarities with songs from the Caribbean (Winn et al 1978, Glotin et al 2021, Chavin 2022). These results are consistent with tagged whales in the Caribbean (Fig.11.1).

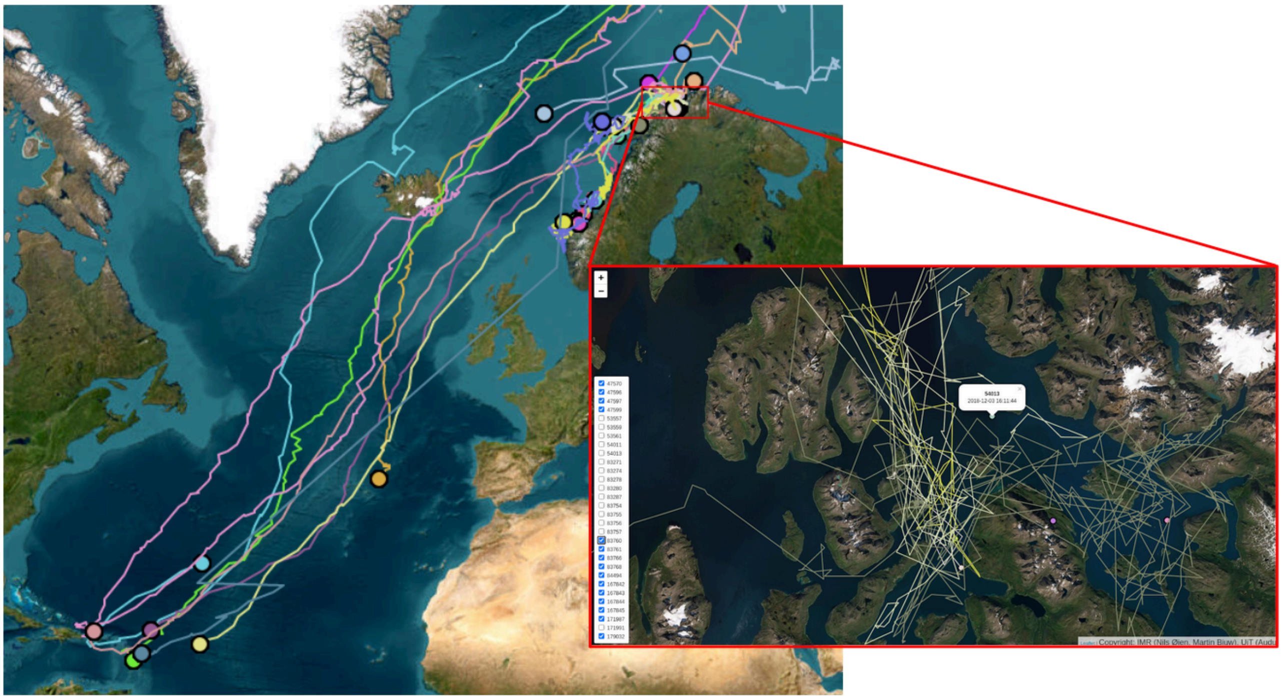


Figure 9.1 : Migration (by GPS TAG) of North Atlantic humpback whales in 2018 according to http://whaletracking2018.uit.no. We find the Eastern focal point Skjervoy / Bombyx EUROPAM as in 2022 following our recorded vocalization densities.

Our first results validate that the bioacoustic protocol, coupled with the photo-identification of individuals, will make it possible to work on the hypothesis of the discrimination of vocalizations individual by individual on orcas (or even the hypothesis of codas), and whales or group, type of song and dependence on the form of the song (Malige et al 2020).

10. Conclusion

The SWOT matrix of these 2022 and 2023 missions is given below. It provides an assessment of the assets and risks following feedback.

Table 11.1 : Project SWOT matrix

SWOT	Positive to achieve objective	Negative
Internal factors	Interdisciplinary team. Strong synergy. Original approaches and new interspecific paradigms Strong experience on previous missions and protocols Whale Way, Sphyrna Odyssée, Bombyx1 and 2 Strong AI data component through the ADSIL AI Chair http://bioacoustics.lis-lab.fr . Scientific instrumentation ahead of the state of the art. Annex of the Isbjorn allows close measurements. Crew completed in 2023 to meet the need. First model of predations of 4 superpredators	2022 crew of the Isbjorn to be consolidated by the addition of a sailor in order to intensify nighttime measures. Isbjorn annex to be reviewed. Note taking by dictaphone. Take more focused films with 2 TVs and 2 cameras per scene. Focus on the large males that sign the pods.
External factors	Opportunities : Link with our Biodiversa Europam 2023-2027 project which is starting in the region. Monitoring of the same humpback whales in the CARIMAM project. There is no other monitoring project on this scale in Norway/Caribbean.	Complex weather and visibility, addition of a week required. Variability of herring recruitment. Lunar cycle dependence? Evolution of fishermen quota? Anthropogenic disturbance?

The evolution of acoustic phenomena in space and time (codas, low-frequency clicks of humpback whales, interspecific modulation of the Call Rate, etc.) is conducted between the data from the two OPALES in 2021 and the OPALES in 2022. In addition, we are currently comparing the Isbjorn data from the start of the 2022 season with the following 12 weeks recorded by the OPALES then by Bombyx and the wire station installed. in Seglvik. The 2022 series is 2 TB and the 2023 mission collected 4 TB of data.

Two other acoustic stations built in Toulon by CNRS LIS, long term, will be installed to complete this first observatory in this area (installation in 2022 in Seglvik and Haudoya, red triangle), to monitor activities in the Fjord in the long term. It is one of the great advantages of the mission to install these instruments in collaboration with our Norwegian partner Akvaplan-niva. These long-term measurements give a precise view of the entries and exits of species and their activities, day and night, at the mouth or at the end of the Fjord. This will include one of our BOMBYX2 buoys equipped with 5 hydrophones and long autonomy (Fig.11.1).

Virtually the same team will be on board in November 2023, less a scientist and more a sailor. Indeed, the reinforced objective in 2023 is to follow groups of cetaceans from a safe distance, and in compliance with anthropogenic pressure, over several hours, by measuring their signals in context: without and with inter-species interaction, with and without fishermen or whale watchers. This on the three groups observed: orca, humpback whale and also rorqual that we also observed and photographed in the eastern zone over several days, from the north to the middle of the fjord.

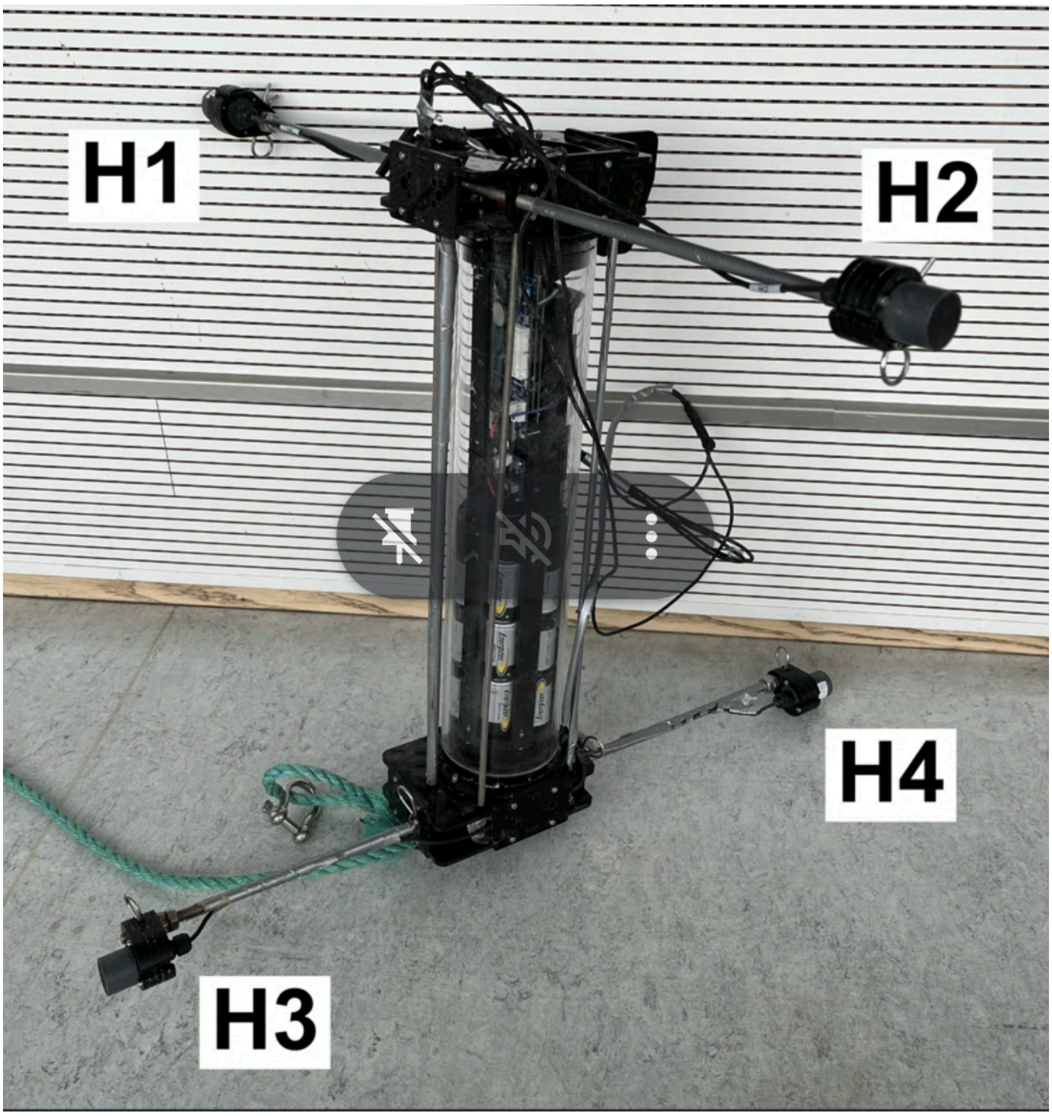


Figure 10.1 : BOMBYX3 DYNI LIS CNRS quadraphonic buoy, resulting from the know-how of the FEDER GIAS long autonomy program. These four hydrophones allow calculation of the bearing in azimuth and elevation of the sources, or even their distance, for detailed monitoring of wildlife over the long term. It was placed north of Haudoya Island, replacing the prototypical test buoy in the area placed (in stereo version) in our 2022 mission, but destroyed when it was taken over by a ship. It was rebuilt into 4 tracks and laid in November 2023 and successfully uploaded in January 2024. The data is being processed. A stereo ambisonic sample is available here:

http://sabiod.lis-lab.fr/pub/ADAPREDAT/bin_MMercier_HGlotin_23.wav

11 Dissemination, popularization and training

A project is currently requesting support from Arte for a film (Ecletic prod) on this mission. Others are requested by Thalassa et al.
A workshop dedicated to this mission is organized on March 15 at UTLN NEPTUNE MAYOL conference center in downtown Toulon, with the team and as guests the DGA AID bioacoustics experts, all members of the IA ADSIL Chair including M. Asch (LAMFA) and P. Cristini (LMA), acoustics experts. As well as PREMAR and the Ministry of the Environment.
A link will be built with the POLARPOD coPI Glotin mission for its Antarctic bioacoustics component, J. L. Etienne's 2026-2028 mission in Antarctica.

These missions will also provide course support, TD and TP in our AI, physics data, and bioacoustics training courses in UTLN masters. And one of the bases of a request for new international M2 training dedicated to bioacoustics AI and anthropogenic impact.

A show was broadcast at the Palais des Congrès Toulon at JS UTLN with TripInLab and spatialization of the signals from this mission.
This show will be broadcast at the United Nations Ocean Conference in May 2025 in Nice (UNOC).
A sample is available online at http://sabiod.lis-lab.fr/pub/ADAPREDAT/bin_MMercier_HGlotin_23.wav

12. ANNEXES

12.1 Example of a field sheet

UNIVERSITÉ DE TOULON | LIS | FJORD3D | Feuille de route N°: 2 | Date : 4 nov 2022 | LONGITUDE 181 La Voix de l'Océan

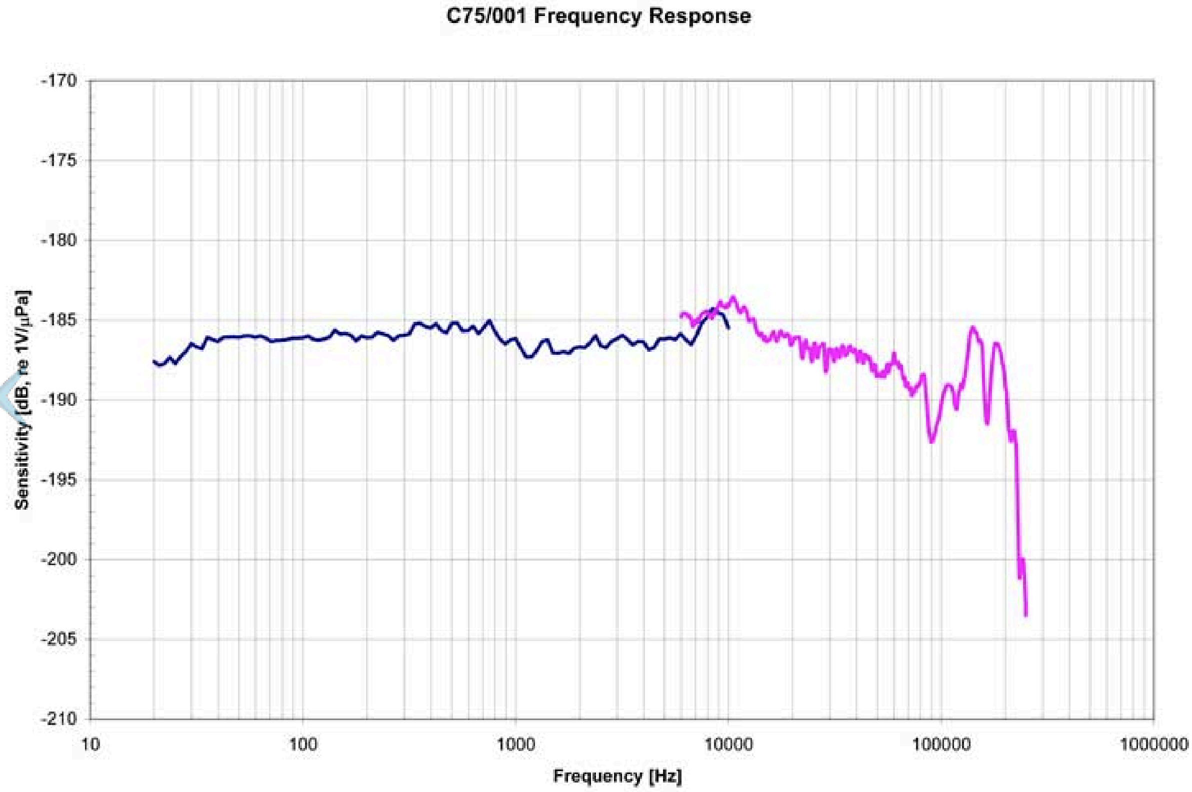
Heure	Latitude	Longitude	Infos : Route / Manip / Espèce / Bateau / Evènement / ...
12h14	70° 04, 61	21°15, 99	descente CTD3 - début : Inclinaison 0° - lest 10kg.
11h53			- souffles toujours au 200° = Groupe 2 de tout à l'heure? - Info whale watcher : feeding au N de Skervoy - - -
12h20	70° 04, 62	21° 15, 97	CTD3 au fond / début remontée
12h35	70° 04, 666	21° 15,985'	CTD3 relevée / Verticale sur toute la remontée
12h38			Remontée du poisson à bord.
12h40			Route vers feeding repéré - cap 260° -> passe S Arnøya info de Walhalla.
12h48	70° 04, 71	21° 13, 94	souffle au 215° = Av Bb à 1,5 mille.
12h50			2 caudales - les 2 B à B ont sondé
12h54			2 souffles.
12h59	70° 04, 75	21°10, 52	3 caudales au 230 à 1 mille, 5. 1 rorqual
13h00			1 orque au 245 à 500m
13h02	04,75	9,10	1 caudale au 210° isolée

12.2 Sensitivity of hydrophones

The hydrophone sensitivities given by the manufacturer follow.

Figure 13.1: SQ26-07 sensitivity

Frequency Response graph for C75



CETACEAN RESEARCH™ C75 hydrophone Frequency Response graph - log scale

	C75 / C75X
Linear Frequency Response Range (±3dB) [kHz]	0.010 to 170
Usable Frequency Range (+3/-12dB) [kHz]	0.003 to 250
Transducer Sensitivity* [dB, re 1V/µPa]	-200
Preamplifier Gain [db]	20 / 33
Effective Sensitivity* [dB, re 1V/µPa]	-180 / -167
SPL Equiv. Self Noise at 1kHz [dB, re 1µPa/√Hz]	51
Power Requirement [Vdc]	5 to 32
RMS Overload Acoustic Pressure [dB, re 1µPa]	184 to 201 / 171 to 188
Maximum Operating Depth ** [m]	920
Operating Temperature Range [°C]	-40 to 85
Output Impedance [Ω]	10
Dimensions [mm]	92**L** x (25 to 18)**is.**
Integral Connector†	Subconn MCBH3MSS
Directionality	omnidirectional

Figure 12.2: C75 sensitivity

12.3 Team CV

Hervé Glotin

Hervé Glotin (http://glotin.univ-tln.fr) is Professor of Computer Science at Toulon Univ. at the LIS CNRS. His PhD focused on adaptive multi-stream automatic speech recognition via voicing and location cues, at the Inst. of Perceptual Artificial Intelligence (AI) (IDIAP EPFLausanne & INP Grenoble). He created the DYNI team in 2008 and has been running AI workshops for bioacoustics since 2007: 10 editions of ERMITES schools, ICML2013-14, NIPS2013, ICDM2015... including the first hackathons for classification or structuring of bird or cetacean songs. Since 2012 he has led the CNRS Big Data Acoustic Biodiversity group (http://sabiod.org), and conducts his research in AI for monitoring biodiversity, particularly marine biodiversity. In 2017 he co-organized the Int. Conf. on learning representation (1500 participants). He is an honorary member of the Inst. University of France, and has held the National Chair in AI for underwater bioacoustics since 2020 (http://bioacoustics.lis-lab.fr). He has been the scientific director of the Sphyrna Odyssey Expeditions since 2018 (https://www.sphyrna-odyssey.com) for the acoustic study of oceans and cetaceans. With his team, he has developed original methods for monitoring cetaceans of several species without disturbance, particularly during their hunting activity. He set up the GIAS BOMBYX program of hearing 'smart' buoys with on-board AI to prevent collisions of cetaceans with traffic in real time (FEDER GIAS). He is a member appointed by the ministry of the National Scientific Committee of the CNRS.

Selected publications:

- **H. Glotin** et al. (2021) Effect of confinement at sea and discovery of sperm whale pack hunting, Mission Sphyrna report, Exploration of Monaco and FPA2 http://sabiod.org/SO1.pdf
- M. Poupard, Ferrari M., Schluter J., Marxer R., Giraudet P., Barchasz V., ... & **Glotin H**. (2019) Real-time passive acoustic 3d tracking of deep diving cetacean by small non-uniform mobile surface antenna. In *ICASSP IEEE Int. Conf. on Acoustics, Speech and Signal Processing* (pp. 8251-8255)
- M. Ferrari, **Glotin H.**, Marxer R., & Asch M. (2020). DOCC10: Open access dataset of marine mammal transient studies and end-to-end CNN classification. In IEEE *Int. Joint Conf. on Neural Networks (IJCNN)*
- M. Ferrari, **Glotin H.,** Marxer R., Barchasz V., Sarano V., Giés V., ... & Sarano F. (2019) High-frequency near-field Physeter macrocephalus monitoring by stereo-autoencoder and 3d model of sonar organ. In IEEE *OCEANS*
- F. Sarano, J. Girardet,, V. Sarano, H. Vitry, A. Preud'homme, R. Heuzey, A M Garcia Segarra, G. Richard, P. Tixie, J. Guinet, F. Delfour, **H. Glotin**, O. Adam & J.L. Jung *(2021), Kin relationships in cultural species of the marine realm: case study of a social group of Sperm Whales off Mauritius Island, Indian Ocean*. Royal Society Open Science 8: 201794. https://doi.org/10.1098/rsos.201794
- M. Poupard, M. Ferrari, P. Best, **H. Glotin**, (2021), Passive acoustic monitoring of Sperm whales & anthropogenic noise using stereophonic recordings in the Mediterranean NW Pelagos Sanctuary, In press Scientific Report Nature Ed.
- M. Poupard, S. Symonds, P. Spong, **H. Glotin** (2021) Intra-Group Orca Call Rate Modulation Estimation Using Compact Four Hydrophones Array, in Journ. Frontiers in Marine Science, Marine Megafauna, https://doi.org/10.3389/fmars.2021.681036
- B. Bouchard, JY Barnagaud, M. Poupard, **H. Glotin**, P. Gauffier, S. Ortiz,T. J. Lisney, S. Campagna, M. Rasmussen, A. Célérier (2019) Behavioural responses of humpback whales to food-related chemical stimuli, In Plos ONe, https://doi.org/10.1371/journal.pone.0212515
- **H. Glotin**, F. Bénard, P. Giraudet (2008), Whale Cocktail Party : a Real Time tracking of multiple whales, Canadian Acoustics Int. Journal, Vol. 36, p. 139-145

Nathalie Prévot D'Alvise

Mlecturer since 2007 at the University of Toulon, CNRS MIO, EMBIO team. His research focuses on the effect of endocrine disruptors on marine organisms through the use of molecular biology tools. During the numerous missions she carried out in the Mediterranean Sea, she was able to assess the impact of glyphosate on Mediterranean wolves (*Dicentrarchus labrax*), female contraceptive pill on speckled seahorses (*Hippocampus guttulatus*), trace metals on sea urchins (*Paracentrotus lividus*)... or even assess the stress of certain farmed fish, such as sturgeon.

Selected publications:

- **Prevot D'Alvise N.**, Ascensio E., Richard S. Influence of EE2 exposure, age and sex on telomere length in European long-snouted seahorse (*Hippocampus guttulatus*). *General and Comparative Endocrinology* 346, 114419 (January **2024**) DOI: 10.1016/j.ygcen.2023.114419

- N. Prévot D'Alvise, S. Richard, P. Aublanc, R. Bunet, JL Bonnefont (**2020**), When males seahorses take the female contraceptive pill. *Environmental Science and Pollution Research*, 27, 16528-16538

- S. Coupé, F. Clergeaud, S. Couvray, G. Durrieu, S. Richard, S. D'Onofrio, S. Gaillard, T. Miard, JL Bonnefont, C. Garnier, **N. Prévot D'Alvise** (**2020**) Differential Acclimation of Juvenile Sea Urchins Transplanted Across a Metallic Trace Element Gradient within the Bay of Toulon. *Jour. of Shellfish Research, 39(1), 143-158*

- S. Coupe, S. Couvray, M. Lechable, - S. Gaillard, **N. Prévot D'Alvise (2019)**, Telomere Length as a Biomarker for Monitoring Wild Populations of the Sea Urchin *Paracentrotus lividus*, J. of Shellfish Research
- R. Simide, S. Richard, **N. Prévot D'Alvise**, T. Miard, S. Gaillard (2016), Evaluation of the accuracy of secondary stress indicators from blood samples for the monitoring of stress, health status and welfare in Siberian sturgeon. *Int. Aquatic Research*, DOI 10.1007/s40071-016-0128-z

Valentin Gies

Valentin Gies received in 2005 the PhD degree in Electronics from Ecole Nationale Supérieure de Techniques Avancées (ENSTA ParisTech) and Paris XI Orsay University in France. His PhD was focused on both circuits and algorithms for artificial Retinas. Before in 2001, he graduated from Ecole Normale Supérieure, obtaining the *agregation* in Applied Physics. He is lecturer and researcher at Toulon University since 2007, and Associate Professor in robotics, embedded electronics and IoT at SeaTech, ISEN Toulon and ENSTA ParisTech. He joined IM2NP CNRS laboratory in 2017, in the Circuits Design Team. His current research topics are focused on embedded algorithms and circuits for ultra low power systems, especially for bioenvironmental embedded systems. He is scientific advisor of several start-ups in IoT and head of SMIoT (Scientific Microsystems for Internet of Things) at Toulon University.

Selected publications:
- **V. Gies** (2021) "Toward Ultra Low-Power Artificial Intelligence" - Authorization to Direct Research.
- S. Marzetti, **V. Gies**, P. Best & al. (2021), A 30 µW Embedded Real-Time Cetacean Smart Detector, J. MDPI Electronics
- M. Fourniol, **V. Gies**, V. Barchasz, E. Kussener, H. Glotin (2018) « Applications of an Ultra Low-Power Analog Wake-up Detector for Environmental IoT Networks and Military Smart Dust », IEEE IoTAIS 2018
- H. Glotin, G. Blakefield, M. Trone, D.E. Bonnett, **V. Gies**, V. Barchasz, J. Patris, P. Giraudet, F. Malige, R. Balestriero (2016) High definition 3D tracking of Amazon River dolphin (Inia g., Sotalia f.), in ASA proc.
- M. Fourniol, **V. Gies**, V. Barchasz, E. Kussener, H. Barthelemy, R. Vauché, H. Glotin (2018), Analog Ultra Low-Power Acoustic Wake-Up System Based on Frequency Detection, IEEE IoTAIS
- M. Ferrari, H. Glotin, R. Marxer, V. Barchasz, V. Sarano, **V. Gies**, M.Asch, F.Sarano (2019), High-frequency Near-field Physeter macrocephalus Monitoring by Stereo-Autoencoder and 3D Model of Sonar Organ, IEEE OCEANS

Francois Sarano

Doctor in eco-physiology of hake reproduction, François was a diver and expedition leader aboard Commander Cousteau's Calypso (1985-1997). Head of the "Fisheries Resources" department for WWF-France, and at the origin of the concept of UEGC, Concerted Exploitation and Management Units, for sustainable management of fishery resources by fishermen. Co-founder of the Longitude 181 association. Diver, scientific advisor and co-writer of the film *Oceans* by J. Perrin and J. Cluzaud. Scientific advisor and/or author and/or director of 8 TV documentaries dedicated to cetaceans and sharks. Author of several books, including "The Return of Moby Dick", Actes Sud, 2017. Since 2013, on behalf of Longitude 181, he has coordinated the study of the sperm whale population of Mauritius to better understand its social structure and its evolution. The study is based on underwater observation and 3D acoustic recordings of a clan of sperm whales for which it produced underwater identity cards and a family tree. This cross-sectional study is carried out in collaboration with the AI bioacoustics and ethoacoustics laboratories (LIS /DYNI/ CNRS Toulon - Hervé Glotin), genetics (MNHN Brest - Jean-Luc Jung - Justine Girardet), ethology (La Sorbonne - Fabienne Delfour) and bioacoustics (La Sorbonne - Olivier Adam).

Selected publications

- J. Girardet, **F. Sarano**, G. Richard, P. Tixier, C. Guinet, A. Alexander, V. Sarano, H. Vitry, A. Preud'homme, R. Heuzey, A. M. Garcia-Cegarra, O. Adam, B. Madon & J-L Jung (2022): *Long distance*

runners in the marine realm: new insights into genetic diversity, kin relationships and social fidelity of Indian Ocean male sperm whales. Front. Mar. Sci. 9:815684. https://doi.org/10.3389/fmars.2022.815684
- **F. Sarano**, J. Girardet,, V. Sarano, H. Vitry, A. Preud'homme, R. Heuzey, A M Garcia Segarra, G. Richard, P. Tixie, C. Guinet, F. Delfour, H. Glotin, O. Adam & JL Jung *(2021), Kin relationships in cultural species of the marine realm: case study of a social group of Sperm Whales (Physeter macrocephalus) off Mauritius Island, Indian Ocean*. Royal Society Open Science 8: 201794. https://doi.org/10.1098/rsos.201794
- V. Sarano, **F. Sarano**, J. Girardet, A. Preud'homme, H. Vitry, R. Heuzey, M. Sarano., F. Delfour, H. Glotin H., O. Adam, B. Madon, J-L. Jung (2022): *Underwater photo-identification of sperm whales (Physeter macrocephalus) off Mauritius.* Marine Biology Research https://doi.org/10.1080/17451000.2022.2040737

- M. Ferrari, H. Glotin, M. Oger, R. Marxer, M. Asch, V. Gies & **F. Sarano** (2020), *3D diarization of a sperm whale click cocktail party by an ultra high sampling rate portable hydrophone array for assessing individual cetacean growth curves*. FA2020, hal-03078655
- **F. Sarano**, V. Sarano, O. Adam, J. Girardet, H. Vitry, A. Preud'homme, R. Heuzey, H. Glotin, J-L Jung & F. Delfour (2019), *A focal animal 6-points Likert scale to rate intra-unit interactions in Sperm whales off Mauritius Island.* World Marine Mammal Conference, Barcelona, Book of Abstracts p.112

L'association Longitude 181 aims to protect the marine environment and equitably share its resources, based on the *International Charter for Responsible Diving*. She leads sperm whale study and awareness programs and the sharks, the program Ocean Academy intended for youth, and the countryside "Here the ocean begins" which pushes everyone to act on a daily basis to reduce their impact on the ocean (see the book "Let's save the ocean")

Marion Poupard

Marion Poupard is a post-doctoral researcher as part of the ADSIL (ADvanced underSea Intelligent Listening) chair in the DYNI team within the LIS laboratory. Marion completed a thesis in bioacoustics within the team, where she was able to work on sperm whales, orcas, and Pantropical spotted dolphins. During this thesis work, she set up with the team an acoustic protocol in Orcalab (Canada, north of Vancouver) for the individual acoustic observation of orcas over several months. She was able to embark on various scientific missions such as the oceanographic vessel Tara Expedition (Papua), Sphyrna Odyssey (Mediterranean Sea), Mission Live Together (Between Nice and Corsica) for the acquisition of bioacoustic data. This thesis work focused on the classification and localization of marine and terrestrial sound sources for different scales of study which are the specific, population and individual scale.

Selected publications:

- **Poupard** M., Symonds H., Spong P., & Glotin H. (2021) Intra-Group Orca Call Rate Modulation Estimation using Compact Four Hydrophones Array. *Frontiers in Marine Science*, 1383.
- **Poupard** M., Ferrari M., Best P., Glotin H. (2021) Passive acoustic monitoring of sperm whales and anthropogenic noise using stereophonic recordings in the Mediterranean North West Pelagos Sanctuary, Scientific Report, Nature Ed.
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- Bouchard, B., Barnagaud, J. Y., **Poupard**, M., Glotin, H., Gauffier, P., Torres Ortiz, S., ... & Célérier, A. (2019). Behavioural responses of humpback whales to food-related chemical stimuli. *PloS one*, *14*(2), e0212515.
- **Poupard**, M., de Montgolfier, B., & Glotin, H. (2019). Ethoacoustic by bayesian non parametric and stochastic neighbor embedding to forecast anthropic pressure on dolphins. In *OCEANS,* IEEE
- **Poupard**, M., Best, P., Schlüter, J., Symonds, H., Spong, P., Lengagne, T., ... & Glotin, H. (2019). Large-scale unsupervised clustering of Orca vocalizations: a model for describing Orca communication systems. In *2nd Int. Workshop on Vocal Interactivity in-and-between Humans, Animals and Robots*.

Maxence Ferrari

Maxence Ferrari is a post-doctoral fellow in the AI chair of the Defense Innovation Agency and the ANR (PI Glotin) ADSIL. He graduated from Centrale Lille and has a doctorate in mathematics. He works mainly in bioacoustics, with signal processing and machine learning techniques. He carried out several missions to place antennas and collect acoustic data at sea, mainly on sperm whales.

Selected publications:

-**M. Ferrari** (2020) *Study of a biosonar based on the modeling of a complete chain of emission-propagation-reception with validation on sperm whales* (Doctoral dissertation, Amiens & UTLN).

- Mr. Poupard, **M., Ferrari**, M., Schluter, J., Marxer, R., Giraudet, P., Barchasz, V., ... & Glotin, H. (2019). Real-time passive acoustic 3d tracking of deep diving cetacean by small non-uniform mobile surface antenna. In *ICASSP IEEE Int. Conference on Acoustics, Speech and Signal Processing* (pp. 8251-8255)
- **M. Ferrari**, H. Glotin., Marxer R., & Asch M. (2020). DOCC10: Open access dataset of marine mammal transient studies and end-to-end CNN classification. In IEEE *Int. Joint Conf. on Neural Networks (IJCNN)*
- **M. Ferrari**, H Glotin, R. Marxer, V. Barchasz, T. Sarano, V. Giés, … & Sarano, F. (2019). High-frequency near-field Physeter macrocephalus monitoring by stereo-autoencoder & 3D model of sonar organ. In IEEE *OCEANS*
- Mr. Poupard, **Ferrari, M**., Schluter, J., Astruch, P., Schohn, B., Rouanet, B., ... & Glotin, H. (2019). Passive acoustics to monitor flagship species near boat traffic in the unesco world heritage natural reserve of scandola. In *Input Academy: Int. Conference on Innovation in Urban and regional planning*.

Pascale Giraudet

Pascale Giraudet is an associate professor of Life and Earth Sciences at the University of Toulon. A graduate of the Ecole Normale Supérieure Ulm and holder of a doctorate in Cognitive Sciences on neuronal coding in mammals, she has been pursuing her research activities in the bioacoustics of marine mammals for 13 years in the DYNI team at the LIS CNRS University of Toulon. She has already participated in numerous bioacoustic scientific missions on land and at sea, notably on Sperm Whales and Orcas.

Selected publications:

- O. Dufour, T. Artières, H. Glotin, **P. Giraudet** (2013), Clusterized Mel Filter Cepstral Coefficients and Support Vector Machines for Bird Song Identification, in Soundscape Semiotics, Localization & Categorization, Tech Open Book
- H. Glotin, **P. Giraudet** et al. (2013), Tracking multiple marine mammals by shortly or widely spaced hydrophones, in Dirac NGO, Detection Classification localization of Marine Mammals using passive acoustics, ISBN 978-2-7466-6118-9, pp. 71-92
- F. Bénard, H. Glotin, **P. Giraudet** (2010) Whale 3D monitoring using astrophysic NEMO ONDE two meters wide platform with state optimal filtering by Rao-Blackwell Monte Carlo data association, J. of Applied Acoustics, V71
- H. Glotin, F. Bénard, **P. Giraudet** (2008), Whale Cocktail Party : a Real Time tracking of multiple whales, Canadian Acoustics Int. Journal, V 36, p. 139-145
- **P. Giraudet**, H. Glotin (2006), Real-time 3D tracking of whales by echo-robust precise TDOA estimates with a widely-spaced hydrophone array, Int. Jour. Applied Acoustics, Elsevier Ed., V67, Issues 11-12, pp 1106-1117

Véronique Sarano

Holder of a doctorate on the assimilation-regeneration system of nutrient salts in the Southern Ocean, she was scientific advisor on Antarctic issues for the Cousteau Foundation: campaign for the moratorium on the exploitation of Antarctica, observation mission on the landing strip in Adélie Land, French Committee for the Polar Environment (1988-1997). Coordinator on board of cetacean observation and study missions in the Mediterranean as part of WWF-France. Co-founder of the Longitude 181 association in 2002, general secretary for 10 years, responsible for shark and waste campaigns, responsible for sperm whale missions at sea and coordinator of the study on sperm whales in Mauritius since 2015 with François Sarano (see details above). Author of around fifteen books (travel books, Libya guide, and youth encyclopedias on nature) as well as numerous popular science reports for magazines.

Selected publications:

- J. Girardet, F. Sarano, G. Richard, P. Tixier, C. Guinet, A. Alexander, **V. Sarano,** H. Vitry, A. Preud'homme, R. Heuzey, A. M. Garcia-Cegarra, O. Adam, B. Madon & J-L Jung (2022): *Long distance runners in the marine realm: new insights into genetic diversity, kin relationships and social fidelity of Indian Ocean male sperm whales*. Front. Mar. Sci. 9:815684. https://doi.org/10.3389/fmars.2022.815684
- F. Sarano, J. Girardet, **V. Sarano**, H. Vitry, A. Preud'homme, R. Heuzey, A M Garcia Segarra, G. Richard, P. Tixie, C. Guinet, F. Delfour, H. Glotin, O. Adam & JL Jung *(2021) Kin relationships in cultural species of the marine realm: case study of a social group of sperm whales (Physeter macrocephalus) off Mauritius Island, Indian Ocean*. Royal Society Open Science 8: 201794. https://doi.org/10.1098/rsos.201794
- **V. Sarano**, F. Sarano, J. Girardet, A. Preud'homme, H. Vitry, R. Heuzey, M. Sarano., F. Delfour, H. Glotin H., O. Adam, B. Madon, J-L. Jung (2022): *Underwater photo-identification of sperm whales (Physeter macrocephalus) off Mauritius.* Marine Biology Research https://doi.org/10.1080/17451000.2022.2040737

- F. Sarano, **V. Sarano**, O. Adam, J. Girardet, H. Vitry, A. Preud'homme, R. Heuzey, H. Glotin, J-L Jung & F. Delfour (2019), *A focal animal 6-points Likert scale to rate intra-unit interactions in sperm whales off Mauritius Island.* World Marine Mammal Conference, Barcelona, p.112

Jean-Marc Prévot

Senior design engineer at UTLN, Systems and network administration, development of embedded solutions on RaspberryPi type cards. A trained electronics engineer and expert in digital data, his role will be to ensure the archiving in RED NAS of the data on board, estimated for the week at 18 TB. He has participated in around twenty missions, over the past ten years, at sea and on land, in order to set up bioacoustic listening devices previously designed in the laboratory.

Selected publications

- R. Bunet, **JM Prévot**, N. Vicente , JR Garcia-March , R Martinović , J Tena-Medialdea , D Joksimovic , JL Bonnefont , S Coupé (2021), First insight into the whole genome shotgun sequence of the endangered noble pen shell *A noble fin*: a giant bivalve undergoing a mass mortality event, Journal of Molluscan Studies, V 87, Issue 1, eyaa041, https://doi.org/10.1093/mollus/eyaa04
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- M. Poupard, P. Best, J. Schlüter, **JM Prévot**, H. Symonds, P. Spong, H. Glotin (2019), Deep Learning for Ethoacoustics of Orcas on three years pentaphonie continuous recording at Orcalab revealing tide, moon and diel effects, OCEANS IEEE, pp. 1-7, 10.1109/OCEANSE.2019.8867251.

Julie Father

Holder of a doctorate in astrophysics (2002, Paris 6) as well as a doctorate in bioacoustics (2019, UTLN), Julie Patris is an associate professor at the University of Aix Marseille in the physics department. For several years, she has been interested in the design, implementation and analysis of bioacoustics missions in Latin America (Atacama, Patagonia). His research focuses on signal analysis and modeling of the propagation of sound of biological or anthropogenic origin, as well as the study of measuring the impact of anthropogenic noise on the ocean environment.

Selected publications:

- **Patris, J** (2019) “Contributions to methods for monitoring mysticetes by passive acoustics”, PhD thesis, 18th of December
- **Patris J.** Malige F., Glotin, H., Asch, M. & Buchan, S. J. A (2019) standardized method of classifying pulsed sounds and its application to pulse rate measurement of blue whale southeast Pacific song units. J. Acoust. Soc. Am. 146, 2145–2154
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- F. Malige, **J. Patris**, S.Buchan, K. Stafford, F. Shabangu, K. Findlay, R. Hucke-Gaete, S. Neira, C. W. Clark & H. Glotin (2020) Inter-annual decrease in pulse rate and peak frequency of Southeast Pacific blue whale song types, Nature, Scientific Reports, V10, 8121
- F. Malige, D. Djokic, **J. Patris,** R. Sousa-Lima & H. Glotin (2020) Use of recurrence plots for identification and extraction of patterns in humpback whale song recordings, Bioacoustics

Franck Malige

Associate professor of mathematics, holder of a doctorate in celestial mechanics, associate researcher at LIS (CNRS France), Franck is currently working on mathematical models to better understand bioacoustic signals. He also participates in the design and implementation of field missions in difficult-to-access areas. Various missions in Chile made it possible to collect signals ranging from very low frequencies (blue whales) to very high frequencies (coastal dolphins, such as the Chilean dolphin, endemic to Patagonia).

Selected publications:

- **F. Malige,** J. Patris, S.Buchan, K. Stafford, F. Shabangu, K. Findlay, R. Hucke-Gaete, S. Neira, C. W. Clark & H. Glotin (2020) Inter-annual decrease in pulse rate and peak frequency of Southeast Pacific blue whale song types, Nature, Scientific Reports, V10, 8121
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