Medium-term acoustic monitoring of Patagonian coastal dolphins

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ABSTRACT

Coastal dolphins and porpoises such as the Chilean dolphin (*Cephalorhynchus eutropia*), the Peale's dolphin (*Lagenorhynchus australis*), and the Burmeister's porpoise (*Phocoena spinipinnis*) inhabit the remote areas of Chilean Patagonia. Human development is growing fast in these parts and may constitute a serious threat for such poorly known species. It is thus urgent to develop new tools to try and study these cryptic species, and find more about their behavior, population levels ~~and habits~~. These odontocetes emit narrow band high frequency clicks and efforts have been made to characterize precisely their acoustic production. Passive acoustic monitoring is a common way to study these animals. Nevertheless, as the signal frequency is usually higher than 100 kHz, storage problems are acute and do not allow for long term monitoring. The solutions for recording NBHF clicks are usually twofold : either short duration, opportunistic recording from a small boat in presence of the animals (short term monitoring) or long term monitoring using devices including a click detector and registering events rather than sound. We suggest, as another possibility, a medium-term monitoring, arguing that today's devices have reached a level in performance allowing for a few days of continual recording even at these extremely high frequencies and in difficult conditions, combined with a long term click detector.
As an example, during 2021, we performed ~~a quasi-~~continuous recording during one week with the recorder Qualilife High-Blue anchored in a Fjord near Puerto Cisnes, Region de Aysen, Chile. We detected more than 13 000 clicks, grouped in 22 periods of passing animals. Our detected clicks are quite similar to precedent results but, due to the large number of clicks recorded, we find a larger variability of parameters. Several rapid sequences of clicks (buzz) were found in the recordings and their features are consistent with previous studies : in average they have a larger bandwidth and a lower peak frequency than the usual clicks. We also installed in the same place a click detector (C-POD) and the two devices compare well and show the same number and duration of periods of animals presence. Passages of odontocetes were happening in average each three hours. We thus confirm the high site fidelity for the species of dolphins emitting NBHF clicks present in this zone. Finally, we confirm that the combined use of ~~a~~ recording and ~~a~~ detection devices is probably a good alternative to study these poorly known species in remote areas.

INTRODUCTION

Coastal small cetaceans are present in many zones of the world, including rivers, fjords and bays. Due to their site fidelity they usually are very sensitive to human presence and some populations are on the verge of extinction (Jaramillo Legorreta et al., 2019; Sucunza et al., 2019; Silva et al., 2020). Many studies of these dolphins focused on areas where human activity and presence is high, because it is usually easier to reach these areas and because the threats are stronger (Heinrich et al., 2019; Palmer et al., 2021). In remote areas such as Patagonia, there is still ~~few~~ little information available on ~~the endemic~~ this species, though they are probably also threatened and population assessments could be decisive for their conservation.

Long term visual studies are costly and are ~~submitted~~ subject to the contingencies of climate and ~~local~~ to the locally available equipment (Stern et al., 2017; Heinrich et al., 2019). Passive acoustic monitoring (PAM) is sometimes a good alternative to assess the presence, sound characteristics and behavior of marine mammals, or to estimate their density and population trends (Marques et al., 2012), especially in remote areas (see for example Schall et al. (2021)). However, in the case of ~~coastal dolphins~~odontocetes emitting narrow band high frequency (NBHF) clicks, there is a serious drawback to PAM methods : the high sample rate needed to record their high frequency emissions prevents autonomous long term ~~full~~ recording. The very few published studies that used ~~full time~~ long term recording had ~~an~~ access to devices and installations that are not commonly found in marine biology (Gillespie et al., 2020). Usually, there are two alternatives for the passive acoustic monitoring of small coastal cetaceans : short term ~~full~~ recording or long term presence detection.

The first method consists in recording during a short time, typically a few hours or less, usually opportunistically from a boat in the wild or in a pool for captive animals. The recording is controlled, sometimes with several hydrophones (array of sensors) and the behavior of the animal is registered ~~(Ladegaard et al., 2015; Macaulay et al., 2020)~~ (Ladegaard et al., 2015; Macaulay et al., 2020; Barlow et al., 2021) . This kind of work is useful for describing the emissions in details (sound characteristics, beam), and/or coupling them with ~~registered behaviour~~behavioral observations. Nevertheless, as these studies are short in duration or done in captivity, the presence of humans is a possible source of disturbance that can affect the behavior and sound production of these marine mammals. Thus, this type of studies is mainly focused on characterizing the sounds emitted by a particular species, but could be biased towards certain types of sound emissions or conducts in reaction with human presence such as anxious, agonistic, attentive, or cautious ~~behaviours~~ behaviors (Martin et al., 2021).

The second widely used method is long term monitoring with click detectors (Sousa-Lima et al., 2013; Weel et al., 2018). Click detectors do not fully record the signal, but detect and log predetermined sounds of interest along with some of their characteristics. Thus, memory use and power consumption are much lower than for recorders, and an area can be monitored for years, due to the high autonomy of the available detectors. A drawback of these very efficient tools is that very ~~few~~ little information is then available on the surrounding low to medium frequency sounds or ~~soundscape~~sound scape. For instance, detectors can hardly be used to assess interactions between marine mammals and human produced noises. Moreover, the differentiation of sounds emitted by species of interest by a logging device is not easy (Jacobson et al., 2017), particularly in species whose repertoire is similar or still not fully known. Besides, the calibration of such devices is often a problem since the data is not recorded and no a posteriori verification can be done (Robbins et al., 2015). To solve this problem some studies proposed a combination of a detector and a recording device, used for calibration purpose, mainly to test the detector performance (Jacobson et al., 2017; Sarnocinska et al., 2016).

~~Interestingly, recent~~ Interestingly, instruments combining low frequency recording, automatic detection and high frequency snippet recording ~~are getting~~ will soon become available (http://www.oceaninstrument though no studies using them have been published yet, to our knowledge. This is an exciting new technology, even if the reliability of the detector is still a potential difficulty.

In this work, we suggest, as another possibility, a ~~mid-term~~ medium-term full recording monitoring for ~~the~~ small coastal ~~cetacean~~cetaceans along with a long term monitoring by mean of a click detector. We argue that today's recording devices have reached a level in performance allowing for a few days of continual recording even at these extremely high frequencies and in difficult conditions or remote places. Custom-built recorders, ~~developed and constructed in a University,~~ ~~allows~~ allow for ~~an~~ adaptation to special conditions or a specific protocol at a relatively low cost. This set-up of two joint devices combines several qualities : the ~~mid-term~~ medium-term recording gives a clear view of the sound produced by the coastal dolphins (and enables future studies in signal processing), of the acoustic context (noises, human and ~~animal~~ other animals sound emissions), can help to calibrate the logging of predetermined sounds by ~~automatic detectors, gives more precision on the signal~~ the detector and is less invasive compared to other approaches such as recording from a boat. We present an example of such a ~~mid-term~~ medium-term recording in the remote fjords of Chilean Patagonia in May 2021, aiming at testing the feasibility of such a monitoring as well as knowing better the acoustical ~~behaviour~~ repertoire of the cryptic small cetaceans inhabiting the inlet waters. After presenting the species of interests, we describe in detail ~~our instruments and show our first results~~ the two instruments used, show some biological results that can be obtained and discuss the advantages and disadvantages of this experimental set up in remote places.

1 COASTAL ODONTOCETES IN PATAGONIA

1.1 Fjords of Northern Chilean Patagonia

The marine ecosystem of Chilean Patagonia (41°5'-55°S) is considered one of the most extensive fjord systems in the world. Numerous islands, peninsulas, channels, straits and fjords form part of its complex geography covering an area of ca. 240 000 km2 (Silva and Vargas, 2014). Oceanographically, sub-antarctic water, rich in nutrients, flow on the surface through "Boca del Guafo" (43°35.7'S – 74°12.8'W) mixing progressively towards the south with estuarine water (Guzmán and Silva, 2006; Silva and Palma, 2008). This oceanographic and ~~geomorphologic~~ geomorphological particularities create many unique habitats that result in a high degree of endemic wildlife and high species richness (Häussermann and Försterra, 2009; Försterra et al., 2017; Betti et al., 2017). The region is classified as highly vulnerable to local and remote processes (Iriarte et al., 2010). Major threats associated to economic activities includes intense salmon farming, demersal and benthic artisanal fisheries and emerging cetacean sightseeing activities.

1.2 Small coastal cetaceans of Northern Chilean Patagonia

Chile is among the countries with the larger diversity of cetaceans, mainly due to its large coastline and variety of climates (Wilson and Mittermeier, 2014). The remote fjords and inlet waters of Aysén are no exception to this diversity (Zamorano-Abramson et al., 2010; Pichinao et al., 2019). Large delphinids, such as the bottlenose dolphin (*Tursiops truncatus*) or the predating killer whale (*Orcinus orca*) are transient regular visitors of the fjords, and large mysticetes such as the blue whale (*Balaenoptera musculus*), the Sei whale (*Balaenoptera borealis*) or the humpback whale (*Megaptera novaeangliae*) are common in the larger channels. Inside the fjords however, and very close to the shore, three species of small cetaceans mostly share the sheltered habitat : the Burmeister's porpoise (*Phocoena spinipinnis*), the Peale's dolphin (*Lagenorhynchus australis*) and the Chilean dolphin (*Cephalorhynchus eutropia*).

These three species are endemic to South America, the Chilean dolphin being even restricted to Southern Chile. They are globally poorly known, with very few studies published, and especially in the inlet waters of Chilean Patagonia. Their conservation status is considered ~~Data Deficient for the Peale dolphin~~ 'near threatened' for the Chilean dolphin (Heinrich and Reeves, 2017) and the Burmeister~~porpoise (Hammond et al., 2008, 2012) and Near Threatened for the Chilean dolphin (Heinrich and Reeves, 2017)~~ 's porpoise (Félix et al., 2018) , mainly because of ~~its~~ their restricted range. Human activities in coastal areas are generally a major threat to coastal cetaceans, through ~~direct fishing for human consumption (such has long been the case with the Burmeister porpoise in Peru (Van Waerebeek et al., 1997)) or~~ baiting (a known practice in Patagonia (Hammond et al., 2012)) ~~,~~ or through interactions with gill nets, fisheries or farms (Heinrich et al., 2019). The Peale's dolphin is often seen in the fjords porpoising ~~in front of the little~~ around the boats or foraging close to the shore. The Burmeister's porpoise and the Chilean dolphin are much more elusive, and do not normally interact with ~~the~~ boats.

~~All of these species emit echolocation clicks that have been known as Narrow Band High Frequency (NBHF)~~ In the Chilean fjords of Patagonia, only the three species of coastal dolphins emit NBHF echolocation clicks. Interestingly, for each species, only one study describing their vocalization has been published (Reyes Reyes et al., 2018; Kyhn et al., 2010; Götz et al., 2010). Additionally, one unpublished study compared the emitted signals of Chilean and Peale's dolphins (Rojas-Mena, 2009). The NBHF click is common in coastal species of toothed whales, it is characterized by a peak frequency around 130 kHz, a half-power bandwidth of about 15 kHz and almost no energy below 100 kHz. It is thought to be an adaptative response to the predation of killer whales, that ~~does~~ do not hear above 100 kHz ~~(Andersen and Amundin, 1976)~~ (Andersen and Amundin, 1976; Morisaka and Connor, 2007) . Recent studies point out that some species of the *Cephalorhynchus* genus can relax this acoustic crypsis, emitting clicks at lower frequencies probably in a communication context (Martin et al., 2018, 2021) . In addition, the Chilean dolphin has three species have been shown to produce 'buzz', or very rapid trains of clicks thought to be used while foraging (Götz et al., 2010; Martin et al., 2019) (Götz et al., 2010; Martin et al., 2019; Rojas-M NBHF signals are very similar between species, and are possibly depending on the environment more than on the species (Kyhn et al., 2010), hence the need of more studies on these species vocalizations, that could allow for future long term passive acoustics monitoring by mean of accurate detectors.

2 AN EXPERIMENT IN THE FJORD OF PUYUHUAPI

2.1 Material and methods

QHB Recorder The main instrument for the experiment is Qualilife HighBlue (QHB) recorder presented in Figure 1. Its functional diagram is presented at Figure 2. This new state of the art recorder have recorder

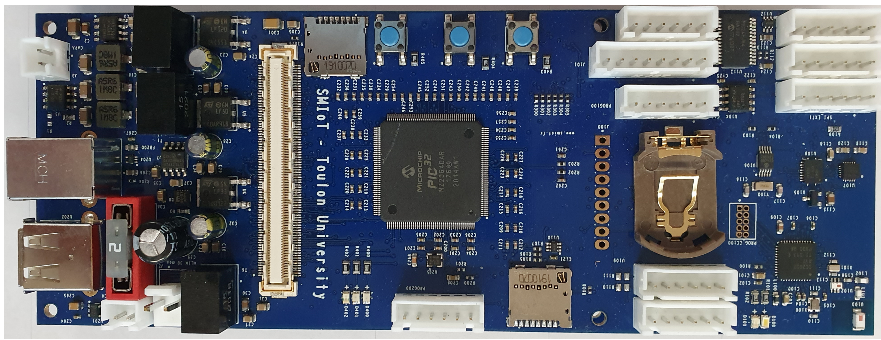

Figure 1. Qualilife HighBlue (QHB) recorder

has the following characteristics (see also Barchasz et al. (2020)):

- Acquisition sample rates up to 512 Ksps (Kilo samples per second) corresponding to a frequency range up to 256 kHz. Recording can be scheduled according to user requirements.
- Up to 6 synchronous recording channels, with an accurate synchronization and time-stamping having less than $1\mu s$ of jitter.
- Signal sampling depth can be adjusted among 8, 16 or 24 bits. In this latter mode, recorder self noise is limited to the 2 least significant bits, meaning 22 bits are truly significant for recording. This increases the signal quality and the potential detection distance compared to standard recorders, especially in quiet environments.
- Differential acquisition front end with $\pm 2.5V$ maximum input level for reducing drastically recording self noise. Each recording channel has an adjustable differential gain : X1, X10, X20, X100.
- Anti-aliasing filtering automatically tuned according to the acquisition sampling rate. Signal having frequencies exceeding 0.55* Sampling Rate are attenuated by more than 120 dB.
- Sensor hub ability : QHB includes a 9-axis IMU sensor (MEMS accelerometer, magnetometer and gyroscope) and several additional sensors can be added depending on user requirements, using UART, SPI and I2C extension buses.

QHB recorder has been set up in a custom made housing allowing resistance to pressure up to 100 m deep, a stable setting on the ground, the adaptation of a C57 hydrophone from Cetacean Research, calibrated with a flat response up to 150 kHz (no available calibration beyond), and a set of 21 D alkaline batteries (`https://smiot.univ-tln.fr/index.php/produits/`).

C-POD Though the main instrument of the experiment was the QHB recorder, we also installed a C-POD, a commercial click detector developed by Chelonia Limited, UK (Tregenza, 2014). The C-POD works in the 20 kHz-160 kHz range, detects and logs all potential clicks in this frequency range, registering several parameters for each detection (central frequency, duration, etc.) as well as the temperature. A post-processing software classifies the detections between high frequency noise and real clicks based on

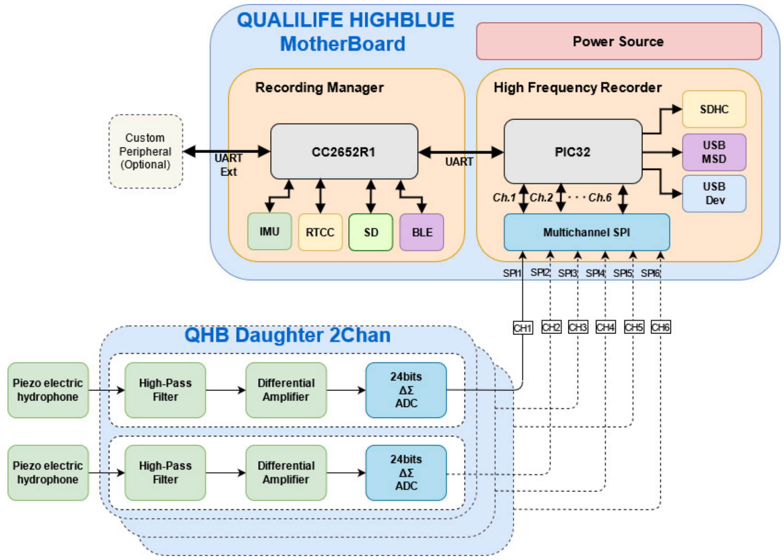

Figure 2. Functional diagram of Qualilife HighBlue (QHB) recorders

the properties of the train of clicks, further offering a classification between NBHF or medium frequency (dolphin) click. The C-POD is widely used for long term monitoring of toothed whales, and especially the Harbour Porpoise (*Phocoena phocoena*) because of its low consumption, low memory requisite and hence its very large autonomy on the field (Sousa-Lima et al., 2013; Gallus et al., 2012).

Data recording Both instruments QHB and C-POD were set on May, 4th of 2021, in a cove close to the shore of Magdalena Island reserve, in the canal of Puyuhuapi opposite the town of Puerto Cisnes (44°36'38.78"S, 72°45'30.43"W, figure 3).
~~Left : Experiment location in South America. Right : Zoom on the experiment zone. In blue, the point chosen for the installation of the different devices (44°36'38.78"S, 72°45'30.43"W).~~

The place was chosen because local tour operators had seen repeatedly Chilean dolphins in this cove during the last months~~, excluding any other species of cetacean~~. The instrument QHB was installed at a depth of approx. 13 meters, on sandy ground (figure 3, right). At 10 m of distance, a mooring was set with a line sustaining the C-POD (at 4m from the ground) and a subsurface buoy. The set up of QHB was a sample rate of 512 kHz, 24 bits of precision, one channel, and a duty cycle of 95% with 9'30" of recording followed by 30" OFF. The C-POD was used with default settings : continuous logging and a 20 kHz high-pass filter (Tregenza, 2014). The QHB was ~~retreived~~ retrieved on May, 11th whereas the CPOD was retrieved on July, 28th. Only Chilean dolphins were observed inside this cove, either by the authors or by the tour operators visiting the place. The only moment when we saw the dolphins was during the operation of changing the memory card on the 8th of May, when 2 individuals of a group of about 15 Chilean dolphins stayed with the diver, interacting below the water.

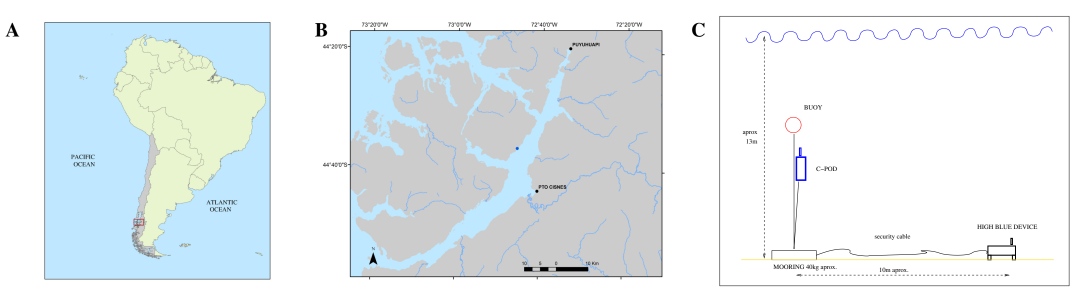

Figure 3. **A** : Experiment location in South America. **B** : Zoom on the experiment zone. In blue, the point chosen for the installation of the different devices (44°36'38.78"S, 72°45'30.43"W).
C : Mooring design.

Click detection A click detector was custom written in Octave (Eaton et al., 2009). It basically detects the maxima of energy in the frequency band of 100 kHz - 250 kHz, and then filters out the signal that have a strong counterpart in the 30-90 kHz bandwidth. Our detector was tested on two 9.5 minutes long files, with clicks detected by a human specialist. The first file has a lot of clicks ($N = 523$) and some high frequency noise, and the other file is without detected click but with a lot of high frequency noise. For the chosen thresholds, we obtain the following characteristics :

- Precision or positive predicted value (PPV= correctly detected / all detections) PPV = 84%
- Miss rate (MR = missed signals / all signals) MR = 17% .

These are conservative values since we chose, for the testing subset, two of the noisiest files. The code of this simple detector is given as supplementary material.

Extraction of clicks parameters As a first analysis of the clicks, we wrote a short code to automatically extract the most commonly used parameters of NBHF clicks (Au, 1993), in concordance with the ~~only other paper~~ papers published about the ~~Chilean dolphin clicks (Götz et al., 2010)~~ NBHF clicks of the three species of dolphins present in the Fjord of Puyuhuapi (Götz et al., 2010; Kyhn et al., 2010; Reyes Reyes et al., 201 The code is given as supplementary material ~~. It computes the following parameters :Peak frequency~~and it computes the classical parameters listed afterward. *Peak frequency* is computed as the maximum of the Fast Fourier Transform (FFT) of 512 samples (1 ms) around the clicks~~; Centroïd frequency~~. *Centroid frequency* (or mean frequency) is the first raw moment of the FFT of the recorded signal during the same extract~~;~~. *Inter-click interval (ICI)* is computed as the time between two detections closer than 300 ms. In the (~~unfrequent~~infrequent) case of two superimposed trains of clicks, this measure does not reflect an intrinsic property of the emitted sound~~;~~. *Frequency bandwidth RMS* (Root Mean Square) is the second central moment of the distribution of frequencies in the same 1 ms extract~~;~~. *Bandwidth at -3 dB* is the frequency band around the peak frequency where the value of the ~~FFT~~ Fast Fourier Transform (FFT) is higher that the maximum of the ~~Fast Fourier Transform (FFT)~~ FFT divided by $\sqrt{2}$~~;~~. *Bandwidth at -10 dB* is the frequency band around the peak frequency where the value of the ~~FFT~~ Fast Fourier Transform (FFT) is higher that the maximum of the ~~Fast Fourier Transform (FFT)~~ FFT divided by $\sqrt{10}$~~; RMS duration~~. *RMS duration* is the second central moment of the distribution of time, where the ~~absolute value~~ modulus squared of the signal divided by its energy is considered a probability density ~~;~~function. *Duration at -10 dB* is the duration around the maximum of the signal where the envelope of the signal is higher than the maximum of the signal divided by $\sqrt{10}$. The envelope is obtained ~~as the modulus of~~ from the Hilbert transform of 1ms of signal around the clicks~~;~~. *Duration at -20 dB* is the duration around the maximum of the signal where the envelope of the signal is higher than the maximum of the signal divided by 10.

The statistical distribution of each of these parameters is ~~computed for each 'event' or~~ then computed for all the data set.

The clicks are organized in trains of several clicks and usually grouped in 'events' or encounters. We defined an 'event' as a series of trains separated by less than 20 minutes~~, and then for the total sample~~. This definition is due to the observation that the number of 'events' obtained is less variable for this time scale.

2.2 ~~First~~ results

Clicks and events detections The QHB instrument ~~had several failures but~~ recorded well from the 4/05/21 at 11h30 local time to the 6/05/21 at 20h local time, ~~and then~~ when it had a failure : it began to record the sound on the same file of 9'30" for the rest of the recording session. Then, in the second session, it recorded from the 8/05/21 at 11h ~~local time~~ to the 10/05/21 at 11h local time until it ran out of battery. We thus have two periods of recording, one of 56 hours with 339 files of 9'30" and one of 48 hours with 291 files of 9'30". We total more than 550 ~~Go~~ GB of recorded sound.

We detected more than 13 000 clicks during the 56 hours from the 4th to the 6th of May, and almost none in the second period from the 8th to the 10th of May. ~~The clicks are organized in trains of several clicks and usually grouped in 'events' or encounters. We define an~~ With the definition of 'event' ~~as a series of trains separated by less than 20 minutes. With this definition~~presented in the previous section, we find 22 events or encounters during the 56 hours. Events were separated by intervals from 30 minutes to 6.5 hours.

The C-POD detector recorded from the 4/05/21 to the 27/07/21. Although all the data have been extracted from the instrument, amounting to about 34 000 clicks (all classified as NBHF) during the whole three months, only the period when both instruments were in the water has been ~~analysed~~ analyzed here. Figure 4 shows the compatibility of the results between the QHB instruments and the C-POD detector for the first three days, when a lot of clicks have been detected by both instruments. Most of the events ~~(or encounters)~~ are detected by both the instruments, even though they were about 10 meters apart. However, the detection rate of the QHB is significantly higher (more than 13 000 clicks as opposed to about 2 000 clicks for the C-POD for the same period). The number of chunks of 10 minutes with at least one detection is 38 in total for the CPOD and 49 for QHB~~, slightly more sensible~~sensitive.

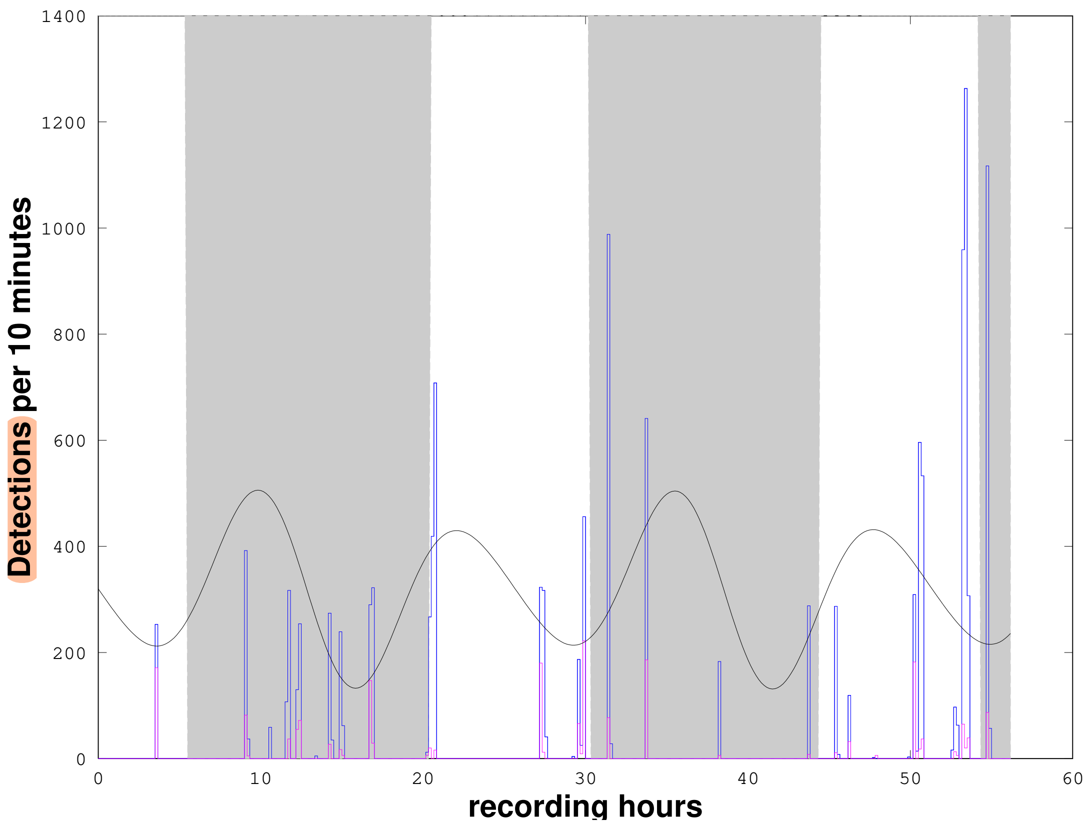

Figure 4. Number of clicks detected per 10 minutes by QHB (blue) and the C-POD (red). Superimposed are night and day ~~lights~~ (night ~~is~~ in grey, day in white) and tides in arbitrary units (green curve).

QHB instrument also recorded contextual noise such as boat engines and sonars, as well as long duration ~~motors~~ motor noise probably linked to a nearby salmon farm (situated at about 2 km), and noise from the natural environment such as crabs, shrimps etc. However, no detailed analysis of background noise has yet been done.

It is intriguing to note that in both instruments, no click are detected between the 8/05 in the morning (when we changed the memory card, with two Chilean dolphins interacting with the diver) and the 10/05 late at night. On the 11th of May, the QHB instrument was removed. In the data of the C-POD, such large intervals without click are quite unusual (only three registered in the three months of data).

Clicks properties The clicks that were registered by QHB have a good definition and are similar to the ~~clicks of Chilean dolphins~~ NBHF clicks described in the literature ~~(Götz et al., 2010)~~ (Rojas-Mena, 2009; Götz et al., 20 The clicks~~parameters,~~' average parameters are given in table 1~~, are consistent with NBHF clicks, as previously mentioned~~.

Nevertheless, the statistical distributions of the parameters are not all Gaussian, as can be seen in figure 5. This is particularly the case with the distribution of ICI, with a standard deviation larger than the average value and two very different modes in the distribution, and the peak frequency distribution, which

Table 1. Parameters of the clicks recorded by QHB instrument (average value and standard deviation, N=13 878.)

Peak frequency	Frequency bandwidth 'rms'	Duration 'rms'
(135 ± 15) kHz	(19 ± 5) kHz	(57 ± 21) μs
Centroid frequency	Frequency bandwidth at -3 dB	Duration at -10 dB
(141 ± 10) kHz	(6 ± 3) kHz	(53 ± 26) μs
Inter-click interval (ICI)	Frequency bandwidth at -10 dB	Duration at -20 dB
(88±117) ms	(16 ± 8) kHz	(106 ± 52) μs

is clearly ~~multimodal~~multi modal. Therefore, the description of the parameters by mean of an average value and a standard deviation is ~~probably~~ not the best way to describe the diversity of clicks recorded.

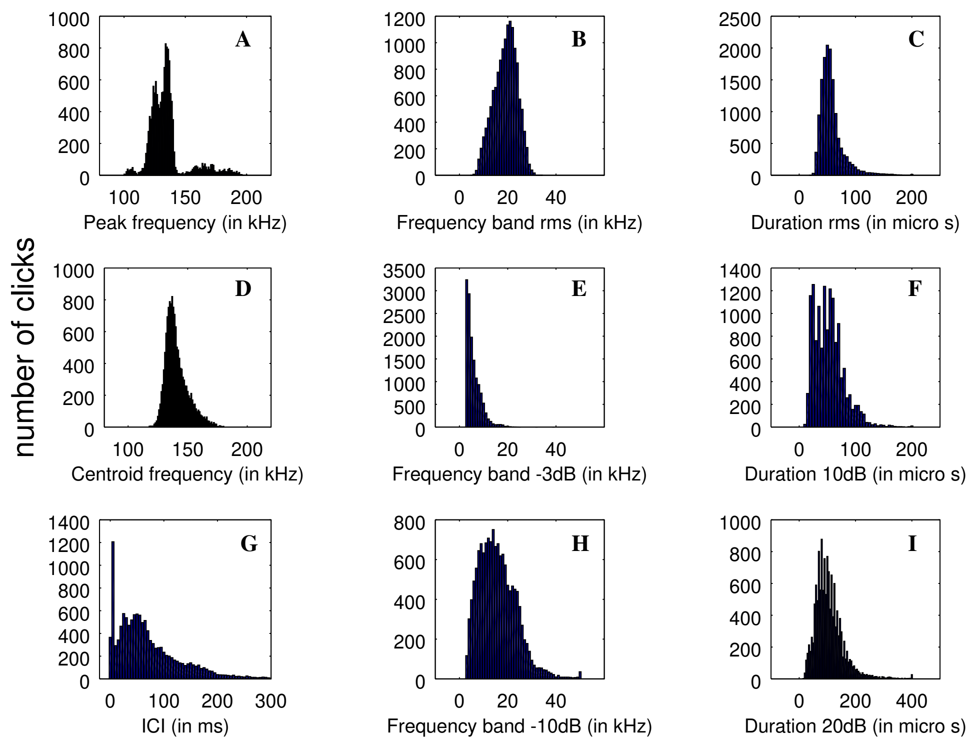

Figure 5. Distributions of the parameters of the detected clicks. Average and standard deviation are given in table 1

The main peak of the distribution of peak frequency is itself bi-modal with a mode around 126 kHz, and another at 134 kHz. On the other hand, a mode is visible at very high frequency around 164 kHz. ~~These three modes have not been described for the Chilean dolphin but are strikingly similar to what Reyes Reyes et al. (2015) describe~~ Three examples of clicks are given in figure 6. We found that some of the clicks had a large bandwidth, with some having a peak of energy at 170 kHz. A clear notch is also present in the spectra at 150 kHz as noticed by Reyes Reyes et al. (2015) for the Commerson's dolphin~~(Cephalorhynchus commersonii), a close parent of the Chilean dolphin found mainly in the Argentina coast, subantarctic islands and Southern Chilean Patagonia (Crespo et al., 2017) . Finally, a last mode is present around 107 kHz, corresponding to a few trains of very rapid clicks, or buzz~~. Interestingly, this notch at around 150 kHz has also been described for different species of porpoises (Reyes Reyes et al., 2018) .

Another type of clicks detected in our data set are usually found in very rapid trains of clicks, usually denominated buzz (fig. 6, right). We define a 'buzz' when the ICI is lower than 5 ms, usually around 2 ms, as compared to normal trains with ICI being between 50 and 100 ms. A visual examination of our data show about 20 such trains, 7 of them within the same file of 9'30". These clicks are also visible in the ICI distribution (very short ICI, fig. 5.G). Visual examination of the clicks with short ICI confirmed there was no superimposed trains of clicks, and thus the ICI actually corresponds to an intrinsic parameter of the emitted sound. Thus, we confirm The last mode in the distribution of frequency peak, around 107 kHz, corresponds to these buzz. It is coherent with the results of Götz et al. (2010) that buzz clicks are emitted Götz et al. (2010); Martin et al. (2021) that NBHF click species emit buzz clicks at a slightly lower frequency.

Three examples of clicks are given in figure 6. We found a lot of the clicks had a bandwidth rather large, with some proportion having more energy at 170 kHz. A clear notch is also present in the spectra at 150 kHz as noticed by Reyes Reyes et al. (2015) for the Commerson's dolphin. Interestingly, this notch at around 150 kHz has also been described for not-so-closely related species, such as different species of porpoises (Reyes Reyes et al., 2018) . The clicks found in a buzz, or rapid sequence, have much shorter ICI and clearly different features. The number of cycles included in the envelope of the click is much lower than for normal classical NBHF clicks, and shows some similarity with typical clicks of larger odontocetes. The spectrum shows a greater bandwidth, with energy lower than 75 kHz. Though we had no means of measuring the distance of the dolphin to the sensor, and thus we could not calculate source levels in this study, the buzz clicks that we found are generally of lower intensity compared to nearby normal classical NBHF clicks.

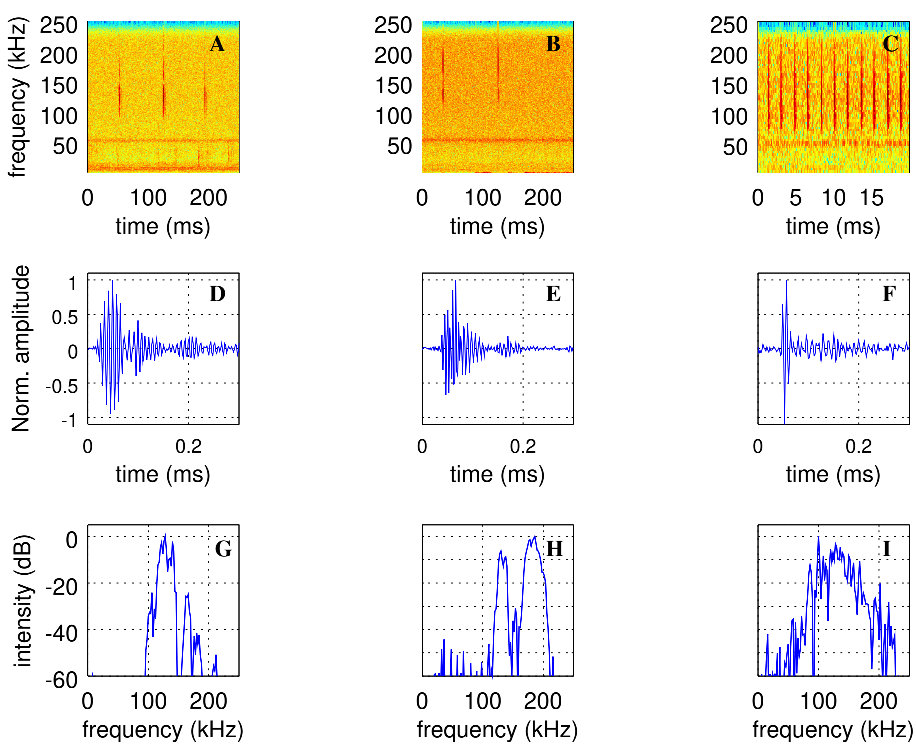

Figure 6. Examples of clicks of Chilean dolphins coastal odontocetes recorded by QHB. On the left, a typical click with peak frequency around 135 kHz. In the center, a less frequent click with peak frequency around 180 kHz. On the right an example of a click found in a buzz, or rapid sequence of clicks. Top : spectrogram of the signal with a FFT on 2^{10} points except for the right picture (2^7 points), Blackman window, 50% overlap. Middle : zoom on the normalized waveform of the click at the center of the figure just above. Bottom : spectra of the click with normalized intensity, FFT of $2^9 = 512$ points (1 ms of the signal), centered on the detection.

3 DISCUSSION

3.1 Validation of C-POD detections

Our results concerning the comparison between C-POD detectors and a recording device are twofold. ~~On the one hand,~~ the absolute numbers of detections are widely different between the two instruments. ~~On the other hand~~ however, almost all 'events' have been detected by both. Although this comparison between C-POD detector and full signal recording has never been done for ~~the Chilean dolphin~~NBHF clicks emitted by theses three species, it has been measured for other species, such as the ~~harbour~~ harbor porpoise, one of the species most studied with clicks detector, with somewhat distinct conclusions. While Sarnocinska et al. (2016) found a rather low correlation between the clicks per minutes detected by a C-POD detector and a Soundtrap recording device, installed at a distance of about 2 meters in the same mooring line, Jacobson et al. (2017) found a much better correlation between the results of the same two instruments, installed so that the two hydrophones were as close as possible. Such differences may be due to the respective position of the instruments, but, more importantly, by the difference of sensibility of each individual instrument. In our experiment, it is obvious that the recorder is much more ~~sensible~~ sensitive than the detector, independently of the difference of the location of the instruments. However, and though the numbers of detected clicks show a difference of 600 %, the number of detected 'events' is a much more robust indicator. Indeed, 20 of the 22 events detected by the QHB recorder have also been detected by the C-POD instrument, a difference of hardly 5% (concerning the weakest events, see fig. 4). ~~We have defined an 'event' as a series of trains separated by less than 20 minutes after observing that the number of 'events' obtained for a given duration were less variable for this time scale~~The two events detected by the QHB recorder and not by the C-POD contain slightly more than ten detections. One of them contains only false positives and, in the other, there are mostly NBHF clicks. The classical parameters of chunks with positive detection is thus much more robust to the global sensibility of the instrument than the absolute number of detections. The size of the chunks should be defined after considering the data, since it can be very different for each experiment, depending on the size of habitual territory of the dolphins (if any), the number of groups inhabiting the area, etc.

In this mark, our study validates the use of a C-POD detector for long-term monitoring of ~~the Chilean dolphin~~ these three species in the Patagonia fjords.

3.2 Clicks properties

~~In a whole, our results for Chilean dolphins clicks compare well with those of Götz et al. (2010) , the only published study for this species to the date. However, a certain difference exists in the peak (or centroïd) frequency measures. While Götz et al. (2010) found peak frequency of around 127 kHz, with a small standard deviation of 4 kHz, we found an average peak frequency about 10 higher at 135 kHz and a much bigger standard deviation of 15 kHz. To compute the average, we took all detected clicks, without reference to on-axis or off-axis clicks. There is no precise study available describing the beam pattern of Chilean dolphins, however, based on measurements of the NBHF clicks of harbour porpoise (Macaulay et al., 2020) , we can expect a narrow beam with little deformation of the clicks in a cone of 10° and then a high attenuation (of more than 10 dB) making the detection difficult. Thus, most of the detected clicks can be practically considered on-axis. What's more, Götz et al. (2010) found very little difference on the average peak frequency between 'on-axis' clicks and the total set ('on axis' being defined as the most intense clicks of a train).~~

~~On the other hand, our~~ Our data set is much larger than the pioneer ~~work of Götz et al. (2010) (almost~~ works of Götz et al. (2010); Kyhn et al. (2010); Reyes Reyes et al. (2018) . Almost 14 000 clicks were ~~analysed~~ analyzed in our study, as compared to ~~less than 1000 in this previous work)~~around 3 000 summing these three studies. The distribution of peak frequencies ~~along the~~ in our data set shows a ~~certain~~ large diversity, ~~as was described in the 'Results' section~~. ~~Four modes are visible in the frequencies distribution, respectively at 107, 126, 134 and 164 kHz. Obviously, the panel of possible frequencies is much bigger and we can imagine that Götz et al. (2010) data is mainly similar to our second mode (second in order of importance) at 126 kHz.~~ Thanks to the large number of clicks of our data set, we can ~~precise~~ compute the values of the main peaks by fitting a sum of Gaussian functions on the histogram of peak frequencies of figure 5. Using an implemented Marquardt-Levenberg algorithm in Octave, we find that the peak frequencies are 105.8, 125.1, 135.5 and 168.3 kHz (with respective standard deviations of ~~4.3~~4.4, 6.0, 4.4, and 18.0 kHz, see figure 7). ~~These values of the standard deviations compares well with the value in Götz et al. (2010) and show the interest of a large data set, made possible by mid-term~~

monitoringGötz et al. (2010) data (N=83 clicks) is mainly similar to our second mode (second in order of importance) at 126 kHz. The first mode at 134 kHz is compatible with productions of Burmeister's porpoise as measured by (Reyes Reyes et al., 2018) .

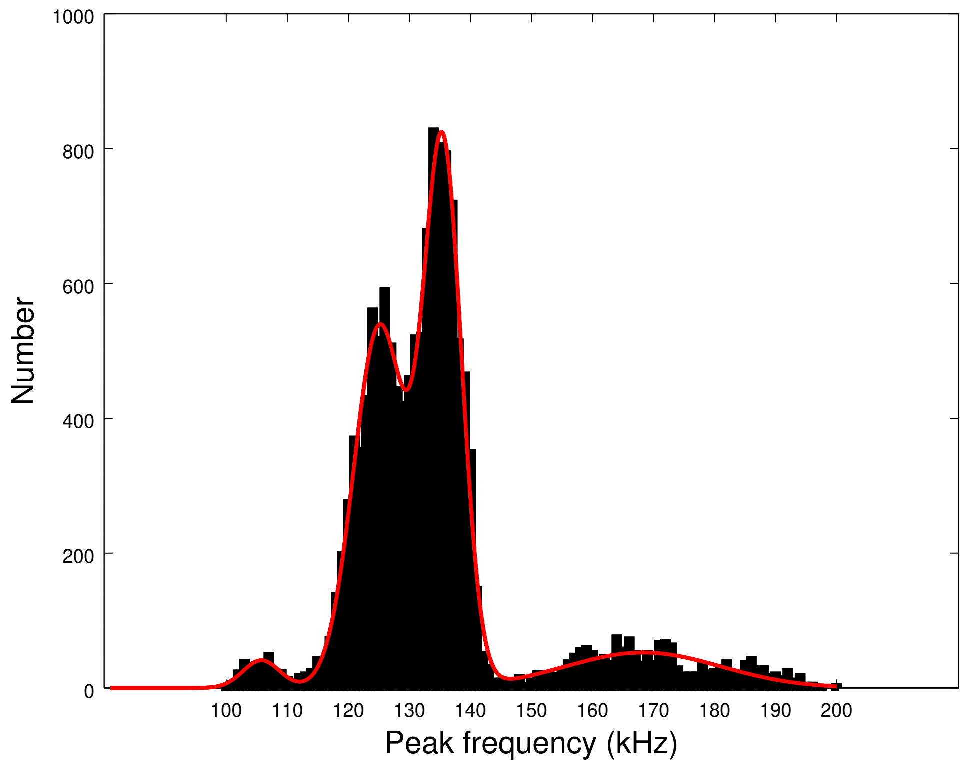

Figure 7. Fitting of the four peaks of the first histogram in figure 5 (peak frequencies) by a sum of four Gaussian functions

Why the first work on Chilean dolphin did not evidence the other types of clicks, such as high frequency clicks, may be explained by the setting of the experiment, which had much less signals and possibly selected certain types of behaviour due to the presence of the boat. Dolphins have been shown to respond actively to the presence of a boat, even without engine (Martin et al., 2021) , and thus their clicks repertoire is possibly modified by the observation. What's more, they probably used a low pass filter (Rojas-Mena, 2009) at 200 kHz, making high frequency not so easily detectable. A last possible explanation is the geographical difference, since Götz et al. (2010) study is located about 1 000 km North of our experiment, in the much more frequented waters of Chiloe archipelagoPrevious studies of the acoustic productions of the three species present in Patagonian fjords give only the average and standard deviation for the peak frequency distribution (see Reyes Reyes et al. (2018) , table 2, for a summary). In the results summarized in Reyes Reyes et al. (2018) , the standard deviation of peak frequency measures grows with the number of clicks indicating that several modes are possibly appearing in a richer data set.

We can remark that the study of the Commerson dolphin by Reyes Reyes et al. (2015) also presented dissimilarity with the pioneer measures of Kyhn et al. (2010) , with higher average frequencies and a much larger standard deviation for peak or centroïd frequencies. They also Interestingly, the modes we found in the peak frequency distribution are similar to what Reyes Reyes et al. (2015) describe for the Commerson's dolphin (*Cephalorhynchus commersonii*), a close congener of the Chilean dolphin found mainly in the Argentina coast, sub antarctic islands and Southern Chilean Patagonia (Crespo et al., 2017) . This species, however, is not present in the fjords of Northern Chilean Patagonia. They describe three clusters of clicks for this species, highly similar to what we found, with the median for each cluster being respectively at 129, 137 and 173 kHz. No lower frequency or larger band buzz clicks are found in Reyes Reyes et al. (2015) studyThis study of the Commerson dolphin (Reyes Reyes et al., 2015) shows a dissimilarity with the pioneer measures of Kyhn et al. (2010) , with higher average frequencies and a much larger standard deviation for peak or centroid frequencies. The study by Reyes Reyes et al. (2015) analyzes a large number of clicks (as our study), which could explain the similarity of the results. Another example is given in Reyes Reyes et al. (2018) , for the Burmeister's porpoise : some of the five hundred clicks analyzed have a peak frequency around 170 kHz and an histogram with two modes is obtained. Reyes Reyes et al. (2015) study of the Commerson's dolphin didn't find low frequency (100 kHz) clicks, nor large-band clicks in a buzz, though some have been described afterwards by Martin et al. (2021). It is probable that a larger set of data, and more quietly recorded than the pioneer studies on these cryptic species

Therefore, it seems that the acoustic productions of the Patagonian coastal dolphins are more diverse than thought by the first papers published on the subject. In our study we cannot assert if the four modes histogram comes from one species (as in Reyes Reyes et al. (2015, 2018)) or is the result of the mixing of different clicks from several species. In the absence of visual monitoring which would confirm the species recorded, our experiment set up draws a picture of the NBHF clicks found in a particular place rather than for a particular species. A visual monitoring would very important to assess if the NBHF clicks are from one species or more and has to be considered during this type of experiment. Nevertheless, a large set of data, with a very quiet mode of recording, lead to a panel of novel types of clicks that is particularly rich and interesting. We can mention that the high frequency component of the clicks cannot be found by automated detectors such as C-POD (low-pass filter at 160 kHz) or more traditional widely used recorders such as classical versions of Soundtrap (low-pass filter at 150 kHz).

Another type of clicks detected in our data set are usually found in a very rapid train of clicks, usually denominated buzz (fig. 6, right) . A visual examination of our data show about 20 such trains, 7 of them within the same file of 9'30". We define a 'buzz' when the ICI is lower than 5 ms, usually around 2 ms, as compared to normal trains with ICI being between 50 and A possible explanation for the presence of several modes in the histogram of figure 7 is that the modes could come from on and off-axis clicks. Indeed, we measured the parameters of all detected clicks without trying to select only on-axis clicks as done in other studies. To compute the average, we also took all detected clicks, without reference to on-axis or off-axis clicks. However, we find that each series of clicks has consistent parameters. Clicks with non-standard peak frequency (such as 100ms. Our kHz or 170 kHz) come in a series. Thus, taking the highest SNR click of a train (a classical method for selecting on-axis clicks as presented by Götz et al. (2010)) would not alter our results. There is no precise study available describing the beam pattern of the three species of dolphins present in Puyuhuapi Fjord, however, based on measurements of the NBHF clicks of harbor porpoise (Macaulay et al., 2020) , we can expect a narrow beam with little deformation of the clicks in a cone of 10° and then a high attenuation (of more than 10 dB) making the detection more difficult. On the whole, Götz et al. (2010) found very little difference on the average peak frequency between 'on-axis' clicks and the total set. For all these reasons, we consider that the four-mode peak frequency distribution is not a consequence of a distortion of the clicks due to the angle of reception, but reflects a intrinsic diversity of emitted clicks.

Concerning the buzzes, our data does not allow a clear separation between 'buzz' and 'burst pulse' as suggested by Martin et al. (2018) for the Heaviside's dolphin (*Cephalorhynchus heavisidii*), a close parent of the Chilean dolphin. While some of the rapid trains are part of normal trains with an accelerating or decelerating pattern, some seem isolated without a normal train around. The characteristics of the clicks are similar in both cases, unlike what was found by the cited authors. Unlike other click trains, we found no superimposed buzzes, which seems to indicate that this type of sound is not emitted by two animals at the same time. Despite some variability, possibly due to a variable signal to noise ratio, a general pattern of a larger bandwidth and a lower intensity is visible for most of the clicks with short ICI, as shown in figure 6, confirming Götz et al. (2010) measures. No visual follow-up was done, so that we cannot link the buzz to a specific behaviour. Nevertheless, in our data we found no superimposed trains (indicating several individuals), so the hypothesis of a foraging comportment seems more probable than social interaction. Obviously, visual monitoring would be necessary to assert this pointbehavior.

3.3 Feasibility of mid-term medium-term monitoring

Even though the experiment described in this study only lasted one week, we classified it as mid-term medium-term monitoring because it combined characteristics of the two usual ways to study of studying acoustic productions of coastal dolphins : several months of long term monitoring by mean of detectors versus few hours short term studies with dipping hydrophones from a boat. We think that our approach could be a good alternative for future studies.

A long term monitoring, such as few months of recording at a sample rate around 500 kHz is still not feasible in remote areas or without very large resources. It produces about one terabyte of data in ten days, which is the order of magnitude of the duration of our experiment. The alternative of a very low duty cycle is not very well adapted to dolphins which produce a few minutes of sound at each passage as presented in this work. On the other hand, the short term studies are usually possibly more invasive or not adapted to remote areas. Much less clicks are recorded and the whole repertoire of the recorded species is difficult to obtain. Our protocol enables to have a relatively non invasive experiment along with a detailed audio data set which is quasi continuous for several days.

We also showed the feasibility of acoustic monitoring of NBHF species in remote habitat, with university built material. Our device is adapted to simple installation (two stable feet) in the sheltered channels of Patagonia, at low depth but can be modulated to other uses, depending of the place or species to monitor. The presence of the material did not seem to probably did not modify the acoustic behavior of the dolphins during the recordings. Nevertheless it is worth noting that during the maintenance, a group of Chilean dolphins present in the zone fled away while two dolphins of the group stayed and repeatedly approached the diver. Afterwards, no acoustic production were recorded by HQB nor detected by the CPOD during three days. The setting-up of this type of device and/or the unusual presence of a diver could have had an impact on the mid-term medium-term presence of coastal dolphins. We thus Obviously, we cannot state that our interactions with the dolphins were the reason why they were not detected afterwards, however, as a conservative measure, we would recommend to install, maintain and retrieve the instruments when dolphins are not present.

Finally, we also showed the feasibility of acoustic monitoring of NBHF species in remote habitat, with university built material. Our device is adapted to simple installation (two stable feet) in the sheltered channels of Patagonia, at low depth but can be modulated to other uses, depending of the place or species to monitor. A medium-term monitoring with full time recording could also offer unique opportunities to study species occurrence and behavior in the context of anthropogenic activities (with noise signatures, e.g. boats, salmon farming activities).

4 CONCLUSION

Mid-term Medium-term recording shows an interesting complementarity with other more traditional methods of acoustic studies of small dolphins or porpoises in remote areas. They allow an insight on a repertoire much more diverse than was previously considered. This detailed examination of clicks recorded from animals as little disturbed as possible opens new questions concerning sound production or sonar utilization by these species. To complete this work, we suggest mid-term medium-term studies should be associated with visual monitoring, ideally from the shore, to avoid disturbing the animals, and taking advantage of the very coastal habits of these species in remote and pristine areas. On the other hand, by comparing our detection results with C-POD detection, this study also validates the use of standard detectors for large term monitoring of the presence of small cetaceans in remote areas.

Working with local communities and international universities, affordable missions can be designed to know more about these sensitive species, very prone to be affected by the unregulated development of human activities on the coastal environment.

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