

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 (NBHF) clicks and many efforts have been made to characterize precisely their acoustic production. Passive acoustic monitoring (PAM) 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.

As an example, during 2021, we performed a quasi-continuously 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. The clicks recorded are quite similar with precedent studies but, due to the larger number of clicks recorded, clicks with different spectra and peak frequencies were recorded. Several rapid sequences of clicks were present in the recordings and, even if they present a high variability, 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 when establishing the number and duration of periods when the dolphins were present. Passages 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. We then confirm that the combined use of a recording and a detection devices is probably a good alternative to study these less 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 little information available on 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 subject to climate and locally available equipment (Stern et al., 2017; Heinrich et al., 2019). Passive acoustic monitoring (PAM) is sometimes a good alternative to assess the presence, characteristics and behavior of marine mammals, or to estimate their density and population trends (Marques et al., 2012). However, in the case of 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 long term full time 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; Barlow et al., 2021). This kind of work is useful for describing the emissions in details (sound characteristics, beam), and/or coupling them with behavioral observations. Nevertheless, as these studies are short in duration or done in captivity, the presence of humans is a 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 conducts in reaction with human presence such as anxious, agonistic, attentive, or cautious behaviours (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 little information is then available on the surrounding low to medium frequency sounds or soundscape. 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). 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, instruments combining low frequency recording, automatic detection and high frequency snippet recording will soon become available (<http://www.oceaninstruments.co.nz/>) 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 medium term full recording monitoring for the small coastal cetacean going 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 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 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 other animals sound emissions), can help to calibrate the logging of predetermined sounds by the detector and is less invasive compared to other approaches such as recording from a boat. We present an example of such a medium term recording in the remote fjords of Chilean Patagonia in May 2021, aiming at knowing better the

103 acoustical behaviour of the cryptic small cetaceans inhabiting the inlet waters. After presenting the species
104 of interests, we describe in detail the two instruments used and show some biological results that can be
105 obtained by this experimental set up in remote places.

106 **1 COASTAL ODONTOCETES IN PATAGONIA**

107 **1.1 Fjords of Northern Chilean Patagonia**

108 The marine ecosystem of Chilean Patagonia (41°S-55°S) is considered one of the most extensive fjord
109 systems in the world. Numerous islands, peninsulas, channels, straits and fjords form part of its complex
110 geography covering an area of ca. 240 000 km² (Silva and Vargas, 2014). Oceanographically, sub-
111 antarctic water, rich in nutrients, flow on the surface through “Boca del Guafo” (43°35.7’S – 74°12.8’W)
112 mixing progressively towards the south with estuarine water (Guzmán and Silva, 2006; Silva and Palma,
113 2008). This oceanographic and geomorphologic particularities create many unique habitats that result in a
114 high degree of endemic wildlife and high species richness (Häussermann and Försterra, 2009; Försterra
115 et al., 2017; Betti et al., 2017). The region is classified as highly vulnerable to local and remote processes
116 (Iriarte et al., 2010). Major threats associated to economic activities includes intense salmon farming,
117 demersal and benthic artisanal fisheries and emerging cetacean sightseeing activities.

118 **1.2 Small coastal cetaceans of Northern Chilean Patagonia**

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

128 These three species are endemic to South America, the Chilean dolphin being even restricted to
129 Southern Chile. They are globally poorly known, with very few studies published, and especially in the
130 inlet waters of Chilean Patagonia. Their conservation status is considered near threatened for the Chilean
131 dolphin (Heinrich and Reeves, 2017) and the Burmeister’s porpoise (Félix et al., 2018), mainly because of
132 its restricted range. Human activities in coastal areas are generally a major threat to coastal cetaceans,
133 through baiting (a known practice in Patagonia (Hammond et al., 2012)), or through interactions with gill
134 nets, fisheries or farms (Heinrich et al., 2019). The Peale’s dolphin is often seen in the fjords porpoising
135 around the boats or foraging close to the shore. The Burmeister’s porpoise and the Chilean dolphin are
136 much more elusive, and do not normally interact with the boats.

137 All of these species emit echolocation clicks that have been known as Narrow Band High Frequency
138 (NBHF) clicks. Interestingly, for each species, only one study describing their vocalization has been
139 published (Reyes Reyes et al., 2018; Kyhn et al., 2010; Götz et al., 2010). Additionally, one unpublished
140 study compared the emitted signals of Chilean and Peale’s dolphins (Rojas-Mena, 2009). The NBHF
141 click is common in coastal species of toothed whales, it is characterized by a peak frequency around 130
142 kHz, a half-power bandwidth of about 15 kHz and almost no energy below 100 kHz. It is thought to
143 be an adaptative response to the predation of killer whales, that do not hear above 100 kHz (Andersen
144 and Amundin, 1976; Morisaka and Connor, 2007). In addition, the Chilean dolphin has been shown
145 to produce ‘buzz’, or very rapid trains of clicks thought to be used while foraging (Götz et al., 2010;
146 Martin et al., 2019). NBHF signals are very similar between species, and are possibly depending on the
147 environment more than on the species (Kyhn et al., 2010), hence the need of more studies on these species
148 vocalizations, that could allow for future long term passive acoustics monitoring.

149 **2 AN EXPERIMENT IN THE FJORD OF PUYUHUAPI**

150 **2.1 Material and methods**

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

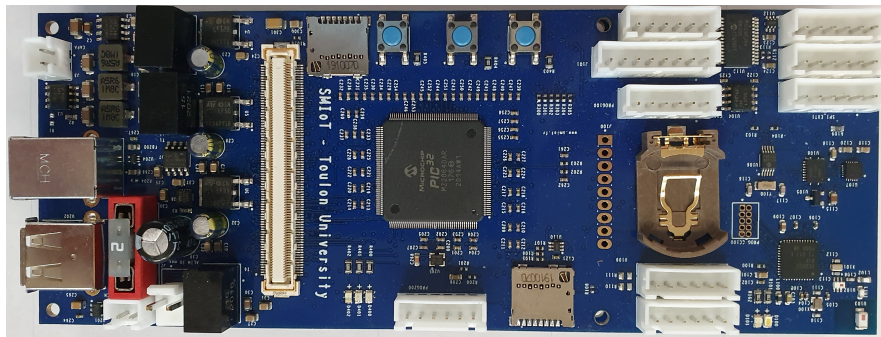


Figure 1. Qualilife HighBlue (QHB) recorder

- 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 $0.55 \times \text{Sampling Rate}$ 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 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 ($44^{\circ}36'38.78''S$, $72^{\circ}45'30.43''W$, figure 3).

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 13 meters, on sandy ground. 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

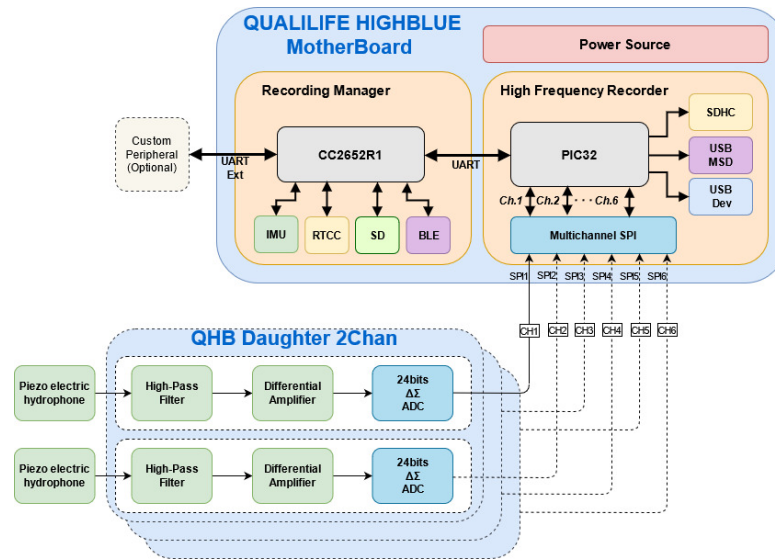


Figure 2. Functional diagram of Qualilife HighBlue (QHB) recorders

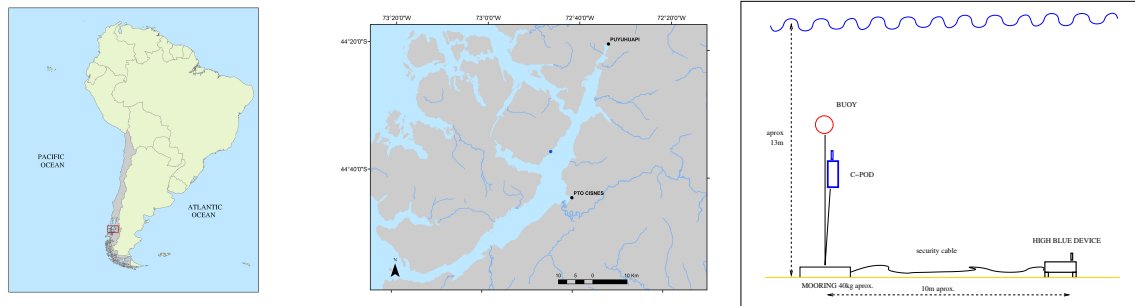


Figure 3. Left : Experiment location in South America. Center : Zoom on the experiment zone. In blue, the point chosen for the installation of the different devices (44°36'38.78"S, 72°45'30.43"W).
Right : Mooring design.

191 filter (Tregenza, 2014). The QHB was retrieved on May, 11th whereas the CPOD was retrieved on July,
 192 28th. Only Chilean dolphins were observed inside this cove, either by the authors or by the tour operators
 193 visiting the place. The only moment when we saw the dolphins was during the operation of changing the
 194 memory card on the 8th of May, when 2 individuals of a group of about 15 Chilean dolphins stayed with
 195 the diver, interacting below the water.

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

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

204 The code of this simple detector is given as supplementary material.

205 **Extraction of clicks parameters** As a first analysis of the clicks, we wrote a short code to automatically
 206 extract the most commonly used parameters of NBHF clicks (Au, 1993), in concordance with the
 207 only other paper published about the Chilean dolphin clicks (Götz et al., 2010). The code is given as

supplementary material and it computes the classical parameters :listed hereafter. *Peak frequency* is computed as the maximum of the Fast Fourier Transform (FFT) of 512 samples (1 ms) around the clicks. *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 (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 is higher than the maximum of the Fast Fourier Transform (FFT) divided by $\sqrt{2}$. *Bandwidth at -10 dB* is the frequency band around the peak frequency where the value of the FFT is higher than the maximum of the Fast Fourier Transform (FFT) divided by $\sqrt{10}$. *RMS duration* is the second central moment of the distribution of time, where the absolute value of the signal divided by its energy is considered a probability density. *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 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 series of trains separated by less than 20 minutes, and then for the total sample.

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 20h local time, and then from the 8/05/21 11h local time to the 10/05/21 11h local time. 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 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 'event' as a series of trains separated by less than 20 minutes. With this definition, 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 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 sensitive.

QHB instrument also recorded contextual noise such as boat engines and sonars, as well as long duration motors 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 described in the literature (Götz et al., 2010). The clicks parameters, 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 the peak frequency, which is clearly multimodal.

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

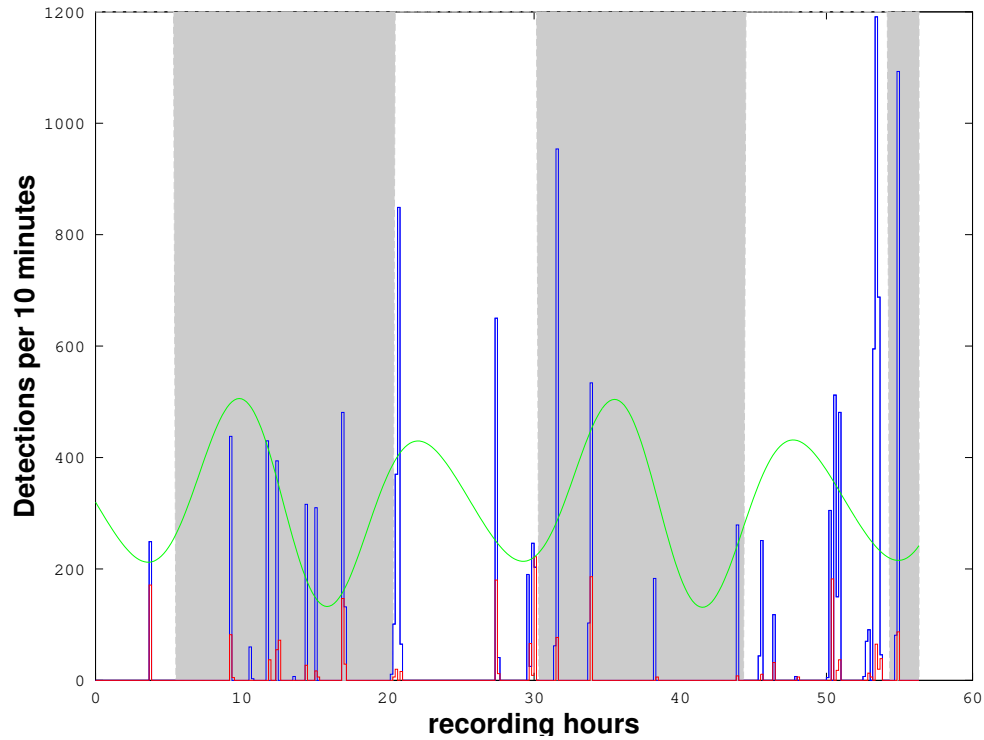


Figure 4. Number of clicks detected per 10 minutes by QHB (blue) and the C-POD (red). Superimposed are night and day lights (night is in grey) and tides in arbitrary units.

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) μ s
Centroid frequency	Frequency bandwidth at -3 dB	Duration at -10 dB
(141 ± 10) kHz	(6 ± 3) kHz	(53 ± 26) μ s
Inter-click interval (ICI)	Frequency bandwidth at -10 dB	Duration at -20 dB
(88 ± 117) ms	(16 ± 8) kHz	(106 ± 52) μ s

Reyes Reyes et al. (2015) describe 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. These clicks are also visible in the ICI distribution (very short ICI). 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 results of Götz et al. (2010) that buzz clicks are emitted 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 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 NBHF

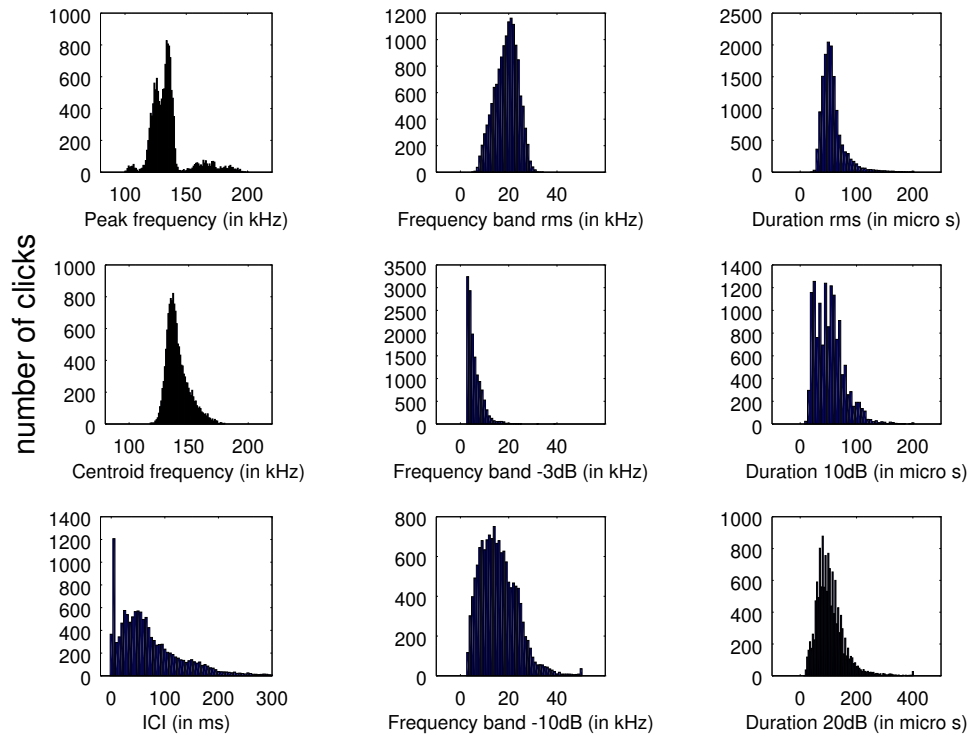


Figure 5. Distributions of the parameters of the detected clicks. Average and standard deviation are given in table 1

clicks.

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, it has been measured for other species, such as the harbour 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 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 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

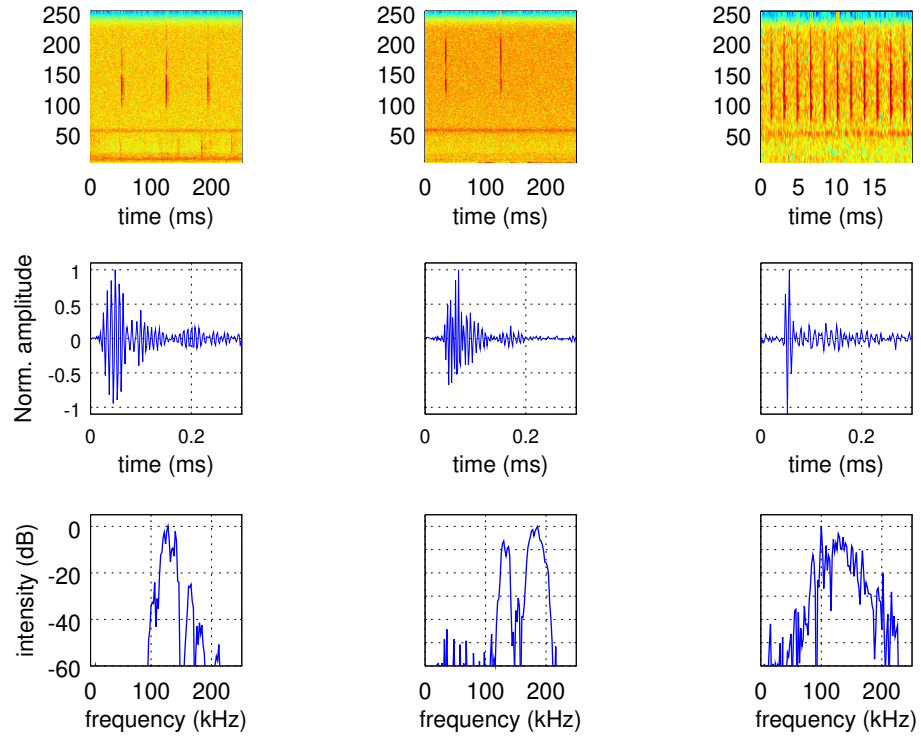


Figure 6. Examples of clicks of Chilean dolphins recorded by QHB. On the left, a typical click with peak frequency around 135 kHz. In the center, a less frequent click with peak frequency around 180 kHz. On the right an example of a click found in a buzz, or rapid sequence of clicks. Top : spectrogram 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.

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 in the Patagonia fjords.

3.2 Clicks properties

Overall, 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 and centroid 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. Moreover, as our device was fixed and in absence of human presence, we can suppose that the dolphins have not been attracted specifically by the device and that most of the clicks recorded correspond to clicks recorded from far away and consequently on-axis. We checked also that each series of clicks have consistent parameters and, for example, that the peaks in frequency around 100 or 170 kHz are common to a series of clicks and thus are probably not coming from distorted off-axis clicks. For all these reasons, we consider that

321 most of the detected clicks can be practically considered on-axis. What's more, Götz et al. (2010) found
 322 very little difference on the average peak frequency between 'on-axis' clicks and the total set ('on axis'
 323 being defined as the most intense clicks of a train). Finally, we think that a «big data approach» could be
 324 a good way in a context of medium term passive acoustics : to record all the clicks (on and off-axis) and,
 325 due to the large number of such clicks, characterize a species or a mix of species by a precise histogram,
 326 with several precise peaks.

327 On the other hand, our data set is much larger than the pioneer work of Götz et al. (2010) (almost
 328 14 000 clicks were analysed in our study, as compared to less than 1000 in this previous work). The
 329 distribution of peak frequencies along the set shows a certain diversity, as was described in the 'Results'
 330 section. Four modes are visible in the frequencies distribution, respectively at 107, 126, 134 and 164 kHz.
 331 Obviously, the panel of possible frequencies is much bigger and we can imagine that Götz et al. (2010)
 332 data is mainly similar to our second mode (second in order of importance) at 126 kHz. Thanks to the large
 333 number of clicks of our data set, we can precise the values of the main peaks by fitting a sum of Gaussian
 334 functions on the histogram of peak frequencies of figure 5. Using an implemented Marquardt-Levenberg
 335 algorithm in Octave, we find that the peak frequencies are 105.8, 125.1, 135.5 and 168.3 kHz (with
 336 respective standard deviations of 4.3, 6.0, 4.4, and 18.0 kHz, see figure 7). These values of the standard
 337 deviations compares well with the value in Götz et al. (2010) and show the interest of a large data set,
 338 made possible by mid-term monitoring.

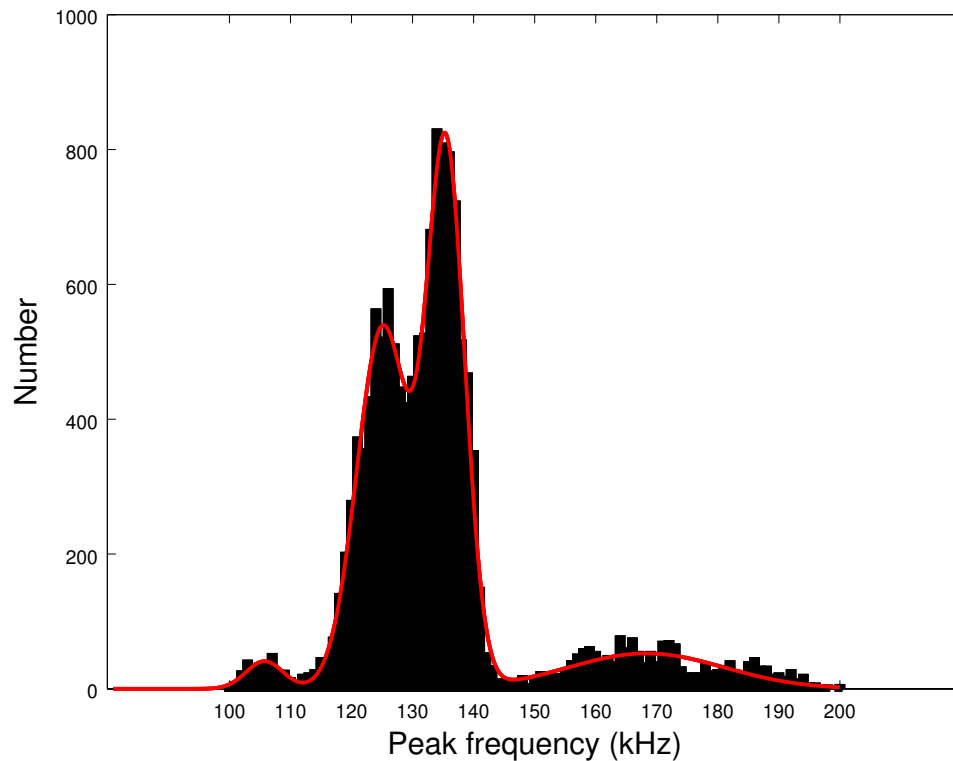


Figure 7. Fitting of the four peaks of the first histogram in figure 5 (peak frequencies) by a sum of four Gaussian functions

339 Why the first work on Chilean dolphin did not evidence the other types of clicks, such as high
 340 frequency clicks, may be explained by the setting of the experiment, which had much less signals and
 341 possibly selected certain types of behaviour due to the presence of the boat. Dolphins have been shown
 342 to respond actively to the presence of a boat, even without engine (Martin et al., 2021), and thus their
 343 clicks repertoire is possibly modified by the observation. What's more, they probably used a low pass
 344 filter (Rojas-Mena, 2009) at 200 kHz, making high frequency not so easily detectable. A last possible
 345 explanation is the geographical difference, since Götz et al. (2010) study is located about 1 000 km North

346 of our experiment, in the much more frequented waters of Chiloe archipelago.

347 We can remark that the study of the Commerson dolphin by Reyes Reyes et al. (2015) also presented
348 dissimilarity with the pioneer measures of Kyhn et al. (2010), with higher average frequencies and a much
349 larger standard deviation for peak or centroid frequencies. They also describe three clusters of clicks
350 for this species, highly similar to what we found, with the median for each cluster being respectively at
351 129, 137 and 173 kHz. No lower frequency or larger band buzz clicks are found in Reyes Reyes et al.
352 (2015) study, though some have been described afterwards by Martin et al. (2021). It is probable that
353 a larger set of data, and more quietly recorded than the pioneer studies on these cryptic species, lead to
354 a panel of novel types of clicks that is particularly rich and interesting. We can mention that the high
355 frequency component of the clicks cannot be found by automated detectors such as C-POD (low-pass filter
356 at 160 kHz) or widely used recorders such as older versions of Soundtrap (low-pass filter at 150 kHz).

357 Another type of clicks detected in our data set are usually found in a very rapid train of clicks, usually
358 denominated buzz (fig. 6, right). A visual examination of our data show about 20 such trains, 7 of them
359 within the same file of 9'30". We define a 'buzz' when the ICI is lower than 5 ms, usually around 2 ms,
360 as compared to normal trains with ICI being between 50 and 100 ms. Our data does not allow a clear
361 separation between 'buzz' and 'burst pulse' as suggested by Martin et al. (2018) for the Heaviside's
362 dolphin (*Cephalorhynchus heavisidii*), a close parent of the Chilean dolphin. While some of the rapid
363 trains are part of normal trains with an accelerating or decelerating pattern, some seem isolated without a
364 normal train around. The characteristics of the clicks are similar in both cases, unlike what was found
365 by the cited authors. Despite some variability, possibly due to a variable signal to noise ratio, a general
366 pattern of a larger bandwidth and a lower intensity is visible for most of the clicks with short ICI, as
367 shown in figure 6, confirming Götz et al. (2010) measures. No visual follow-up was done, so that we
368 cannot link the buzz to a specific behaviour. Nevertheless, in our data we found no superimposed trains
369 (indicating several individuals), so the hypothesis of a foraging comportment seems more probable than
370 social interaction. Obviously, visual monitoring would be necessary to assert this point.

371 3.3 Feasibility of mid-term monitoring

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

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

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

395 4 CONCLUSION

396 Mid-term recording shows an interesting complementarity with other more traditional methods of acoustic
397 studies of small dolphins in remote areas. They allow an insight on a repertoire much more diverse than
398 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 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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