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STUDY OF WHISTLE SPATIO-TEMPORAL DISTRIBUTION AND REPERTOIRE OF A SCHOOL OF FALSE KILLER WHALES, *PSEUDORCA CRASSIDENS*, IN THE EASTERN SOUTH PACIFIC

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ABSTRACT

Eight recording sessions were performed with a Ca20 hydrophone of a school of false killer whales, *Pseudorca crassidens*, circling Chañaral Island, Chile, at 8.1 knots of average speed during almost 16 hours. From a total of 153 whistles, 148 were selected by their quality and analyzed with Linux-based Baudline DSP software. General whistles and new whistles were recorded at rates of 5.3 and 2.4 per minute, respectively. Four recording sessions, at three sites, resulted in a whistle repertoire composed of 69 distinct spectrograms with 6.9 kHz of average frequency (3.8 - 13.6 kHz) and 0.09 to 2.86 seconds of duration. Whistle abundance and diversity were correlated at all recording sites (Pearson corr.: 1, P-value: 0.008). Despite the less than four hours between sessions, only 11.6 % of the individual *spectra* were shared by two sites. Sessions at the same site presented a different vocal composition. On an intra-vocalization level, the number of inflection points (less than four) is slightly related to whistle duration (Pearson corr.: 0.207, P-value: 0.012), and whistle structure is determined by variations on frequency, duration and, also, energy. With distance, the lower intensity sections of six of the vocalizations faded-out, resembling different individual whistles. Therefore, vocal repertoires may be overestimated if this effect is not considered. Only 4.3 % of the assessed whistle repertoire was represented at all recording sites. These results suggest that neither the vocal repertoire nor its conservative section is likely to be able to be assessed by a single recording event.

Key words: False killer whale, *Pseudorca crassidens*, Bioacoustics, Vocalizations.

RESUMEN

Estudio de la distribución espacio-temporal y repertorio de los silbidos de una escuela de falsas orcas, *Pseudorca crassidens*, en el Pacífico suroriental. Se realizaron ocho sesiones de registro acústico, con hidrófono Ca20, a una escuela de falsas orcas, *Pseudorca crassidens*, que rodearon Isla Chañaral, Chile, por casi 16 horas a 8.1 nudos promedio. De un total de 153 silbidos, 148 fueron seleccionados por calidad y analizados con el programa Baudline. Los silbidos en general y los nuevos, fueron registrados en tasas de 5.3 y 2.4 por minuto, respectivamente. Cuatro sesiones de registro, en tres sitios, resultaron en un repertorio compuesto por 69 espectrogramas con 6.9 kHz de frecuencia media (3.8 - 13.6 kHz) y 0.09 a 2.86 segundos de duración. La abundancia y diversidad de silbidos estuvieron correlacionadas en todos los sitios (Pearson corr.: 1, P-value: 0.008). Sólo 11.6 % de los espectros individualizados, fueron compartidos por dos sitios, pese a una separación menor a cuatro horas entre sesiones. A nivel intravocal, el número de inflexiones (menor a cuatro) está levemente relacionado con la duración (Pearson corr.: 0.207, P-value: 0.012), y la estructura del silbido está determinada por variaciones en frecuencia, duración y también, energía. Las secciones con menor intensidad, tienden a desaparecer del espectrograma con la distancia, confundiendo su identificación individual. Sin considerar este efecto, es posible sobre-estimar el repertorio vocal. Sólo el 4.3 % del repertorio estuvo representado en todos los sitios de registro. Estos resultados sugieren que ni el repertorio vocal ni su sección más conservada, son posibles de determinar mediante un evento único de registro.

Palabras clave: Falsa orca, *Pseudorca crassidens*, Bioacústica, Vocalizaciones.

INTRODUCTION

Excluding cases of cetacean populations with high site fidelity, most studies of free ranging small cetacean vocalizations are opportunistic, resulting from single sightings/recording events. During inter-specific vocal repertoire comparative analysis, often it is assumed that at least part of their vocal composition is conservative. In open waters, free ranging small cetacean schools are difficult to re-encounter in different environments and displaying different behaviors. To follow cetacean schools is not always productive as most wired hydrophones have to be used while drifting. When tolled, the hydrophones can register a higher amount of noise from the vessel's engine, vibration of the wire/cable holding the sensor, friction with the water, and bubbles among other noise sources, resulting in the loss of valuable information. Even with highly technological hydrophones, the research vessel's presence can have uncertain effects on cetacean behavior. Yet, intra-populational and comparative studies are needed in order to assess which vocalizations present higher probabilities of being recorded which can characterize the specific school, quantify the most conservative vocal repertoire section, and determine how much of the vocal repertoire can be retrieved from single recording events, and its variation rate.

The water in the vicinity of Chañaral Island presents a high cetacean diversity (González *et al.,* 1989; Yáñez, 1997; Capella *et al.,* 1999; Van Waerebeek *et al.,* 1999; 2006; Sanino and Yáñez, 2000; 2001a; 2001b; Sanino and Canepa, 2005; Sanino *et al.,* 1996; 2003a; 2003b; 2005). Research is needed to verify its potential for long term studies based on the implementation of specific recording stations with methods that prevent disruption of the cetaceans and without noise.

To date, a limited library of acoustic studies on free-ranging *P. crassidens* is available. Studies have been published for offshore waters of the Maldives and Sri Lanka in the spring of 2003 (Madsen *et al.,* 2004), and for the eastern Tropical Pacific during 1999 (Oswald *et al*., 2003). In Chile, analysis of cetacean vocalizations is considered anecdotal and with little participation of local researchers.

Acoustic efforts in Chile have been limited mainly to large whales including blue whales (Cummings and Thompson, 1971; Ljungblad and Clark, 1998, and Ljungblad *et al.,* 1998) and recently sperm whales (Rendell, L. and H. Whitehead, 2005). We are aware of other efforts during international and occasional cetacean surveys but we did not find publications of their analysis. Local management and scientific authorities do not have additional information. Our studies of cetacean acoustics in Chile began in 1999 with the collaboration between PS and Dr. Mark McDonald.

In this contribution, we present the retrieved whistle repertoire of a free ranging school of false killer whales, *Pseudorca crassidens*, using analytical methods to identify individual vocalizations as well as their properties in an *inter* and *intra*-vocalization level. Comparing captive and free-ranging individuals (Madsen *et al.,* 2004), echolocation sound production has been found to be dynamic in *P. crassidens*. We tested if the most repeated vocalizations are also the ones most frequently shared among the different recording sites in space and time, and, therefore, if the vocal composition is stable enough to be retrieved by single recording events. Assuming that most vocalizations are repetitions of few individual vocalizations, we tested if lower vocal diversity was related to recording sites where the vocalization's abundance was higher.

Being the first study of acoustic properties of small cetacean in Chile and, possibly in the eastern South Pacific for the species, we tested, for Chañaral Island, the potential to develop cetacean acoustic studies, the capabilities of a mobile recording unit, and the need of a hydrophone network. In order to promote low-cost acoustic studies on free ranging cetacean populations, we present analytic methods using free software or under GNU General Public License (GPL).

MATERIALS AND METHODS

Equipment and acoustic recording procedure

The platform used to perform the recording sections was the Leviathan II, a 22 feet long sailboat designed and built for cetacean research purposes and suitable for the nearby environment. The cabin is acoustically insulated except the hull section in contact with the water, and the electricity for equipment is provided by a deep-cycling battery that is charged during the night by wind-generator.

Two volunteers were posted near to the anchoring site in the northern extreme of Chañaral Island (29º01'26.03"S-71º34'00.6"W), Karime Tala and Macarena Sagaceta, in order to notify the sailboat in case of cetacean sightings.

Search for cetaceans was carried out from the sailboat and the team in the island using Nikon 7X50 binoculars. Navigation was mainly by sail in order to keep the boat silent. However, at exceptional times when 45º sailing tracks were not useful and the navigation course was facing the wind, a small 3.5 HP outboard engine (Tohatsu) was used. Once cetaceans were sighted, and the dolphins' swim direction was determined, the sailboat approached them silently and indirectly using the procedures described by Sanino and Yáñez (2000) in order to diminish impact on the dolphins' behavior. Indirect tracks were engaged to obtain a position >400 meters ahead of the dolphins, where the hydrophone was deployed while drifting in silence. In some cases, a 3.5 m diameter parachute storm anchor was used to limit drifting. The hydrophone output was recorded until vocalization signals were absent for five minutes or until losing visual contact with the cetaceans.

For this study the Cetacean Research Ca20 hard wired hydrophone unit (Bandwidth 10 Hz - 35 kHz; Sensitivity: -161 dB, re. 1 V/μPa) was chosen as its deployment and recovery is faster and easier than the modified sonobuoy hydrophones. Also, it is managed easily by volunteers.

The audio recorder was the Sony TCM-453V, with Phillips headsets (frequency range 10-22000 Hz). A Sony DCR-VX1000 video camcorder registered the general behavior of the dolphins to compare it with the underwater acoustic recordings.

Collected data

In addition to the acoustic tapes, the data collected included: date/time, geographic position, start sighting time, start recording time, recording duration, heard whistles (binary), closest estimated distance to the dolphins while recording, sea state (Beaufort scale), sea surface temperature and general notes. Additionally, cetacean behavior was noted from the sailboat and the station on the island, both during and between the acoustic recording sessions. To be consistent with the methods of the Scientific Committee of the International Whaling Commission, we used criteria and codes similar to the IWC-SOWER research program when classifying the cetaceans' reaction to the presence of the sailboat, how compact were the cetacean schools, their general behavior, and school dynamics for each sighting and acoustic session (Findlay *et al.,* 1998).

Acoustic material

Seven acoustic recording sessions of false killer whales, *Pseudorca crassidens*, were performed on February 12th and one session was performed on February 13th 1999, at seven stations corresponding to positions where the sailboat was drifting, anchored or towing the deployed hydrophone. The dolphins were turning in a counter-clockwise direction and circled Chañaral Island at least eight times. The average sea surface temperature was 17.8 ºC.

Two cassettes were recorded, digitalized (Sound board SB-AWE64) and transferred to CDs, as *.wav audio files. A first edition (Sound editing software Audacity 1.2) was utilized to remove vocal marks and useless sections (e.g. when the hydrophone is being deployed, recovered or towed), remaining 1724 minutes.

Spectral analysis

The sound analysis was performed with Baudline 1.01, a DSP software. As OS, we used the linux distribution SUSE Linux 9.3 in a generic AMD Athlon desktop computer. Baudline has an excellent spectrogram display (time vs. frequency vs. spectral energy as a color gradient) positioned over the spectrum display (current slice of frequency vs. intensity). Baudline's settings included: sampling rate set to 44100 Hz, output playdeck with -50 Hz and +60 Hz filters enabled, Fast Fourier Transform (FFT) size set in 1024 points when searching for vocalizations, 2048 points when analyzing intra-vocalization characteristics in Blackman windowed data, and the spectrum peak smoothing display was set to 2 dB per second.

Baudline was operated in open file mode (instead of real time mode) as the acoustic material was in two *.wav audio files. For every whistle spectrogram, the following actions were taken:

(a) the primary wave was differentiated from its harmonics with Baudline's harmonic helper bars;
(b) the counter (position) was retrieved and "*shape subgroup*" and "*quality*" were estimated;
(c) duration, maximum and minimum frequencies, and maximum spectral energy were measured;
(d) the slope of each inflection point (+,-,0) was recorded;
(e) the slope sign sum and the total number of inflection points were determined;
(f) the average frequency and delta frequency (range) were calculated;
(g) a JPG image file was captured from the screen with KsnapShot;
(h) under the status of a preliminary vocalization or "*prevoc*", the record was identified with a unique and incremental number;
(i) and, the *prevoc* record was stored in the database together with the information retrieved in the previous steps.

Vocalization classification

Quality selection

The complete session recording, as well as the signals themselves, can present different qualities affecting both the spectrogram determination and further analysis. To diminish this error, sessions as well as preliminary vocalization spectrograms were classified depending on their quality (see Table 1), arbitrarily based on how identifiable was/were the spectrogram(s) from their background noise. Only sessions and *prevocs* with a score equal to or higher than "4" were considered for further analysis.

TABLE 1. Criteria used to classify the quality of the material recorded per session and for each preliminary vocalization spectrograms.

Qualification	Score
Useless (Actually)	1
Defective or not very useful	2
Some technical defects (e.g. noise)	3
Partially good for science and/or education	4
Good for science and/or education	5
Excellent for science and/or education	6
Outstanding	7

Categories of vocalization

The vocal repertoire of false killer whales includes click trains, burst-pulse sounds, and whistles as well as intermediate and gradually modulated sounds between whistles and burst-pulse trains (Murray *et al*., 1998). Among the different signal types, this study is focused on a whistle-based vocal repertoire assessment and analysis. Click trains and burst-pulse sounds were not included. To simplify the identification of each individual vocalization, we included "*shape subgroups*" based on the most representative vocalization spectrogram shapes found in a preliminary analysis of the recorded material.

Database

To store and manage the collected data, we used the Sighting, Weather, Acoustic Record, and Vocalization forms for survey cruises of the database CetaceanResearchDB4.0. This is the forth significant upgrade of the database used during the SOWER97/98 (Findlay K. *et al.,* 1998) and other similar studies in the same area (Sanino G.P. and J.L. Yáñez, 2000; 2001; 2003 and 2005). The original database was transferred from MS Access to OpenOffice2.0, in order to limit software use to free, opensource or General Public License. The vocalization *shape subgroups* also were included.

Vocalization identification criteria and procedure

Despite the ease in recognizing vocalization spectrograms with qualities "6" and "7", a specific criterion was implemented to prevent depending on the observer's abilities and therefore, obtaining different errors for different vocalization comparisons. Two vocalization spectrograms or *prevocs* were considered to be the same one, when all of the following criteria were satisfied:

(a) they are grouped in the same vocalization shape subgroup;
(b) both have the same number of inflection points, with a tolerance of one;
(c) the duration difference is smaller than 15 % between both vocalizations or the average duration of their *shape subgroup;*
(d) the average frequency difference is smaller than 15 % between both vocalizations or with the average frequency of their *shape subgroup;*
(e) vocalizations with a delta frequency smaller than 100 Hz, and without inflections points, were considered as monotonic. Two monotonic vocalizations were considered to be the same one if their average frequency and duration differences were smaller than 15 %.

To transfer this criterion from a rational language to a binary language, an OpenOfficeCalc2.0 datasheet was implemented seeking to compare each *prevoc* to the others in order to find its repetitions, and therefore, the vocalization abundance and diversity. This way, the datasheet was constructed from the database, listing for each *prevoc*, its identification number, *shape subgroup*, number of inflections points, duration (s), average frequency (average between its maximum and minimum frequency), and the frequency range (delta frequency). With "A", "B", "C", "D", and "E" as the *shape subgroup*, number of inflections, duration, average frequency and delta frequency respectively, both *prevocs* "x" and "y" were considered to be the same one when:

IF(SameTone=”N”;((IF(SameShape=”Y”;1;0)+IF(SameNInfl=”Y”;1;0)+IF(SameDur=”Y”;1;0)+
IF(SameFreq=”Y”;1;0)))/y;(IF(SameShape=”Y”;1;0)+IF(SameNInfl=”Y”;1;0)+IF(SameDur=”Y”;1;0)+
IF(SameFreq=”Y”;1;0)+1)/5) = 1 corresponding to a 100 % of similarity between the two *spectra*.
with:
SameShape = IF(Ay=Ax;”Y”;”N”)
SameNInfl = IF(By=Bx;”Y”;IF(By=Bx+1;”Y”;IF(By=Bx-1;”Y”;”N”)))
SameDur = IF((IF(Cy>Cx;Cy-Cx;Cx-Cy))/Cx<0.15;”Y”;”N”)

SameFreq = IF((IF(Dy>Dx;Dy-Dx;Dx-Dy))/Dx<0.15;"Y";"N")
SameTone = IF(Ex>=100;"N";IF(Ey>=100;"N";IF(IF(Ey>Ex;Ey-Ex;Ex-Ey)/Ex>0.15;"N";"Y")))

Whistle abundance and diversity determination

For each *prevoc*, the resulting *prevoc(s)* repetitions that were identified by the previous test were grouped and listed under the column, *"repetition(s) list"*. Therefore, a whistle can be represented in the acoustic material by a single *prevoc* or several repetitions of it. The code used to individually identify a whistle and later shared within the *prevoc(s)* on its *repetition(s) list*, was VOCa with "a" as an incremental number. A three-column table was developed, identifying *prevoc(s)*, their *repetition(s) lists*, and VOCa code. Using the algorithm in Fig. 1, the diversity of vocalizations (*repertoire*) and the abundance (*occurrence*) of each vocalization were determined.

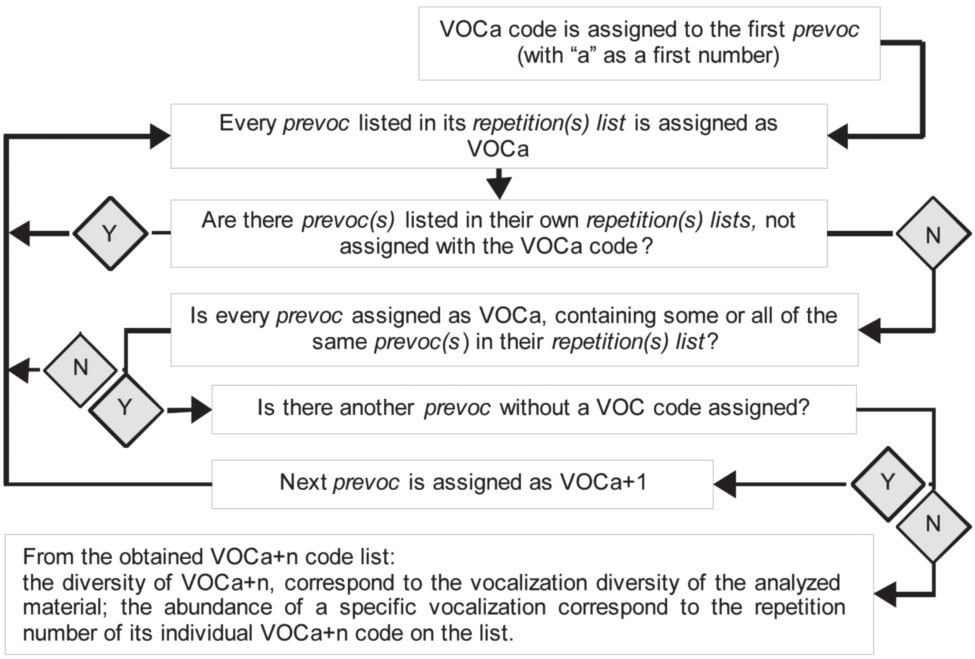

FIGURE 1. Algorithm of the procedure used to individually identify the vocalizations and their vocal abundance and diversity for a school of false killer whales, *P. crassidens*, Chañaral Island, Chile.

Other analysis

The intensity, measured with Baudline, is negative with the maximum possible spectral energy in 0. To measure the energy of the vocalizations, we used the strongest spectral peak tool (Primary) in dB, double checked directly in the vocalization spectrogram. The average or the minimum are more affected than the maximum intensity, by the distance from the sound source to the hydrophone and the background noise. For each recording site, the average and range of vocal intensity was measured with a 95 % confidence interval.

The vocalization abundance and diversity among the recording sites was analyzed as absolute values as well as normalized by their effort. The effort was determined as a rate of production per minute. For statistical analysis we used OpenOffice Calc 2.0 and Minitab (free demo, release 14.20).

RESULTS

Recording sessions

Details including position, duration in seconds of the records, estimated closest distance to the dolphin school, sea state (Beaufort scale) and the quality of the recordings are presented in the Table 2.

TABLE 2. Characteristics of acoustic recording sessions in presence of false killer whales, *P. crassidens*, Chañaral Island, Chile.

Session:	1	2	3	4	5	6	7	8
Position:	29º01'09"S 71º34'35"W	29º02'40"S 71º35'37"W	29º03'03"S 71º33'50"W	29º02'33"S 71º33'30"W	29º01'27"S 71º34'05"W	29º01'36"S 71º33'35"W	29º01'25"S 71º34'07"W	29º01'25"S 71º34'07"W
Start Time:	11:02:00	12:02:00	12:52:00	14:00:00	18:00:00	20:30:00	23:15:00	02:40:00
Duration (s):	540	450	144	60	16	285	163	66
Whistles:	Yes	Yes	None	None	None	Yes	Yes	Yes
Est. Dist. (m):	0	20	50	1000	50	150	0	0
Sea state:	1	1	2	2	1	3	1	1
Quality:	3	5	5	5	6	6	7	7
Hydrophone was Towed:	Yes	Both	No	No	No	No	No	No
Relative position to cetaceans:	Aside	Ahead	Behind	Behind	Behind	Ahead	Ahead	Ahead
Island Site:	North-west	South-west	West	South-east	Anchorage	North-east	Anchorage	Anchorage

Geographically, 47 % (69) of the vocalizations were recoded in the north of the island at Anchorage site (Session 7 and 8), while 42 % (62) were recorded in the South-west site (Session 2) and 11 % (17) in the North-east site (Session 6). Vocalization's abundance and diversity as well as the dolphin's behavior for each of the recording sessions are presented by the Table 3.

TABLE 3. Behavior and vocalization abundance and diversity: Acoustic recordings of a false killer whale school, *P. crassidens*, Chañaral Island, Chile.

Session	Vocalization's		Behavior			
	Abundance	Diversity	Ship Reaction	School Compact	General Behavior	School Dynamics
1	0 (0 %)	0 (0 %)	Attraction when <= 5 nm	All animals within 5 body lengths.	Slow Travel <10 kn	Unchanged
2	62 (41,9 %)	35 (43,2 %)	No reaction	All animals within 5 body lengths.	Slow Travel <10 kn	Unchanged
3	0 (0 %)	0 (0 %)	No reaction	All animals within 5 body lengths.	Fast Travel >10 kn	Into small subgroup number
4	0 (0 %)	0 (0 %)	Undetermined	All animals within 5 body lengths.	Fast Travel >10 kn	Into small subgroup number
5	0 (0 %)	0 (0 %)	No reaction	All animals within 5 body lengths.	Slow Travel <10 kn	Unchanged
6	17 (11,5 %)	12 (14,8 %)	No reaction	All animals within 5 body lengths.	Slow Travel <10 kn	Unchanged
7	8 (5,4 %)	5 (6,2 %)	No reaction	All animals within 5 body lengths.	Slow Travel <10 kn	Unchanged
8	61 (41,2 %)	29 (35,8 %)	No reaction	All animals within 5 body lengths.	Slow Travel <10 kn	Unchanged

Vocalization quality

From a total of 153 vocalizations, 148 were selected as having a quality of at least “4”. For the stations in the South-west site, North-east site and the Anchoring site in the bay, the average Quality of the vocalizations was 5, 6 and 7 respectively, The Sea State at these same sites on the Beaufort scale was 1, 3, 1 respectively, with no relationship between them (N: 8; Person corr.: 0; P-value: 1).

Vocalization spectrogram shape subgroups

After a preview of the vocalization spectrograms, 18 subgroups were proposed to distribute the vocalizations and facilitate their identification. The characteristics of the resulting subgroups are presented in the Table 4.

TABLE 4. Acoustic characteristics of arbitrarily assigned *shape subgroups* of vocalization of a school of false killer whales, *P. crassidens*, around Chañaral Island, Chile.

Code	Shape	N	Div.	N Inflections			Duration (s)			Av. Freq. (Hz)		
				Min	Max	Avr	Min	Max	Avr	Min	Max	Avr
A1	Almost monotone, but starts with an increasing.	7	5	0,0	1,0	0,1	0,175	0,993	0,550	5954,0	7138,5	6626,0
A2	Almost monotone, but starts with a decreasing.	4	3	0,0	0,0	0,0	0,254	0,420	0,340	5157,0	7343,0	6457,3
A3	Almost monotone, but ends with some inflections.	3	3	0,0	0,0	0,0	0,205	0,622	0,430	5997,0	7061,0	6409,0
A4	Monotone with no slope or close to 0.	19	5	0,0	0,0	0,0	0,167	1,428	0,520	5728,0	8419,5	6682,0
B1	Almost straight, always soft increasing slope.	11	5	0,0	0,0	0,0	0,303	1,224	0,830	5889,5	7859,5	6755,5
B2	Almost straight, always soft decreasing slope.	6	4	0,0	0,0	0,0	0,142	0,476	0,330	5878,5	7030,5	6219,5
C1	Curved, mainly increasing.	8	5	150,0	0,0	20,0	0,211	0,766	0,500	6083,0	8570,0	7115,3
C2	Curved, mainly decreasing.	22	6	0,0	0,0	0,0	0,290	1,732	1,090	5384,5	8656,5	6799,4
D1	Curved with one positive inflection point.	23	9	1,0	1,0	1,0	0,095	1,716	0,860	5835,5	8559,5	7501,9
D2	Curved with one negative inflection point.	4	4	1,0	1,0	1,0	0,334	1,080	0,720	6600,0	8872,0	7472,1
E1	Straight lines, with one positive inflection point.	0	0	-	-	-	-	-	-	-	-	-
E2	Straight lines, with one negative inflection point.	1	1	1,0	1,0	1,0	0,650	0,650	0,650	7870,5	7870,5	7870,5
F	Like an M.	9	5	1,0	3,0	2,8	0,123	0,601	0,250	6115,5	7224,5	6700,6
G1	Square root shaped.	12	3	1,0	2,0	1,9	0,264	2,859	1,450	4920,0	5458,5	5263,0
G2	Inverted Square root shaped.	2	1	2,0	2,0	2,0	1,178	1,209	1,190	9841,0	10196,0	10018,5
H	Two or more inflections forming a complex voc.	10	6	2,0	4,0	2,6	0,298	1,816	1,010	6320,0	8592,0	7707,9
I	Shorter than 0,16s and less than two inflections.	7	5	0	0	0	0,09	0,16	0,12	5911	9291,5	7032,14

Nineteen percent of the *shape subgroups* represented whistles from just one recording site, while 44 % represented whistles from the three sites. The abundance of whistles in the South-west, North-east and Anchoring recording sites, organized in s*hape subgroup*, is highly heterogeneous (see Figure 2).

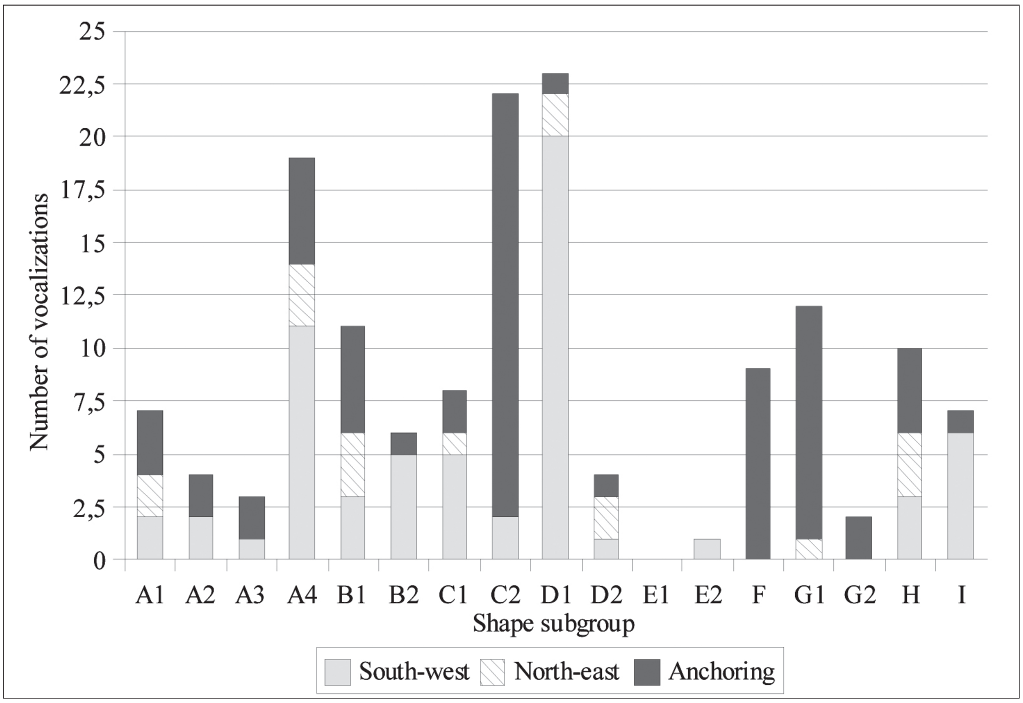

FIGURE 2. Abundance of whistles of *P. crassidens*, organized by *shape subgroup*, for the South-west, North-east and Anchoring recording sites in Chañaral Island.

Among the 148 preliminary vocalizations, 69 were individually identified. Only a few whistles were shared by the three recording sites, particularly at the North-east site. Four vocalizations were repeated in a significantly higher number than the other vocalizations. The individual vocalizations, identified by their code, were plotted by their occurrence and grouped by recording site in Figure 3.

Whistle repertoire characteristics

Whistle frequency ranged from 3812 to 13631 Hz, with an average of 6869 Hz. Almost no correlation was found between Inflection Number and Duration (N: 148; Pearson corr.: 0.207; P-value: 0.012). The general whistle characteristics found in the recorded material is presented in the Table 5.

TABLE 5. Vocal repertoire characteristic of a school of false killer whales, *P. crassidens,* around Chañaral Island, Chile.

	Max. Freq. (Hz)	Min. Freq. (Hz)	Δ Frequency (Hz)	X Freq. (Hz)	Duration (s)	Inflection number	Energy (-dB)
Maximum :	13631	9044	6870	10196	2,859	4	82,17
Minimum :	4974	3812	0	4920	0,087	0	5,50
Average :	7457	6282	1175	6869	0,755	0,73	41,98
St. Dev. :	1332	1065	1308	1013	0,521	1,02	15,75
Coef. Var. :	17,86	16,95	111,3	14,75	68,94	139,89	37,53

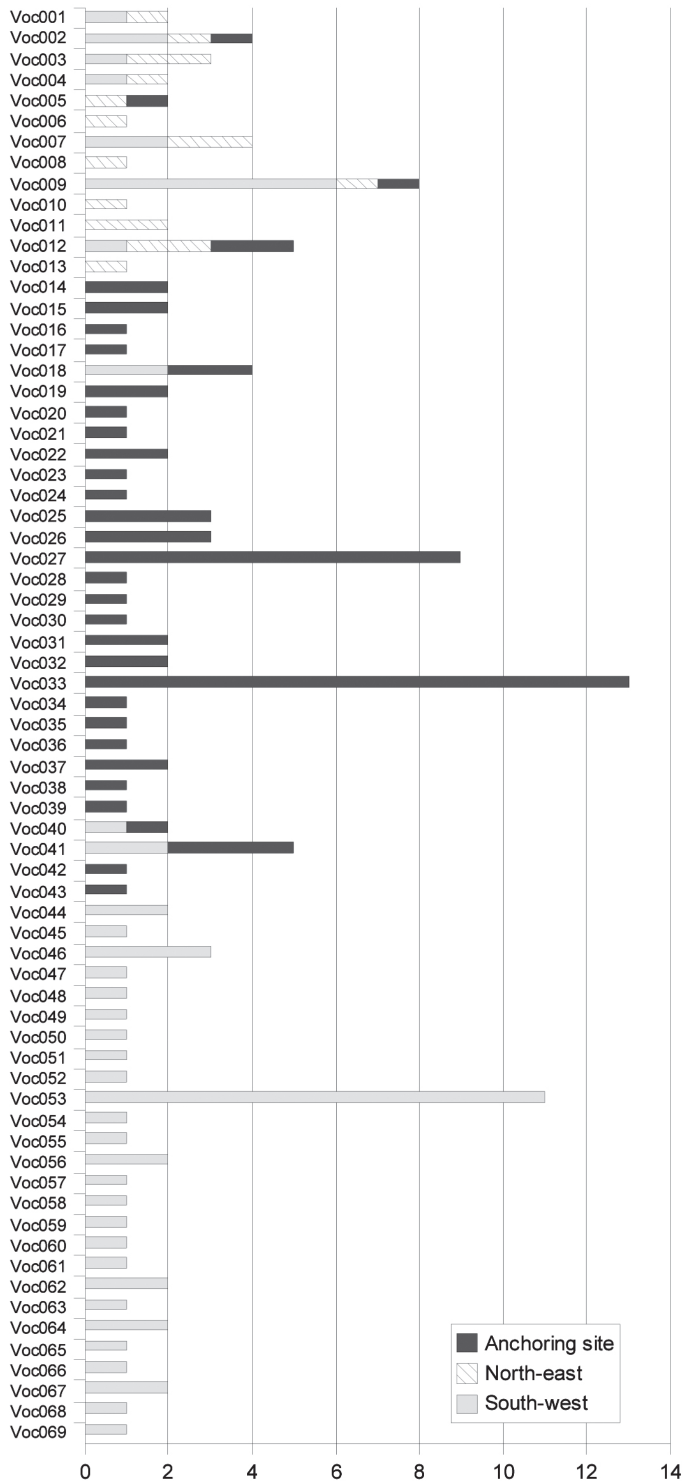

FIGURE 3. Individual vocalization occurrence of a school of false killer whales, *P. crassidens*, at the recording sites of South-west, North-east and the Anchoring site.

In a comparison of the three recording sites, the higher average and maximum intensities for the vocalizations were found in the Anchorage site. The highest intensities were measured for voc026 and voc025, -5,50 dB and -9,94 dB, respectively. The Table 6, shows the different values found for the South-west, North-east and anchoring recording sites.

TABLE 6. Average and range of the peak intensities for the South-west, North-east and Anchoring recording sites.

	Mean (dB)	Max (dB)	Range (95 % conf. interval)
South-west site :	-55,71 dB	-38,25 dB	-58,07 : -53,34
North-east site :	-41,17 dB	-17,00 dB	-48,16 : -34,19
Anchoring site :	-29,84 dB	-5,50 dB	-32,16 : -27,51

Abundance, diversity and distribution of vocalizations

Vocalization abundance and diversity were positively correlated (N: 148, Pearson corr.: 0.803, P-value: 0.000) for all data, as well as among the South-west, North-east and Anchoring recording sites during the four sessions (N: 4, Pearson corr.: 1, P-value: 0.000). The highest vocalization abundance was found to correspond with the highest diversity. Whistle production per minute was 8.27, 3.58, 2.94 and 55.45 for Sessions 2, 6, 7 and 8, respectively. Distribution by recording site is presented in Figure 4.

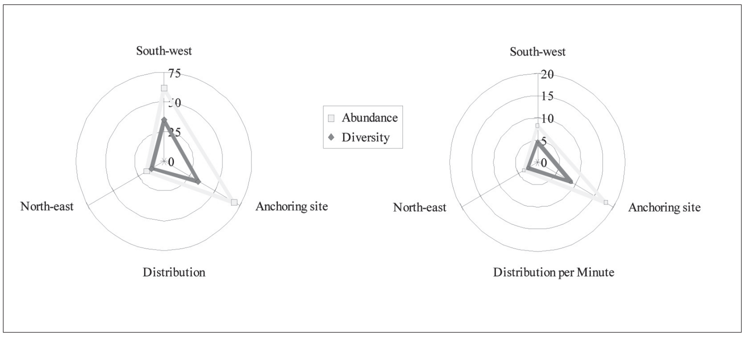

FIGURE 4. Whistle abundance and diversity of *Pseudorca crassidens*, in Chañaral Island, distributed among the South-west, North-east and Anchoring sites in absolute values (left) and normalized per minute (right). An error of 3.3 % can be added to these values, resulting from the removal of five preliminary vocalizations.

As at the three recording sites, the vocalization's abundance and diversity co-varied among the *shape subgroups* as well, with *shape subgroups* D1, C2 and A4 as the most abundant. Details are presented in Figure 5.

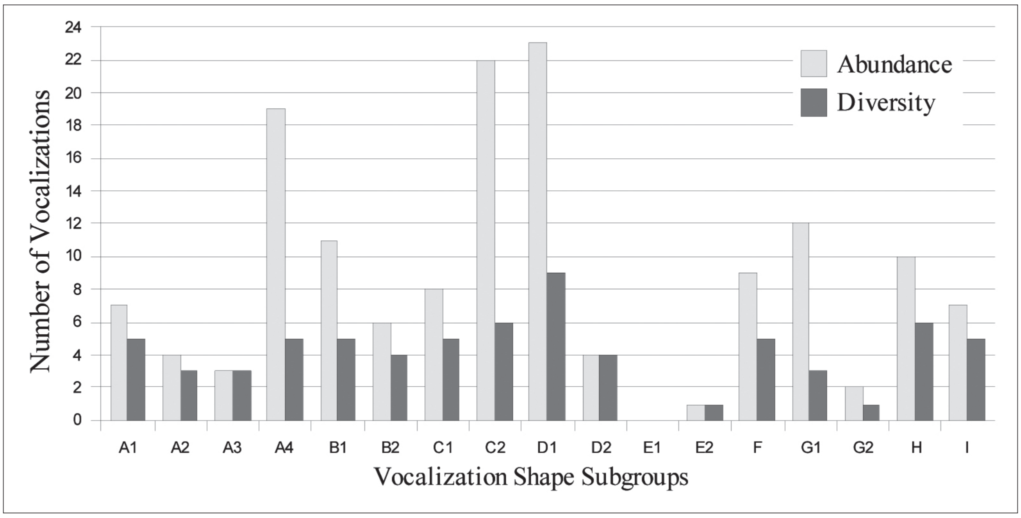

FIGURE 5. Whistle abundance and diversity of *P. crassidens*, distributed by *shape subgroup*.

More than half (57 %) of the individual vocalizations were recorded only once (without repetition) during 28.7 minutes. However, during this same time, vocalization voc33 occurred exceptionally, 13 times. The percentage of individual vocalizations of the vocal repertoire, grouped by their occurrence and recording site, is presented in Figure 6.

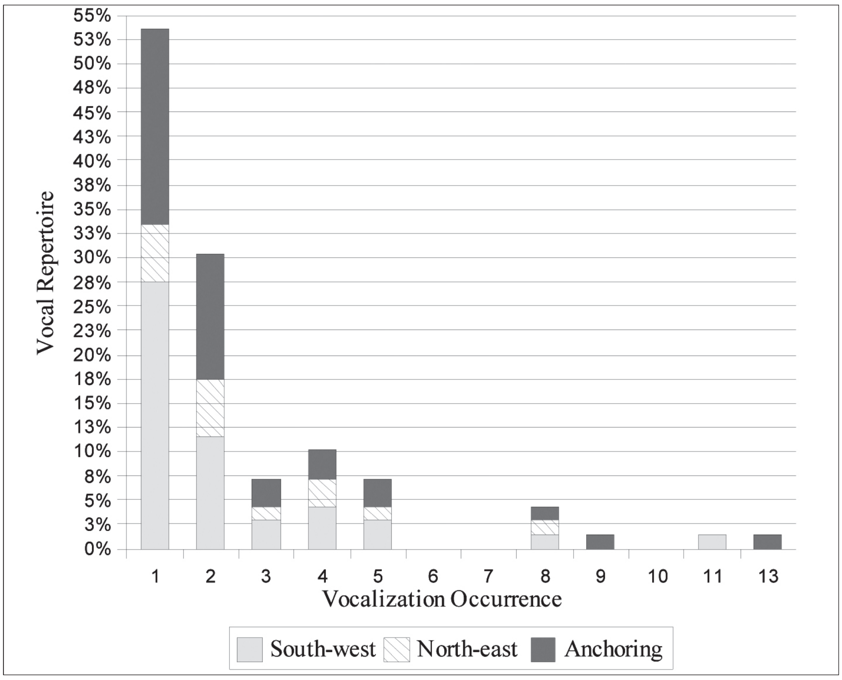

FIGURE 6. Vocalization occurrence of the whistle repertoire of a school of false killer whales, *P. crassidens*, in Chañaral Island.

The dolphins swam a path of 11.3 km around Chañaral Island. The fastest recorded turn was at an average speed of 8.1 knots, while the average speed among all turns was 6.3 knots. The speed was not constant, there being some sites around the island where the dolphins increased their speed while in others they almost rested. The fastest speed recorded in a known path, was 10.7 knots (20 km/h), with a course 0º in the extreme Southeast of the island, swimming in the same direction as the waves.

CONCLUSIONS

This is likely to be the first attempt to retrieve the vocal repertoire of *Pseudorca crassidens* in the eastern South Pacific. From a total of 148 whistles, 69 compose the whistle repertoire, obtained from an analysis of 28.7 minutes. The recording rate was 5.3 vocalizations per minute (including the five vocalizations removed) and 2.4 of new vocalizations per minute.

Geographic distribution

If the vocalization production of *P. crassidens* were uniform, we would have expected to find that the most repeated whistles would also be those most often shared among the different recording sites. Yet, the North-east site presented the smallest number of repetitions but the highest number of vocalizations shared with other sites (61.5 %). Only voc002, voc009 and voc012 were shared between all sites. The vocalization voc009 was mainly recorded in the South-west site, while voc002 and voc012 were found more evenly distributed between the recording sites. On the other hand, the three most abundant vocalizations (voc033, voc53, voc027) were found in the Anchoring site or in the South-west site without being shared with other sites (Fig. 3). Only 11.6 % of the individual vocalizations where shared between two sites. Each geographic site had a different vocal composition despite that the recording sessions were separated by less than four hours.

This finding increases the difficulties in assessing vocal characteristics suitable to identify distinct populations. But difficulties have been found with photo identification techniques, also, as the species presents a tendency to heal scars with the same color as the background pigmentation (Baird *et al.,* 2005). Distinguishing false killer whale populations is needed in order to evaluate fishing interactions and conflicts such as with the longline tuna and swordfish industries (Baird *et al.,* 2005; Carretta *et al.,* 2004; Nitta and Henderson, 1993).

Vocal repertoire representativity

Because less than half of the vocalizations were recorded more than once (Fig. 6), the actual repertoire represents only a small part of the vocal diversity of this specific school of false killer whales. We did not find available data from other schools in the area for comparison that would allow us to contribute with our data to generalize the vocal repertoire for the species in this area.

At the beginning of this study, every vocalization was new. In the first 28.7 minutes of effective recorded material, 57 % of the vocalizations appeared only one time. Considering this rate stable, we would expect that after 4.2 hours of effective time analyzed, we would have only 5 % of vocalizations recorded for the first time. Therefore, it is likely not reliable to assume that a representative vocal repertoire, of these dolphins, and at the time of this study, could have been assessed from a material smaller than 4.2 hours. This would take approximately one week of monitoring time with the present technique.

Some vocalizations were found to be repetitive and with sections fading-out, inside or in the extremes. Because the sailboat was drifting while recording the traveling dolphin school, the obtained vocalizations had a gradient of intensity as the school became more distant from the hydrophone. Because of this, some vocalizations were losing the *spectrum* of their sections with lower intensities, and, as a result, may have been mistakenly identified as different individual vocalizations. This seems to be the case, after analyzing the vocalization sequences for voc015, with voc016, voc017 and, possibly, with voc018. Decreasing the likelihood to 75 % when identifying the individual vocalizations yielded useful results when checking among a smaller sample size for possible repetitions mistakenly identified as different vocalizations. This way, the *shape subgroups* G1 and G2 become similar to A1, A2, A3, and A4 when the low intensity sections are no longer retrieved by the hydrophone. Consequently, it is possible that some vocalizations of the A *shape subgroups* were originally G1 and G2 vocalizations.

Vocalization occurrence

Vocalization abundance and diversity are correlated among the three main sites. The Anchoring site presented more than twice the whistle rate production, both in abundance and diversity, than the other sites. The recorded abundance of vocalizations cannot be attributed to the distance between the dolphins and the sailboat nor the depth of the hydrophone as both the higher and lower vocal rate occurred at the same recording site with the same hydrophone setting (Table 2 and Sessions 7 and 8).

Gobbo *et al.,* (2005), found that the striped dolphin, *Stenella coeruleoalba*, in the Ligurian sea, increased its vocal activity (as well as ultrasound production) during the night. Considering whistle production per minute as vocal activity, similar behavior was not found in this school of false killer whales during the night (Fig. 4). As the day advanced, the production rate decreased significantly but in the first hours after midnight, the production rate increased 15.5 times. However, this study includes data from only one day, and therefore we cannot assure that this is a regular pattern.

Respectively, Session 8 was 18.8 times more productive in vocalization abundance and diversity per minute than Session 7, without sharing individualized vocalizations despite that both sessions were with the same dolphins and from the same site. This dolphin school showed a dynamic vocal production in time and geographic position that could not be generalized.

Despite how abundant voc033 was, it does not have the highest probability to be recorded. The use of *shape subgroups* did not prove useful to characterize the vocal production because less than half of *shape subgroups* represented vocalizations from all the recording sites. The *shape subgroups* more evenly distributed among the recording sites were those with small abundance (e.g. “A1”, “B1”, “D2” and “H” *shape subgroups* in Fig. 5).

Therefore, the shape subgroup with the highest occurrence is not necessarily the most evenly distributed.

Intra-vocalization complexity

The false killer whale’s vocal production results were more complex than expected. The number of inflections of the vocalizations presents almost no correlation to their duration (Pearson corr.: 0.207, P-value: 0.012). Even in short duration vocalizations (e.g. “F” *shape subgroup* vocalizations), several inflection points can be found, that do not seems to correspond to an accidental case, considering its occurrence (Fig. 5). The vocal structure is not only determined by intra-vocalization variations in the frequency and the duration, but also its energy. Intra-vocalization sections with lower energy were found at initial and/or ending extremes as well as in the first inflection points in voc014, voc015, voc026, voc027, voc032, and voc033.

Behavior

Despite the differences in vocal composition between the three main recording sites, at all sites, the dolphins presented no reaction to the boat, the distance between the individuals and other school members remained unchanged, and the school did not change their course on approach or departure of the sailboat (See Table 3).

In general, the school of false killer whales, *P. crassidens*, was swimming at low speeds (average 8.1 knots) but not evenly distributed. The fastest speeds were recorded in the eastern coastline of the island, with a northern course. The faster speeds in the eastern coastline as well as the very slow speeds in some areas of the western coast of Chañaral Island, can be partially explained by the course of the waves. In the western coastline and with a swim direction to the South, the dolphins had to face the waves while in the eastern coastline they swim in favor of them and the wind.

At the Anchoring site, school of false killer whales, *P. crassidens*, was not hunting. Our ecosounder did not find any significant fish school at this site at night or during the day and the sea lions that use this path are not present during the night to the nursing area in the opposite side of the island. So, the site does not seems to be a prey source for the dolphins and therefore, we do not have an explanation for the differences between Session 7 and 8, other than the day and night conditions. At night, the vocal activity of this school increased in energy (Table 6), able to be heard inside the sailboat cabin without the need of any special equipment, as well as in production rate (Fig. 4). At the North-east site, the dolphins were returning from the area in front of the sea lion colony, and their vocalizations were mostly those shared with the other recording sites. At the South-west site, the dolphins were bowriding at the front of the sailboat minutes before they were recorded. The swim direction of the dolphins was facing the waves and wind, passing through the most complex coastline of the island, where we recorded the highest background noise. The acoustic recordings of this site included vocalizations of a blue whale at the same time as the dolphins, with their interactions being analyzed in a separate study. This was the only site where we recorded lobtailings, single and multiple jumps (see Fig. 7), spyhoping behavior, and the lowest swim speed of the dolphin school. They were neither hunting nor fishing, and there are no sea lions in this part of the island.

FIGURE 7. Two members of a school of false killer whales, *P. crassidens*, in the South-west of Chañaral Island, Chile.

The geographically closest study on *P. crassidens* was done by Oswald *et al.* (2003) from recordings in the eastern Tropical Pacific. The southernmost records were from the first degrees of Latitude North. Comparing our data with the results of Oswald *et al.* (2003), our material presents a higher average of the minimum frequency (+1,58 kHz), a higher average of the maximum frequency (+1,36 kHz), a lower average of the intra-vocalization frequency range or "Δ Frequency" (-0,22 kHz), a higher average of the duration (0,35 s) and a higher average of inflection points number (+0,23).

Environment conditions for acoustic recordings

Most of the vocalizations were recorded when the sailboat was drifting. No vocalizations were recorded successfully during a non-stop active approach (e.g. Session 1), due to the non-functionality of the hydrophone when it is being towed.

The quality of the recorded vocalizations was more affected by their intensity rather than the sea state. The retrieval of vocalizations was successfully achieved even under a sea state of Beaufort 3, that we attribute mainly to the use of limiting drift by using the storm anchor, as well as a bungee cord incorporated into the Ca20 hydrophone's wire to absorb the pulling effect of the waves over the boat and then the sensor.

As long as the hydrophone Ca20 is used under limited drifting status, the quality of the vocalizations is not affected by the sea state at least on the first three Beaufort degrees. The experience of the Session 6 presented the worst sea state conditions but a high vocalization quality (Table 2), suggesting that under rough conditions it is appropriate to increase the distance to the closest coast in order to diminish background noise (e.g. shrimp and waves against the coast), rather than trying to get closer to the animals, even when they are passing closer to the coast.

The removal of five from the initial 153 *prevocs* from the analyzed material, because of their low quality, can affect the abundance and diversity estimations of the recording sites. Considering the worst situation, which would be to have all the removed *prevocs* being recorded from the same recording site, the calculated vocal abundance and diversity for that site would be affected by an error of 3.3 %. However, the use of low quality *spectra*, can lead to misinterpretations as new distinct individual vocalizations. Considering that the lowest diversity site had 13 individual vocalizations, to not remove the low quality spectra, would affect it with a 38 % error. Therefore, it is recommended to remove low quality *spectra* rather than force their identification.

Equipment

For computer-based marine mammal sound analysis, scientists often use software such as Dave Mellinger's Ishmael, SpectraLab, or John Burt's Syrinx (all MS Windows platform based). Since 1999 we have been exploring the use of Baudline, a Linux based software developed by Erik Olson. This is our first publication using this spectral analysis software. Baudline has been improved every year becoming, in our opinion, the best real time audio analyzer in the Linux world. The speed managing long audio files and the quality of the spectrogram makes it particularly useful. We have not found any another publications using Baudline for marine mammal applications but it recently has been used as a bioacoustic software for studies of wolf vocalizations by the University of San Diego (Moriarty *et al.,* 2005).

Considering the intra-vocalization complexity and the effect of distance on the recorded vocalizations, we do not recommend the use of fully automated classification systems, unless they include in their properties, the ability to identify vocalizations whose lower intensity sections are fading-in/out due to the distance of the animal to the sensor or during its emition. During signal classification, Oswald *et al*. (2003) found the four frequency-based variables the most discriminatory and the number of inflections, the least discriminatory. Considering the presence of lower energy and fade-out intra-whistle sections in our material and, that those sections are often at the beginning and/or at the end of the vocalizations, we considered the frequency measurement more subjective than the number and slope of inflection points. Because of these sections and the impact of distance, we did not use the initial and final frequency variables. We found database form multi-filter tools based on the sign of inflection points more useful when inflection points were present.

To test the acoustic properties around Chañaral Island, the use of the sailboat as a mobile recording station was successful and confirmed that acoustic studies can be developed in this area. However, in order to estimate if/how much our method to identify individual vocalizations is overestimating the vocal repertoire due to the lower intensity intra-vocalization sections, an analysis of material recorded simultaneously from two different hydrophones positioned in-line with the dolphin swim direction is needed. In order to develop long-term acoustic studies, a fixed hydrophone network needs to be installed. Considering the dolphins' behavior of turning around the island, staying in the area for periods of up to 16 hours in duration, and the presence of a high diversity of large and small cetacean species, this is an ideal site for such a hydrophone network. (González *et al*., 1989; Yáñez, 1997; Capella *et al.,* 1999; Van Waerebeek *et al.,* 1999; 2006; Sanino and Yáñez, 2000; 2001a; 2001b; Sanino and Canepa, 2005; Sanino *et al.,* 1996; 2003a; 2003b; 2005).

Considering the quality of the vocalizations as well as the results from these recording session and the environmental conditions during these events, the best place to install a fixed hydrophone in Chañaral Island seems to be the Anchoring site, which also is generally protected from the wind and waves.

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