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Geographic variability in the acoustic parameters of striped dolphin's (*Stenella coeruleoalba*) whistles

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ABSTRACT

Geographic variation in the acoustic features of whistles emitted by the striped dolphin (*Stenella coeruleoalba*) from the Atlantic Ocean (Azores and Canary Islands) and the Mediterranean was investigated. Ten parameters (signal duration, beginning, end, minimum and maximum frequency, the number of inflection points, of steps, of minima and maxima in the contour and the frequency range) were extracted from each whistle. Discriminant Function Analysis correctly classified 73% of sounds between Atlantic Ocean and Mediterranean Sea. A cline in parameters was apparent from the Azores to the Mediterranean, with a major difference between the Canaries and the Mediterranean than between Azores and Canaries. Signal duration, maximum frequency and frequency range measured in the Mediterranean sample were significantly lower compared to those measured in the Atlantic. Modulation parameters played a considerable role in area discrimination and were the only parameters contributing to highlight the differences within the Atlantic Ocean. Results suggest that the acoustic features constrained by structural phenotype, such as whistle's frequency parameters, have a major effect on the Atlantic and Mediterranean separation while behavioural context, social and physical environment may be among the main factors contributing to local distinctiveness of Atlantic areas. These results have potential passive acoustic monitoring applications.

KEY WORDS: whistles, geographic variation**,** striped dolphin, Atlantic Ocean, Mediterranean Sea

I. INTRODUCTION

Geographic variation in the acoustic features of signals of a species have been investigated for several delphinids, including *Tursiops* sp. (May-Collado and Wartzok 2008, Morisaka et al. 2005, Hawkins et al. 2010, Baron et al. 2008, Jones and Sayigh 2002, Wang et al. 1995), *Stenella coeruleoalba* (Azzolin 2008), *Stenella frontalis* (Baron et al. 2008), *Stenella longirostris* (Bazua-Duran et al. 2004), *Delphinus delphis* (Petrella 2009, Griffiths 2009), *Orcinus orca* (Ford et al. 1983), *Sotalia guianensis* (Rossi-Santos and Podos 2006), *Pseudorca crassidens*, *Grampus griseus*, *Globicephala melas* and *Globicephala macrorhynchus* (Rendell et al. 1999). Geographic variation in signal acoustic structure results from the combination of genetic and environmental characteristics, both physical and social. Moreover, acoustic parameters are under morpho-physiological constraints and different selective pressures (Gerhardt 1991). Isolation due to geographic or cultural factors can lead to acoustic diversification (Janik and Slater 2000). The role of geographic distance in acoustic differentiation has already been assessed in species distributed in continuous basins or in contiguous areas. Wang and colleagues (1995) reported a continuous variation for bottlenose dolphins with a change in acoustic parameters between the oceans, whereas Rossi-Santos and Podos (2006) found differences in an apparently continuous geographic distribution of *Sotalia fluviatilis* in Brazil. For the Mediterranean striped dolphins, Azzolin (2008) highlighted that advancing in the Mediterranean Sea from the Gibraltar Strait most of the whistle parameters gradually change.

The species analyzed in this study, the striped dolphin (*Stenella coeruleoalba,* Meyen, 1833), is a cosmopolitan species and occurs in tropical, sub-tropical and temperate pelagic waters (Folkens and Reeves 2002). The species is abundant in the Atlantic and considered the most common species in the Mediterranean (Forcada et al 1994 and Panigada et al 2011). Striped dolphins are sometimes observed, both in Mediterranean Sea and in the Atlantic Ocean, in mixed groups with common dolphin, Risso's dolphin and other species of the genus *Stenella*. The species is gregarious with pods varying in size between a few and over 1000 individuals with average school sizes ranging between 100-500 individuals.

Striped dolphins are classified as 'lower risk' but 'conservation dependent' at the oceanic level by IUCN experts (Cetacean Specialist Group 1996), and in the Mediterranean Sea they are considered "Vulnerable" (Reeves and Notarbartolo di Sciara 2006).

Significant genetic differentiation was detected between the Mediterranean and the Atlantic populations using five polymorphic microsatellite loci (Bourret et al 2007). No haplotype was shared between Mediterranean and Atlantic areas, indicating the existence of two different populations. A very limited amount of gene flow across the Strait of Gibraltar is hypothesised (Garcia-Martinez et al. 1999). Moreover, skull dimensions of Mediterranean striped dolphins are smaller than their counterparts in the Eastern North Atlantic (Archer 2002). To date, geographic variation in striped dolphin acoustic behaviour has been studied only in the Ligurian Sea (Gitter 2009) and in the Mediterranean (Azzolin 2008).

In this study we evaluate for the first time if whistles produced by *Stenella coeruleoalba* across the Mediterranean Sea are different from the eastern North Atlantic Ocean. We then estimate patterns of geographic variability in the acoustic features, comparing the acoustic structure of whistles from two archipelagos belonging to Macaronesia (the Azores and the Canaries) in relation to the Mediterranean.

II. MATERIALS AND METHODS

Study area

Recordings were collected from two macro-geographic areas: the Mediterranean Sea and the Atlantic Ocean (Fig. 1). From the Atlantic, sound recordings from two of the five archipelagos of the Macaronesian area were analyzed (the Azores Islands and the Canary Islands). Both archipelagos are located in the North Atlantic Ocean and are geological hot spots of the Mid-Atlantic ridge. They are separated by a distance of about 1200 km. The three areas considered for the analysis are:

1) The Azores, located approximately 1500 km west of Portugal between 36º and 40º latitude North and 24º and 32º longitude West, composed of nine islands divided into 3 subgroups (western, central and eastern), extending about 600 km along a northwest-southeast axis. The seabed around the islands is deep (ca. 1500 m at 3.7 km) with numerous scattered seamounts (Santos et al. 1995, Morato et al. 2008).

2) The Canary Archipelago, located between 27° and 30° North and 13° and 19° West, made up of seven main islands located 115 km away from the African coast. The archipelago extends north to south approximately 500 km and the bathymetry is characterized by steep island slopes with depths reaching 1000m only 1.8 km from the coast (Canales et al 1998).

3) The Mediterranean Sea which is a basin connected with the Atlantic Ocean by the Strait of Gibraltar. Two main sub-basins make up the Mediterranean: the Eastern and Western basins, separated by the Sicily Strait (Astraldi et al 1999). The bathymetry is deeper in the eastern, or Levantine, basin where the Hellenic trench reaches 5093 m depth, while in the western basin the deepest area is found in the Tyrrhenian Sea, around 3800 m.

Data collection

Four research groups participated in the data collection for this study: IMAR-DOP/UAç (Centre of Institute of Marine Research, Department of Oceanography and Fisheries, University of the Azores, Portugal), SECAC (Society for the study of Cetaceans in the Canary Archipelago, Spain), IFAW (International Fund for Animal Welfare, United Kingdom) and GREC (Research Group about Cetaceans, France) (Table I). GREC used a mono towed hydrophone with *Benthos* AQ4 in 1999 and a stereo towed with the same hydrophone elements the other years with a flat response of ± 2 dB from 200Hz to 30 kHz, a 29 dB pre-amplifier and 200Hz high-pass filter. An external high-pass filter unit (Magrec Ltd) set to 1kHz was used on the hydrophone output to improve the quality of recording.

IMAR-DOP/UAç and IFAW recorded with either an omnidirectional hydrophone (*HTI*-94-SSQ) or a towed array with 2 hydrophones *(Benthos* AQ4 with a linear flat response of ± 1 dB between 1 Hz and

15 kHz, and of ± 3 dB between 15 kHz and 30 kHz. Recordings were made with a digital tape recorder *Tascam ®DA-P1*, with a sampling frequency of 48 kHz, 16 bits resolution and frequency responses from 20 Hz to 20 kHz ± 0.5 dB) and SECAC utilized a towed array with 4 elements: 2 hydrophones *Benthos* AQ4 and 2 spherical ceramic hydrophone elements with a frequency response of ~2-150 kHz (Seiche UK Ltd). Sounds were digitalized at a sampling rate of 48 kHz by IMAR-DOP/UAç, IFAW and GREC, and 192 kHz by SECAC. No recording off scale was considered in the analysis.

Data from the Mediterranean (Alboran Sea, Balearic and Spain, Corso-ligure-provençal basin, Tyrrhenian, Ionian Sea) were collected in 1996, 1998 and 1999 by GREC and in 2003-2004 by IFAW. Data from the Azores were collected by IMAR-DOP/UAç in the summers 2000 and 2002, and year-round in 2003. In the Canary Islands data were recorded by SECAC from 2008 to 2011 (Table I).

All the recordings were collected when only one group of animals formed by only one species was within visual range in order to identify the species and avoid the risk of considering emissions by mixed groups of sympatric species.

Data analysis

Each whistle was also classified by assigning a quality index between 0 and 3 (Fig. 2). The assigned score was: 0) when detection of the complete time-frequency contour of the whistle was impossible because of overlapping with other sounds and low intensity; 1) when low intensity and/or low signal to noise ratio prevented to recognise the complete contour, 2) when the complete contour can be recognised but intensity was low and 3) when intensity was high and time-frequency contour well defined. Only whistles classified as 2 or 3 were considered of high quality and used in the analysis. Moreover, sounds with similar time-frequency contours were considered only once to avoid potential autocorrelation effects.

Recordings were analyzed by extracting whistle parameters using the spectrogram view in the program CoolEdit 2000 (Syntrillium Software, U.S.A.). Ten signal parameters (duration, 5 for frequency and 4 for modulation of the sound) were manually measured from each whistle after the method of Oswald et al (2003, 2007) and Azzolin (2008). These included: signal duration, beginning frequency, end frequency, minimum frequency, maximum frequency, the number of inflection points (change from positive to negative or negative to positive slope), the number of steps (a discontinuous change in frequency) and the number of minima and maxima in the contour (Fig. 3). We calculated also the frequency range as maximum frequency minus minimum frequency.

The statistical software package PASW Statistics 18.0 (SPSS Institute Inc., Chicago, Illinois, USA) was used for the descriptive (mean, standard deviation) and comparative statistical analysis of whistle parameters. Once it was verified that the data distribution was not normal, the nonparametric Mann-Whitney and Kruskal-Wallis tests were used to determine whether parameters varied between populations. The analysis of the Coefficient of Variation (CV) provided a fine scale estimation of the variability of the parameters between and within the three areas. We also performed a Discriminant Function Analysis (DFA) in order to evaluate whether recorded whistles could be correctly assigned first between the Mediterranean Sea and the Atlantic Ocean, and then between the Mediterranean Sea, the Azores Archipelago and the Canary Archipelago. The leave-one-out procedure (Lachenbruch and Mickey, 1968) was then used for cross-validation. For all the multivariate statistics we did not used frequency range as a predictor variable due to its dependence from maximum and minimum frequency parameters.

III. RESULTS

Study effort

We used 3.70 hours of recordings from 13 sightings for the Atlantic area. We extracted 1141 whistles but used only 553 high quality whistles (scored 2 and 3) for the analyses (111 from the Azores and 442 from the Canary Islands). From the Mediterranean area, we used 18.71 hours of recordings from 38 sightings. We extracted 1802 whistles and analyzed 1062 (346 in the Eastern basin and 716 in the Western basin).

Whistle diversity between Atlantic Ocean and Mediterranean Sea (Table II)

An analysis of parameters variability within the basins showed higher values in the parameters associated with signal modulation (92-166) and lower CVs associated with variables related to signal frequency (20-50). Whistles produced by striped dolphins in the Atlantic showed significantly higher values compared to the Mediterranean ones for duration (Mann-Whitney test N=1615; Z=-4.726; P<0.001), maximum frequency (Mann-Whitney test N=1615; Z=-7.889; P<0.001) and frequency range (Mann-Whitney test N=1615; Z=-8.671; P<0.001). Modulation parameters, like number of steps (Mann-Whitney test N=1615; Z=-13.502; P<0.001), number of maxima (Mann-Whitney test N=1615; Z=-7.407; P<0.001) and number of minima (Mann-Whitney test N=1615; Z=-7.557; P<0.001), were significantly higher in the Atlantic Ocean whistles while the number of inflection points were significantly lower (Mann-Whitney test N=1615; Z=7.962; P<0.001). The results of the cross validated Discriminant Function Analysis performed between whistles recorded in the Atlantic and in the Mediterranean, showed that 73.4 % of signals could be correctly classified to the study areas on the basis of the number of inflection points, number of maxima, number of minima and minimum frequency (coefficients: n° inflection points= -1.05, n° of maxima= 0.75, n° of minima=0.48, minimum frequency =-0.42).

Whistle variation among the Azores, Canaries and Mediterranean Sea

The same pattern of differences found between the sounds of the Atlantic and the Mediterranean was evident when we analyzed separately whistles recorded at the Azores and Canaries in comparison with the Mediterranean Sea recordings. The analysis of the degree of variability within the three areas showed higher CVs in parameters associated with signal modulation and lower variability for frequency-related parameters (Table III). All the frequency parameters had inter areas CVs ranging from 3.80 to 12.33. Frequency parameters did not differ significantly between sounds from the Atlantic Archipelagos but again, both Atlantic Archipelagos recordings differed significantly from the Mediterranean (Fig. 4). Between the Azores Islands and Mediterranean Sea sounds significant differences were found in the number of steps (Mann-Whitney test N=1173; Z=-10.791; P<0.001), maxima (Z=-2.167; P=0.03), the frequency range (Z=-6.316; P<0.001), signal duration (Z=-3.271; P=0.01) and the maximum frequency (Z=-5.153; P<0.001) that presented values significantly lower in the Mediterranean sea, while the number of inflection points (Z=9.447; P<0.001) were higher in the Mediterranean sea whistles. Between the Canary Islands and the Mediterranean Sea sounds significant differences occurred in the number of steps (Mann-Whitney test N=1504; Z=-10.965; P<0.001), maxima (Z=-7.662; P<0.001), minima (Z=-8.972; P<0.001), the frequency range (Z=-7.255; P<0.001) signal duration (Z=-4.030; P<0.001), and maximum frequency (Z=-6.863; P<0.001), all significantly lower in the Mediterranean whistles but the number of inflection points was significantly higher (Z=5.021; P<0.001) (Fig. 4).

In addition, all whistle modulation parameters had higher inter areas CVs than frequency parameters and they were all significantly different not only between Atlantic archipelagos and the Mediterranean whistles, but also between the recordings from the two Atlantic archipelagos (Fig. 4). Significant differences existed between the Azores and the Canary Islands sounds for number of steps (Mann-Whitney test N=553; Z=4.576; P<0.001), which was significantly lower in the Canary Archipelago. Inflection points (Z=-6.131; P<0.001), minima (Z=-5.258; P<0.001) and maxima (Z=-2.236; P=0.02) were significantly higher in the Azores archipelago whistles. Number of steps and of minima were also the only parameters contributing to the Discriminant Function Analysis performed between the Canaries and the Azores (coefficients: n° steps= 0.72, n° of minima= -0.69).

The cross-validated Discriminant Function Analysis correctly assigned 63% of whistles recorded in the different areas. Mediterranean Sea whistles had a correct assignment rate of 73%, the Azores of 55% and Canary Islands 40%. For the Canary Islands, 30.1% of whistles were misclassified to the Azores and 29.9% to the Mediterranean Sea, while for Azores 27% were misclassified to the Canary

Islands and only 18% to the Mediterranean (Table IV). The parameters that contributed most to the analysis were the number of inflection points, maxima, steps and minimum frequency (coefficients: n° of inflection points=-1.02, n° of maxima=0.77, steps=0.45 and minimum frequency=-0.41).

The canonical DFA scatter plot (Fig. 5) displayed a clear pattern of difference among areas. The whistles recorded in the Azores and in the Mediterranean Sea were definitely separated while the Canaries signals showed an intermediate group centroid between them.

IV. DISCUSSION

The communication signals of delphinids play an important role in both species and group recognition, although the degree of modulation of signals can vary widely among populations (Janik 2009). Furthermore each parameter can vary independently under the pressure of different selective forces (Wang et al 1995).

Atlantic and Mediterranean whistles exhibited characteristics that were significantly different, both in parameters related to morphological constraint (such as frequencies), duration and in modulation parameters, which are more influenced by the physical and social environments (May-Collado and Wartzok 2008). DFA correctly classified 73% of whistles emitted in the two basins. Our findings are in agreement with differences described by genetic studies (Garcia-Martinez et al 1999, Bourret et al 2007) which identified two populations inhabiting the two sides of the Gibraltar Strait. These two populations are partially reproductively isolated.

The analyses carried out among the recordings of the three study areas showed significant differences within the Atlantic Ocean samples only in modulation parameters, suggesting the presence of a gradual variation in the vocal characteristics and a possible pattern linked to geographic distance. A cline in parameters is apparent from the Azores to the Mediterranean, with a major difference between the Canaries and the Mediterranean than between Azores and Canaries whistles. As shown in the DFA classification, whistles can be discriminated between the areas but the whistles collected at the Canary

Islands have a correct assignment of just 40%. The misclassification score is subdivided into about 30% of wrong assignments to either the Azores or to the Mediterranean Sea. Parameters recorded in whistles of the Canary Islands striped dolphins have intermediate values between the Azores and the Mediterranean, with the exception of the beginning and end frequency (which do not contribute to the discrimination) and the number of maxima and minima. A likely explanation for this result is the geographic position of the Canary Islands. This Archipelago is located at about midway between the other two sites, at a distance around 1000 km from the Gibraltar Strait and of 1200 km from the Azores Archipelago. Striped dolphins are sighted throughout the year both in the Azores (Hartman et al 2008) and the Canary Islands. The year-round occurrence of striped dolphins in the Gibraltar Strait has yet to be evaluated. The Canary Islands may represent an overlap area between striped dolphins inhabiting waters around the Strait of Gibraltar, that are likely to have Mediterranean acoustic features, and oceanic animals carrying Azorean characteristics.

Nevertheless, within the Atlantic Ocean differences are limited to modulation parameters while the signal duration, maximum frequency and range of frequency measured in whistles from the Mediterranean are significantly different than in the Canaries and Azores whistles. Since modulation parameters show a higher degree of variability between the areas as compared to frequency parameters, as well as the highest values of intra area variability, they may be linked to factors unrelated to those deriving from genetic relatedness. Furthermore no studies evidenced the occurrence of genetic differences between the two archipelagos. Considering that modulation parameters contribute the most to the differentiation within the Atlantic Ocean it is possible that behavioural context, social and physical environment may be among the main factors influencing the separation between Azores and Canaries sounds.

The separation between the Atlantic Ocean and the Mediterranean Sea can instead be related also to other factors including genetic variability. Minimum frequency, considered as the parameter most constrained by the structural phenotype (May-Collado et al 2007), displays the lowest inter area and low intra area CVs and is the only parameter of frequency contributing to the Discriminant Function.

The maximum frequency, another morphological constraint parameter with a negative relationship with body size (Wang et al 1995), differs significantly between the basins. Also the range of frequency (a parameter dependent from the maximum and minimum frequency values), shows significant inter-basins differences, but not within Atlantic. Furthermore the signal duration displays inter-basins differences between sounds recorded in the waters of Mediterranean and Canaries or Azores whistles but not between the Azores and the Canary Archipelagos.

Within-basin geographic variation among acoustic structure of whistles emitted in different areas was obtained for the Mediterranean by Gitter (2009). He found acoustic differences between inshore and offshore striped dolphins of the Ligurian Sea a difference that parallel the genetic differences reported by Gaspari (2004). Azzolin (2008) confirmed the acoustic differences for the whistles emitted by in-off-shore animals of the whole basin, and found differences in vocalizations between the Eastern and the Western basins according to the genetic differences hypothesized by Valsecchi et al (2004). In the present study the geographic barrier of Gibraltar can be an obstacle similarly to what was proposed for the Italian peninsula in the Mediterranean Sea by Azzolin (2008).

We can conclude that the acoustic features such as the whistle's frequency parameters, which have a lower variation, are more strongly constrained by the structural phenotype and are likely to be genetically related, are significantly different between the Atlantic and the Mediterranean. On the other hand, modulation parameters, which are less dependent on structural phenotype are probably more tied to context, social, environmental and random individual variation (May-Collado and Wartzok 2008) and consequently show higher variability. According to Bazua-Duran and Au (2004) the acoustic characteristics of whistles may be important in defining the limits and arrangement of a school, especially if acoustic signals are learned socially (Janik and Slater 2000, Sayigh et al 1995, Watwood et al 2004, Riesch 2006), and may reveal affiliative relationships (Watwood et al 2004). Also Rossi-Santos and colleagues (2006) suggest that the social interactions and the sharing of sounds among dolphins which spend time in the same group could be the cause of the geographic gradient.

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VII. TABLES

Table I Details of the data collection

Area		Period	Instruments	Research Group	Equipment
Atlantic Ocean (3.70 hours)	Azores Archipelago	2000-2002-2003	Omnidirectional hydrophone and towed array with 2 hydrophones	DOP/Uaç	Flat response: ± 1 dB between 1Hz and 15kHz, and of ± 3 dB between 15kHz and 30kHz. Sampling frequency: 48kHz
	Canary Archipelago	2008-2011	Towed array with 4 hydrophones	SECAC	Flat response: ± 1 dB between 1Hz and 15kHz, and of ± 3 dB between 15kHz and 30kHz and ~2-150 kHz Sampling frequency: 192kHz
Mediterranean Sea (18.71 hours)	Alboran Sea	1999	Mono towed hydrophone	GREC	Flat response of ± 2 dB from 200Hz to 30 kHz Sampling frequency: 48kHz
	Balearic and Spain	1999	Mono towed hydrophone	GREC	
	Corso-ligure-provençal basin	1996-1998-1999	Stereo towed hydrophone	GREC	
	Tyrrhenian	2003	Omnidirectional hydrophone and towed array with 2 hydrophones	IFAW	Flat response: ± 1 dB between 1Hz and 15kHz, and of ± 3 dB between 15kHz and 30kHz. Sampling frequency: 48kHz
	Ionian Sea	2003-2004	Omnidirectional hydrophone and towed array with 2 hydrophones	IFAW	
		1998	Stereo towed hydrophone	GREC	

Table II Descriptive statistic for each parameter in the two areas (***significant differences P< 0.001) (frequency parameters in Hz)

	Atlantic Ocean				Mediterranean Sea				Z
	Min	Max	Mean (SD)	CV	Min	Max	Mean (SD)	CV	
Maximum freq. ***	7636	30743	17171 (3500)	20.39	3520	24000	15597 (3501)	22.45	-7.89
Minimum freq.	1108	13487	7882 (1723)	21.86	1468	13619	7977 (1935)	24.26	0.88
Frequency Range ***	598	23603	9288 (3506)	37.75	135	19764	7616 (3388)	44.50	-8.67
Duration ***	0.15	2.23	0.95 (0.33)	34.54	0.04	4.61	0.90 (0.45)	50.46	-4.73
Beginning freq.	4264	24000	11753 (4772)	40.61	1468	24000	11012 (4054)	36.82	-1.76
End freq.	3371	30743	11897 (4420)	37.15	2420	23092	11288 (3543)	31.39	-1.76
Number of Inflection points ***	0	11	1.02 (1.42)	139.40	0	13	1.50 (1.54)	102.92	7.96
Number of Steps ***	0	21	3.84 (3.54)	91.93	0	16	1.73 (2.27)	131.59	-13.50
Number of maxima ***	0	5	0.77 (0.85)	109.65	0	8	0.49 (0.79)	159.00	-7.41
Number of minima ***	0	6	0.84 (0.95)	112.41	0	9	0.56 (0.93)	165.80	-7.56

Table III Descriptive statistics for each parameter in the three areas of the analysis and results of the Kruskal-Wallis test (X^2, significant P (P< 0.001) value is represented by stars in the table) (frequency parameters in Hz)

	Azores Archipelago				Canary Archipelago				Mediterranean Sea				CV inter areas	X^2
	Min	Max	Mean (SD)	CV	Min	Max	Mean (SD)	CV	Min	Max	Mean (SD)	CV		
Maximum freq. ***	10016	23107	17439 (3403.29)	19.52	7636	30743	17104 (3525.10)	20.61	3520	24000	15597 (3501.80)	22.45	5.87	63.66
Minimum freq.	1108	11950	7727 (1877.82)	24.30	3371	13487	7921 (1682.02)	21.23	1468	13619	7977 (1935.22)	24.26	1.67	0.9
Frequency Range ***	3074	21602	9712 (2924.44)	30.11	598	23603	9182 (3633.85)	39.57	135	19764	7616 (3388.86)	44.50	12.33	79.28
Duration ***	0.34	2.23	0.97 (0.26)	27.06	0.15	2.21	0.95 (0.34)	36.26	0.04	4.61	0.90 (0.45)	50.46	3.89	22.98
Beginning freq.	4264	22710	11433 (5108.49)	44.68	4661	24000	11833 (4686.90)	39.61	1468	24000	11012 (4054.92)	36.82	3.59	4.57
End freq.	4710	23107	11627 (4836.09)	41.59	3371	30743	11965 (4312.93)	36.04	2420	23092	11288 (3543.32)	31.39	2.91	4.75
Number of Inflection points ***	0	5	0.39 (0.82)	212.22	0	11	1.18 (1.50)	126.84	0	13	1.50 (1.54)	102.92	55.99	100.76
Number of Steps ***	0	18	5.28 (4.04)	76.67	0	21	3.49 (3.30)	94.77	0	16	1.73 (2.27)	131.59	50.80	201.31
Number of maxima ***	0	2	0.59 (0.65)	111.55	0	5	0.82 (0.88)	107.85	0	8	0.49 (0.79)	159.00	26.28	59.61
Number of minima ***	0	3	0.47 (0.72)	152.52	0	6	0.94 (0.97)	104.00	0	9	0.56 (0.93)	165.80	37.78	85.87

Table IV Results of cross-validate DFA analysis among the Canary Archipelago, Azores Archipelago and Mediterranean Sea

	Area	Predicted Group Membership		
		Canary Archipelago	Azores Archipelago	Mediterranean Sea
Cross-validated	Canary Arcipelago	40.0 %	30.1 %	29.9 %
	Azores Arcipelago	27.0 %	55.0 %	18.0 %
	Mediterranean Sea	15.8 %	11.3 %	72.9 %

VIII. FIGURES

Figure 1 – Map of the recording locations analyzed for Atlantic Ocean and Mediterranean Sea. Black dots represent the approximate position of sightings. Inserts show major details of areas where sightings were closer. Depth contour of 200 meters is shown.

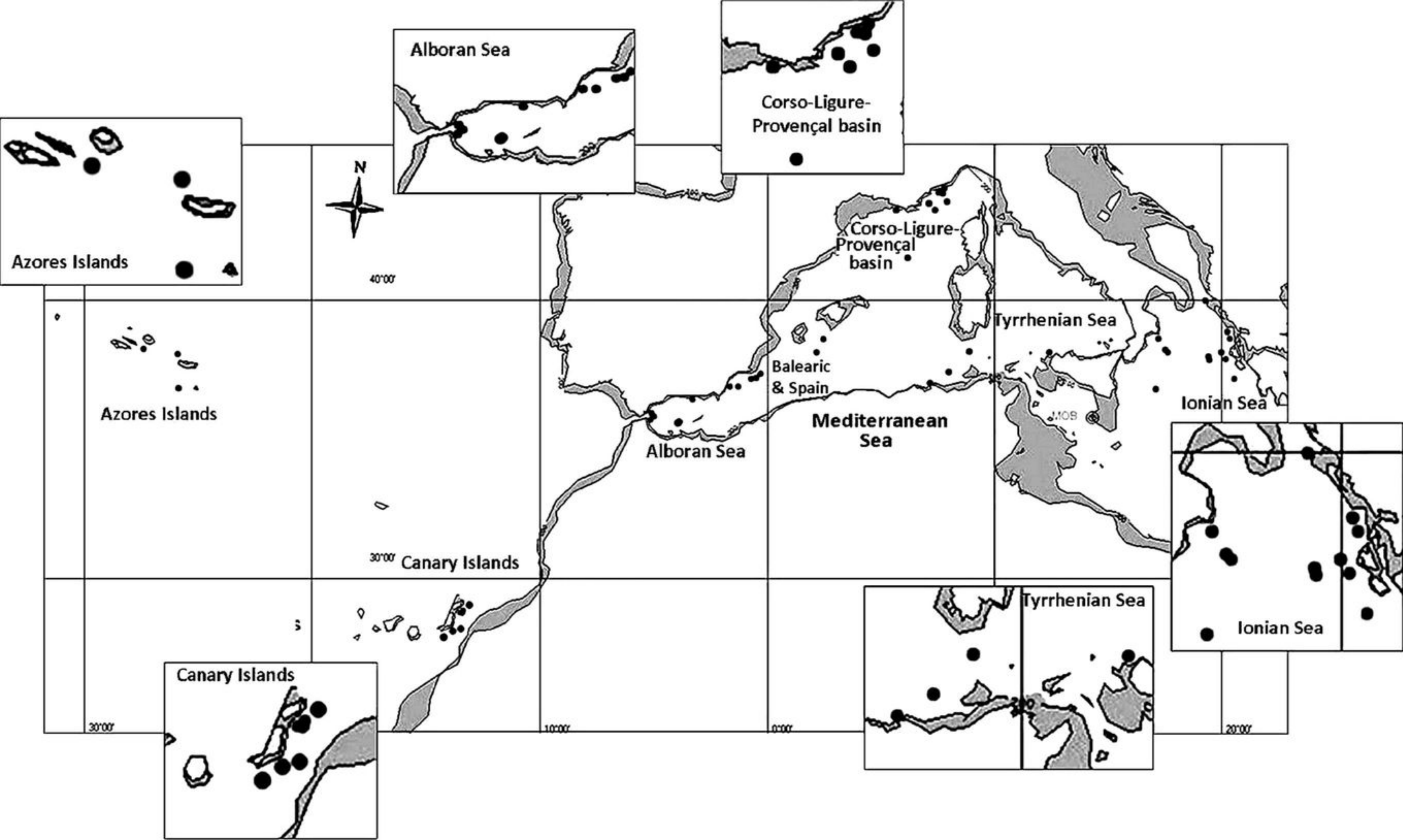
Figure 2 –Figure including spectrograms of all different levels of quality of the whistles. Only whistles with quality 2 and 3 have been analyzed in the study.

Figure 3 - A sample spectrogram representing a striped dolphin whistle. Parameters manually measured for each whistle are shown: signal duration, beginning frequency, end frequency, minimum frequency, maximum frequency, the number of inflection points, the number of steps and the number of minima and maxima in the contour. Frequency range was calculated as maximum frequency minus minimum frequency.

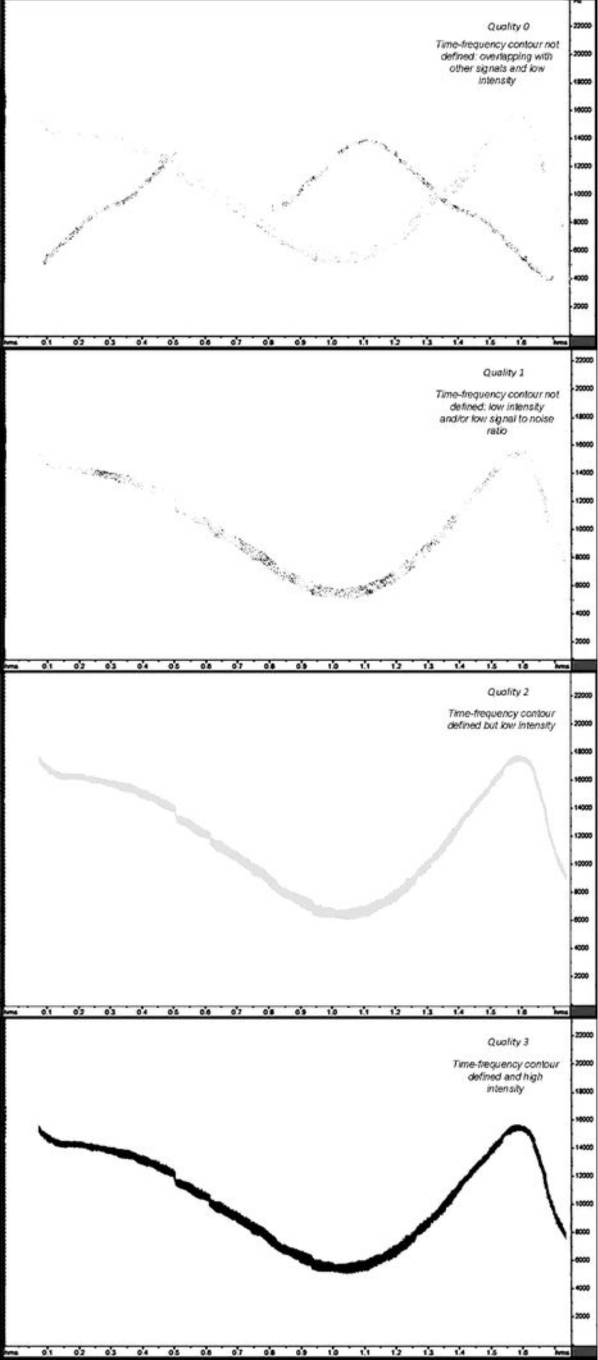
Figure 4 – Box plot graphs showing minimum, first quartile, median, third quartile and maximum values of maximum frequency (in Hz), frequency range (in Hz), signal duration (in seconds), the number for inflection points, the number of steps and the number of maxima in the contour. Significant differences among sounds of Azores islands, Canary islands and Mediterranean Sea are represented by stars (one star $P < 0.05$, two stars $P < 0.001$).

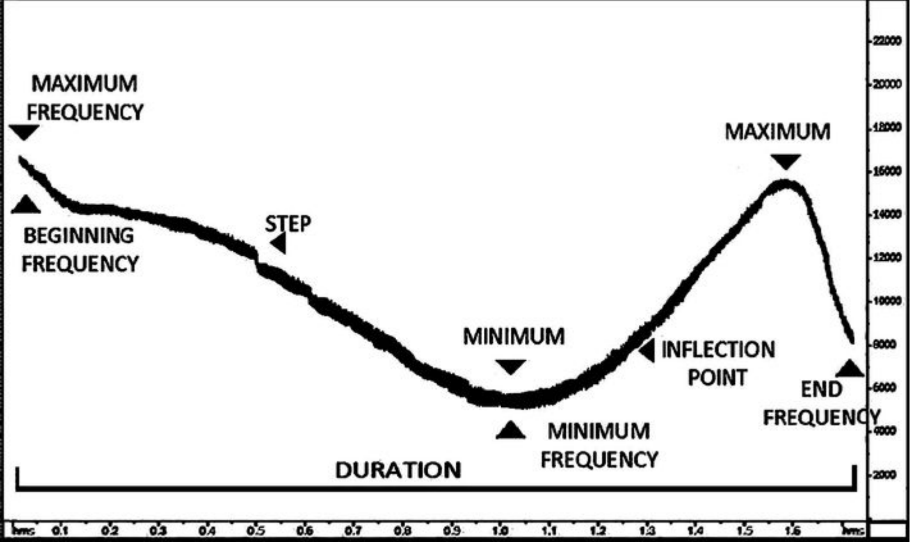
Figure 5 - Canonical Discriminant Function scatter plot of the striped dolphins populations of Canary islands, Azores islands and Mediterranean Sea, from the two functions that accounted for 100% of the observed variance (Coefficients Function 1: number of inflection points = -1.02, number of maxima = 0.77, number of steps = 0.45, minimum frequency = -0.41, number of minima = 0.40; Coefficients Function 2: number of minima = 0.70, number of

steps = -0.58, end frequency = 0.27, number of inflection points = -0.24, minimum frequency = -0.24).

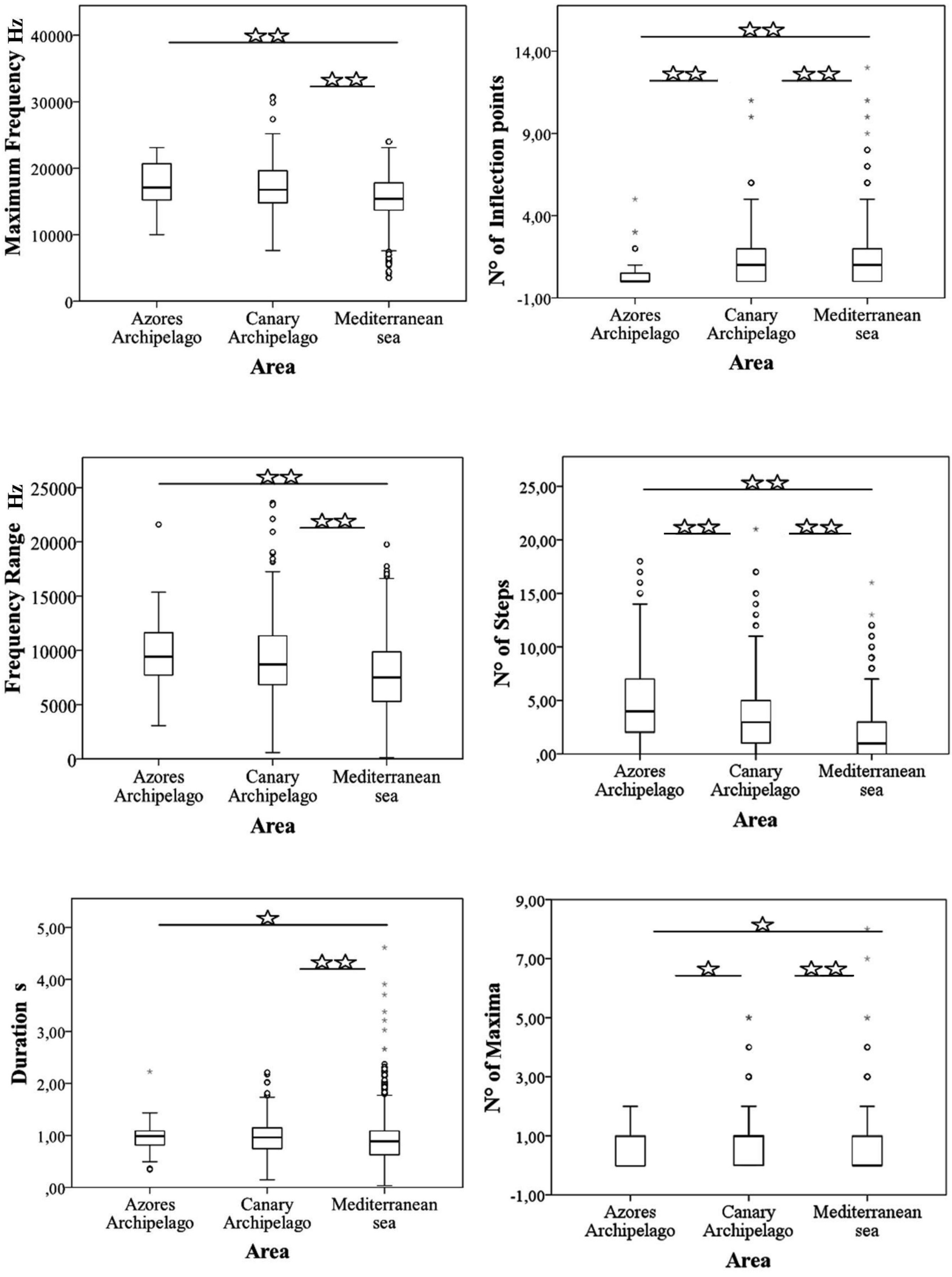


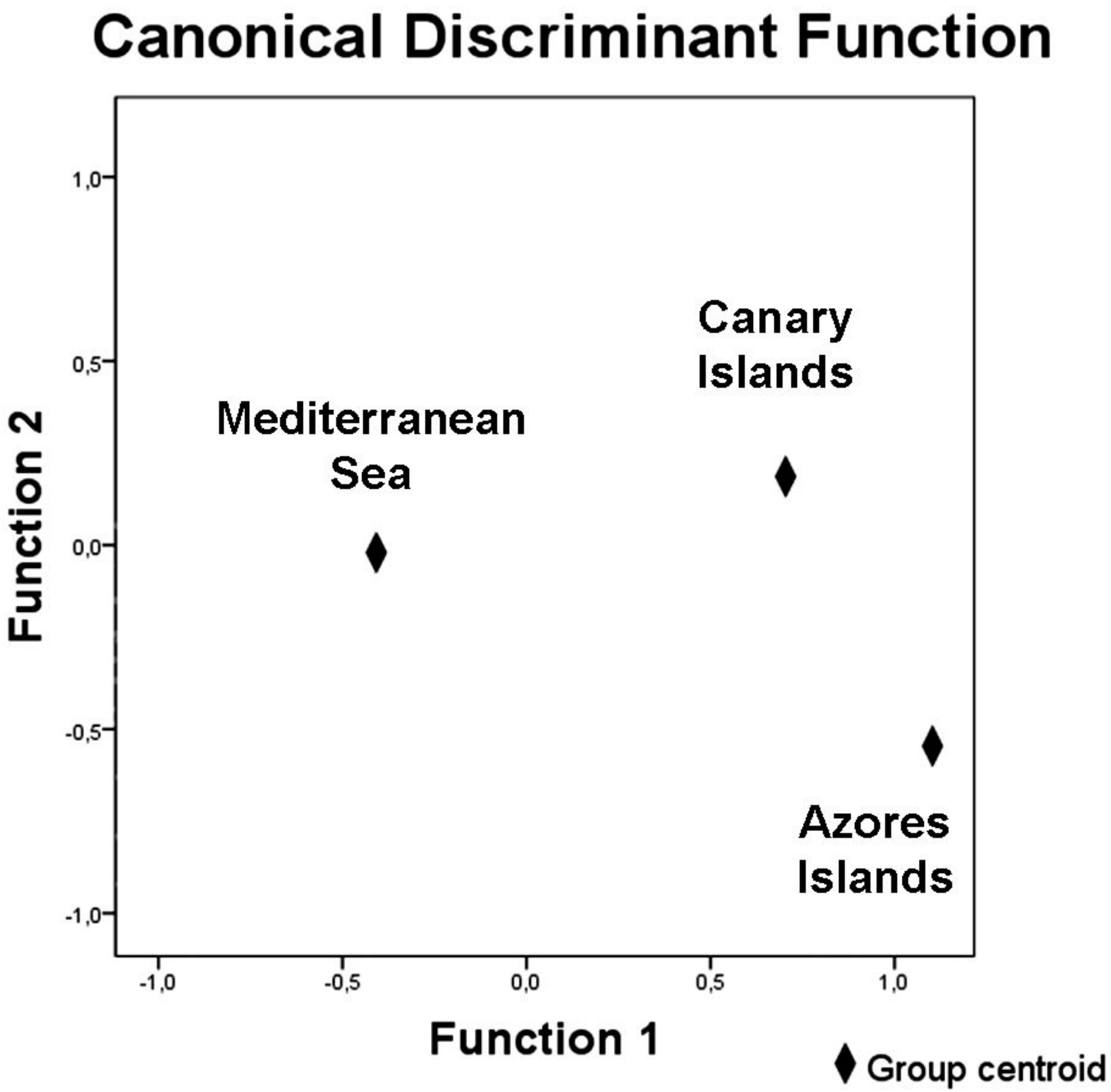
Alboran Sea
Corso-Ligure-
Provençal basin
Azores Islands
N
40°00'
Corso-Ligure-
Provençal
basin
Tyrrhenian Sea
Balearic
& Spain
Azores Islands
Ionian Sea
Mediterranean
Sea
Alboran Sea
MOB
30°00'
Canary Islands
Tyrrhenian Sea
Ionian Sea
Canary Islands
30°00'
10°00'
0°00'
20°00'


Quality 0
Time-frequency contour not defined: overlapping with other signals and low intensity
Quality 1
Time-frequency contour not defined: low intensity and/or low signal to noise ratio
Quality 2
Time-frequency contour defined but low intensity
Quality 3
Time-frequency contour defined and high intensity



MAXIMUM FREQUENCY
BEGINNING FREQUENCY
STEP
MINIMUM
MINIMUM FREQUENCY
INFLECTION POINT
MAXIMUM
END FREQUENCY
DURATION
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6


Maximum Frequency Hz
40000
30000
20000
10000
0
Azores Archipelago
Canary Archipelago
Mediterranean sea
Area
N° of Inflection points
14,00
9,00
4,00
-1,00
Azores Archipelago
Canary Archipelago
Mediterranean sea
Area
Frequency Range Hz
25000
20000
15000
10000
5000
0
Azores Archipelago
Canary Archipelago
Mediterranean sea
Area
N° of Steps
25,00
20,00
15,00
10,00
5,00
,00
Azores Archipelago
Canary Archipelago
Mediterranean sea
Area
Duration s
5,00
4,00
3,00
2,00
1,00
,00
Azores Archipelago
Canary Archipelago
Mediterranean sea
Area
N° of Maxima
9,00
7,00
5,00
3,00
1,00
-1,00
Azores Archipelago
Canary Archipelago
Mediterranean sea
Area


Canonical Discriminant Function
Function 2
1,0
0,5
0,0
-0,5
-1,0
-1,0
-0,5
0,0
0,5
1,0
Function 1
Mediterranean Sea
Canary Islands
Azores Islands
Group centroid