PELAGIC DELPHINIDS OF THE MEDITERRANEAN SEA HAVE DIFFERENT WHISTLES

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INTRODUCTION

The western Mediterranean basin shelters five common delphinid species among which the bottlenose dolphin (*Tursiops truncatus*), Risso's dolphin (*Grampus griseus*), striped dolphin (*Stenella coeruleoalba*) and short-beaked common dolphin (*Delphinus delphis*) (Gannier, 2005). Whistles are commonly emitted by all four species. In the eastern tropical Pacific, Oswald et al. (2003, 2007) found that striped dolphin whistles were difficult to discriminate from those of eight other delphinids, in particular common dolphins ; these authors did not include Risso's dolphin in their studies. Their classification method involved extraction of 12 variables from whistle spectrographic contours. The aim of this study was to test a classification method for whistles of Mediterranean bottlenose, Risso's, striped and common dolphins, taken from GREC sound archives (1994-2007). We developed a new software (Seafox) to extract 15 variables and processed our data using statistical testing and a multi-variate discriminant analysis.

MATERIAL AND METHODS

The development data set comprised 277 whistles of striped dolphin, 158 of Risso's dolphins, 120 of common dolphins, and 76 of bottlenose dolphins (Figure 1). The striped dolphin signals were taken from 18 sightings made in the northwestern basin (north of 41°N). Those of Risso's dolphins came from six sightings obtained in the whole western basin. Whistles of common dolphins came from six sightings in the western basin including Alboran Sea and Sicily surroundings and those of bottlenose dolphins came from four sightings. The primary data set was used to design a discriminant model from the most significant combination of extracted variables. A test data set consisted in 263 striped dolphin whistles from the southwestern basin (south of 40°30 N): the same 15 variables were extracted and entered to test the discriminant model. Although the hydrophone response was flat (+/- 3 dB) up to 32 kHz, only the 0.2-22 kHz bandwidth was collected either with a Sony TCD-8 DAT or a Marantz PMD-670 (digital compact flash storage). DAT format were converted to *.wav file by digital-analog conversion and re-digitized by the PC sound card.

All delphinid recordings were played and stored in files of about 90 seconds, the content of which being individually described and coded in an Access database. Data-base requests were performed to select relevant whistles recordings from this 4000+ sample set. The whistles were individually extracted from the selected 90 second recordings and stored for subsequent contour extraction.

An extraction program called Seafox was written in Matlab 6.0 : it was based on 512 points Fast Fourrier Transforms of whistles sampled at 44.1 kHz, using a hanning window with 25% overlap. Peak frequencies were extracted from every window and stored for contour extraction. The synthetic spectrogram contours could be improved by several software options: high/low filtering, selective amplification, click removing, smoothing, and automatic or manual interpolation (see Figure 2).

Fifteen variables were extracted from each contour: the duration, frequency range, number of frequency extrema, initial, final, maximal and minimal frequencies, minimal, maximal initial and final frequency slopes (computed on three or seven points), presence of harmonics.

Statistical study started with a pair-wise comparison of each variable for the three species (Mann-Whitney test). A discriminant function was researched to optimize the classification of the three species whistles. This discriminant function was then used as a model to classify individually every sample, i.e. to test the efficiency of the whole process. Finally, we introduced the additionnal SW striped dolphin sample set to check the robustness of our model with an independent data set.

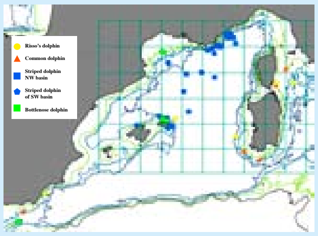

Figure 1 : Locations of recordings used for the classification study.

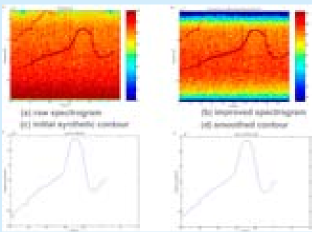

Figure 2 : Seafox software principle.
From the initial spectrogram (a) to the final contour (2) from which 15 variables are extracted.

	Dd (N=120)		Gg (N=158)		Sc nw (N=277)		Tt (N=76)	
	Average	SD	Average	SD	Average	SD	Average	SD
Duration (sec)	**0,47**	0,29	**0,65**	0,36	**0,73**	0,35	**0,71**	0,40
Initial frequency	**10912**	3526	**11750**	3929	**9994**	4039	**8886**	3157
Final frequency	**11919**	2900	**11877**	3522	**11819**	3797	**8612**	3470
Minimal frequency	**8527**	1942	**8287**	2027	**7868**	1843	**6421**	1684
Maximal frequency	**13149**	2696	**14652**	3270	**15163**	3611	**12719**	3949
Mean frequency	**10475**	1827	**10877**	2350	**10906**	2116	**9485**	2337
Frequency range	**4622**	2738	**6365**	3244	**7296**	3543	**6297**	3957
Initial slope (3 pts)	**-21878**	57703	**-8203**	42243	**-3740**	38334	**23043**	64459
Final slope (3 pts)	**28074**	58080	**35872**	69810	**30222**	103851	**2073**	13486
Initial slope (7 pts)	**-18263**	41351	**-3806**	32586	**-3024**	33318	**21014**	56975
Final slope (7 pts)	**14977**	19331	**19532**	36517	**13222**	40649	**644**	14623
Maximal slope	**33512**	56968	**45268**	61059	**51910**	90170	**15187**	18715
Minimal slope	**-9412**	10295	**-13712**	19372	**-21885**	39396	**-16165**	13471

Table 1 : Average values and SD of 13 variables for the four species. Dd = common dolphin, Gg = Risso's dolphin , Sc(nw) = striped dolphin of NW basin, Tt = bottlenose dolphin. All frequencies in Hz. All slopes in Hz/sec.

	Dd / Gg	Dd / Sc nw	Dd / Tt	Gg / Sc nw	Gg / Tt	Tt / Sc nw
Duration	yellow	yellow	yellow	yellow	grey	grey
Number of harmonics	yellow	yellow	yellow	yellow	grey	yellow
Initial frequency	grey	yellow	yellow	yellow	yellow	grey
Final frequency	grey	grey	yellow	grey	yellow	yellow
Minimal frequency	grey	yellow	yellow	yellow	yellow	yellow
Maximal frequency	yellow	yellow	grey	yellow	yellow	yellow
Mean frequency	grey	grey	yellow	grey	yellow	yellow
Frequency range	yellow	yellow	yellow	yellow	grey	yellow
Initial slope (3 pts)	yellow	yellow	yellow	grey	yellow	yellow
Final slope (3 pts)	grey	yellow	yellow	grey	yellow	yellow
Initial slope (7 pts)	yellow	yellow	yellow	grey	yellow	yellow
Final slope (7 pts)	grey	yellow	yellow	grey	yellow	yellow
Maximal slope	grey	grey	yellow	grey	yellow	yellow
Minimal slope	yellow	yellow	yellow	grey	yellow	grey
Number of extrema	yellow	yellow	yellow	grey	grey	grey

Table 2 : Pairwise comparison of 15 variables for the four species. Dd = common dolphin, Gg = Risso's dolphin , Sc(nw) = striped dolphin of NW basin, Tt = bottlenose dolphin Yellow filling indicates significant differences at 95% confidence level.

	common dolphin	Risso's dolphin	striped dolphin	bottlenose dolphin
common dolphin	**67.5**	7.5	22.5	2.5
Risso's dolphin	24.1	**28.5**	39.9	7.6
striped dolphin (nw)	11.2	11.9	**71.1**	5.8
bottlenose dolphin	18.4	3.9	34.2	**43.4**

Table 3 : Classification rate using the discriminant model. Dd = common dolphin, Gg = Risso's dolphin , Sc(nw)= striped dolphin of NW basin, Tt = bottlenose dolphin.

RESULTS

Seafox software enabled processing of the contours of most whistles - only 10-12% of the initial data set was discarded during the contour extraction process.

Some of the basic characteristics showed clear trends (see Table 1):

- whistle durations of common dolphins (0.47 sec) were shorter than those of the other species (0.65 sec, 0.73 sec, 0.71 sec)
- frequency range of common dolphins (4,622Hz) was narrower than for striped dolphins (7,296Hz), Risso's (6,365Hz) and bottlenose dolphin (6,297Hz)
- bottlenose dolphin whistles were in average lower in frequency for all frequency variables

For the species pairwise comparisons, none of the 15 variables were significantly different for all four species (Table 2). The greatest difference between whistle repertoires was found between the striped and common dolphins (14 distinct variables out of 15), and the lesser was found between Risso's and striped or common dolphins (six different variables).

The most useful variables to discriminate species data set were : the frequency range (all comparisons significant but Risso's/bottlenose dolphins), the initial slopes (all comparisons significant but Risso's/ striped dolphins), the maximal frequency (all comparisons significant but common/striped dolphins), the minimal frequency (all comparisons significant but Risso's/common dolphins), and the percentage of whistles with harmonics.

The average and final frequencies, and the maximal slope were the less useful variables to discriminate species (only three significant pairwise comparisons).

The discriminant analysis was carried out with 12 variables and showed the best classification could be obtained with a combination of three discriminant axes, the first one with the presence of harmonics, the second with final and minimal frequencies, and the initial slope, and the third with the initial frequency.

Globally, the discriminant model attributed 56.4 % of the whistles to the correct species : the percentage of correct classification was high for the striped (71.1%) and common dolphin (67.5%), moderate for the bottlenose dolphin (43.4%), and low for the Risso's dolphin (28.5%). About 40% of Risso's dolphin whistles and 34% of bottlenose dolphin were attributed to striped dolphins (Table 3). Chi-2 testing showed that correct classification was significantly better than chance for striped, common and bottlenose dolphins.

The striped dolphin test data set (SW basin, n= 263) was analysed with the discriminant model, 68.8% were correctly attributed to their species and the rest were wrongly classified either as Risso's dolphins (14.4%), common (9.9%) or bottlenose dolphins (6.8%) The percentage of correct classification was similar for the « test » striped dolphin whistles as for the initial data set, suggesting that our model was robust.

DISCUSSION

Classification efficiency

Our discriminant model was efficient to classify the independent striped dolphin test set ($\chi 2$ test, $\alpha = 0.05$). By contrast, correct classification of ETP whistles to species was not significantly greater than chance for this species (Oswald et al., 2003; 2007). But ROCCA (Real-time Odontocete Call Classification Algorithm), a contour analysis software previously developed for delphinids in the Eastern Tropical Pacific, performed equally well to differentiate the Mediterranean common and striped dolphins (Oswald et al., 2008).

The introduction of slopes variables in our method led to more significant variables to differentiate the species, in particular the initial slope, but the whistle repertoire of Risso's dolphin could be not discriminated with our statistical analysis. However, Risso's dolphin could also be acoustically identified with its pulsed sounds emissions, the analysis of which was not included in our program.

Differences in whistle repertoires

One major finding was that striped and common dolphins in the Mediterranean Sea could be discriminated while they could not in the Eastern Tropical Pacific (Oswald et al., 2003; 2007). Discriminant function analyses indicated that correct classification was significantly greater than chance when classifying whistles of the same species to study area (Oswald et al., 2008), i.e. whistles of a given species were significantly different from one area to the other. A high degree of sympatry may eventually cause species repertoire to be more distinct compared to another species, in order for individuals to recognize conspecifics. Alternatively, high sympatry may led species to adopt more similar repertoire, if mimicry plays an important role. This issue has to be documented further.

CONCLUSION

In future acoustic survey systems, it is of primary importance to discriminate the different odontocete species that are recorded but not visually checked. Other Mediterranean species (pilot whale) or sub-populations may be included in our whistle comparison model, as well as samples from the eastern Atlantic Ocean. Passive Acoustic Monitoring methods are being increasingly used to mitigate the effect of adverse anthropogenic activities.

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