TOWARDS A BOTTLENOSE DOLPHIN WHISTLE ETHOGRAM FROM THE SHANNON ESTUARY, IRELAND

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ABSTRACT

An ethogram of whistle types from the Shannon Estuary is presented. A total of 1715 whistles recorded over a three-year period between 2003 and 2005 were analysed. They were categorised into six fundamental shapes and 25 sub-categories. The most common whistle type encountered in the analysis was a simple rising tone. Whistles ranged in duration from 0.061 to 1.61 seconds. Whistle contour mean frequencies ranged between 13.21kHz and 7.71kHz, but there was a great deal of variability in all characteristics of the whistles within each category.

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INTRODUCTION

Bottlenose dolphins (*Tursiops truncatus* Montagu 1821) produce a wide range of vocalisations. These include high-frequency broad-band pulsed clicks for echolocation (Au 1993) and frequency-modulated sounds called whistles. Whistles have a fundamental frequency usually below 20kHz with harmonics up to 100kHz and durations between 0.05 and 3.2 seconds (Lammers *et al.* 2003). Communication in dolphins is also thought to involve a series of other, less well-defined pulse sounds termed chirps, grunts, buzzes and barks (Caldwell and Caldwell 1968; Van Parijs and Cockeron 2001). However, it is the whistle that is most associated with intra-specific communication among dolphins (Caldwell *et al.* 1990; Tyack and Clark 2000).

Caldwell *et al.* (1990) suggested that each dolphin had an individual 'signature whistle'. The function of signature whistles is thought to be involved in group cohesion (Herzing 1996). Other whistles, termed 'variant whistles' can include a diverse range of rising, falling and flat tones (Janik and Slater 1998). Wang *et al.* (1995) reported variation in the whistle repertoire used between populations of bottlenose dolphins and Morisika *et al.* (2005) found significant geographic differences in whistles between three populations of Indo-Pacific bottlenose dolphins (*Tursiops aduncus* Ehrenberg 1933). Differences in vocalisations between populations may reflect different environmental conditions and may over time lead to the development of local dialects. In cetaceans, group dialects have been most commonly observed in killer whales (*Orcinus orca*) (Ford 1991; Deeke *et al.* 2000; Yurk *et al.* 2002).

The Shannon Estuary is the only site in Ireland where bottlenose dolphins are known to be resident and has been designated a candidate Special Area of Conservation (cSAC). Dolphins occur throughout the estuary, but seasonal fluctuations in abundance have been reported with highest numbers recorded between the months of May and September (Berrow *et al.* 1996; Ingram and Rogan 2003). The presence of calves between July and September suggests that there is a distinct calving season in this population and that the estuary is an important breeding area. Abundance estimates using mark–recapture models have estimated a population size of around 113–140 individuals (Ingram 2000; Ingram *et al.* 2003; Englund *et al.* 2007).

There have been a number of acoustic studies in the Shannon Estuary (Leeney *et al.* 2007; Philpott *et al.* 2007) but only one has attempted to record dolphin whistles (Berrow *et al.* 2006). In order to understand the function of whistles it is essential to produce a catalogue of whistle types. Here we describe the characteristics of whistles from bottlenose dolphins in the Shannon Estuary in an attempt to produce an ethogram of whistle types to facilitate acoustic studies within the estuary and enable comparisons with bottlenose dolphins elsewhere.

METHODS

We obtained whistles from bottlenose dolphins in the Shannon Estuary in 2003 (between May and

August), 2004 (August and September) and 2005 (July and August). All recordings were made using an underwater hydrophone (MAGREC HP30), which was fixed to a metal frame, approximately 1m above the seabed, at a depth of 10m–12m and approximately 100m offshore at Kilcredaun Point, Co. Clare (52° 34.7' N, 9° 41.3' W). Details of the system can be obtained from Berrow *et al.* (2006). The hydrophone cable ran ashore where the signal passed through a high pass filter and was recorded onto a Sony TCD8 DAT recorder at an acquisition rate of 48kHz. The function of the high pass filter was to suppress the influence of low frequency (below 1kHz) ambient noise that could prevent dolphin whistles being detected. Recordings were made during all states of the tidal cycle and in various sea-states.

DATA ANALYSIS

The DAT recordings were played back and whistles were detected by ear. The time of each whistle was noted so that short, 10-second recordings containing one or more whistles could be downloaded onto a PC using a Marian Marc 2 Digital sound card, with optical input and output, via a Sony optical digital cable compatible with the DAT recorder. The recordings were then saved as PCM wav files (.wav) using the audio program Cool Edit 2000. Files were named using date and time of when the whistle was recorded. The wav files were then imported into MATLAB (version 5.2) and converted into vector format using 'wav2raw' M-file* (copyright 1984–94 by The MathWorks, Inc., modified by Mark Johnson, September 1995). A further M-file called 'Delphi' (written by John Goold) was used to digitise the time/frequency contour of each whistle. This M-file creates a spectrogram of the sound sample, which can be scrolled forward by the user, and allows the contour of the whistle to be marked into discrete data points. An M-file is a series of MATLAB commands stored as a text file, allowing automatic repetition of operations.

When the whistle had been located by eye using the Delphi script, the programme allowed the user to trace the contour of the whistle using a crosshair. Each click of the mouse along the contour recorded the time and frequency at that point. The amount of mouse clicks used to trace a whistle ranged from 25 to 50 depending on the duration and complexity of the whistle contour. The data matrices of time and frequency for each whistle can then be saved as a text file (.txt) and imported into Excel spreadsheets where the shape of each whistle could be graphed and the following parameters calculated: Duration (in seconds) of each whistle; Maximum; Minimum; Starting, Ending and Mean frequencies; and Gradient from start to end. Once in this graphical format the whistles could be categorised. The *x*- and *y*-axes of each graph were standardised (1.5 seconds long, with a frequency range of 0Hz to 24kHz) to prevent distortion of whistles caused by axes of differing length influencing the interpretation and categorising process.

RESULTS

A total of 1715 whistles from the Shannon Estuary were digitised and analysed (628 from 2003, 116 from 2004 and 971 from 2005). Whistles were categorised into one of six fundamental shapes: Rising (A), Falling (B), Flat (C), Convex (D), Concave (E) or Continually Modulated (F) (Fig. 1). Once in these general categories, whistles were then put into sub-categories according to the combinations of shapes that comprised the whistle contour, e.g. a whistle that started with a rise (A) and levelled off into a flat section (C) was categorised as 'AC'. Whistles were sorted into 25 different sub-categories (Table 1).

The most frequent whistle type encountered in the analysis was a simple rising tone (Category A), which accounted for 15.0% of all whistles. The next most frequent was a pure unmodulated tone (Category C), which accounted for 11.7% of whistles; 9.4 of whistles had a falling tone (Category B); 9.2% whistles had a convex shape (Category D); 3.0% showed a concave shape (Category E); and 1.6% had a continually modulated shape (Category F). The proportions of all categories and sub-categories are shown in Table 1.

Whistles ranged in duration from 0.061 to 1.610 seconds. Category EE1 whistles were found to have the longest mean duration (1.026 seconds), while the Category AA1 had the shortest (0.079 seconds) (Table 2). Frequency means ranged between 19.432kHz, which belonged to Category DD1 whistles, and 8.505kHz, of Category AA1. The highest mean frequency for any whistle was 21.454kHz. This was the mean frequency of a category C whistle. It is possible, however, that this represents a harmonic, although no fundamental frequency was detected on the spectrogram. The lowest mean frequency was also a Category C whistle (7.690kHz). The variation of frequency means observed in category C whistles illustrates the high degree of variance within the whistle categories.

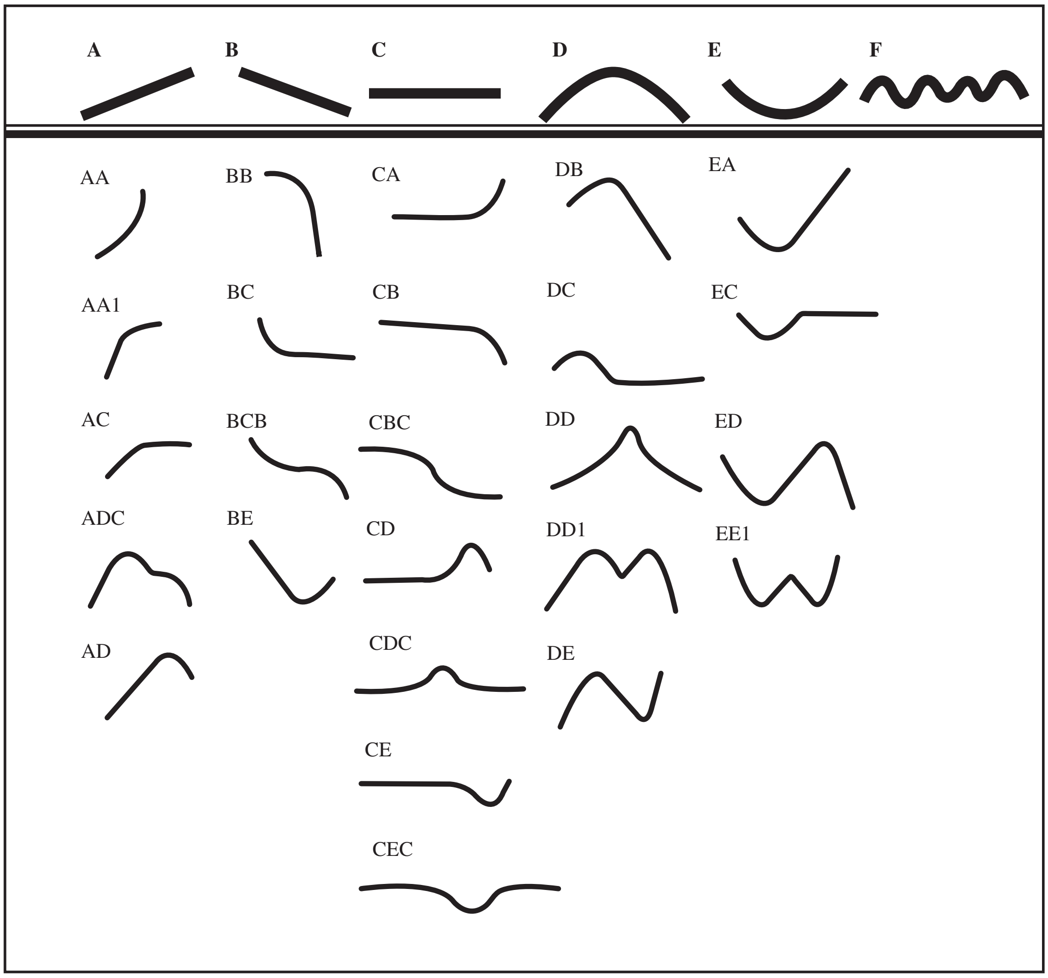

Fig. 1—Contour shapes of bottlenose dolphin whistles, recorded in the Shannon Estuary.

DISCUSSION

In studies that require the analysis of dolphin whistles, it is necessary to describe and measure whistles in an unambiguous way that allows for suitable statistical tests to be performed. Three approaches to categorising dolphin whistles have been made. The first involves assigning descriptive names to differing whistle types. For example, a whistle that begins with high frequency and decreases continually to end on a low frequency would be termed a 'downsweep' (Lilly 1963; Caldwell *et al.* 1990; Janik *et al.* 1994). The advantage of this method is that whistles that are common in a population can be described in an easily understood way. However, this qualitative method is open to a large degree of ambiguity and can result in confusion, particularly in describing more complex whistle types. The second technique is to carry out Fast Fourier Transform analyses (FFT) on the data, to create a visual representation of the acoustic signal by plotting it on a spectrogram; usually with time and frequency on the x- and y-axes, respectively, and amplitude represented by greyscale or colour intensity (Lilly 1963; Janik and Slater 1998; Cockeron and Van Parjis 2001). While this method is easily understood and can be useful for depicting individual whistle types, studies on dolphin whistles often require large data sets with many different whistle types. The process of looking at large amounts of spectrograms could become confusing and may result in error or even bias. To eliminate the possibility of human error, a third technique is to use a range of univariate parameters (for example whistle duration, maximum and minimum frequencies) to describe the whistle (Janik *et al.* 1994; Morisika *et al.* 2005). However, the lack of a standard set of parameters can make comparisons between studies difficult. These multivariate statistical methods have the advantage of being objective and repeatable. Despite these advantages, however, comparisons

Table 1—Number and percentage of whistles in each category and sub-category from bottlenose dolphins in the Shannon Estuary.

Category	*Sub-category*	*Total number*	*Percentage*
A		257	15
	AA	13	0.8
	AA1	2	0.1
	AC	125	7.3
	ADC	22	1.3
	AD	73	4.3
B		161	9.4
	BB	6	0.3
	BC	53	3.1
	BCB	20	1.2
	BE	5	0.3
C		200	11.7
	CA	79	4.6
	CB	57	3.3
	CBC	39	2.3
	CD	32	1.9
	CDC	8	0.5
	CE	3	0.2
	CEC	5	0.3
D		158	9.2
	DB	63	3.7
	DC	42	2.4
	DD	14	0.8
	DD1	67	3.9
	DE	43	2.5
E		52	3.0
	EA	31	1.8
	EC	11	0.6
	ED	38	2.2
	EE1	8	0.5
F		28	1.6
Total		1715	100

between multivariate and subjective methods have shown that automated techniques are no better (Deeke *et al.* 1999), and in some cases less reliable (Janik 1999), than human inspection.

The data acquisition system in the Shannon Estuary is very efficient at acquiring dolphin whistles. The fixed hydrophone enabled data to be acquired over long periods of time at relatively little expense. Its passive nature meant that it had no impact on the dolphins and thus no influence on their vocalisations. The home ranges of bottlenose dolphins in the Shannon Estuary may cover only certain parts of the estuary (Ingram and Rogan 2003). Kilcredaun Point occurs in a large number of these ranges, so the same dolphins may be encountered a number of times in this area during the summer. This means that there was a strong possibility that the same individuals were recorded in more than one encounter and the potential for pseudo-replication in this study was high (Hurlbert 1984).

The whistle types recorded by Berrow *et al.* (2006) from the Shannon Estuary are also included in the present analysis but the categories in this dataset were less extensive (Categories A, BCB, EE1, EC and F). Berrow *et al.* (2006) suggested that Category A was associated with foraging, BCB with traveling and EC with travel/feeding. In this study, all recordings were of foraging animals. Dolphins tend to be most abundant at Kilcredaun Point on a mid-ebb tide, when foraging is the principle activity (Berrow *et al.* 1996). In a study examining bottlenose dolphins off the coast of Costa Rica, Acevedo-Gutiérrez and Stienessen (2004) concluded that bottlenose dolphins produced more whistles while feeding than during resting periods. It was suggested that the increase in whistles during this period was related to increasing group size. An increase in group size would benefit these animals by increasing feeding efficiency and by acting as a deterrent to competing species (Acevedo-Gutiérrez 2002). The former might be more relevant to this study as there seems to be no other top predator competing with bottlenose dolphins in the Shannon Estuary. This is supported by the idea that dolphin whistles (specifically signature whistles) are cohesion calls (Janik and Slater 1998). Acevedo-Gutiérrez and Stienessen (2004) described an increase in whistle rate during periods for feeding, although they did not make reference to the whistle types used. Dolphins have been found to produce different sounds relative to their behavioural context (Herzing 1996). If dolphins do use different vocalisations in different contexts, then the over-representation of feeding dolphins in the Shannon Estuary could skew the data towards foraging-related whistle types. More recordings during different behaviours would enable exploration of the influence of behaviour on whistle types.

The whistle ethogram presented here should be complemented by additional recordings from other locations within the Shannon Estuary and during different behaviours to see if different whistles types are used and can be added to this ethogram.

Table 2—The duration and frequency characteristics of each whistle type from bottlenose dolphins in the Shannon Estuary.

Category	*Mean duration (seconds) ± SD*	*Frequency (Hz) Mean ± SD*					
		Start	*End*	*Maximum*	*Minimum*	*Mean*	*Gradient*
A	0.416±0.234	8689±3327	10547±2928	12341±2912	7615±2503	10029±2283	5367±19228
AA	0.270±0.200	9332±3316	11107±2288	12320±1344	7999±2649	10301±1707	9466±22908
AA1	0.079±0.065	5819±723	11370±779	11370±779	5819±723	8505±518	11216±211
AC	0.459±0.251	8616±3396	10121±2757	11672±2576	7203±2404	9567±2073	3708±13037
ADC	0.872±0.246	8402±2313	10309±3025	12080±2526	7154±1440	9821±1723	2451±8865
AD	0.478±0.215	8787±3091	10271±2711	12607±1790	7266±2203	10051±1605	3914±10758
B	0.380±0.252	9691±3836	10132±3054	12831±2814	7756±2659	10363±2360	−240±10717
BB	0.304±0.213	7597±1863	11008±2993	12156±3299	7361±1422	10315±2116	3941±4517
BC	0.375±0.221	9135±3059	10044±3031	12047±2794	7715±2034	9863±2039	1770±17608
BCB	0.430±0.213	10184±3102	10438±2634	12798±2572	8418±2507	10662±2082	−1070±13996
BE	0.470±0.246	11310±1929	10410±3938	11980±2499	9669±3322	10688±2995	−1123±10878
C	0.409±0.248	9180±3390	9645±2893	11495±3520	8025±2575	9799±2652	528±11015
CA	0.440±0.754	9375±3791	10467±3152	12288±3215	8068±3274	10185±2943	3455±10020
CB	0.360±0.227	9789±3757	10832±3436	12885±3299	8622±3396	10901±2936	1834±7660
CBC	0.559±0.305	9758±3636	10633±3034	12423±2615	8104±2854	10369±2268	1143±9500
CD	0.708±0.209	8103±2889	9865±2672	11455±2826	7335±2381	9532±2195	5160±10316
CDC	0.753±0.255	9756±3163	9944±4197	12793±2481	8214±3353	10862±1822	259±8234
CE	0.713±0.322	9497±3843	10395±3231	12496±1087	8552±3942	10765±2220	579±6222
CEC	0.420±0.226	8188±4094	9220±3584	10875±4424	7087±2839	9440±3510	3310±7594
D	0.463±0.279	9036±3225	8972±2901	11893±2739	7524±2296	9617±2115	230±8656
DB	0.600±0.242	9772±3259	10326±3148	12990±2658	8238±2546	10686±2264	1046±10813
DC	0.604±0.239	10339±3774	9720±2996	12105±3107	8236±3142	10121±2726	−4790±20934
DD	0.959±0.153	9019±3773	9534±2993	13060±2165	7838±2714	10468±2003	−412±8001
DD1	0.360±0.059	19529±2398	14330±8679	22718±1271	15808±2002	19432±1340	−12780±17772
DE	0.803±0.301	8444±2993	10881±2996	12871±2504	7323±2521	10321±1890	5124±11227
E	0.297±0.253	8401±2848	9557±2591	11853±2138	6917±1911	9435±1654	5935±24052
EA	0.416±0.218	10457±3864	11388±4085	13196±3654	8913±3654	11166±3509	4654±13971
EC	0.438±0.213	9835±4271	10600±4065	12543±3490	8912±4444	10903±3653	1421±7146
ED	0.692±0.301	9624±4052	10684±2318	13040±2502	7869±2656	10723±2172	1408±9991
EE1	1.026±0.213	10999±3321	10314±3475	12233±3217	9018±3025	10659±3234	−1833±17501
F	0.991±0.226	9265±2797	9037±2244	12572±2150	7661±2058	10093±1637	−1502±7715

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