



Whistle Characteristics of Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) in the Fremantle Inner Harbour, Western Australia

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Received: 15 October 2015 / Accepted: 22 December 2015 / Published online: 26 January 2016
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Abstract Bottlenose dolphins use whistles to communicate with their conspecifics and maintain group cohesion. We recorded 477 whistles of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in the Fremantle Inner Harbour, Western Australia, on nine occasions over a six-week period during May/June 2013. Over half (57 %) of the whistles had complex contours exhibiting at least one local extremum, while 32 % were straight upsweeps, 5 % downsweeps and 6 % constant-frequency. About 60 % of whistles occurred in trains. Fundamental frequency ranged from 1.1 to 18.4 kHz and whistle duration from 0.05 to 1.15 s. The maximum numbers of local extrema and inflection points were 7 and 9, respectively. Whistle parameters compared well to those of measurements made from other *T. aduncus* populations around Australia. Observed differences might be due to ambient noise rather than geographic separation.

Keywords Whistle characteristics · Bottlenose dolphin · *Tursiops aduncus* · Fremantle Inner Harbour

1 Introduction

Bottlenose dolphins (Genus *Tursiops*) are found globally in tropical to temperate and coastal to offshore waters. Around Australia, morphological and genetic studies support the existence of three distinct species of *Tursiops*: (1) *T. truncatus* occurring offshore in deep water as well as in coastal areas [1], (2) *T. aduncus*, a smaller inshore form found only in coastal and some estuarine waters of the Indian and Western Pacific Ocean [1,2] and (3) *T. australis* found in the coastal waters of southern Australia [3,4]. Bottlenose dolphins can occur in genetically segregated populations or in sub-populations or communities with overlapping home ranges (i.e. regularly used geographic areas [5]). Site fidelity and home ranges of dolphins are thought to be influenced by food availability, predation risk, social parameters within the population and associated habitat preferences (e.g. topography, ambient noise levels, etc.) [6–9].

The Fremantle Inner Harbour, located in south-western Australia, is a year-round hotspot for about 45 individuals from two resident communities of Indo-Pacific bottlenose dolphins (*T. aduncus*) [10–13]: one occurring mainly in Cockburn Sound just west of Fremantle and in the open water, and the other in the Swan-Canning River estuary. The Fremantle Inner Harbour is located at the entrance of the Swan-Canning River estuary and connects Cockburn Sound to the estuary, thus bordering the core home range areas of the two communities. Thus, the home ranges of some of the individuals from the Cockburn Sound community overlap with individuals from the Swan-Canning River estuary within the Fremantle Inner Harbour and proximal locations. However, dolphins from the Cockburn Sound community do not appear to use the middle and upper reaches of the Swan River, while dolphins from the Swan-Canning River estuary community are regularly sighted many tens of kilometres further up the river [12]. The Fremantle Inner Harbour is also the location of the Port of Fremantle, which is the largest and the busiest general cargo port on the west coast of Australia. As such, the underwater acoustic environment of the Inner Harbour has contributions from various human activities including shipping, as

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well as biological sounds from snapping shrimp, fish and dolphins [14].

Bottlenose dolphins rely heavily on acoustic signals to maintain contact with their conspecifics and to actively sense their environment [15], even in relatively noisy environments such as the Fremantle Inner Harbour. The sound repertoire of bottlenose dolphins is comprised of whistles, clicks, burst pulse sounds and low-frequency, narrow-band harmonic sounds [16–18]. Clicks primarily have a biosonar function and are used for sensing the environment, navigation and foraging [19]. Whistles and burst-pulse sounds serve for communication [20]. Specific vocalisations have been associated with specific behaviours in many dolphin species (e.g. [21–26]). Furthermore, bottlenose dolphins have been shown to develop individually distinctive signature whistles during the first few months of their lives and emit these when in isolation and when meeting conspecifics as a way of broadcasting identity; they also copy signature whistles of others interpreted as ‘calling others’ (e.g. [27–33]).

The vocalisation characteristics described above have been found to vary among populations, possibly due to habitat differences, ambient noise, sympatry with other dolphin species, etc. (e.g. [34–38]). In this article, the whistle characteristics of Indo-Pacific bottlenose dolphins measured in the Fremantle Inner Harbour are described, compared to measurements from other populations in Australia, and correlated to ambient noise to assess whether whistle features were associated with noise energy.

2 Methods

2.1 Study Area

Data were collected in the Fremantle Inner Harbour (32°02′ 31.23″ S, 114°45′ 10.21″ E) located 17 km south-west of the city of Perth on the west coast of Australia. The Port of Fremantle is situated at the entrance of the Swan River from the Indian Ocean, and serves as a major port for importing and exporting products and natural resources in Western Australia. Acoustic recordings were collected from a 50 m long jetty (Fig. 1).

2.2 Data Collection

Data were collected on nine occasions over a period of six weeks (13th May 2013 to 21st June 2013), using a HTI-96-MIN hydrophone with a built-in preamplifier, sensitivity of -163.9 dB re 1 V/ μ Pa, and a frequency response of 2 Hz–30 kHz (± 3 dB). A Jammin Pro HR-5 recorder sampled sound at 96 kHz and stored data as 24-bit WAV files. Prior to fieldwork, the recording system was calibrated with white noise of known level. During recordings, the hydrophone was



Fig. 1 A satellite image of the study area, Fremantle Inner Harbour, Western Australia. The *white X* indicates the location where all observational and acoustic data were collected. The *white dot* in the *insert* of Western Australia indicates the location of Fremantle. *Source* Google Earth

deployed over the north side of the Port of Fremantle small craft jetty (Fig. 1) at a depth of 1.5 m below the surface of the water. On one occasion (23rd May 2013), the hydrophone was lowered over the west side of the jetty due to a strong current, which could have resulted in flow noise. Recordings commenced once a group of dolphins was observed in the study area and ended when dolphins could no longer be sighted. A group of dolphins was defined as any aggregation of dolphins observed in an apparent association, frequently engaged in the same general activity (modified from Shane [39]). Counts of individuals were made several times during recordings and the minimum and best estimate recorded. While groups were often very dynamic consisting of smaller social units such as mother–calf pairs or male alliances, they were considered to be part of the group if they were observed in the same aggregation. Individuals within groups were not identified, nor were they identified as belonging to either one of the two communities occurring in the Fremantle Inner Harbour (i.e. the Swan–Canning River estuary or the Cockburn Sound community); therefore, groups may have no, some, or all common individuals from previous times and days of recording. Because of this, we do not relate whistle parameters to individuals, or to the proportion of the total number of dolphins that use the Fremantle Inner Harbour. Rather, we focus our discussion on parameters of whistles produced by some of the dolphins occurring in the Fremantle Inner Harbour during the periods of recordings.

2.3 Data Analysis

Acoustic analysis focussed on the identification and description of whistles emitted by bottlenose dolphins in Fremantle Inner Harbour. Whistles were identified aurally and visually

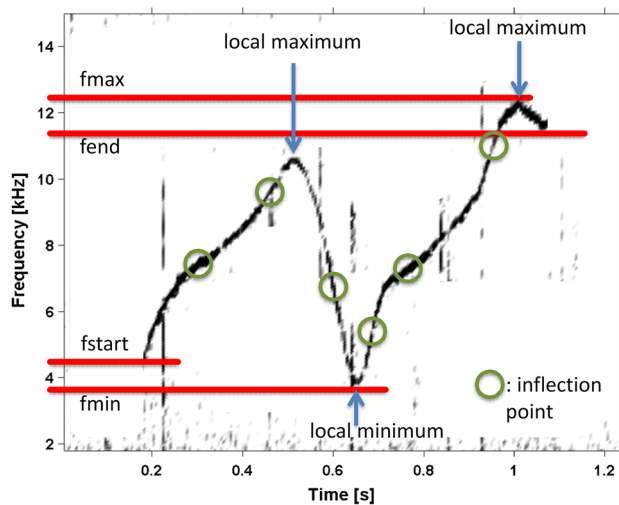


Fig. 2 Example spectrogram showing several of the parameters measured from each whistle. (Color figure online)

(from spectrograms) using Audition CS6 (Adobe Systems Inc. 2013). To describe the whistles, nine parameters were measured from the fundamental contours in the spectrograms: (1) start frequency (fstart); (2) end frequency (fend); (3) minimum frequency (fmin); (4) maximum frequency (fmax); (5) bandwidth ($\Delta f = f_{\max} - f_{\min}$); (6) duration; (7) number of extrema (points of local maxima and minima, i.e. where the first derivative of the whistle contour is zero); (8) number of inflection points (defined as a point of change in the whistle curvature, i.e. where the first derivative of the whistle contour would have a local extremum and its second derivative would be zero); and (9) number of steps (a discontinuity in the frequency domain), see Fig. 2. We did not measure any parameters of potential whistle overtones, but focussed on the fundamental contours instead. Due to the low signal-to-noise ratio (SNR) of most whistles, all measurements were performed manually by visual inspection of the spectrograms.

Spectrograms presented in the results were generated in Matlab R2013a (The MathWorks Inc.), by Fourier transform of the calibrated pressure time series, using Hamming windows of 2048 samples and 50% overlap. Whistles were subdivided into four groups based on their fundamental time-frequency contours: (a) upsweep, (b) downsweep, (c) constant-frequency, and (d) more complex frequency modulation, i.e. successive up and downsweeps.

Histograms of the various whistle measures were generated to show their frequency of occurrence and statistical distribution. Scatter and box plots were created to examine whether a relationship existed between two whistle parameters.

Whistles were considered similar if their contours had the same numbers of local extrema and inflection points, if fstart,

fend, fmin and fmax agreed to within 1 kHz, and if the order of local and absolute extrema was the same. This 1 kHz tolerance was to allow for the variability in frequency parameters which can be between 6 and 26% in other *T. aduncus* populations [40]. The inter-whistle-interval was measured for all similar whistles, as the difference between the end time of one whistle and the start time of the next whistle [41, 42]. If whistles were emitted in bouts of at least five whistles of similar shape, where four out of five whistles in the bout had inter-whistle-intervals of 1–10 s, this whistle was considered a signature whistle, following the criterion of Gridley *et al.* [40]. Whistles of similar shape that occurred with inter-whistle-intervals of <1 s were considered to be part of a train.

Ambient noise levels in the Inner Harbour were calculated for each recording when dolphins were present and hence included dolphin vocalisations and clicks. The recordings were Fourier transformed in 1/8 s windows, and averaged over 60 s. Power spectral density percentiles were computed over all 60 s spectra. In addition, octave band levels (0.5–1, 1–2, 2–4, 4–8, 8–16, and 16–32 kHz) of ambient noise were calculated for 10 s prior to each whistle or whistle train in order to assess whether ambient noise levels determined whistle parameters.

3 Results

While this paper aims to describe whistles recorded in the study area, it does not associate whistles to individuals, presenting a description of groups in the area when recordings were made provides context, and ensures that limitations are transparent and results are not over-interpreted. Recordings were made in the presence of 16 groups on nine days of measurement, ranging in group size from 1 to 8 individuals per group (Table 1). Whistles from eight of these days had sufficiently high SNR for analyses. Most whistles used in the analyses were obtained on three days, with 64% during an approximate 3 h period in the presence of two groups (one of 8 individuals and the other of a single individual), 16% during a 1 h period in the presence of a group with 6 individuals, and 9% during 13 min in the presence of three groups (the first with 5 individuals, the second with 4, and the third with 2). Based on the sample obtained, 80% of the whistles in the analyses could have been produced by up to as many as 15 individuals (if whistles from all animals were recorded, and if the groups sampled on different days were composed of different individuals). However, fewer numbers of individuals would have been sampled if groups on different days consisted of the same animals. If all individuals' vocalisations were recorded, but the same animals visited the area on the different recording occasions, then vocalisations from a minimum of nine animals would have been captured.

Table 1 Summary of data collected including recording date, dolphin groups present during recordings, recording times and durations, number of whistles used in analyses, and the percentage of whistles from each period

Date	# Dolphin groups present (minimum # of individuals per group)	Recording period (hh:mm)	Recording duration (min)	# Whistles	% of total whistles
13-5-2013	2 (8,1)	14:20–17:24	164.88	168	63.9
16-5-2013	2 (5,3)	8:55–11:29	107.27	1	0.4
23-5-2013	2 (5,2)	14:07–15:45	92.89	6	2.3
30-5-2013	1 (5)	14:47–16:23	27.23	9	3.4
31-5-2013	1 (6)	11:08–12:10	58.31	7	2.7
02-6-2013	2 (6,2)	9:48–11:47	92.52	6	2.3
03-6-2013	1 (6)	11:53–12:55	54.80	42	16.0
17-6-2013	3 (5,4,2)	14:18–14:33	12.56	24	9.1
21-6-2013	2 (2,6)	10:01–11:14	53.69	0	0.0

However, if not all individuals' vocalisations were recorded, then fewer could have been sampled.

3.1 Whistle Contours

A total of 11 h, 4 min and 8 s of acoustic recordings were collected. A whistle was described if all parameters were clearly shown on the spectrogram. In total, 477 whistles were analysed. Of these whistles, 32 % ($n = 152$) were upsweep, 5 % ($n = 26$) were downsweep, 6 % ($n = 27$) were constant-frequency and 57 % ($n = 272$) were complex (Fig. 3).

Two simultaneously occurring upsweeps of similar duration and received level, and that were not harmonically related, are shown in Fig. 4, which could be a biphonation [32,43,44]. This combination of upsweeps was only seen once; hence we cannot confirm that the two contours were part of the same vocalisation, or instead, whether two animals were whistling at the same time. There were no other whistles with partial temporal overlap within 22 s before and after this potential biphonation, and full temporal overlap as in Fig. 4 was not seen on other occasions.

3.2 Whistle Features

Figure 5 shows histograms of the parameters measured from all 477 whistle contours. The fundamental contours spanned a frequency range from 1.1 to 18.4 kHz (f_{start} : 1.1–12.5 kHz, f_{end} : 1.1–18.4 kHz, f_{min} : 1.1–9.0 kHz, f_{max} : 1.4–18.4 kHz). The duration of all whistles was short, ranging from 0.05 to 1.15 s, peaking at 0.3–0.4 s. Out of the 477 fundamental whistle contours, 439 did not have any steps, 30 had one step and eight had more than one step. Roughly half of the calls had neither local extrema nor inflection points. The maximum numbers of local extrema and inflection points were 7 and 9 respectively.

Figure 5 indicates that there may be several relationships and dependencies between the measured parameters, e.g. the distributions of f_{start} and f_{min} are similar, as are the distributions of f_{end} and f_{max} . Figure 6a shows that there is no

correlation between f_{end} and f_{start} ; i.e. if the whistle starts at a higher frequency, it does not necessarily end at a higher frequency. Similarly, there is no correlation between f_{min} and f_{max} (not shown). Any increases in bandwidth are entirely determined by increases in f_{max} (Fig. 6b) as opposed to decreases in f_{min} (not shown). f_{end} is mostly larger than f_{min} , and only a few calls end in f_{min} (Fig. 6c). This is due to the mostly upsweep nature of whistle contours in Fremantle Inner Harbour; even if the contour is complex, the vast majority of contours end on f_{max} (Fig. 6d). Similarly, f_{start} is mostly equal to f_{min} (Fig. 6e). Mathematically speaking, there always has to be an inflection point between two local extrema; therefore the number of local extrema cannot be greater than the number of inflection points by more than 1 (Fig. 6f). However, the number of inflection points can exceed the number of extrema by any number, e.g. if the contour is monotonically increasing in a “wavy” rather than straight line. The number of inflection points increased with the whistle duration (Fig. 6g) and bandwidth (Fig. 6h).

3.3 Whistle Trains

Out of the 477 whistles analysed, 293 occurred in trains. A total of 112 trains were noted, 63 of which consisted of two similar whistles; 37 trains consisted of three similar whistles; nine trains had four similar whistles; two trains had five similar whistles; and one train was a repetition of 10 whistles of similar contours. The inter-whistle interval (i.e. the time between the end of one whistle and the start of the next whistle in a train) of all trains was $0.28 \text{ s} \pm 0.20 \text{ s}$.

3.4 Signature Whistles

We further considered whistles that were repeated at much larger inter-whistle-intervals of 1–10 s, whether other whistle contours were interspersed or not. We found five different whistles that were each emitted in bouts of at least five whistles, with inter-whistle-intervals of 1–10 s between at least four out of five whistles in the bout. These were candidates

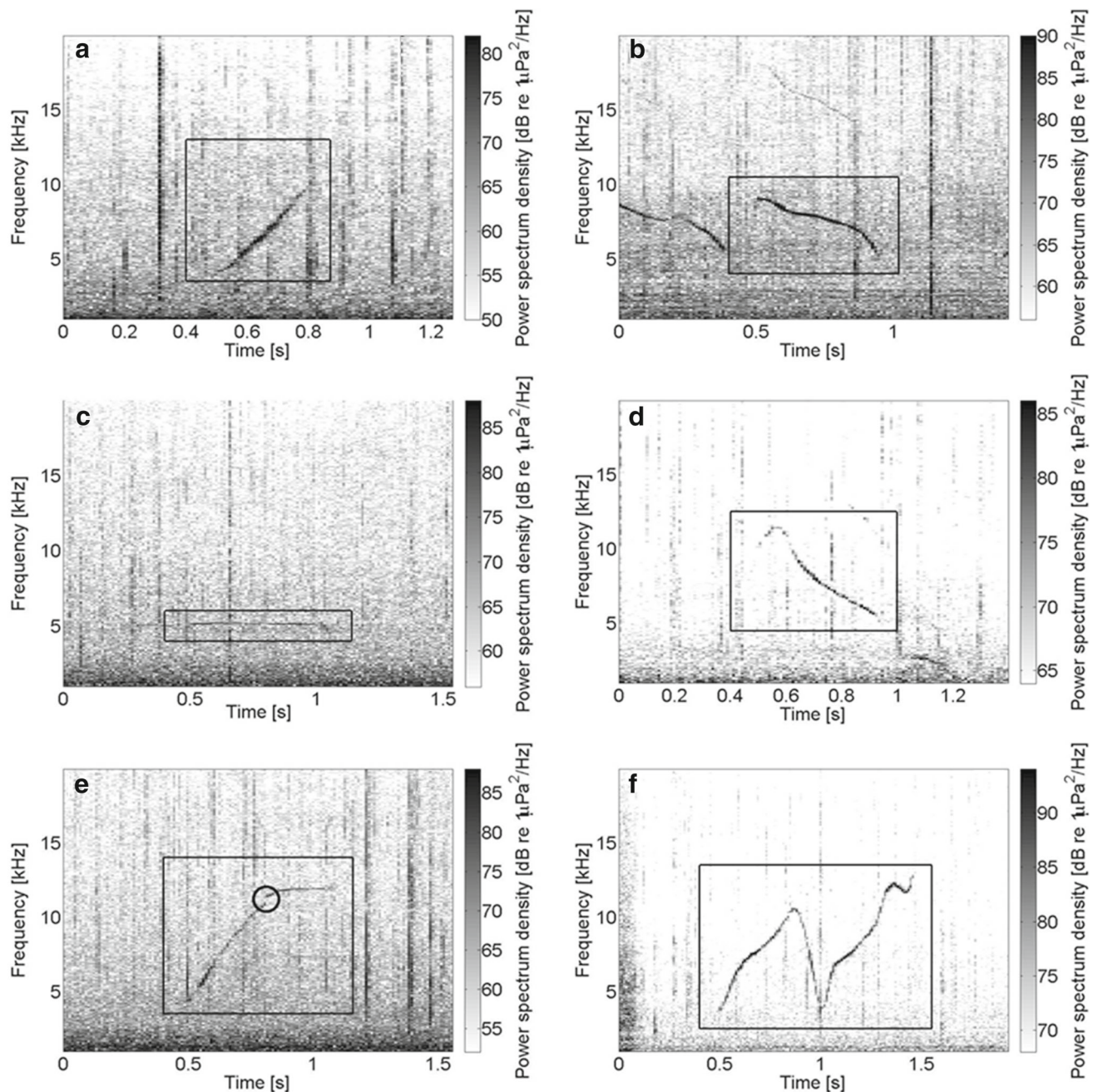


Fig. 3 Spectrograms of all four whistle types; (a) upsweep, (b) downsweep, (c) constant-frequency, (d) complex (in this example an up-down call), (e) upsweep (with step at 12 kHz indicated by the *circle*) and (f) complex (with multiple local extrema and inflection points). Sampling frequency = 96 kHz, NFFT = 2048, Hamming window, 50% overlap

for signature whistles according to the criterion of Gridley *et al.* [40] Two of the whistles were upsweep, one downsweep and two complex.

3.5 Comparison to Other Studies

Three previous studies have looked at Indo-Pacific bottlenose dolphin whistle characteristics in Western Australia: in Koombana Bay, Bunbury, approximately 150 km south

of Fremantle [34,45] and in Shark Bay, approximately 880 km north of Fremantle [34,38]. One study measured this species' whistles on the Australian east coast [34]. Hawkins [34] included the data collected by Jensen *et al.* [45] in Bunbury. Figure 7 compares the relative occurrences of different whistle types measured in Fremantle with those measured at four other Australian locations by Hawkins [34]. Along the west coast, Fremantle showed the highest percentage of complex whistles and downsweeps, and the lowest percentage of

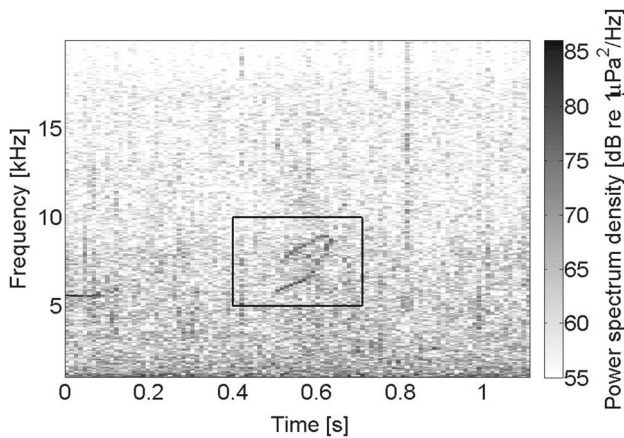


Fig. 4 Spectrogram of a potential biphonic whistle. Sampling frequency = 96 kHz, NFFT = 2048, Hamming window, 50% overlap

upsweeps. The percentages in Fremantle compared better to those from the Australian east coast than the other Western Australian sites.

Figure 8 compares the whistle measurements pooled over all whistle types amongst the different sites. There is good agreement between all of the frequency measurements; the ranges of f_{min} , f_{max} , f_{start} and f_{end} are very similar; the means \pm standard deviations overlap. The range of whistle durations was less in Fremantle and Bunbury than at the other sites; but the means were all less than 1.1 s. What was called

an inflection point by Wang *et al.* [38] and Hawkins [34] (“defined as a change in the slope of the sonogram contour from negative to positive or vice versa”), is generally called a local extremum in mathematics, and therefore we compared their inflection data with our counts of local extrema.

3.6 Ambient Noise

Ambient noise in the Fremantle Inner Harbour is very variable, changing by up to 50 dB at frequencies below 1 kHz (Fig. 9). Some of this variability is likely due to changing environmental conditions (e.g. wind) and anthropogenic operations (e.g. vessel traffic, cargo handling). Also, dolphin vocalisations were present in the recordings when ambient noise was computed. The “humped” noise floor between 1 and 20 kHz is due to the always present snapping shrimp (e.g. [46,47]). Dolphin echolocation clicks are responsible for the spectrum level increase above 30 kHz [48], seen in the 1st – 75th percentiles.

Octave band levels of ambient noise, averaged over 10 s prior to each whistle or whistle train, were correlated with every whistle parameter to see if ambient noise determined whistle features. No relationship was found between any of the octave band levels (0.5–1, 1–2, 2–4, 4–8, 8–16, and 16–32 kHz) and any of the whistle parameters, i.e. frequency

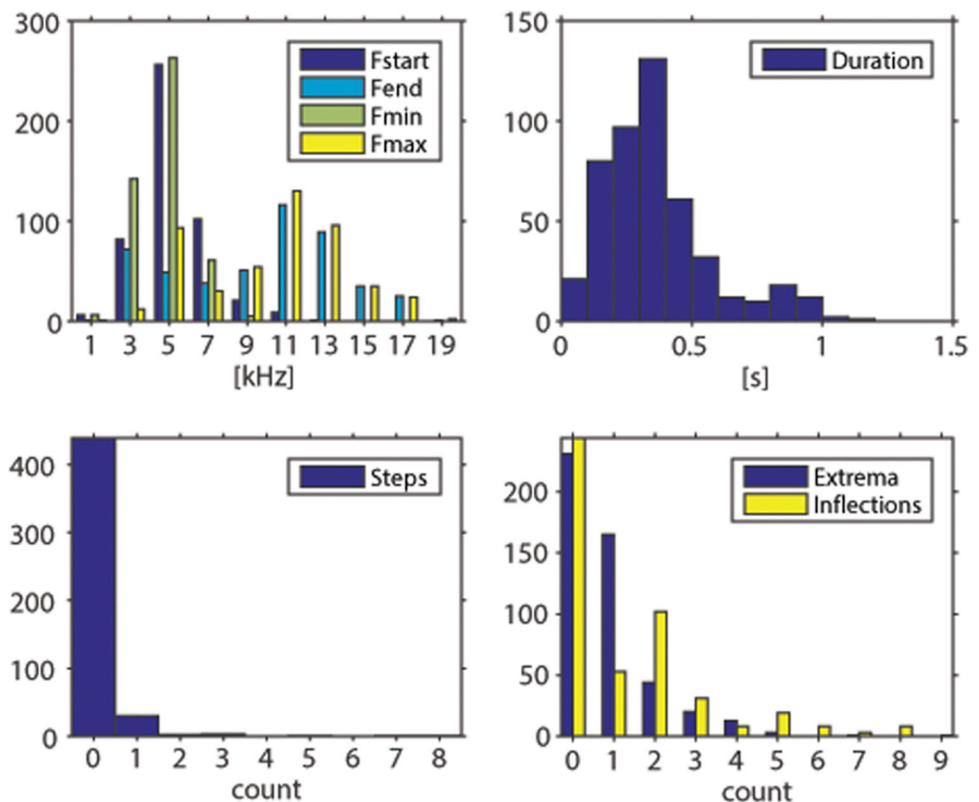


Fig. 5 Histograms of the start, end, minimum and maximum frequencies of 477 fundamental whistle contours, as well as their duration, and numbers of steps, local extrema and inflection points. (Color figure online)

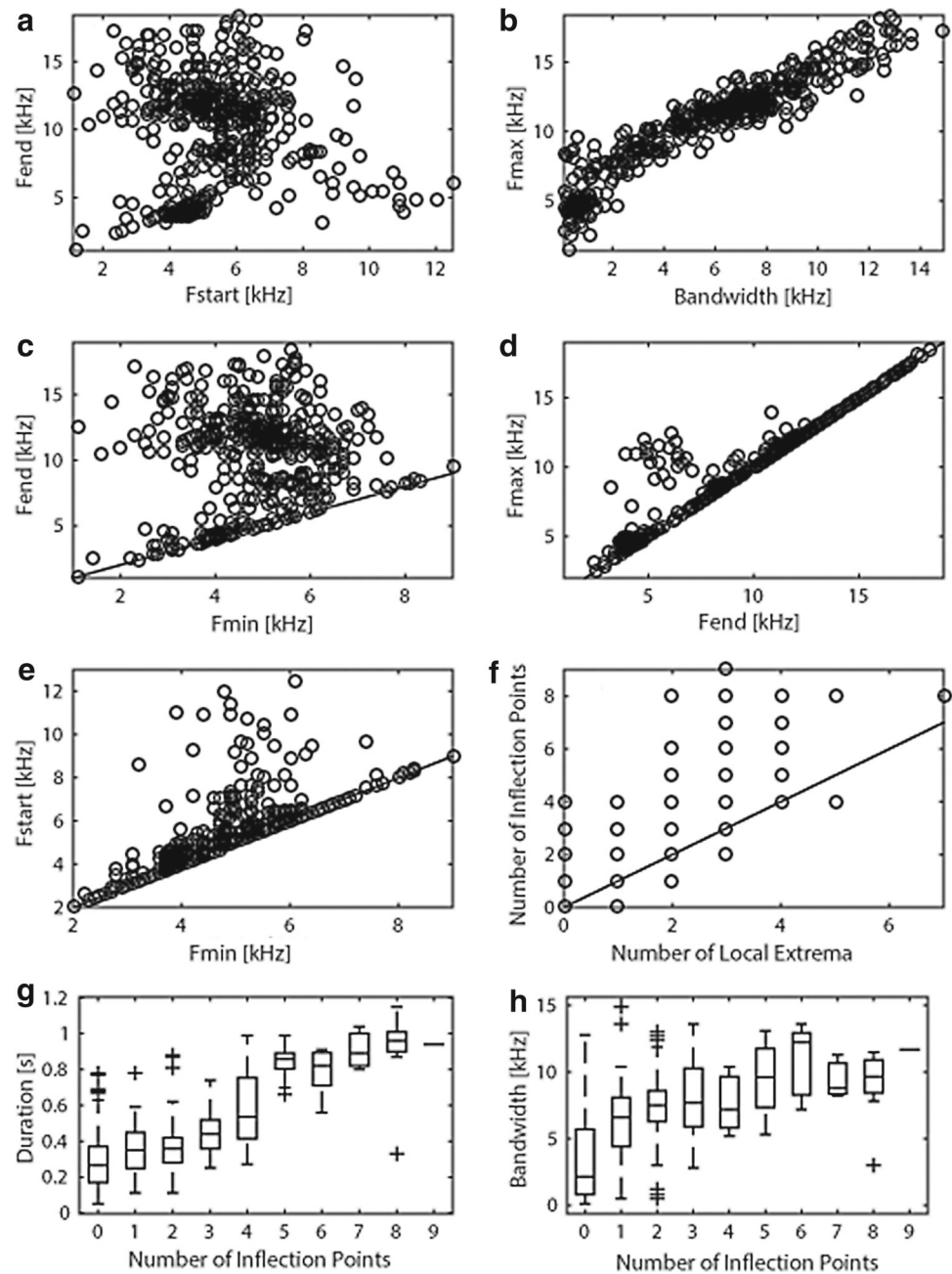


Fig. 6 Relationships between parameters measured off the fundamental whistle contours, i.e., between **(a)** Fend and Fstart, **(b)** Fmax and the fundamental contours' bandwidths, **(c)** Fend and Fmin, **(d)** Fmax and Fend, **(e)** Fstart and Fmin, **(f)** the numbers of inflection and stationary (local extrema) points, **(g)** duration and the number of inflection points, and **(h)** bandwidth and the number of inflection points. Lines of equality are shown in **(c–f)**

measurements, duration, and numbers of extrema, inflection points and steps.

4 Discussion

We recorded the whistles of *T. aduncus* in the Fremantle Inner Harbour, Western Australia. Whistles were grouped according to features measured off the fundamental contours in spectrographic images. Over half of the whistles were complex (having at least one local extremum), with the oth-

ers classified as upsweep, downsweep or constant-frequency. Most of the whistles were of overall upsweep nature, starting at a low frequency and ending at a higher frequency, with and without frequency undulations and local extrema in between.

Five whistles qualified as signature whistles, agreeing with Gridley *et al.* [40] that not only *T. truncatus* (whose signature whistles have been well documented), but also *T. aduncus* emit signature whistles. The criterion used to identify signature whistles was based on the observation that signature whistles in wild dolphins occur in bouts with inter-whistle intervals of 1–10 s [40,42]. The criterion

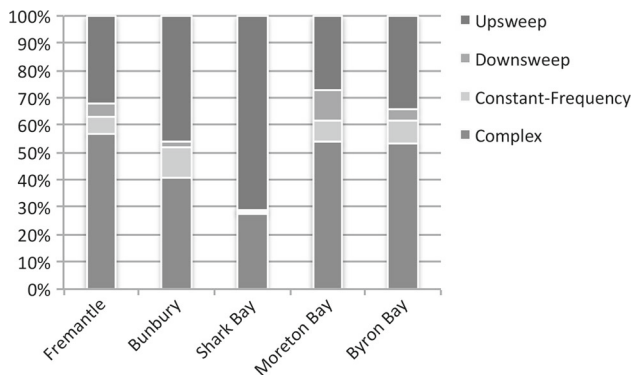


Fig. 7 Comparison of the occurrences of four whistles types at Fremantle, Bunbury and Shark Bay on the Australian west coast, and Moreton Bay and Byron Bay on the Australian east coast; Fremantle data from this study, all other sites from Hawkins [33]

was deemed conservative, likely missing potential signature whistle candidates [40,42]. In fact, almost half of the whistles emitted by wild dolphins might be signature whistles, increasing to 100 % if animals are separated from the group [29,49].

The spectrographic characteristics of dolphin whistles have been shown to vary within a species depending on

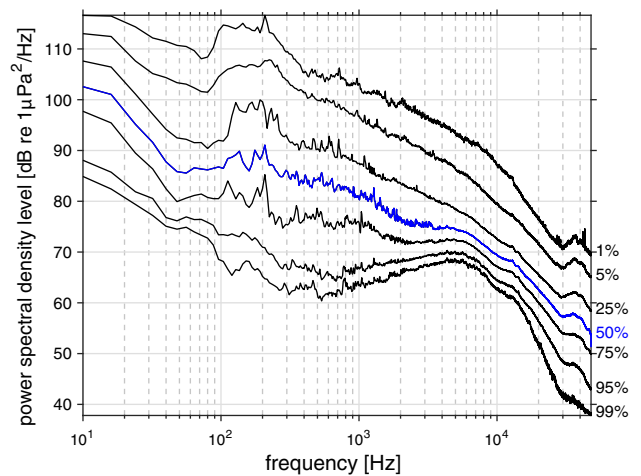


Fig. 9 Power spectral density percentiles computed over 11 h, after averaging the power spectral density into 60 s windows. Shown are the *n*th percentiles (*n* = 1, 5, 25, 50, 75, 95, 99), indicating the power spectral density level that was exceeded *n*% of the time. The 50th percentile (blue line) is the median. (Color figure online)

geographic location, environmental parameters (e.g. ambient noise), group composition, behaviour and context [16,21, 25,32,35–37,50–53]. In addition, dolphins have been shown to vary the frequency parameters and duration of whistles

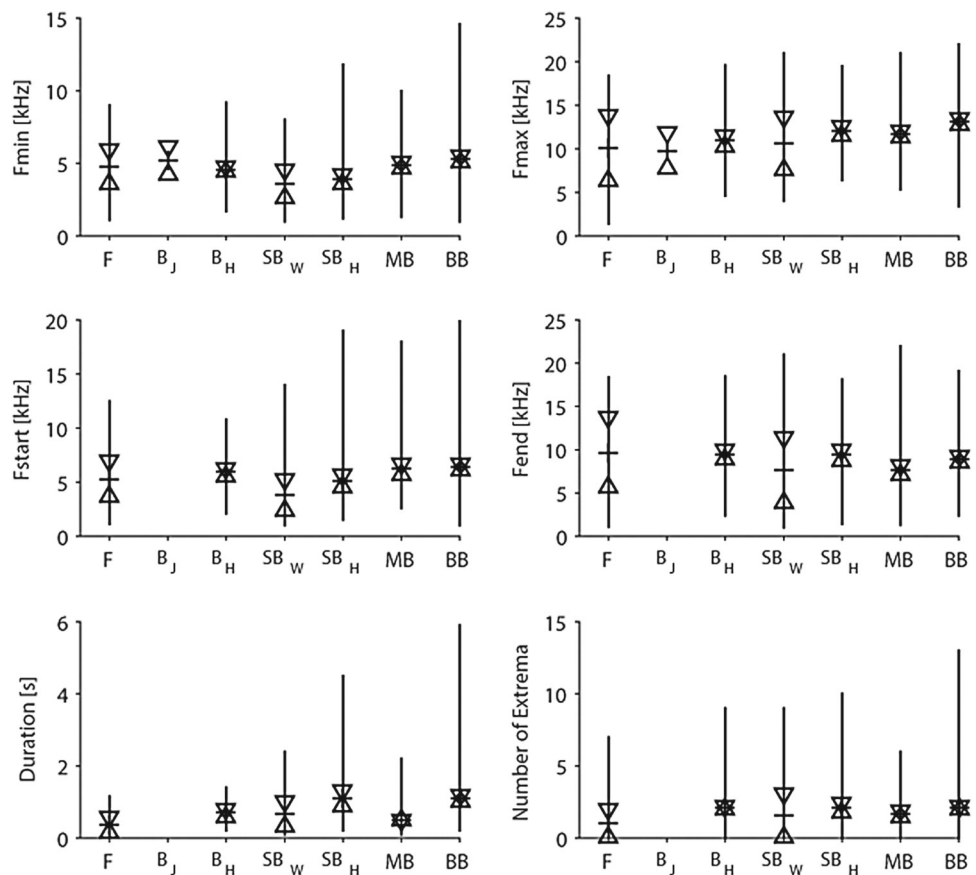


Fig. 8 Comparison of whistle measurements at different sites, Fremantle (F, this study), Bunbury (B_J, [44], B_H, [33], Shark Bay (SB_W, [37], SB_H, [33], Moreton Bay (MB, [33] Byron Bay (BB, [33]). Shown are the means ± standard deviations, and the ranges. Jensen et al. [44] only reported means and standard deviations for *f*_{min} and *f*_{max}. Note that Hawkins [33] included the recordings of Jensen et al. [44] in her Bunbury data. The sample sizes are 477 (F), 180 (B_J), 743 (B_H), 658 (SB_W), 1842 (SB_H), 5178 (MB), 1930 (BB)

of the same type, i.e. with the same spectrographic “shape” (contour, frequency-modulation pattern). Such frequency-shifting and time-warping may be due to changes in context, behaviour, group composition, and social and emotional state [54–57].

The relative occurrences of whistle types and the features measured off the fundamental contours were similar to other studies of *T. aduncus* around Australia. Geographical variation may contribute to differences in bottlenose dolphin whistle structure. Wang *et al.* [38] found that difference in whistle structure was more prominent between far-separated locations than closer locations. Similarity in repertoires was explained by dolphins from nearby areas mimicking the others’ whistles, or due to the periodic change of individuals across locations [38, 54]. However, whistles recorded in this study in the Fremantle Inner Harbour consisted of more complex whistles and fewer upsweeps than those reported for other Western Australian populations, and whistle type occurrences were more similar to results reported for two east Australian populations. The observed differences may be due to different contexts and behaviours, or an artefact of greater numbers of whistles recorded for some individuals than others, or different sample sizes, which ranged from 180 [45] to 5178 [50].

Another explanation may be ambient noise. Background noise reported from Bunbury [45] was similar to the 95th percentile in the Fremantle Inner Harbour, i.e. it seemed ambient noise in the Fremantle Inner Harbour was louder than in Bunbury 95 % of the time that dolphins were present in our study. Noting that the measurements in Bunbury were done at sea state 0 and in the absence of nearby boats, hence not representative of the full range of potential ambient noise, the Bunbury underwater soundscape is expected to have a lesser anthropogenic input than the Fremantle underwater soundscape, and it is likely that ambient noise is generally lower in Bunbury. Ambient noise at the time of our measurements in the Fremantle Inner Harbour was up to 20–40 dB louder than at the time of measurement in Bunbury [45] at 1–10 kHz. Shark Bay in Western Australia is very remote and hence the least affected by anthropogenic noise of all of the study sites compared. Interestingly, the percentage of complex calls was the highest in the Fremantle Inner Harbour, followed by Bunbury and then Shark Bay. Ambient noise levels could also be a reason for the similarity in whistle types (i.e., the relative occurrence of constant frequency, upsweep, downsweep and complex whistles, see Fig. 7) between Fremantle and Moreton Bay, which has a lot of ship noise as well.

Ambient noise levels may directly influence the frequency parameters, number of inflection points, durations and repetitions of whistles, and lengths of whistle trains in bottlenose dolphins [35, 36, 51, 53, 58–60]. It has been suggested that dolphins shift the frequencies of their whistles above the peaks in the ambient noise spectrum [35, 38, 59, 60]. Ambient

noise in Fremantle varied by up to 30–55 dB (depending on frequency) during our recordings, but we did not observe any upwards shifts in the frequency of entire whistle contours. Rather, any increase in f_{max} resulted in an increase in bandwidth, with f_{min} remaining the same. We examined whether such increases in bandwidth happened at times of higher noise levels, but found no correlation between ambient noise levels immediately preceding whistles and whistle parameters. However, our recordings and observations were all done during daytime during nine occasions, with no data having been collected during night time when anthropogenic operations and hence anthropogenic noise would be minimum.

It would be insightful to compare whistles from dolphins in the Fremantle Inner Harbour to those recorded further up the Swan River as well as in Cockburn Sound, which is part of the same habitat. For the Swan-Canning estuary dolphin community, upriver from the Fremantle Inner Harbour would consist of mostly a progressively quieter habitat. For the Cockburn Sound community, underwater noise conditions would likely vary widely throughout the sound. Furthermore, obtaining recordings of whistles from all ~45 individuals using the Fremantle Inner Harbour, and identifying the whistles to individual (if possible) would also allow for the results to be more directly related to the two communities (the Swan-Canning River and the Cockburn Sound communities) that use the Fremantle Inner Harbour, and would improve the chances of detecting any changes directly linked to background noise conditions. Future work aimed at obtaining more recordings over a longer temporal scale would also provide a larger, more robust sample size which could potentially be generalized over longer periods of time, and could provide insight into temporal and seasonal variability.

Acknowledgments The authors are grateful to the Centre of Marine Science and Technology (Curtin University), in particular to Malcolm Perry and Frank Thomas for providing field support and assistance. We thank Fremantle Ports for granting us access into the Port to carry out data collection.

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