



## Whistle characteristics of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand

VINCENZO PETRELLA

EMMANUELLE MARTINEZ  
Coastal-Marine Research Group,  
Institute of Natural Sciences,  
Massey University,  
Private Bag 102 904, NSMSC,  
Auckland, New Zealand

MICHAEL G. ANDERSON

Ecology and Conservation Group,  
Institute of Natural Sciences,  
Massey University,  
Private Bag 102 904, NSMSC,  
Auckland, New Zealand

KAREN A. STOCKIN

Coastal-Marine Research Group,  
Institute of Natural Sciences,  
Massey University,  
Private Bag 102 904, NSMSC,  
Auckland, New Zealand  
E-mail: k.a.stockin@massey.ac.nz

### ABSTRACT

Quantifying the vocal repertoire of a species is critical for subsequent analysis of signal functionality, geographic variation, and social relevance. However, the vocalizations of free-ranging common dolphins (*Delphinus* sp.) have not previously been described from New Zealand waters. We present the first quantitative analysis of whistle characteristics to be undertaken on the New Zealand population. Acoustic data were collected in the Hauraki Gulf, North Island from 28 independent dolphin group encounters. A total of 11,715 whistles were collected from 105.1 min of recordings. Seven whistle contours were identified containing 29 subtypes. Vocalizations spanned from 3.2 to 23 kHz, with most whistles occurring between 11 and 13 kHz. Whistle duration ranged from 0.01 to 4.00 s (mean  $\pm$  SD;  $0.27 \pm 0.32$ ). Of the 2,663 whistles analyzed, 82% have previously been identified within U.K. populations. An additional six contours, apparently unique to New Zealand *Delphinus* were also identified. Data presented here offer a first insight into the whistle characteristics of New Zealand *Delphinus*. Comparisons with previously studied populations reveal marked differences in the whistle frequency and modulation of the New Zealand population. Interpopulation differences suggest behavior and the local environment likely play a role in shaping the vocal repertoire of this species.

Key words: common dolphins, *Delphinus* sp., vocal behavior, whistles, Hauraki Gulf, New Zealand.

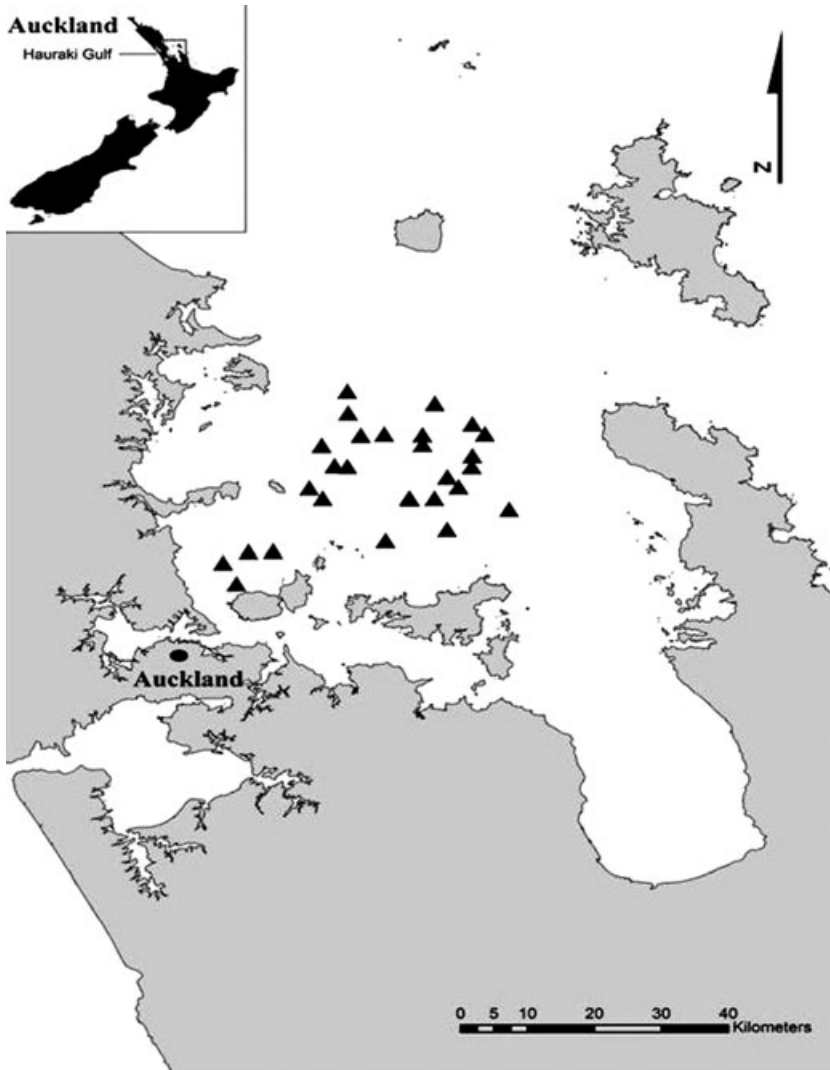
Like most delphinids, common dolphins (*Delphinus* spp.) are a vocal species that produce echolocation click trains, burst pulse calls and whistles (Moore and Ridgway 1995, Richardson *et al.* 1995, Soldevilla *et al.* 2008). Whistles are narrowband tonal calls with durations up to a few seconds and fundamental frequencies that typically fall between 5 and 20 kHz. Frequency modulated and often described in terms of their frequency as a function of time (spectrograms), whistles are likely used for communication (Richardson *et al.* 1995). Whistles have been typically examined *via* their contours (*e.g.*, Janik 1999, Bazua-Duran 2004), as well as by the extraction of acoustic parameters from each whistle contour (*e.g.*, Azevedo and Van Sluys 2005, Lopez 2010). Contour categories commonly used include unmodulated constant frequency whistles, upsweeps, downsweeps, U shapes (or concave), inverted U shapes (or convex), or wavering sinusoidal whistles. However, odontocete repertoires are often more complex and may include intermediate types between those categories, as well as whistles that consist of repeated types or a combination of different types. The whistle repertoires of odontocetes show great variability among species, populations, or even individuals of a population (Rendell *et al.* 1999). Within populations, parameters such as duration or number of inflections or steps are usually more variable than parameters related to the frequency. Furthermore, such parameters carry information about individual identity or behavior (Rendell *et al.* 1999, Morisaka *et al.* 2005).

Acoustic studies of free-ranging common dolphins have primarily focused upon Northern Hemisphere populations, particularly within British (*e.g.*, Goold 1996, 1998, 2000; Ansmann *et al.* 2007) and North Pacific (*e.g.*, Oswald *et al.* 2003, 2007; Henderson *et al.*, in press) waters. Prior to this study, the whistle characteristics of *Delphinus* within southern Pacific waters have remained unexamined. Within New Zealand, common dolphins (*Delphinus* sp.) occur around much of the coastline, especially off the east coast of the North Island (Gaskin 1968, Bräger and Schneider 1998). However, their occurrence, especially in southern waters, appears to be restricted by a seasonal influx of cooler water (Webb 1973). Within the Hauraki Gulf, 60 km north of Auckland City (36° 51' S, 174° 46' E), common dolphins are the most frequently observed cetacean (Stockin *et al.* 2008a). The Hauraki Gulf is considered an important habitat for this species (Stockin and Orams 2009), and is documented for both its feeding (Stockin *et al.* 2009a) and potential breeding (Stockin *et al.* 2008a) importance to this population. However, human-induced impacts including pollution (Stockin *et al.* 2007), net entanglement (Stockin *et al.* 2009b) and tourism (Stockin *et al.* 2008b) are known to affect *Delphinus*. Surprisingly, although boat interactions with this species occur year round, potential acoustic impacts of these interactions remain unexamined. Here, we investigate the whistle characteristics of free-ranging New Zealand common dolphins for the first time and examine the role of behavioral states in relation to different whistle parameters.

## MATERIALS AND METHODS

### *Study Site*

The Hauraki Gulf is a shallow (60 m maximum depth), semienclosed body of temperate water (Manighetti and Carter 1999) extending from Bream Head



*Figure 1.* Locations of common dolphin groups sampled during acoustic surveys conducted in the Hauraki Gulf, New Zealand between February 2008 and May 2009.

to Cape Colville at the northern tip of the Coromandel Peninsula, on the east coast of North Island, New Zealand ( $36^{\circ}10' - 37^{\circ}10'S$ ,  $174^{\circ}40' - 175^{\circ}30'E$ ; Fig. 1). Adjacent to New Zealand's most urbanized city, the gulf is open to the north, while landlocked to the south and west, and partly protected in the east by Great Barrier Island and the Coromandel Peninsula. In addition to its popularity as a recreational fishing and water activities area, the Hauraki Gulf hosts three shipping channels with an excess of 4,000 commercial vessel movements per year (Behrens 2009).

### Data Collection

Nonsystematic surveys were conducted in Hauraki Gulf between February 2008 and May 2009 using a 20 m commercial dolphin tour catamaran *Dolphin Explorer* powered by 350 hp engines. Surveys were conducted in daylight hours during calm sea conditions (Beaufort <3, swell <1 m) and good visibility (>1 km). Acoustic recordings of common dolphins were made using a PZ-1A (LAB-core systems) hydrophone fitted to a Sony MZ-NH700 HiMD Minidisc (Sony Corporation, Tokyo, Japan) and recorded as 44.1 kHz, 16 bit wav files. Observations were conducted using a continuous scanning methodology (Mann 1999) by naked eye and with binoculars (Bushnell 8 × 42 magnification). Once within 400 m of a group of dolphins, the vessel would slow to an approach speed (~5 knots). At this point, environmental parameters (*i.e.*, water depth, sea surface temperature [SST], sea state, visibility, and weather) and data relating to group size and composition were recorded. The boat slowly tracked parallel to the course of moving animals, approaching slightly to the rear of the group in a slow and continuous maneuver. Once within approximately 100 m of the animals, the start time and location for the encounter were recorded. Maneuvering close to the center of the focal group, the vessel engines and generator were switched off so as to reduce background noise. The hydrophone (20–24 kHz) was subsequently lowered 6 m under the surface of the water and recordings were made for up to 5 min per sample. Visual observations of each focal group resulted in the collection of behavioral data, using states defined in Stockin *et al.* (2009a). Focal group follows with instantaneous scan sampling of the predominant behavior (Altmann 1974, Mann 1999) was used as the sampling protocol. Only behaviors that could be reliably and consistently recorded were sampled. The behavioral state of each focal group was determined by the activity of >50% of group members (Stockin *et al.* 2009a). Vocalizations were recorded at the group, rather than the individual level. If more than one dolphin group was encountered during any one survey, acoustic recordings were only sampled from the first group, unless the distance between groups (either spatially, >10 km or temporally, >1 h) prevented the resampling of the same individuals. This reduced the probability of pseudo-replication within a survey, although it cannot exclude the possibility of multiple recordings from the same animals within and between surveys. A different approach to that explained previously was made during the travel activity due to the rapid movement of animals through the area. When dolphins were traveling, the boat maneuvered ahead of the pod and then subsequently stopped along the predicted pathway of the group in order to record the dolphin vocalizations as individuals swam past the vessel.

Common dolphin behavior is considered to be relatively cyclical and can be characterized by five main behavioral states: forage, mill, rest, social, and travel (see Neumann 2001, Stockin *et al.* 2009a for definitions). However, only forage and travel were observed consistently throughout the period of recorded vocalizations. While milling and socializing dolphins were detected, these behaviors only ever occurred in combination with other behavioral states. As such, it was not possible to decipher which vocalizations related to each behavioral state. Only groups with similar numbers of dolphins were used to assess differences between behavior. As only forage and travel were observed consistently during acoustic recordings, just these two behaviors were analyzed. This resulted in six independent encounters (travel:  $n = 568$  s, 60 whistles; forage:  $n = 551$  s, 772 whistles) where group size and behavior were consistent for comparisons.

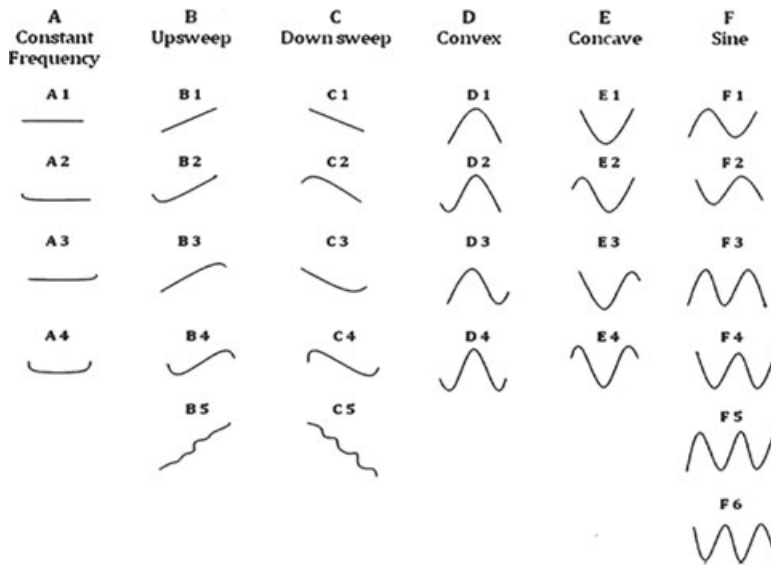


Figure 2. Idealized contours of the different whistle types (modified from Ansmann *et al.* 2007).

Recordings were digitally downloaded onto a laptop computer at the end of each encounter and analyzed using Raven Pro 1.3 (Charif *et al.* 2007, Cornell Lab of Ornithology, Ithaca, NY). All sound recordings were digitally transferred to Raven 1.3 and spectrograms (Hann, window size 5.33 ms, 3 dB bandwidth of 270 Hz, overlap coefficient of 50%, frequency grid discrete Fourier transform (DFT) size 256 samples and 188 Hz) were created for analysis. Acoustic data were only included when species identification was confirmed visually by the first author (VP). The sounds within recordings were categorized as clicks, whistles, burst pulses, and boat noise. The continuous recordings of each survey day were first dismantled into 1-min intervals and the number of whistles in each file counted visually using Raven Pro 1.3. Each whistle was subsequently categorized based on the six contour types previously described for this species (Ansmann *et al.* 2007, see Fig. 2).

#### Data Analysis

Key acoustic parameters were measured from whistle spectrograms (Table 1) to quantify each whistle type, (duration (s), minimum, maximum, and mean frequency, as well as frequency range and gradient) and whistle characteristics counted (number of inflections and steps). Differences in whistle characteristics between encounter, group size and whistle types were tested using StatsDirect 2.7.7 (StatsDirect Ltd, Cheshire, UK). The distributions of continuous response variables were initially tested for normality using Kolmogorov–Smirnov test (Zar 1996). In most cases, data were nonnormal so the nonparametric Kruskal–Wallis test was applied. Mann–Whitney *U*-tests were used to assess differences between foraging and traveling dolphin groups. All tests were considered statistically significant at  $P \leq 0.05$ . Recordings were classified on whistle density and considered high (up to 8 w/s), medium (1.71–8 w/s), or low (1–1.70 w/s).

Table 1. Parameters used to describe vocalizations of New Zealand common dolphin in Hauraki Gulf, New Zealand.

Parameter	Description
Duration	Time duration of the whistle (end time minus start time).
Start frequency	Frequency (Hz) at the start point of the whistle.
End frequency	Frequency (Hz) at the end point of the whistle.
Minimum frequency	Frequency (Hz) at the lowest point of the whistle.
Maximum frequency	Frequency (Hz) at the highest point of the whistle.
Mean frequency	Average frequency (Hz) of all point marked along the whistle.
Frequency gradient	Overall gradient/steepness (Hz/s) of the rise or fall of the whistle, calculated as $FG = (EF - SF)/Duration$ .
Frequency range	Range of frequency (Hz) spanned by the whistle, calculated as $FR = MaxF - MinF$ .
Inflections	Turning points where frequency modulation or slope of the whistle changes from falling to rising or rising to falling frequency.
Steps	Periods of constant frequency between two periods of the same frequency modulation, that is, two periods of rising or two periods of falling frequency.

## RESULTS

### *Whistle Characteristics*

Data were collected between February 2008 and May 2009 during 22 vessel-based surveys conducted in the Hauraki Gulf, New Zealand. A total of 29 independent common dolphin groups (mean  $\pm$  SD =  $35.2 \pm 18.28$ ) were encountered. Of these, vocalizations were recorded during 26 encounters. A total of 105.10 min of recordings were made in the visual presence of common dolphins, resulting in 11,715 whistles. Continuous recordings for each encounter (mean  $\pm$  SD =  $4.38 \pm 3.13$ ) were broken down into a total of 105 independent intervals of 1 min each. Of these, 17 (mean = 0 whistles per second; w/s) had no acoustic detections, 9 (mean  $\pm$  SD =  $10.5 \pm 2.14$  w/s) showed high whistles density, 14 (mean  $\pm$  SD =  $3.96 \pm 1.90$  w/s) exhibited medium whistles density and 65 (mean  $\pm$  SD =  $0.80 \pm 1.61$  w/s) were classified as low whistles density. Whistle density ranged from 0.015 to 15.2 w/s (mean  $\pm$  SD =  $1.96 \pm 2.42$  w/s). In addition, from a total of 11,715 whistles, 2,663 whistles resulting from 28 min of recordings were classified. These comprised 1,831 whistles randomly chosen and 832 whistles analyzed in relation to behavior.

All vocalizations analyzed ( $n = 2,663$  whistles) from different groups in the Hauraki Gulf showed a mean whistle duration of 0.27 s (range = 0.01–4.00 s, SD = 0.32) and an average frequency range of 2,211.63 Hz ( $\pm 2,605.78$ ). The mean values of the minimum and maximum frequencies for this population were 11,393.1 ( $\pm 3,898.84$ ) and 13,604.9 Hz ( $\pm 4,133.09$ ), respectively. The mean number of inflection and steps recorded for Hauraki Gulf common dolphins was 0.56 ( $\pm 0.86$ ) and 0.06 ( $\pm 0.35$ ), respectively. All six contours (A–F) described previously by Ansmann *et al.* (2007) for U.K. *Delphinus* were evident in the New Zealand sample set. However, the whistle parameters of the Hauraki Gulf population differed from those collected in U.K. waters (Table 2). Of the 2,663 whistles analyzed from Hauraki Gulf common dolphins, downsweep contours were the most prevalent whistle type (35.9%) followed by upsweeps and constant types, accounting for 28.5 and 16.4%,

Table 2. Vocalization parameters in common dolphins from the Hauraki Gulf, New Zealand compared with U.K. populations detailed in Ansmann *et al.* (2007). Values given are means with standard deviations shown in parentheses.

Sound parameter	Hauraki Gulf	Celtic Sea	English Channel
	23 kHz bandwidth limit <i>n</i> = 2,663 whistles	24 kHz bandwidth limit <i>n</i> = 1,835	48 kHz bandwidth limit <i>n</i> = 435
Start frequency (Hz)	12.59 (4.07)	12.03 (3.47)	12.64 (3.95)
End frequency (Hz)	12.29 (4.07)	11.97 (3.25)	12.48 (3.97)
Minimum frequency (Hz)	11.39 (3.89)	9.45 (2.06)	9.80 (2.46)
Maximum frequency (Hz)	13.60 (4.13)	14.69 (3.13)	15.84 (3.28)
Mean frequency (Hz)	12.46 (3.81)	11.89 (2.05)	12.67 (2.37)
Frequency gradient (Hz/s)	-0.89 (-14.39)	0.38 (9.73)	0.51 (11.63)
Frequency range (Hz)	22.13 (2.60)	5.24 (3.25)	6.03 (3.42)
Duration (s)	0.27 (0.32)	0.65 (0.33)	0.64 (0.32)
Number of inflections	0.56 (0.863)	0.64 (0.98)	0.56 (0.91)
Number of steps	0.06 (0.349)	0.13 (0.39)	0.10 (0.34)

respectively. Concave and convex contours (6.1% each) accounted for the smallest proportion of whistles identified within the repertoire of Hauraki Gulf common dolphins. Sine contours were detected in 7% of recordings analyzed from the New Zealand data set. Of all the whistle types identified in the present study, the least modulated subtypes appeared to be the most frequent. Analyses of the Hauraki Gulf data set revealed 45 whistle contours (Fig. 3) that could not be accounted for within Ansmann *et al.* (2007). Consequently, this resulted in six new whistle contours being described for the G and H classes, five for the M class, and a further seven and eight for classes L and I, respectively. A further 13 new whistles contours were added within N class (Fig. 3).

Of 11,715 whistles, certain whistles (R contours, Fig. 4) appear to have a high repetition rate over a short temporal scale (Fig. 4). Each R contour exhibited an extraordinary similarity in duration and other whistle frequency parameters. A total of 20 different repetitions were recorded, 12 of which occurred only within one encounter, while a further 8 occurred over multiple (two to three) encounters. R12 was the whistle repetition that showed the highest number of repetitions in association with the highest number of encounters (35 repetitions within 3 encounters). Conversely, R16 displayed the lowest number of encounters and whistles (five repetitions within one encounter).

All parameters examined in the present study were found to be significantly different between encounters (Table 3), except for mean frequency and number of steps ( $P > 0.05$ ). All examined parameters were also found to differ between whistle types (Table 3), except for minimum frequency and number of steps ( $P > 0.05$ ). Finally, all parameters with the exception of the number of steps ( $P > 0.05$ ) varied significantly with group size (Table 3).

#### *Whistle Characteristics in Relation to Behavior*

Analyses revealed large differences between vocalizations of dolphins engaged in different behavioral states. First, whistle density was markedly different between forage (F) and travel (T) groups, despite a comparable sample period (*ca.* 8 min)

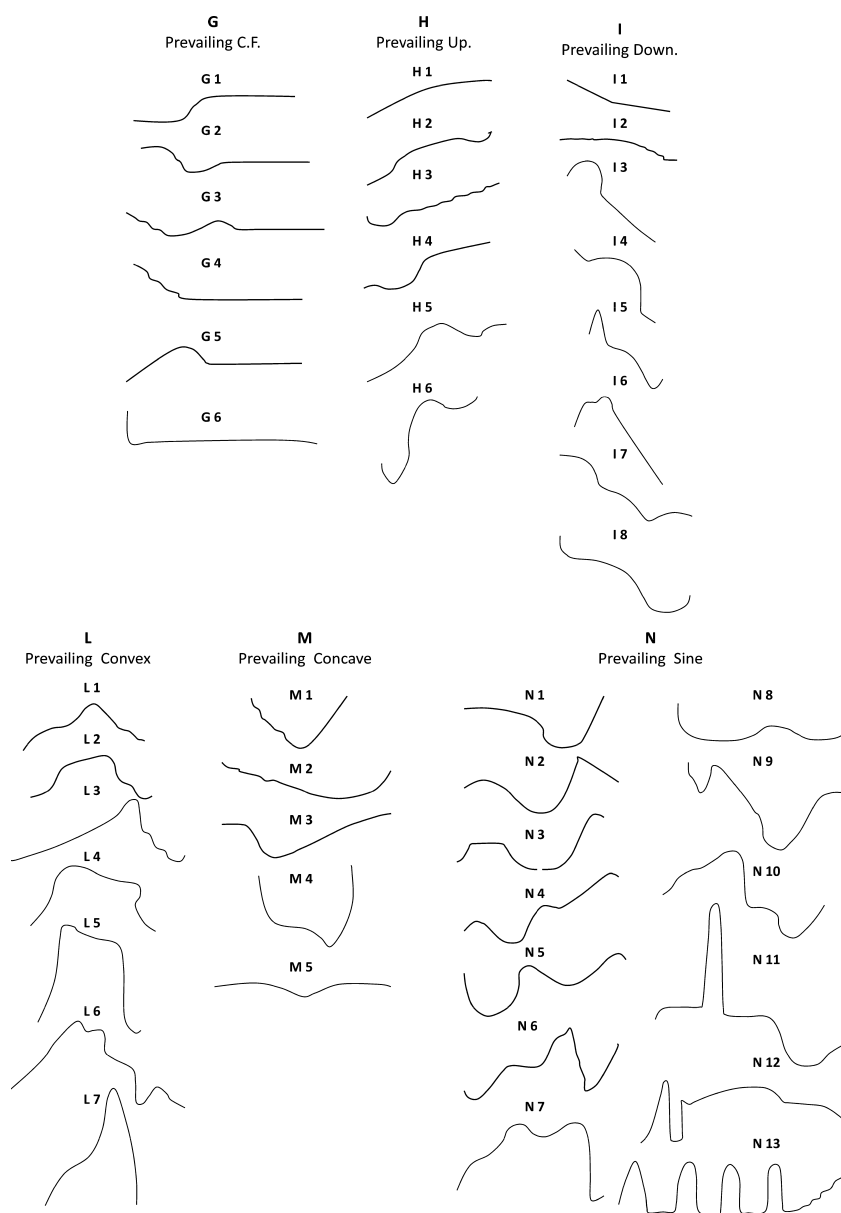


Figure 3. Alternative idealized contours of the different whistle types detected in common dolphins in the Hauraki Gulf, New Zealand.

and similar group sizes. To be more precise, the whistle density within the foraging groups was on average, approximately 13 times higher than that recorded in traveling groups (Fig. 5). This resulted in a whistle density of  $1.61 \pm 0.65$  w/s for foraging dolphins *vs.*  $0.12 \pm 0.15$  w/s for traveling dolphins. A comparison of whistle duration, range frequency, inflections, and steps revealed similarities between the foraging and



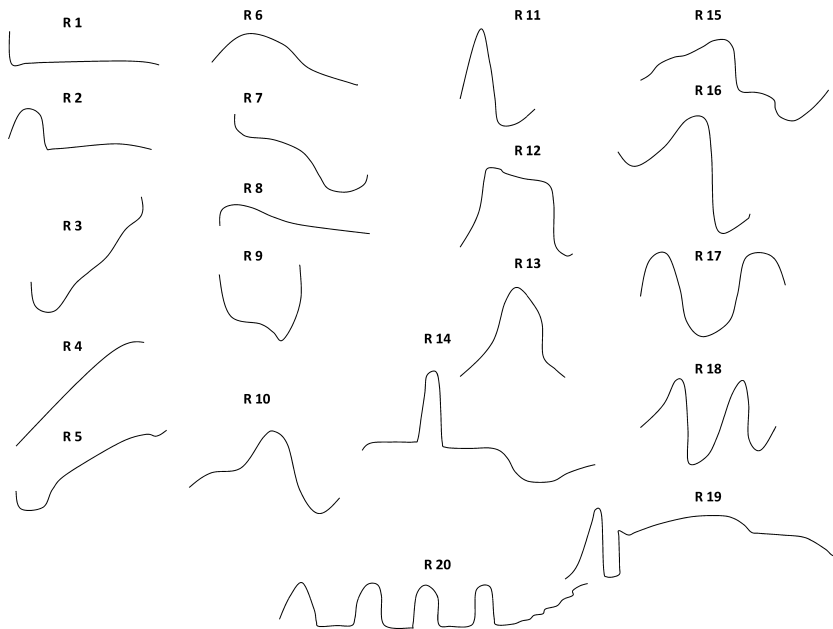


Figure 4. Frequently repeated whistle contours detected in the population of common dolphins in Hauraki Gulf, New Zealand.

traveling dolphins, with the exception of duration ( $P < 0.0001$ ) and frequency range ( $P < 0.0001$ ).

During traveling, whistles were typically longer ( $T$ : mean =  $0.55 \pm 0.38$  s, range: 0.04–1.75 s;  $F$ : mean =  $0.34 \pm 0.31$  s, range: 0.01–4 s) than those recorded by foraging dolphins ( $P = 0.0001$ ). The range of frequency was also different between these two behavioral states, with the minimum frequency lower ( $T = 9,622$  Hz,  $F = 11,036$  Hz) during traveling activity ( $P = 0.0007$ ). The frequency range was significantly larger ( $T$ : 5,042 Hz,  $F$ : 3,010 Hz) in traveling groups ( $P < 0.0001$ ). No difference in maximum frequency ( $T$ : 14,664 Hz,  $F$ : 14,046 Hz;  $P = 0.876$ ), number of steps ( $T$ : 0.08,  $F$ : 0.07,  $P = 0.761$ ) or inflections ( $T$ : 0.68,  $F$ : 0.73,  $P = 0.666$ ) between behavioral states.

## DISCUSSION

Quantification of the vocal repertoire of a species is critical for subsequent analyses of signal functionality, geographical variation, social relevance, and transmission (Boisseau 2005). While signal repertoires have been documented for numerous species, detailed descriptions for cetaceans remain rare. This is true of common dolphins, and particularly so of Southern Hemisphere populations. Data presented here represent the first account of whistle characteristics for this species within New Zealand waters. We found that the behavior of New Zealand common dolphins does appear to affect the whistle characteristics, at least in relation to traveling and foraging groups. Furthermore, findings suggest that the majority of whistle parameters

Table 3. Kruskal–Wallis statistical analyses on encounters, whistle type, and group size for common dolphins in Hauraki Gulf between February 2008 and May 2009.

Encounters	Groups	df	Total observations	<i>H</i>	<i>P</i>
Duration	9	8	2,662	1,075.67	<0.0001
Start frequency	9	8	2,662	30.21	<0.0002
End frequency	9	8	2,662	68.75	<0.0001
Range frequency	9	8	2,662	764.19	<0.0001
Minimum frequency	9	8	2,662	86.36	<0.0001
Maximum frequency	9	8	2,662	36.84	<0.0001
Mean frequency	9	8	2,662	14.04	0.0807
Frequency gradient	9	8	2,662	133.65	<0.0001
Number of inflections	9	8	2,662	96.23	<0.0001
Number of steps	9	8	2,662	1.63	0.9919
Whistles type	Groups	df	Total observations	<i>H</i>	<i>P</i>
Duration	6	5	2,662	154.84	<0.0001
Start frequency	6	5	2,662	161.63	<0.0001
End frequency	6	5	2,662	117.47	<0.0001
Range frequency	6	5	2,662	484.28	<0.0001
Minimum frequency	6	5	2,662	15.92	0.0071
Maximum frequency	6	5	2,662	116.99	<0.0001
Mean frequency	6	5	2,662	39.53	<0.0001
Frequency gradient	6	5	2,662	1,814.20	<0.0001
Number of inflections	6	5	2,662	795.74	<0.0001
Number of steps	6	5	2,662	20.47	<0.0001
Groups size	Groups	df	Total observations	<i>H</i>	<i>P</i>
Duration	5	4	2,662	178.45	<0.0001
Start frequency	5	4	2,662	101.43	<0.0001
End frequency	5	4	2,662	47.71	<0.0001
Range frequency	5	4	2,662	435.12	<0.0001
Minimum frequency	5	4	2,662	18.46	<0.0001
Maximum frequency	5	4	2,662	96.84	<0.0001
Mean frequency	5	4	2,662	27.67	<0.0001
Frequency gradient	5	4	2,662	855.93	<0.0001
Number of inflections	5	4	2,662	626.29	<0.0001
Number of steps	5	4	2,662	7.96	0.0931

Note: df = degree of freedom, significant level is a  $P < 0.005$ .

examined in New Zealand common dolphins differ to those previously published for U.K. populations.

Typically common dolphins in the Hauraki Gulf emitted far fewer whistles per minute when traveling. Conversely, feeding dolphins exhibited a much higher whistle density. Since whistle density is likely affected by the number of dolphins (assuming that more whistles per unit time can be emitted from a larger group), only dolphin groups of comparable size (*ca.* 30 animals) were assessed. Results suggest that during foraging, whistle density was approximately 13 times higher than during traveling activity. This finding appears logical, since it is appropriate to suggest that the level of coordination required between foraging individuals would be higher than that necessary in traveling dolphins. This is supported by other studies that indicate

Survey	Behavior	Group size	Number of whistles	Duration of recordings (s)
27-Feb-08	1	30	0	60
12-Mar-08	2	30	26	60
12-Mar-08	3	30	7	58
12-Mar-08	4	30	9	60
12-Mar-08	5	30	13	60
12-Mar-08	6	30	0	64
1-Apr-08	7	30	2	60
21-Nov-08	8	30	0	58
<hr/>				
15-Jan-09	1	30	82	60
15-Jan-09	2	30	166	60
15-Jan-09	3	30	115	60
15-Jan-09	4	30	108	60
30-Mar-09	5	30	123	60
30-Mar-09	6	30	66	60
30-Mar-09	7	30	47	60
30-Mar-09	8	30	65	60

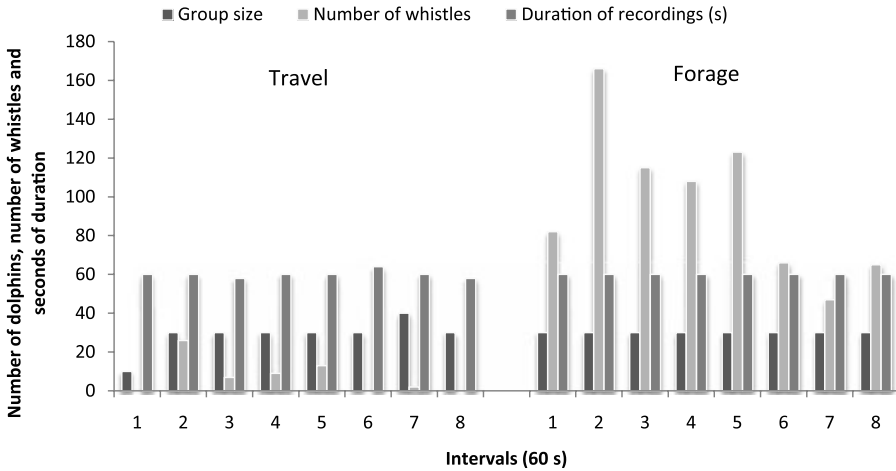


Figure 5. Parameters used to describe vocalizations of traveling vs. foraging common dolphins in Hauraki Gulf, New Zealand between February 2008 and May 2009. Note: T = travel, F = forage.

New Zealand common dolphins employ a number of foraging behaviors, several of which include coordinated group strategies (Neumann and Orams 2003, Burgess 2006). Presumably, less coordination (and communication) is required by traveling groups, since by definition, traveling implies animals moving in a uniform speed and direction. Possibly, the few whistles that are emitted by traveling individuals act as signals to maintain group cohesion only. Alternatively, the multiple approaches made towards traveling groups during recordings may in part also explain differences in whistle density detected. However, since *Dolphin Explorer* was able to track ahead of traveling groups and cut engines prior to any secondary sampling, it seems unlikely that disturbance as a result of data collection alone would explain the differences

reported here. Presumably, to be coordinated during cooperative feeding strategies, individuals within a group need to communicate efficiently, that is, within the shortest lapse of time possible. This fits with the findings of the present study, which showed feeding common dolphins display a shorter whistle duration than groups engaged in traveling behavior only.

Previous studies suggest parameters such as duration or number of inflections or steps are usually, within the same population, more variable than other parameters (Rendell *et al.* 1999, Morisaka *et al.* 2005). When comparing the Hauraki Gulf acoustics with published data for the Celtic Sea and English Channel populations (Ansmann *et al.* 2007), notable differences were found in almost all descriptive parameters analyzed (Table 2). Furthermore, the mean maximum and minimum frequencies in Hauraki Gulf animals were lower and higher, respectively than those recorded within U.K. waters. Consequently, this resulted in a smaller frequency range than that previously reported by Ansmann *et al.* Nevertheless, based on a comparable number of analyzed whistles, frequency ranged from 3.20 to 23.0 kHz in the Hauraki Gulf population ( $n = 2,663$  whistles), with most whistles detected between 10 and 14 kHz. This is comparable to the frequency span of 3.56–23.51 kHz recorded within U.K. waters ( $n = 1,835$  and 435 whistles for the Celtic Sea and English Channel, respectively), with most whistles occurring at between 9 and 15 kHz (Ansmann *et al.* 2007).

In the Hauraki Gulf, the mean recorded whistle duration was 0.27 s (range = 0.01–4.00 s) compared with 0.65 s (range = 0.05–2.02 s) for U.K. waters. Reasons why whistles appear shorter in the Hauraki Gulf population remain unclear. Potentially, the extensive geographical separation between the populations may offer some explanation. This rationale is based on the similar whistle durations reported for two neighboring U.K. populations (*i.e.*, Celtic Sea and English Channel) examined by Ansmann *et al.* (2007). Nonetheless, this remains surprising given parameters of modulation (*e.g.*, duration, number of inflections and steps) are typically more diverse within rather than between populations (Morisaka *et al.* 2005).

The present study examined a Southern Hemisphere population of common dolphins inhabiting inshore, shallow coastal waters. Data presented by Ansmann *et al.* (2007) represent Northern Hemisphere *Delphinus* inhabiting deep open oceanic waters. Clearly, these two environments not only differ by hemisphere but also by local environmental conditions, especially depth and oceanography. The way in which common dolphins use differing environments may contribute, at least in part, to some of the differences outlined here. For example, the Hauraki Gulf is an important feeding area for common dolphins (Stockin *et al.* 2009a). The associated influence this may have on whistle density and parameters measured as part of the present study are important factors to consider. Furthermore, the use of inshore Hauraki Gulf waters for nursing (Stockin *et al.* 2008a) may also have some bearing on the results presented, especially since differences in whistle parameters between the sexes have been identified in other delphinids (Sayigh *et al.* 1995). Unfortunately, no data describing the behavior of British common dolphins waters exist, thus precluding further discussion of how habitat use may account for differences identified between the regions.

Whistle types identified in the present study were in many cases, similar to those previously documented for this species (Ansmann *et al.* 2007). However, the proportion to which each contour featured within the vocal repertoire differed significantly between Hauraki Gulf and U.K. common dolphins. For example, whistle types A and C appeared more frequently in the repertoire of the Hauraki Gulf population.

This resulted in common dolphins displaying less modulation in their whistles when compared with previously studied populations. This trend was consistent throughout whistle types. Before examining potential reasons to explain these apparent differences, it is first necessary to consider the methodologies used in both the present and the previously published study. Of importance are the different manners in which acoustic data were collected. For example, Ansmann *et al.* used a towed hydrophone array during systematic transect surveys. This differs considerably to the nonsystematic surveys and static hydrophones used in the present study. Arguably, parameters may vary purely as a result of these sampling differences. For example, towed arrays have a number of inherent limitations, which may influence comparisons drawn here. First, only in a proportion of recordings is it often possible to confirm species identity *via* visual observations. As such, the acoustic presence of similar delphinids, namely white-sided (*Lagenorhynchus acutus*), white-beaked (*L. albirostris*), and striped dolphin (*Stenella coeruleoalba*) cannot be completely discounted. Second, the mobile nature of towed hydrophones likely biases certain behaviors (*e.g.*, travel). However, towed hydrophones do typically evoke less of a behavioral response compared with the static methods used within the present study. As such, the likely impact such differences have on comparisons discussed herein remains unclear.

Analyses presented here are not without limitation. First, all acoustic recordings analyzed were collected from a commercial dolphin tour vessel. While this platform of opportunity has previously been used for research purposes (*e.g.*, Stockin *et al.* 2008a, Wiseman *et al.* 2011), this has not been without constraint. Unfortunately, due to the obligatory schedule of this vessel, most interactions with dolphins were kept to a minimum, since multiple independent encounters were expected within any single survey (Stockin *et al.* 2008a). As such, in most cases the duration of recordings collected from each focal group was relatively short (mean = 4.31 min). Nonetheless, fixed sampling methods, as used in this study, have several benefits. Most importantly, vocalizations of animals recorded can be correlated with direct physical observations. This allowed species confirmation, group size and behavior to be assessed in relation to whistles characteristics. However, this procedure required recordings to only be undertaken when the engine and sonar of the boat were switched off.

An important limitation when recording the vocal behavior of free-ranging delphinids is the ability to discern between the vocalizations of the focal group (*i.e.*, near the boat) *vs.* others dolphins that compose the wider group. Using whistle intensity, it is possible to assess the distance from the hydrophone and thus, facilitate analysis of the spectrogram. While dolphin vocalizations can be detected from a distances of more than 1 km (Rankin *et al.* 2008), this issue was not considered a serious limitation within the current study, owing to the small, cohesive focal groups detected and examined within Hauraki Gulf waters. Within these small pods, the focal group often constitutes the entire pod under observation. This is due to the relatively small group sizes frequently encountered within this region (Stockin *et al.* 2008a).

Another limitation in common with many acoustic studies involving free-ranging cetaceans, and possibly the main source of variance between encounters, is the non-independence of the data collected. During the present study, it was not possible to determine which individual within a group produced the vocalizations. Therefore, it is likely that recordings often included more than one whistle from each individual, thus it cannot be guaranteed that each whistle used in the analysis is from a different dolphin (Oswald *et al.* 2003).

While data could not be recorded during all months during the present study owing to field logistics (*e.g.*, bad weather), survey effort was spread across the entire

year. This ensured that sampling occurred throughout all austral seasons and therefore, included any temporal variance within the whistle characteristics of common dolphins using Hauraki Gulf waters (Table 4). Survey effort was also spatially representative of common dolphin occurrence within the study site (Stockin *et al.* 2008a), with acoustic recordings collected in various water depths (14–48 m), thus covering a range of habitats. As such, any variance in vocalizations as a result of habitat use (Stockin *et al.* 2008a, 2009a) was reflected within the analyzed data set. However, whistle densities presented should be considered as best estimates of whistle number only. Inaccuracies in these counts are likely, especially during times of high vocal activity, as whistles often overlap each other and cannot always be clearly distinguished. Significant differences in the whistle density between traveling and feeding groups ( $T$ : 0.12 w/s,  $F$ : 1.61 w/s) also likely influenced the whistle parameters.

In the present study, there was no conclusive way to determine if whistle repetitions identified within the Hauraki Gulf population were signature whistles. This was because these whistles were recorded incidentally and no experimental protocol was carried out to synthesize and test whether a particular animal emitted the same whistle over time. Nonetheless, of the 20 whistle repetitions identified in the present study, 8 appeared in at least two different independent encounters (up to 15 mo apart). These data suggest there is a good possibility that during the field work that either (1) the same pod was encountered more than once or (2) some of the same dolphins occurred within different pods. The first explanation is plausible since previous research has indicated that common dolphins in the Hauraki Gulf exhibit site fidelity (Stockin 2008). The second hypothesis is also possible since common dolphins are known to live in fission–fusion societies (Bruno *et al.* 2004). A third alternative hypothesis is that these types of vocalization may be created by different individuals but within the same pod. While this is not reported within the literature for common dolphin, whistle imitation has been documented in bottlenose dolphins, *Tursiops truncatus* (Miksis *et al.* 2002). Regardless of the explanation, signature whistles can facilitate continued contact between individuals both within and between groups.

Assessing acoustic recordings in relation to observed behavior is problematic when dealing with a free-ranging, highly mobile delphinids. The analyses presented here for the Hauraki Gulf population are no exception. While captive studies often involve a single animal whose behavior can be directly correlated with vocalizations produced (*e.g.*, Caldwell and Caldwell 1968), the same cannot be said for studies examining wild populations. As such, this study attempted to understand whistle communication at the group level, since individual recognition was not possible. Nonetheless, common dolphins can form large groups (*e.g.*, Oswald *et al.* 2003, Rankin *et al.* 2008) and may be structured into subgroups (Stockin *et al.* 2008a). These subgroups often engage in distinct behaviors (Stockin *et al.* 2009a), which is why during the present study, only recordings of smaller pods (*ca.* 20–30 animals) not comprising of multiple subgroups were made. This enabled the focus to be on specific behaviors for which all focal group members were engaged. As only travel and forage states were recorded in isolation of other behaviors in the Hauraki Gulf population, only these states were compared in relation to recorded vocalizations.

Findings presented here suggest that the majority of whistle parameters examined in New Zealand common dolphins differ to those previously published for U.K. populations. Furthermore, unlike other populations, behavior does appear to affect the whistle characteristics of New Zealand common dolphins. However, our preliminary findings are restrictive to the Hauraki Gulf and therefore, additional research is

Table 4. Vocalization parameters in common dolphins from the Hauraki Gulf, New Zealand. Values given are means with the range shown in parentheses.

Whistle type	Duration (s)	Minimum frequency (Hz)	Maximum frequency (Hz)	Mean frequency (Hz)	No inflections (Hz)	No steps (Hz)	Gradient frequency (Hz)	Range frequency (Hz)	Traveling (%)	Foraging (%)
A	0.20 (0.01-1.35)	11,149.78 (4,095-21,902.30)	11,747.54 (4,095-21,913.30)	11,552.94 (4,095-2,509.90)	0.18 (0-5)	0.17 (0-2)	332.02 (-22,500-37,412.50)	597.76 (0-8,964.30)	5	8.8
B	0.23 (0.005-1.56)	11,541.50 (3,915-21,493.70)	13,671.72 (4,558.7-22,050)	12,601.53 (4,449.66-23,608.32)	0.29 (0-4)	0.04 (0-9)	12,032.86 (-9,684.40-12,8830)	2,130.21 (49.20-13,565.50)	23.3	25.8
C	0.26 (0.01-1.75)	11,535.52 (4,328.80-21,825)	14,104.37 (5,261.40-22,005.7)	12,786.03 (4,983.28-60,115.86)	0.42 (0-4)	0.03 (0-2)	11,835.98 (-10,9319.05-89,365.06)	2,568.86 (52.20-14,572.20)	61.8	42.5
D	0.40 (0.01-1.73)	11,440.24 (4,956.6-20,936.4)	14,520.86 (6,084.30-22,050)	12,902.23 (5,927.22-21,640.22)	1.08 (0-3)	0.01 (0-1)	14,69.55 (-27,426.09-8,578.47)	3,080.62 (98.40-12,044.5)	3.3	5.4
E	0.32 (0.01-1.29)	11,219.70 (4,419.40-21,607)	13,597.08 (6,174-22,050)	12,358.94 (5,472.54-21,695.60)	1.08 (0-6)	0.07 (0-2)	111.68 (-15,737.50-13,216.67)	2,377.39 (149.70-10,596.60)	3.3	9.3
F	0.55 (0.02-4)	10,732.72 (3,197.70-21,133.30)	14,301.97 (3,388.60-22,044.70)	12,477.21 (3,350.44-21,615.08)	2.44 (0-5)	0.02 (0-2)	323.41 (-20,801.89-23,779.02)	3,569.26 (98.20-10,506.5)	3.3	8.2

recommended on other *Delphinus* populations around New Zealand. Future studies should facilitate focal group follows and consider the role of group composition, associated species (e.g., Bryde's whales, *Balaenoptera brydei*) and boat traffic on common dolphin vocalizations. Since differences in the vocal repertoire of delphinids have been identified between year (Morisaka *et al.* 2005) and sex (Sayigh *et al.* 1995), future research should also aim to span multiple years and target nursery and bachelor pods independently. Finally, effort should be made to (1) obtain recordings from milling, resting and socializing groups and (2) collect vocalizations of foraging animals engaged within different strategies (e.g., line abreast, wall formation). This would allow for the examination of different behaviors and assessment of communication between individuals involved within specific foraging strategies.

#### ACKNOWLEDGMENTS

The authors thank the staff and crew of *Dolphin Explorer* and the late Stephen Stemberge for providing an observation platform. We also thank Mark Orams (AUT University) and Silvia Scali (University of Otago) for providing the hydrophone and technical assistance in the field. VP also thanks Dianne Brunton and Marianna Crispino for making this research a possibility in New Zealand. Aspects of this work were privately funded as well as supported by University of Naples and the Institute of Natural Sciences, Massey University. We dedicate this publication to the late Keith Algie—his interest and passion for the ocean chatter was notable.

#### LITERATURE CITED

- Altmann, J. 1974. Observational study of behavior: Sampling methods. *Behaviour* 49:227–267.
- Ansmann, I. C., J. C. Goold, P. G. H. Evans, M. P. Simmonds and S. G. Keith. 2007. Variation in the whistle characteristics of short-beaked common dolphins, *Delphinus delphis*, at two locations around the British Isles. *Journal of the Marine Biological Association of the United Kingdom* 87:19–26.
- Azevedo, A. F., and M. Van Sluys. 2005. Whistles of tucuxi dolphins (*Sotalia fluviatilis*) in Brazil: Comparisons among populations. *Journal of the Acoustical Society of America* 117:1456–1464.
- Bazua-Duran, C. 2004. Differences in the whistle characteristics and repertoire of bottlenose and spinner dolphin. *Anais da Academia Brasileira de Ciências* 76:386–392.
- Behrens, S. 2009. Bryde's whales (*Balaenoptera brydei*) in the Hauraki Gulf and the effects of vessel traffic. M.Sc. thesis, University of Auckland, Auckland, New Zealand. 97 pp.
- Boisseau, O. 2005. Quantifying the acoustic repertoire of a population: The vocalizations of free-ranging bottlenose dolphins in Fiordland, New Zealand. *Journal of Acoustical Society of America* 117:2318–2329.
- Bräger, S., and K. Schneider. 1998. Near-shore distribution and abundance of dolphins along the west coast of the South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 32:105–112.
- Bruno, S., E. Politi and G. Bearzi. 2004. Social organisation of a common dolphin community in the eastern Ionian Sea: Evidence of a fluid fission-fusion society. *European Research on Cetaceans* 15:49–51.
- Burgess, E. A. 2006. Foraging ecology of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. M.Sc. thesis, Massey University, Auckland, New Zealand. 143 pp.
- Caldwell, M. C., and D. K. Caldwell. 1968. Vocalization of naive captive dolphins in small groups. *Science* 159:1121–1123.



- Charif, R. A., C. W. Clarck and K. M. Fristrup. 2007. Raven Pro 1.3 user's manual. Cornell Laboratory of Ornithology, Ithaca, NY.
- Gaskin, D. E. 1968. The New Zealand Cetacea. New Zealand Fisheries Resources Laboratory Bulletin 1:1–92.
- Goold, J. C. 1996. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. Journal of the Marine Biological Association of the United Kingdom 76:811–820.
- Goold, J. C. 1998. Acoustic assessment of populations of common dolphin off the West Wales coast, with perspectives from satellite imagery. Journal of the Marine Biological Association of the United Kingdom 78:1353–1364.
- Goold, J. C. 2000. A diel pattern in vocal activity of short-beaked common dolphins, *Delphinus delphis*. Marine Mammal Science 16:240–244.
- Henderson, E. E., J. A. Hildebrand, M. H. Smith and E. A. Falcone. In press. The behavioral context of common dolphin (*Delphinus* sp.) vocalizations. Marine Mammal Science.
- Janik, V. M. 1999. Pitfalls in the categorization of behaviour: a comparison of dolphin whistle classification methods. Animal Behaviour 57:133–143.
- Lopez, B. D. 2010. Whistle characteristics in free-ranging bottlenose dolphins (*Tursiops truncatus*) in the Mediterranean Sea: Influence of behaviour. Mammalian Biology 76:180–189.
- Manighetti, B., and L. Carter. 1999. Across-shelf sediment dispersal, Hauraki Gulf, New Zealand. Marine Geology 160:271–300.
- Mann, J. 1999. Behavioral sampling methods for cetaceans: A review and critique. Marine Mammal Science 15:102–122.
- Miksik, J. L., P. L. Tyack and J. R. Buck. 2002. Captive dolphins, *Tursiops truncatus*, develop signature whistles that match acoustic features of human-made model sounds. Journal of the Acoustical Society of America 112:728–739.
- Moore, S. E., and S. H. Ridgway. 1995. Whistles produced by common dolphins from the Southern California Bight. Aquatic Mammals 21:55–63.
- Morisaka, T., M. Shinihara, F. Nakahara and T. Akamatsu. 2005. Geographic variations in the whistles among three Indo-Pacific bottlenose dolphin *Tursiops aduncus* populations in Japan. Fisheries Science 71:568–576.
- Neumann, D. R. 2001. The behavior and ecology of free-ranging short-beaked common dolphins (*Delphinus delphis*) on the east coast of the Coromandel Peninsula, North Island, New Zealand. Ph.D. thesis, Massey University, Auckland, New Zealand. 347 pp.
- Neumann, D. R., and M. B. Orams. 2003. Feeding behaviours of short-beaked common dolphins, *Delphinus delphis*, in New Zealand. Aquatic Mammals 29:137–149.
- Oswald, J. N., J. Barlow and T. F. Norris. 2003. Acoustic identification of nine delphinid species in the eastern tropical Pacific Ocean. Marine Mammal Science 19:20–37.
- Oswald, J. N., S. Rankin, J. Barlow and M. O. Lammers. 2007. A tool for real-time acoustic species identification of delphinid whistles. Journal of the Acoustical Society of America 122:587–595.
- Rankin, S., J. Barlow, J. Oswald and L. Ballance. 2008. Acoustic studies of marine mammals during seven years of combined visual and acoustic line transect surveys for cetaceans in the eastern and central Pacific Ocean. Southwest Fisheries Science Center Technical Memorandum NOAA-TM-NMFS-SWFSC-429. 59 pp.
- Rendell, L., J. Matthews, A. Gill, J. C. D. Gordon and D. W. Macdonald. 1999. Quantitative analysis of tonal calls from five odontocete species, examining interspecific and intraspecific variation. The Zoological Society of London 249:403–410.
- Richardson, W. J., C. R. Green, Jr., C. I. Malme and D. H. Thomson. 1995. Marine mammals and noise. Academic Press, London, U.K.
- Sayigh, L. S., P. Tyack, R. S. Wells, M. D. Scott and A. B. Irvine. 1995. Sex differences in signature whistle production of free-ranging bottlenose dolphins, *Tursiops truncatus*. Behavioral Ecology 36:171–177.

- Soldevilla, M. S., E. E. Henderson, G. S. Campbell, S. M. Wiggins, J. A. Hildebrand and M. A. Roch. 2008. Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks. *Journal of the Acoustic Society of America* 124:609–624.
- Stockin, K. A. 2008. The New Zealand common dolphin (*Delphinus* sp.)—Identity, ecology and conservation. Ph.D. thesis, Massey University, Auckland, New Zealand. 235 pp.
- Stockin, K. A., and M. B. Orams. 2009. The status of common dolphins (*Delphinus delphis*) within New Zealand waters. Report of the Scientific Committee of the Sixty-First International Whaling Commission. Madeira, Portugal. SC/61/SM20.
- Stockin, K. A., R. J. Law, P. J. Duignan, et al. 2007. Trace elements, PCBs and organochlorine pesticides in New Zealand common dolphins (*Delphinus* sp.). *The Science of the Total Environment* 387:333–345.
- Stockin, K. A., G. J. Pierce, V. Binedell, N. Wiseman and M. B. Orams. 2008a. Factors affecting the occurrence and demographics of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Aquatic Mammals* 34:200–211.
- Stockin, K. A., D. Lusseau, V. Binedell, N. Wiseman and M. B. Orams. 2008b. Tourism affects the behavioral budget of the common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Marine Ecology Progress Series* 355:287–295.
- Stockin, K. A., V. Binedell, N. Wiseman, D. H. Brunton and M. B. Orams. 2009a. The behavior of free-ranging common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Marine Mammal Science* 25:283–301.
- Stockin, K. A., P. J. Duignan, W. D. Roe, L. Meynier, M. Alley and T. Fetterman. 2009b. Causes of mortality in stranded common dolphins (*Delphinus* sp.) from New Zealand waters between 1998 and 2008. *Pacific Conservation Biology* 15:217–227.
- Webb, B. F. 1973. Cetaceans sighted off the West coast of the South Island, New Zealand, summer 1970. *New Zealand Journal of Marine and Freshwater Research* 7:179–182.
- Wiseman, N., S. Parsons, K. A. Stockin and C. S. Baker. 2011. Seasonal occurrence and distribution of Bryde's whales in the Hauraki Gulf, New Zealand. *Marine Mammal Science*. doi:10.1111/j.1748-7692.2010.00454.x
- Zar, J. H. 1996. *Biostatistical analysis*. Third edition. Prentice-Hall International (UK) Ltd., London, U.K.

Received: 14 August 2010

Accepted: 29 March 2011