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FIRST DESCRIPTION OF WHISTLES OF PACIFIC FRASER'S DOLPHINS *LAGENODELPHIS HOSEI*

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ABSTRACT

Acoustic recordings were made in the presence of four single-species schools of Fraser's Dolphin *Lagenodelphis hosei* during combined acoustic and visual shipboard line-transect cetacean abundance surveys. Recordings were made using a towed hydrophone array and sonobuoys. Echolocation clicks were detected during only one recording session and no burst pulses were detected. Whistles were present in all four recording sessions. Fourteen variables were measured from the fundamental frequencies of 60 whistles. The whistles were generally simple, with few inflection points or steps. Whistles ranged from 6.6 kHz to 23.5 kHz, with durations ranging from 0.06 to 0.93 sec. Whistle characteristics closely match those reported for *L. hosei* recorded in the Gulf of Mexico (Leatherwood *et al.* 1993) and the Caribbean (Watkins *et al.* 1994), although, in general, the Pacific dolphins were less vocally active than the Caribbean dolphins described by Watkins *et al.* (1994). This difference may be related to the orientation of the hydrophone array relative to the dolphins. It may also be due to behaviour, as the Caribbean dolphins were engaged in feeding activities and the Pacific dolphins were fast travelling to evade the approaching vessel.

Keywords: whistles, *Lagenodelphis hosei*, tropical Pacific

INTRODUCTION

Fraser's Dolphin *Lagenodelphis hosei* was first described in 1956 from the skeleton of a stranded animal in the South China Sea (Perrin *et al.* 1994). Scientific description of the species based on live animals was not made until 1971, when nearly concurrent sightings of *L. hosei* were made in three locations worldwide (Perrin *et al.* 1973). *L. hosei* is a tropical offshore species, with a distribution ranging from 30ºN to 30ºS in the Pacific, Atlantic, and Indian Oceans (Rice 1998). They are generally found in large schools and are often associated with other species, especially the Melon-headed Whale *Peponocephala electra* (Au & Perryman 1985).

Few published reports of observations of free-ranging *L. hosei* exist (Jefferson & Leatherwood 1993; Perrin *et al.* 1994), and information on their vocalizations is rarer still. Vocalizations of *L. hosei* have been described based on one recording session that took place in the Gulf of Mexico in 1992 (Leatherwood *et al.* 1993) and two recording sessions that took place in the Caribbean in 1991 (Watkins *et al.* 1994). The eight whistles recorded from *L. hosei* in the Gulf of Mexico were found to be either short duration (0.2 sec) whistles centred at approximately 12 kHz, or longer whistles (0.4–0.5 sec) centred between 7 and 14 kHz (Leatherwood *et al.* 1993). The 166 whistles analyzed from the Caribbean recording sessions had fundamental frequencies between 4.3 kHz and 24 kHz and an average duration of 0.77sec (Watkins *et al.* 1994). Watkins *et al.* (1994) also noted that most recordings contained overlapping sequences of whistles. Many of the whistles were repeated in stereotyped fashion, and an increase in surface behaviour was often associated with an increase in whistle production (Watkins *et al.* 1994). Echolocation clicks were detected during the Gulf of Mexico recording; however, the limited bandwidth of the recordings precluded examination of these sounds (Leatherwood *et al.* 1993). Click trains associated with echolocation were detected during both Caribbean recordings, where animals were observed herding large schools of fish (Watkins *et al.* 1994). No burst pulses were reported in either study.

Leatherwood *et al.* (1993) and Watkins *et al.* (1994) both describe sounds produced by Atlantic *L. hosei*. To our knowledge, there have been no published descriptions of the vocalizations of Pacific *L. hosei*. This paper provides a description of the whistles produced by *L. hosei* recorded from four single-species schools in the central and eastern tropical Pacific Ocean.

METHODS

Recordings were made during three different shipboard line-transect surveys in the tropical Pacific Ocean conducted by the Southwest Fisheries Science Center (NOAA, NMFS). The Stenella Population Assessment and Monitoring (SPAM 1998) and Stenella Abundance Research (STAR 2003) surveys were designed to study cetacean populations impacted by the tuna purse-seine fishery in the eastern tropical Pacific Ocean (ETP). The Pacific Islands Cetacean Ecosystem Assessment Survey (PICEAS 2005) was focused on cetacean populations surrounding Johnston and Palmyra Atolls, 800 nmi south of the Hawaiian Islands. During all surveys, a team of three experienced biologists actively searched for marine mammals using two sets of 25x150 binoculars and near-field observation by naked eye. When cetaceans were sighted, they were approached for species identification and group size estimation. *L. hosei* are visually identified based on their body shape and complex coloration. This small delphinid species has a robust body shape with a short beak and very small, dark appendages. They are blue-gray dorsally and light pink ventrally. A single, broad, dark flank stripe runs from the beak and eye to the anus and an additional faint stripe runs from the lower jaw to the flipper (Leatherwood *et al.* 1988).

Cetacean vocalizations were monitored and recorded using a towed hydrophone array and U.S. Navy surplus type 57A sonobuoys. The array was towed 200 m behind a 68 m or 56 m research vessel at a depth of approximately 4–6 m during all daylight hours on all three surveys. Characteristics of the three arrays used during these surveys are given in Table 1. During the SPAM survey, signals were recorded onto digital audio tape (DAT) using Sony TCD-D7 and TCD-D8 DAT recorders (sampling rate = 48 kHz). During the STAR and PICEAS surveys, signals from the array were sent through a Mackie CR1604-VLZ mixer for equalization and an Avens Model 4128 bandpass filter for anti-aliasing. The sounds were then recorded directly to a computer hard drive using a 200 kHz sampling rate. Additionally, during the STAR survey, Navy surplus type 57A sonobuoys (flat frequency response approximately 10 Hz to 20 kHz) were deployed from the ship in close proximity to dolphins. Signals from the sonobuoys were transmitted to the ship via radio frequency, received by an ICOM R100 radio receiver in the acoustics lab, and recorded to a Sony TCD-D7 DAT recorder (sampling rate = 48 kHz).

Only recordings of groups that had been seen and identified by experienced visual observers were included in the analysis. To ensure that the whistles being recorded were produced by the dolphins being observed, only whistles that were at least 9 dB above the background noise in the spectrogram were analyzed. These 'loud and clear' whistles were assumed to be produced by the animals being observed close to the ship and not more distant animals that may have been in the area. In addition, with one exception, recordings were only included if there were no other dolphins sighted within at least 3 nmi of the dolphins being observed. An exception was made for one recording session during the PICEAS survey (sighting number 101, Table 2). When this recording was made there was a group of *P. electra* in the area. The recording was included in the analysis, however, because during the PICEAS survey, whistles were localized using a beamforming algorithm in the spectrographic software application ISHMAEL (Mellinger 2001). The two species in the area were in very different locations relative to the ship, which made it possible to match the source of each whistle to the location of the *L. hosei* and rule out the possibility that they were produced by the *P. electra*.

Loud and clear whistles that did not overlap extensively with other whistles were chosen for analysis. In order to be of sufficient

TABLE 1

Characteristics of hydrophone arrays used and sampling rates of recordings made during the SPAM 1998, STAR 2003 and PICEAS 2005 marine mammal abundance surveys. The array used during the PICEAS survey had 4 elements, 3 relatively narrowband and 1 relatively broadband.

Cruise	# Hydrophone elements	Flat frequency response (re 1v/μPa)	Manufacturer	Sampling rate (kHz)
SPAM	5	500 Hz to 150 kHz at –163 dB ±3 dB	SonaTech Inc., Santa Barbara	48
STAR	3	500 Hz to 30 kHz at –155 dB ±5 dB	Built in-house	200
PICEAS	3	1 kHz to 40 kHz at –150 dB ±5 dB	Built in-house	200
	1	2 kHz to 150 kHz at –166 dB ±2 dB	Seiche Measurements, Ltd., Devon, UK	200

TABLE 2

Date, location, and group size for all *Lagenodelphis hosei* groups encountered during SPAM 1998, STAR 2003, and PICEAS 2005 marine mammal abundance surveys. Sighting number is the identification number assigned to the encounter. Group size is the mean of the best estimates made by all biologists who observed the encounter. Other species refers to additional species seen in the group. Observation time refers to the amount of time spent observing the school visually and/or acoustically. Recording time refers to the length of recordings analyzed. Number of whistles refers to the number of whistles that were of sufficient quality to be included in the analysis.

Cruise	Date	Sighting number	Latitude	Longitude	Group size	Other species	Observation time (minutes)	Recording time (minutes)	# Whistles
SPAM	8/16/1998	104	N 01:30.17	W 129:35.37	299	unidentified dolphin species	120	n/a	n/a
	8/19/1998	113	N 06:59.32	W 136:59.10	42	no	73	73	7
	9/6/1998	143	N 05:29.23	W 146:37.59	475	*Peponocephala electra*	43	n/a	n/a
STAR	10/17/2003	401	S 09:32.69	W 099:45.22	60	no	65	46	10
PICEAS	8/22/2005	101	N 3:11.14	W 163:47.69	222	no	120	52	15
	8/25/2005	130	N 6:56.41	W 161:07.74	186	no	35	95	28

quality for analysis, the entire whistle contour must be clearly visible on the spectrogram. Whistle contours were extracted and measurements were made using custom Matlab software (M. Lammers, J. Oswald) which extracts whistle contours from wav files by stepping through files one window at a time (FFT window size = 1024 points, window overlap = 0.25). The fundamental frequency of the whistle contour was selected based on the peak frequency in each window, and the software included a routine to ensure that random transient peaks in the spectrum were not mistaken for the fundamental peak frequency. When the whistle contour had been extracted, the software automatically measured fourteen variables from the fundamental, including: 1) centre frequency (kHz), 2) start frequency (kHz), 3) end frequency (kHz), 4) minimum frequency (kHz), 5) maximum frequency (kHz), 6) frequency range (kHz, maximum frequency minus minimum frequency), 7) duration (sec), 8) number of steps (defined as a 10% or greater change in frequency over two contour points), 9) number of inflection points (defined as a change from positive to negative or negative to positive slope), 10) mean slope (kHz/sec), 11) percent upswept (percent of whistle with positive slope), 12) percent downswept (percent of whistle with negative slope), 13) percent flat (percent of whistle with zero slope, where zero slope is defined as a 1% or smaller change in slope over two contour points), and 14) presence/absence of harmonics (binary variable). Measurements of relative energy in harmonics were not taken due to the low amplitude of many of the whistles that were analyzed. Whistles recorded during the SPAM 1998 and STAR 2003 surveys were analyzed with an upper bandwidth limit of 24 kHz (due to equipment constraints) and whistles recorded during the PICEAS 2005 survey were analyzed with an upper bandwidth limit of 100 kHz.

RESULTS

A hydrophone array was towed for approximately 17,980 km during the SPAM 1998 survey (31 July to 9 December 1998, Figure 1), 9,274 km during the STAR 2003 survey (7 October to 10 December 2003, Figure 1), and 15,183 km during the PICEAS 2005 survey (28 June to 12 November 2005, Figure 1). Due to weather conditions, the hydrophone array was not deployed on 16–17 October 2003. U. S. Navy sonobuoys were opportunistically deployed on dolphin sightings during this time.

A total of six schools of *L. hosei* were sighted during the three surveys (Table 2, Figure 1). Of these sightings, four were single-species schools, one was a school composed of *L. hosei* and *P. electra*, and one was a school composed of *L. hosei* and an unidentified dolphin species (possibly *Stenella coeruleoalba*). Recordings were obtained from all four

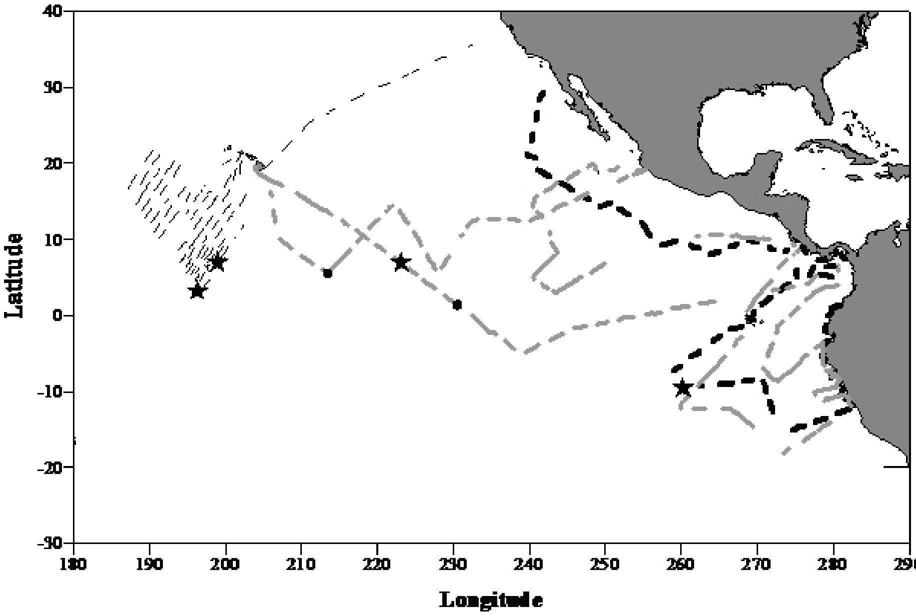
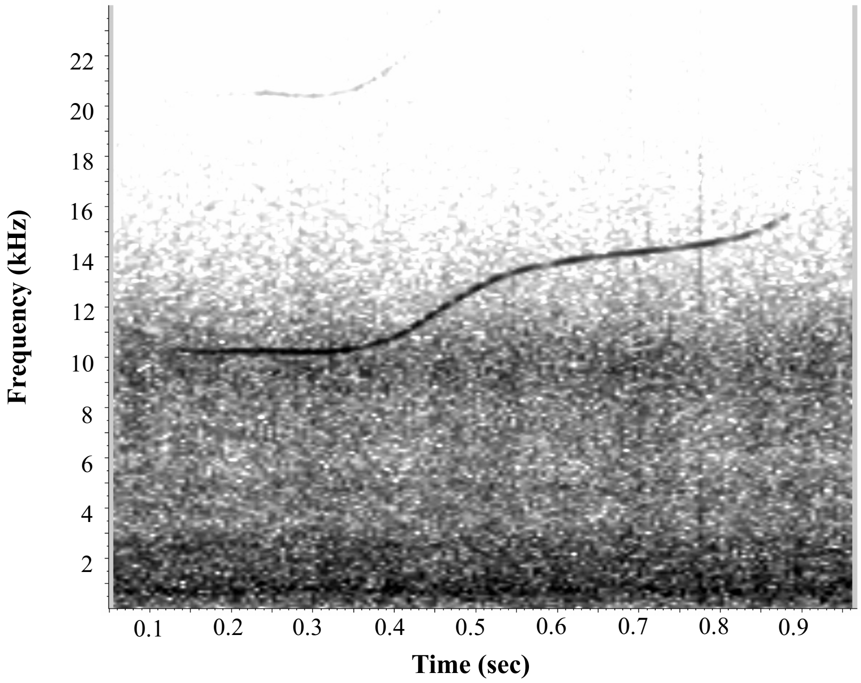
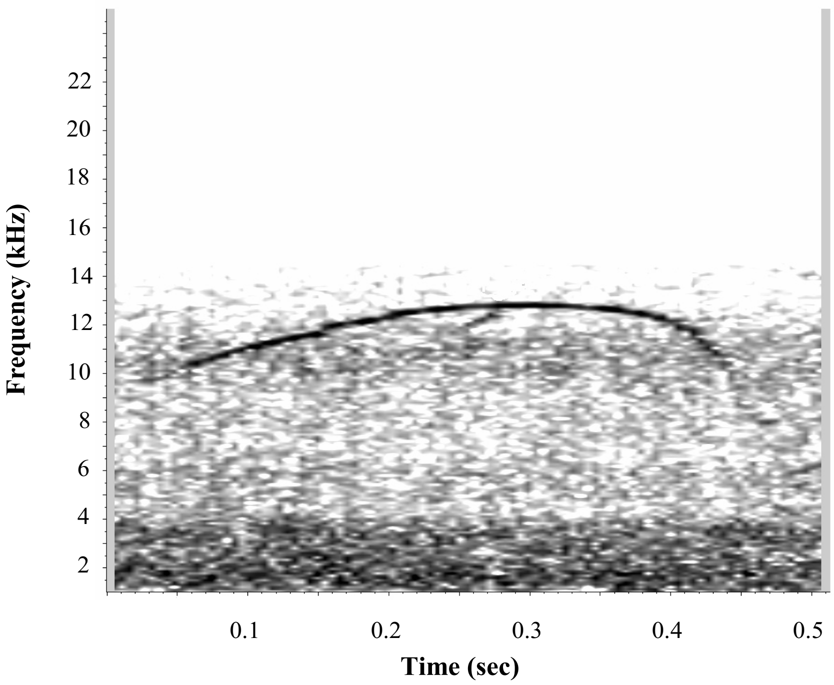


Figure 1. Acoustic survey effort for SPAM 1998 (thick gray lines), STAR 2003 (thick black lines) and PICEAS 2005 (thin lines). Stars represent visual and acoustic detections of single-species schools of *Lagenodelphis hosei*. Circles represent visual and acoustic detections of mixed-species schools containing *Lagenodelphis hosei*.

of the single-species schools. Recordings made during SPAM 1998 and PICEAS 2005 were made using a towed hydrophone array. Recordings made during STAR 2003 were made using a sonobuoy. The schools observed were large, ranging from 60 to 475 individual dolphins. All of the schools exhibited evasive behaviour when approached by the research vessel. Observations lasted from 35 minutes to 2 hours for each school (Table 2).

Relatively few vocalizations were detected during the four single-species recording sessions. Echolocation clicks were detected only during the SPAM 1998 recording session. These clicks had very low signal-to-noise ratios and thus could not be analyzed. No burst pulses were detected in any of the recordings. A total of 60 whistles were analyzed from the four recording sessions (Table 2). Descriptive statistics for these whistles, as well as the whistles analyzed by Watkins *et al.* (1994) and Leatherwood *et al.* (1993) are given in Table 3. The Pacific whistles were generally simple, with few inflection points or steps. The overall mean slope of the whistles was positive (5.9 kHz/sec, SD = 9.7 kHz/sec), and 40% of whistles had a positive slope for 80% or greater of their duration. Only 3.3% of whistles had a negative slope for at least 80% of their duration. Fundamental frequencies ranged from 6.6 kHz to 23.5 kHz. The fundamental frequency range of


Frequency (kHz)
22
20
18
16
14
12
10
8
6
4
2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Time (sec)


Frequency (kHz)
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0.2
0.3
0.4
0.5
Time (sec)

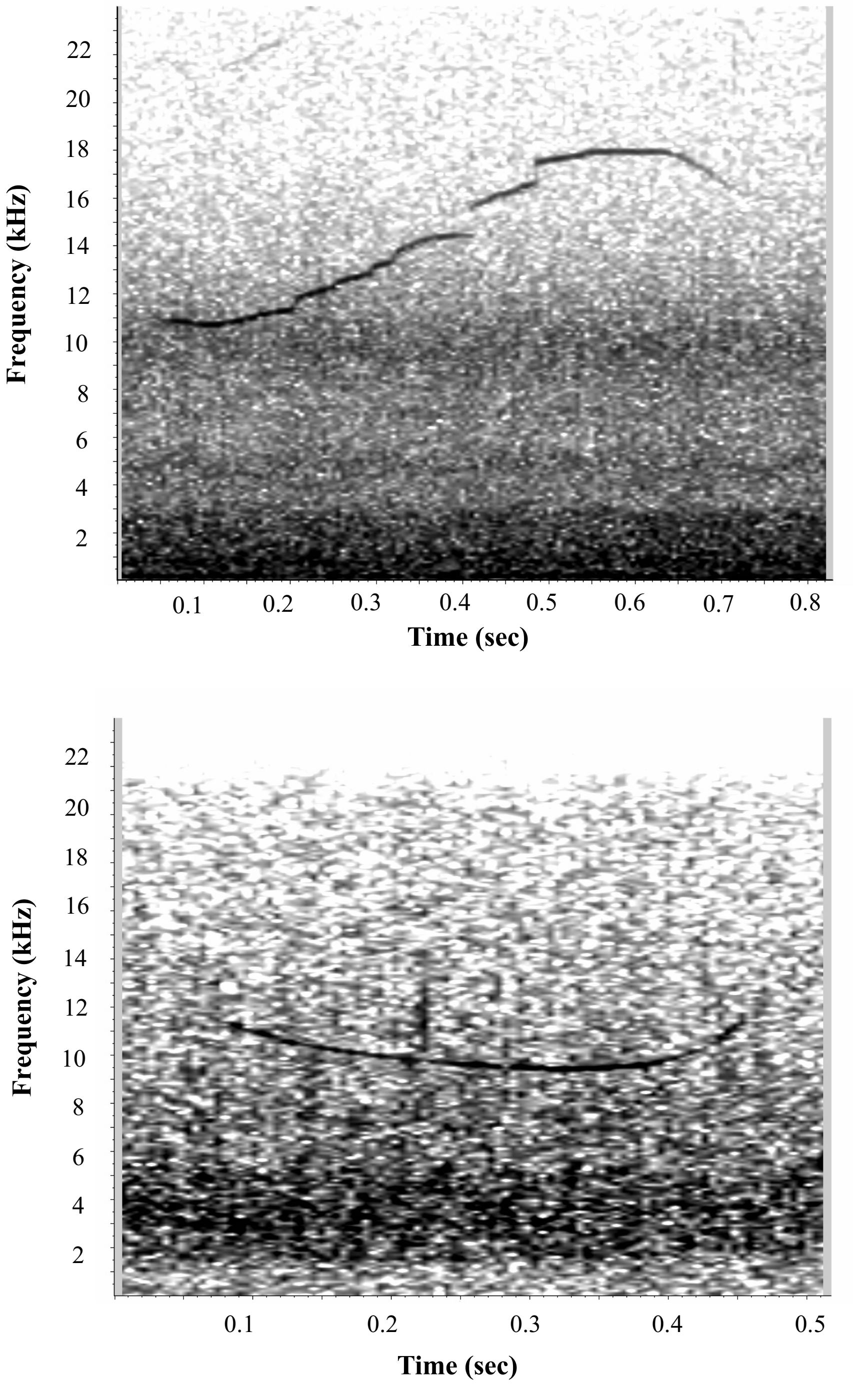

Figure 2. Spectograms of *Lagenodelphis hosei* whistles recorded in the tropical Pacific Ocean (512 point FFT, Hanning window).

TABLE 3

Descriptive statistics for variables measured from whistles recorded from *Lagenodelphis hosei* in the tropical Pacific Ocean (n = 60, current study), the Caribbean (n = 166, Watkins *et al.* 1994), and the Gulf of Mexico (n = 8, Leatherwood et al. 1993). Means with standard deviations and ranges are given for Pacific whistles. Only means were available for Caribbean whistles. Means were not available for Gulf of Mexico whistles and therefore only ranges are presented. 'Flat' was defined as a 1% or smaller change in slope over two contour points.

	Frequency (kHz)						Duration		# Inflection	Mean slope			
	Centre	Start	End	Min	Max	Range	(sec)	#Steps	points	(kHz/s)	% Up	% Down	% Flat
Pacific mean	13.0	11.9	13.9	11.0	14.9	3.9	0.46	0.7	0.8	5.9	67.3	23.7	8.9
	±12.9	±2.9	±3.5	±2.3	±0.23	±1.2	±0.7	±1.2	±0.7	±9.7	±30.4	±27.9	±12.9
Pacific range	7.0–18.4	7.5–18.8	8.3–23.5	6.6–18.3	8.3–23.5	0.1–9.6	0.06–0.93	0.0–8.0	0.0–3.0	−19.8–35.8	0.0–100.0	0.0–100.0	0.0–66.7
Caribbean mean	–	11.9	13.1	9.4	16.9	–	0.77	–	–	–	–	–	–
Gulf of Mexico range	7.6–13.4	–	–	–	–	–	0.2–0.5	–	–	–	–	–	–

individual whistles however, was relatively narrow (mean = 3.9 kHz, SD = 2.3 kHz), and was centred at 13 kHz (SD = 2.7 kHz). Duration ranged from 0.06 to 0.93 sec. Harmonics were present in only 10% of the measured whistles. Some examples of whistles included in the analysis are shown in Figure 2.

DISCUSSION

This study represents the first description of the whistles of *L. hosei* in the Pacific Ocean. These whistles closely resemble those recorded in the Caribbean (Watkins *et al.* 1994) and the Gulf of Mexico (Leatherwood *et al.* 1993). Mean start and end frequencies of the fundamentals of the Pacific Ocean whistles were remarkably similar to those reported for the Caribbean by Watkins *et al.* (1994), and mean duration was within the range reported by Leatherwood *et al.* (1993) for whistles recorded in the Gulf of Mexico. Unfortunately, measures of variance were not provided for the Caribbean or Gulf of Mexico whistles, so it was not possible to perform a statistical comparison of whistles recorded in the three study areas.

The major difference between the recordings described by Watkins *et al.* (1994) and those described here is that Watkins *et al.* (1994) reported 'considerable underwater sound production', including many overlapping whistles as well as echolocation clicks. Despite the fact that the research vessel was able to approach to within 500 m of all four schools that were recorded for the current study, and within 100 m of one school, most of the recordings contained few whistles. There were very few echolocation clicks detected and both the echolocation clicks and many of the whistles had relatively low signal-to-noise ratios. One of the recordings made during the PICEAS 2005 survey (sighting 130, Table 2) contained a brief period of high vocal activity which including overlapping whistles but many of these whistles also had relatively low signal-to-noise ratios.

This difference in vocal activity is likely related to two factors. The first is the constant manoeuvring of the ship required for the approach and observation of evasive dolphin schools. This manoeuvring inevitably keeps the dolphins directly ahead of the bow of the ship for the bulk of the encounter. The towed hydrophone array has decreased sensitivity to sounds forward of the ship due to the sensitivity of the cylindrical hydrophone elements and to masking by ship noise. Therefore, fewer sounds from directly ahead of the ship will be clear enough for detection and measurement. The addition of a bow-mounted hydrophone to the ship could reduce or eliminate this problem. This factor did not affect the recordings made during STAR 2003, as these recordings were made using a sonobuoy. In this case, the sonobuoy was dropped in close proximity to the dolphins and the ship moved away while monitoring signals being detected by the sonobuoy.

A second factor that may explain the observed differences in vocal activity is group behaviour. The high level of vocal activity reported by Watkins *et al.* (1994) occurred while the dolphins were driving, circling, and catching fish. There was an observed increase in the production of clicks during fish herding behaviour and an increase in whistle production after fish herding behaviour. During travel, few whistles or clicks were detected. One of the recordings presented in the current study (PICEAS 2005 sighting 130) contained a brief period of relatively high vocal behaviour near the beginning of the encounter. At this time, the dolphins were observed in a loosely aggregated school and many leaps and splashes were noted. When the ship turned towards the dolphins they changed their behaviour to fast travel away from the ship and their vocal activity decreased. This is consistent with Watkins *et al.*'s (1994) observation of an increase in vocal activity with increased surface activity and a decrease in vocal activity during travel. The other three groups that were recorded during the current study were initially travelling or milling and exhibited a marked change in behaviour to fast travel away from the ship as the ship changed course to approach them. Fast travel away from the ship appeared to be an effort to evade the ship. The paucity of vocalizations detected in these situations suggests the dolphins may have perceived an immediate threat and tended towards silence in order to avoid detection. These observations are also consistent with Watkins *et al.*'s (1994) observation of very few vocalizations during travel.

Lagenodelphis hosei is a poorly understood species. Live specimens had not been observed until the 1970s (Perrin *et al.* 1973) and sightings have been rare during cetacean surveys ever since. Despite significant survey effort (over 11 months and 42,000 km), only six groups of *L. hosei* were sighted during the three surveys discussed here. An understanding of the vocalizations produced by species such as *L. hosei* can lead to the ability to acoustically identify this species during shipboard acoustic surveys (Oswald *et al.* 2005; Oswald *et al.* 2003). Acoustic identification of dolphin vocalizations will also allow for an examination of temporal and spatial distribution of species using seafloor-mounted hydrophones. The recordings obtained during these surveys therefore represent an important step forward in the endeavour to gain knowledge about this seldom-observed species. Future studies should include broadband recordings of *L. hosei* in different behaviour states and incorporation of their whistle characteristics into acoustic species identification programs.

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REFERENCES

Au, D. W. K. & Perryman, W. L. (1985). Dolphin habitats in the eastern tropical Pacific. *Fish. Bull.*, **83**, 623-643.

Jefferson, T. A. & Leatherwood, S. (1994). Lagenodelphis *hosei*. *Mammalian Species*, **470**, 1-5.

Leatherwood, S., Jefferson, T. A., Norris, J. C., Stevens, W. E., Hansen, L. J. & Mullin, K. D. (1993). Occurrence and sounds of Fraser's dolphins in the Gulf of Mexico. *Tex. J. Sci.*, **45**, 349-354.

Leatherwood, S., Reeves, R. R., Perrin, W. F. & Evans, W. E. (1988). *Whales, dolphins, and porpoises of the eastern north Pacific and adjacent Arctic waters*. New York: Dover Publications, Inc.

Mellinger, D. K. (2001). *Ishmael 1.0 User's Guide*. NOAA Technical Memorandum OAR PMEL-120, available from NOAA/PMEL, 7600 Sand Point Way, NE, Seattle, USA.

Oswald, J. N., Barlow, J. & Norris, T. (2003). Acoustic identification of nine delphinid species in the eastern tropical Pacific ocean. *Mar. Mamm. Sci.*, **19**, 20-37.

Oswald, J. N., Rankin, S., Barlow, J. & Lammers, M. (2005). A new tool for real-time acoustic species identification of delphinid whistles. *J. Acoust. Soc. Am.*, **118**, 1909.

Perrin, W. F., Best, P. B., Dawbin, W. H., Balcomb, K. C., Gambell, R. & Ross, G. J. B. (1973). Rediscovery of Fraser's dolphin *Lagenodelphis hosei*. *Nature*, **241**, 345-350.

Perrin, W. F., Leatherwood, S. & Collet, A. (1994). Fraser's dolphin *Lagenodelphis hosei* Fraser, 1956. In *Handbook of Marine Mammals, Vol. 5* (Ed. by S. H. Ridgway & S. R. Harrison), pp. 166-168. London: Academic Press.

Rice, D. W. (1998). *Marine mammals of the world: systematics and distribution*. Society for Marine Mammalogy, Special Pub. Number 4, Lawrence, Kansas.

Watkins, W. A., Daher, M. A., Fristrup, K. & Notarbartolo di Sciara, G. (1994). Fishing and acoustic behavior of Fraser's dolphin (*Lagenodelphis hosei*) near Dominica, Southeast Caribbean. *Caribbean J. Sci.*, **30**, 76-82.

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