ACOUSTIC SIGNALS FROM FREE-RANGING FINLESS PORPOISES (*NEOPHOCAENA PHOCAENOIDES*) IN THE WATERS AROUND HONG KONG

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ABSTRACT. – Acoustic signals from free-ranging finless porpoises were recorded in the waters around Hong Kong during March 2000. Finless porpoises produced short-duration high-frequency clicks. Signal analysis showed finless porpoise clicks to be both "typical" phocoenid sounds, i.e. narrowband, high frequency ultrasonic pulses, and "atypical" broadband pulses with sharp onsets. Peak energy in the narrowband porpoise click spectrum occurred at 142 kHz, with negligible energy below 100 kHz. Energy was more diffuse in the spectra of broadband clicks, with a tendency towards higher frequencies. Mean pulse duration of narrowband clicks was 104 microseconds, whereas mean pulse duration of broadband clicks was 61 microseconds. Generally, finless porpoise clicks were inaudible to the human ear, except on occasion when faint, but distinct, pulses were heard from animals close to the hydrophone.

KEY WORDS. – Porpoise, finless porpoise, *Neophocaena phocaenoides*, acoustic, bioacoustic, echolocation, click, sonar, ultrasonic, narrowband, broadband, Hong Kong.

INTRODUCTION

Porpoises typically use high-frequency, narrowband ultrasonic clicks for echolocation and food finding. They are ultrasonic specialists and the characteristics of their emitted sounds are such that they are seldom audible to the human ear. The harbour porpoise (*Phocoena phocoena*) is known to produce narrowband echolocation pulses with peak energy at approximately 120 kHz (Mohl & Anderson, 1973; Verboom & Kastelein, 1995; Kastelein et al., 1999) and it is the concentration of energy into such a narrow, high frequency band that generally makes them inaudible to human hearing. Unlike delphinids, which typically produce sharp onset, broadband echolocation pulses that span both the audible and ultrasonic spectrum, the porpoise click is a fairly pure ultrasonic tone, that is smoothly 'enveloped' into a short pulse. This enveloping progressively ramps the signal amplitude up to maximum, without creating a sharp waveform discontinuity, that would otherwise lead to a broadband signature such as is typical in dolphin clicks.

Data exist of finless porpoise vocalisations from animals in captivity (Mizue et al., 1968; Wang, 1996; Kamminga et al., 1996; Nakahara et al., 1997) and in semi-natural environments (Pilleri et al., 1980; Akamatsu et al., 1998). Most findings were limited by the equipment used, (i.e. tape recorders with primarily audio capabilities). The early studies indicated that finless porpoises produce low frequency pulses (clicks) and some time-continuous type signals. Later studies made with ultrasonic recording equipment indicated that finless porpoises produce typical phocoenid clicks, with narrowband ultrasonic pulse characteristics and less emphasis on low frequency components. There are no substantive data on acoustic signals from truly free-ranging finless porpoises. This report documents and describes the acoustics of free-ranging finless porpoise in the waters around Hong Kong.

METHODS

Data Collection. – During March 2000, underwater acoustic recordings were made of finless porpoises during a series of ongoing line-transect surveys conducted by the Ocean Park Conservation Foundation (OPCF) (Jefferson et al., 2002). Line transect surveys were conducted from a 15m, diesel powered vessel, typically travelling at 13-15 km/h during surveys. Underwater sound recordings were made through a custom built, 50m towed hydrophone deployed from the stern of the vessel during the period of this acoustic study. The hydrophone unit enclosed a half inch ceramic ball and pre-amplifier, which passed acoustic signals up the tow cable

to the boat. Hydrophone frequency response was flat ±3 dB from 4 kHz to 200 kHz, and the signal output was split into two channels onboard ship. One channel was used for audio monitoring/recording on a Sony TCD-D7 digital audio tape recorder (DAT), the other channel was used for ultrasonic recording via solid state sampler to computer disk. The audio channel signal was high-pass filtered at approximately 3 kHz, using a custom built 2nd order active high pass filter, to reduce ship, engine and flow noise on the tape recording. The audio channel served as a useful indicator of the general underwater acoustic environment, but was not expected to capture porpoise clicks, due to the limited recording bandwidth of the system. The ultrasonic channel was filtered at a higher frequency with a separate custom built 2nd order high pass filter, set to roll off below approximately 50 kHz to prevent dynamic range saturation of the recording system from lower frequency noise. This configuration was designed to capture signals in the expected range for finless porpoises (i.e., 100-150 kHz), but with sufficient bandpass to enable recording of signal components within approximately one octave either side of the expected peak.

The filtered ultrasonic signal was digitised at 500 kHz sample rate using an IOTech Wavebook 512 and recorded directly as digital data onto a laptop computer hard disk. The Wavebook acts as a high speed, 12 bit A/D converter, which then passes the sampled wavedata to the computer via a PCMCIA slot. Data recording takes place on the hard disk, which is the ultimate limitation to the system storage capacity, but at high sample rates memory buffering takes place in RAM, which is the proximate limitation in terms of continuous recording capacity. The sample rate chosen (500 kHz) allowed signal components up to 250 kHz to be captured, and was considered adequate to record the essential features expected of finless porpoise clicks, with considerable additional bandwidth for unexpected components. Due to the rapid sampling rate; a finite amount of space on the computer disk; the need to create manageable file sizes; and the intensive task of sifting and analysing the waveform data, it was not feasible to perform continuous recording on the ultrasonic channel. Instead, recordings were only made when finless porpoises were spotted visually in the immediate vicinity of the vessel. In order to maintain manageable file sizes, recordings were made in 10 sec bursts, activated manually at the computer console in conjunction with visual cues from the cetacean observers on the upper deck.

Data Analysis. – Captured digital waveform data were imported into MATLAB for analysis. A user written MATLAB program scanned the data channel for waveform values exceeding a threshold level set above the ambient background noise amplitude. Sections of waveform selected and marked by the threshold scanning program, were displayed and the user accepted or rejected the segment depending upon whether the data were judged to be a porpoise click or a noise spike.

Sequential click markers generated in this way enabled easy recall of individual clicks for further examination. Pulse durations were measured manually for clicks with high signal to noise ratio, using pulse start-stop boundary markers in the waveform channel under interactive user control via keyboard. The start and stop points of each pulse were defined as the points at which the pulse oscillations rose from, and descended into, the background noise amplitude. The boundary markers were moved in steps of 1 sample point (2 microseconds), and high signal to noise ratio clicks were chosen to reduce measurement errors. However, we acknowledge the slightly subjective nature of the measurements, and the fact that background noise cannot be completely eliminated, so we do not claim a precision of measurement to 1 sample point. That said, the difference in pulse shape and duration is substantial and quite evident from mere visual inspection, hence we have confidence in our measurements. Frequency domain characteristics of porpoise clicks were obtained by running spectral density analysis on sequential clicks within selected file sequences. Spectral values of sequential clicks were stored in matrices and subsequently displayed as 3-dimensional waterfall spectra, giving a click by click illustration of their spectral characteristics. The frequencies at which peak energy occurred in the click spectra were measured by using a peak-seeking program to determine the position of the highest peak in each spectral slice. The program keyed on the highest value in each spectral slice and then found the point on the frequency axis to which that value corresponded.

RESULTS

Acoustic signals from finless porpoises were successfully captured during line-transect encounters on 21 and 28 March (Table 1 & Fig. 1). The vessel made slow circles of the area and numerous close passes to small sub-groups of animals, while repeated recordings were made on the Wavebook system. A total of 161 file sequences from the 21 March encounter were viewed and marked, and a sub-set of these were further analysed (i.e., spectra, pulse durations, etc). In total, the 21 March file sequences yielded 504 porpoise clicks over acoustic samples totalling 1610 sec (26 min, 50 sec). Many of the click waveforms had excellent signal to noise ratio and hence enabled good representations to be made of their temporal and spectral characteristics. A total of 34 file sequences from the 28 March encounter were viewed, marked, and yielded 286 porpoise clicks over acoustic samples totalling 480 sec (eight min) – the last seven files were each of 30 sec duration.

Many clicks have a clear sinusoidal waveshape and are smoothly enveloped (Fig. 2) in a manner consistent with clicks from finless porpoise in captivity (Kamminga et al., 1986) and phocoenid clicks in general (Kamminga & Cohen Stuart, 1996; Kamminga et al., 1996). The pulse envelope depicts a waveform with smoothly graded 'ramp up' to the maximum signal amplitude, followed by a similar decay; the envelope is almost gaussian in shape. Spectrally, the clicks have a characteristic narrowband, dominant ultrasonic frequency component at approximately 140 kHz (Fig. 3). The peak-seeking algorithm determined a mean peak frequency across all high signal to noise ratio, narrowband spectra, of 142 kHz.
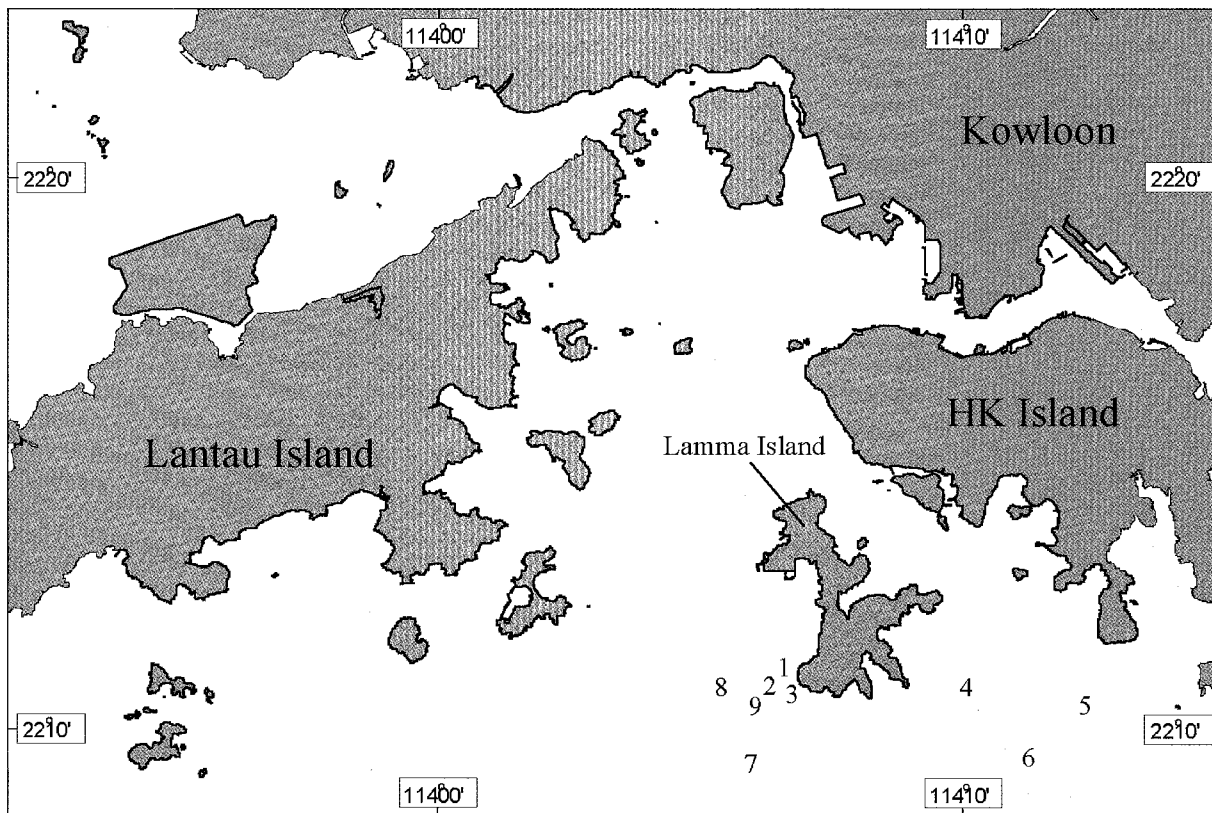
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Fig. 1. Location in Hong Kong territorial waters of the finless porpoise encounters detailed in Table 1.

Table 1. Details of finless porpoise encounters.

| Enc #	Date	Time	Position	Details	Acoustic Recordings
1	21 March	11:21	22.185 N 114.111 E	12 animals. South of Lamma Island, circling & foraging	Y
2	21 March	11:57	22.181 N 114.108 E	2 animals. South of Lamma Island.	Y
3	21 March	12:37	22.183 N 114.112 E	15 animals. South of Lamma Island, circling & foraging.	Y
4	28 March	10:48	22.181 N 114.171 E	8 animals.	Y
5	28 March	11:19	22.175 N 114.207 E	1 animal	N
6	28 March	11:32	22.158 N 114.190 E	6 animals	Y
7	28 March	12:26	22.159 N 114.099 E	5 animals	N
8	28 March	13:20	22.181 N 114.090 E	12 animals	Y
9	28 March	13:42	22.179 N 114.103 E	13 animals	Y
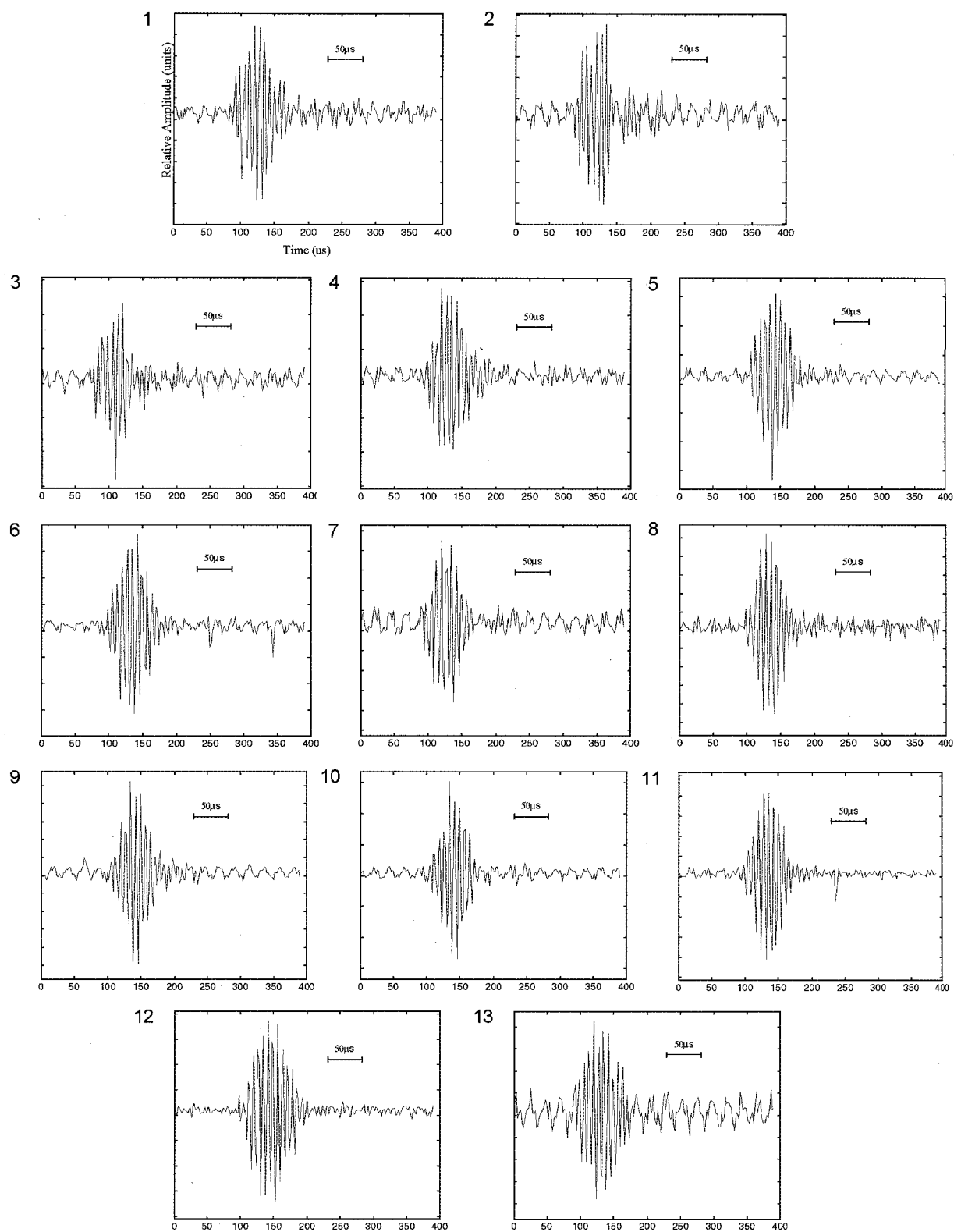
Fig. 2. Narrowband finless porpoise click waveforms from recorded sequence F164. Clicks are sequential, numbered in order of occurrence, and are likely from a single animal. Timescale is in microseconds, amplitudes are relative and scaled in linear waveform units.

However, not all clicks recorded followed this model pattern of a gently ramped sinusoidal waveform with a narrowband spectral peak. Over half of the clicks (442 vs 347) viewed during the course of this analysis were designated as 'broadband'; examples are illustrated in Figs. 4 & 5. The broadband clicks have a much sharper pulse onset, and a shorter pulse duration, than the narrowband clicks. Their spectra show a more diffuse pattern of spectral density, with a tendency for energy to extend to higher frequencies. Interestingly, there were also instances when porpoise clicks

were faintly audible to us over the hydrophone, suggesting either a broadband signature or some low frequency artefact of the click production mechanism. The latter is perhaps more likely, since broadband clicks clearly skew energy to even higher frequencies than the narrowband ones (Figs. 3 & 5), which would not enhance their audibility to humans. Audible clicks were 'faint' and heard very infrequently, hence the source level may be weak and the events indicative of animals in close proximity to the hydrophone, where such a low energy artefact could be detected. It is clear from the
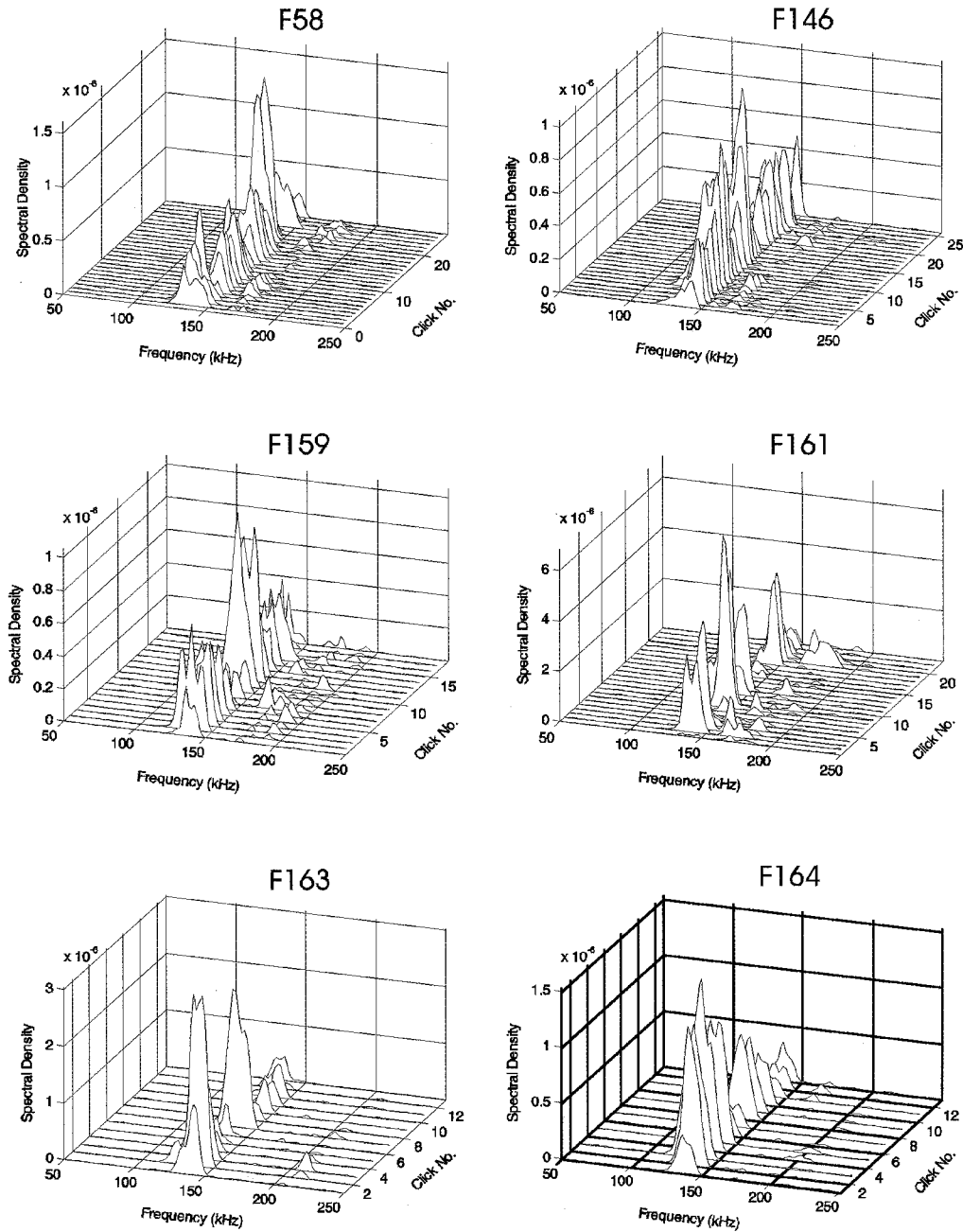

Fig. 3. Waterfall spectral displays of six sequences of narrowband finless porpoise clicks. Each sequence is labelled alpha-numerically from its recording ID (F58, F146 etc.), and each slice within a given waterfall display is the spectrum of an individual click. Spectral density is shown on a linear scale, in waveform units squared per hertz.

characteristics of these clicks that they should be audible to humans (Fig. 6).

A comparison of pulse durations was made between the narrowband clicks and the broadband clicks. Two datasets were constructed from measurements of high signal to noise ratio clicks; one containing 140 pulse durations measured from the narrowband clicks and the other containing 37 pulse durations measured from the broadband clicks (Fig. 7). Narrowband clicks had a mean pulse duration of 104 microseconds (104 ± s.d. 20.85), whereas broadband clicks had a mean duration of 61 microseconds (61 ± s.d. 8.34). Analysis of variance showed the two datasets to be significantly different at the 95% level (F=150.72, p=0.000).

Inter-click intervals from finless porpoise clicks were difficult to assess and meaningfully illustrate, since the number of clicks per file sequence was often quite low, and nearly all recordings were made in the presence of multiple porpoises. For this reason, inter-click interval analysis has not been attempted.

DISCUSSION AND CONCLUSIONS

Finless porpoise exhibited both the typical phocoenid characteristics of narrowband, high-frequency ultrasonic pulses, and also a more broadband form. Peak energy in the narrowband porpoise click spectrum occurs at 142 kHz, a finding consistent with signals recorded from finless porpoises in captivity (Kamminga et al., 1986; Nakahara et al., 1997), and in a semi-natural environment (Akamatsu et al., 1998). Energy in the broadband clicks is more diffuse and appears to have a tendency towards higher frequencies. Why such broadband clicks should exist is unclear, although it is perhaps a directional effect of the clicks being recorded off the main axis of transmission – which should be a narrow beam ahead of the animal. Broadband clicks slightly outnumbered the narrowband clicks, perhaps reflecting a large number of clicks recorded off the main axis of transmission. We might expect this type of bias since, all other things being equal, a porpoise echolocating directly at the hydrophone represents a somewhat special condition. It is more likely that animals swimming in the vicinity and performing normal echolocation behaviours, will be doing
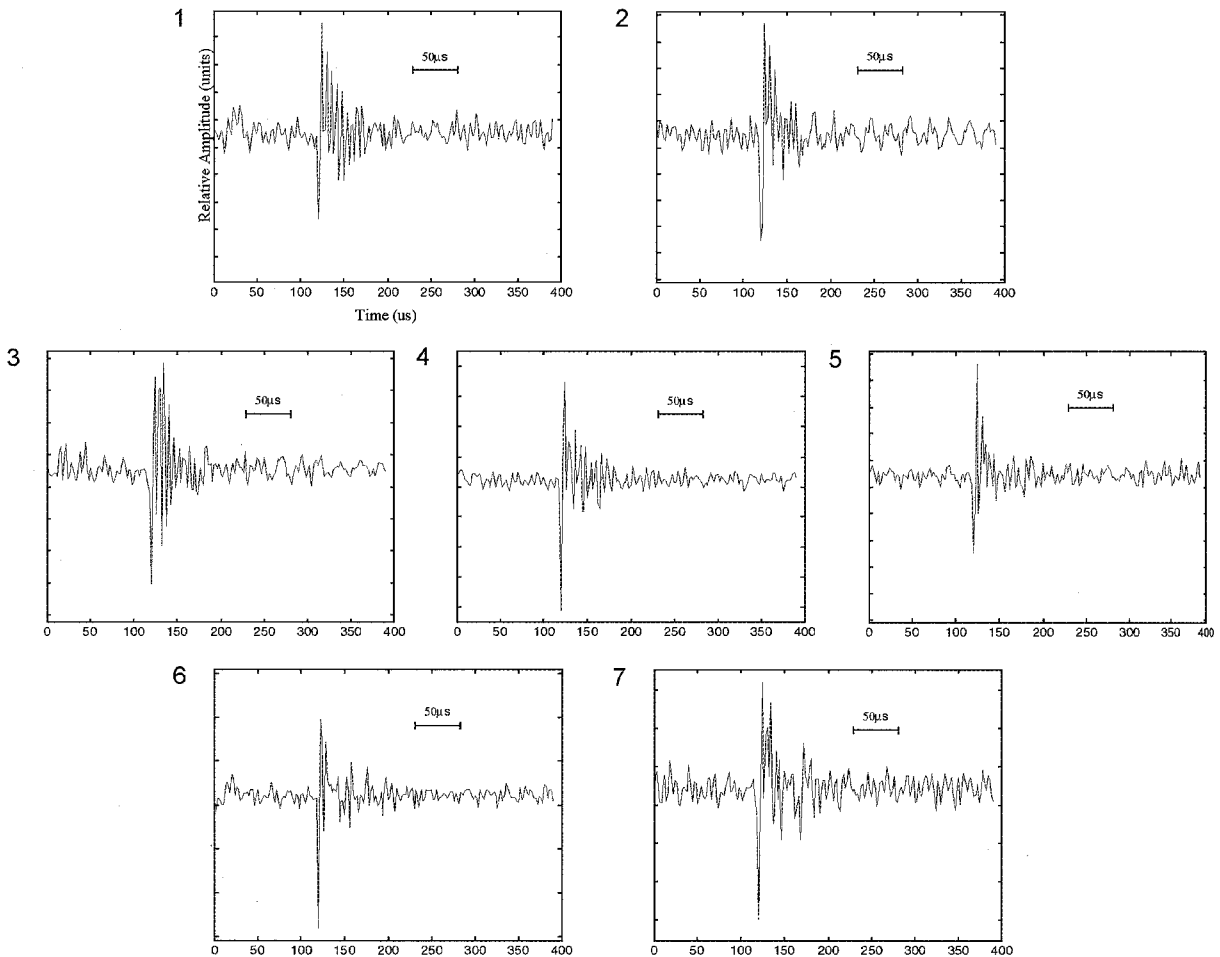

Fig. 4. Broadband finless porpoise click waveforms from recorded sequence F273. Clicks are sequential, numbered in order of occurrence, and are likely from a single animal. Timescale is in microseconds, amplitudes are relative and scaled in linear waveform units.
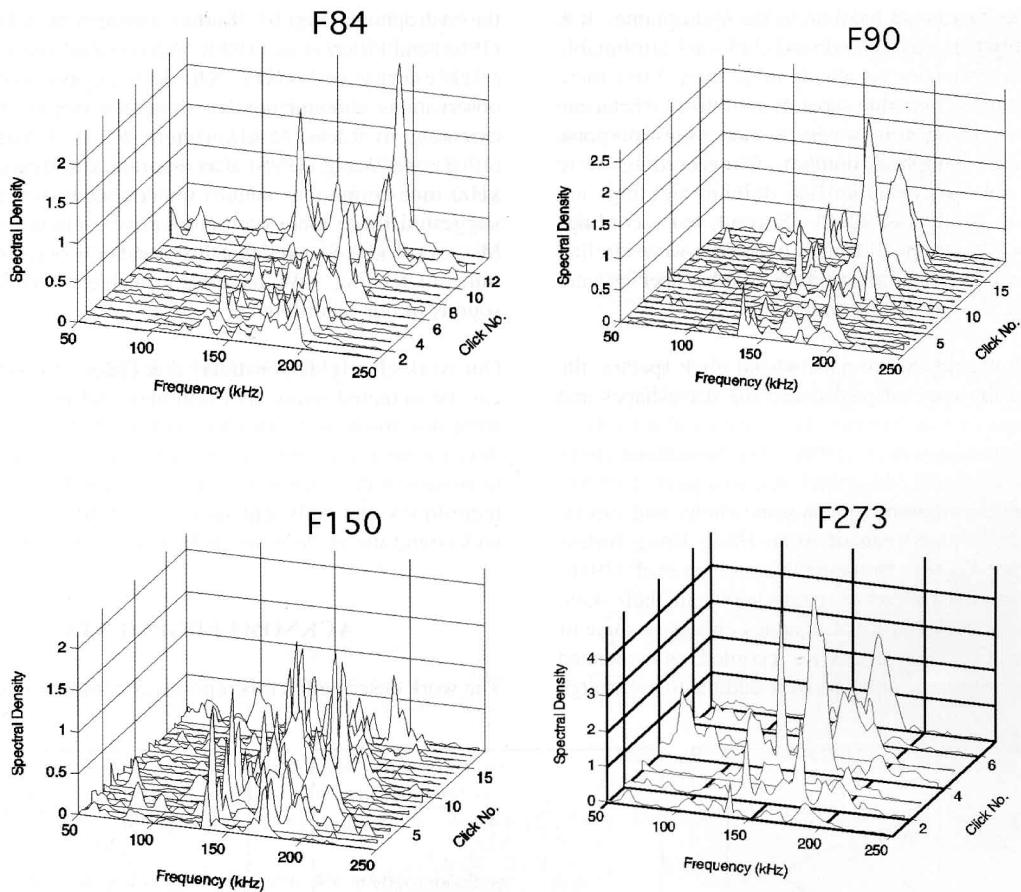
Fig. 5. Waterfall spectral displays of four sequences of broadband finless porpoise clicks. Each sequence is labelled alpha-numerically from its recording ID (F84, F90 etc.), and each slice within a given waterfall display is the spectrum of an individual click. Spectral density is shown on a linear scale, in waveform units squared per hertz.
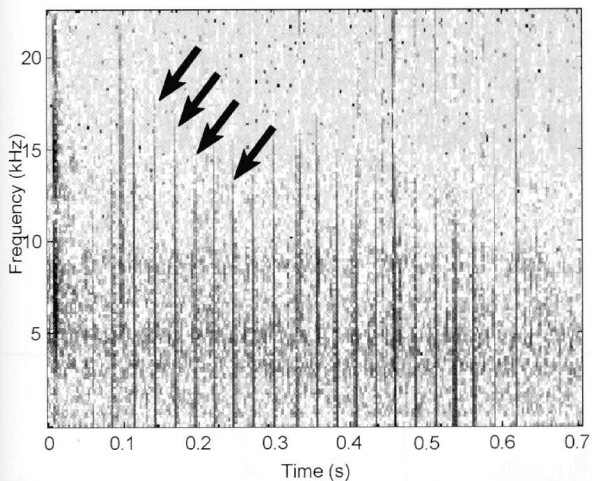
Fig. 6. Spectrogram taken from the DAT recording, showing characteristics of finless porpoise clicks audible through the hydrophone. The clicks appear as vertical bars in the spectrogram, several of which are denoted by arrows.
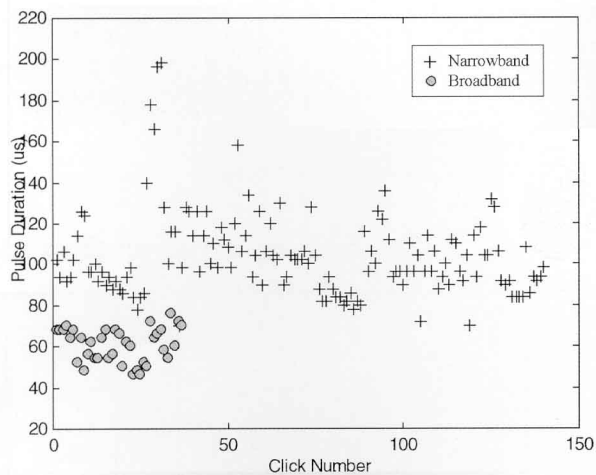
Fig. 7. Scatter plot showing pulse durations of narrowband clicks and broadband clicks.

so at an aspect that is not head on to the hydrophone. It is highly unlikely that these broadband clicks are attributable to other cetacean species vocalising in the area. First, there is a fairly distinct geographic separation of the two cetacean species found in Hong Kong waters; namely finless porpoise and Indo-Pacific humpback dolphin. Our recordings were made in an area where humpback dolphin sightings are extremely rare (Jefferson, 2000). Second, our recordings were made while groups of finless porpoises were circling the boat and the hydrophone, whereas no other species were sighted in the vicinity at any time.

The peak frequencies in the narrowband click spectra, the bandwidth of the spectral peaks, and the waveshapes and pulse durations of narrowband clicks are similar to those reported by Kamminga et al. (1986). The broadband clicks have not been previously described. Kamminga et al. (1986) also illustrated reverberant tails on some clicks, and similar reverberant tails were seen in some Hong Kong finless porpoise clicks (Fig. 8). However, Kamminga et al. (1986) did not detect low frequency components in their data, whereas there was clearly low frequency energy in some of the Hong Kong porpoise clicks we recorded, as evidenced by the fact that a number of clicks were audible to us through the hydrophone (Fig. 6). Earlier accounts by Mizue et al. (1968) and Pilleri et al. (1980) both reported low frequency click energy (<4 kHz), which is supportive of our observations, although our data show 'low frequency' energy extending to at least 15 kHz (Figure 6). Both Mizue et al. (1968) and Wang (1996) also reported low frequency (<8 kHz) time-continuous sounds (analogous to whistles) and suggested these were communicative / emotive sounds. Mizue et al. (1968) noted that this sound only occurred during times of feeding. We have been unable to confirm such sounds in our recordings.

Our work clearly demonstrates that finless porpoise clicks can be detected using hydrophones and high-frequency recording equipment. This has positive implications for the development and integration of passive acoustic survey techniques with visual monitoring. The combination of such techniques can only enhance our ability to study and understand the ecology and ethology of these animals.
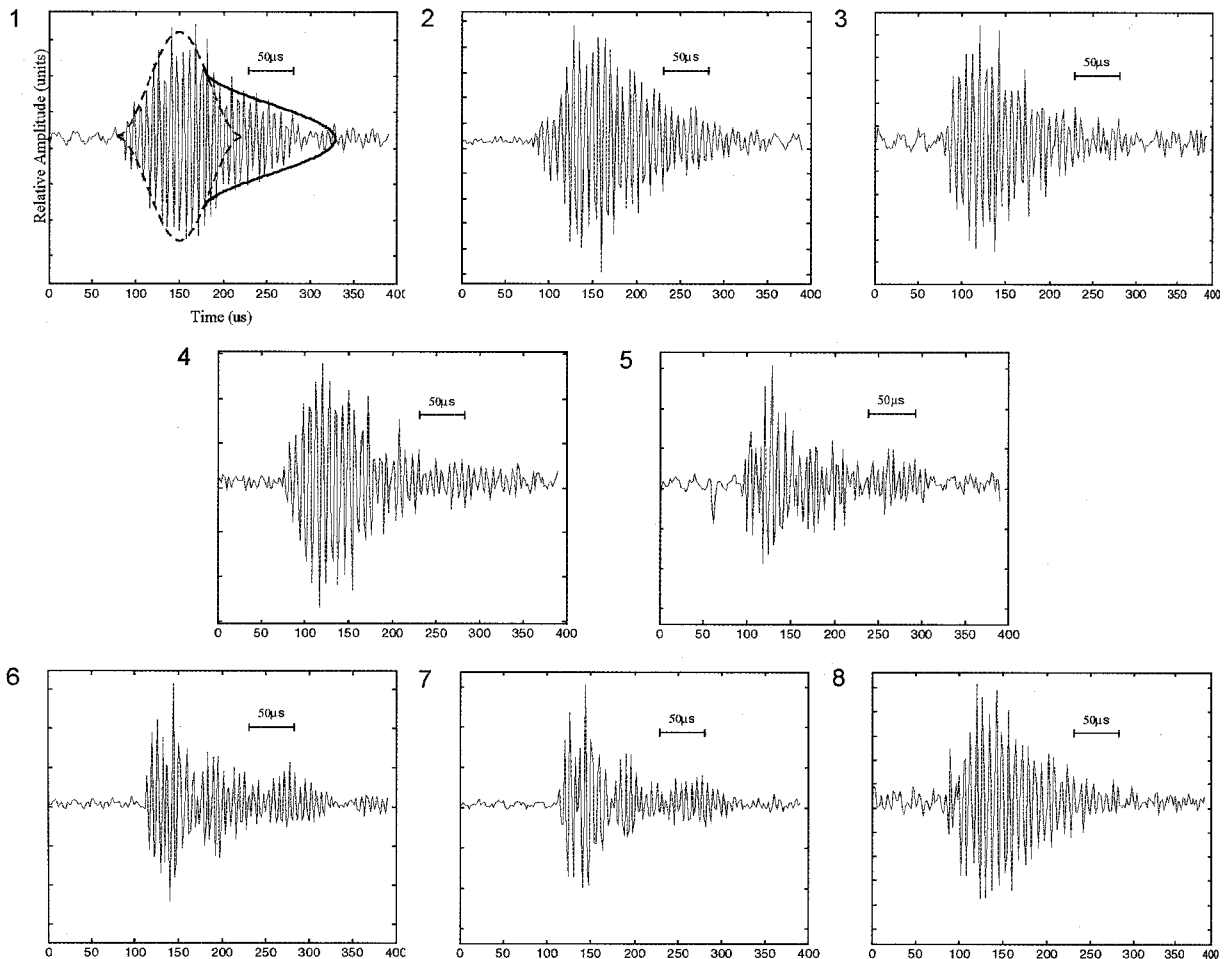
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Fig. 8. Examples of 'reverberant' click waveforms captured from finless porpoises. A typical pulse envelope is superimposed on (1) for comparison (dashed line), followed by an indication of the reverberant tail envelope (solid line).

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