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Remote acoustic monitoring of aquatic mammals

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ABSTRACT
Underwater ultrasonic sound of finless porpoises *Neophocaena phocaenoides* were monitored concurrent with visual observations in the Yangtze River, China. In a total of a 774 km cruise, 588 finless porpoises were sighted by visual observation and 44,864 ultrasonic pulses were recorded. The acoustic monitoring system could detect presence of the finless porpoises 82% of the time. False alarms in the system occurred with a frequency of 0.9%. The high frequency acoustical observation is suggested as an effective method for field surveys of small cetaceans, which produce high frequency sonar signals.

KEYWORDS: echolocation, finless porpoise, dolphin, sonar, underwater sound

INTRODUCTION

Acoustical surveys of cetaceans have several advantages compared with visual surveys. The acoustical survey can be operated automatically and maintain an identical detection threshold over long periods. The acoustical survey enables all day observation even nocturnally. In contrast, the advantages of the visual surveys are that they can recognize different species and count numbers of animals directly. Abundance of populations can be estimated using line transect surveys (Buckland et al. 1993, Shirakihara et al. 1994).

Acoustical methods have been applied for detection of cetaceans, such as minke whale (*Balaenoptera acutorostrata*) (Nishimura and Conlon 1994), blue whales (*Balaenoptera musculus*) (Stafford et al. 1998), Hawaiian spinner dolphins (*Stenella longirostris*) (Aubauer et al. 2000), bottlenose dolphins (*Tursiops truncatus*) (Freitag and Tyack 1993, Furusawa 1998), sperm whale (*Physeter macrocephalus*) (Goold 1996, Bondaryk et al. 1999), humpback whales (*Megaptera novaeangliae*) (Norris et al. 1998), bowhead whales (*Balaena mysticetus*) (Cummings and Holliday 1985), harbour porpoise (Akamatsu et al. 1994, 1998).

So far, the detection probability of cetacean by acoustical surveys could not be compared with visual findings quantitatively except for several baleen whales (McDonald and Fox 1999, Clark and Fristrup 1997), because the performance of an acoustical observation system is highly variable. The detection performance depends on vocalization rates, distances of animals and background noise levels. To determine the reliability of acoustical detection, simultaneous visual survey is needed. Here we report a detection performance of a passive acoustical survey of finless porpoises in the Yangtze River, concurrent with visual observations (Akamatsu et al. 2001).

MATERIALS AND METHODS

The research vessel surveyed from Wuhan to the mouth of Poyang Lake downstream. Two visual observers on the top of the research vessel (6.25 m high from the water surface) searched left and right sides of the frontal area, respectively. When an observer found a group of finless porpoises, the minimum number, the distance and direction from the research vessel and behavioral remarks of the animals were recorded. The minimum group size was defined as the number of the animals surfaced at the same time. After determination of the minimum group size, the observer switched the observation area to the downstream area below the last observed animals. This protocol prevented double counting, because the vessel speed is likely larger than the swim speed of the animal.

Two broad band hydrophones (B&K8103, sensitivity -211dB re: 1V/uPa +2/-9 dB, up to 180 kHz) were deployed at a depth of 0.8 m, 6.3 m apart from each other on two sides of the vessel (Kekao No.1 of Institute of Hydrobiology, The Chinese Academy of Sciences). A pre-amplifier with 10 kHz high pass filter (OKI ST-80B) eliminated the low frequency noises caused by water flow and engine operation. A digital data recorder (SONY PCHB 244, sampling rate of 384 kHz, DC to 147 kHz within 3dB) allowed only one channel broad band recording at a time. Hence the channel on the appropriate side where animals frequently appeared was recorded accordingly. The calibration of the present system was done in a test tank of System Giken Co. by projecting 100 kHz and 10-cycle tone bursts. All the pulses more than 133 dB peak-to-peak re 1uPa were digitized by using an analogue digital converter (System Design Service, DASS BOX 1000). A data analysis program on MATLAB (c) developed for this study calculated dominant frequency (analysis bandwidth of 2.49 kHz) and the pulse interval of each pulse. Since the dominant frequencies of finless porpoise sonar signals were usually higher than 110 kHz (Kamminga et al. 1986, Akamatsu et al. 1998), only the pulses having more than a 100 kHz dominant frequency were processed. The maximum sound pressure levels in a click train detected on the animals at 100 m from the research vessel were averaged.

RESULTS

In total, 588 finless porpoises were sighted visually during the 774 km cruise along the Yangtze River, in November 1998. During 1,835 minutes effective recording time, echolocation clicks of finless porpoises were present and recorded during 214 minutes. The acoustical observation system detected 93,418 ultrasonic pulses with dominant frequencies higher than 100 kHz. The dominant frequency distribution of these pulses had a local peak at 140 kHz and local minimum at 125 kHz as shown in FIG.1. While higher than 125 kHz, the pulses showed typical narrow band characters of sonar signals of the finless porpoises. Pulses with dominant frequencies less than 125 kHz showed broadband and long duration characters, which were considered to be noise. Therefore, only pulses with dominant frequencies higher than 125 kHz (n=44,864) were analyzed hereafter. Numbers of pulses and finless porpoises observed in every minute are presented in FIG.2, showing 500 minutes (about two days cruise) effective recording time. Clear coincidence between visual and acoustic detection can be seen.

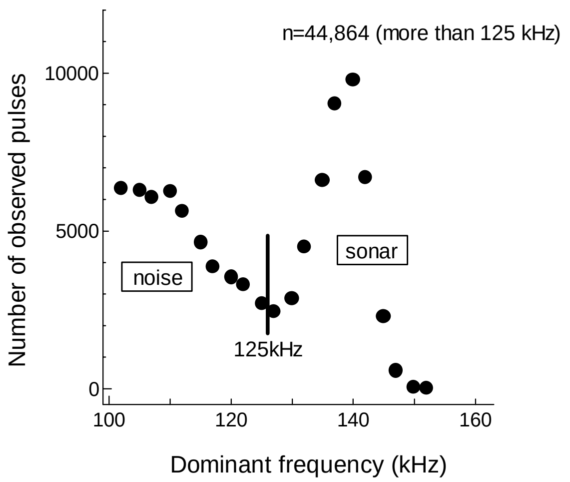

FIG.1 Dominant frequency distribution of ultrasonic pulses detected by the acoustical observation system. To exclude the noise, only the pulses having peak frequency more than 125 kHz were analyzed.

Correct detection by the acoustical observation system is defined as the detection of more than a cutoff number of pulses (15 pulses/minute) as depicted by the horizontal bar in FIG.3 within a time window. The window width was set as +/-2 minutes from the moment of visual sighting of the animals. Miss is defined as less than 15 pulses captured in a minute within the time window. False alarm is defined as more than the cutoff number of pulses associated without visual finding within +/-5 minutes.

The receiver operating characteristic (ROC) curve

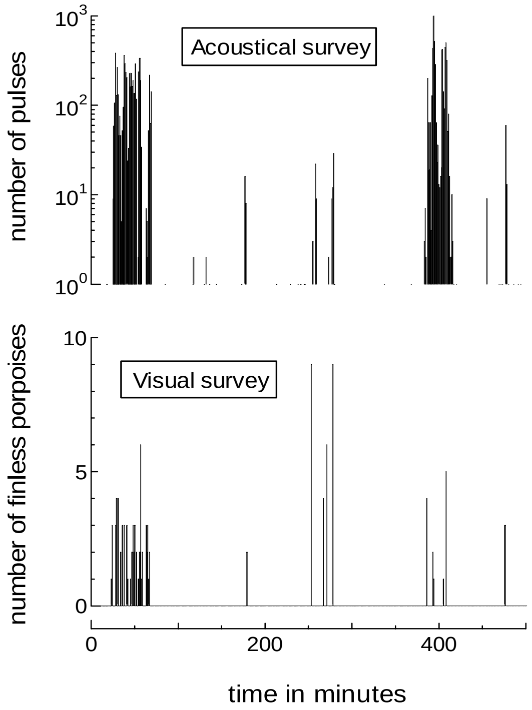

FIG.2 Comparisons between the number of finless porpoises and pulse signals every minute during part of the observation (500 minutes). Clear coincidence between visual and acoustical detection is indicated.

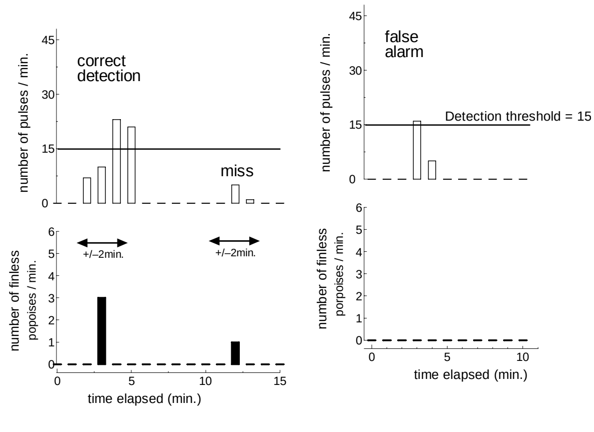

FIG.3 Schematic of correct detection, miss and false alarm of the acoustical observation system. A time window centered at the visual detection was depicted as two arrows. The acoustical correct detection of the animals was defined that the number of the observed

according to the cutoff number of pulses in a minute were shown in FIG.4. At the cutoff number of pulses (15), reliable correct detection (82%) and small false alarm levels (0.9%) were indicated. This was the reason to choose 15 as the cutoff number of pulses. The miss rate according to the distance from research vessel is depicted in FIG.5. The porpoises could be observed visually up to 600 m at maximum. Out of 300 m range, miss rate of the acoustical observation system was higher than 45%, whereas it was less than 25 % within 300 m range. The average of maximum sound pressure level corresponding with visual detection at 100 m was 137.4 dB p-p re 1uPa.

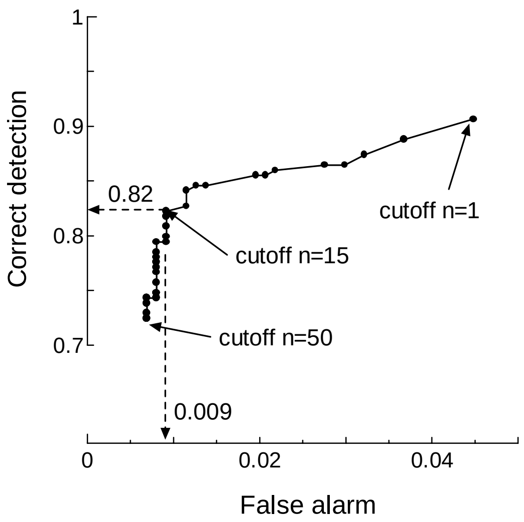

FIG.4 ROC curve according to the cutoff number of pulses. The false alarm decreased until up to 15 cutoff number of

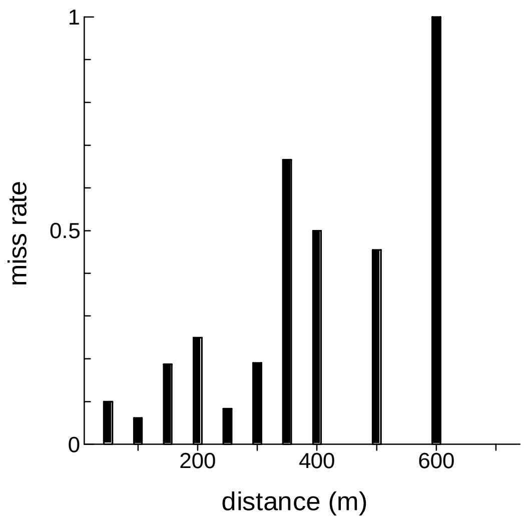

FIG.5 Miss rate according to the distance from the research vessel. The larger miss rate was observed more than 300 m distance.

DISCUSSION

This study showed that a high frequency acoustical survey of finless porpoises has reliable performance to detect echolocating cetaceans with a small false alarm rate. However, acoustic detection probability of the finless porpoises depends on the source level of the echolocation signal, directionality of the beam pattern and vocalization rate. Evaluation of these factors will help to understand the high detection probability of the present system.

The averaged sound pressure level of finless porpoises' signal was 137.4 dB at 100 m apart from the observer. In the shallow water system, the sounds propagate spherically up to the depth of the water, then become a cylindrical propagation. Assuming the depth of the Yangtze River is 10 m, the sound produced from a porpoise propagates spherically up to 10 m with -20 dB attenuation. Then, the sound propagates cylindrically and has another -10 dB attenuation up to 100 m. Therefore the source level of the finless porpoises is calculated to be 167.4 dB. Using this source level and 133 dB detection threshold level, the effective acoustic detection distance is calculated as 275 m. This is consistent with the higher missing rate more than 300m (FIG.5). If we exclude the data out of 300 m range, the correct detection rate will increase to be 88%.

The two-minute time window used in the definition of correct detection and miss was chosen from the 300 m effective acoustical detection distance estimated above. During two minutes the research vessel proceeded 330 m. A porpoise might produce sound before or after visual finding. The two-minute time window is adequate to detect a sound produced within the acoustic detection distance. On the other hand, the five-minutes time window used for the definition of false alarm and correct rejection was chosen to exclude any possibility of porpoise existence around the research vessel. Within +/-5minutes cruise, the vessel proceeds 1660 m, which is approximately five times longer than the acoustical detection range. If there was no visual finding with no acoustical detection, it is considered to be correct rejection. If there was no visual finding with more than the cutoff number of pulses recording, it should be treated as false alarm.

Dolphin sonar signals are directional and the sound pressure levels change by 0 dB to -20 dB depending on the relative angle of a bottlenose dolphin toward a hydrophone (Au 1993). Au et al. (1999) reported that the 3-dB beam width of a harbor porpoise (*Phocoena phocoena*) was approximately 16.5 degree. This is wider than other species, for example 9.7 degree for bottlenose dolphins (Au 1993) and 6.5 degree for beluga (*Delphinapterus leucas*) (Au et al. 1987). According to the acoustic datalogger recording of free-ranging finless porpoises, the 120 degrees off-axis sonar signals still had 160 dB peak-to-peak sound pressure level at one meter from the animal (Akamatsu et al. 2000). In this case, the detection range of the present system is expected to be 50 m even if the animals are 120 degrees off the direction to the hydrophone.

Two free-ranging finless porpoises in clearer water of the semi-natural reserve (an oxbow of the Yangter River) produced 14.5 to 19.1 click trains in a minute (Akamatsu et al. 2000). This suggests that, a sufficient number pulses can be recorded when the animals were around the hydrophone since a click train consists of several tens of ultrasonic pulses. Especially, in the muddy water of the Yangtze River, finless porpoises are thought to use echolocation much more frequently, because of the limited visual sense.

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