

Estimation of the detection probability for Yangtze finless porpoises (*Neophocaena phocaenoides asiaeorientalis*) with a passive acoustic method

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Yangtze finless porpoises were surveyed by using simultaneous visual and acoustical methods from 6 November to 13 December 2006. Two research vessels towed stereo acoustic data loggers, which were used to store the intensity and sound source direction of the high frequency sonar signals produced by finless porpoises at detection ranges up to 300 m on each side of the vessel. Simple stereo beam forming allowed the separation of distinct biosonar sound source, which enabled us to count the number of vocalizing porpoises. Acoustically, 204 porpoises were detected from one vessel and 199 from the other vessel in the same section of the Yangtze River. Visually, 163 and 162 porpoises were detected from two vessels within 300 m of the vessel track. The calculated detection probability using acoustic method was approximately twice that for visual detection for each vessel. The difference in detection probabilities between the two methods was caused by the large number of single individuals that were missed by visual observers. However, the sizes of large groups were underestimated by using the acoustic methods. Acoustic and visual observations complemented each other in the accurate detection of porpoises. The use of simple, relatively inexpensive acoustic monitoring systems should enhance population surveys of free-ranging, echolocating odontocetes. © 2008 Acoustical Society of America. [DOI: 10.1121/1.2912449]

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I. INTRODUCTION

Estimating abundance of marine mammals is essential for their conservation and management. Visual observation is the most commonly used method to estimate abundance of aquatic mammals. These animals must surface to breathe and then are visible to ship-based or airborne observers. However, on ship or aerial surveys, not all aquatic mammals surface within the visual range of observers due to relatively long dive times for some species (e.g., Okamura *et al.*, 2006) and avoidance of ships (Richardson *et al.*, 1995). Consequently, an unknown proportion of animals near or on the survey track line are not detected.

Strip or line transect survey methods allow the estimation of total population size based on the incomplete detection of local abundance (Buckland *et al.*, 1993). A key assumption of this method is that all animals within the strip width or on the transect line are detected. This condition is generally not satisfied. However, the detection probability can be calculated by using independent visual observers, which is often based on the same observation platform. Observation events of an individual animal, or a group of ani-

mals, by two independent observers are then matched. Based on an assumption of independent sampling, the detection probability of the primary observer can be calculated as the number of matched events over the total number of events observed by the secondary observer (Buckland *et al.*, 1993). In the present study, we employed the strip transect method to compare independent visual and acoustical detections of finless porpoises.

Detection probability is the key to estimate the number of animals. Once the detection probability within a specific distance of the survey track line has been determined, the total number of animals can be estimated from this probability (Buckland *et al.*, 1993). This simple but well established method has been widely applied to assess abundance of marine mammals including blue whales (Calambokidis and Barlow, 2004), humpback whales (Calambokidis *et al.*, 2004), sperm whales (Lewis *et al.*, 2007; Barlow and Taylor, 2005), killer whales (Zerbini *et al.*, 2007), dugongs (Shirakihara *et al.*, 2007), spotted seals (Mizuno *et al.*, 2002), and several species of dolphins and porpoises (de Segura *et al.*, 2006;

Mullin and Fulling, 2004; Hammond *et al.*, 2002) including finless porpoises (Yoshida *et al.*, 1997).

Small odontocetes, such as dolphins and porpoises, are relatively difficult to detect. Group size is difficult to estimate because of the brief periods that animals appear at the surface when breathing and close interanimal distances. Odontocetes swim at speeds of 1.2–5 m/s (Akamatsu *et al.*, 2002; Hanson and Baird, 1998) with a dive duration of 1–3 min and perhaps longer when feeding. This means that dolphins and porpoises can travel several hundred meters underwater without being observed visually at the surface.

Acoustical method can be used as an independent observation to compare to the primary visual observer. Vocalizations of marine mammals stand out from ambient noise (Wartzok and Ketten, 1999; Richardson *et al.*, 1995). They can be detected remotely with passive acoustic methods. Low frequency vocalizations of baleen whales are good candidates for passive acoustic surveys as they propagate relatively great distance underwater. Vocalizations (i.e., song patterns) are often unique to species. Extensive acoustic studies of blue whales (Oleson *et al.*, 2007), right whales (Wade *et al.*, 2006), minke whales (Rankin *et al.*, 2007), and humpback whales (Tiemann *et al.*, 2006) have been conducted.

Not only the presence of the specific species but also additional information could be monitored by acoustical observations. Vocalizations of sperm whales have been helpful in estimating abundance (Barlow and Taylor, 2005) and even documenting dive patterns (Thode, 2004). Passive acoustic methods have applied the identification of multiple species by the characteristics of whistles (Oswald *et al.*, 2007).

High frequency sonar signals of odontocetes have been also used for the observation of odontocetes. For example, a monaural acoustic detection system (T-POD) has been developed that is now commercially available for detecting high frequency sonar pulses of a few species (Philpott *et al.*, 2007; Verfuss *et al.*, 2007). Jefferson *et al.* (2002) applied line transect methods for the survey of finless porpoises simultaneously with T-PODs.

Acoustic detection methods have several advantages over simple visual observations. Detection performance of hardware and software systems can be standardized independent from the observers' abilities. Moreover, they prevent cueing of observers to sightings allowing independent observations between the methods. A hydrophone array determines the distance and direction to a vocalizing animal, which can be directly compared to visual estimates. Because acoustic detection methods do not require human observers, they are useful as an independent detection method during visual transect surveys.

Acoustic detection methods are not without limitations. The probability of detecting animals with passive acoustic methods is affected by the signal-to-noise ratio and by the production rate and the temporal pattern of vocalizations. Vocalizations with low source levels can only be detected when the receiver is close to the source in noisy environments. Animals that are silent for long periods will evade detection.

The echolocation signals of odontocetes are a primary target of passive acoustic detection methods. Source levels of

those sounds are up to 170 dB for small porpoises (Akamatsu *et al.*, 2002) and over 220 dB for other species (e.g., bottlenose dolphins; Au, 1993). Yangtze finless porpoises (*Neophocaena phocaenoides asiaeorientalis*) in the semi-natural reserve at Shishou, Hubei, China, produce series of ultrasonic echolocation pulses (i.e., click trains) every 5.1 s on average (Akamatsu *et al.*, 2005a). They rarely travel more than 20 m without vocalizing. Harbor porpoises also produce click trains relatively often (i.e., every 12.3 s; Akamatsu *et al.*, 2007), suggesting that porpoises do not usually travel far without producing detectable sounds. Frequent sound production is essential for effective detection using passive acoustic monitoring systems. Because of these characteristics, porpoises appear to be good candidates for applying passive acoustic monitoring systems while avoiding the few limitations of the method.

II. MATERIALS AND METHODS

A. Acoustic observation

We used acoustic data loggers (i.e., A-tags; ML200-AS2, Marine Micro Technology, Saitama, Japan) to make passive acoustic observations of Yangtze finless porpoises during surveys on the Yangtze River between Yichang and Shanghai, China. The survey was conducted between 6 November and 13 December 2006. The hydrophone sensitivity of the data logger was -201 dB/V at 120 kHz (100–160 kHz within -5 dB band), which is close to the dominant sonar signal frequency of finless porpoises. Each data logger had two hydrophones 11 cm apart to record the difference in the arrival time of each pulse with a resolution of 271 ns. Every 0.5 ms, the logger stored the intensity of the received pulse in the dynamic range of 136.1–160.7 dB peak to peak, which is referred to a 1 μ Pa reference. The A-tag that we used during this survey had an identical signal processing to the earlier model (W20-ASII; Little Leonardo, Tokyo, Japan; Akamatsu *et al.*, 2005b) but also had a digital detection threshold setting. These A-tags record the difference in time of arrival between sounds received by each hydrophone, which can be used to estimate the conical bearing angle to a sound source.

We made a round-trip survey in two research vessels (*Kekao* and *Honghu*) simultaneously, between Yichang and Shanghai covering the entire habitat of the baiji and Yangtze finless porpoise (Turvey *et al.*, 2007) between 6 November and 13 December 2006. Here, we report acoustic survey data only for the downriver survey (1669 km) because water flow noise contamination was lower when traveling with the river current. As depicted in Fig. 1, one vessel (*Kekao*) towed two data loggers; the distal one was 2 m ahead of a monaural hydrophone (C54XRS; Cetacean Research Technology, Seattle, WA, USA) on an 87 m cable that included a 7 m proximal extension to a preamplifier (VP2000, Reson, Denmark) that was onboard. This hydrophone was used to monitor low frequency whistles of baiji (*Lipotes vexillifer*) during the survey (Turvey *et al.*, 2007). The second data logger was 17 m ahead of the distal one. We calculated the spatial locations of the porpoises by simple geometric determination when sonar signals were received by both A-tags. Each A-tag stored the

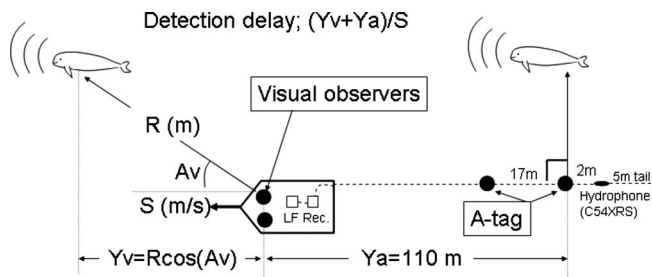


FIG. 1. Two A-tags were towed 110 m behind the visual observers on the vessel (Kelao). Supplemental hydrophone for the low frequency monitoring is placed 2 m behind the distal A-tag. Pictorial representation of parameters used to calculate the expected delay time between visual and acoustic detections. Black circles are the locations of the visual observers and acoustic recorders. Visual detection occurred before the acoustic detection. The delay lag was calculated by using the difference between the distances of visual and acoustic detection along the cruise line. The time of acoustic detection is the zero crossing point at the rear A-tag, which means that the animal was almost perpendicular to the cruise line and abeam of the data logger.

sound source direction calculated from the time arrival difference of sound between the stereo hydrophone of A-tag. By using two independent angles from the separated two data loggers, location of the sound source could be calculated. The other vessel (Honghu) towed one data logger on a rope 80 m behind the ship.

We added a 5 m length of 5-mm-diameter kremona rope behind the distal data logger on each vessel to stabilize the position of data loggers and to prevent them from swinging. We placed floats at 5 m intervals on the tow cable or rope to prevent the data loggers from dragging on the river bottom. A 2 kg lead weight was fixed 1 m in front of each data logger to keep it approximately 50 cm underwater and prevent surface splashing that would result in broadband noise contamination.

B. Acoustic counting of animals

Biosonar signals from porpoises were identified by their regular interpulse intervals of approximately 30–70 ms (Fig. 2), which is typical of free-ranging finless porpoises (Akamatsu *et al.*, 1998). The source of noise we recorded came mostly from passing cargo vessels and had randomly changing interpulse intervals and intensities unlike the biosonar signals from porpoises. The time arrival difference that corresponded to the bearing angle of porpoise vocalizations always changed from positive to negative (Fig. 2), which meant that the porpoise was passing by the vessel from bow to stern. Because the survey vessels were moving faster (i.e., at 15 km/h) than the average swimming speed of porpoises (4.3 km/h; Akamatsu *et al.*, 2002), none of the animals could catch up with the vessel. The detection time of the animal was defined as the point at which the signal arrival time difference was nearly equal to zero (i.e., the zero crossing point). At that moment, the animal was adjacent to the data logger on a line perpendicular to the cruise line. When two or more porpoises could be discriminated in a group, the time at each zero crossing point was used for the analysis. In the present study, we used the data obtained by the distal A-tag for the Kekao vessel. If sound was detected away from the zero crossing point and the animal was not vocalizing

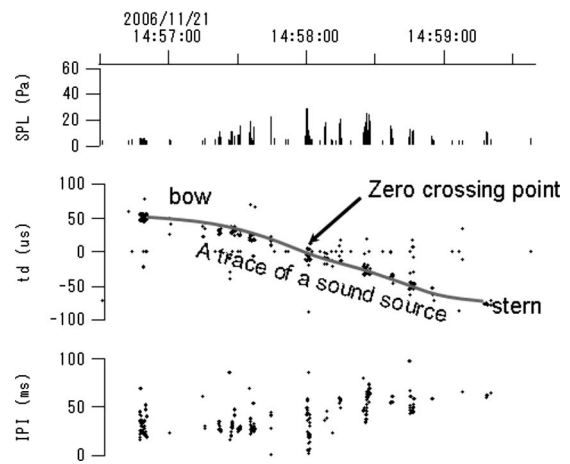


FIG. 2. Echolocation signals from single porpoise passing by the data logger. Top panel: The received sound pressure level (SPL) in Pa; middle panel: the time arrival difference of sonar sounds (T_d) in μ s. A trace of the time difference (T_d), indicated as a gray line, changing from positive to negative corresponds to an individual passing from bow to stern relative to the data logger. Lower panel: Interpulse interval in ms. Note that the SPL has a maximum value near the zero crossing point of T_d , which suggests that the porpoise was closest to the data logger at that time.

near the data logger, the time of the sonar signal detection was used. To avoid double counting for short traces that were temporally close, we conservatively assumed that traces within 3 min of each other were from the same porpoise. The 3 min duration corresponds to the 750 m distance the vessel proceeds. This is similar to ± 300 m, which is the detection distance of the A-tag presented in Sec. III.

C. Visual observation

We made continuous visual observations during daylight hours from the top decks of both vessels. The primary observation team on each vessel consisted of two observers (left and right observers) who continually searched for porpoises using 7×50 Fujinon binoculars and occasionally with unaided eyes (Turvey *et al.*, 2007). A data recorder in the middle of the visual observers recorded sighting time, latitude and longitude position, estimated radial distance and bearing to the animals by using an angle board, observer number, group size, distance from the sighting to the nearest river bank, and a code for habitat type (Turvey *et al.*, 2007). Six or seven observers rotated among these positions every half hour and rested for 90–120 min between shifts.

There was one independent observer on watch continuously during daylight hours on each vessel to look for porpoises that may have been missed by the primary observers. The independent observer focused on the area directly ahead of the vessel to guard the track line (Buckland *et al.*, 1993). Two very experienced observers alternated in the independent observer's position every 60 min. Independent observers searched with $25 \times$ binoculars on Kekao and with $7 \times$ binoculars on Honghu.

For the analysis hereafter, visual detection made within 300 m of the vessel track was used to match the maximum detection distance of acoustic recording system for the comparison of two types of observations.

D. Matching of multimodal detections

To calculate the probability of detection of porpoises, we matched detections made by the primary visual observers with those from the acoustic data loggers to determine if they referred to the same porpoise or porpoise group. Matched detections are defined as the detection of the same animals by both visual and acoustical modes during a particular time window. We could not directly compare time of visual observation (T_v) with the time of acoustic detection (T_a) because porpoises were visually observed only abeam of or ahead of the vessels, whereas they were acoustically detected behind the vessel (Fig. 1). This resulted in a time difference between the two independent detections. The time lag can be estimated based on the distance along the cruise line between the visual detection and the data logger ($Y_v + Y_a$ in Fig. 1) divided by the vessel speed (S , 15 km/s). The standard clocks of visual observers and the acoustic system were set to GPS time. The distance to an animal ahead of the cruise line from the visual observer (Y_v) was calculated from the visually observed distance (R) and the relative angle to the animal (A_v) as

$$Y_v = R \cos(A_v). \quad (1)$$

For both vessels, the distance from the visual observer to the data logger (Y_a) was 110 m, including the cable length (80 m) and the distance from the visual observer to the stern (30 m) of the vessel. The delay time between the visual and acoustic detection of identical animals (T_d) was calculated by using the survey vessel speed (S) as

$$T_d = (Y_v + Y_a)/S. \quad (2)$$

For this, we assumed that the animal did not move far (at 1.2 m/s) compared to the distance traveled by the vessel (at 4.2 m/s) during the period.

We used an arbitrary time window (T_w) for matching detections from the independent methods. Each detection time was assigned to a time bin of T_w s and the number of animals detected in each time bin was summed. If the number of animals in any time bin was one or more for both visual and acoustic detections, the detection was defined as being matched. The matched detection should satisfy the following condition:

$$\text{integer}(T_a/T_w) = \text{integer}[(T_v + T_d)/T_w], \quad (3)$$

where T_v and T_a are the times of visual and acoustic detection and T_d is the expected delay time of the acoustic detection compared to the visual detection of the identical porpoise or porpoise group. We considered any porpoises detected during the time window to belong to the same group. Although this working definition is different from the biological definition of a group, we think that it is most useful for comparing multimodal detections from a moving platform.

E. Estimate of detection probability

The comparison of data obtained by primary observers and that obtained by an independent observer allows the estimation of the probability of detection of porpoises by visual

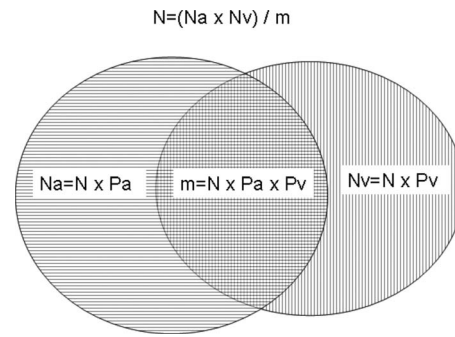


FIG. 3. Simple detection model of two independent observation methods in a strip transect. Here, we assume that the acoustic and visual observers have detected N_a and N_v individuals in the strip transect during the entire survey. The number of matched detections is m . All these parameters are observable, whereas the total number of the target animals in the strip transect (N) and the detection probabilities of two independent methods (P_a and P_v) are possible to calculate.

observers (Buckland *et al.* 1993). The total number of animals in the strip transect (N) within 300 m of the vessel track can be calculated by using the number of visual detections (N_v ; Fig. 3), the number of acoustic detections (N_a), and the number of detections matched by both methods (m). The number of detections matched by both methods is calculated according to the procedure in the previous section. All these numbers are observable. The total number of animals in the strip transect (N) as well as the detection probability by visual (P_v) and acoustic (P_a) methods are unknown. The number of groups detected acoustically is the total number of animals in the strip transect times the acoustic detection probability,

$$N_a = NP_a. \quad (4)$$

Further, the number of groups detected visually (N_v) is

$$N_v = NP_v. \quad (5)$$

As long as the two observation methods are independent, the number of matched groups (m) is

$$m = NP_a P_v = N(N_v/N)(N_a/N). \quad (6)$$

Here, the total number of animals in the strip transect (N) and each of the detection probabilities using known parameters is

$$N = (N_v N_a) / m, \quad (7)$$

$$P_a = m / N_v, \quad (8)$$

and

$$P_v = m / N_a. \quad (9)$$

III. RESULTS

We counted 204 porpoises from Kekao and 199 from Honghu, by using acoustic methods. In comparison, primary observers detected 163 porpoises from Kekao and 162 from Honghu within 300 m of the vessel track. An example of acoustical and visual detections is depicted in Fig. 4. Many single porpoises were detected acoustically and large group size was detected visually. On November 20 and 21, 2006,

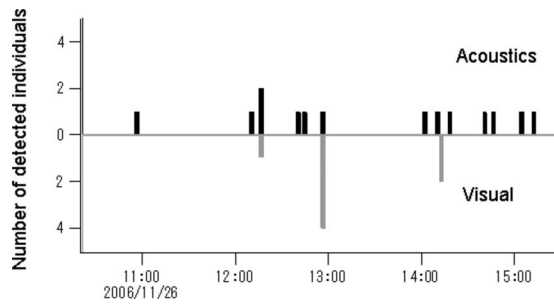


FIG. 4. An example of detection events by acoustics and visual observations from Kekao. Visual detections farther out than the 300 m strip width perpendicular to the cruise line are not included.

the vessels went into Poyang Lake, where some populations of finless porpoises were found. We excluded this period because the towed hydrophone array system was not used due to heavy ship traffic.

A. Observable distance by acoustic systems and an appropriate transect width

We calculated spatial locations of porpoises from a simple geometric determination of the angle of the acoustic signals from each of the two data loggers towed 17 m apart behind Kekao. Simultaneous recording of direction with two data loggers matched the visual detection 49 of the 204 sightings. The maximum detection distance of porpoises using data loggers was 329 m though most porpoises were detected only within 250 m (Fig. 5). The visual observation distances were up to 400 m from the vessels.

We assumed that the observable transect width for our acoustic system was 300 m, which included 95% of the acoustic detections. Consequently, porpoises that were beyond 300 m could not be detected acoustically. Appropriate truncation of distant sightings can reduce the bias of density estimation (Barlow, 1995).

B. Time window

The number of the matched events is related to the duration of the time window. A longer time window results in a greater number of matched events. Increasing the window length too much could potentially result in incorrectly matched groups. A shorter time window produces a lower

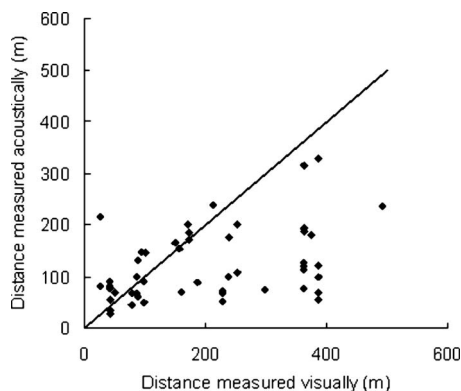


FIG. 5. Comparison of visual and acoustic detection distances for groups that were linked by a detection time window of 120 s.

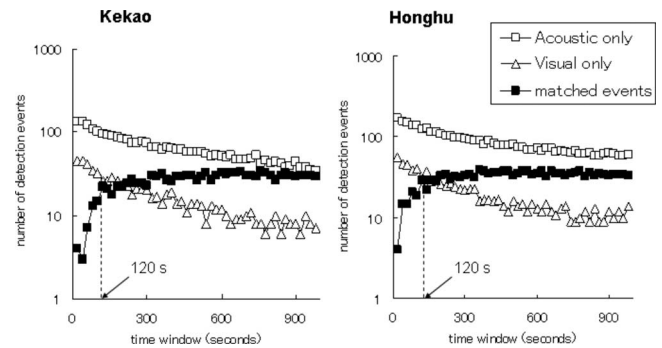


FIG. 6. Number of matched and unmatched detection events. As the time window increases, the number of matched events (black squares) increases while the number of unmatched acoustic and visual events decreases. The number of matched events becomes saturated for a time window of 120 s.

number of matched events and reduces false matching. However, this has the potential of missing matches even if the two independent detections were the same animal.

To determine an appropriate length of the time window, detected numbers of matched events were calculated according to time window lengths ranging from 20 to 1000 s (Fig. 6). For both vessels, the number of matched events (black squares) was quite low when the time window was short (e.g., 20 or 40 s). In this case, many matches are expected to be missed. Matched events increased quickly as the duration of the time window increased up to 120 s, indicating that the number of matching events for identical groups increased. However, the number of matched events became saturated for time window over 140 s. As the time window lengthened, the total number of time bins decreases, whereas the number of matched events including false matches rises. Therefore, the total number of matched events is stable and independent of the time window, even for two detection events that are random and uncorrelated. This means that visual and acoustic detection events are correlated with each other for time windows shorter than 120 s.

C. Detection probability

The calculated probability of acoustic detections was approximately twice that of visual detections for any time window less than 1000 s duration for both vessels (Fig. 7). Acoustic detection probability was consistently greater than that of visual observations regardless of the time window's

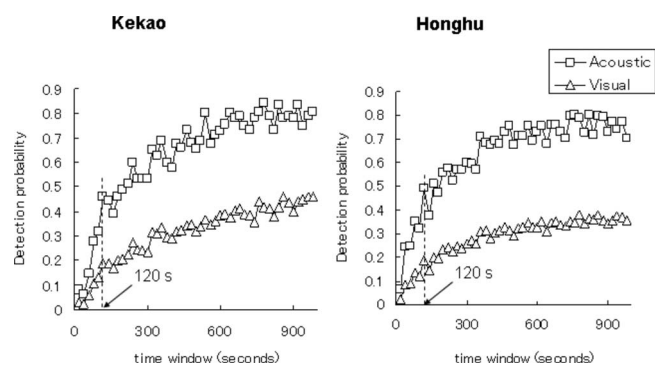


FIG. 7. Detection probability of acoustic (squares) and visual (triangles) observations as a function of the time window width.

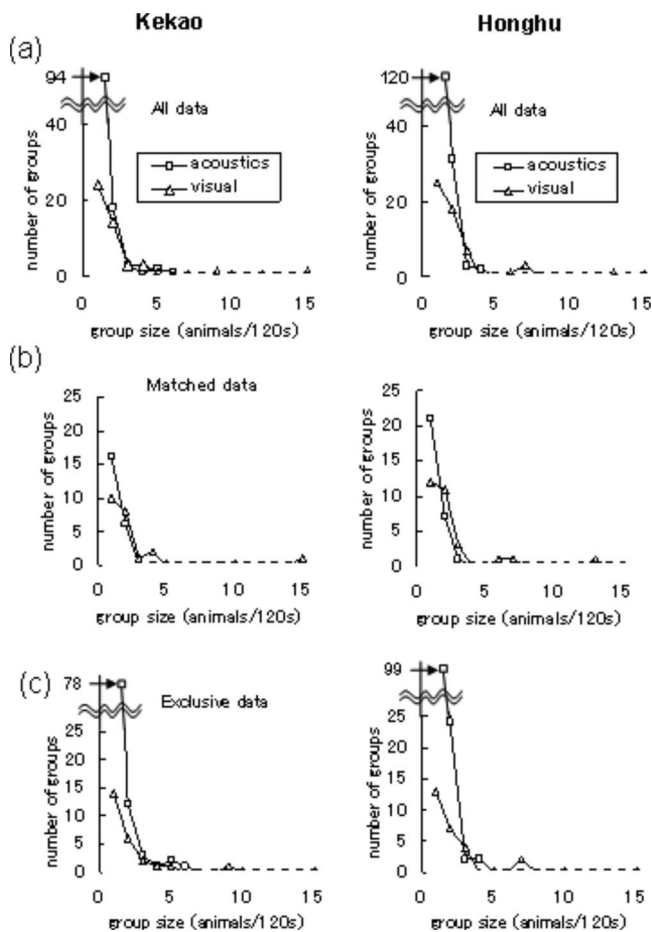


FIG. 8. Comparisons of group size detected acoustically and visually. (a) Accumulated data of all detections show a large difference in the detected number of isolated animals. (b) Matched detection of the two methods that is linked by a 120 s time window. (c) Exclusive data indicate a large difference in the number of detections of single animals depending on method.

duration, though the detection probability for time window lasting more than 140 s may have included false matches of acoustic and visual detections.

D. Group size

We defined group size as the number of porpoises detected during a particular time window. We chose a 120 s time window to compare the estimated group size from the methods. There was a large difference between the acoustic and visual observations for groups of one or two animals [Fig. 8(a)]. This pooled distribution can be resolved into a matched component and an exclusive component [Fig. 8(b) and 8(c)]. The exclusive component is the animals that are detected only by the acoustic or visual method. The matched component shows 50% more acoustic detections than visual detections of single porpoises. For exclusive data, the number of acoustic detections of single porpoise was five times the number from visual observations [Fig. 8(c)].

The large difference in the detection of isolated animals shown in Fig. 8 is the probable cause of the differences in detection probabilities between visual and acoustic methods shown in Fig. 7. To examine this effect, we recalculated the matched number of detections by using only two or more individuals observed in the time window. That is, all of the

single animals detected visually and acoustically within a specific time window were ignored. The results are shown in Fig. 9. In this case, the detection probabilities for the two methods were almost the same at any time window. The number of matched events (black squares) gradually increased compared to Fig. 6.

IV. DISCUSSION

The stereo passive acoustic system using A-tag data loggers was successful in detecting and counting finless porpoises in the Yangtze River. The numbers of porpoises counted by the two survey vessels were similar for acoustic (204 vs 199) and visual (163 vs 162) methods. The maximum acoustic detection range of 300 m is approximately double the effective detection distance for finless porpoises using acoustic data loggers reported by Wang *et al.* (2005). In that study, the distance was 150 m with a correct detection level of 77.6% and a false alarm level of 5.8%. Correct acoustic detections did not occur at distances greater than 250 m in their study, possibly because of the less sensitive hydrophone (-210 dB/V). The strip width of 300 m was chosen for the present analysis of acoustic and visual detection based on the maximum acoustical detection distance collected in this study.

The probability of detecting finless porpoises using passive acoustic methods was twice that for visual observations for both vessels during any time window (Fig. 7). This was due to a large difference between the two methods in detecting single porpoises. The acoustic system detected five times more porpoises than did the visual observations [Fig. 8(c)].

Finless porpoises are known to be among the most difficult aquatic animals to detect visually because they are small, lack a dorsal fin, do not jump or porpoise above the water surface, are only slightly darker than the turbid waters of the Yangtze River, and are undetectable from a ship when submerged. Small groups of dolphins and porpoises are generally more difficult to detect compared to large whales. Baleen whales and large toothed whales usually produce large and visible respirations that may linger for several seconds or more and are visible over relatively great distances. Only large schools of dolphins and porpoises are easier to detect visually though estimates of group size may be more difficult.

When we considered detections of two or more porpoises and ignored sightings of solitary porpoises, the detection probabilities were similar for visual and acoustic methods on both vessels (Fig. 9). This indicates that the differences between the estimates of porpoises seen from the two methods was due to the difficulty in visually detecting solitary porpoises.

A. Performance of acoustic detection system

Although the acoustic method was better than the visual method in detecting solitary animals, acoustic detection of porpoises was limited by its inability to count more than five porpoises simultaneously during a 120 s time window. For animals congregated in a small area, it is difficult to differentiate the sources of sounds from individual porpoises es-

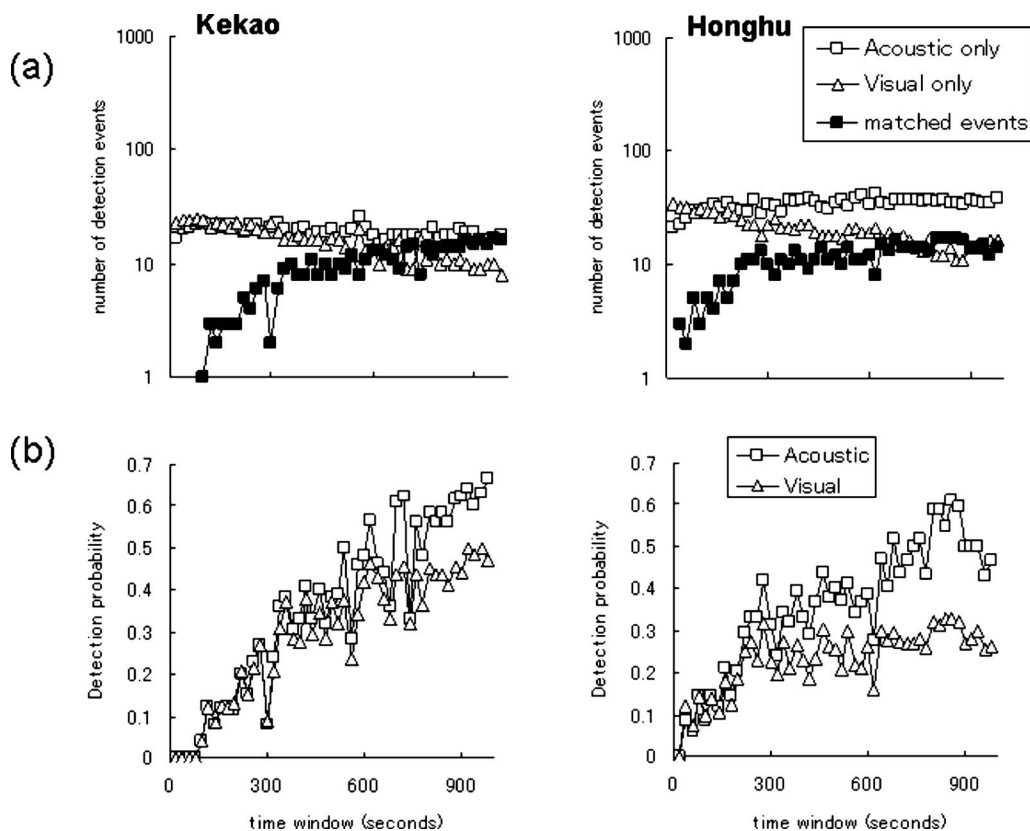


FIG. 9. (a) Number of matched detections using only the data for group size of two or more porpoises. (b) The detection probabilities of visual and acoustic methods for multiple individual groups were similar during all time windows shorter than 300 s. Note that longer time window tends to include two separated detection of animals in single time bin. This caused the total number of detection of multiple individuals occasionally increased according to the time window.

pecially for larger groups. This is evidently due to the short 11 cm base line of the A-tag data logger. The 271 ns time of arrival difference resolution corresponds to a 3.7 MHz sampling frequency, which is sufficient to measure the trigger within a wavelength. However, the level of received pulses was not the same for the two hydrophones on a single data logger. Even within a wavelength, the trigger point of each hydrophone changed. This robust resolution will be improved by using systems with longer base lines.

The acoustic detection distance is influenced by the source level, source directionality, and sound propagation. The source level of finless porpoises is estimated at approximately 163.7–185.6 dB re 1 μ Pa at 1 m for the on-axis direction (Li *et al.*, 2006), and the sound pressure level for the off-axis beam is 162 dB peak to peak for a 1 μ Pa reference (Akamatsu *et al.*, 2005c). The detection threshold level of the A-tag data logger was 136.1 dB, which is around 30–50 dB lower than the source levels in different directions from a porpoise. Sound propagation in shallow water systems, such as the Yangtze River, is complex. Our vessel traveled mostly within the shipping lane, which is around 20 m deep, though porpoises could travel in shallow waters along the river banks.

B. Future works

Once the detection probability within the strip transect is obtained, the number of animals within the strip transect can be calculated as the observed number of animals divided by

the detection probability. Abundance is the density of the animal within the strip width times the area of the focal sites as long as the density is able to be used outside of the transect width. However, several parameters should be examined before conducting this calculation.

First, the rate of sound production by an animal strongly affects the detection probability. Biologging observation of phonation behavior will help to understand this parameter (Akamatsu *et al.*, 2005a). Second, animal behavior affects the detection probability. For the precise matching between visual and acoustical detections, extrapolation of animal movement during two detections will be needed. Ship avoidance behavior can be observed by the hydrophone array system to identify the sound source. Third, the detection probability is also influenced by the heterogeneity of the independent observers, for example, one may be much better at locating animals than the other. If some of the animals are easy to spot but others are difficult, this also contributes to a heterogeneity bias in the calculated detection probability. To solve this issue, independent double acoustical monitoring will work. When identical systems are operated simultaneously, no heterogeneity is expected. Comparing detections by primarily and secondary acoustical system will provide less biased detection probability.

In conclusion, simple and relatively inexpensive acoustic logging systems like the one we used in this survey of finless porpoises in the Yangtze River should enhance population surveys of cetaceans that vocalize often and travel in relatively small groups. The passive acoustic survey system

worked well for detecting solitary porpoises, which are hard to detect otherwise by visual methods, though it did not work as well for counting porpoises in large groups. Consequently, combining stereo passive acoustic methods with traditional visual observation methods should provide more accurate estimates of population abundance for dolphins and porpoises.

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