Acoustic capture-recapture method for towed acoustic surveys of echolocating porpoises

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Passive acoustic monitoring for cetaceans mainly employ fixed-location methods or point transect samplings; an acoustic survey from a moving platform to conduct line transects is less common. In this study, acoustic capture–recapture by combining a double-observer method with line transect sampling was performed to observe Yangtze finless porpoises. Two acoustic devices were towed with the distance between them varying 0.5 to 89.5 m. The conditional probabilities that both devices would detect the porpoises within the same time window were calculated. In a 1-s time window, it became smaller as the distance between the devices increased, approaching zero when the distance between them was more than 50 m. It was considered that the devices with less than 50 m distance detected the same signals from the same animals, which means the identical detection. When the distance between them is too great, the recapture rate is reduced and the incidence of false matching may increase. Thus, a separation distance of around 50 m between two devices in acoustic capture–recapture of Yangtze finless porpoises was recommended. Note that the performance of the double detections can change depending on the particular device used and on animal behaviors such as vocalizing interval, ship avoidance.
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I. INTRODUCTION

Effective conservation and management of animal populations requires knowledge of the animals' absolute density or abundance. Strip or line transect sampling (Buckland *et al.*, 2001) is a common method of estimating population size in a relatively large area for both terrestrial (e.g., Marques *et al.*, 2001; Buckland *et al.*, 2007) and aquatic animals (e.g., Hammond *et al.*, 2002; Innes *et al.*, 2002; Slooten *et al.*, 2004). The animal density or abundance of cetaceans can be estimated using passive acoustic monitoring (reviewed by Marques *et al.*, 2013). However, density estimates surveys mainly employ fixed-location method or point transect samplings; acoustic survey from a moving platform to conduct line transects is less common.

One of the key assumptions of strip or line transect sampling is that animals within the strip or on the line are certain to be detected (Buckland *et al.*, 2001), described as $g(0) = 1$. Marine mammals may engage in long dives that result in missed detections even on the transect line. If animals on the survey line are not always detected, i.e., $g(0) < 1$, the abundance is underestimated. In this situation, it is helpful to use double-observer or double-platform sampling (e.g., Borchers *et al.*, 1998; Chen, 2000; Buckland *et al.*, 2010; Walsh *et al.*, 2010). To date, the validity of the acoustic capture–recapture method for phonating animals has not been confirmed.

Akamatsu *et al.* (2008) applied an acoustic and visual capture–recapture method for Yangtze finless porpoises (*Neophocaena asiaeorientalis asiaeorientalis*) to strip-

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transect sampling. They used an acoustic sensor with multiple hydrophones that could identify individual sound sources (i.e., count the number of porpoises) using the bearing angle of the recorded sounds (Kimura *et al.*, 2009; Akamatsu *et al.*, 2008), which was calculated from the time difference of their arrival in the system. The difference in position between visual observers (in the bow of the boat) and acoustic sensors (being towed 120 m behind the boat), as well as the difference in their detection times, could result in false matching of individual animals. To compensate the distance between them, Akamatsu *et al.* (2008) considered the detections to be matched when a porpoise was detected by both visual observers and acoustic detectors within a certain time window.

However, there was a fundamental problem with this technique. It is that visual and acoustic methods detect completely different cues. A visual observer detects the animals only when they approach the surface, whereas the acoustic method detects them only when they produce sounds. The rate of cue production is very different for visual and acoustic cues. The surfacing intervals in two individual Yangtze finless porpoises were 15.4 or 28.7 s on average (Akamatsu *et al.*, 2002), as monitored by biologging systems, and click train phonation intervals were 5–6 s on average for click train production in six individuals (Akamatsu*et al.*, 2005a; Akamatsu *et al.*, 2007).

Acoustic capture–recapture using two identical acoustic detectors (i.e., hydrophones) from the same survey platform is an ideal solution that avoids the issues described above. The advantages of passive acoustic observation for small odontocetes have been addressed extensively (e.g., reviewed by Mellinger *et al.*, 2007; Marques *et al.*, 2013). The signal-to-noise ratio of their echolocation signals is high. Source levels of those sounds can be up to approximately 200 dB for small porpoises (Li *et al.*, 2009; Villadsgaard *et al.*, 2007) and over 220 dB for Delphinidae species (e.g., bottlenose dolphins *Turshiops truncatus*; Au, 1993). Moreover, acoustic surveys can be completed using fewer people and avoid human observation bias due to inexperience or fatigue. The same detectors (i.e., hydrophones) have identical detection sensitivity, so leading less observational bias.

One concern regarding the use of two acoustic detectors is that the detections should not be identical. If two detectors are towed in very close proximity to each another, they may obtain identical data. This situation is analogous to fixing two video cameras at the same location and directing them at the same angle. To avoid this problem, it is necessary to place the detectors with a large distance between them. However, when the distance between them is too great, the recapture rate is reduced and the incidence of false matching may increase, like two independent ships cruising on the same line for baleen whale visual observations. It needs to estimate a distance that minimizes detection of identical sounds and allows recapture of same animals.

In this study, we demonstrated acoustic capture–recapture by towing recording systems with different distances between them. We deployed devices called A-tags to record the echolocation signals of Yangtze finless porpoises and calculated the probability that both A-tags would detect the individual within a given time window. First, we compared visual and acoustic detection with different distances of the A-tags as a reference to Akamatsu *et al.* (2008). Then, we compared detection by two acoustic devices in order to determine the best distance between the acoustic systems.

II. MATERIALS AND METHODS

A. Acoustic observations

The A-tags, acoustic data loggers manufactured by Marine Micro Technology, Saitama, Japan (Akamatsu *et al.*, 2005b), were towed as passive acoustic observations around the junction between the middle reaches of the Yangtze River and Poyang Lake (N 29°35′–53′, E 116°02′–24′) in August and November 2010, February, May, and December 2011, and May 2012. In the survey area, the water level was highest in August (summer), lowest in February (winter), and mid-level in May (spring) and November (autumn). The survey boat (∼12 m in length) was operated at a distance of about 300 m from the bank. We chose this distance because the A-tag detection distance was approximately 300 m (Akamatsu *et al.*, 2008), although sometimes we had to change the boat's position to avoid ship traffic and shoals. The river width was 1–2 km, which was larger than the observable range of the A-tags. Therefore, the detection range of the system is always within the river. To prevent counting the same animal more than once, we ran the boat at 4.5–6 km/h upstream and 10–15 km/h downstream, which was faster than the average swimming speed of the porpoises, 1.2–1.4 m/s (Akamatsu *et al.*, 2002), i.e., 4.5 km/h approximately.

The A-tag consists of two ultrasonic hydrophones approximately 170 mm apart, with a passive band-pass filter circuit (−3 dB, range 55–235 kHz), a high-gain amplifier (+60 dB), a CPU (PIC18F6620; Microchip, Detroit, MI, USA), flash memory (128 MB), and a lithium battery (CR2), all housed in a waterproof aluminum case. This system uses a pulse-event recorder to measure the sound pressure level and the difference in sound arrival time between the two hydrophones. It does not record the waveform of the received sound. A band-pass filter of 55–235 kHz was used to eliminate background noise. This filter received the frequency band of Yangtze finless porpoise sonar signals, which are in the 87–145 kHz range and average 125 ± 6.92 kHz (Li *et al.*, 2005).

B. Visual observations

Detections by visual observation during August 2010 were used as ground truth data and compared with results obtained by the acoustic detectors towed from the same boat. Two observers in the bow of the boat searched for animals without binoculars to cover the 90° on his side, with essentially no overlap. After being on duty for 1 h, they rested for 30 min; eye height was fixed approximately 2 m above the water surface. All visual observers estimated distances to objects were in good agreement with true distance measured by a laser range finder (Elite 1500 7 mm × 26 mm, Bushnell, Overland Park, KS).

C. Signal processing

Before we counted the number of animals acoustically, we eliminated noise contaminating by using a custom-made program developed IGOR PRO 6.03 (Wave Metrics, Lake Oswego, OR). The detection threshold level of the data logger was set to 132.5 dB re 1 μPa (peak to peak). Because the A-tags differ slightly in sensitivity, we employed the maximum detection threshold level among the different A-tags used in this experiment to standardize the data set for comparison. Pulses within 1 ms after the direct path pulse were possible surface or bottom reflections and were eliminated by the offline noise filter (Kimura *et al.*, 2010).

Cleaned data (Fig. 1) illustrate the sound pressure level and the bearing angle calculated by the difference in the time of the sound's arrival as measured by the two hydrophones, and the inter-click interval (ICI) of the detected porpoise clicks. ICIs and sound pressure levels changed smoothly, whereas background or boat noise caused randomly changing patterns in ICI and sound pressure (Li *et al.*, 2010). The bearing angle for porpoise vocalizations always changed from positive to negative (see Fig. 1, middle), indicating that the survey boat always passed the animals from bow to stern because it was moving faster than they could swim (see above). Although the clocks in the A-tags were synchronized before the survey was performed, we synchronized the clocks between loggers using characteristics ICI (Fig. 1) as a signal for data matching.

D. Number of porpoises detected in a given time window

Animals were counted when they passed abeam (Fig. 1). If a sound was not detected at that point, they were counted as they passed at the closest angle to abeam. When more than two animals were swimming in synchrony, the sound source directions were similar and could not be separated. When more than two animals were swimming in synchrony, the sound source directions were similar and could be identified through the double different cyclic characteristics of the sound pressure and/or ICIs within a single trace (Kimura *et al.*, 2009). In Yangtze finless porpoises, it was confirmed that the sound production rate did not differ as group size increased (Kimura *et al.*, 2010), which implies independent use of the signals and means that the signals can still be used to count the number of individuals (Akamatsu *et al.*, 2008, Kimura *et al.*, 2009).

We applied the method of Akamatsu *et al.* (2008) to estimate the probability of detecting the same animal. When one or more porpoises were detected by both A-tags in the same time window, the detections were considered to be matched. Because this species does not form large groups and the population density is low (e.g., Akamatsu *et al.*, 2008; Kimura *et al.*, 2010), it was likely that the A-tags were detecting the same animals. The time window was changed from 5 s to 600 s every 5 s in order to provide visual–acoustic comparison and from 1 s to 200 s every 1 s in order to provide two acoustic detections.

The probability that observer 1 detected the animals was defined as the ratio between the number of the time windows in which the animal was detected by observer 1 (N_1) and the total number of animals in the strip transect (N). N could not be measured directly. Additionally, the detection probability cannot be modeled without detailed information about sound source characteristics such as phonation rate, source level, and beam pattern, which are not available for many species and circumstances. Instead, we calculated the conditional probability to detect the same animals by examining changes in the number of porpoises detected in a given time window. If we assume that the number of animals detected by observer 2 (N_2) is another sampling population, we can estimate $P(2|1)$from the number of both positive detections (N_m) over the total number of detections by observer 2 (N_2) and vice versa, as shown in Eq. (1) and (2). Matched detections (N_m) were defined as detection of the porpoises by both observers during a particular time window; see details in Akamatsu *et al.* (2008). Note that the physical detection performance of the acoustic system remained the same at all times by using the same detection threshold level of sound pressure.

$$\hat{P}(2|1) = N_m/N_1, \tag{1}$$

$$\hat{P}(1|2) = N_m/N_2. \tag{2}$$

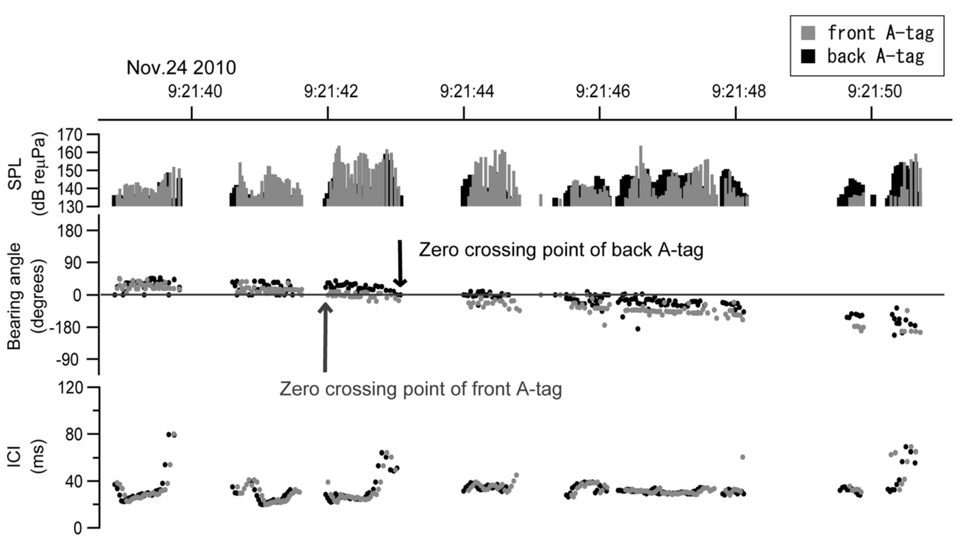

FIG. 1. An example of identical echo-location signals from a single porpoise passing data loggers A5 and A6, which were 3.5 m apart. The time of detection was defined as the zero crossing point of relative bearing angle (middle). Note that the time in the front A-tag was intentionally shifted by 0.1 s.

TABLE I. Summary of visual (V) and acoustic observations (A1 to A24).

Aug. 2010	V	A1	A2	A3	A4	
number of porpoises detected	77	104	96	107	110	
km surveyed	161	161	161	161	161	
porpoises detected/km	0.478	0.646	0.596	0.665	0.683	
distance from the boat stern	-	35.5	40	57	125	
Nov. 2010	A5	A6	A7			
number of porpoises detected	62	68	66			
km surveyed	127	127	127			
porpoises detected/km	0.488	0.535	0.520			
distance from the boat stern	40	43.5	44.5			
Feb. 2011	A8	A9	A10	A11		
number of porpoises detected	78	81	73	75		
km surveyed	124	124	124	124		
porpoises detected/km	0.629	0.653	0.589	0.605		
distance from the boat stern	34.5	35.5	36.5	39		
May 2011	A12	A13				
number of porpoises detected	82	84				
km surveyed	126	126				
porpoises detected/km	0.651	0.667				
distance from the boat stern	38.5	39				
Dec. 2011	A14	A15	A16	A17	A18	
number of porpoises detected	71	80	86	89	96	
km surveyed	126	126	126	126	126	
porpoises detected/km	0.563	0.635	0.683	0.706	0.762	
distance from the boat stern	45	65	75	43	58	
May 2012	A19	A20	A21	A22	A23	A24
number of porpoises detected	75	69	68	74	48	71
km surveyed	172	172	172	172	119	119
porpoises detected/km	0.436	0.401	0.395	0.430	0.403	0.597
distance from the boat stern	30	40	50	90	35	65

III. RESULTS

A. Comparison between visual and acoustical observations

The A-tags were towed with the distance of 0.5 to 89.5 m (Table I). Simultaneous visual observation noted 77 porpoises in August 2010 (Table I). The average time difference between visual detections of two animals was 1617 s (483–2571 s, 95% C.I.); by acoustic observation, it was 378 s (218–538 s, 95% C.I.) in August 2010, 618 s (199–1038 s, 95% C.I.) in November 2010, 624 s (367–880 s, 95% C.I.) in February 2011, 533 s (246–820 s, 95% C.I.) in May 2011, 521 s (398–645 s, 95% C.I.) in December 2011, and 781 s (555–1008 s, 95% C.I.) in May 2012. The conditional probability of acoustic detection was about twice that of visual detection, regardless of the time windows and distances between the visual observer and the acoustic detector (Fig. 2). On the other hand, the number of porpoises sighted by visual observation in a given time window showed about twice that of acoustic method (Fig. 3). The numbers of porpoises detected acoustically within a given time window did not exhibit any seasonal variation (Fig. 3).

B. Comparison between two acoustic observations

The probability of detecting the same animals calculated from acoustic observations was very similar between the detectors [Figs. 4(a)–4(d)]. When they were in close proximity, the two acoustic detectors showed high conditional probabilities, even within very short time windows [Figs. 4(a) and 5]. When the A-tags were deployed 0.5 m apart, the probability that they would detect the animals within the same time window was approximately 0.7 even in the 0 s time window. The conditional probabilities during a 1-s time window reduced as the distance between the A-tags increased and approached zero, less than 0.05, when the

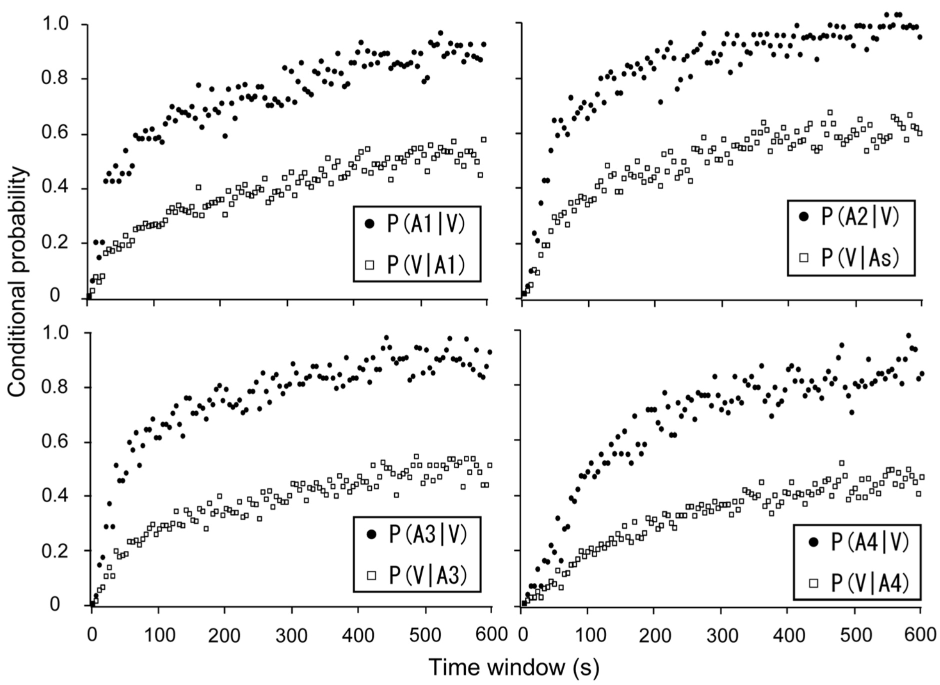

FIG. 2. Conditional probabilities of visual and acoustic observations. The number of acoustic systems corresponds to the numbers in Table I.

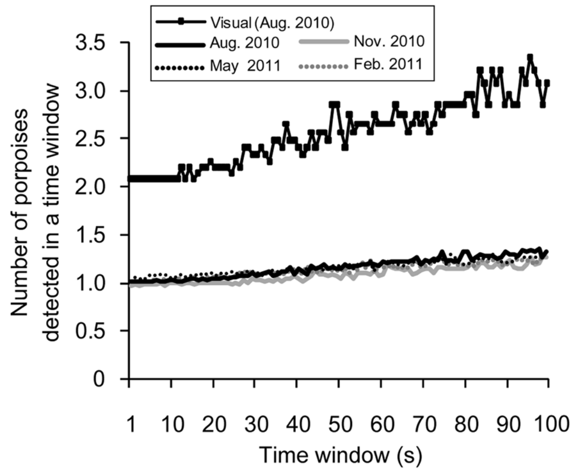

FIG. 3. Number of porpoises detected in a given time window. Although there was no difference in the number of porpoises detected by acoustic observations during four different seasons, there were about twice as many visual detections as acoustic observations. This fact highlights the difficulty of sighting a single animal by visual observation as mentioned in previous studies (Akamatsu *et al.*, 2008; Kimura *et al.*, 2009).

distance between the A-tags exceeded 50 m [Fig. 5(a)]. The rear A-tags tended to detect more porpoises than the front A-tags (Figs. 4 and 5).

IV. DISCUSSION

Not surprisingly, acoustic detectors in close proximity to each other (such as 0.5 m apart) exhibited a high rate of detecting the same animals even with a very short 1-s time window [Figs. 4(a) and 5]. Because of the high speed of sound underwater (1500 m/s), it was likely that the A-tags detected the same signals from the same animals. This was considered as identical detection due to the close positioning between the A-tags, which should not be used for mark-recapture. However, even if two A-tags are very close together, such as only 0.5 m apart, they cannot detect all animals [Figs. 4(a) and 5]. Animal swimming behavior and a narrow beam of directionality are possible reasons. The rope beside the hydrophone that is used to tow the system also might cast a sound propagation shadow.

At a long time window (Fig. 4), such as 100 s [Fig. 5(b)], the probability of detecting the porpoises was as high as 0.8–0.9 approximately when the A-tags were deployed shorter than 50 m apart from each other (Fig. 5). When the distance between the devices was too great, especially longer than 50 m, the conditional probability was reduced (Fig. 5) and the incidence of false matching may increase. The identical detection was small and the recapture rate was still high at a distance of 50 m (Fig. 5). Thus, we determined that the best separation distance between two A-tags to detect Yangtze finless porpoises was around 50 m.

Porpoises swim at an average speed of 1.2–1.4 m/s (Akamatsu *et al.*, 2002). Therefore, a porpoise can swim either away from or into the detection range and can change the sonar axis during a 40–70 s time window. The time window should be at least longer than the cue production rate, i.e., phonating intervals for acoustic and surfacing intervals for visual observation (Akamatsu *et al.*, 2013). Kimura *et al.* (2013) reported that the inter-click train interval of this species is 6.3 s on average. Additionally, the acoustic devices were placed at a maximum distance of 89.5 m in this study, which needs approximately 90 s to encounter the same animals with the minimum boat speed of 4.5 km/h. Thus, at least about 100 s was deemed necessary as time windows to detect the same animals by two A-tags.

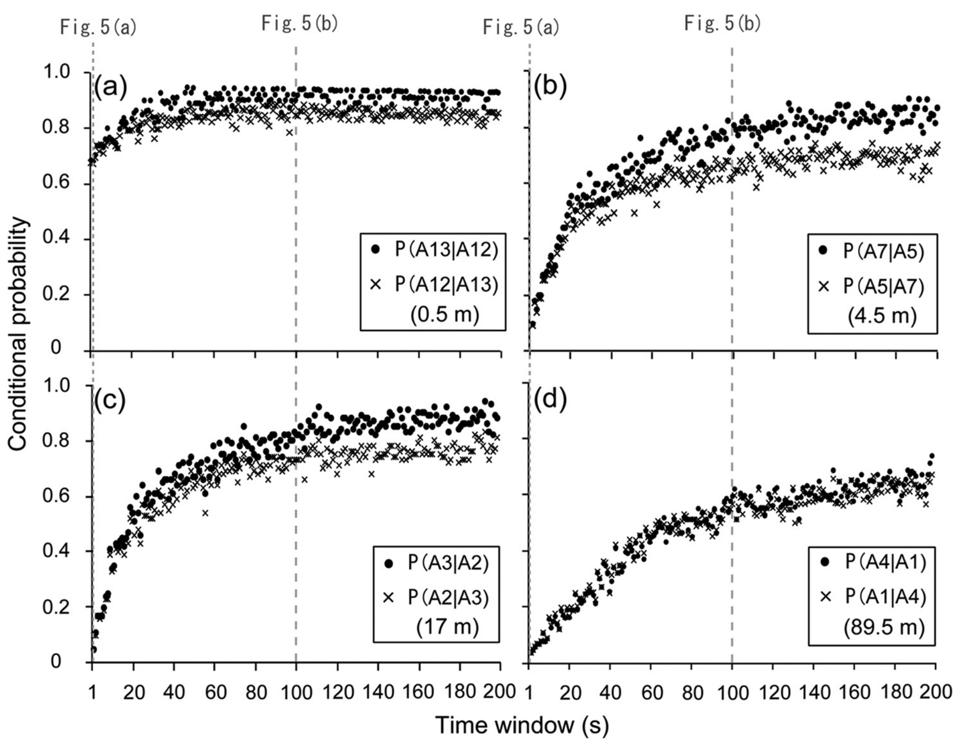

FIG. 4. Condition probabilities of acoustic observations. The number of acoustic systems corresponds to the numbers in Table I.

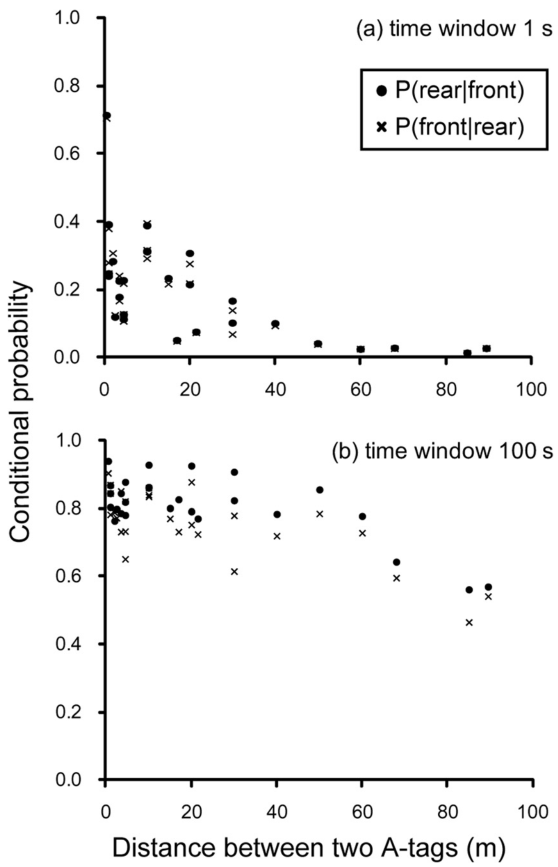

FIG. 5. The association between conditional probability and distance between A-tags in 1-s and 100-s time windows.

As suggested by Akamatsu *et al.* (2008), the passive acoustic observation found Yangtze finless porpoises approximately twice as often as visual observation at four different distances between them (Fig. 2). The low conditional probabilities of the visual method were attributed mainly to a large ratio of missed single porpoises as described in Akamatsu *et al.* (2008), as more than two porpoises were detected visually (Fig. 3). In contrast, the number of porpoises detected by acoustics within a given time window, which may be close to group size, was around one during all four seasons of data collection (Fig. 3). This finding would be beneficial for acoustic monitoring of this population with less biased detections in different seasons.

With the exception of one case in which there was a short distance between two A-tags, the rear A-tags had a slightly higher probability of detecting the animals (Figs. 4 and 5). This finding indicates that more porpoises can be detected further from the survey boat. Li *et al.* (2008) also suggested that the porpoises might have been moving away from the vessel initially. Furthermore, our results indicated that they might come back toward the line after the boat crossed it. To reduce the effect of responsive movement to the survey boat (Palka and Hammond 2001), the acoustic detector should be towed as far back as possible from the boat.

This study demonstrates that the acoustic capture–recapture method is a viable alternative to visual observation. Although animal density of cetaceans can be estimated using passive acoustic monitoring (reviewed by Marques *et al.*, 2013), to date, fixed-location surveys with a stationed sensor akin to the point transect are mainly used. Acoustic observation from a moving sensor platform (i.e., towed passive acoustic monitoring) akin to the line transect expands the usefulness of passive acoustic monitoring for estimating population abundance in a large territory. Note that the performance of the systems can be affected by the specific acoustic device used and by animal behaviors such as their vocalizing interval, sound propagation, and ship avoidance. Thus, the technique should be adapted to suit the individual target species, device, and platform.

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Akamatsu, T., Matsuda, A., Suzuki, S., Wang, D., Wang, K., Suzuki, M., Muramoto, H., Sugiyama, N., and Oota, K. (**2005b**). "New stereo acoustic data logger for tagging on free-ranging dolphins and porpoises," Mar. Technol. Soc. J. **39**, 3–9.

Akamatsu, T., Teilmann, J., Miller, L. A., Tougaard, J., Dietz, R., Wang, D., Wang, K., Siebert, U., and Naito, Y. (**2007**). "Comparison of echolocation behaviour between coastal and riverine porpoises," Deep Sea Res., Part II **54**, 290–297.

Akamatsu, T., Ura, T., Sugimatsu, H., Bahl, R., Behera, S., Panda, S., Khan, M., Kar, S. K., Kar, C. S., Kimura, S., and Sasaki-Yamamoto, Y. (**2013**). "A multimodal detection model of dolphins to estimate abundance validated by field experiments," J. Acoust. Soc. Am. **134**, 2418-2426.

Akamatsu, T., Wang, D., Wang, K., Li, S., Dong, S., Zhao, X., Barlow, J., Stewart, B. S., and Richlen, M. (**2008**). "Estimation of the detection probability for Yangtze finless porpoises (*Neophocaena phocaenoides asiaeorientalis*) with a passive acoustic method," J. Acoust. Soc. Am. **123**(6), 4403–4411.

Akamatsu, T., Wang, D., Wang, K., and Naito, Y. (**2005a**). "Biosonar behaviour of free-ranging porpoises," Proc. R. Soc. Lond. B. **272**, 797–801.

Akamatsu, T., Wang, D., Wang, K., Wei, Z., Zhao, Q., and Naito, Y. (**2002**). "Diving behavior of freshwater finless porpoises (*Neophocaena phocaenoides*) in an oxbow of the Yangtze River, China," ICES J. Mar. Sci. **59**, 438–443.

Au, W. W. L. (**1993**). *The Sonar of Dolphins* (Springer, New York), pp. 1–273.

Borchers, D. L., Zucchini, W., and Fewster, R. (**1998**). "Mark-recapture models for line transect surveys," Biometrics **54**, 1207–1220.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., and Thomas, L. (**2001**). *Introduction to Distance Sampling: Estimating Abundance of Biological Populations* (Oxford University Press, Oxford, UK), pp. 1–432.

Buckland, S., Borchers, D., Johnston, A., Henrys, P., and Marques, T. (**2007**). "Line transect methods for plant surveys," Biometrics **63**, 989–998.

Buckland, S. T., Laake, J. L., and Borchers, D. L. (**2010**). "Double-observer line transect methods: Levels of independence," Biometrics **66**, 169–177.

Chen, S. X. (**2000**). "Animal abundance estimation in independent observer line transect surveys," Environ. Ecol. Stat. **7**, 285–299.

Hammond, P. S., Berggren, P., Benke, H., Borchers, D. L., Collet, A., Heide-Jørgensen, M. P., Heimlich, S., Hiby, A. R., Leopold, M. F., and Øien, N. (**2002**). "Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters," J. Appl. Ecol. **39**, 361–376.

Innes, S., Heide-Jørgensen, M. P., Laake, J. L., Laidre, K. L., Cleator, H., Richard, P., and Stewart, R. E. A. (**2002**). "Surveys of belugas and narwhals in the Canadian high Arctic in 1996," Sci. Publ. North. Atl. Mar. Mamm. Comm. **4**, 169–190.

Kimura, S., Akamatsu, T., Li, S., Dong, S., Dong, L., Wang, K., Wang, D., and Arai, N. (**2010**). "Density estimation of Yangtze finless porpoises using passive acoustic sensors and automated click train detection," J. Acoust. Soc. Am. **128**, 1435–1445.

Kimura, S., Akamatsu, T., Wang, D., Li, S., Wang, K., and Yoda, K. (**2013**). "Variation in the production rate of biosonar signals in freshwater porpoises," J. Acoust. Soc. Am. **133**, 3128–3134.

Kimura, S., Akamatsu, T., Wang, K., Wang, D., Li, S., Dong, S., and Arai, N. (**2009**). "Comparison of stationary acoustic monitoring and visual observation of finless porpoises," J. Acoust. Soc. Am. **125**, 547–553.

Li, S., Akamatsu, T., Wang, D., and Wang, K. (**2009**). "Localization and tracking of phonating finless porpoises using towed stereo acoustic data-loggers," J. Acoust. Soc. Am. **126**, 468–475.

Li, S., Akamatsu, T., Wang, D., Wang, K., Dong, S., Zhao, X., Wei, Z., Zhang, X., Taylor, B., Barrett, L., Turvey, S. T., Reeves, R. R., Stewart, B. S. Richlen, M., and Brandon, J. R. (**2008**). "Indirect evidence of boat avoidance behavior of Yangtze finless porpoises," Bioacoustics **17**, 174–176.

Li, S., Dong, S., Kimura, S., Akamatsu, T., Wang, K., and Wang, D. (**2010**). "Detection of Yangtze finless porpoise in the Poyang Lake mouth area via passive acoustic data-loggers," in *Biology, Evolution, and Conservation of River Dolphins within South America and Asia*, edited by M. Ruiz-Garcia and J. M. Shostell (Nova Science Pub Inc., New York), pp. 343–355.

Li, S. Wang, K., Wang, D., and Akamatsu, T. (**2005**). "Echolocation signals of the free-ranging Yangtze finless porpoise (*Neophocaena phocaenoides asiaeorientialis*)," J. Acoust. Soc. Am. **117**(5), 3288–3296.

Marques, F. F. C., Buckland, S. T., Goffin, D., Dixon, C. E., Borchers, D. L., Mayle, B. A., and Peace, A. J. (**2001**). "Estimating deer abundance from line transect surveys of dung: Sika deer in southern Scotland," J. Appl. Ecol. **38**, 349–363.

Marques, T. A., Thomas, L., Martin, S. W., Mellinger, D. K., Ward, J. A., Moretti, D. J., Harris D., and Tyack, P. L. (**2013**). "Estimating animal population density using passive acoustics," Biol. Rev. **88**, 287–309.

Mellinger, D. K., Stafford, K. M., Moore, S. E., Dziak, R. P., and Matsumoto, H. (**2007**). "An overview of fixed passive acoustic observation methods for cetacean," Oceanography **20**, 36–45.

Palka, D. L., and Hammond, P. S. (**2001**). "Accounting for responsive movement in line transect estimates of abundance," Can. J. Fish. Aquat. Sci. **58**, 777–787.

Slooten, E., Dawson, S. M., and Rayment, W. J. (**2004**). "Aerial surveys for coastal dolphins: abundance of Hector's dolphins off the South Island west coast, New Zealand," Mar. Mamm. Sci. **20**, 117–130.

Villadsgaard, A., Wahlberg, M., and Tougaard, J. (**2007**). "Echolocation signals of wild harbour porpoises, *Phocoena phocoena*," J. Exp. Biol. **210**, 56–64.

Walsh, P., Reynolds, J., Collins, G., Russell, B., Winfree, M., and Denton, J. (**2010**). "Application of a double-observer aerial line-transect method to estimate Brown bear population density in Southwestern Alaska," J. Fish Wildl. Manage. **1**(1), 47–58.