# Passive acoustic survey of Yangtze finless porpoises using a cargo ship as a moving platform

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In order to periodically investigate the population and distribution of the Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) in its main distribution range in the Yangtze River, a passive acoustic system deployed on a cargo ship as a moving platform, rather than a dedicated research ship, was developed. A stereo acoustic event data-logger (A-tag) was installed on the cargo ship to passively detect phonating animals. In three surveys carried out in the Yangtze River from Wuhan to Shanghai, an average of 6059 clicks in each survey and 284 porpoises in total were acoustically detected along an 1100-km stretch. The animals were detected frequently in most of the survey range except two "gap sections" with 40 and 60 km lengths, respectively, where no animals were detected in all three surveys. Detected group sizes of the animals in each 120-s time window were not significantly different among the surveys, but the distribution pattern was different and suggested seasonal migration. The cargo ship based passive acoustic survey was effective in detecting phonating animals and can potentially monitor the distribution and population trend over time. Compared to surveys that used dedicated research ships, the present method is more cost effective. © *2011 Acoustical Society of America*. [DOI: 10.1121/1.3625257]

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## I. INTRODUCTION

The Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) is the only freshwater subspecies of the narrow-ridged finless porpoise (*Neophocaena asiaeorientalis*), inhabiting the middle and lower reaches of the Yangtze River (Wang *et al.*, 2008). Previous field surveys indicated that the population size of the Yangtze finless porpoise has been continuously decreasing in the past several decades (Zhang *et al.*, 1993; Zhou *et al.*, 1998; Wang *et al.*, 2000; Wei *et al.*, 2002). Population size was estimated to be approximately 1000–1200 in its historical distribution area in the main channel of the Yangtze River during the Yangtze Freshwater Dolphin Expedition 2006 (YFDE2006), suggesting a population decrease of over 50% since the early 1990s (Zhao *et al.*, 2008). Presumably, the continuous and rapid decrease of the porpoise population in the Yangtze River is related to human activities, such as heavy shipping-traffic, overfishing, and chemical pollution (Wang *et al.*, 2000). However, to convincingly relate human activities to effects on the porpoises, information on population distribution patterns of the porpoises acquired by well-designed methods is required.

Previous investigations on the population of the Yangtze finless porpoise typically utilized a visual survey method, in which observation platforms of varying heights and observers with nonequivalent experience were involved (Zhang *et al.*, 1993; Wei *et al.*, 2002), making comparison among different surveys difficult (Zhao *et al.*, 2008). The traditional visual observation technique based on the line transect method has other intrinsic disadvantages such as variable results (Mellinger *et al.*, 2007) and usually needs a number of observers rotating on duty (Zhao *et al.*, 2008). In addition, the Yangtze finless porpoise's small body size (1.5–1.7 m length), lack of dorsal fin, and short surfacing durations (1–2 s), make the animals very difficult to detect and count visually.

In addition, visual survey usually requires dedicated research ships with appropriate platforms for visual observation. High cost of the survey with the dedicated research ships would restrict its performance periodically with relatively short time period to document a seasonal or annual change pattern of population size and distribution of a target species.

As a complement or potential substitute for the traditional visual survey, acoustic monitoring was demonstrated to be a powerful method for detecting mysticetes (McDonald, 2006) and odontocetes (Wang *et al.*, 2005; Carstensen *et al.*, 2006; Akamatsu *et al.*, 2008; Li *et al.*, 2010). Passive acoustic methods that detect animal sounds were widely used for cetacean

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detection (McGregor *et al.*, 1997; McDonald and Fox, 1999; Oswald *et al.*, 2003; Wang *et al.*, 2005; Mellinger *et al.*, 2007; Li *et al.*, 2010). The Yangtze finless porpoise, as a small odontocete, possesses a highly developed sound production system likely used in navigation, orientation, and prey capture (Au, 1993; Akamatsu *et al.*, 2005; Verfuss *et al.*, 2009). The animal frequently produces high-frequency narrow-band ultrasonic pulses (Akamatsu *et al.*, 2005), which have peak frequencies ranging from 87 to 145 kHz with an average of 125 kHz (S.D. = 6.92), and pulse durations ranging from 30 to 122 $\mu$s with an average of 68 $\mu$s (S.D. = 14.12) (Li *et al.*, 2005a). These narrow-band ultrasonic pulses are quite different from background noise and other artificial sources, and therefore can be easily detected acoustically. Recently, passive acoustic surveys have been widely utilized for porpoise monitoring in the Yangtze River system using either mobile or fixed survey platforms (reviewed by Li *et al.*, 2010). A stereo acoustic event data-logger (A-tag) was demonstrated to be an effective instrument for picking up click phonation events of the porpoises and therefore detecting the presence of the animals.

In this paper, a passive acoustic survey method using a mobile cargo ship as the survey platform and the A-tag as the detection instrument was introduced. This survey demonstrated a labor-saving and economical survey method, feasible for regular use to potentially document seasonal and annual changes in population size and distribution of the Yangtze finless porpoise.

## II. MATERIALS AND METHODS

### A. Cargo ship survey platform and instrumentation

The cargo ship survey was conducted in the main channel of the Yangtze River, approximately 1100 km from Wuhan (30°35' N, 114°10' E) to Shanghai (31°20' N, 121°32' E) (Fig. 1), covering the main habitat of the Yangtze finless porpoise (Zhao *et al.*, 2008). This area has a depth varying from over 20 m at the main channel in the flood seasons (during summer) to 10 m in the low water seasons (during winter). The cargo ship transported beer products from Wuhan to Shanghai approximately once per month. To avoid flow noise contamination resulting from travel against the current, our survey was performed only during downstream travel from Wuhan to Shanghai, which lasted approximately 5 days at a speed of about 15 km/h.

A stereo acoustic event recorder (A-tag, ML200-AS2; Marine Micro Technology, Saitama, Japan) 21 mm in diameter, 300 mm in length, 135 g in weight, with two external hydrophones, was deployed on the cargo ship platform. The A-tag is equipped with an analog-to-digital converter, a CPU (PIC18F6620; Microchip, USA) for system control and data processing, a 128-MB flash memory module for data storage, a miniature high-frequency pulse event recorder, and a battery cell containing two UM1 alkaline batteries in a waterproof tube (Li *et al.*, 2009). The hydrophones are positioned 17 cm apart and can be used to identify the direction of the sound source and estimate its bearing angle. With 2 kHz sampling rate, once one of the hydrophones was triggered at the predetermined threshold (137.6 dB re: 1 $\mu$Pa), sound pressure and the time were recorded. If no signal over the threshold level was detected, the A-tag did not record anything to save memory. In the meantime, once trigger happened, signal arrived time difference (TD) between the two hydrophones of A-tag counting started until the next trigger at the second hydrophone with 271 ns time resolution (3.7 MHz sampling), which is sufficient to measure the trigger timing within a wavelength duration of ultrasonic sonar sound (Akamatsu *et al.*, 2008). The measured TD was stored with sound pressure and the time simultaneously every 0.5 ms. The hydrophone sensitivity was −202 dB re: 1 V/$\mu$Pa at a frequency of 120 kHz (100–160 kHz, 5 dB bandwidth), which is close to the dominant frequency of finless porpoise clicks (Li *et al.*, 2005a). The band pass filter in the A-tag was adjusted to 55–235 kHz to receive the frequency band of the porpoise clicks.

Active detection distance of the A-tag was empirically determined to be around 300 m in a joint visual-acoustic survey (Akamatsu *et al.*, 2008). In the present study, the detection threshold of the A-tag was set to be 1.5 dB higher than that in Akamatsu *et al* (2008). Assuming all other conditions between the two studies were same, the detection radius of the instrument in this study should be around 250 m.

The A-tag was deployed by attaching it to the end of an iron bar with a length of approximately 4.5 m (Fig. 2). The bar was vertically deployed on the side of the ship and tightly supported by two ropes which were fixed to the bow and stern of the ship. The primary hydrophone was set to point to the bow with the second hydrophone pointing toward the stern. The depth of the hydrophone was 3.5 m, and

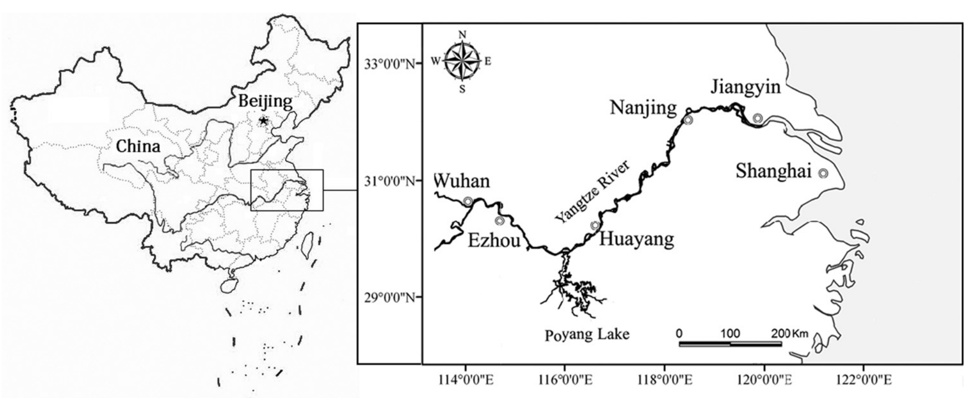


FIG. 1. The study range in the Yangtze River, from Wuhan to Shanghai, China.

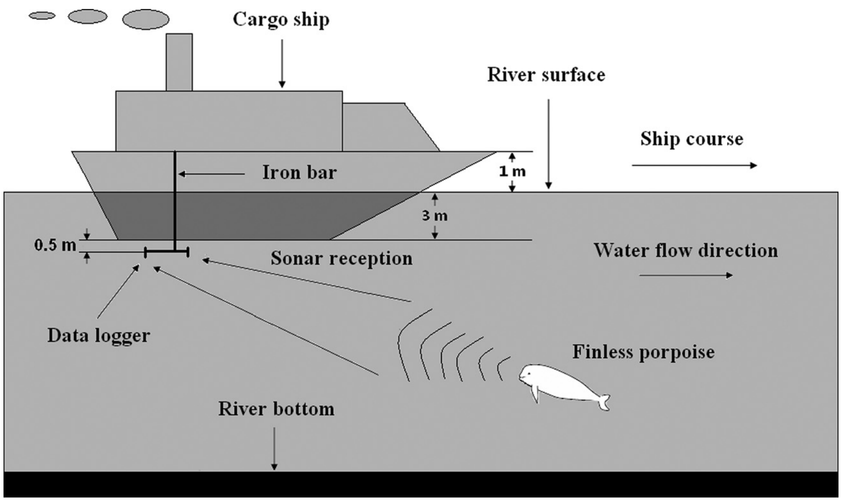


FIG. 2. Deployment of the passive acoustic monitoring system using a cargo ship as the survey platform to evaluate the Yangtze finless porpoise population. The acoustic event recorder (A-tag) was fixed to the side of the ship to avoid risk of collision. Note that the A-tag was immersed below the ship bottom by 0.5 m so that the A-tag received biosonar signals from both sides of the ship.

the bottom of the ship was about 3 m. Therefore the hydrophones were placed 0.5 m below the bottom of the ship to prevent shadowing of sounds from the other side of the ship. The A-tag has a battery life of approximately 50 h so the data was downloaded once every two days.

The effective detection strip width of the A-tag attached to the cargo ship platform is twice the detection radius, 500 m. The ratios of the detection strip width to the widths of different river regions in the dry seasons are shown in Table I (the widths of the river sections would not change in magnitude during the flood seasons). Nearly 80% of the river regions surveyed had width of 2 km or less even if the river regions width varied from several hundred meters to tens of kilometers. For the upper and middle regions, the proportion of the detected strip width was as high as 33% and 28%, respectively (Table I), and the proportion declined to 6% for the lower region. We should note that the lower region was located at the junction of the Yangtze River and the East China Sea and occupied only 15.6% of total survey length, where very few Yangtze finless porpoises were detected in YFDE2006 (Zhao *et al.*, 2008).

## B. Data acquisition

A customized program was developed on Igor Pro 5.01 (WaveMetrics, USA) and used to extract animal sonar events from ambient noise events. Each click train of biosonar signals produced by the Yangtze finless porpoises usually contains five to several hundred clicks with regular intensities and interclick intervals (ICI) of approximately 20–70 ms (Akamatsu *et al.*, 1998; Akamatsu *et al.*, 2008; Li *et al.*, 2010). Noise recorded by the A-tag had randomly changing intensities and interclick intervals, which is quite different from the porpoise clicks. Since the cargo ship (15 km/h) moved faster than the porpoise (average, 4.3 km/h) (Akamatsu *et al.*, 2002), all the animals passed from bow to stern of the cargo ship. The time arrival difference between two hydrophones of A-tag which corresponded to the bearing angle of phonating animals always changed from positive to negative. Frequency information was not used to exclude noise because A-tags do not record waveform. For noise reduction, a 55 kHz high pass filter was applied, and a human operator distinguished "porpoise" from "noise" in the off-line screening using the criterion that a porpoise click train was identified only when at least five successive click events with gradually changed sound pressure and interclick interval within 20–70 ms were recorded. The sound signal trains which contain less than five successive click events were eliminated from our data analysis conservatively, even if their interclick interval and sound pressure changed gradually. Any irregular successive clicks greater than twice or less than half the previous interclick intervals were also considered to be noises and excluded (Akamatsu *et al.*, 1998, 2001). In addition, the sound source of the five pulses should come from same direction to make sure all pulses originated from a single sound source (reviewed in Li *et al.*, 2010).

The multipath propagation in the Yangtze River can cause echolocation signals to have a multipulse structure (Li *et al.*, 2005b). Reflected signals are produced just after the direct path sonar signal in our survey area, a shallow freshwater system (Kimura *et al.*, 2009). The delay time of the reflected signal was very short, within 2 ms due to the

TABLE I. Summary of the three regions investigated. Lengths were measured along the middle of the shipping channel. The upper, middle, and lower regions spanned the area from Wuhan to Huayang, Huayang to Jiangyin, and Jiangyin to Shanghai, respectively. The boundary of upper/mid/lower section is shown in FIG. 5 with the gray vertical lines. Part of the data cited from Zhao *et al.* (2008), and the area of different regions was estimated by Google Earth (Google, Inc.). The last volume "percentage" is the percentage of habitat surveyed in each river section was estimated based on an assumed detection strip width of 0.5 km.

| Geographic strata | Length km | Percentage of total length % | Total area $km^2$ | Average width km | Percentage % |
|---|---|---|---|---|---|
| Upper region | 306.6 | 30.6 | 459.3 | 1.5 | 33 |
| Middle region | 537.7 | 53.7 | 970.1 | 1.8 | 28 |
| Lower region | 156.3 | 15.6 | 1220.3 | 7.8 | 6 |

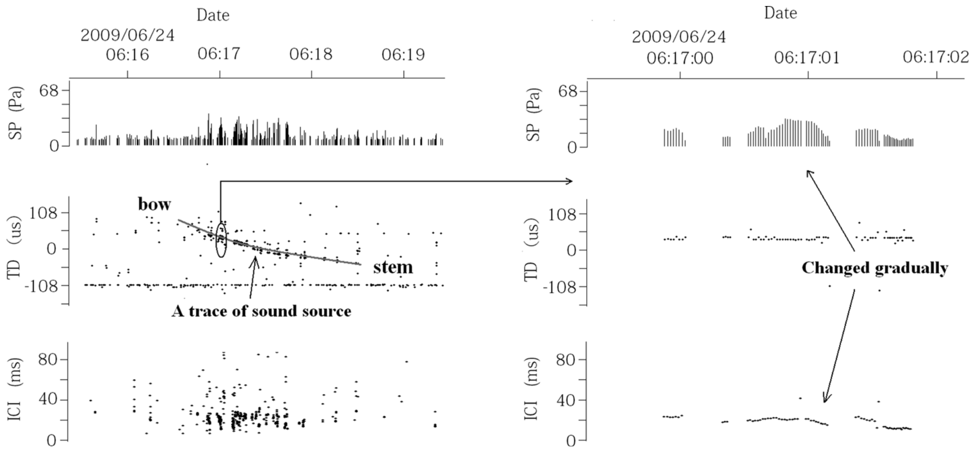


FIG. 3. The image of a series of finless porpoise click trains recorded by the data logger. A trace of the time difference (TD) of the sonar signals corresponds to an animal moving from bow to stern, indicated as a gray line. The sound pressure (SP, peak to peak over the narrow band) of the pulse string and the interclick interval (ICI) of the signals received by the two hydrophones are also depicted. Four click trains are shown in the right inset of the figure.

shallow depth of animals and the similar angle of the surface reflection to the direct path signal. Considering that the interclick intervals of the animal's click trains are typically between 20–70 ms, the interclick intervals shorter than 2 ms were subsequently eliminated to exclude the reflection pulses.

The number of phonating animals was counted manually by identification of biosonar click trains, each of which is considered an independent phonating individual (see review by Li *et al.*, 2010). When one phonating animal passes by the A-tag, there is a gradual change in the time arrival difference, changing from positive to negative. When two or more animals phonating simultaneously but swimming separately relative to the A-tag, there are two or more traces with gradual change in the time arrival difference. The number of independent traces of the time arrival difference could be used for counting of passing animals. Simultaneous phonation of two individuals swimming together could be identified by the different characteristics of the sound pressure and/or interclick interval within a single trace of the time arrival difference. In contrast, if the interclick interval or the sound pressure shows similar characteristics while the time arrival difference shows parallel traces, only one porpoise is counted because the parallel traces were caused by an error in the trigger point among multiple wavelengths in a click (Kimura *et al.*, 2009). For avoidance of double counting for short traces that were temporally close, we considered traces within 2 min of each other from a single porpoise for a conservative count (see Akamatsu *et al.*, 2008). The time at each zero crossing point of the arrival time difference trace was used as the acoustical detection time of animals for the analysis. The acoustical detection times and the locations of the porpoises were both identified by the GPS log (Garmin Olathe, KS, USA).

For analysis, we divided the survey area into 22 sections at 50-km intervals (Fig. 4(a)). Each section was serially numbered from 01 to 22, upstream to downstream. Following the definition of Akamatsu *et al.* (2008), the group size was defined as the number of detected animals per 120-s time window, which corresponds to 500 m survey length at the cruise speed of 15 km/h. A Kruskal–Wallis test was used to compare the difference in group size in three surveys. We also compare this study with the results of YFDE2006. The comparison of the cargo ship survey and the previous passive acoustic part of YFDE2006 was made to show the advantages of the present survey. For a more accurate comparison, only the overlapped survey areas between the two surveys were selected for comparison.

## III. RESULTS

Three cargo ship surveys were successfully conducted in March 2008, December 2008, and June 2009. It took approximately five days to conduct each survey. The total effective recording time for all three surveys was 246 h. An average of 6059 clicks of the Yangtze finless porpoise were recorded in each survey. There were 90, 117, and 77 animals detected on March 2008, December 2008, and June 2009, respectively, which correspond to an encounter rate of 0.079, 0.102, and 0.067 individuals per km. Figure 3 presents an example showing one porpoise passing by.

Positions where animals were detected are shown in Fig. 4(b) and the encounter rate of animals in each section are shown in Fig. 5, including results of YFDE2006 with towing platform for comparison. In most of the examined sections, animals were present in all three surveys; however, areas with low encounter rates were found in sections 1, 2, 18, 21, and 22 (Fig. 5). Notably, no porpoises were detected in a 40-km stretch below Wuhan, and a 65-km stretch between section 15 and 16 below Nanjing during all three surveys of the present study as indicated by arrows in Fig. 4(b).

Most of the groups observed in the 120-s time windows contained 1 or 2 individuals. The average group size was 1.39 individuals in the March 2008 survey, 1.46 individuals in December 2008, and 1.66 individuals in June 2009. No significant group-size differences were found among the three surveys (Kruskal–Wallis test, $n = 193$, $H = 2.85$, $p = 0.24$, Fig. 6).

## IV. DISCUSSION

### A. Feasibility of passive acoustic observation of the Yangtze finless porpoise using a cargo ship platform

In this study, a cargo ship mounted with an A-tag data logger was successfully used as an acoustic observation platform to detect and count the finless porpoises in the Yangtze River from Wuhan to Shanghai. In this paper we did not examine the detection probability on this specific cargo ship survey but focused on the distribution pattern and possible seasonal

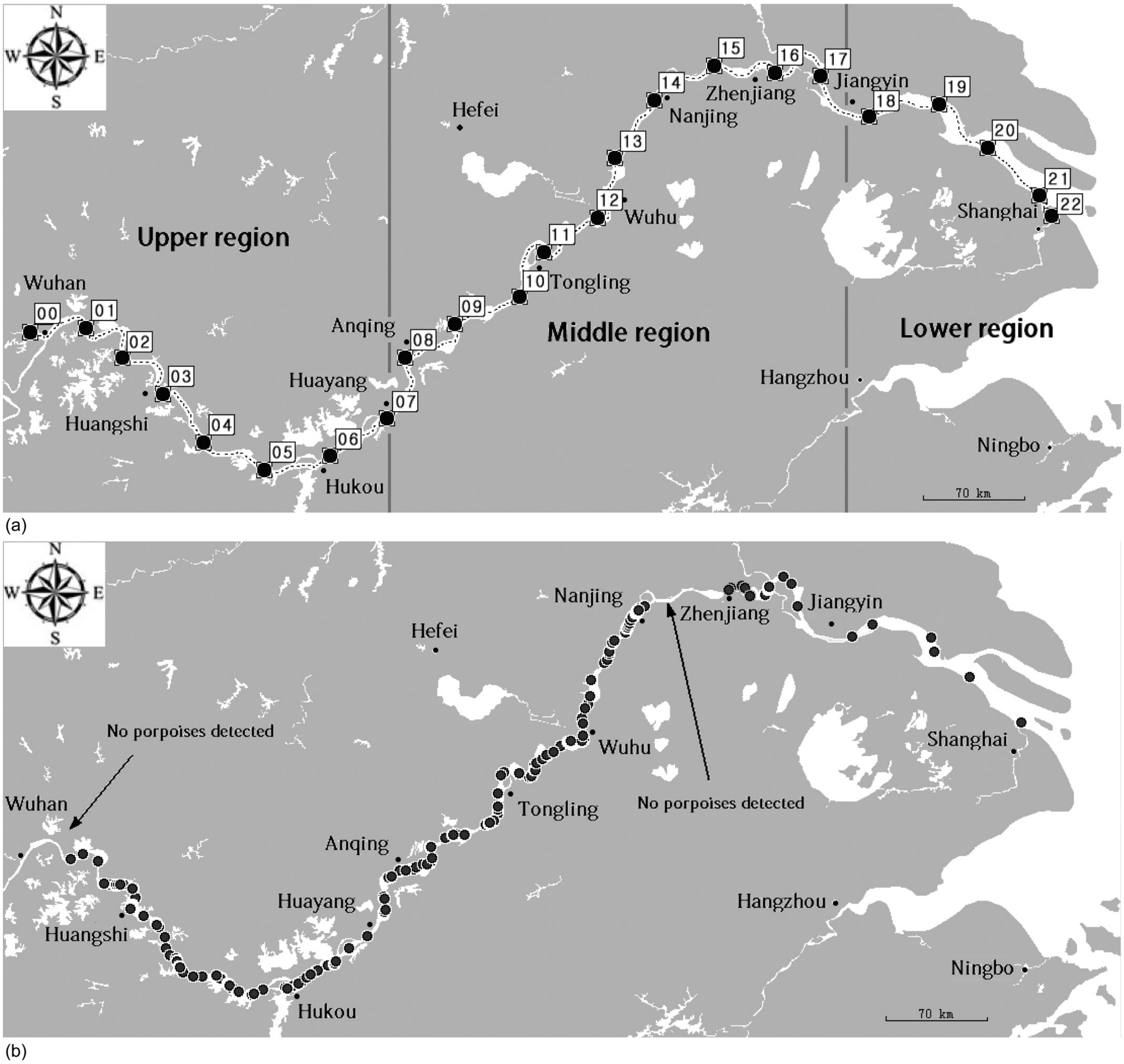


FIG. 4. Survey area and animal detection details. (a) The study area was divided into 22 sections, which are separated by big black circles, and designated by serial numbers. The small black dots show the big cities along the Yangtze River. (b) The big black dots show where the animals were detected during three surveys from March 2008 to June 2009. One big black dot means one porpoise was detected in this place. Some of the big black dots overlap each other. The small black dots showed the big cities along the Yangtze River.

changes of the porpoises in a wide range and long time scale and did not convert the encounter rate of animals to estimated density. The detected group size did not change significantly among the three surveys. Most detections were of single individuals, which is consistent with the results of a previous passive acoustic detection experiment (Akamatsu *et al.*, 2008) and a standard visual line transect survey (Zhao *et al.*, 2008). This indicated that the majority of the detected Yangtze finless porpoises were solitary or in pairs.

The A-tag range was adequate for detecting the Yangtze finless porpoises. The effective detection radius from the cargo ship platform was approximately 250 m wide. This detection width allowed for 28%–33% water coverage in most regions (Table I). The results suggest that the cargo ship is practical as a platform to monitor this species in the Yangtze River.

Comparison between the passive acoustic data from YFDE2006 in the region from Wuhan to Shanghai and the present data show that there was a higher encounter rate in YFDE2006 (Fig. 5). A few reasons may have contributed this difference. First of all, the platform and system deployment setup are different. In our survey the A-tag was deployed closer to the survey platform, facing a noisier environment from the ship engine and propeller. Since the animals may stay away from the survey platform, documented by Li *et al*. (2008), a lower encounter rate in the present

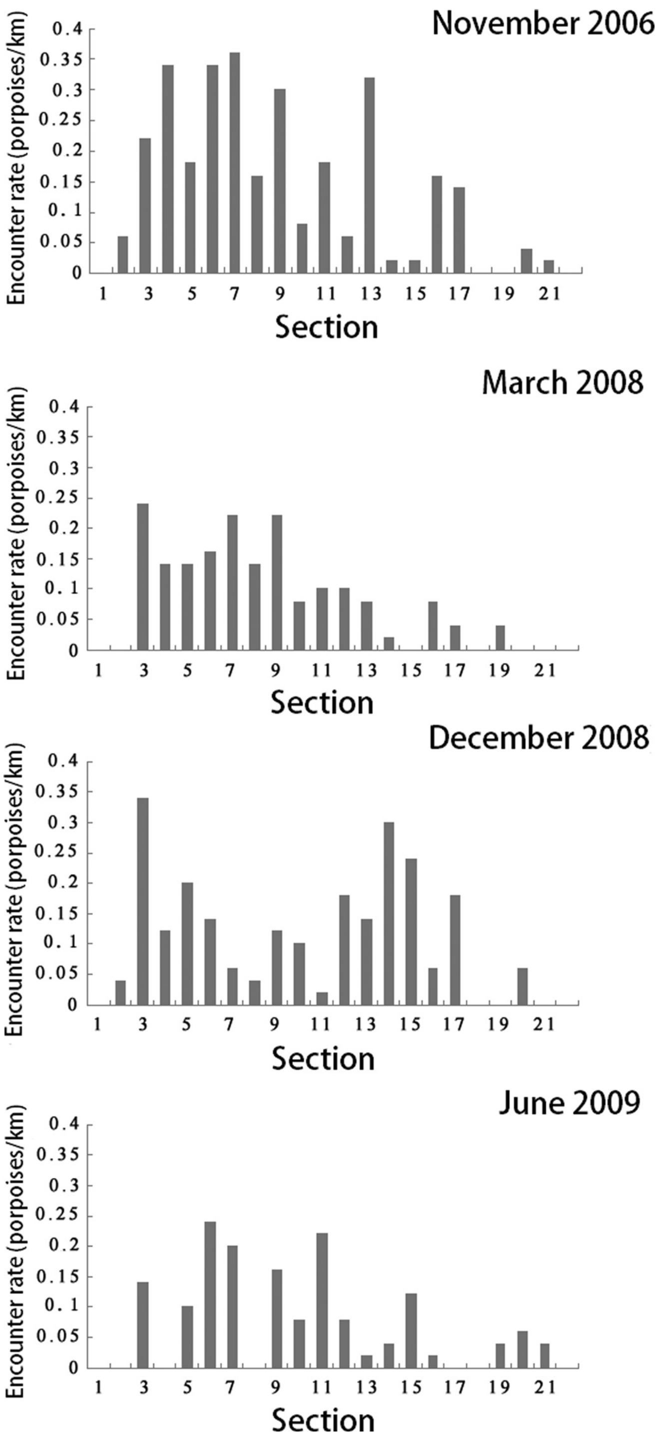


FIG. 5. Differences in the encounter rate (porpoises/km) in different seasons. The first fig in it is the result form YFDE2006, which is compared with our results here.

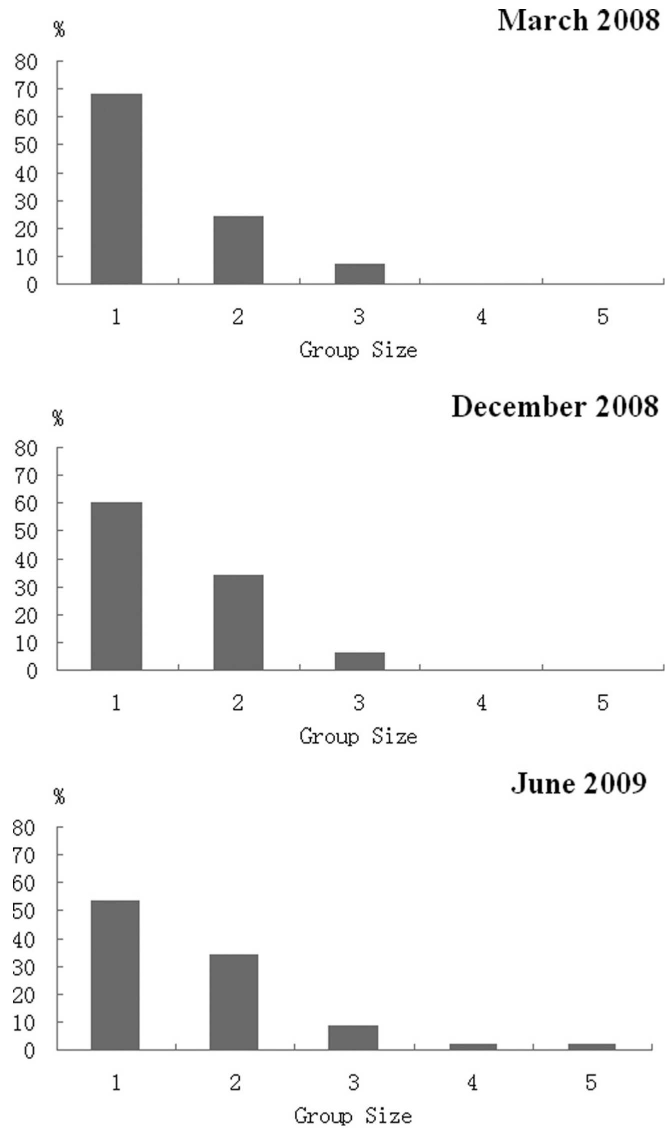


FIG. 6. The ratios of the group sizes detected in different seasons. The group size components are consistent with the results of previous studies, and there is no clear difference between the group sizes in different seasons. This suggests that the finless porpoises in the Yangtze River are solitary or in pairs in most cases.

study is anticipated. Second, the survey lines are not exactly the same between the YFDE2006 and the present cargo ship surveys. The cargo ship uses the center of the ship lane in the river, but the ship in YFDE2006 used the edge of the ship lane to avoid heavy ship traffic (Zhao *et al.*, 2008). Since the distribution of the porpoises along the transverse section may not be well-proportioned, the encounter rate of the animals among different surveys could be different. Another explanation is that the population of the porpoise in the survey area has been decreasing in the past few years.

### B. Advantages of the cargo ship platform versus a dedicated research ship for the passive acoustic survey of the porpoises

Acoustic detection on a cargo ship is more cost-effective than hiring a vessel specialized for a survey. If acoustic monitoring does not interfere with the normal operation of the ship, additional costs such as fuel, personnel, and ship maintenance will not be a factor. The passive acoustic method employed in the present study does not require human intervention except for installation and retrieval of the acoustic system.

Comparison of the results of our cargo ship survey in December 2008 and the previous dedicated research ship passive acoustic survey (YFDE2006) had been made as follows. YFDE2006 required four operators to perform the acoustic survey. The surveys downstream from Wuhan to Shanghai lasted 15 days. The costs for the passive acoustic survey with a dedicated research ship included those associated with ship operation, fuel, daily expenses, and staff wages, which amounted to more than several tens of thousands of dollars. In contrast, for the cargo ship survey, travel from Wuhan to Shanghai lasted only 5 days. The ship did not stop at night and the acoustic survey was continuous. Only two operators were required for the setup and data acquisition. As a result, the survey cost was greatly reduced in comparison to that in YFDE2006. The only fees needed were to cover researcher meals and minor funding for crew support, which amounted to only several hundreds of dollars. In addition, during the towing passive acoustic survey in YFDE2006, observers are needed to confirm that the instrument is not struck by another vessel (Akamatsu *et al.*, 2008). However, the ship-side deployment used in this study reduced the risk of acoustic recorder damage during the survey.

### C. Possible seasonal change of the distribution and the gaps among populations

The animals could be effectively detected by the cargo ship based A-tag system. Due to relatively fixed cruise line of the cargo ship and the unchanging pre-determined set course, results obtained in different survey seasons were considered comparable. It is feasible to monitor the distribution patterns, potential seasonal and annual population change of the Yangtze finless porpoise.

The data demonstrated that the distribution pattern appeared to vary among different seasons (Fig. 5). In March 2008, the animals were detected at higher concentrations mainly within sections 3–13 (Fig. 5). In December 2008, the animals exhibited bimodal distribution—they were detected mostly in sections 3–6 and sections 12–17 (Fig. 5). In contrast, at the beginning of flood season in June 2009 when the river was wider, animals were detected concentrating in sections 3–15 (Fig. 5), but the encounter rate had decreased relative to that in March 2008 (Fig. 5). This distribution pattern of the Yangtze finless porpoise could be caused by the local migration of the animals similar to the harbor porpoise (*Phocoena phocoena*) (Gilles *et al.*, 2009). In addition, the very low encounter rate of detections in the eastern end of the river could be a result from the very wide area of the river, over 10 km, which is different from the area below Wuhan and Nanjing. The similar result was also addressed in a previous joint visual-acoustic survey, the YFDE2006 survey (Zhao *et al.*, 2008). By periodically conducting such surveys over a long period of time, we can monitor yearly population trends and gain an understanding of seasonal migration and distribution of the animals. Additional years of data will be needed to distinguish between seasonal and random movements of porpoises.

## V. CONCLUSION

The cargo ship based passive acoustic survey of the Yangtze finless porpoises offers a simple, time-saving, effective, and inexpensive method to collect valuable information on the distribution and relative number of finless porpoises, which suggests that this method can be used to monitor the Yangtze finless porpoise population for seasonal changes, distribution, and yearly changes. In addition, the survey method developed in this study could be applied to other species facing a similar situation, especially river dolphins of other developing countries.

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