Mitigating the effect of shipping on freshwater megafauna: the case study of the Yangtze finless porpoise

Zhigang Mei[1], Yi Han[1], Samuel Turvey[2], Jiajia Liu[3], Zhitao Wang[1], Ghulam Nabi[4], Mao Chen[1], Peiyu Lei[1], Yujiang Hao[1], Kexiong Wang[1, *], Jay Barlow[5], Ding Wang[1, *]

[1] Key laboratory of Aquatic Biodiversity and Conservation of the Chinese Academy of Sciences, Institute of Hydrobiology, Wuhan 430072, China

[2] Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK

[3] Ministry of Education Key Laboratory for Biodiversity Science and Ecological Engineering, Fudan University, Shanghai, China

[4] Key Laboratory of Animal Physiology, Biochemistry and Molecular Biology of Hebei Province, College of Life Sciences, Hebei Normal University, Shijiazhuang 050024, China

[5] NOAA Southwest Fisheries Science Center, 8901 La Jolla Shores Drive, La Jolla, CA 92037 USA

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Email addresses: meizhigang@ihb.ac.cn (Z. Mei), hanyi@ihb.ac.cn (Y. Han), samuel.turvey@ioz.ac.uk (S. Turvey), liujiajia@fudan.edu.cn (J. Liu), wangzt@ihb.ac.cn (Z. Wang), ghulamnabiqau@gmail.com (G. Nabi), chenmao@ihb.ac.cn (M. Chen), lei_py@ihb.ac.cn (P. Lei), hao.yj@ihb.ac.cn (Y. Hao), wangk@ihb.ac.cn (K. Wang), jay.barlow@noaa.gov (J. Barlow), wangd@ihb.ac.cn (D. Wang).

*Author for correspondence; current address: Key Laboratory of Aquatic Biodiversity and Conservation, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China, email: wangk@ihb.ac.cn (K. Wang) & wangd@ihb.ac.cn (D. Wang)

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Authors’ contributions

Z Mei, Y Han, K Wang and D Wang conceived the ideas and designed methodology; Z Mei, Y Han, M Chen, P Lei, Y Hao, K Wang and Z Wang collected the data; Z Mei, G Nabi, S Turvey, J Barlow, Y Han and J Liu analysed the data; Z Mei, J Liu, J Barlow, Y Han, S Turvey, Z Wang and G Nabi led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Competing interests

There are no conflicts of interest to declare.

Mitigating the effect of shipping on freshwater cetaceans: the case study of the Yangtze finless porpoise

Abstract: Shipping has increasingly become a major threat to cetaceans due to its direct effect (e.g. ship strikes) and indirect effects (e.g. noise and habitat displacement). Most previous studies have focused on the deleterious effects of shipping traffic on marine species, while the effect of shipping on freshwater cetaceans has received little attention. The Yangtze River is a major trade artery in China, and shipping traffic there caused deaths of the now-extinct Yangtze river dolphin or baiji (*Lipotes vexillifer*). Here, we examine the distributional overlap of another cetacean species, the critically endangered Yangtze finless porpoise (*Neophocoena asiaorientalis asiaorientalis*) and cargo ships in a busy section of Yangtze River from Ezhou to Zhenjiang City. We use vessel-based survey data from 2006, 2012, and 2017 to quantify the distribution of porpoise. We use satellite images to quantify the distribution of cargo vessels travelling upstream. Most porpoise were concentrated within 300 m of the river banks. Shipping increased by 65% from 2006 to 2017, and ~60% of the upstream vessels was also within 300 m of the banks. This increase in shipping may have caused an observed shift in porpoise distribution away from the banks after 2006. Enhanced enforcement of existing shipping regulations that limit vessels to established shipping lane and set refuges in the side channels could help reduce the distributional overlap of porpoise and ships and aid in porpoise conservation. This could be applied and benefit the cetacean conservation under continued growth of shipping in rivers.

Key words: River cetaceans, Yangtze River, Shipping management, conservation

1. Introduction

Cetaceans are flagship species with high ecological, cultural and social value (Enquist et al. 2019; Pirotta et al. 2019). Unfortunately, recent decades have witnessed a rapid decline of megafauna across the world's ecosystems due to overharvesting (Barnett et al. 2017; He et al. 2019), habitat degradation (Ripple et al. 2015) and climate change (Payne et al. 2016). In particular, freshwater cetaceans are severely at risk at a global scale due to a wide range of additional anthropogenic threats including vessel collisions, dam construction, pollution, and accidental mortality in fishing gear, as many freshwater systems now support high human populations and heavy industrial activity (He et al. 2017). Populations of freshwater megafaunal species decreased by 94% from 1970 to 2012 (He et al. 2019). Targeted conservation responses have been made to address some of the issues associated with megafaunal declines. However, emerging threats to freshwater cetaceans in industrialized landscapes, such as the potential impact of global shipping, have rarely been addressed in previous studies (Pirotta et al. 2019).

Shipping accounts for 80% of the world's commercial trade, and global ship traffic is an increasing threat to aquatic species (Merchant et al. 2014) by facilitating biological invasions (Seebens et al. 2013), release of pollutants such as spills and waste gas (Hassellöv et al. 2013), vessel strikes (Pirotta et al. 2019), and underwater noise (Merchant et al. 2014). Large-bodied mammal species in marine and freshwater systems are especially vulnerable to the effect of ship traffic. First, ship strikes constitute major direct impacts that are often fatal or result in serious injury to large aquatic mammals (van der Hoop et al. 2015) and can have population-level effects when species of concern are threatened and declining (Vanderlaan and Taggart 2007). For example, almost 30% of dead Yangtze River dolphin or baiji (*Lipotes vexillifer*) individuals found in the late twentieth century in the lower Yangtze River are thought to have been killed by ship strikes (Zhou and Li 1989). Second, underwater noise caused by shipping is one the largest contributors of anthropogenic noise in the ocean (Wilcock 2013) and is of particular concern for cetaceans due to their reliance on sound for navigation, feeding and communication (Blair et al. 2016). Consequently, shipping modifies animals' behaviour (e.g. through avoiding areas of high ship traffic), which can alter their habitat use and landscape-level distribution (Pirotta et al. 2019). Most previous studies on the effects of shipping have focused on marine species, and the lack of studies on the effect of shipping on freshwater cetaceans represents an important knowledge gap (Dey et al., 2019; Erbe et al., 2019). Furthermore, commonly suggested conservation mitigation approaches that have been adopted in marine environments are often inappropriate in riverine systems (Smith et al. 2000). Empirical studies on the ecological interactions and effects of ship traffic on freshwater cetaceans are therefore needed urgently, to inform specific conservation efforts for these highly threatened animals and to address broader concerns about biodiversity conservation and sustainability of human use of the world's river systems.

Following the recent likely extinction of the baiji, the Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) is now the largest freshwater mammal in the Yangtze River system of eastern China (Turvey et al. 2007). It is endemic to the middle and lower reaches of the main Yangtze River and the adjoining Poyang and Dongting Lakes, and has recently been uplisted to Critically Endangered on the IUCN Red List due to rapid recent population decline (Mei et al. 2014). The Yangtze River is now the world's busiest navigable inland waterway. Ship traffic has increased from hundreds of vessels per year in the 1970s to hundreds per day in the 2010s (Zhang et al. 2013), and is projected to continue increasing (Mei et al. 2014). In 2006 alone, at least 19,830 large shipping vessels (1000-30,000 tonnage, 50-200 m length), equating to more than 1 vessel per 100 m, were counted in the main Yangtze channel during a freshwater cetacean survey between Yichang and Shanghai (Turvey et al. 2007). This dramatic level of ship traffic is considered a major threat to the Yangtze finless porpoise (Wang 2009; Turvey et al. 2013). Although the fishers reported that mortalities caused by vessel strikes have increased over time (Turvey et al. 2013), evidence of porpoise directly killed by vessel strikes is rarely observed according to our systematic collection of porpoise carcasses since 1978. Unlike the Yangtze River dolphin, the frequency of echolocation signals of the Yangtze finless porpoise far exceeds the range of ship navigation noise (Fang et at., 2015), and the ship speeds are too slow (6-8 knot/h) to cause vessel strikes. Moreover, increased vessel traffic noise within cetacean habitat leads significant avoidance behavior of the Yangtze finless porpoise may be one of the reasons why few finless porpoises are hit by ships. Excluding the risk of ship collision, the direct impact of shipping on animals is the avoiding behavior which can alter their habitat use and landscape-level distribution(Richardson et al. 1995; Zhao et al. 2008). These impacts cannot be observed directly which leaded the lower estimation of the effect from shipping in the Yangtze River. So far, there is no research on shipping effects on habitat uses of the Yangtze finless porpoise and no actually measurement was taken.

The Yangtze finless porpoise prefers habitats close to river banks (Wei et al. 2002; Yu et al. 2001; Zhang et al. 1993). These environments generally have muddier substrates with algae and submerged vascular plants that provide important habitats for small fishes, which are the porpoise’s primary food resource (Mei et al. 2017). Areas close to river banks also constitute important sites for porpoise reproduction and nursing (Yu et al. 2001). These areas also have moderate slopes and slow water speeds, which facilitate energy-saving behavior in porpoises (Kasuya and Kureha 1979). However, these hydrodynamic properties of near-shore environments are also optimal conditions for ships travelling upstream in the Yangtze to avoid strong currents in the mid-channel (Zhang et al. 2018). Considering that the Yangtze finless porpoise is sensitive to vessel noise and avoids boats (Wang et al. 2014; Zhao et al. 2008), it is therefore important for Yangtze finless porpoise conservation management to determine whether these preferred habitats are impacted by ship traffic, and to investigate whether the species has experienced a shift in habitat use and distribution in response to the effect of shipping.

In this study, 1) we investigate the potential effect of ship traffic on the Yangtze finless porpoise in the main Yangtze River channel between Ezhou and Zhenjiang, by estimating spatial overlap of areas used by porpoises and ship traffic in the river. 2) We evaluate whether porpoises have adapted their habitat use in response to ship traffic, by comparing their distribution in this river section over time as determined by range-wide surveys conducted in 2006, 2012 and 2017. To better guide managements on shipping, 3) we also investigate the relationship between vessel size and distance to river bank. We use our findings to suggest a compensatory conservation management approach, which could be applied more widely to support the conservation of freshwater cetaceans in other heavily industrialized river systems.

2. Material and methods

2.1 Study area and porpoise data collection

The study area from Ezhou City, Hubei Province to Zhenjiang City, Jiangsu Province represents a ~650 km section along the main Yangtze River channel (Fig. 1). Total counts of 439, 180 and 238 porpoise sightings were made within the Ezhou-Zhenjiang river section in 2006, 2012, and 2017, respectively. This river section contains almost 80% of the surviving Yangtze finless porpoise population present in the main Yangtze River channel (Huang et al. 2019; Mei et al. 2014; Zhao et al. 2008). It supports heavy ship traffic and has a river width of 1.5 to 2.5 km (Zhao et al. 2008). In comparison, the upstream river section from Yichang to Ezhou is less than 1.2 km in width and has few porpoises (encounter rate ~0.025) and a relatively low shipping density, whereas the downstream section below Zhenjiang is estuarine (river width >8 km in most areas) and has intensive shipping but very few porpoise sightings (encounter rate 0.054, Huang et al. 2019).

Yangtze finless porpoise sighting data were collected during range-wide visual boat-based surveys conducted in 2006 (Zhao et al. 2008), 2012 (Mei et al. 2014), and 2017 (Huang et al. 2019). Two boats each ~33 m long, with ~4 m-high viewing platforms were used to carry out independent observations for each survey, and one boat covering each side of the channel; full details of survey methods are provided in these references. During these surveys, the positions of all porpoise sightings were recorded with a portable GPS receiver (Garmin eTrex Legend C), and the distance between observed porpoises and the nearest river bank was estimated by the observer. Calibration tests were conducted weekly using a Bushnell range-finder to maintain accurate observer distance estimation; all observers showed a significant improvement in distance estimation after a week of training (Mei et al. 2014; Zhao et al. 2008). Two survey vessels operated independently at all times during each survey, keeping separate records and not sharing information about porpoise sightings during the survey. Since there are no statistical differences in the visual sighting data from the two vessels for each survey, the data were analyzed as a single dataset in each survey year (Huang et al. 2019; Mei et al. 2014; Zhao et al. 2008).

2.2 Upstream cargo travelling vessel and environmental feature data collection

We counted upstream travelling cargo vessels (UTCVs) and recorded their locations and distance from the river bank using high-resolution (~2 meter) aerial images of the study area obtained from Google Earth Pro version 7.1.5.1557 (Google Ltd.). Google Earth Pro maintains a history of images, so we were able extract historical shipping data to correspond with the timing of the three range-wide surveys. However, available satellite imagery did not cover the whole study area for 2006 and 2012, so the associated satellite imagery collection times were expanded to 2004-2008 and 2010-2014 (respectively), assuming that there was minimal change in ship traffic density across these five-year periods according to our field observations. Available images covered the study area in 2017. Imagery in each time period was selected closest to the survey periods of December 2006, 2012 and 2017 (supplementary kml files). We only counted upstream ships because they will choose to sail close to the riverbanks while downstream ships will use currents to navigate in the middle area of the river. This makes upstream ships are more likely to overlap with the potential distribution of the finless porpoise (Fig. 2). Travel direction was determined from the direction of the wake in aerial images. We calculated relative vessel size (i.e., vessel length × vessel width, for the year of 2017), and also identified above-water margins of river banks and boundaries of sand bars in Google Earth Pro from satellite imagery to allow direct assessment of porpoise habitat use (Fig. 3).

2.3 Spatial analyses and statistics

We converted porpoise and UTCV sighting/count data and habitat boundary data to KML files and used them to construct data layers in ArcGIS (ESRI, ArcGIS, 10.3.2). We used the “near” function in ArcGIS to calculate the distance of each porpoise sighting to the nearest sand bar and the distance of each UTCV to the nearest river bank, and used these distance data to model porpoise and UTCV distribution patterns in relation to sand bars and river banks respectively.

We identified areas within 300 meters of river banks and sand bars as representing most important habitat for Yangtze finless porpoises in the main Yangtze River channel, based on previous assessment of local porpoise habitat use (Wei et al. 2002; Yu et al. 2001; Zhang et al. 1993). We buffered the most important porpoise habitat within the study area and calculated its percentage area in 2017 using complete-coverage satellite imagery, and calculated the density of porpoise sightings and UTCVs inside and outside critical porpoise habitat across all three survey years.

Despite the five-year time windows used, satellite imagery did not cover the entire study area for the 2004 to 2008 time period. We therefore used one-way ANOVAs to compare UTCV densities within river sections with high-definition imagery across the three survey years. The distribution pattern of UTCVs in 2006 was calculated by data within these sections, while data from across the whole study area was used in 2012 and 2017. We compared porpoise and UTCV distribution patterns in relation to distance from river bank across the three survey years using two-tailed Kolmogorov-Smirnov tests. Porpoise distribution patterns in relation to the nearest sand bars were also compared using Kolmogorov-Smirnov tests across the three survey years. We also used Spearman's rank correlation coefficient to investigate the relationship between vessel size and distance to nearest river bank. All statistical analyses were conducted in R (R 3.5.3).

3. Results

3.1 Porpoise sightings and UTCVs

Of these total porpoise counts, almost 55% were observed within 300 meters from the bank; and more than 78% were observed within 500 meters from the bank. There was no change in porpoise distribution in relation to river bank between 2012 and 2017 ($p=0.150$). The proportion of porpoises within 300 m of the bank in 2012 and 2017 was significantly lower than in 2006 (Table 1, Fig. 3), especially within 100 m of the bank (2006 vs 2012, $p=0.000$; 2006 vs 2017, $p=0.014$).

The distance of UTCVs from the river bank did not change significantly across the three survey years (2006 vs 2012, $p=0.059$; 2012 vs 2017, $p=0.093$; 2006 vs 2017, $p=0.263$). Over 16% of UTCVs were travelling within 100 meters from the bank, around 60% were travelling within 300 meters from the bank, and around 80% were travelling within 500 meters from the bank (Table 1, Fig. 3).

Within our 650 km study area, high-resolution satellite images were available for 356 km of river section in the 2004 to 2008 time period, mostly between Hukou and Zhenjiang. We counted 770 UTCVs in the 2006 dataset, with a density of 2.16 vessels/km. UTCVs increased significantly in this comparative 356 km section from 2006 to 2012 (2012: N=1084, density of 3.04 vessels/km; $p<0.001$) and also from 2012 to 2017 (2017: N=1272, density of 3.57 vessels/km; $p<0.001$). In total, 1657 UTCVs were identified in 2012 (mean density, 2.55 vessels/km), and 1898 UTCVs were identified in 2017 (mean density, 2.92 vessels/km) (Fig. 3).

A total of 1839 UTCVs were identified in 2017. Mean vessel size was 1008.43 m^2 (SD=713.76), which equates to around 2500 tons. Quartile boat size was 513–1335 m^2, corresponding to 600–3000 tons (Fig. 4). There was a slight positive relationship between vessel size and distance to river bank ($\rho = 0.081$, $p=<0.001$).

3.2 Habitat preferences

Proportions of porpoise sightings decreased progressively with distance from sand bars in all three survey years (Fig. 5): more than 55% (56.72% in 2006, 61.11% in 2012, 55.04% in 2017) were observed within 2 km of a sand bar, and around 30% (28.25% in 2006, 26.11% in 2012, 30.26% in 2017) were observed more than 4 km from a sand bar, with distribution patterns not significantly different across the three survey years (2006 vs 2012, $p=0.128$; 2012 vs 2017, $p=0.598$; 2006 vs 2017, $p=0.202$). Important porpoise habitat (areas within 300 meters of river banks and sand bars) covered 709.23 km^2 of the river section between Ezhou and Zhenjiang, representing 30.21% of the total study area in 2017. This habitat area included 53.75% of porpoise sightings and 62.12% of identified UTCVs. Therefore, it was clear that there is a significant overlap between preferred habitats of Yangtze finless porpoise and shipping zones.

4. **Discussion**

4.1 The effect of shipping on Yangtze finless porpoise distribution

Increasing studies have realized the importance of shipping traffic as a potential threat to aquatic megafauna (Gomez et al. 2016). However, most previous studies have focused on the deleterious effects of shipping traffic on marine megafauna, such as humpback whales (*Megaptera novaeangliae*) and North Atlantic right whales (Blair et al. 2016; Kraus et al. 2007) (*Eubaleana glacialis*). Unlike marine ecosystems, the movement of vessels transiting river systems is highly restricted, and therefore the physical overlap between freshwater megafaunal habitats and shipping zones is higher than in open-ocean environments. Our study provides important new evidence that shipping traffic occupies the priority habitat of a Critically Endangered range-restricted freshwater cetacean, the Yangtze finless porpoise, and that porpoises have altered their distribution pattern within the Yangtze River over the past 12 years, possibly in response to this anthropogenic disturbance.

Previous studies have revealed that the Yangtze finless porpoise prefers habitats close to river banks and sand bars (Wei et al. 2002; Yu et al. 2001; Zhang et al. 1993), which have more food resources and slow water speeds that reduce energy costs (Kasuya and Kureha 1979). For example, studies in 2002 and 2005 found that 80% of Yangtze finless porpoises were found within 200 m of the bank (Wei et al. 2002; Yu et al. 2001). Unfortunately, ships travelling upstream in the main Yangtze channel also navigate relatively close to the bank to avoid stronger currents in the mid-channel (Zhang et al. 2018). We found that there is a substantial overlap between shipping zones and optimal porpoise habitats in the Yangtze, with nearly 80% of observed large cargo vessels being distributed within 500 meters from a bank, and more than 60% within 300m from a bank.

This observed spatial overlap between shipping and porpoise habitat has a significant impact on the distribution of the Yangtze finless porpoise. First, large vessel shipping routes act like roads in terrestrial environments (Laurance et al. 2014), directly impacting large-bodied animals via collisions and hampering animal movements by altering wave climate and water turbidity (Pirotta et al. 2019). Second, large vessels produce relatively broadband noise that can interfere with Yangtze finless porpoise communication and foraging (Li et al. 2005). Moreover, the impact of vessel noise on finless porpoises may be greater than the other species because they have wider hearing bandwidths (Mooney et al. 2011). Patterns of direct porpoise mortality associated with both ship strikes and other factors remain poorly understood in the Yangtze River, (Turvey et al. 2013), but the Yangtze finless porpoises exhibit clear ship-avoidance behavior, with very few porpoises observed within 50 m of survey vessels in the 2006 range-wide Yangtze survey (Zhao et al. 2008). As such, frequent movements to avoid ship traffic can result in unnecessary energy waste and decreased fitness (Rolland et al. 2012). Other short-term responses to shipping noise in cetaceans include long-term diving, shorter surfacing behavior, changes in sound characteristics, increased swimming speed, and moving away from affected areas (Pine et al. 2018). In addition, young porpoises may be unable to communicate effectively with their mothers and so experience increased mortality risk (Li et al. 2005), with elevated juvenile mortality a major driver of population decline in porpoises (Mei et al. 2012). From a long-term perspective, the impact of shipping noise is also presumed to be the deterioration of the porpoises’ acoustic environment and the impact on animal immunity and reproduction rates (Nabi et al. 2018; Richardson et al. 2013).

Our data suggest that Yangtze finless porpoises may be shifting their habitat use to waters further from the river bank in order to reduce the effect of high shipping traffic. Such habitat range shifts to potentially more suboptimal mid-channel regions with less prey availability and stronger currents might therefore accelerate the population decline of the Yangtze finless porpoise. Our findings are comparable to those of several studies in terrestrial ecosystems, where primary forests have been transformed into agricultural landscapes and many animal species have been forced to use suboptimal habitats, resulting in population declines (Liu and Slik 2014).

Impacts of ship traffic are not just a concern for the Yangtze finless porpoise, but also for many other freshwater species. Other freshwater cetaceans such as the Irrawaddy dolphin (*Orcaella brevirostris*) and Ganges River Dolphin *(Platanista gangetica gangetica)* are also threatened by shipping lanes (Whitty 2016; Dey et al. 2019), and freshwater fish species respond with increased cortisol secretion when exposed to ship noise (Wysocki et al. 2006). Shipping traffic is increasing globally. Recent estimates suggest that there will be a twofold increase of global shipping traffic by 2050 (Sardain et al. 2019). The Yangtze River is China’s most important shipping route, and our data indicate that large cargo vessels have increased from 2.16 vessels per kilometer in 2006 to 3.57 vessels per kilometer in 2017. Shipping will continue to increase regionally into the future with the development in the highly commercial region, and is likely to exacerbate ecological problems such as species invasions, habitat fragmentation, and pollution (Hassellöv et al. 2013; Seebens et al. 2013; Seebens et al. 2016). It has to be kept in mind that we only analyzed upstream ships, and this might underestimate the vessel impacts on the porpoise when downstream vessels were included. How to reduce the impact of shipping on the Yangtze finless porpoise is therefore a crucial question that has so far received little conservation attention, and our study calls for urgent research into the effects of shipping on freshwater cetaceans and more widely on freshwater biodiversity.

4.2 Conservation policy recommendations

Current conservation efforts for the Yangtze finless porpoise are mostly focused on setting priority protected areas (Zhao et al. 2013), and reducing the impact of fisheries bycatch and competition (Mei et al. 2019; Wang 2009). However, these efforts have not yet taken habitat quality into consideration. Whereas most of the middle and lower reaches of the Yangtze River are around 2 km wide, we demonstrate that most porpoises are found within 300 meters from the river bank. It is therefore a management priority to relocate shipping routes away from this important porpoise habitat. Indeed, to guarantee shipping safety, the current designated shipping routes in most sections of the Yangtze River mainstem are also far from the river banks. However, our study shows that vessels heading upstream generally choose to travel in the shallow waters near the banks to take advantage of lower flow rates. It is therefore critical to strengthen the effectiveness of Yangtze law enforcement and strictly limit upstream vessels to travel only within designated navigation channels.

Our results also show that Yangtze finless porpoises are distributed relatively close to sandbars, on the other side of main channel of the sandbars which might form shallow secondary channels that contain reduced ship traffic (Chen et al. 2018; Mei et al. 2014). These areas might be able to constitute formal protected “porpoise refuges”, where navigation and mooring should be completely prohibited (Fig.2).

Our results show a slight positive relationship between cargo vessel size and distance from the bank, indicating that porpoises might be particularly threatened by very large vessels within their optimal near-bank habitat. However, many of the vessels travelling close to the bank are relatively small cargo ships (around 2000 tonnage based on boat size). These ships are generally relatively poorly powered and may be difficult to navigate in the main channel. Though slower ship speeds were proved to be efficient to reduce vessel impact by less underwater noise. But this might be ruled out in the Yangtze River because the heavy shipping and relatively narrow space and most of the upstream vessels were already travelling quite slowly, like 6-8 knot/hour. We therefore recommend that further research should also be conducted into the relative impacts of different navigation patterns and vessel types on Yangtze finless porpoise, and promote the elimination of those high impact vessels (mostly small cargo ships) to achieve standardization of shipping vessels. At the same time, the standardization can also slow down the growth trend of shipping along the Yangtze River. Finally, we also recommend applying models to conducting research on ship collision risk as a way forward to explore the impacts of shipping on Yangtze finless porpoises in the coming years (Martin et al. 2016).

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Figures

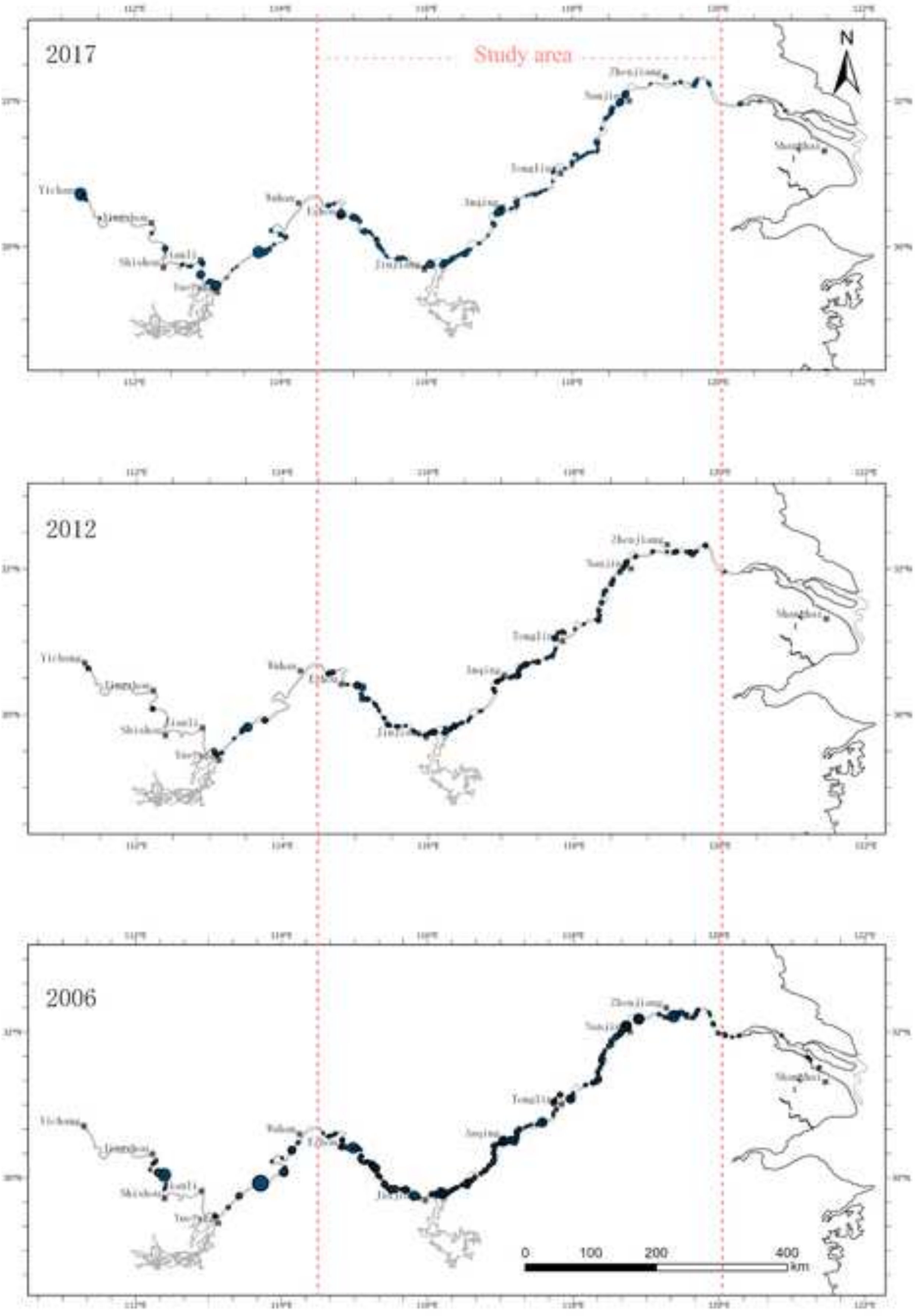
Figure 1. Study area between Ezhou and Zhenjiang, a ~650 km section along the main Yangtze River channel. Porpoise sightings are shown for 2006, 2012 and 2017 (blue dots, the dot size represent the porpoise sighting size).

Figure 2. High-resolution satellite images used to identify cargo vessels travelling upstream (yellow labels). Sub-channel areas around sand bars could constitute protected “porpoise refuges” where navigation and mooring could be prohibited (green polygon).

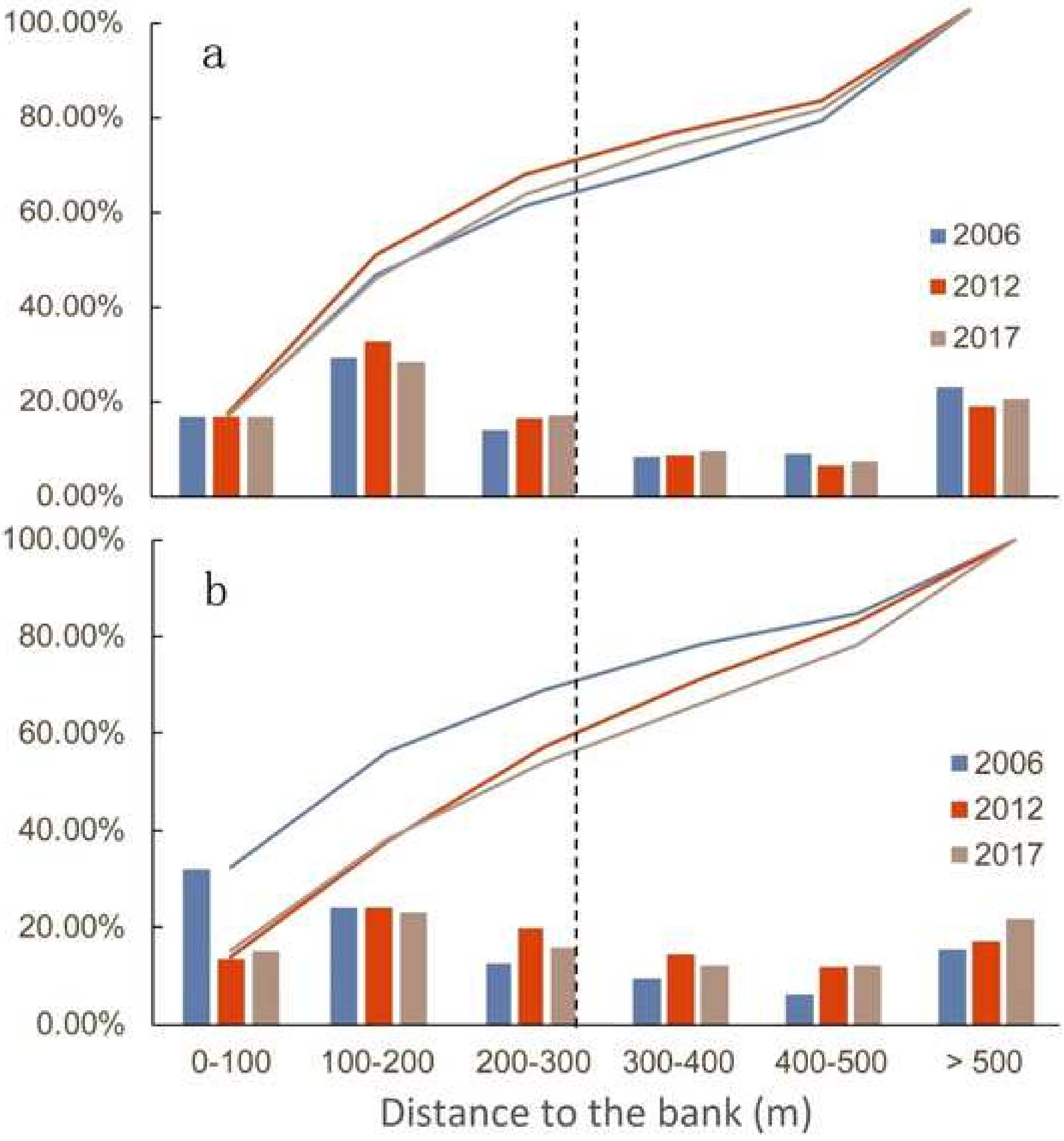
Figure 3. Distribution patterns (distance from river bank) of (a) cargo vessels travelling upstream, and (b) Yangtze finless porpoises. Histograms show distribution probabilities and line graphs show cumulative distribution probabilities. The black dotted line indicates important porpoises habitats (within 300 meters of river bank).

Figure 4. Relationship between distance from bank and log size of shipping vessels. The square brackets means including this distance and the round brackets means not including.

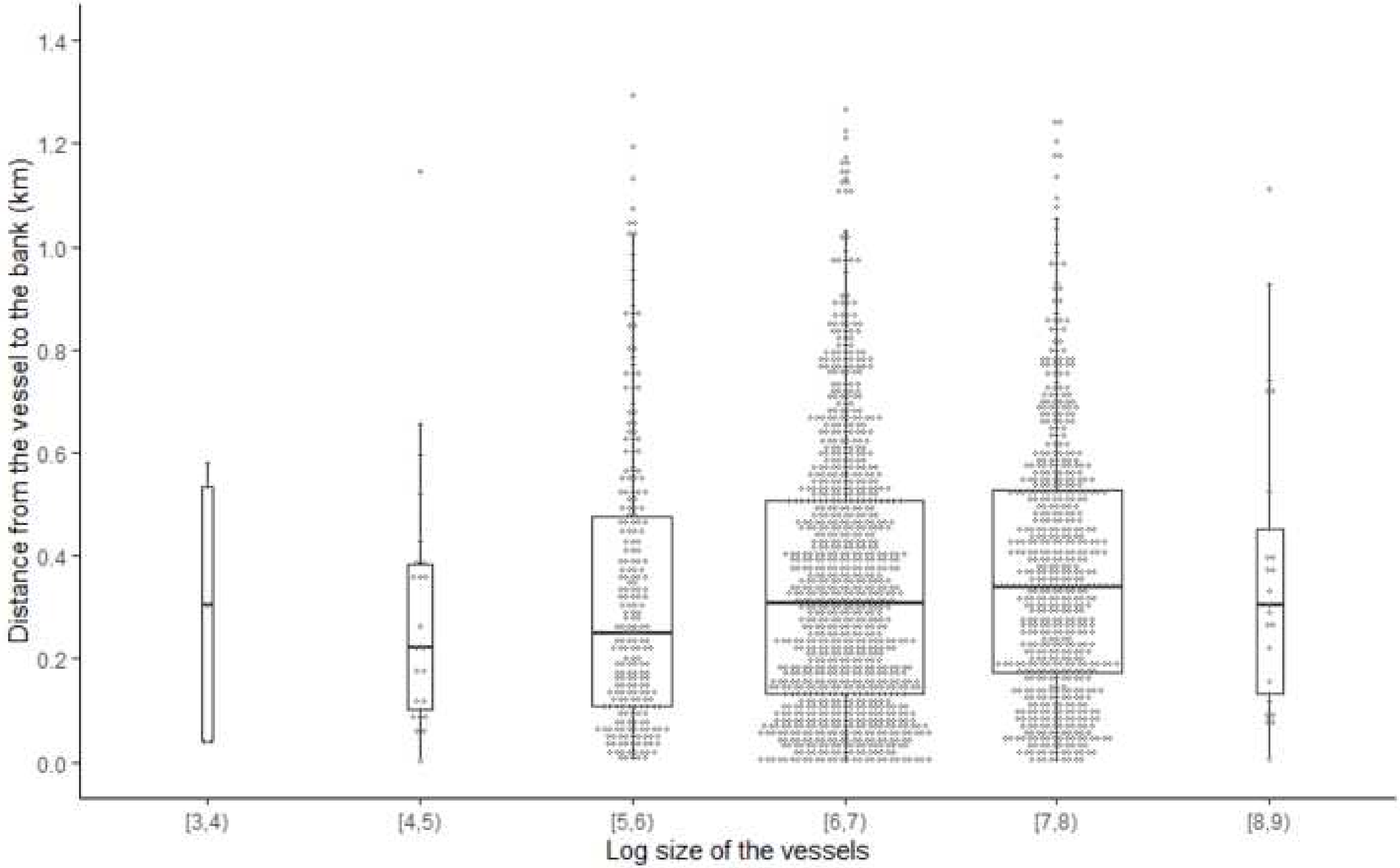
Figure 5. Distribution probabilities of Yangtze finless porpoises to the nearest sand bars in 2006 (blue), 2012 (brown), and 2017 (gray). The square brackets means including this distance and the round brackets means not including.

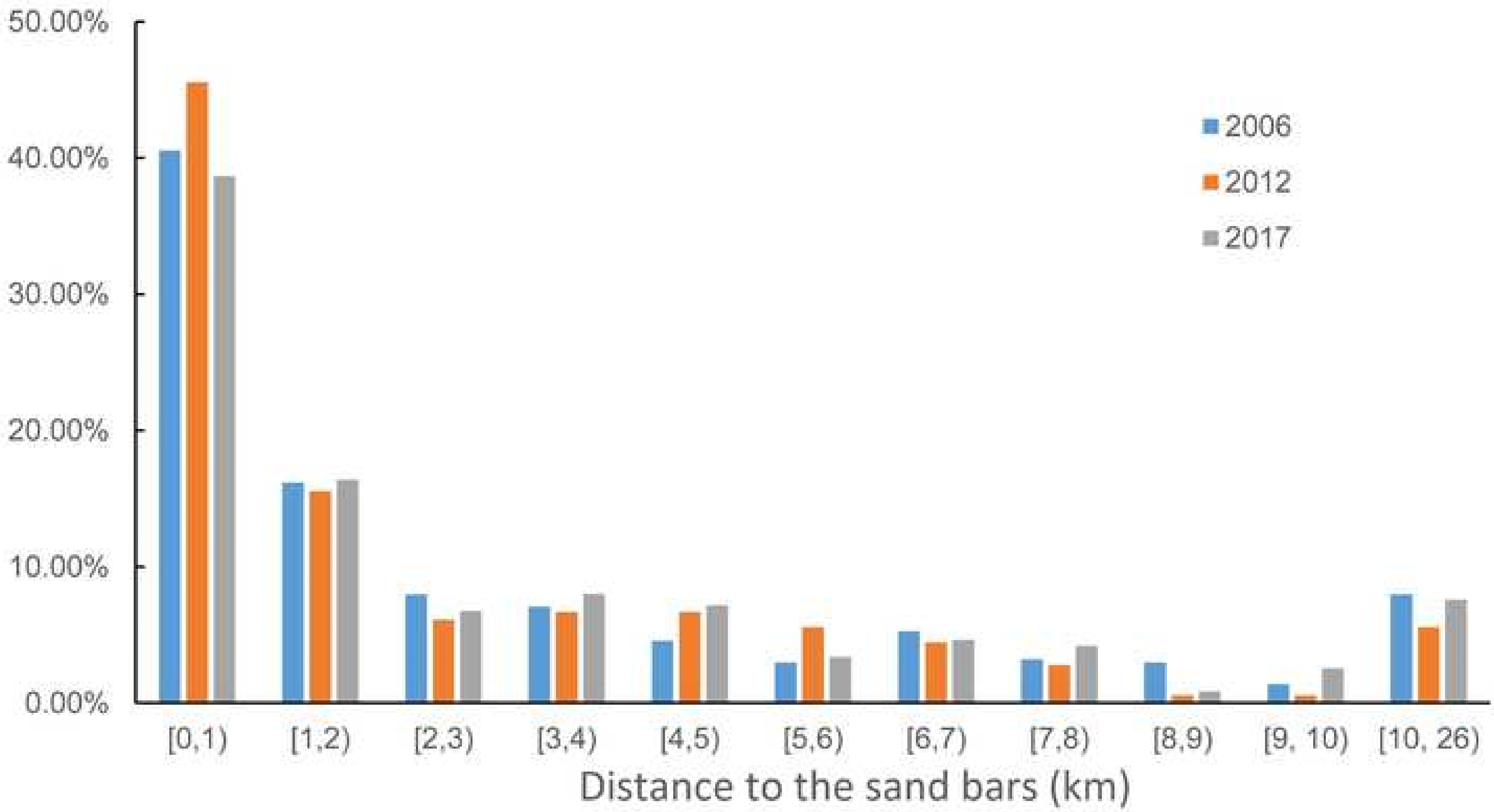

2017
Study area
N
Zhenjiang
Nanjing
Shanghai
Tongling
Anqing
Yichang
Wuhan
Ezhou
Jingzhou
Jianli
Shishou
Yueyang
Jiujiang
2012
2006
0
100
200
400
km


porpoise refuges
5km
N
200m


a
b
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
■ 2006
■ 2012
■ 2017
0-100
100-200
200-300
300-400
400-500
> 500
Distance to the bank (m)

Click here to access/download;Figure;Fig.4.png




50.00%
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2006
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[10, 26)
Distance to the sand bars (km)

Table 1 Distribution patterns (distance from river bank) of cargo vessels travelling upstream (UTCVs) and Yangtze finless porpoises (Porpoise) in the three time-periods.

Distance from river bank	2006		2012		2017	
	UTCVs	Porpoise	UTCVs	Porpoise	UTCVs	Porpoise
0-100 m	16.62%	32.10%	16.84%	13.30%	16.65%	15.02%
100-200 m	29.09%	23.99%	32.59%	23.94%	28.40%	22.92%
200-300 m	14.03%	12.55%	16.48%	19.68%	17.07%	15.81%
300-400 m	8.18%	9.59%	8.75%	14.36%	9.69%	12.25%
400-500 m	9.09%	6.27%	6.52%	11.70%	7.53%	12.25%
> 500 m	22.99%	15.50%	18.83%	17.02%	20.65%	21.74%