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# Distribution patterns of Yangtze finless porpoises in the Yangtze River: implications for reserve management

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## Abstract

The Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) is a highly threatened cetacean endemic to the middle and lower reaches of the Yangtze River that has suffered a dramatic decline in recent decades. We characterize and quantify recent distribution patterns of porpoises in the Yangtze River in order to facilitate strategic management of existing *in situ* cetacean reserves and maximize effective utilization of limited conservation resources. We calculated porpoise relative abundance (encounter rate) using a 1-km moving average along the Yangtze main stem based on a combined visual and acoustic survey conducted in 2006. We then evaluated conservation priority areas based on encounter rates along the river. High-porpoise density areas ($> 0.20$ porpoises km$^{-1}$) cover approximately one-third (33.9%, 599 km) of the survey area and contain approximately two-thirds of the porpoise population, making them priority areas for porpoise conservation. In contrast, low-porpoise density areas ($\leq 0.05$ porpoises km$^{-1}$) cover 28.8% (509 km) of the survey area but contain only 4.5% of the porpoise population, and may already be of little value for porpoise conservation. Five high-priority porpoise conservation sites and five sections that now contain few or no surviving porpoises are identified. Proposed spatial modifications to existing reserves and associated conservation recommendations are made for five existing protected areas along the Yangtze main stem, and we emphasize that some additional river sections should urgently be designated as new protected areas given their high porpoise density. Our approach for identifying conservation priorities may provide lessons for reserve design and management in other protected area networks.

## Introduction

### Population status of the Yangtze finless porpoise

The Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) is an obligate freshwater subspecies of the narrow-ridged finless porpoise that is endemic to the middle and lower reaches of the Yangtze River between Yichang and Shanghai and two appended lakes, Dongting Lake and Poyang Lake (Fig. 1; Gao & Zhou, 1995; Chen *et al*., 2010). During the past three decades (1980s–2000s), the Yangtze finless porpoise population has experienced rapid population decline and fragmentation (Zhao *et al*., 2008; Wang, 2009). The estimated size of the finless porpoise population in the main stem of the Yangtze River was approximately 2550 animals in the early 1990s (Zhang *et al*., 1993). This number is almost certainly an underestimate because of failure to account fully for the porpoises missed during surveys (for details see Zhao *et al*., 2008). The population had declined to *c.*1200 animals in 2006, with an average rate of decline of at least 5% year$^{-1}$ (Zhao *et al*., 2008). A 150-km gap in porpoise distribution between Shishou and Yueyang was also identified in the 2006 range-wide survey (Fig. 1; Zhao *et al*., 2008). The main threats to the long-term survival of finless porpoises in the Yangtze are a range of anthropogenic activities, including incidental by-catch in fishing gear, electrofishing, collisions with heavy ship traffic, pollution and water construction projects (Wang, Zhang & Liu, 1998; Wang *et al*., 2005, 2006a,b; Wang, 2009; Turvey *et al*., 2013), which were also responsible for the decline and recent probable extinction of the sympatric Yangtze River dolphin or baiji (*Lipotes vexillifer*; Turvey *et al*., 2007). The tragedy of the baiji emphasizes the severity of the situation

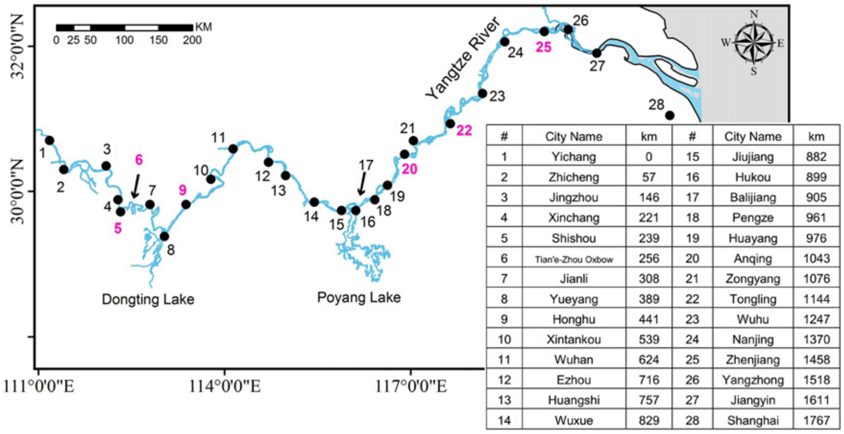


**Figure 1** Sketch map showing locations of cetacean reserves (pink numbers) and major cities, indicated by downstream distance in km from Yichang along the Yangtze main stem. Light blue line shows current distribution of Yangtze finless porpoise.

**Table 1** Summary of cetacean reserves in the Yangtze main stem

| Reserves | Upper limit index (km) | Lower limit index (km) | Position DD°MM′ | Grade | Year established | Length (km) |
|---|---|---|---|---|---|---|
| Shishou | Xinchang | Wumakou | E 112°25′, N 29°57′ | National | 1992 | 89 |
| | 214 | 303 | E 112°51′, N 29°46′ | | | |
| Honghu | Xintankou | Luoshan | E 113°16′, N 29°36′ | National | 1992 | 136 |
| | 410 | 546 | E 113°52′, N 30°13′ | | | |
| Anqing | Sanhaozhou | Zongyang | E 116°22′, N 29°51′ | Municipal | 2007 | 223 |
| | 919 | 1142 | E 117°39′, N 30°46′ | | | |
| Tongling | Zongyang | Jinniudu | E 117°39′, N 30°46′ | National | 1993 | 58 |
| | 1122 | 1180 | E 117°55′, N 31°05′ | | | |
| Zhenjiang | – | – | E 119°24′, N 32°15′ | Provincial | 2006 | 15 |
| | 1458 | 1473 | E 119°32′, N 32°13′ | | | |
| Total | – | – | – | | – | 501 |

Boundaries of reserves are given as downstream distance (in km) from Yichang. Notes: (1) There is a *c.*20 km overlap between the area covered by Anqing reserve and Tongling reserve. For convenience of analysis, this overlap area was only counted in Tongling reserve, so that the range of Anqing reserve used in our analyses is 919–1122 km. (2) Lengths given for Shishou and Tongling reserves exclude their additional *ex situ* sections (see text for further details).

now facing the Yangtze finless porpoise, and the need for urgent conservation action for this highly threatened cetacean. Indeed, the current status of the finless porpoise is not much better than the status of the baiji in the late 1970s and early 1980s (Zhou *et al.*, 1982), and environmental conditions in the Yangtze River are continuing to deteriorate (Dudgeon, 2010). The Yangtze finless porpoise may now be critically endangered according to the categories and criteria of the IUCN Red List (Mei *et al.*, 2012), and many conservationists have been urging immediate actions to insure the long-term persistence of this cetacean (Wang *et al.*, 1998, 2006a; Guo, 2006; Zhao *et al.*, 2008; Wang, 2009; Stone, 2010).

## Cetacean reserves in the Yangtze River

Five *in situ* cetacean reserves have been established in the main stem of the Yangtze River since the 1990s under the approval of the Chinese authorities (Table 1; Fig. 1). Following the conservation recommendations proposed during the 'Workshop on Biology and Conservation of Platanistoid Dolphins' held in Wuhan in 1986 (Perrin *et al.*, 1989), three national-level reserves were established at Shishou (1992), Honghu (1992) and Tongling (initially established as a provincial sanctuary in 1993 and upgraded to a national reserve in 2006; Fig. 1). The Shishou reserve consists of a 21-km *ex situ* reserve (the Tian'e-Zhou oxbow) and an 89-km *in situ* protected area in the Yangtze main stem. Similarly, Tongling reserve consists of a 1.6-km *ex situ* reserve and a 58-km *in situ* protected area. We will focus only on the *in situ* areas of both reserves in this study. These three protected areas were established primarily for conservation of baiji, and were established in regions of perceived high baiji abundance (see Turvey *et al.*, 2010), but they are now considered to provide protection for finless porpoises. Two further *in situ* protected areas, established more recently in 2003 at Zhenjiang (a provincial reserve) and in 2007 at Anqing (a municipal reserve; Fig. 1), were primarily set up to conserve finless porpoises. Different levels of reserve status (national, provincial and municipal) in China receive different levels of financial support and public attention. National reserves receive the maximum level of funding and public attention, and so can provide the most effective protection.

The Yangtze River, the so-called 'golden channel' of China, is now an extremely busy waterway that acts as an essential transport route supporting the country's rapidly growing industry and economy (Wang *et al.*, 2006a; Turvey *et al.*, 2007), and it is unfortunately unrealistic to expect that all threatening anthropogenic activities within the Yangtze system will be regulated or prohibited even in cetacean reserves. However, within these reserves, riverside factory construction is restricted, water construction projects (ports, dams, bridges sand dredging) are either prohibited or require strict environmental impact assessments, and monitoring is conducted regularly by reserve administration agencies. Electrofishing and use of rolling hooks are illegal throughout the Yangtze River main stem, and more vigorous enforcement of these activities for cetacean conservation should be expected in reserves. However, in recent interviews with Yangtze fishermen, Turvey *et al.* (2013) found that these fishing methods are still commonly used throughout the Yangtze region and that informants appeared to be generally unaware of legislation prohibiting the use of rolling hooks. While we recognize that protected areas will still provide only imperfect protection for the threatened Yangtze finless porpoise, in this paper, we hope that at least some harmful anthropogenic activities, notably illegal fishing activities (electrofishing, rolling hooks, gillnets) and sand dredging, could be effectively reduced or restricted in reserves using available management methods.

### Conservation effectiveness of Yangtze cetacean reserves

The five cetacean reserves in the Yangtze main stem cover 501 km of river channel, and represent a relatively large proportion (28.9%) of the finless porpoise's distribution along the middle-lower Yangtze River. The recent and continuing decline of porpoises demonstrates that protection is currently insufficient, but it is unclear whether the decline is primarily driven by lack of enforcement of existing laws or by the suboptimal placement of the current reserves. Future conservation certainly relies on full enforcement but can also be aided by careful placement of reserves to maximize efficiency in reducing porpoise mortality and to minimize economic hardship resulting from regulations. The current distribution and abundance of finless porpoises is probably not fully congruent with the past distribution and abundance of baiji (Turvey *et al.*, 2010), the species for which most of the reserves were originally established. Porpoise distribution may also have changed in response to differing levels of anthropogenic threat across its range since the establishment of this protected area network. Furthermore, these reserves are under the jurisdiction of different levels of management authority and different governmental departments, and a lack of effective communication between national, provincial and municipal levels and different bodies has prevented the development of an integrated conservation management plan for finless porpoises across the Yangtze River basin. It is therefore imperative to evaluate the current effectiveness of these reserves for finless porpoise conservation using the most up-to-date information on porpoise distribution and abundance, in order to achieve more efficient conservation management for the species.

We provide a quantitative analysis of finless porpoise distribution and abundance across its known range in the Yangtze River main stem based on data from a range-wide, line transect visual survey combined with a towed-array acoustic survey that we conducted simultaneously in 2006 (Akamatsu *et al.*, 2008; Zhao *et al.*, 2008). We then use these data to evaluate and identify priority regions for porpoise conservation across the middle-lower Yangtze, and to make new management recommendations for Shishou, Honghu, Anqing, Tongling and Zhenjiang cetacean reserves.

## Material and methods

### Data collection

Survey work was conducted from 6 November to 13 December 2006, using both line transect sampling and towed acoustic surveying with A-tags (ML200-AS2, Marine Micro Technology, Saitama, Japan), for the purpose of estimating the abundance and characterizing distribution patterns of finless porpoises in the Yangtze River main stem. The survey was deliberately conducted in the low-water season when porpoises concentrate in the relatively narrow river channel, permitting a higher detection probability. The expedition employed two 40-m research vessels, which departed from Wuhan, travelled upstream to Yichang then downstream to Shanghai and finally back upstream again to Wuhan (Fig. 1). This route covered the section between Yichang and Shanghai twice, with a total on-effort distance of 3400 km made by both vessels. Line transect sampling was carried out by both vessels for the entire survey period. We used 'passing mode' and 'closing mode' line transect methods (Buckland *et al.*, 2001) throughout the survey, with a 'passing mode' vessel ahead and a 'closing mode' vessel approximately 5 km behind. The two vessels operated independently at all times, kept independent records and did not share information about porpoise sightings, so that visual data from both vessels could be analyzed independently or jointly. Group size was estimated by the observer who made the sighting, and the observers in the 'closing mode' vessel also had the option to stop and/or approach the porpoises following a sighting for further confirmation of group size. Acoustic arrays were towed by both vessels, one continuously and one intermittently, during the downstream part of the survey because of high noise contamination when travelling upstream. Field data collected for all porpoise sightings/detections included local time, geographical position and group size, as well as additional data (described in Zhao *et al.*, 2008). Vessel tracks were recorded automatically by a portable Global Positioning System (Garmin eTrex Legend, Garmin Corporation, Taipei County, Taiwan) once per minute. Further details of the visual and acoustic survey methods are given in Akamatsu *et al.*, (2008) and Zhao *et al.* (2008).

## Analytical methods

Distance in kilometres along the survey transect downstream from Yichang was used to reference the location of all points of interest (e.g. towns/cities, reserve boundaries, porpoise sightings).

### Encounter rate calculation

We employed a 1-km moving average to generate encounter rates along the survey transect. We tested different moving average window sizes (1 km, 10 km, 20 km, 30 km, 40 km, 50 km), with the window equally distributed upstream and downstream, and generated simple moving average encounter rates by totalling the number of porpoises within the window divided by window size. For points at the two ends of the transect (i.e. Yichang and Shanghai) where use of a moving average is not applicable, we calculated encounter rates by using a simple average instead. Encounter rates using 50-km window size were plotted. The window size was selected to be similar to the size of several gaps in finless porpoise distribution (40 to 65 km) described by Dong *et al*., 2011. Based on our understanding of the home range of this species, Yangtze finless porpoise is considered to have stable site fidelity pattern (Kimura *et al*., 2012) generally travelling at most 90 km in a day (Akamatsu *et al*., 2002), and mtDNA haplotypes evidence (Zheng, 2005) also revealed Yangtze finless porpoise do not move far.

Visual and acoustic encounter rates were calculated separately using custom codes in R (R Development Core Team, 2008). All visual data from both vessels were pooled together for integrated analysis because there was no significant difference ($Z$-test, $z = 0.18$, $P = 0.86$) between the visual porpoise survey data collected by the two survey vessels (Zhao *et al*., 2008). Meanwhile, as acoustic coverage of both vessels was incomplete, we therefore integrated acoustic datasets from two vessels into one by mutual complementation, virtually representing one perfect one-way downstream acoustic survey coverage of whole range. Our custom programming calculated the encounter rate by counting the total number of observed animals and calculating total survey effort (length in km) in a specific section automatically. Because both acoustic and visual surveys will miss animals, we further define a combined encounter rate (Abbr. C-Encounter rate) to represent the minimum encounter rates along the survey transect, based on the highest respective encounter rate at any point along the river from either visual or acoustic calculation.

### Ranking combined encounter rates

C-Encounter rate values were graded into several 'porpoise density ranks'. We summarized the number of observed porpoise individuals within each of these ranks, and used this information to highlight porpoise high-density areas across both the entire Yangtze main stem and also each Yangtze cetacean reserve, to identify the highest priority river sections for porpoise conservation and determine the usefulness of each reserve. Analysis was conducted in R (R Development Core Team, 2008).

## Results

### Data summary

The line transect sampling data presented in this paper consisted of 486 on-effort porpoise sighting events, representing a total of 968 individuals in a roundtrip survey by two vessels. Acoustic data consisted of 200 on-effort detection events, representing a total of 225 individuals in a single one-way downstream coverage. Previous analyses on these data revealed that the acoustic arrays had a higher detection probability than the visual method, in particular for detecting single porpoises, and on the other hand, visual observation is powerful to estimate large group size better than acoustics (Akamatsu *et al*., 2008). Consequently, the combined encounter rate would greatly reduce miss rate and improved maximize encounter rate (Fig. 2a). The calculated length of the survey transect downstream from Yichang, based on tracking data from one research vessel, was 1767 km. Distances from Yichang to major points of interest along the river are listed in Fig. 1. As these downstream distances were calculated based on our survey track line, there are slight differences from shipping distances along the Yangtze given in official navigation charts; however, all analyses in the current study are indexed to our baseline, and so these discrepancies do not provide any bias in our analyses.

Visual, acoustic and combined encounter rates were plotted in Fig. 2b.

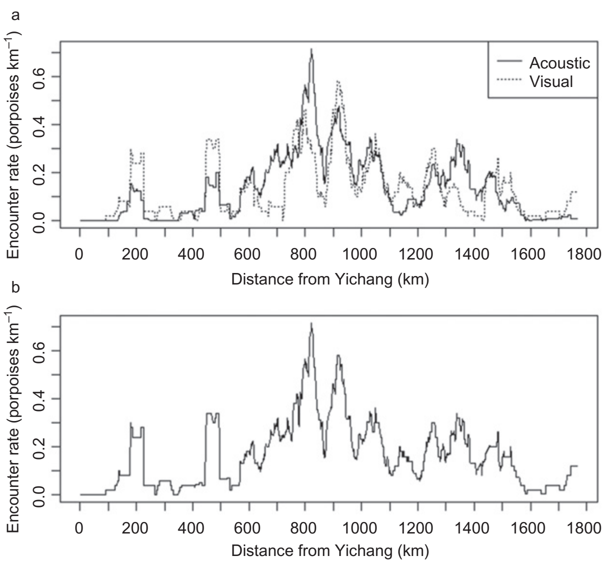


**Figure 2** Moving average encounter rate for finless porpoises (window size = 50 km) in the Yangtze main stem between Yichang and Shanghai, showing (a) visual and acoustic encounter rates separately, and (b) combined encounter rates (i.e. maximum detection rate of either method).

## Ranked C-Encounter rates in Yangtze main stem and cetacean reserves

Finless porpoise C-Encounter rates in the Yangtze main stem ranged from 0.00 to 0.72 porpoises km$^{-1}$ (0.16 porpoises km$^{-1}$ in average, $n = 1767$). The highest recorded encounter rate was 822 km downstream from Yichang, near Wuxue (Figs 1 and 2; E 115°29′22″, N 29°50′36″). We categorized C-Encounter rates for different regions of the Yangtze main stem into 16 porpoise density ranks, according to an interval of 0.05 porpoises km$^{-1}$ (i.e. 0.00, > 0.00–0.05, > 0.05–0.10 . . . > 0.70–0.75 porpoises km$^{-1}$; Fig. 3, Table 2). C-Encounter rates were 0.00 over a length of 116 km, representing 6.6% of the total length of the surveyed main stem. The lowest porpoise density rank for which at least some porpoises were detected (> 0.00–0.05 porpoises km$^{-1}$) covered 393 km, the longest length of any of the porpoise density ranks, accounting for 22.2% of the survey area (Fig. 3). C-Encounter rates ≤ 0.05 porpoises km$^{-1}$ (i.e. less than one porpoise encountered per 20 km) therefore covered 509 km,

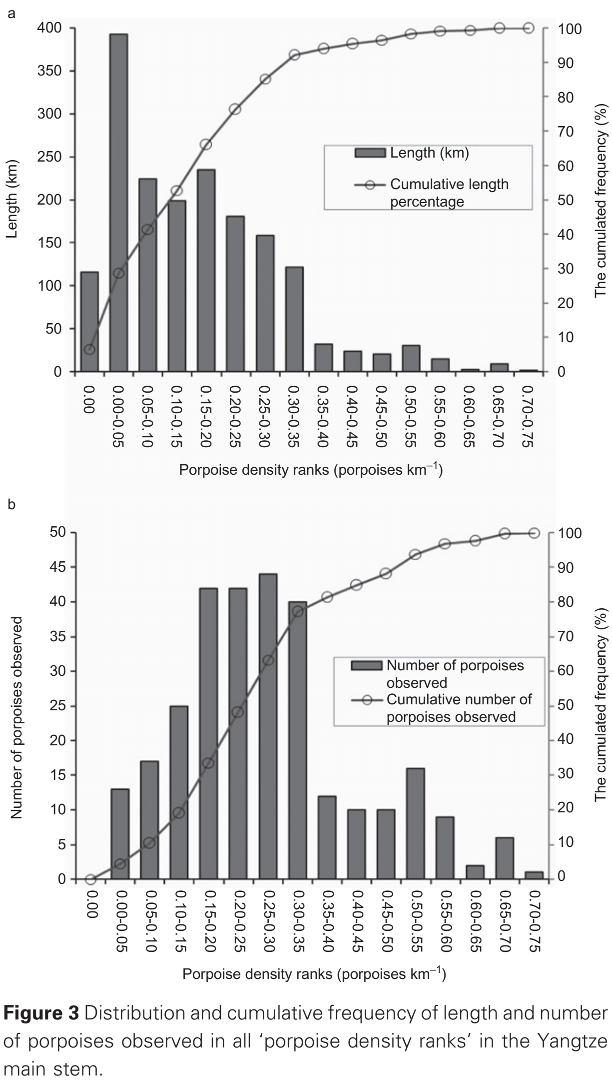


**Figure 3** Distribution and cumulative frequency of length and number of porpoises observed in all ‘porpoise density ranks’ in the Yangtze main stem.

**Table 2** The length (L), length percentage (L%), and number of porpoises observed (*N*) for all ‘porpoise density ranks’ in each reserve; the total length (TL), total length percentage (TL%), and total number of porpoises observed (TN) for all ‘porpoise density ranks’ in all reserves combined; and the length (RL) for each of the 16 ‘porpoise density ranks’ in the Yangtze main stem

| Combined encounter | Shishou reserve | | | Honghu reserve | | | Anqing reserve | | | Tongling reserve | | | Yangtze main stem | | | Reserves combined | | | Yangtze main stem |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| rate porpoises km$^{-1}$ | L km | L% | *N* | L km | L% | *N* | L km | L% | *N* | L km | L% | *N* | L km | L% | *N* | TL km | TL% | TN | RL km |
| = 0.00 | 7 | 7.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 1.4 | 0 | 116 |
| > 0.00–0.05 | 49 | 55.1 | 2 | 48 | 35.3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 97 | 19.4 | 4 | 393 |
| > 0.05–0.10 | 21 | 23.6 | 1 | 35 | 25.7 | 2 | 21 | 10.3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 77 | 15.4 | 5 | 225 |
| > 0.10–0.15 | 0 | 0 | 0 | 3 | 2.2 | 0 | 19 | 9.4 | 2 | 26 | 44.8 | 3 | 0 | 0 | 0 | 48 | 9.6 | 5 | 199 |
| > 0.15–0.20 | 0 | 0 | 0 | 1 | 0.7 | 0 | 30 | 14.8 | 5 | 32 | 55.2 | 6 | 15 | 100 | 3 | 78 | 15.6 | 14 | 235 |
| > 0.20–0.25 | 1 | 1.1 | 0 | 1 | 0.7 | 0 | 35 | 17.2 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 37 | 7.4 | 8 | 181 |
| > 0.25–0.30 | 11 | 12.4 | 3 | 11 | 8.1 | 3 | 36 | 17.7 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 58 | 11.6 | 16 | 159 |
| > 0.30–0.35 | 0 | 0 | 0 | 37 | 27.2 | 12 | 37 | 18.2 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 74 | 14.8 | 24 | 122 |
| > 0.35–0.40 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.4 | 1 | 32 |
| > 0.40–0.45 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.8 | 2 | 24 |
| > 0.45–0.50 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 4.4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 1.8 | 4 | 21 |
| > 0.50–0.55 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 1.2 | 3 | 31 |
| > 0.55–0.60 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.8 | 2 | 15 |
| > 0.60–0.65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| > 0.65–0.70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| > 0.70–0.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Total | 89 | 100 | 6 | 136 | 100 | 19 | 203 | 100 | 51 | 58 | 100 | 9 | 15 | 100 | 3 | 501 | 100 | 88 | 1767 |

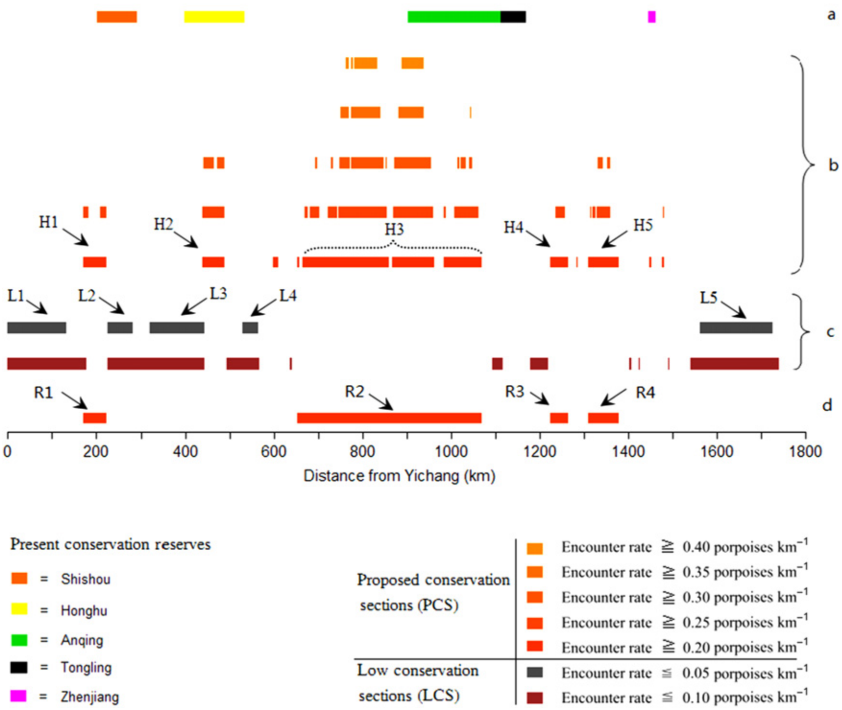


**Figure 4** High conservation value areas (HCVs) and low conservation value areas (LCVs) for finless porpoises in the Yangtze main stem between Yichang and Shanghai. (a) Distribution of the five existing cetacean reserves along the Yangtze main stem. (b) HCVs defined at different combined encounter rate levels (≥ 0.20, 0.25, 0.30, 0.35 and 0.40 porpoises km$^{-1}$). Five sections (H1-H5) are identified as new potential protected areas reserves at the 0.20 porpoises km$^{-1}$ combined encounter rate level. (c) Identification of LCVs where combined encounter rate is (1) < 0.05 porpoises km$^{-1}$, and (2) < 0.10 porpoises km$^{-1}$. Five sections (L1-L5) are identified with extremely low-porpoise encounter rates and conservation values. (d) Recommended reserves (R1-R4). Downstream distance of major cities for references: Yichang-0, Shishou-239, Honghu-441, Wuhan-624, Hukou-899, Anqing-1043, Tongling-1144, Nanjing-1370, Zhenjiang-1458, Shanghai-1767.

representing 28.8% of the survey area. Over half of the survey area (933 km, 52.8%) had C-Encounter rates of ≤ 0.15 porpoises km$^{-1}$, and approximately two-thirds of the survey area (1168 km, 66.1%) had rates of ≤ 0.20 porpoises km$^{-1}$. A cumulative distribution of these 16 ranks (Fig. 3a) shows an inflection point at 0.35 porpoises km$^{-1}$, with an C-Encounter rate of > 0.35 porpoises km$^{-1}$ being very rare. Only 7.8% of the survey area (137 km) showed C-Encounter rates of > 0.35 porpoises km$^{-1}$, and only 6% (105 km) showed rates of > 0.40 porpoises km$^{-1}$. C-Encounter rates for existing cetacean reserves are given in Table 2 and comparison between C-Encounter rates for existing and proposed reserves (see below) are given in Fig. 4.

## Discussion

### Rationale for analytical techniques

The use of observed encounter rates as an index of relative abundance has been widely used in marine mammal research when measures of absolute population density are not available (Edwards & Perkins, 1992; Thompson *et al.*, 1997; Calkins *et al.*, 1999; Oviedo & Silva, 2005; Gray & Burlew, 2007). We calculated porpoise encounter rates along the Yangtze River through smoothing by using the moving average method. Encounter rates obtained from visual and acoustic datasets show close spatial congruence in our study (Fig. 2a), and have been demonstrated to provide comparable detection probabilities in previous studies (Akamatsu *et al.*, 2008), so that integrating these two independent sources of data to generate a combined encounter rate is expected to provide a more robust dataset for analysis. We therefore consider that our combined encounter rate curve represents a meaningful approximation of the true distribution of finless porpoises in the Yangtze main stem, and that our evaluation of relative patterns of conservation priority areas across the survey region is also reliable.

We recognize that the moving average is only used to smooth the data to emphasize the general distribution patterns, rather than to artificially reduce the variance of abundance estimates. Inclusion of all variance is particularly important when using abundance estimates to assess sustainable limits to by-catch or other human-caused mortality, which is not our focus here. We also recognize that our study is based on only one range-wide survey, and so possible seasonal variation in porpoise distribution and movements has not been taken into account; we therefore hope to supplement our data in the future by conducting similar studies in other seasons. However, our conclusions on patterns of porpoise distribution and abundance are likely to be robust, because available data indicate that porpoises do not travel long distances upstream and downstream across the survey region (Zheng, 2005; Kimura *et al.*, 2012), and previous qualitative surveys of relative porpoise distribution patterns over different seasons and years show similar overall distribution patterns to our study (Zhang *et al.*, 1993; Wang *et al.*, 1998; Zhou *et al.*, 1998; Yu *et al.*, 2001; Wei *et al.*, 2002; Zhao *et al.*, 2008; Dong *et al.*, 2011).

### Identifying high-priority areas for porpoise conservation

The total number of porpoise individuals detected across a given river section can be calculated based on the

C-Encounter rate and survey effort (i.e. survey length in km) across the section. Following this approach, our data show that finless porpoises have a very uneven distribution among upper (0–600 km), middle (600–1400 km) and lower reaches of the Yangtze main stem. For instance, about two-thirds (66.4%) of all porpoises occur in about one-third (33.9%) of the survey area, where C-Encounter rates are higher than 0.20 porpoises $km^{-1}$ (Table 2, Fig. 4a).

The spatial pattern of porpoise encounter rates can be used as an index for assessing the suitability of different parts of the Yangtze main stem for supporting porpoises, and for assessing the conservation significance of the existing protected area network. The current Yangtze cetacean reserve network covers a length of 501 km (28.4% of the Yangtze River habitat). This research revealed that the reserve area does not fully cover the high-density area of the porpoises. If resources are only available to support a conservation network of approximately this size, then we propose that this protected area network should be redefined and relocated to cover the areas that have been identified as having C-Encounter rates above 0.20 porpoises $km^{-1}$, corresponding to a total river length of 599 km. These areas are distributed in five discrete river sections, referred to here as sections H1-H5 (Table 3, Fig. 4b). Of these five sections, H3 contains the 248-km section with the highest C-Encounter rates of > 0.35 porpoises $km^{-1}$ (758–844 km, Huangshi to Wuxue, and 889–1049 km, Jiujiang to Anqing; Figs 2 and 4), and represents the contiguous section with highest porpoise conservation value along the entire main stem. Within H3, the 770–839 km and 896–942 km sections have relatively high C-Encounter rates of > 0.40 porpoises $km^{-1}$ (Fig. 4b). However, of these five sections, only H2 and a small part of H3 are currently covered by the existing reserve network (Fig. 4).

In contrast to these porpoise high-density areas, some river sections with extremely low encounter rates may already be of minimal value for porpoise conservation. These areas now cover 509 km of river, mainly upstream of Wuhan and close to the Yangtze estuary, and include five identified sections (L1-L5) covering 116 km of river where no porpoises at all were detected, and 393 km with encounter rates ≤ 0.05 porpoises $km^{-1}$ (Table 3). Of these, sections L2 and L3 represent the area between Shishou and Yueyang (Fig. 1) that was identified as a 150-km 'gap' in porpoise distribution by Zhao *et al.* (2008).

## Evaluating conservation effectiveness of existing Yangtze cetacean reserves

Our data demonstrate that the current distribution of cetacean reserves in the Yangtze main stem does not reflect the distribution pattern of finless porpoise abundance. Of the 599-km high-priority conservation value areas (encounter rates > 0.20 porpoises $km^{-1}$), only 194 km (32.4%) are currently covered by the existing protected area system (Fig. 4). In contrast, the 501 km of highest density porpoise sections, representing the same area to that currently covered by existing reserves, contain 60.7% of the total number of observed porpoises. The same conservation efficiency as that provided by the current protected area network (i.e. protecting 30.4% of the surviving porpoise population) could be achieved through protection of a much smaller

**Table 3** Distribution of discrete river sections along the Yangtze main stem that represent key high-density (combined encounter rates > 0.20 porpoises $km^{-1}$; sections H1-H5) and low-density (combined encounter rates ≤ 0.05 porpoises $km^{-1}$; sections L1-L5) regions for finless porpoises

| Sections | Upper limit index (km) position (longitude, latitude) | | Lower limit index (km) position(longitude, latitude) | | Length km |
|---|---|---|---|---|---|
| High-density sections | | | | | |
| H1 | 178 | | 226 | | 50 |
| | E 112°11′42″ | N 30°06′54″ | E 112°23′36″ | N 29°51′25″ | |
| H2 | 446 | | 494 | | 50 |
| | E 113°30′49″ | N 29°49′23″ | E 113°54′37″ | N 30°02′01″ | |
| H3 | 659 | | 1073 | | 416 |
| | E 114°33′37″ | N 30°37′41″ | E 117°13′11″ | N 30°36′45″ | |
| H4 | 1231 | | 1269 | | 40 |
| | E 118°13′43″ | N 31°17′39″ | E 118°22′48″ | N 31°31′36″ | |
| H5 | 1315 | | 1383 | | 70 |
| | E 118°24′31″ | N 31°41′14″ | E 118°47′41″ | N 32°08′28″ | |
| Low-density sections | | | | | |
| L1 | 0 | | 131 | | 131 |
| | E 111°17′07″ | N 30°41′19″ | E 112°02′55″ | N 30°16′49″ | |
| L2 | 227 | | 282 | | 56 |
| | E 112°23′22″ | N 29°50′28″ | E 112°39′24″ | N 29°45′58″ | |
| L3 | 322 | | 443 | | 122 |
| | E 112°55′18″ | N 29°41′09″ | E 113°30′07″ | N 29°48′14″ | |
| L4 | 532 | | 566 | | 35 |
| | E 113°57′00″ | N 30°12′25″ | E 114°01′03″ | N 30°15′22″ | |
| L5 | 1564 | | 1728 | | 165 |
| | E 120°05′55″ | N 31°56′48″ | E 121°12′22″ | N 31°39′36″ | |

amount of river (197 km, equivalent to 39.3% of the current cetacean reserve area) if high-density river sections are instead established as protected areas.

The different existing cetacean reserves also differ in their relative porpoise densities, and thus their relative importance for porpoise conservation (Table 2, Fig. 4). Surprisingly, the two non-national protected areas have higher porpoise densities than the three national protected areas (Table 2, Fig. 4). The total river length covered by the national protected areas is 335 km (19.0% of survey area), but they only contain 13.5% of the total number of porpoise observations (C-Encounter rate: 0.12 porpoises $km^{-1}$ in average ranged from 0.00 to 0.34 porpoises $km^{-1}$), and include some very low-density sections: L2 is within Shishou reserve, and parts of L3 and L4 fall within Honghu reserve (Fig. 4b). In contrast, the 218-km non-national reserves (12.4% of survey area) contain 18.7% of all porpoise observations (C-Encounter rate: 0.25 porpoises $km^{-1}$ in average ranged from 0.08 to 0.58 porpoises $km^{-1}$).

## Proposed adjustments to the cetacean reserve network

From the viewpoint of effective site selection, the current protected area network in the Yangtze main stem does not afford protection to the most important river sections for porpoise conservation. Based on our survey data, we propose the following modifications to improve the existing protected areas network.

Firstly, the conservation of a relatively small but high-density section of porpoise habitat in the upstream part of the river can be achieved by extending the Shishou reserve upstream to also include the contiguous 50-km section H1, which can be balanced by removing part of the reserve's low-density section (Fig. 1; 227–282 km downstream from Yichang, from E 112°23′22″, N 29°50′28″ to E 112°39′31″, N 29°46′01″, where C-Encounter rates are ≤0.10 porpoises $km^{-1}$) from formal protection.

Secondly, monitoring and management activities at Honghu reserve should be considerably strengthened because this section has the highest C-Encounter rates for all sections upstream of Wuhan. Section H2, in which the rate is relatively high, falls completely inside the existing 136-km boundaries of Honghu reserve, and so is already covered by existing *in situ* conservation legislation. As this section is only 50 km long, it should be possible for the reserve administration agency to increase targeted conservation actions using available resources.

Thirdly, we propose that the entirety of section H3 should be given national protected area status immediately. This section has the highest porpoise density anywhere in the Yangtze main stem, and includes the Balijiang section, a 40-km section between Hukou and Pengze that currently contains *c.* 90 porpoises (Fig. 1; Zhao & Wang, 2011). However, currently, only a small part of section H3 falls within an existing protected area (Anqing reserve).

Fourthly, Tongling reserve should be connected to Anqing reserve at its upstream end, and connected with the two high-density porpoise sections H4 and H5 at its downstream end. Although encounter rates within the Tongling section itself are relatively low, this river region may function as an important ecological corridor between two nearby sections with high porpoise density, and so should continue to receive a high level of protection. Sections H4 and H5 should also be established as protected areas.

Yangtze finless porpoises are now extremely threatened and require efficient conservation action to ensure their long-term survival. Our suggested changes to the existing protected area network are the first step needed on the road to reversing the decline of this subspecies, but this will not be sufficient. It goes without saying that protected areas will not work without vigorous enforcement. In addition, as protection is currently not extended across the middle-lower Yangtze main stem, effective porpoise conservation using *in situ* reserves will require knowing whether porpoises move out of or between reserves. More information, therefore, is also needed on porpoise population movements throughout the year. Acoustic monitoring holds great potential for monitoring trends in abundance and changes in distribution both in the short term (seasonal movements) and the long term (potential continued loss of range or fragmentation) (Akamatsu *et al.*, 2008; Dong *et al.*, 2011). In addition, available genetic data suggest that porpoises occurring upstream of Wuhan may be isolated from animals further downstream (Zheng, 2005). These populations may require connectivity between areas of current higher density to maintain genetically viable populations and so reserves may need to be larger or even continuous across substantial parts of the Yangtze main stem.

## Wider conservation implications of survey methodology

Besides identification of high-priority conservation areas, the moving average encounter rate curve could also be employed for recognition of possible seasonal migration or distributional trends shown by species of interest, by comparing distribution curves derived from different surveys. Indeed, because the acoustic method is very cost-effective, towed acoustic surveys utilizing the moving average analytical technique have great potential to be widely applied in cetacean strip surveys. This survey approach has already been implemented in the Yangtze River through the use of acoustic equipment attached to cargo vessels to collect porpoise data regularly in different seasons over recent years (Dong *et al.*, 2011). The moving average encounter rate could also be employed in more open areas (e.g. lakes, ocean) rather than confined to habitat strips, as the moving average encounter rate of a point in an open area could be calculated by totalling the number of animals within a specific radius divided by the area of the circle. A contour map of encounter rates could then be easily produced to identify high-priority conservation areas.

The combined application of both visual and acoustic methods could improve the estimation of g(0), which is a very influential and often poorly estimated parameter of the probability of detecting an animal on a trackline. The acoustic observation could be treated as an independent observer, and used to estimate g(0) using the conditionally independent observer method (Barlow, 1995).This will improve the estimate of g(0) compared to using independent visual observer because the detection probability of the acoustic method is approximately twice that for visual detection (Akamatsu *et al*., 2008).

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