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Abundance and Conservation Status of the Yangtze Finless Porpoise in the Yangtze River, China

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Abundance and conservation status of the Yangtze finless porpoise in the Yangtze River, China

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A B S T R A C T

The Yangtze finless porpoise (*Neophocaena phocaenoides asiaeorientalis*) is endemic to the middle and lower reaches of the Yangtze River, China. It is the only freshwater population of porpoises in the world and is currently listed as Endangered by IUCN. In November and December 2006 we used two boats and line transect methods to survey the entire current range of the population, except for two lakes (Poyang and Dongting). Sighting results were similar for both boats, so we pooled all data and analyzed them using two line transect models and a strip transect model. All models produced similar estimates of abundance (1111, 1225 and 1000). We then added independent estimates of the number of porpoises from the two lakes for a total estimate of approximately 1800 porpoises. Our findings indicate that the population continues to decline and that its distribution is becoming more fragmented. Our current estimate in the main river is slightly less than half the estimate from surveys between 1984 and 1991 (which was probably an underestimate). We also found an apparent gap in the distribution of porpoises between Yueyang and Shishou (~150 km), where sightings had previously been common. Continued threats to Yangtze finless porpoises include bycatch in unregulated and unselective fishing, habitat degradation through dredging, pollution and noise, vessel strikes and water development. Immediate protective measures are urgently needed to ensure the persistence of finless porpoises in the Yangtze River. The survey design and analytical methods developed in this study might be appropriate for surveys of cetaceans in other river systems.

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1. Introduction

The Yangtze finless porpoise (*Neophocaena phocaenoides asiaeorientalis*) is endemic to the middle-lower Yangtze River drainage in eastern China. It is now primarily restricted to the main river channel and its two largest appended lakes (Poyang and Dongting). It occasionally occurred in some large adjacent tributaries (Fig. 1), but now has been extirpated from most of them (Zhang et al., 1993; Yang et al., 2000; Xiao and Zhang, 2002). Of the six extant species of porpoise (Phocoenidae), this is the only population found in fresh water (Gao and Zhou, 1995). The amount of river and lake habitat available to this subspecies is relatively small compared to that available to marine populations of finless porpoises, which occur in coastal waters from Japan to the Arabian Sea (Kasuya, 1999).

The Yangtze River has been greatly altered by human activities that have made it much less suitable as habitat for cetaceans, especially during the last three decades with the booming Chinese economy. Numerous surveys of porpoises have been conducted in the Yangtze River since the late 1970s and all have indicated low and rapidly decreasing numbers (Wang et al., 1998, 2000; Wei et al., 2002b; Xiao and Zhang, 2000, 2002; Yang et al., 2000; Yu et al., 2001; Zhang et al., 1993; Zhou et al., 1998b). Based on the survey data collected by Wei et al. (2002b), we calculated that the population had declined at an exponential rate of 13%/year (based on abundance going from 260 to 71 between 1989 and 1999) in the ~40 km Balijiang section alone which is the confluence area of Poyang Lake and Yangtze River (Fig. 1). *N. p. asiaeorientalis* was listed as Endangered by IUCN in 1996 (Baillie and Groombridge, 1996) in terms of the criteria that fewer than 2500 mature individuals remained and the population was continuing to decline.

The first range-wide estimate of finless porpoise abundance in the Yangtze River system (~2700 porpoises) was based on many small-scale surveys conducted between 1984 and 1991 (Zhang et al., 1993). Non-standard methods were used in that study to correct for the fraction of missed porpoises. Thereafter, fragmentary surveys in different sections of the Yangtze River were carried out by various researchers using essentially the same survey methods (Wang et al., 1998; Yang et al., 2000; Yu et al., 2001; Zhou et al., 1998b). The latest abundance estimate of ~2000 porpoises was based on three range-wide surveys from 1997 to 1999 (Ding Wang, unpublished data; Zhang et al., 2003). During those surveys, the Yangtze River, Dongting and Poyang Lakes, and their tributaries were divided into 21 sections or areas, and two large boats (~30 m long) searched each section or area simultaneously.

Here we report results of a line transect survey covering most of the current range of finless porpoises in the main channel of the Yangtze River between Yichang and Shanghai in November and December 2006. We estimate abundance, characterize current distribution, and review threats to the population's survival. We apply rigorous line- and strip-transect survey methods and estimate a correction factor for missed animals based on data collected on this survey. Our results increase concern that the only freshwater population of finless porpoises in the world appears to be rapidly declining towards extinction, as seems to have happened already to the baiji (*Lipotes vexillifer*) (Turvey et al., 2007).

2. Materials and methods

2.1. Field sampling methods

We conducted our survey from 6 November to 13 December 2006. The survey covered approximately 3300 km of the main channel of the Yangtze River during a roundtrip survey between Yichang and Shanghai (Fig. 1). The width of the river in this total section varied from several hundreds of meters to 3 km, but was generally less than 2 km. We did not cover tributaries because most of them are unlikely to be viable habitat (Xiao and Zhang, 2002; Yang et al., 2000; Zhang et al., 1993). We also did not cover any small side channels that were considered unnavigable.

A pilot survey was conducted in March 2006 to investigate possible survey designs. A systematic zig-zag transect design, such as that used to survey river dolphins in the Amazon River (Vidal et al., 1997; Martin et al., 2004), was determined to be infeasible due to the high-density of large cargo vessels in the Yangtze River (approximately one ship every 100 m) and the requirement to travel in the relatively narrow shipping channels. Consequently, we could only travel parallel to the banks when heading either up- or down-river. These factors imposed substantial constraints on possible survey methods.

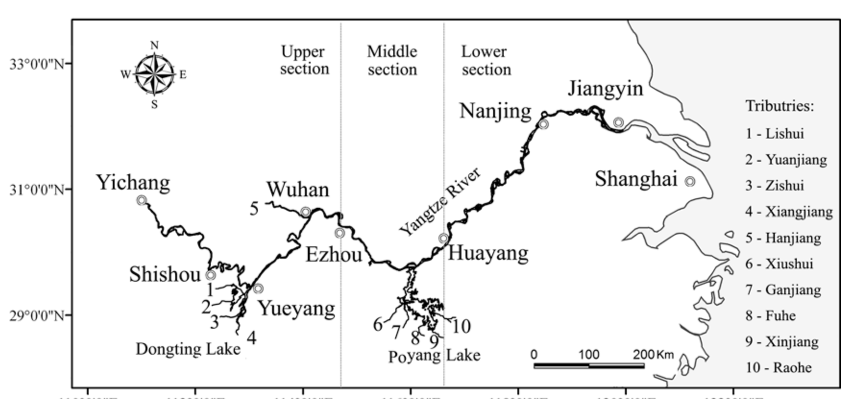

Fig. 1 – Study area in the Yangtze River, China, from Yichang to Shanghai; also shown are the designated boundaries of the upper, middle and lower regions of the surveyed area and large tributaries Yangtze finless porpoise formerly occurred.

We used two boats, each 33 m long, with 4 m-high viewing platforms, and surveyed parallel to the riverbanks with one boat covering each side of the channel, at a constant ground speed of ~14–16 km/h for the entire survey. The boats were piloted by captains who were extremely familiar with shipping conditions on the Yangtze River and they decided whether a side channel was navigable based on their experience and with the assistance of a civil river chart. Target routes for both boats were 300 m offshore, but actual distances varied from 100 to 500 m depending on traffic, the location of the designated shipping channel, and other navigational conditions.

We used passing mode and closing mode line transect methods (Buckland et al., 2001; Butterworth and Borchers, 1988; Dawson et al., 2008) throughout the survey. Generally, when the river was less than 2 km wide (as it was for most of the survey), we conducted the survey with a passing mode boat in front and a closing mode boat far enough behind that it would not be alerted to sightings by the leading boat (approximately 5 km). The second boat then had the option to approach animals to determine group size as necessary. The boats alternated positions every day. Occasionally, when the channel was wider than 2 km and the boats could avoid mutual distractions (i.e. too far away to make a cue mutually), both surveyed in closing mode. Similarly, when the main channel split into two channels and both channels were navigable, each boat would cover one of the channels and both would survey in closing mode. The two boats operated independently at all times, kept independent records, and did not share information about porpoise sightings. These independent data were also used to find duplicate sightings made by both boats in low-density areas by comparing the sighting time and position using the approach employed by Smith et al. (2006). The boats switched sides of the river when turning at Yichang and Shanghai, so that each covered both sides of the shipping channel.

The primary observation (PO) team on each boat consisted of three observers (left, center, and right) searching with 7×50 mm Fujinon binoculars (mounted on hand-held monopods) and unaided eye. The left and right observers searched from 90° abeam to 10° on the other side of the bow, and they typically searched 90% of the time with binoculars. The center observer (also the data recorder) searched approximately 50% of the time with binoculars and 50% with unaided eye. Six or seven observers rotated among the three positions every 30 min and rested for 90–120 min between shifts. A random schedule for each observer was determined in advance to ensure equal effort by all observers. The data recorder entered sighting and effort data on a standard form. Effort data recorded every 30 min included local time, position, survey mode (passing or closing), weather condition (excellent, good, fair or poor determined subjectively based on wave height and visibility), identity and position of each observer, distance from the boat to the nearest bank (every 10 min), and boat direction (upstream/downstream). Data recorded for sightings included local time, position, estimated radial distance and bearing angle, identity of observer, group size and distance from the sighting to the nearest bank. Boat positions were recorded automatically once a minute on a portable GPS receiver (Garmin eTrex Legend C).

To estimate the proportion of porpoises that observers missed from perception bias (i.e. animals were on the surface but missed due to distraction or fatigue of observers, etc.), additional sighting data were collected on one boat by a Conditionally Independent Observer (CIO; Barlow, 1995). The CIO stood on a 50 cm high platform behind the POs and searched the forward 180° area using 7×50 mm binoculars; two experienced observers alternated in this position every hour. The CIO sightings were not communicated to the POs and were only recorded if they were clearly missed by the POs.

Distance from the observer to the animals could not be measured directly with a laser range-finder or with binocular reticles. Instead, observers estimated distance by eye and were required to frequently practice estimating distances to boats, buoys and other objects whose distance could be measured with a range-finder. Distance calibration tests were conducted at least once each week, and the results were later discussed with the observers to improve their abilities to estimate distances. We used distance calibration data in the analyses to correct each observer's estimates.

A towed acoustic array allowed an independent estimate of the proportion of porpoises missed by the POs using a porpoise detecting device (cf. Akamatsu et al., 2005) which was reported elsewhere by Akamatsu et al. (2008).

2.2. Analytical methods

2.2.1. Distance calibration

Distance calibration coefficients were estimated by linear regression (through the origin) using the estimated and measured distances to boats, buoys, and other objects in the river. Individual calibration coefficients were developed for most observers who participated in the entire survey (those with 30 or more porpoise sightings) as suggested by Smith et al. (2004). A collective calibration factor was used for those observers with fewer than 30 sightings. Different calibration factors were estimated for two stages of the survey (11–26 November and 27 November–13 December) to allow for improvement in distance estimation during the course of the survey.

2.2.2. Abundance estimation

Because finless porpoises had been previously reported to prefer habitat near the river banks (Wei et al., 2003; Zhang et al., 1993), we used two different line transect approaches to estimate density and abundance. The first approach (the simple method) assumes that porpoises are uniformly distributed across the width of the river. For this method, we pooled sightings on both sides of the boat and extrapolated the mean density to estimate the abundance of finless porpoise for the entire width of the river. Our second approach (the complex method) estimated density separately for the area near the river banks and for the mid-channel area. Densities along the river banks were extrapolated to estimate the abundance of finless porpoises within 300 m of the banks and density in the mid-channel was extrapolated to the rest of the river. Based on an initial inspection of porpoise density, we post-stratified the portion of the river that we surveyed into upper (Yichang – Ezhou), middle (Ezhou – Huayang), and lower (Huayang – Shanghai) regions, and then used both line

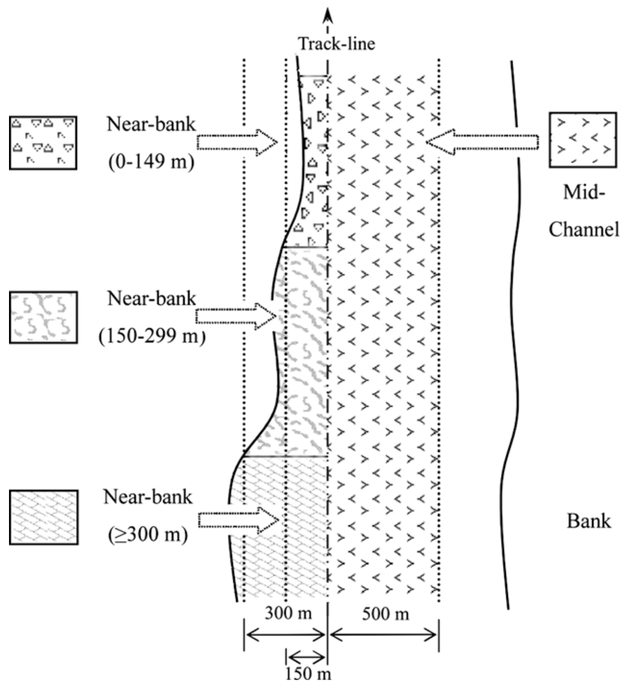

Fig. 2 – An overhead view of the river and banks showing stratification in the complex method.

transect methods to estimate detection functions and density for each region (Figs. 1 and 2, Table 1).

In addition, we estimated abundance using a strip transect analysis for comparison with the line transect estimates. We followed the same stratification as was used for the complex method (see below). We calculated the density of each strip by dividing the number of porpoises seen in the strip by the strip area and by then applying the $g(0)$ correction for missed groups.

2.2.3. *Simple method*

The simple method used a conventional line transect analysis. It assumes that animals are distributed uniformly across the river without regard to distance from the bank. We included only sections of survey effort where the boat was 300 m or more from the river bank. We estimated $f(0)$ from the pooled sightings made on both sides of the boat within the truncation distance of 300 m. We fitted half-normal, hazard rate and uniform models to the detection function using Distance 5.1 software (Thomas et al., 2006), and the best model was chosen using Akaike's Information Criteria (AIC). In each region of the main Yangtze channel, porpoise abundance N_i was determined as

$$N_i = A_i \times \hat{D}_i = A_i \times \frac{n_i \cdot \hat{f}(0) \cdot \bar{s}}{2Lg(0)}$$

where A_i is the area of region i; D_i is the density of animals within region i; n_i is the number of sightings in region i; $\bar{s}$ is the mean group size; $f(\hat{0})$ is the sighting probability density at the trackline in region i; L is the total length of the transect line covered in region i; and $g(0)$ is the probability of sighting a group on the trackline.

Overall abundance was estimated as the sum of the abundances of all regions.

2.2.4. *Complex method*

The complex method estimated $f(0)$ using a multiple-covariate distance sampling (MCDS) approach based on a half-normal detection function (Marques, 2001; Marques and Buckland, 2003). In all regions, we stratified the river into a mid-channel stratum and a near-bank stratum along the trackline, and then further stratified the near-bank stratum into three different substrata with different truncation distances based on the distance from bank to trackline (Fig. 2). This approach assumes that animals are uniformly distributed within strata, but it does allow for differences in density among strata. The mid-channel stratum (>500 m from the opposite bank to the boat) had a truncation distance of 500 m. The near-bank stratum was subdivided into three substrata: 300–500 m from bank (truncation distance equals 300 m), 150–299 m from bank (truncation distance equals 150 m), and <150 m from bank (treated as a strip transect where density was estimated as the number of porpoises seen divided by the area between the trackline and the bank). This complex approach therefore used more data than the simple method by including sightings made when the boat was less than 300 m from the bank and sightings made in the mid-channel that were 300–500 m from the boat. Covariates (boat identity, survey mode, survey direction) were included to improve the fit of the detection function, and the best model was selected by stepwise fitting and model selection using AIC.

The density of porpoises within each stratum i was estimated as

$$D_i = \frac{1}{2 \cdot L_i} \cdot \sum_{j=1}^{n_i} \frac{f(0, c_j) \cdot s_j}{g_j(0)}$$

where L_i is the length of on-effort transect lines in stratum i, $f(0, c_j)$ is the probability density of the detection function evaluated at zero perpendicular distance for sighting number j with associated covariates c_j, s_j is the number of individuals

Table 1 – Lengths and areas of the three regions used to estimate densities and abundances of finless porpoise

Geographic strata	Length (km)	Total area (km^2)	Near-bank area (km^2)	Mid-channel area (km^2)
Upper region	716.4	1078.7	444.4	634.3
Middle region	216.1	371.6	136.0	235.6
Lower region	694.0	2463.1	455.3	2007.8

Lengths are measured along the middle of the shipping channel. Areas are subdivided into near-bank areas within 300 m of the main river banks and all other mid-channel areas.

in each group, $g_j(0)$ is the trackline detection probability of sighting j, and n_i is the number of sightings in stratum i.

2.2.5. g(0) Estimation

We estimated $g(0)$ using the CIO method (cf. Barlow, 1995). Though conditionally independent observers worked on only one boat, the POs alternated between the boats, so that the calculated $g(0)$ could apply to both boats for both the simple and complex analyses in all strata (or substrata).

We estimated $g(0)$ as

$$g(0) = 1 - \frac{n_{2w} f_2(0)}{n_{1w} f_1(0)}$$

where $g(0)$ is the probability of detecting a group directly on the trackline by primary observers. $n_{1\omega}$ is the total number of groups seen within the truncation distance by primary observers. $n_{2\omega}$ is the total number of groups seen within the truncation distance by independent observer. $f_1(0)$ is the sighting probability density at zero perpendicular distance by primary observers. $f_2(0)$ is the sighting probability density at zero perpendicular distance by independent observer.

We also estimated the variance of $g(0)$ as in Barlow (1995).

2.2.6. Estimation of area

We calculated the area for each stratum and region using ArcGIS (ESRI, ArcGIS 9.2) and a fundamental GIS map (ESRI, 2004). The satellite images we used were collected at different times from 1998 to 2002. The near-bank area was defined as being within 300 m of either bank or any major island. The mid-channel area was calculated as the total river area minus this near-bank area.

3. Results

3.1. Survey summary

Both boats were confined to the main channel and large navigable side channels of the Yangtze River from Yichang to Shanghai in both upstream and downstream directions (Fig. 3). When on-effort, one boat surveyed 3100 km with 240 sightings and a mean group size of 1.87 resulting in 0.077 sightings/km, while the other boat surveyed 3065 km with 198 sightings and a mean group size of 2.05 resulting in 0.065 sightings/km. These values did not differ significantly between the boats (Z test, $z = -0.11$, $p = 0.91$ for group size; Z test, $z = 0.18$, $p = 0.86$ for encounter rate). Duplicate sightings

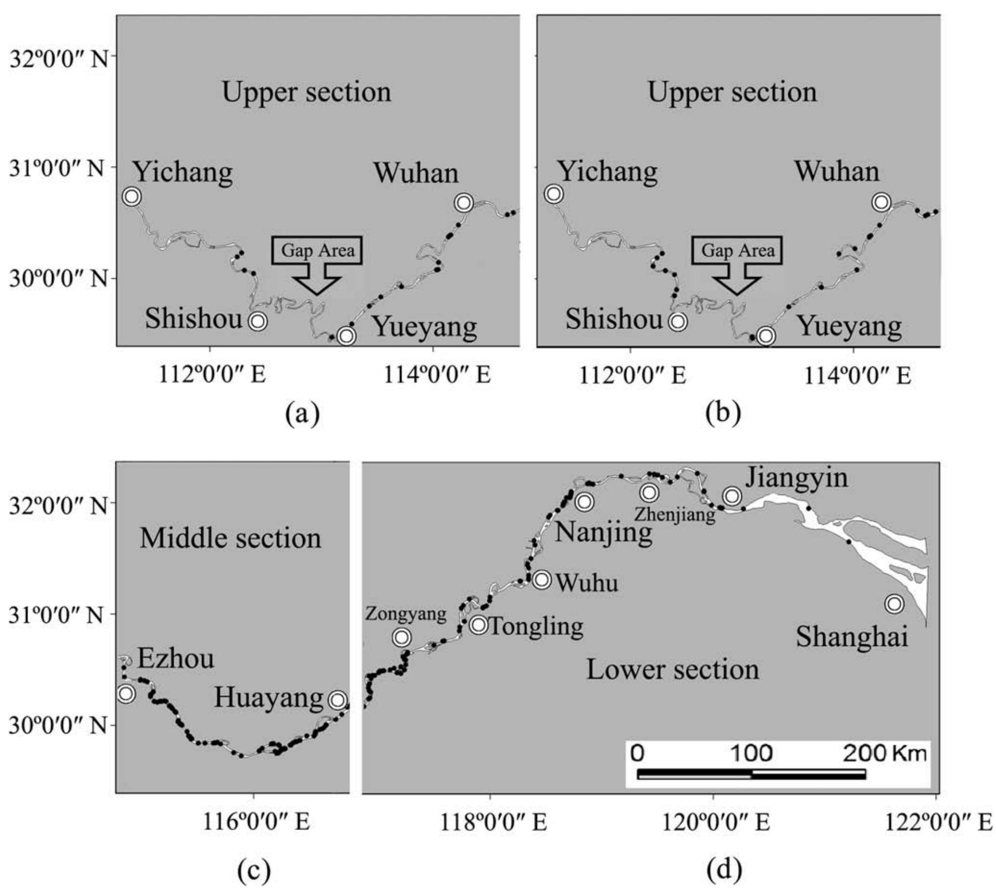

Fig. 3 – The locations of porpoise sightings are indicated by black dots. Survey coverage was complete from Yichang to Shanghai in both up-river and down-river directions for both boats. Maps (a) and (b) show the similarity of sighting locations between the two survey boats in the low-density area, the upper region. Maps (c) and (d) show the sightings from just one boat, and there were no meaningful differences between the sighting distributions of the two boats. A gap in the distribution of porpoises is indicated between Shishou and Yueyang.

were difficult to discriminate in high-density areas (i.e. the middle and lower regions). In areas of low-density (i.e. mainly in the upper region), however, we found a high proportion of presumed duplicate sightings between the two boats. Of 124 sightings made by both boats in the low-density areas, 28 were seen from only one boat, 25 were seen only from the other boat, and 71 were seen from both.

3.2. Distance calibration

All observers underestimated distances in the trials. Nonetheless, estimated distances to objects correlated significantly with actual distances ($F = 8049.3$, $p = 0.00$, $R^2 = 0.673$; Fig. 4). We found the fit to a linear model was good with no apparent non-linearity. We calculated ten sets of regression coefficients for each of the regular observers (all observers with fewer sightings were regarded as one virtual observer), and the regression coefficients differed significantly between early and late periods of the survey (paired samples t-test, $t = -2.566$, $df = 9$, $p = 0.03$). Most observers improved their estimates with time, as the later mean regression coefficient (0.919 ± 0.052) was closer to 1 than the early one (0.877 ± 0.059).

3.3. Group size and density

Group size estimates did not differ significantly between the two boats (Z test, $p = 0.82$) or between the upstream and downstream transects (Z test, $p = 0.28$), so we pooled data from both boats and both directions to estimate the mean group size. Mean group size was also not significantly different for passing and closing modes (Z test, $p = 0.74$). The largest group sizes were in the upper region of the river (2.92 ± 0.54, range: 1–15) where the porpoise density was lowest (0.094 porpoises/km^2; Table 2). In the middle region of the river, group sizes were smallest (1.56 ± 0.10, range: 1–9) and density was highest (0.709 porpoises/km^2; Table 2). No consistent patterns were found in comparing group sizes between mid-channel and near-bank strata (Table 3).

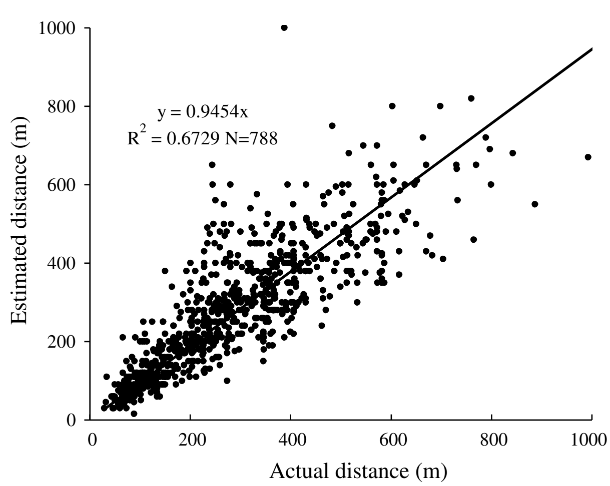

Fig. 4 – Regression plot for distance estimation showing paired estimated and actual distances for all observers pooled.

3.4. g(0) Estimation

We used the sightings from one boat in specific river sections where distance between boat and bank was more than 300 m as the data source ($n_1 = 47$, $n_2 = 22$, $f_1(0) = 3.371$, $f_2(0) = 4.325$, CV ($f_1(0)$) = 0.18, CV ($f_2(0)$) = 0.19), and estimated $g(0)$ as 0.399 (CV = 0.394) using the CIO method.

3.5. Detection function

To estimate the detection function we excluded sightings made off effort or during ‘poor’ weather. Of 438 total sightings, 151 were used for the simple method and 242 were used for the complex method (Tables 2 and 3). The encounter rate (number of sightings per km of transect) and effective strip width (ESW) did not differ significantly between the two boats (Z test, $z = -0.05$, $p = 0.96$ for encounter rate; $z = -0.23$, $p = 0.82$ for group size; $z = 0.00$, $p = 1.00$ for ESW) or between the upstream and downstream transects (Z test, $z = 0.99$, $p = 0.32$ for encounter rate; $z = -1.08$, $p = 0.28$ for group size; $z = 0.00$, $p = 1.00$ for ESW), so we pooled data from both boats and both directions to estimate the detection function. Mean group size and ESW were also not significantly different for passing and closing modes (Z test, $z = -0.33$, $p = 0.74$ for group size; $z = -0.85$, $p = 0.40$ for ESW). Encounter rate could not be compared for the entire survey between passing and closing modes because closing mode was used more often in the low-density areas. For the high-density middle region, the encounter rate did not differ significantly between passing and closing modes, so data from both survey modes were pooled to estimate the detection function (Z test, $z = 0.00$, $p = 1.00$).

For the complex model, we used an MCDS model for forward stepwise selection. Although there was a small decrease in the AIC value when the boat mode was included as a covariate in the mid-channel stratum, the decrease was so small that the estimates of abundance remained the same. Because there were very few sightings in the 150–299 m near-bank substratum (Table 3), we combined all three regions (upper, middle and lower) for a single ESW and then calculated the respective densities directly. We treated the near-bank substratum (0–149 m) with a strip transect method because there were too few sightings ($n = 5$) to estimate a detection function and the data for other areas indicated a constant probability of detection out to 300 m. We modeled the ESW of the mid-channel stratum in all three regions and applied it to the mid-channel stratum of the upper region. We derived the mean density in the near-bank stratum by a weighting method for each substratum area (Table 3).

The probability of detecting porpoises did not vary with distance out to 300 m in the near-bank stratum but appeared to show a gradual decrease between 300 and 500 m in the mid-channel stratum (Fig. 5). In addition, the drop in the detection of porpoises close to the transect line suggested a certain amount of boat avoidance behavior (Fig. 5), as is also indicated by concurrent acoustic survey (Li et al., 2008). Such behavior has also been observed in surveys of harbour porpoises *(Phocoena phocoena)* (Palka and Hammond, 2001), and equivalent patterns of detection functions indicative of avoidance by target species have also been identified in other stud-

Table 2 – Abundance estimation from the simple line transect analysis method

Stratum	*n*	*e* (km^{-1})	ESW (m)	S	*D* (km^{-2})	*D*′ (km^{-2})	*A* (km^2)	CV (N) (%)	*N*
Upper region	12	0.0077	300	2.92	0.032	0.094	’ 1078.7	35.27	101
Middle region	70	0.1090	300	1.56	0.455	0.709	371.6	20.20	263
Lower region	69	0.0355	300	2.04	0.148	0.303	2463.1	18.51	747
Total	151						3913.4	15.23	1111

Abundance estimates for the three strata with symbols as in equations: *n* = number of sightings; *e* = encounter rate (sightings/km); ESW = effective strip width; S = mean group size; *D* = density of groups; *D*′ = density of porpoise; CV = coefficient of variation; A = area and *N* = abundance.

Table 3 – Line transect estimates of density and abundance of finless porpoises, stratified by region and distance from the river bank

Stratum	*n*	*e* (km^{-1})	Truncation (m)	ESW (m)	S	*D* (km^{-2})	*D*′ (km^{-2})	A (km^2)	CV(N) (%)	N LCI	N UCI	*N*
Upper region												
Mid-channel	12	0.0099	500	413.36[a]	4.67	0.028	0.129	634.3	52.09	25	179	82
Near-bank pooled	9					0.037	0.116	444.4	36.86	17	491	51
N-bank (⩾300 m)	6	0.0084	300	299.19[b]	3.23	0.032	0.104	334.7	78.71			35
N-bank (150–299 m)	3	0.0070	150	150.00[c]	2.98	0.054	0.161	102.3	113.48			16
N-bank (0–149 m)	0	0.0000	–	149.00[d]				7.4	0.00			0
Middle region												
Mid-channel	65	0.1514	500	440.20	1.57	0.395	0.621	235.6	22.33	95	226	146
Near-bank pooled	56					0.607	1.083	136.0	9.14	76	306	147
N-bank (⩾300 m)	41	0.1395	300	299.19	1.69	0.549	0.929	105.5	25.90			98
N-bank (150–299 m)	12	0.1003	150	150.00[c]	2.08	0.767	1.597	28.8	57.20			46
N-bank (0–149 m)	3	0.1916	–	149.00[d]	1.33	1.466	1.954	1.7	87.39			3
Lower region												
Mid-channel	53	0.0447	500	349.28	2.14	0.147	0.314	2007.8	21.98	411	967	631
Near-bank pooled	47					0.171	0.370	455.3	10.83	87	463	168
N-bank (⩾300 m)	39	0.0439	300	299.19	1.92	0.168	0.323	387.9	25.86			125
N-bank (150–299 m)	6	0.0224	150	150.00[c]	3.67	0.171	0.627	64.5	69.19			40
N-bank (0–149 m)	2	0.0738	–	149.00[d]	1.50	0.565	0.847	2.9	150.02			2
Total	242							3913.4	13.26	907	1543	1225

The symbols are the same as in Table 2. Bank distance is based on the distance from the river bank to the transect line, and line transect truncation distances were chosen to be less than or equal to this distance. The near-bank pooled estimates on *D* and *D*′ are the mean of their components (near-bank (⩾300 m), near-bank (150–299 m) and near-bank (0–149 m)) weighted by respective area. Effective strip widths (ESW) were based on fitting a multiple-covariate line transect model with a cosine key function to the observed distribution of perpendicular sighting distances.
a, b, c: ESW of a, b and c were generated by pooling data in respective strata (or substrata), mid-channel, near-bank (⩾300 m) and near-bank (150–299 m), and then the relevant density was calculated directly.
d: The near-bank (0–149 m) substrata data was treated as a strip sampling.

ies (e.g. Cassey and Ussher, 1999). Because the near-bank strata were effectively treated as a strip transect, no assumption is required that animals are uniformly distributed in the near-bank strata.

3.6. *Estimates of abundance*

The overall abundance estimated from the complex model was 1225 porpoises (95% CI = 907–1543, CV = 0.13), with estimates of 133 in the upper region, 293 in the middle region, and 799 in the lower region. Both the simple method (1111 porpoises, 95%CI = 825–1496, CV = 0.15) and the strip transect method (1000 porpoises, 95%CI = 755–1245, CV = 0.13) produced estimates of abundance similar to those from the complex model (Table 2).

Porpoise density was not uniform along the Yangtze River. It was highest in the middle region of the study area (0.789 porpoises/km^2), lowest in the upper region (0.123 porpoises/km^2), and intermediate in the lower region (0.324 porpoises/km^2) as calculated with the complex model. Because we stratified the river at the end of the survey, based on apparent density differences, we cannot compare these differences statistically, but the differences are so large that statistical comparisons are hardly relevant. Further, animals were not evenly distributed within each region. In the upper region, high densities were found ~90 km upstream from Shishou, and near Honghu where the largest group of present survey (13 ~ 15 individuals) was observed. In the middle region, density was consistently high. In the lower region, high densities were found from Huayang to Zongyang and near Tongling, Wuhu, Nanjing and Zhenjiang (Fig. 3). Density was higher in the near-bank

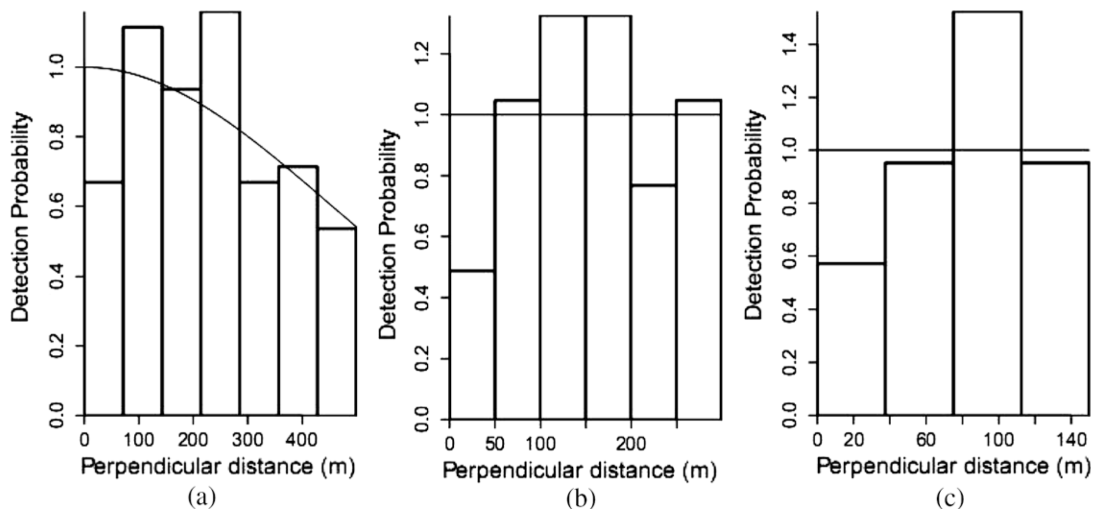

Fig. 5 – Histogram of all regions detection data for each stratum generated from the complex method with half-normal model + cosine adjustment. (a) Mid-channel stratum, *n* = 130 and truncated at 500 m. (b) Near-bank substratum (⩾300 m), *n* = 86 and truncated at 300 m. (c) Near-bank substratum (150–299 m), *n* = 21 and truncated at 150 m.

stratum than in the mid-channel stratum in the two lower regions but not in the upper region (Table 3).

4. Discussion and conclusions

4.1. *Survey design*

4.1.1. *Limitations*

As suggested by Dawson et al. (2008), in a confined water body a zig-zag transect design or parallel transect design (placing transect lines at 45° to the center line of the channel) would have provided better coverage of the study area. However, experience from our pilot survey in March 2006 demonstrated that neither design would have been practical. We think that our survey design was optimal under the circumstances. While one boat traveling along the center of the channel will almost always result in unequal coverage probability (Dawson et al., 2008), our two boats could get good coverage of the river because the channel was generally less than 2 km wide and this distance was within range of observers using 7 × 50 mm binoculars. However, the need to stay within shipping lanes limited the ability of our survey design to resolve how much of the decline in detection probability with distance was because of our ability to detect porpoise and how much was a real drop-off in porpoise numbers toward the center of the river resulting from non-random porpoise distribution (see discussion below).

4.1.2. *Potential biases in abundance estimation*

The decline in sightings with distance from the transect in the mid-channel stratum (Fig. 5a) may be due to the expected decline in ability to see distant animals or may be due to a real decline in density towards the middle of the river. If the latter were true, then the line transect approach (which assumes a random distribution of animals within a stratum) would be biased and would overestimate density. Compared with the line transect methods, the strip transect method does not require this critical assumption (i.e. random distribution of animal), however, the strip transect method would underestimate density if detection probability decreases with distance from the transect line. There are no significant differences among the strip and line transect estimates (Z test, $z = -0.49$, $p = 0.62$ for simple–complex pair; $z = 1.1$, $p = 0.27$ for complex–strip pair; $z = -0.53$, $p = 0.60$ for strip–simple pair), but as expected, the strip transect estimates are slightly lower. Consequently, we propose that strip transect method would present the minimum estimates, while complex method produced the maximum one. In addition, the similarity of both simple and complex estimates in abundance (total and by sections), densities, and rates of encounter suggests that resulting porpoise numbers are robust to both pooling of data and stratification decisions with line transect method (Tables 2 and 3).

The ESWs were equal to the truncation distances for all three regions in the simple method, suggesting that this method is actually also a strip transect method where the strip width is twice the ESW (600 m) and calibrated by $g(0)$. Therefore, a strip transect method could produce estimates of abundance if an appropriate strip width is chosen and corrections are made for missed groups. Similarly, Martin et al. (2004) considered that the most effective and simplest method to conduct abundance surveys in the Amazon River is to use strip transect method along the margins of rivers and account for the relatively low numbers of dolphins in mid-river with a correction factor. Such an approach might be used to re-estimate Yangtze finless porpoise (and even baiji) abundance from the non-systematic survey data collected over the last two decades by others.

The low $g(0)$ value greatly increased our abundance estimates. The CIO method employed in the present study does not account for availability bias (i.e. these animals are underwater for most of the time and expose only a small part of their body when surfacing) but primarily perception bias (Marsh and Sinclair, 1989). We evaluated the significance of availability bias by reference to the surveys by Smith et al.

(2006) of Irrawaddy dolphins (*Orcaella brevirostris*) and Ganges River dolphins (*Platanista gangetica*). The mean dive time of the Yangtze finless porpoises is ~18 s (Akamatsu et al., 2002; Wei et al., 2002a; Zhang et al., 1996). With that dive time, porpoises would be present at the surface about four times before we had covered a distance of 300 m at our normal survey speed of 15 km/h or 4.17 m/s. Therefore, we believe that availability bias did not contribute appreciably to our abundance estimation. In addition, Dawson et al. (2008) considered that low $g(0)$ would be largely caused by perception bias, and this bias is potentially largest for species that occur as single animals or in small groups and do not show much of their body when surfacing. The low $g(0)$ value (~0.4) that we derived is consistent with expectations of small-bodied animals like the finless porpoise and owing to its lack of a dorsal fin and brief surfacing behavior (Akamatsu et al., 2002; Wei et al., 2002a; Zhang et al., 1996). Similarly, in a survey of harbour porpoises in the Gulf of Maine and Bay of Fundy, $g(0)$ estimates for two survey teams were 0.41 and 0.54 (Palka, 1996). A concurrent acoustic survey during our study also confirmed the low detection probability by the visual team with an acoustic detection probability of twice that of the visual one (Akamatsu et al., 2008).

4.2. Significance of low abundance and distribution

4.2.1. Abundance

Our estimate of finless porpoise abundance is only for the main channel of the Yangtze River. To better evaluate the conservation status of the entire population, we need to include estimates from Poyang and Dongting Lakes. We speculate that the numbers of porpoises in these two lakes have not changed much over the last ten years because encounter rates (in same season) have remained fairly constant between earlier surveys (~400 in Poyang, Xiao and Zhang, 2000; 100–150 in Dongting, Yang et al., 2000) and the latest regular line transect surveys conducted from 2005 to 2007 by staff of the Institute of Hydrobiology, Chinese Academy of Sciences (Ding Wang, unpublished data). We roughly estimate that there are ~600 porpoises in the two lakes, although the most recent survey data need to be analyzed properly and published. Adding 600 to our estimates of numbers in the main river channel suggests that the total number of porpoises in the Yangtze system is now around 1800 individuals.

Ours was the first systematic survey of porpoises in the Yangtze River. Consequently, our results are not directly comparable to those from previous surveys. The best earlier estimate by Zhang et al. (1993) (~2700 totally, and ~2550 porpoises in the river) presumably was biased downwards because inter alia those authors applied a complicated series of subjective correction factors which incompletely accounted for missed porpoises. Those correction factors were determined by three parameters: (a) ratio between the observers' effective detection distance and the river width; (b) proportion of the available animals (i.e. those that surfaced at least once before passing abeam) missed, and (c) ratio between the estimated group size and the real one. The parameters were generally set subjectively based on the authors' experience. For example, in a typical section of river that was 1.5–2.0 km wide, they estimated that 16.2% of porpoises would be seen by two observers with unaided eyes in a small boat making one pass along of that section. In contrast, we estimated that 12.0–16.0% of porpoises would be seen by a team of three observers using binoculars, standing higher above the river surface and on a more stable and larger boat. In addition, the surveys analyzed by Zhang et al. (1993) only partially covered the two lakes yet the numbers of porpoises counted were assumed to constitute the entire populations of the lakes. The previous survey work is clearly very important for determining the conservation status of finless porpoises in the Yangtze River. However, the results would have been more convincing and easier to compare with those from our survey if the correction factors had been estimated from data (cf. Marsh and Sinclair, 1989). Further analysis will be required to quantify the bias in historical abundance estimates, but for the moment the balance of evidence leads us to conclude that those estimates were negatively biased. This, in turn, leads us to believe that at least half the porpoise population has been lost in the river since the early 1990s, implying an annual rate of decline of at least 5% (assuming the decline was exponential).

4.2.2. Distribution

Most porpoises were concentrated in the middle and lower regions of the study area from Ezhou to Jiangyin, with the lowest densities in the upper region and the estuaries of the Yangtze River. This was the same general pattern reported by Zhang et al. (1993), but we found what appear to be new gaps in distribution that were not evident from earlier surveys (see below).

The porpoises in the upper region from Yichang to Ezhou (~130 porpoises in 716.4 km, Fig. 3) appear to be at highest risk of local extirpation. The observed density in this region decreased from 0.11 porpoises/km in 1991 (Zhang et al., 1993) to 0.02 porpoises/km now. Moreover, there appeared to be significant gaps in the distribution in this part of the river, since no porpoises were detected during either the upstream or the downstream pass by the two boats in the 150 km subsection between Yueyang and Shishou (Fig. 3). Despite the possibility of false negatives in determining presence due to imperfect detection in this study (i.e. $g(0) = 0.399$), the number of porpoises in this region must be extremely low or nil. The ~90 km subsection upstream of this gap included the most-upriver population (roughly 60 porpoises) observed in our study. If the porpoises in this subsection were to become extirpated, the linear extent of the recent historical range of this subspecies on the river would have shrunk by ~400 km, or by about 24%. It may be noteworthy that this was also the river section where the baiji first became extirpated (Chen et al., 1997; Zhang et al., 2003; Zhou et al., 1977). Although limited photo-identification studies suggested that baiji traveled over hundreds of kilometers up and down the river (Zhou et al., 1998a), the significantly different patterns of mtDNA haplotypes among finless porpoises in different sections of the Yangtze River implies that these animals do not move far (Zheng, 2005). This means that even if all threats were eliminated and habitat conditions improved, there is little chance that porpoises from other areas would repopulate the upper region of the Yangtze River below Yichang. Therefore, unless the current trend is reversed, there seems to be a good chance that finless porpoises will soon disappear permanently from that area. In the middle and lower regions between Wuhan and Jiangyin, porpoise distribution appeared continuous but the abundance has decreased from the (presumably underestimated) level of 1652 (surveys of 1984–1991, Zhang et al., 1993) or 1481 (surveys of 1989–1992, Zhou et al., 1998b) to the current level of ~800.

4.3. Threats and conservation

A number of anthropogenic factors are known or suspected to be responsible for the population decline and range contraction of the Yangtze finless porpoises. Turvey et al. (2007) concluded that entanglement in gear used in unregulated and unselective fishing (rolling hooks, electrofishing gear and gillnets) was the main factor responsible for the probable extinction of the baiji. This same factor likely explains much of the ongoing decline of the Yangtze finless porpoise (Wang et al., 1998, 2005; K. Wang et al., 2006). Illegal fishing is widespread in the Yangtze River (Reeves et al., 2000; IWC, 2001; Smith et al., 2007) and we observed it daily during our survey (Turvey et al., 2007). Zhou and Wang (1994) reported that 'most' of the 80 finless porpoise specimens collected by Nanjing Normal University since 1974 had been killed by rolling hooks or gillnets. Other studies indicate that bycatch in gillnets is adversely impacting marine populations of finless porpoises (Jefferson and Curry, 1994; Zhou et al., 1995; Reeves et al., 1997; Yang et al., 1999). Because the preferred habitat of Yangtze finless porpoises overlaps extensively with gillnetting areas in the river (Yu et al., 2005), the impact of gillnet mortality may be much more serious than has been generally assumed based on the infrequency of actual reports.

Boat traffic, which is increasing rapidly in the Yangtze River and lakes, also likely causes mortality of finless porpoises (from propeller strikes) and boat noise may mask their social communication and ability to forage efficiently (K. Wang et al., 2006).

Widespread mining of the river bed, lake beds and banks (much of it illegal) is destroying important habitat of the porpoise's prey and adversely affecting primary productivity. This problem is especially serious in Poyang Lake, currently with a population of around 400 finless porpoises (Xiao and Zhang, 2000; Wang et al., 2006).

Compared with cetaceans that live in marine habitats, riverine forms may be at a higher risk from pollution. Indeed, cetaceans in rivers generally occur in the world's most densely populated human environments (Reeves et al., 2000). Four hundred million people live in the Yangtze River basin and thousands of factories along the river bank discharge tremendous quantities of domestic sewage and industrial effluents. Furthermore, because rivers are relatively small water bodies, their water quality can be degraded much more easily than larger water bodies. However, there remain relatively few data with which to assess the impacts of pollutants on Yangtze finless porpoise health, fertility or population status. In April 2004, five porpoises died in Dongting Lake within one week, apparently due to the combination of a short-term exposure to the pesticide hostathion and a long-term exposure to mercury and chromium (Dong et al., 2006).

Finally, water development projects, especially dams, have major effects on river ecology. In the Yangtze River system, structures can block porpoise movements between the river and adjoining lakes or tributaries (Liu et al., 2000; Smith and Reeves, 2000), as well as the movements of their prey (Xie and Chen, 1996). This has also been observed in Bangladesh where flood control schemes are affecting the habitat of endangered Ganges River dolphins (*Platanista gangetica gangetica*) (Halls et al., 1998). The Three Gorges Dam in particular has altered and will continue to alter downstream hydrologic conditions in the Yangtze River (Tong et al., 2008), and consequently, may adversely affect the habitat of finless porpoises, in the Yangtze River.

Although the relative importance of each of the above threats has not been quantified, all have contributed to the decline of the Yangtze finless porpoise. And despite the fact that for many years these same factors were also known to be pushing the baiji towards likely extinction, none has been aggressively or seriously addressed and most of them have escalated dramatically over recent decades. Consequently, we must reiterate that immediate action is urgently needed to reduce the threats, with highest priority given areas with greatest abundance in all regions based on the findings of our survey (see Section 3.6). If porpoise are to persist in the Yangtze River, several key steps must be taken. Most of the porpoise high-density areas that we identified were within or adjacent to nominally designated reserves and it is likely that the survival of the porpoise will depend heavily on the effectiveness of these in situ reserves. The most important thing will be the complete removal of illegal fishing gear (rolling hooks, gillnets, electrofishing, etc.) and the banning of illegal fishing practices and dredging throughout the river, and that all fishing in the reserves be prohibited in accordance with existing laws. To preserve genetic diversity, priority should also be given to the small population that appears to now be fragmented upriver. These measures alone may not be enough to reverse the decline of porpoises; especially if, for example, vessel strikes and pollution are the most important mortality factors. It will therefore be necessary to continue to monitor the population for signs of improvement (see below).

In addition to in situ solutions, some studies have also argued for establishment of more ex situ reserves (or expanding existing ones) where most of the above threats can be eliminated, greatly reduced, or at least closely managed. A good example is the Tian'e-Zhou Reserve at Shishou, which contains a population of around 30 Yangtze finless porpoises and has produced 2–4 new calves per year in the last 10 years as a result of natural reproduction for more than a decade (Zhang et al., 1995; Wang et al., 2000, 2005, 2006; Wei et al., 2002a; Ding Wang et al., unpublished data). The successful maintenance of Yangtze finless porpoises in captivity, including the birth of naturally conceived calves in 2005, 2007 and 2008 (Wang et al., 2005; Ding Wang, unpublished data), bodes well for captive breeding efforts – both to preserve the genome and to raise awareness and promote conservation. We emphasize that although these ex situ initiatives can be constructive, the central objectives must be to restore porpoise habitat in the Yangtze River and preserve a population in the wild. This can be achieved most certainly and most efficiently by stopping and reversing the decline of the population in the river.

4.4. *Future surveys*

We suggest that regular surveys be conducted with the same design and analytical methods used for this study to provide comparable data and make it possible to track changes in abundance and distribution. The precision of surveys should be maximized because it is extremely difficult to detect trends in abundance, particularly when population size is low (Taylor et al., 2007). Given the level of decline that has already occurred and the need for quick action, we estimate the significance criterion that would be needed to detect an ongoing decline at current levels in four years of annual surveys. We make the fairly conservative assumption that over-protection errors (α) and under-protection errors (β) should be equal. Assuming the same detection accuracy that we achieved (i.e. CV = 0.13) and the same estimated 13% per year exponential rate of decline calculated from data from Wei et al. (2002b), that the decline is exponential and that the CV is proportional to 1/squareroot of abundance, the recommended significance criterion (α) is 0.17 ($\beta = 0.18$ and Power to detect the trend = 0.82) (Trends 3.0 program; Gerrodette, 1993). Four years at this rate of decline would result in loss of an additional 43% of the remaining population. Thus, a four year period is warranted to indicate that stronger conservation actions are required. Since the gap in porpoise populations found in the present study has highly important conservation implications, more dedicated surveys need to be conducted in order to discover porpoise distribution at a finer scale in the Yangtze. The corresponding recommendation is to incorporate an occupancy model based on double concurrent counts made by independent teams in future surveys, which also might be considered as an alternative approach to our present survey method with perception bias estimated by a mark-recapture analysis. Further, acoustic studies using towed hydrophones appear to be effective supplemental or perhaps alternative methods for documenting distribution of porpoises with greater sensitivity and consequently reduced perception bias (Akamatsu et al., 2008).

Though future surveys should be used to evaluate the effectiveness of any management actions taken, such actions are urgently needed now and should not be delayed until more surveys have been completed. The current data clearly indicate that the finless porpoise subspecies in the Yangtze River is declining rapidly and that its range is becoming progressively fragmented. As early as 1999, a population viability analysis estimated a mean extinction time of 100 years or, considering environmental variation, 24–94 years (Zhang and Wang, 1999). The small and declining population size and range fragmentation documented by this study will only increase the extinction risk.

Our survey design and analytical methods had the following advantages. First, it is easy to navigate in the busy main Yangtze channel, and so it is easy to repeat the survey, even using a single boat. Second, observers were able to cover the study area well with binoculars given the Yangtze's fairly constant and relatively narrow width ($\sim$2 km). Third, the analytical methods provided robust results even though some critical assumptions of distance sampling might have been violated. However, this survey design is a compromise under the specific and complex conditions presented by the Yangtze River. Researchers surveying cetaceans in other river systems will require a good understanding of the distribution of their study cetaceans (e.g. uniform or not) and of conditions in the study area (e.g. easy to navigate or not, wide or narrow channel) before planning their own surveys using the methods described here. For instance, in some situations (e.g. when the channel is <600 m wide), a strip transect method may be more appropriate. Whatever method is chosen (strip transect or line transect), the proportion of sightings missed should be carefully considered.

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