



Survival rate and population size of Indo-Pacific humpback dolphins (*Sousa chinensis*) in Xiamen Bay, China

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ABSTRACT

The survival rate and population size of Indo-Pacific humpback dolphins (*Sousa chinensis*) in Xiamen, China, were estimated from vessel-based surveys during 2007–2010. Over the course of 202 d (881.1 observation hours), 76 groups were observed, and 52 dolphins were successfully identified. The Cormack-Jolly-Seber model estimated a constant apparent survival of 0.948 (95% CI: 0.922–0.966). Based on the open/POPAN model, the population size was estimated at 70 individuals (95% CI: 63–88). To explore the effect of uneven yearly survey effort, we pooled the data with seven sampling occasions with similar effort. This data set generated similar results of a constant survival of 0.957 (95% CI: 0.918–0.978) and population size of 72 (95% CI: 65–88). The small population size of the Xiamen humpback dolphins satisfies the Critically Endangered criterion of IUCN (D), and emphasizes urgency of the need for protection of the population. Improved monitoring efforts should be focused on enhancing our understanding of current status and evaluating impacts of all anthropogenic activities. A conservation plan for the population should also be drawn up.

Key words: capture/mark/recapture, *Sousa chinensis*, Indo-Pacific humpback dolphin, population size, survival, Xiamen Bay.

The population parameters of survival and population size are essential for facilitating management and conservation strategies of wildlife populations (Tyne *et al.* 2014), and this is also true for coastal cetaceans (Mizroch *et al.* 2004). Indo-Pacific humpback dolphins (*Sousa chinensis*, hereafter called humpback dolphins, and in China known as Chinese white dolphins), are distributed in shallow coastal areas, and are subjected to multiple forms of anthropogenic disturbance. The species is currently listed as Vulnerable (A3cd+4cd) on the IUCN Red List. These animals appear to be decreasing throughout their range (Reeves *et al.* 2008, Jefferson and Smith 2016). Throughout the species' range from central China (near the mouth of

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the Yangtze River) in the east, southward throughout Southeast Asia, and westward around the coastal rim of the Bay of Bengal to at least the Orissa coast of eastern India (Jefferson and Rosenbaum 2014), population assessments have been carried out in only a few regions (see Xu *et al.* 2015, Jefferson and Smith 2016). Further, estimates of survival (S) for this species are rarely available (but see Huang *et al.* 2012, Wang *et al.* 2012, Smith *et al.* 2015). Estimates of survival and population size would be useful for assessing the status of these populations.

Some populations, especially those in Chinese waters, are facing serious threats. The Eastern Taiwan Strait population (now listed as a subspecies, *S. c. taiwanensis*; Wang *et al.* 2016) has been listed as Critically Endangered (C2aiii, fewer than 250 mature individuals, a continuing decline, and at least 90% are found in one population) (Reeves *et al.* 2008). Coastal development projects are damaging to the environment of Taiwan's humpback dolphins. Without effective and precautionary *in situ* conservation efforts, their continued existence in the coastal waters of western Taiwan has been deemed unlikely (Wang *et al.* 2007). Under increasing anthropogenic pressure, 74% of the current Pearl River Estuary "population" is projected to be lost after three generations, which would satisfy the criterion of Endangered for IUCN (A3) (Huang *et al.* 2012).

The humpback dolphin population in Xiamen has not been evaluated under the IUCN criteria previously, perhaps in part because its population ("subpopulation" in IUCN terminology) distinctness has not been confirmed. Throughout this paper, the Xiamen dolphins are assumed to be a distinct population. Like the Eastern Taiwan Strait population, Xiamen humpback dolphins also face serious anthropogenic impacts (see Table 1). Its population size of fewer than 100 (Jefferson and Hung 2004; Liu and Huang 2000; Chen *et al.* 2008, 2009) is similar to that of the Eastern Taiwan Strait population (Wang *et al.* 2007), and is well below that of the Pearl River Estuary (2,637 dolphins in the mid-2000s, see Jefferson and Smith 2016), Beibu Gulf (393–506, Chen *et al.* 2016), and Zhanjiang populations (1,485, Xu *et al.* 2015) (Table 1). In the past two decades, anthropogenic activities have increased greatly, *e.g.*, at least five ports and five bridges have been constructed or are currently under construction in their habitat. At least one dolphin was considered to have been killed by an underwater explosion for clearing the navigation channel (Wang *et al.* 2003). Some identified individual humpback dolphins showed injuries possibly caused by fishing net entanglement or collisions with vessels (Fig. 1). In light of the above considerations, there is an urgent need to estimate population parameters such as survival and population size for management and conservation of this population.

Photographic capture/mark/recapture (CMR) is a common technique used to estimate survival and population size of cetaceans (Buckland 1990, Conn *et al.* 2011, Rosel *et al.* 2011, Cantor *et al.* 2012), and this method has previously been applied to humpback dolphins (Chen *et al.* 2009, Wang *et al.* 2012). It is particularly well-suited to small populations with distinctive individuals that are restricted to small home ranges in shallow coastal waters (Wang *et al.* 2012). In Xiamen, our team has used CMR to calculate population size in the past (Chen *et al.* 2009). But, the photographic capture probability was low at the beginning of that study, due to the researchers being unfamiliar with photographic technology. In the present study, we therefore used CMR data collected during 2007 to 2010 (with similar photographic effort) to re-estimate current population size and to calculate S for the first time. These data provide crucial information necessary for assessing the current population status and updating the IUCN status of the Xiamen population.

Table 1. Population parameters of five putative Indo-Pacific humpback dolphin populations in Chinese waters. Ningde, Shantou and Sanya population data were not available.

	Hong Kong/PRE	Eastern Taiwan Strait	Xiamen	Beibu Gulf	Zhanjiang
Population size	2,637	74 ^a -99	70-78	398-444	1,485
Adult proportion	60%-75%, about 1,560-1,950	50%-60%, 37-59	40%-72.7%, 28-57	<50%, <222	36%, 535
Trend	decreasing	decreasing	decreasing	unknown	unknown
Distinct social communities	Yes	Yes	Yes	Yes	unknown
Distribution Range (km ²)	Probably < 5,000	515	About 700	At least 410.5	1,500
Anthropogenic impact level ^b	2	1	1	3	3
IUCN RL category ^c	EN (A3b)	CR (C2a (ii)), D	CR (D)	EN (D)	Not evaluated
References	Jefferson 2000, Chen <i>et al.</i> 2010, Huang <i>et al.</i> 2012, Jefferson and Smith 2016, Karczmarski <i>et al.</i> 2016	Wang <i>et al.</i> 2007, 2016; Dungan <i>et al.</i> 2011, 2015	Liu and Huang 2000; Chen <i>et al.</i> 2008, 2009, 2011; present study	Chen <i>et al.</i> 2016	Xu <i>et al.</i> 2015

^aNumber of identified humpback dolphin from Dungan *et al.* 2015.

^bTwo of the authors (BC, TAJ), who have experience with multiple populations, estimated the order among the five populations, 1-3: heavy to light.

^cCR, Critically Endangered, EN, Endangered.

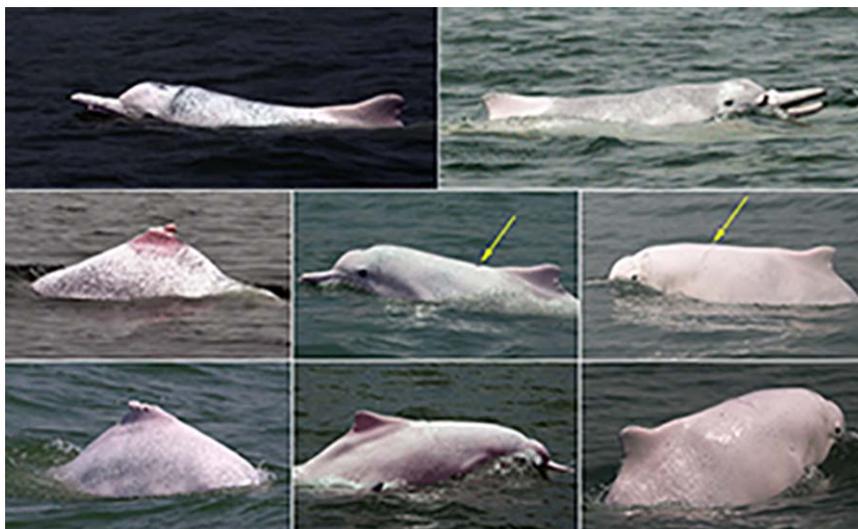


Figure 1. Five identified Indo-Pacific humpback dolphins, showing examples of anthropogenic injuries, possibly caused by fishing nets/ropes or collisions with vessels. Photographed by B. Chen.

MATERIALS AND METHODS

Study Site and Vessel-based Survey Protocol

Xiamen is located on the southeastern coast of China. Daily tide changes are normally semidiurnal, and the mean height of spring tides is about 5.68 m. The Jiu-long River west of Xiamen is the most important local freshwater input source with a mean annual flux of $>10^{10}$ m³ (Chen *et al.* 2011).

From 2007 to 2010, photo-identification surveys were carried out (see survey route in Fig. 2) in an area of about 700 km², including the entire Xiamen waters, and adjacent areas of Kinmen and Zhangzhou. The vessel-based survey method has been described in detail by Chen *et al.* (2011). Briefly, when weather permitted, in conditions of Beaufort ≤ 3 and swells ≤ 1 m, surveys were undertaken aboard fishing vessels travelling at 7–13 km/h. At least two trained observers and the vessel driver searched for dolphins from the deck, which was 1–3 m above the water. When dolphins were sighted, the vessel approached them slowly. Locations were recorded using GPS (see sightings in Fig. 3), photos were taken with digital cameras equipped with 100–400 mm zoom lenses. Group size was counted in the field as the total number of dolphins in different pigmentation/age classes, *i.e.*, unspotted calves (UC), unspotted juveniles (UJ), mottled (SJ), speckled (SS), spotted adults (SA), and unspotted adults (UA) (see Jefferson and Leatherwood 1997, Jefferson 2000, Jefferson *et al.* 2012).

Photo-identification

All photos were graded as excellent, good, or poor, according to the clarity, focus, degree of contrast, relative angle, dorsal fin visibility, and distance to the subject. For minimizing the introduction of bias and to avoid misidentification, only

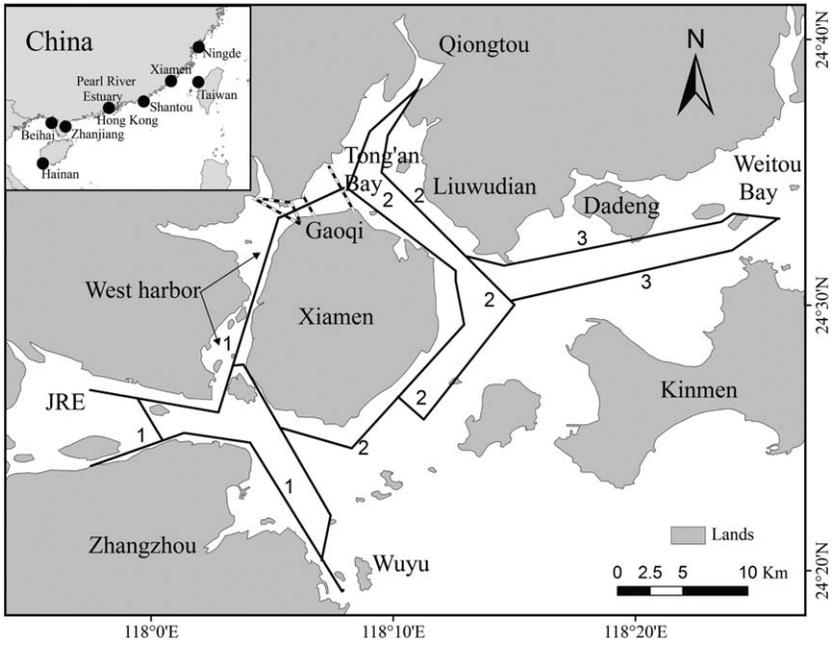


Figure 2. Map of the Xiamen area and survey route for Indo-Pacific humpback dolphins between 2007 and 2010. JRE: Jiulong River Estuary.

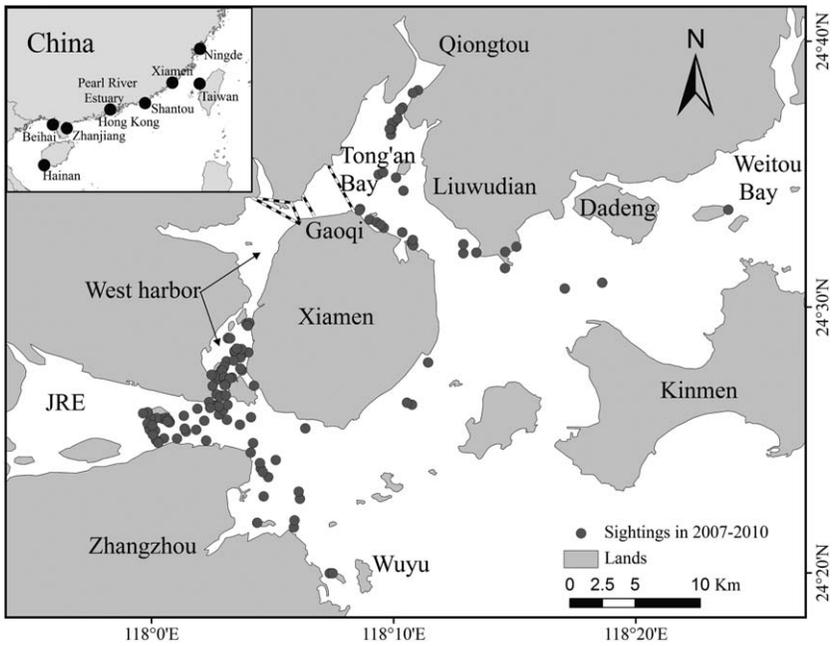


Figure 3. The distribution of Indo-Pacific humpback dolphin sightings between 2007 and 2010. JRE: Jiulong River Estuary.



Figure 4. Examples of nine identified Indo-Pacific humpback dolphins in the Xiamen photo-identification catalog. Photographed by B. Chen.

excellent and good photos (see examples in Fig. 4) were used for individual identification. By examining scars, marks, and pigmentation/spotting patterns on or near the dorsal fin, individual humpback dolphins could be effectively identified during the study period (see Jefferson and Leatherwood 1997). Each individual in the catalog was given a unique name. Photographs from each encounter were matched against the catalog. If photographs of a dolphin did not match with any identified individual, it was added as a new entry. Specifically, the shape and scarring on the trailing edge of dorsal fin were compared when different sides of dolphins were matched. If an apparent difference was found, the dolphin in question was identified as a new individual.

In the CMR analysis, we assumed that: (1) individual marks did not change significantly during the study period, and if they did, misidentification probability was low, by combining scars and nicks with spotting patterns; (2) the probability of identifying all animals in a sample/occasion was approximately even—we strived to photograph each dolphin in a group, regardless of its apparent markings; (3) every marked animal in the population immediately after time (i) had the same probability of surviving to time ($i + 1$); and (4) all samples were instantaneous relative to the interval between occasion (i) and ($i + 1$).

Survival and Capture Probability Estimation

We estimated survival and capture probability using a Cormack-Jolly-Seber (CJS) model fit within Program MARK (Cooch and White 2011). We grouped the identification data of all marked individuals within each year to maximize the capture probability (Stensland *et al.* 2006), creating four sampling occasions. Prior to fitting CJS models, we examined goodness of fit (GOF) using the “program RELEASE GOF” test in MARK. The overall GOF result (TEST 2 + TEST 3 = 1.0899) was not significant ($P = 0.7795$), indicating that the CJS model adequately fit the data. The CJS model is structured to estimate survival (ϕ) and capture probability (p) (Lebreton *et al.* 1992, Alves *et al.* 2015). When fitting the CJS model, we used a logit links for both survival and capture probabilities. Parameters were estimated using simulated annealing, the “alternative optimization method” in MARK, which works well if there are multiple local maxima. The best approximating model was selected using Akaike’s Information Criterion corrected for small sample sizes (AICc) (Burnham and Anderson 1998). We adjusted parameter variances using a variance inflation factor (\hat{c}), provided by the median \hat{c} estimator in MARK.

Population Size Estimation

Because the Xiamen humpback dolphin population was likely open to birth and death during the 2007–2010 study period, we used an open population model to estimate abundance. The model we used is known as a POPAN model (Schwarz and Arnason 1996); these models are used to model the size of the “super-population”, which is a hypothetical population that serves as a source of individuals from the population of interest. The super-population consists of the pool of all animals that entered the population during the study, through birth and immigration, and includes animals that leave the population through death or emigration. One feature of the model is that members of the super-population need not be present within the sampling area at all times. This is important because not all dolphins may be within the study area during each sampling period. Although dolphins are typically observed only within the entire study area (Liu and Huang 2000, Jefferson and Hung 2004, Chen *et al.* 2009, Chou *et al.* 2013), one individual has been observed in adjacent waters (Wu 2013). We fit POPAN models of abundance in MARK version 8.0 (White 2015). A suite of candidate models was developed to allow for fixed or time-varying effects on the entry probabilities (β), apparent survival (ϕ) and capture probabilities (p) in POPAN. We used logit link functions when estimating survival, capture probability, and the probability of entry; a log link was used when estimating abundance. Parameters were estimated using simulated annealing, the “alternative optimization method” in MARK, which works well if there are multiple local

maxima. The best approximating model was selected using Akaike's Information Criterion corrected for small sample sizes (AICc) (Burnham and Anderson 1998).

The estimate of population size from MARK only pertains to the number of identifiable animals within the entire population. The total population size (and its variance) can then be scaled upwards by taking into account the proportion of identifiable individuals (θ). In the present paper, we calculated θ using the formula: $\theta = \text{number of humpback dolphin with marks} / (\text{number of dolphins with marks} + \text{number of dolphins without marks})$. The number of dolphins with marks was identified and counted with the aid of photography identification technology. The number of dolphins without marks was directly counted in the field. Although we cannot guarantee that unmarked dolphins were not double counted, the error of repeated counts is limited due to the small number of unmarked dolphins in any group, individuals' temporary discrimination, and comprehensive count methods: (1) Groups had an average of 7.2 dolphins, of which an average of 1.7 were unmarked. (2) The unmarked individuals included small gray unspotted calves, dark gray unspotted juveniles, or larger mottled dolphins. These dolphins could be discriminated from each other, especially when they were in one group. (3) For those dolphins with similar age, color, and body size, in some cases, some temporary character (*e.g.*, tooth-marks, algae films) can help us to discriminate them from each other. (4) Additionally, for those calves or juveniles without any temporary marks, we counted the number of unmarked dolphins that moved out of water simultaneously, or accumulate the number of unmarked dolphins that were far apart from each other. The θ was calculated for each "group"; mean θ was 0.791 with 95% confidence intervals of 0.748–0.834.

The total population size was adjusted by θ using the formulas:

$$N_{\text{mean}} = EN_{\text{mean}} / \theta_{\text{mean}}$$

$$N_{\text{lower}} = EN_{\text{lower}} / \theta_{\text{upper}}$$

$$N_{\text{upper}} = EN_{\text{upper}} / \theta_{\text{lower}}$$

where N is the total population size, EN is the estimated number of identifiable dolphins, and θ is the proportion of identifiable individuals. We also calculated 95% confidence intervals.

RESULTS

Between June 2007 and June 2010, 76 groups (including some solitary dolphins) were sampled/photographed on 202 d surveys (881.1 observation hours) in Xiamen (see sightings in Fig. 3). The data from 52 individually identified humpback dolphins (see examples of identified individuals in Fig. 4) were used for estimating survival and population size. The discovery curve of the cumulative number of humpback dolphins identified in Xiamen had begun to level off by 2008 (Fig. 5), though several new identifications were obtained in later surveys.

Survival and Capture Probability

The estimate of \hat{c} from median \hat{c} , as run in Program MARK, was 0.8761. Rather than shrink our variances, we assumed \hat{c} was 1, as recommended by Cooch and White (2011).

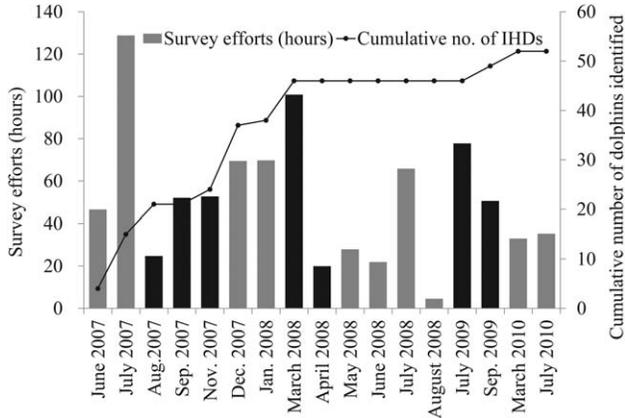


Figure 5. Discovery curve of the cumulative number of humpback dolphins identified between June 2007 and July 2010 in Xiamen, represented together with an index of survey effort in hours per month spent in the field. The different color columns show the seven sampling periods for exploring the effects of survey effort.

As suggested by Burnham and Anderson (1998), when the difference in AICc between two models is fewer than 2, both models fit to the data. The first two CJS models had 0.86 units difference of AICc (Table 2), indicating both models fit the data equally well. The fit of these two models were not significantly different ($\chi^2 = 1.379 P > 0.05$). The first model of $\phi_c p_t$ resulted in a constant apparent survival of 0.948 (95% CI: 0.922–0.966) (Table 3). The capture probability was 0.559 (95% CI: 0.393–0.713), 0.93 (0.636–0.99), and 0.813 (0.413–0.965), respectively, for 2007–2008, 2008–2009, and 2009–2010.

In order to explore the effects of uneven effort, we divided the data into seven sampling occasions with similar effort (175.3, 129.4, 139.2, 120.7, 120, 128.3, and 68.2 h; see Fig. 5, Table S2), and then examined a similar model set as in the prior

Table 2. The Cormack-Jolly-Seber (CJS) models fitted to the capture histories of all identified Indo-Pacific humpback dolphin in Xiamen, China, for apparent survival estimate. Goodness of fit results (TEST 2 + TEST 3) by Group: $\chi^2 = 1.0899$, $df = 3$, $P = 0.7795$; $\chi^2 = 25.2495$, $df = 11$, $P = 0.0084$.

Method	Occasions	Model	AICc	$\Delta AICc$	AICc Weight	Model Likelihood	Number of parameters	Deviance
CJS	4 occasions	$\phi_c p_t$	166.01	0	0.52	1	4	9.57
		$\phi_t p_r$	166.87	0.86	0.34	0.65	5	8.20
		$\phi_c p_c$	169.31	3.30	0.10	0.19	2	17.20
		$\phi_t p_c$	171.01	5.00	0.04	0.08	3	16.76
	7 occasions	$\phi_c p_r$	271.34	0	0.9996	1	7	111.67
		$\phi_c p_c$	287.00	15.66	0.0004	0.0004	2	138.13
		$\phi_t p_t$	1005.3	733.97	0	0	11	836.35
		$\phi_t p_c$	1033.4	762.09	0	0	7	873.76

Note: ϕ , apparent survival; p , recapture probability.

Table 3. Estimate of survival and relative parameters of Indo-Pacific humpback dolphins in Xiamen, China, from the Cormack-Jolly-Seber (CJS) models.

	Period	Survival rate	SE	Lower	Upper
4 occasions ($\phi_t p_t$)	2007–2010	0.948	0.0111	0.922	0.966
7 occasions ($\phi_c p_t$)	2007–2010	0.957	0.0146	0.918	0.978

analysis. The best approximating model assumed constant survival ($\phi = 0.957$; 95% CI: = 0.918–0.978) and time-dependent capture probability ($p = 0.867$, 0.781, 0.388, 0.444, 0.922, and 0.622 (Table 3).

Population Size

We evaluated eight models with constant or time-varying effects on entry probabilities (β), apparent survival (ϕ), and capture probabilities (p) in POPAN. However, only three models were successfully fit (see list in Table 4).

There were about five AICc units between the first two models (Table 4). The best approximating model ($\phi_t p_t \beta_t$) had 12.4 times the AICc weight as the second model ($\phi_t p_c \beta_t$). The likelihood value generated the same results, *i.e.*, the first model was better than the second model (12.5 times) ($\chi^2 = 9.735$ $P < 0.01$). Essentially, the third model ($\phi_t p_c \beta_c$) and the fourth model ($\phi_t p_c \beta_t$) did not have support in the data.

The best approximating model ($\phi_t p_t \beta_t$) estimated the number of identifiable dolphins as 56 (95% CI: 53–66) (Table 5). By adjusted by θ of 0.791 (0.748–0.834), the total population size was adjusted to 70 (95% CI: 63–88) (Table 5).

Similar to the survival estimate, the data from seven occasions with similar effort were also used to estimate population size. As a result, the first model of $\phi_t p_t \beta_t$ was significantly better than the other models (Table 4). This model generated a similar identifiable population size of 57 (54–66), and the adjusted total population size was 72 (65–88) (Table 5).

Table 4. Capture/mark/recapture Open/POPAN models fitted to the capture histories of all identified Indo-Pacific humpback dolphin in Xiamen, China, for population size (N) estimate.

Interval	Model	AICc	Δ AICc	AICc Weight	Model Likelihood	Number of parameters	Deviance
4 occasions	$\phi_t p_t \beta_t$	252.15	0.00	0.92	1	9	–3.92
	$\phi_t p_t \beta_c$	257.19	5.03	0.07	0.08	7	5.81
	$\phi_t p_t \beta_t$	262.05	9.89	0.01	0.01	6	12.96
	$\phi_t p_c \beta_t$	52,592.2	52,340	0.00	0	5	52,345.32
7 occasions	$\phi_t p_t \beta_t$	150.95	0	1	1	4	7.54
	$\phi_t p_t \beta_c$	634.67	483.72	0	0	9	480.27
	$\phi_t p_t \beta_t$	634.82	483.87	0	0	9	480.42
	$\phi_t p_t \beta_t$	9,782.61	9,631.66	0	0	11	9,623.59

Note: ϕ apparent survival; p , recapture probability; β , the entry probabilities.

Table 5. Estimate of population size and relative parameters of Indo-Pacific humpback dolphins in Xiamen, China, from open capture/mark/recapture model.

Model	Number of occasions	Model	Identifiable dolphins				Total population size	
			<i>N</i>	SE	95% CI	θ (95% CI)	<i>N</i>	95% CI
Open/ POPAN	4	ϕ, p, β	56	2.85	53–66	0.791(0.748–0.834)	70	63–88
Open/ POPAN	7	ϕ, p, β	57	4.20	54–66	0.791(0.748–0.834)	72	65–88

Note: ϕ apparent survival; p recapture probability; β the entry probabilities. The total population size was calculated using identifiable dolphins divided by θ . In this table, we only record an integer, but we calculated total population size using the precise true number.

DISCUSSION

Apparent Survival

This study is the first concerted effort to estimate apparent survival for the Xiamen Indo-Pacific humpback dolphin population. The Xiamen population inhabits Xiamen waters year-round (Liu and Huang 2000) and the mean linear range is no more than 36.2 km (Chen *et al.* 2011), and therefore permanent emigration could be assumed to be low. Consequently, apparent survival should be representative of true survival. Only one humpback dolphin has been found outside the study area; a humpback dolphin (white adult, less spots) was found in Quanzhou waters in December 2011 (Wu 2013), which is at least 70 km away from Xiamen. This dolphin did not match known dolphins in Xiamen. Therefore, mixing between Quanzhou and Xiamen humpback dolphins is apparently rare. Our survival and population size analysis is likely representative of the Xiamen population.

Although POPAN models can also estimate survival, we relied on survival estimates from the CJS model because we suspected survival estimates were more reliable with a small data set because the CJS model has fewer parameters. For a reliable survival estimate, Buckland (1990) suggested that sighting probabilities should be at least 0.2 in a given year. Our p estimates (0.559, 0.93, and 0.813) were higher than the recommended 0.2. CJS generated a reliable constant survival of 0.948 (0.922–0.966). Although uneven annual survey effort possibly affects the survival estimate, data with similar survey effort (seven occasions) generated a similar survival of 0.957 (0.918–0.978). All these results support a survival rate of greater than 0.94 for the Xiamen humpback dolphin population. It is important to note that since the animals in our MCR analysis included some younger dolphins with distinguishable and stable marks, our estimate showed the survival of subadults, adults, and some younger dolphins. Therefore, the survival might be lower than the adult and subadults' true survival, but higher than the true survival of the whole population. Although some uncertainty exists, future research may provide some insights.

An important question is whether survival is at or above the threshold necessary to sustain the population over time. Survival rates estimated here are higher than for humpback dolphins in coastal waters of Bangladesh, where apparent survival for adults and juveniles was estimated to be 0.85 (95% CI: 0.725–0.919) (Smith *et al.* 2015). In the Pearl River Estuary, the mortality rates of adult humpback dolphins from 10 yr to 25 yr range from about 0.03 to 0.15 (survival approximately 0.85–0.97), and this “population” was estimated to be declining at a continuous annual rate of 2.46% (Huang *et al.* 2012). Slooten and Lad (1991) have calculated that the minimum ϕ required for population growth is 0.91 for Hector’s dolphin (*Cephalorhynchus hectori*) populations within the most optimistic reproductive scenario. The survival of humpback dolphin in Xiamen Bay (≥ 0.948) was much higher than that for humpback dolphins in Bangladesh and the Pearl River Estuary, and also for Hector’s dolphin, which seems to be reason for some optimism about the future of this population.

Population Size Estimates, Trend and IUCN Category

This research produced an average total population size of 72 (95% CI: 65–88) individuals, which gives us a profile of the Xiamen population. It is still challenging to obtain the exact population size, due to the population dynamics of birth, death, statistical bias, *etc.* In the θ estimate, the total number of individuals in each group was calculated in combination with field direct counts and adjustment by photography. For those calves or juveniles without reliable marks (*i.e.*, scars, pigmentation, tooth marks), we estimated numbers by experience in the field, which could produce bias. This bias should be low due to low proportion (20.9%) of unmarked calves or juveniles in a group.

Xiamen humpback dolphin abundance/population size has been reported before. For periods in the late 1990s, Liu and Huang (2000) estimated fewer than 100 humpback dolphins, and Jefferson and Hung (2004) used line-transect methods that produced an estimate of approximately 80 dolphins. Chen *et al.* (2008) produced an estimate of 86 (CV = 20.16%) using line-transect methods. With the application of photographic techniques, we earlier reported 76 (43–109) humpback dolphins using the CMR method (Chen *et al.* 2009). But in the early years of that study, researchers were unfamiliar with photographic techniques, which might have resulted in low photographic probability. As such, the present estimate was necessary and valuable for reassessing the population size ($N = 72$, 95% CI: 65–88) using relatively consistent data from 2007 to 2010 and based on refined photographic techniques.

Although there is general agreement, with all estimates below 100 individuals, due to different methods, the present results could not be directly compared with those of previous research. The population trend remains unknown. We introduced the encounter rate (individuals/km survey tracks), and found that in 2004 (0.077, Chen *et al.* 2009) and 2008–2012 (0.082; BC, unpublished data) these were lower than that in 1990s (0.138, Liu and Huang 2000). We agree with Liu and Huang’s (2000) deduction that the Xiamen humpback dolphin population was possibly declining. In the 1960s, 36 individuals in Xiamen were killed by fishermen, who were testing their potential commercial use (Wang 1965). This large capture suggests that there may have been a much higher abundance in the early 1960s than currently. Therefore, the Xiamen population has likely declined since the 1960s (nearly three generations, see Taylor *et al.* 2007), and this is supported by results of

fishermen interviews, while in the recent decade, the population is possibly somewhat more stable.

The 95% CI of population size of the Xiamen humpback dolphins was 63–88, which is in agreement with information from previous studies (Liu and Huang 2000, Jefferson and Hung 2004, Chen *et al.* 2009). Based on our field records during 2007–2010 and 2012, excluding calves and juveniles (UC, UJ), 72.7% of individuals (*i.e.*, 47–64) are subadults and adults (SJ, SS, SA, and UA). Considering the adult proportion (*ca.* 65.7%) of all identified individuals, approximately 30–42 individuals would be considered to be adults. This number is just below the threshold of 50 individuals that meets the Red List Criterion D of Critically Endangered (CR).

Xiamen humpback dolphins face some of the most serious anthropogenic impacts among the putative Chinese populations. There is no evidence that the current disturbance or threats, such as port construction, busy vessel traffic, prey depletion, *etc.*, will cease or be largely mitigated in the near future. Based on small population size, the Xiamen population of humpback dolphins is considered to be at some risk of local extinction. The uncertainty about its distinctness should not delay nor hamper conservation efforts, as in any event, it can be considered to be a stock for management. It should be given the highest priority of protection among those populations in mainland China. Future monitoring efforts should be focused on the improvement of our understanding of the population's current status, *e.g.*, distribution patterns and long-term survival. Finally, anthropogenic threats should be quantitatively evaluated as soon as possible, and a conservation plan should be developed and implemented for this population to ensure its long-term survival.

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SUPPORTING INFORMATION

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Table S1. Effort and number of sampled and recaptured Indo-Pacific humpback dolphins from 2007 to 2010 in Xiamen, China.

Table S2. The seven sampling occasions with similar observation effort used for assessment of Indo-Pacific humpback dolphins between 2007 and 2010 in Xiamen, China.