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The world's second largest population of humpback dolphins in the waters of Zhanjiang deserves the highest conservation priority

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Chinese white dolphins (*Sousa chinensis*) inhabiting shallow coastal waters are vulnerable to impacts from human activities in the near shore waters. This study examined the population of Chinese white dolphins occurring off the coast of Zhanjiang in the northern South China Sea. A total of 492 Chinese white dolphins were identified, 176 of which were photographed on more than one occasion. The Zhanjiang Chinese white dolphin population is isolated from populations of conspecifics along the Guangdong coast. It is composed of approximately 1485 individuals (95% CI = 1371–1629; SE = 63.8), with estimates of mean representative range and core area of 168.51 and 44.26 km^2, respectively. The high site fidelity and long-term residence of Chinese white dolphins in the study area are well established. A review of all available data indicates that based on what is currently known, the Zhanjiang Chinese white dolphin population is the second largest of the species and genus in the world. However, the recent industrial boom along the Zhanjiang coast has increased concerns regarding the conservation of the Zhanjiang Chinese white dolphin population. We recommend the designation of a national nature reserve as a most urgent measure for protecting Chinese white dolphins in Zhanjiang waters.

Coastal dolphins are among the most threatened species of cetaceans because of their close proximity to human activities[1,2]. Humpback dolphins (*Sousa* spp.) inhabit shallow coastal waters, where they come into particularly frequent contact with human activity. The humpback dolphins found in Chinese waters are known as Chinese white dolphins (*Sousa chinensis*). In recent decades, human activities along the Chinese coast have been increasing because of rapid economic growth[3]. As a result, the water quality along China's coast has been progressively deteriorating[4,5]. The Chinese white dolphin populations, historically distributed in nearshore waters south of the Yangtze River, have declined drastically and become fragmented since the 1960s due to anthropogenic factors. Sightings of Chinese white dolphins in coastal waters of Dongshan, Shantou, Jiazi, Shanwei and Magong were reported by aged fishermen in survey questionnaires in 2010 in 12 fishing ports. The result suggests that the Chinese white dolphins lived in coastal waters between Xiamen and Pearl River Estuary approximately 20–30 years ago, and the current fragmentation is secondary and the result of human impacts[6]. The colonies now exist in five discontinuous locales, including Xiamen, western Taiwan, Pearl River Estuary, Zhanjiang, and Beibu Gulf in the East China Sea and South China Sea[7] (Fig. 1).

In this study, we acquired comprehensive survey data on the abundance, long-term site fidelity, and home range patterns of Chinese white dolphins found off the east coast of Zhanjiang city in the northern South China Sea. Assessing the number of animals in a population is a fundamental requirement for effective wildlife management. Site fidelity refers to the degree to which an individual or a population maintains residency in a particular region and is thus important for a basic understanding of population ecology and behavior. Knowledge regarding home ranges is essential for understanding the resources required by a species, identifying critical habitats, and revealing the overlap with anthropogenic impacts[8,9]. This information is fundamental for identifying conservation and research that will help the survival of this major dolphin population and drive recommendations for governmental agencies.

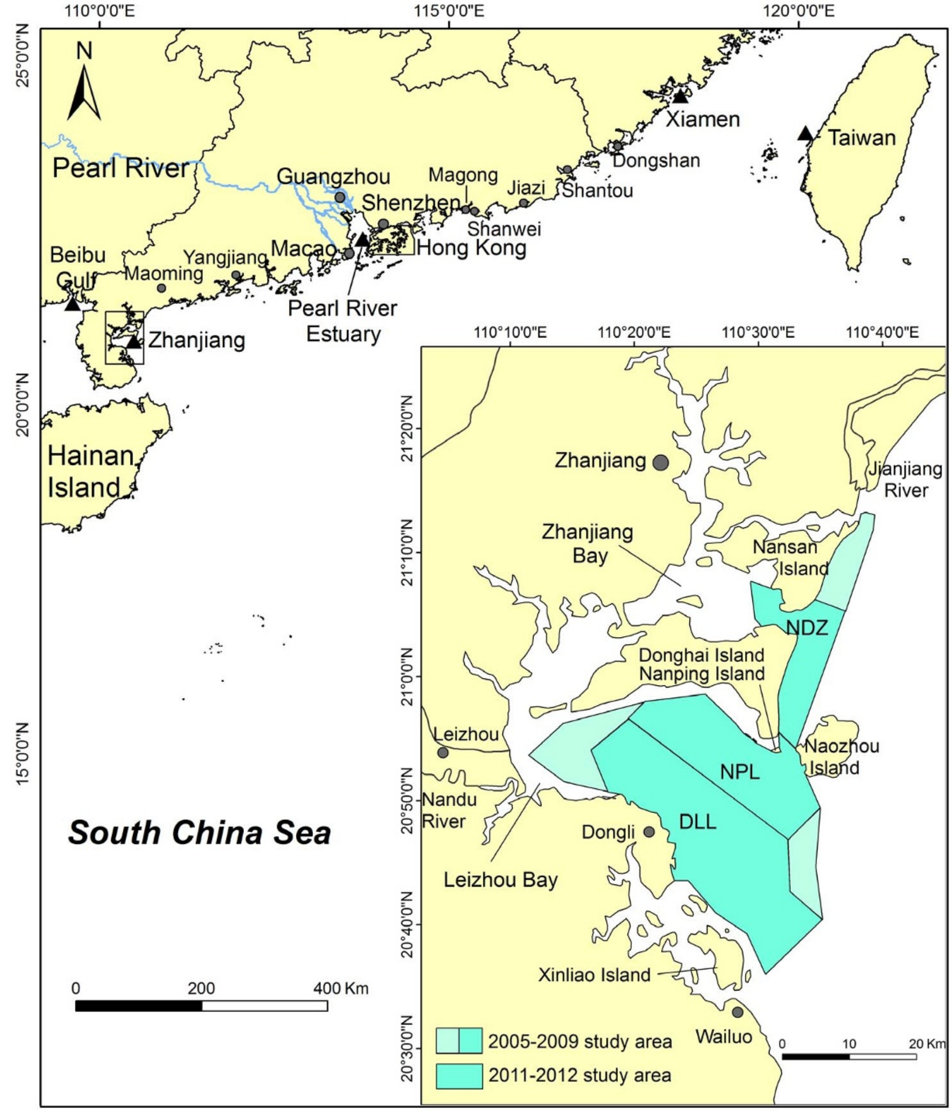

Figure 1 | Distribution of *S. chinensis* in Chinese waters. Solid triangles, recognized small populations of *S. chinensis*. Inset, detailed map of Leizhou Bay and Zhanjiang Bay indicating the survey areas. DLL, Dongli village area in Leizhou Bay; NPL, Nanping Island area in Leizhou Bay; NDZ, Nansan and Donghai Islands area in and adjacent to Zhanjiang Bay. Figure was produced using ArcMap in ArcGIS 9.3.

Results

Survey effort and photo-identification. Across the 7-year (2005–2009, 2011–2012) study, 374 boat-based surveys were conducted, resulting in a total of 2310.14 survey hours and 4959 dolphin sightings. The study revealed an identical sighting rate of 0.27 (the number of groups/h of search effort[10]) for two of the three principal areas: Nanping Island area in Leizhou Bay (NPL) and Dongli village area in Leizhou Bay (DLL). The sighting rate for the Nansan and the Donghai Islands area in and adjacent to Zhanjiang Bay (NDZ), 0.22, was slightly lower.

A total of 611 groups of Chinese white dolphins were sighted. The group size ranged from 1 to 35 individuals with a mean of 8.12 ± 5.85 and a median of 7 individuals. Most solitary individuals were adult or elderly animals. Age classes were determined for all 4959 sighted dolphins. Most of the sighted dolphins were adult (n = 1787, 36%) and subadult (n = 2032, 41%). The 992 juvenile dolphins made up 20% and the 149 newborn calves were 3% of the total sighted individuals. In addition to the carcass of an adult recovered in February 2008[7], a decayed adult carcass was found drifting in NPL on 6 August 2012.

From 2005 to 2012, 492 distinct Chinese white dolphins were identified by photographs. The number of new photo-identified individuals per year fluctuated from 30 in 2009 to 178 in 2008. The cumulative number of Chinese white dolphins increased throughout the study period. The slope of the discovery curve for newly photographed dolphins showed a sharp rise (Fig. 2), suggesting that we have not yet captured all of the dolphins in Zhanjiang waters or that the population is not closed and 'new' animals are arriving from outside the study area.

Validation of open model assumptions. Utilization of an open model requires the validation of basic assumptions, the violation of which can lead to bias in parameter estimates[11]: (1) Capture and survival probabilities are the same for all animals (marked and unmarked) between each pair of sampling occasions (homogeneous survival). The pooled χ^2 statistic (Test 2 + Test 3) indicated that the assumptions of homogeneous capture and survival probabilities were not violated (GOF Test: $\chi^2 = 175.74$, df = 26, $P = 0.0122$); (2) Capture results in similar risks and fates for all individuals. With photo-identification techniques, animals were not subject to stress associated with capturing, handling, or physical marking by researchers; (3) Marks are recognized properly, unique (no twins), and do not change or become lost. To identify and catalog individuals, we used only good or excellent

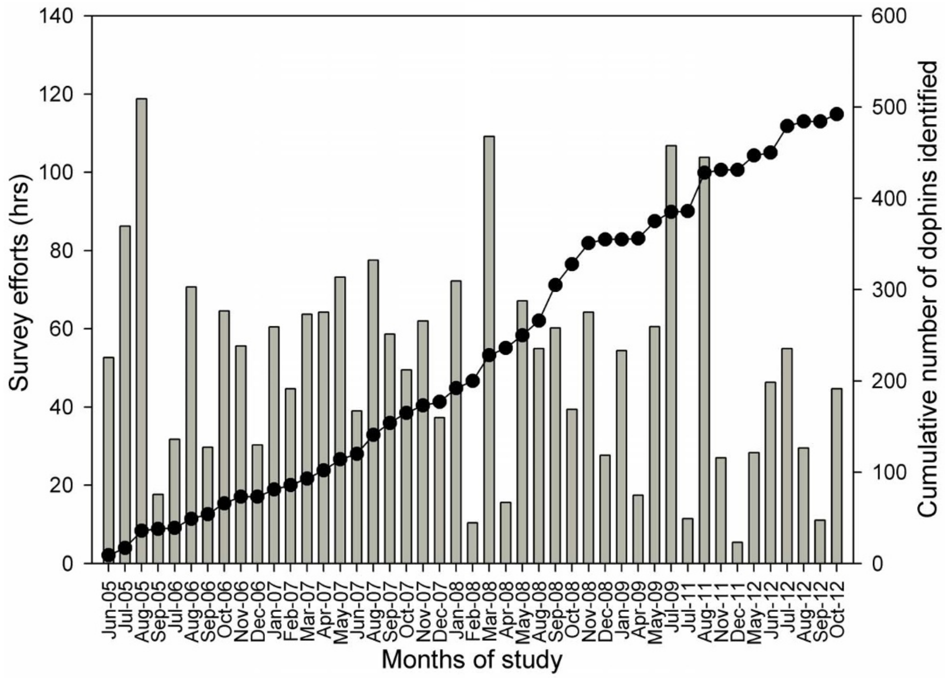

Figure 2 | Discovery curve showing the cumulative number of Chinese white dolphins (grey line) identified in relation to the hours of survey effort per month (grey bars) in Zhanjiang waters between 2005 and 2012.

quality photos of dolphins showing permanent marks, so marks could be recognized and identified on each sighting occasion; and (4) Samples are instantaneous, and all individuals are released after capture. Photo-identification avoided problems of dolphins being captured or retrieved from the environment. To guarantee that all the dolphins in the area were captured and that the entire region was surveyed, 6 mo was used as the sampling unit, a relative short time compared with the dolphins' lifespan (30–40 yr).

Population abundance. Of the 8 models tested, the {ϕ_t P. b_t} model appears to be the most appropriate and the one that best describes our data and accounts for the proportion of identifiable individuals (Table 1). This model allows constant capture probability (P) and allows survival (ϕ) and probability of entry (b) to vary with time. The proportion of identifiable individuals (all marked individuals) was 0.52, and the total population was estimated at 1485 (95% CI = 1371–1629; SE = 63.8) (Table 1).

Site fidelity. A total of 176 cataloged individuals (n = 492, 36%) showed some degree of site fidelity and were resighted from 2 to 29 times. Sixty-five individuals were seen on five or more occasions, and eighteen individuals were seen on ten or more occasions. Multiyear site fidelity was displayed by 28% (n = 136) of the identified individuals. Long-term site fidelity (up to 5 yr = 60 mo) was observed in a small number of individuals (n = 23, 5%) (Fig. 3). Individuals ZJ25 and ZJ29 were first documented in 2005 in DLL and subsequently resighted 7 and 8 times, respectively, in five different years in Leizhou Bay over a 7-year period. In addition, another 10 Chinese white dolphins were resighted between 71 and 86 months in the study area. Continued resightings of some dolphins substantiated the regular use of the study area by the animals.

Representative range and core area. Univariate kernel density estimates of home range were calculated for the 18 individuals with 10 or more sightings. The areas of individual ranging patterns for each dolphin differed in size and shape. The mean estimates of 95% KDE (representative range) and 50% KDE (core area) were 168.51 km^2 and 44.26 km^2, respectively (Table 2). Kernel density plots showed a home range of habitat use of one individual in DLL, NPL and NDZ, four individuals in NPL and NDZ, and one individual in NPL and DLL. The home range was split between two areas (NPL and NDZ, or NPL and DLL) for six individuals and three

Table 1 | Model choice criteria, identifiable individuals population size estimate (*N*) and total population size estimate (N_{total}, corrected for the proportion of identifiable individuals) for 8 models tested in a mark-recapture analysis of individual sighting histories of Chinese white dolphins in the Zhanjiang region, using the open-population POPAN parameterization in program MARK. AIC = Akaike's Information Criterion value, No. Par = number of parameters, SE = standard error, 95% CI = 95% confidence interval, CV = coefficient of variation

	Model choice criteria					Identifiable individuals				Total population				
Model	AICc	ΔAICc	AICc weight	Model Likelihood	No. Par	N	SE	95% CI	CV	θ	N_{total}	SE	95% CI	CV
ϕ_t P. b_t	1640.0232	0.0000	0.99727	0.1000	18	772	33.8	713–847	0.043	0.52	1485	63.8	1371–1629	0.043
ϕ_t P_t b_t	1652.4084	12.3852	0.00204	0.0020	25	687	28.9	638–752	0.042	0.52	1321	55.5	1227–1446	0.042
ϕ. P. b_t	1654.6481	14.6249	0.00067	0.0007	10	768	32.7	711–840	0.043	0.52	1477	63.5	1367–1615	0.043
ϕ. P_t b_t	1661.2300	21.2068	0.00002	0.0000	19	781	42.8	709–878	0.054	0.52	1502	81.1	1363–1688	0.060
ϕ_t P_t b.	52132.9909	50492.9677	0.00000	0.0000	17	492	0	492–492	0	0.52	946	0	946–946	0
ϕ_t P. b.	52235.0293	50595.0061	0.00000	0.0000	9	492	0	492–492	0	0.52	946	0	946–946	0
ϕ. P. b.	52247.0086	50606.9854	0.00000	0.0000	3	700	20.0	665–743	0.028	0.52	1346	37.7	1278–1428	0.026
ϕ. P_t b.	Numerical convergence not reached													

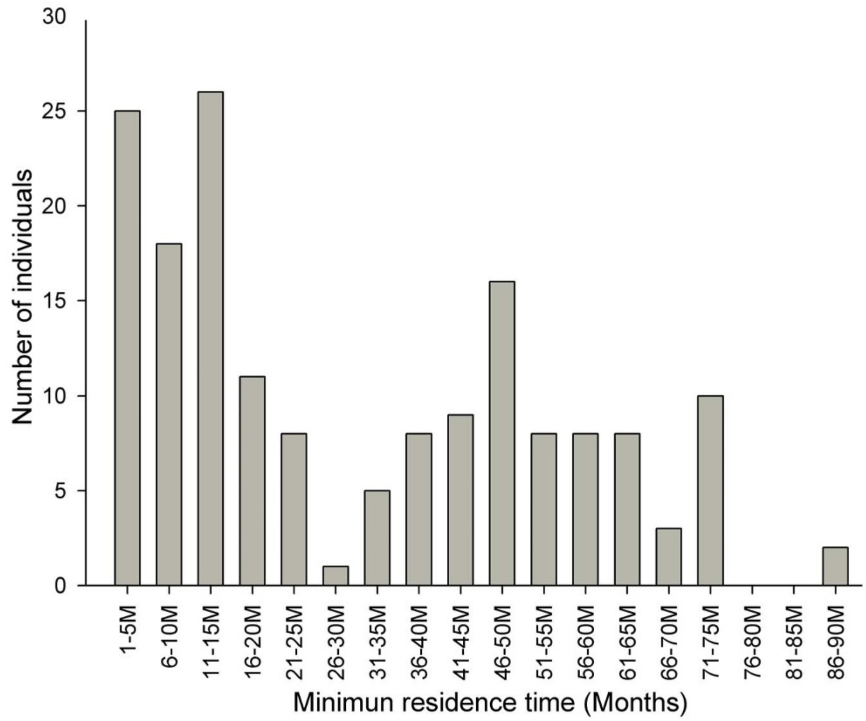

Figure 3 | Minimum residence time of Chinese white dolphins identified between 2005 and 2012 in Zhanjiang waters.

areas (DLL, NPL and NDZ) for two individuals. Relatively shallow waters near Nanping Island in Leizhou Bay and Nansan Island in Zhanjiang Bay, particularly near shallow sand beaches, appeared to be most frequently used by Chinese white dolphins, and there was extensive overlap in the home ranges for all individuals. Photo-identification data showed that animals moved among these two or three areas, indicating that a single population is present in the study area. Examples of individual ranging patterns of dolphins with 10 sightings or more are shown in Figure 4. Through the individual range use analysis (Fig. 4), we observed that the dolphins are a strictly inshore coastal and estuarine species most often found in waters less than 20 m deep and within 10 km of the coast.

Discussion

Mendez *et al*[12] proposed that the humpback dolphin genus includes at least four member species: the Atlantic humpback dolphin (*Sousa teuszii*), the Indo-Pacific humpback dolphin (*Sousa plumbea*), the Chinese white dolphin (*Sousa chinensis*), and a fourth yet-to-be-named *Sousa* species found off northern Australia. Estimates of population sizes available for selected areas around the world indicate that most humpback dolphin populations are small, with only a few hundred or dozens of individuals, except for the populations of the Pearl River Estuary and the Zhanjiang Chinese white dolphins (Table 3). Several hundreds of *Sousa teuszii* were found in the waters of Canal do Gêba and Bijagos Archipelago in Guinea-Bissau. The

Table 2 | Ranging patterns of 18 individual dolphins with 10 or more sightings each. DLL, Dongli village area in Leizhou Bay; NPL, Nanping Island area in Leizhou Bay; NDZ, Nansan and Donghai Islands area in and adjacent to Zhanjiang Bay

Dolphin ID #	No. of sightings	95% KDE (km²)	50% KDE (km²)	Area
ZJ40	25	161.84	39.53	NPL, NDZ
ZJ50	14	218.78	66.94	NPL-NDZ
ZJ52	11	279.58	67.26	NPL-NDZ
ZJ60	20	181.01	46.99	NPL-NDZ
ZJ70	19	59.06	12.48	NPL, NDZ
ZJ81	15	115.99	24.80	NPL, NDZ
ZJ86	18	117.62	30.58	NPL, NDZ
ZJ88	11	137.76	42.98	NPL-NDZ
ZJ186	11	163.76	36.83	NPL, NDZ
ZJ63	10	403.31	116.63	NPL-DLL
ZJ98	12	169.54	35.40	NPL, DLL
ZJ23	10	616.18	179.96	DLL-NPL-NDZ
ZJ43	29	59.68	13.93	DLL, NPL, NDZ
ZJ85	13	238.74	54.81	DLL, NPL, NDZ
ZJ44	17	15.16	2.74	NDZ
ZJ46	18	16.72	2.85	NDZ
ZJ78	10	16.25	3.29	NDZ
ZJ259	11	62.23	18.69	NPL
	Mean	168.51	44.26	
	Range	15.16–616.18	2.74–179.96	

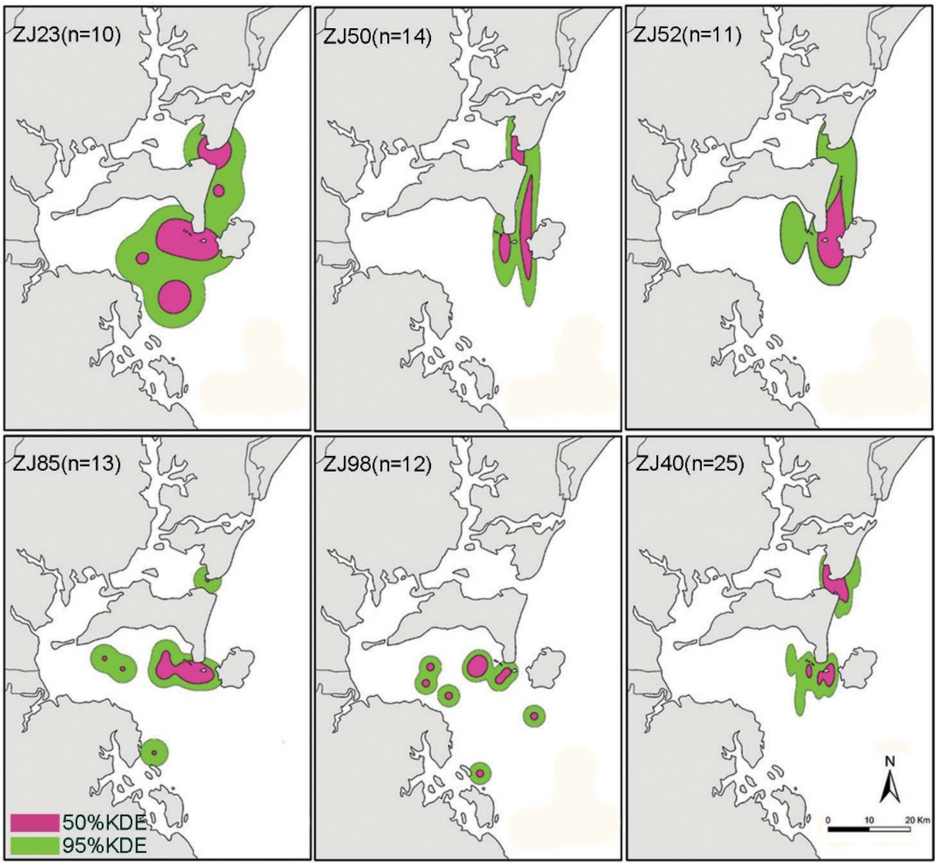

Figure 4 | Individual ranging patterns of six identified Chinese white dolphins with 10 sightings or more from the waters of Zhanjiang using the fixed kernel home-range analysis. Figure was produced using ArcMap in ArcGIS 9.3 and home range tools.

sampled population of *Sousa plumbea* in Algoa Bay, South Africa, yielded an estimate of 466 individuals[13]. The largest population reported for the Australian humpback dolphins is approximately 150 dolphins in the Great Sandy Strait Marine Park, Queensland[11]. Based on line-transect surveys conducted in the Pearl River Estuary between 2005 and 2008, the total population size of the PRE Chinese white dolphins was estimated to be 2555 during the wet season and 2517 during the dry season[14]. A total population of approximately 1485 individuals was estimated for the Zhanjiang Chinese white dolphin from the current study. This result is 5–6 times larger than the previous estimates (2005: 237, 95% CI = 189–318; 2005–2007: 268, 95% CI = 189–413)[7,15]. This makes the Zhanjiang Chinese white dolphin population the second largest in the genus *Sousa* and particularly of *Sousa chinensis* in the world, based on what is currently known.

Interannual site fidelity of Chinese white dolphins to the area off the eastern coast of Zhanjiang was reported in our previous study[7]. If we suspect that there are emigrant individuals leaving and immigrant individuals joining the Zhanjiang Chinese white dolphin population, we must ask where the emigrant individuals are going and where the immigrant individuals are coming from.

The distribution of Chinese white dolphins in the western section of the Pearl River Estuary extends from the mouth of Modaomen to the channel between Shangchuan and Xiachuan Islands[14]. The Leizhou and Zhanjiang Bays are located 250 km from the western section of the Pearl River Estuary, where the PRE Chinese white dolphins live. The northernmost distribution of Chinese white dolphins in the waters of Zhanjiang is the mouth of Jianjiang River (authors' unpublished data). Maoming and Yangjiang are located between the Pearl River Estuary and Zhanjiang. Survey questionnaires supported by Ocean Park Conservation Foundation, Hong Kong, (OPCFHK Project: Initial Establishment of Southern China Marine Mammal Stranding Network) were employed along the coast of Maoming and Yangjiang in January 2003. Boat surveys and questionnaire surveys supported by the Oceanic and Fisheries Administration of Guangdong Province were undertaken in November 2012 along the Maoming coast. During these surveys, no sightings or incidental catches of Chinese white dolphin were reported by fishermen, and no Chinese white dolphins were sighted during the boat surveys. Although no attempt has been made to assess the genetic distinctiveness of the Zhanjiang Chinese white dolphin population, considering the high resighting rate of marked individuals in the study area and the absence of nearby populations of Chinese white dolphins to the north of Zhanjiang Bay and Leizhou Bay, emigration from or immigration to the PRE Chinese white dolphin population appears unlikely. The data suggest that the Zhanjiang Chinese white dolphin population is isolated from populations of conspecifics along the Guangdong coast and support the findings of this study that high site fidelity and long-term residence of Chinese white dolphins are well established in the study area.

The water quality in Leizhou Bay and the outer portions of Zhanjiang Bay is good overall; the Pearl River Estuary receives residential and industrial water discharges that are severely polluted with both sewage and industrial wastes. Most Grade IV and greater than Grade IV waters are concentrated in the Pearl River Estuary, with inorganic nitrogen and active phosphate being the main pollutants[16]. An ecosystem health assessment in the Pearl River Estuary shows that the ecosystem health index (EHI) over the last three decades has decreased from 0.91 to 0.50, indicating deterioration from healthy to unhealthy status[17]. Although a small portion of Leizhou Bay is lightly polluted by oil and inorganic nitrogen, the rest of Leizhou Bay is within Grade I or II of the National Seawater Quality Standards for China. The inner portions of Zhanjiang Bay suffer from inorganic nitrogen and reactive phosphorus pollutants

Table 3 | Reported population sizes of humpback dolphins in the genus *Sousa* around the world

Species	Location	Time	Population size[1)]	Reference
Sousa teuszii	Banc d'Arguin, Mauritania	1997–2006	<100	40
	Saloum Delta, Senegal	1997–2006	Low hundreds	40
	Canal do Gêba and Bijagos Archipelago, Guinea-Bissau	1997–2006	Several hundred	40
Sousa plumbea	Algoa Bay, South Africa	1991–1994	466	13
	Richards Bay, South Africa	1998	74	41
	Maputo Bay, Mozambique	1995–1997	105	42
	Bazaruto Bay, Mozambique	1990s	60	43
	Anakao, Madagascar	1999	65	44
	South coast of Zanzibar, Tanzania	1999–2002	63	45
	Shimoni Archipelago, Kenya	2006	104	46
	Saudi–Bahrain–Qatar	1986	(16 groups)	47
	United Arab Emirates	1986	(13 groups)	47
	United Arab Emirates	1999	(2 groups)	47
	Arabian Sea coast of Oman		(Groups of 30 individuals or more)	48
	Jubail, Saudi Arabia	1991–1993	(50 groups, 1–15 individuals)	49
	Indus Delta, Pakistan	2005–2009	Low hundreds	50
	Gulf of Kachchh Marine Protected Area, Gujarat, India	2002	21	51
	Goa, India	2002	135	51
Sousa chinensis	Between the Sundarbans mangrove forest and the Swatch-of-No Ground submarine canyon, Bay of Bengal, Bangladesh	2010–2011	191	52
	Khanom, Nakhon Si Thammarat, Thailand	2008–2009	49	53
	Xiamen	2004–2008	76	54
	Central west coast of Taiwan	2002–2004	99	55
	Pearl River Estuary	2005–2008	2517–2555	14
	Zhanjiang	2005–2012	1485	This study
	Beibu Gulf	2003–2004	153	54
Sousa spp.[2)]	Moreton Bay, Queensland	1984–1987	119–163	56
	Great Sandy Strait, Queensland	2004–2007	150	11
	Capricorn-Curtis coast, Queensland	2007–2011	Approximately 150	57
	Cleveland Bay, Queensland	2001–2002	<100	34
	North West Cape, Western Australia	2010	53 identified individuals	58

[1)]Number of groups and group size in parentheses,
[2)]The Australian humpback dolphins are an as-yet-unnamed species of *Sousa*[12].

and have water quality grades of IV or worse. Water quality in the outer portions of Zhanjiang Bay, where the Chinese white dolphins live, was assessed as Grade I or II per the national standards[16]. The coastal waters of Zhanjiang city are rich in fish, with more than 220 species[18]; many are prey of Chinese white dolphins. Compared with the Pearl River Estuary, where about sixty Chinese white dolphin carcasses were found between 2010 and 2012[19,20], only two dead adults have been recorded in the waters of Zhanjiang since 2005. A *Sousa* carcass was found in oyster piles near Sanhewo Fishing Port in Zhanjiang Bay in February 2008[7], and another carcass was found drifting in Leizhou Bay in August 2012 (the current study).

The frequent sightings of young and neonate dolphins in Zhanjiang waters are indicative of a healthy population. Thus, it appears that Leizhou Bay and the outer portions of Zhanjiang Bay are relatively healthy habitat for Chinese white dolphins. However, the Zhanjiang water conditions may soon begin to deteriorate. Construction work for two large industrial facilities on the northern coast of Donghai Island is underway. Bao Steel Zhanjiang, the country's largest steel manufacturer, is scheduled to start trial operations for the Guangdong Iron and Steel Base Project in October of next year. The petrochemical complex, a joint venture of China Petroleum and Chemical Corp. (Sinopec) and Kuwait Petroleum Corp., is scheduled to start production by 2017. The coveted steel and petrochemical deals, plus a papermaking development, are expected to generate an output of 250 billion Chinese yuan (39.1 billion U.S. dollars) by 2016. The annual throughput of goods at Zhanjiang Port is expected to surpass 300 million tons in 2016, up from the current 171 million.

These projects may increase the lethal threats to *Sousa chinensis* in Zhanjiang Bay, such as deteriorating water quality, loss of the capacity of the habitat to provide critical resources for dolphins, and direct mortality and injury through boat strikes. Direct evidence supporting such concerns comes from the recent extinction of the baiji (*Lipotes vexillifer*)[21] and the rapid decline of the Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*)[22] and the PRE Chinese white dolphin[23], which are directly related to fast economic growth and large-scale developments. If not promptly protected, the Zhanjiang Chinese white dolphin population may follow its counterparts in the Pearl River Estuary and risk an unrecoverable collapse from inevitable habitat degradation. Therefore, the Zhanjiang population of Chinese white dolphins and its habitat deserve the highest degree of attention and protection.

In China, the Chinese white dolphin is listed as a Grade 1 National Key Protected Animal under the Wild Animal Protection Law approved in 1988. Three of the five populations of Chinese white dolphins are currently under the protection of national natural reserves. The PRE Chinese white dolphin population is protected by the Pearl River Estuary Chinese White Dolphin National Nature Reserve. The Xiamen and Beibu Gulf Chinese white dolphin populations are protected by the Xiamen Rare Species National Marine Nature Reserve and the Hepu Dugongs National Nature Reserve, respectively. Although a municipal nature reserve designation for the Chinese white dolphin population in Leizhou Bay was established by the Zhanjiang city government in 2007, the conservation effort for this dolphin population is insufficient in many

Table 4 | The 2005 to 2012 data were organized into nine time periods, showing the number of new identified individuals and cumulative number of identified individuals in each period

Time periods	Number of new identified individuals	Cumulative number of identified individuals	Survey efforts (h)
2005 (second half year)	38	38	275.00
2006 (second half year)	35	73	282.58
2007 (first half year)	47	120	345.23
2007 (second half year)	57	177	284.87
2008 (first half year)	73	250	274.48
2008 (second half year)	105	355	246.45
2009 (first half year)	30	385	239.11
2011 (second half year)	46	431	147.57
2012 (second half year)	61	492	214.85

aspects because the reserve does not have independent and permanent offices and full-time employees.

We have learned a profound lesson from the extinction of a marine mammal in the Yangtze River. The baiji, or Yangtze River dolphin (*Lipotes vexillifer*), found only in the Yangtze River, was declared "functionally extinct" in 2007[21]. The baiji experienced a catastrophic population collapse in recent decades, due largely to various extreme anthropogenic pressures[24]. The first estimate of baiji abundance based on quantitative survey data (1979–81) was approximately 400 animals[25]. At the time, we warned that in the absence of drastic protection measures, the baiji could be extinct in half a century. The same warning was repeated with heightened urgency in subsequent publications with additional survey data[26,27]. Despite all of the efforts made to conserve the baiji since the early 1980s, the population declined drastically in less than 2 decades as rapid industrialization led to heavy river transportation traffic, over-fishing, and hydroelectric dam construction.

We hope that the loss of the baiji serves as a stern lesson and raises concerns regarding the safeguarding of the Chinese white dolphin population in the waters of Zhanjiang. We recommend the designation of a national nature reserve as an urgent measure to protect Chinese white dolphins in the waters of Zhanjiang. As we envision it, the national nature reserve would manage existing and future activities with higher impacts to maintain the viability of this dolphin population. This national nature reserve would also be an area with a greater degree of legal protection. Given these rights, the reserve could promote ecologically sustainable development to maintain, protect and restore key habitat features and to ensure that the ecosystem is sustained for the Chinese white dolphins.

Methods

Data were collected with approval from the Oceanic and Fishery Bureau of Zhanjiang city and from the Animal Research Ethics Committee of Nanjing Normal University (Permit No. AREC 2005-05-008). The methods were carried out in accordance with the approved guidelines.

Study area and data collection. Leizhou and Zhanjiang Bays are subtropical bays of the northern South China Sea, located on the southernmost Chinese mainland, on the eastern coast of the Leizhou Peninsula. The study area included the nearshore waters of east Leizhou Peninsula, from the Jianjiang River mouth to Wailuo Town, including Leizhou and Zhanjiang Bays (110°37′E, 21°11′N; 110°31′E, 20°36′N). The area includes approximately 1,500 km^2 along the coast (Fig. 1). Leizhou Bay is located on the south end of Donghai Island; the water depth is 8–28 m. With an elongated beach, Nanping Island, approximately 7 km long and less than 1 km in width, lies near the south side of Donghai Island. Zhanjiang Bay (formerly known as Guangzhou Bay) is located on the north of Donghai Island.

Our study of the Zhanjiang population of *S. chinensis* was initiated in 2005. Exploratory surveys for Chinese white dolphins were conducted throughout the entire area of Leizhou Bay from June to September 2005[15]. A follow-up project, intended to broaden our overall knowledge of the dolphins in Zhanjiang waters, began in 2006. Line-transect surveys were conducted in Leizhou Bay, Zhanjiang Bay and the mouth of Jianjiang River between July 2006 and June 2007[7] and between January 2008 and July 2009 (unpublished).

To ensure maximal habitat coverage of the above regions, three principal areas were selected for boat-based surveys in 2011 and 2012: the Dongli village area in Leizhou Bay (DLL), the Nanping Island area in Leizhou Bay (NPL), and the Nansan and Donghai Islands area in and adjacent to Zhanjiang Bay (NDZ) (Fig. 1). These areas were selected based on our previous line-transect surveys conducted throughout the entire region[7,15].

Vessel-based surveys were conducted in permissible weather and marine conditions, with winds not exceeding 3 on the Beaufort scale, in a range of 5.5–15 km/h. Two or three researchers searched for dolphin groups (i.e., aggregations of dolphins with relatively close spatial cohesion and involved in similar behavioral activities[28]), with one researcher on each side of the boat and the driver observing the forward area. Upon sighting a group of dolphins, the boat slowed to idling speed. One researcher photographed the individuals in the group, and the other recorded time, position, tidal changes, depth, salinity, temperature, group size, group composition, and predominant behavior. A sighting of a 'group' of 10 would count as 10 'dolphin sightings' and 1 'group sighting'. The predominant behavior was recorded as the activity displayed by the majority of the animals in the group, based on the initial observation. The dolphins photographed in the same group were considered associated. However, individual associations of humpback dolphins seemed unstable[7,13]; some individuals could appear in many different groups in one day. If individuals were rediscovered within the same day, the later groups containing the rediscovered individuals were excluded from analysis. Information on the boat's position was logged every 30 s with a Geographic Positioning System unit (Garmin *GPSmap* 60CSx, position accuracy: $<$15 m; GARMIN Corporation, Lenexa, Kansas, USA).

Photographs were taken with a Nikon D3 equipped with an 80 mm to 400 mm zoom lens. Laboratory photo-analysis began with the initial sorting and identification of a collection of digital images[7]. Initial analysis and comparison of photographs were conducted via digital images on computers. Photographs were rated for quality, and those with the highest quality rating were compared manually to cataloged photographs. The best pictures of the identified dolphins were compiled into a catalog of all identified dolphins in the study area. All animals that had not been previously identified were given a unique catalog number.

Population abundance and mark-recapture population models. The population size was estimated assuming an open-population, using photo-ID data and the mark–recapture method. The data sets from 2005 to 2012 were organized into nine events (Table 4) and were analyzed using the software program MARK v.7.1[29], which uses Maximum Likelihood models to estimate population parameters[30]. Population parameters were estimated using the open-population POPAN parameterization[31], where parameter *N* represents population, parameter ϕ represents apparent survival rate, *P* is the probability of capture, and *b* denotes the probability of entry into the group. In model notation, the subscripts (*t*) and (.) represent time-dependent and constant parameters, respectively. The initial analysis was based on the fully time-dependent/Cormack–Jolly–Seber (CJS) model $\{\phi_t\ P_t\ b_t\}$. The first step in the analysis involves Goodness-of-Fit (GOF) tests for the CJS model, using the program RELEASE GOF[30] to validate model assumptions. Taking into consideration the biology of the species and the sampling method, 8 models were further constructed. The appropriate model for inference was selected using the Akaike Information Criterion (AICc) corrected for small sample sizes[32]. AICc weighs the deviance (quality of fit) and the precision based on the number of estimable parameters to select a model or models that best describe the data[33]. Models differing by less than two units from the model with the minimum AICc (ΔAICc) provide good descriptions of the data[32]. When more than one model provided a good description of the data, we followed the principle of parsimony and selected the model with the lower number of parameters as the most appropriate[34].

The mark-recapture population estimates apply only to the marked animals. Therefore, we calculated the total population size, N (total), using equation (1)

$$N_{total} = N/\theta$$

where θ is the proportion of marked individuals calculated within the area. The proportion of marked individuals, θ, is the ratio between the cumulative number of dolphins identified and the total number of dolphins sighted during the study. Standard errors for the total population size were derived from the variance of *N*, given generally by equation (2)

$$\mathrm{var}(N^2) = N_{total}^2\left(\frac{\mathrm{var}(N)}{N^2} + \frac{1-\theta}{n\theta}\right)$$

where n is the total number of marked individuals from which θ was calculated. Confidence intervals for N_{total} assumed the same error distribution as the mark-recapture estimates[35].

Site fidelity. We used the entire 7-yr (2005–2009, 2011–2012) collection of photographs to assess site fidelity. To investigate the presence of marked animals in the study area throughout the study period, we calculated: (i) the total number of sightings for each cataloged individual from all sighting data in the study area; and (ii) the minimum residence time or the maximum month interval between captures. To maintain data independence, we used only one sighting per day for each dolphin.

Representative range and core area. We used the kernel density estimation (KDE) to estimate utilization distributions (UDs). The fixed kernel density estimator uses probability density functions to identify areas of intense use[36,37]. Animals with ten or more sightings were selected to calculate kernel density estimates of home range between 2005 and 2012. Using a geographic information system (GIS), global positioning system (GPS) coordinates for identified individuals were downloaded and converted to shapefiles (point layers) (ESRI, v. 9.3). Shapefiles were then analyzed for the ranging pattern using the kernel home range (KHR) analysis[38]. The fixed KHR with the least-squares cross-validation technique (LSCV) was used to create a 50% kernel and 95% kernel UD[39]. The 95% kernel was used for the overall occurrence estimations, and the 50% kernel was used for the core occurrence area estimation. Area calculations were based on a Universal Transverse Mercator (UTM) projection, zone 49 N.

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Author contributions

K.Z. conceived and coordinated the research. X.X. and G.Y. contributed to the research design. X.X., J.S. and Z.Z. conducted the surveys and collected the data. J.S. and P.L. contributed to the data analysis. K.Z. and J.S. wrote the paper.

Additional information

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