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Range Patterns of Resident Indo-Pacific Humpback Dolphins (*Sousa chinensis*, Osbeck 1765) in Xiamen, China: Implications for Conservation and Management

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Bing-Yao Chen, Dong-Mei Zheng, Jian-Feng Ju, Xin-Rong Xu, Kai-Ya Zhou, and Guang Yang (2011) Range patterns of resident Indo-Pacific humpback dolphins (*Sousa chinensis*, Osbeck 1765) in Xiamen, China: implications for conservation and management. *Zoological Studies* **50**(6): 751-762. Because Xiamen, China's *Sousa chinensis* population is under heavy anthropogenic pressure, there is an urgent need for effective management and protection especially at key sites which are associated with vessel traffic. In the present paper, the home range sizes of 21 resident dolphins in Xiamen were estimated, and interactions of their range sizes with features such as social clusters, paired or unpaired, coefficients of association (COAs) were assessed. In addition, various interactions of age class and sex were also explored. As a result, the mean range sizes based on the minimum convex polygon (MCP), 95% kernel, and 50% kernel, and the linear distance were respectively 84.06 km^2, 162.48 km^2, 29.7 km^2, and 20.74 km. Individuals' home ranges were concentrated around the Jiulong River Estuary and Tongan Bay, corresponding well with 2 social clusters. Range sizes of the 2 social clusters did not significantly differ. Paired dolphins (preferred partners) had significantly smaller ranges than unpaired ones. At the multiple-partner level, dolphins with more partners had significantly larger ranges than those with fewer partners. Animals with high COAs had significantly smaller MCP range sizes and linear distances than those with low COAs. In general, there were no significant changes of home ranges of individuals in different age classes of the population. The range sizes of 8 females were slightly (non-significantly) larger than those of other dolphins of unknown sex. According to our results, the Jiulong River Estuary and Tongan Bay are identified as core areas should be given priority consideration. Further understanding of the overall range pattern of this population requires cooperation with scientists who work in neighboring waters of Kinmen I. as well as other nearby populations along the Chinese coast.
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Key words: Association, Kernel, MCP, Range, Resident.

The Indo-Pacific humpback dolphin (*Sousa chinensis*, Osbeck 1765) is classified as "near threatened" by the World Conservation Union (IUCN) (IUCN 2011). This species is distributed in shallow, inshore waters, and is threatened by anthropogenic activities: fast-moving vessels often cause disruption of behavior and social life (Ng and Leung 2003); some incidental catches of humpback dolphins in gill nets were reported (Keith et al. 2002, Parra et al. 2004); development of large infrastructure projects often results in negative impacts (Jefferson et al. 2009); and toxic contamination highly accumulates in tissues of humpback dolphins (Leung et al. 2005, Hung et al. 2006, Yeung et al. 2009).

A small population is known to occur throughout the entire year in waters with an area of 700 km^2 around Xiamen, southeastern

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China. Since the 1990s, Xiamen's population has been surveyed by different research groups, and all estimates on the mean population size were fewer than 100 individuals (Liu and Huang 2000, Jefferson and Hung 2004, Chen et al. 2008 2009). Comparing our surveys with those conducted in 2004 and 2010, it was found that the encounter rates (individual dolphins per kilometer of survey line) (0.077 vs. 0.087) were stable, and the distribution area did not significantly vary. However, this population is subject to heavy anthropogenic threats. In the 1960s, 36 Indo-Pacific humpback dolphins were deliberately captured (Wang 1965). Recent coastal construction (such as bridges and container ports) has resulted in land reclamation, the dredging and dumping of spoil, underwater blasting, large increases in vessel traffic and containers, and other impacts. In 2002, a stranded dolphin was thought to have been killed by underwater blasting (Wang et al. 2003). Nowadays, busy vessel traffic has become a major threat to this species (Chen et al. 2009). The population might be more endangered than the other 4 known populations (Hong Kong/Pearl River Estuary, Leizhou, Beibu Gulf, and Taiwan), and needs to be protected as soon as possible.

In recent years, management of marine species has become increasingly reliant on protecting key sites (Wilson et al. 2004). Studying an animal's home range size is essential for identifying, revealing, and understanding their critical habitats, required resources, and overlap of the marine ecosystem with anthropogenic impacts, and thus provides valuable information for decision-making in management (Parra 2006, Rayment et al. 2009).

According to Burt (1943), the home range of an animal is defined as "that area traversed by the individual in its normal activities of food gathering, mating, and caring for young." Herein, we estimated the area used by animals during the study period, and use of the term "range" for what we measured is reasonable. There are several methods to estimate range sizes of wildlife: (1) polygonal methods, including the minimum convex polygon (MCP) (Flores and Bazzalo 2004); (2) the center-of-activity method (Hayne 1949); (3) kernel methods (in which the fixed kernel method is the most basic) (Worton 1987); (4) Burgman and Fox's (2003) a-hull construction method and Getz and Wilmers' (2004) local convex hull method; and (5) methods based on spatial statistics using a local index of correlated associations and spatial analyses using distance indices (Dale et al. 2002). Among these methods, (4) (5) are intricate and have not been widely applied (Getz and Wilmers 2004); the center of activity method is mainly applicable for analyzing activity data and activity radii (Hayne 1949); and the MCP and fixed-kernel methods are basic, comparable, operational methods for calculating home range sizes of animals (Anderson 1982, Seaman et al. 1998, Flores and Bazzalo 2004, Boyle et al. 2009).

Recently, a few studies focused on the home range of this species. In Australia, humpback dolphins were sighted within approximately 60 km of the shore, and a 95% kernel population range of only 190 km^2 was found (Parra 2006). In the eastern Taiwan Strait, dolphins occur within a stretch of inshore waters approximately 100 km long and within 2 km from shore (Wang et al. 2007). In Algoa Bay and Richards Bay, South Africa, dolphins are distributed along a narrow strip of relatively straight coastline, and long-range movements within approximately a few hundred kilometers of some individuals were revealed (Karczmarski et al. 1998, Keith et al. 2002). In the Pearl River Estuary (PRE) and Hong Kong, China, a much-shorter linear distance of only tens of kilometers and a minimum convex polygon (MCP) with an individual range size of 99.5 km^2 were found, and the overall PRE population's geographic range size was more than 1800 km^2 (Hung and Jefferson 2004). In summary, the range patterns of this species in different waters show significant variation. Whether the linear range (e.g., in Taiwan and South Africa) and polygonal range (e.g., in the PRE) represent 2 ends of a continuum is unknown, since this species has not been well studied in other areas (Hung and Jefferson 2004). To clarify this issue, information about range patterns of Xiamen's population is important.

Some Indo-Pacific humpback dolphins utilize fixed habitats year round, while others infrequently and irregularly visit certain areas and display longer-range movements (Karczmarski 1999, Keith et al. 2002, Parra et al. 2006). The former are usually described as "residents", and the latter as "transients" (Karczmarski 1999, Gubbins 2000, Keith et al. 2002, Parra et al. 2006). For example, in Algoa Bay and Richards Bay, South Africa, residents display long-term residency within some specific areas, while transients cover a distance of > 100 km (Karczmarski 1999, Keith et al. 2002). In Cleveland Bay, Australia, some permanent residents were found within < 14 km around their mean center; others (transients) regularly traveled along the coast from year to year following a model of emigration and remigration (Parra et al. 2006). Therefore, whether a dolphin is a resident or transient should be considered when attempting to understand the range pattern of this species.

Typically, the home range reflects habitat use, and thus may be influenced by parameters such as the availability of food resources, age class, association with fishing boats, and other adaptations to human activities and disturbances (Hung and Jefferson 2004). For example, seasonal shifts in the home range use by humpback dolphins correspond to the seasonal distribution of prey in the PRE; Hung and Jefferson (2004) also found that individuals with more boat-associated sightings had larger habitats. In addition, adult individuals require larger home ranges than subadults.

For social animals, individuals with higher associations commonly spend more time together, and are more likely to use similar areas. Because of practical difficulties in data collection; however, few studies on marine mammals have considered the complex interactions between range and association patterns. The bottlenose dolphin is 1 species with relatively more information. It was found that paired males had significantly larger range areas than unpaired males (Owen et al. 2002). While the degree of overlap between home ranges among females was positively correlated with female association patterns, preferred associations were found among females showing as little as 27% range overlap, while some pairs showed avoidance despite 100% range overlap (Frère et al. 2010). However for humpback dolphins, the correlation between social associations and habitat use has not been studied yet.

The objectives of this study were to investigate the range sizes and locations of resident Indo-Pacific humpback dolphins at Xiamen. We assessed interactions between the range size and association patterns, and also explored the effects of year, season, age class, and sex. Our results may provide key information for the conservation and management of this species at Xiamen.

MATERIALS AND METHODS

Photo identification survey protocol

Xiamen is situated 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 Jiulong River is located just west of Xiamen, and is the most important local freshwater resource with a mean annual flux of > 10^{10} m^3. In addition, there are many other small rivers to the north and northeast of Xiamen. During 2007-2010, 202 boat-based surveys to photograph and identify dolphins were conducted in 12 mo of 4 seasons at Xiamen and adjacent waters (Fig. 1), which covered a total area of 700 km^2.

Boat surveys were conducted during the daytime when weather permitted (≤ Beaufort 3 and swells of ≤ 1 m). The survey boats were powered by 24-36 horsepower diesel engines, had an open deck, and traveled at speeds of 7-13 km/h.

Schools were defined as individuals moving in the same direction, and usually showing the same behavior patterns. Once a dolphin school was sighted, we slowly approached it to record its location and take photos, estimate the group size, assess the age composition of the school, and identify any mother-calf associations. Dolphin school positions were recorded using a global positioning system (GPS, Etrex Venture, Taiwan, with a position accuracy of 15 m). Out of 88 sighted schools of humpback dolphins, 76 were successfully followed for a total of 134 h and photographed. Photographs of individuals were taken as perpendicular to the body axis of the dolphin as possible and concentrated mainly around the dorsal fin using a Canon EOS-1Ds Mark II with a 100-400 mm zoom lens and a 400 mm lens and a Nikon D200 digital camera with a 80-400 mm zoom lens. All photographs were examined and graded (excellent, good, or poor) according to the focus, contrast between the dorsal fin and background, relative angle between the body axis and x-axis, and the size of the dorsal fin relative to the frame (Parra et al. 2006). About 5000 photographs were classified as excellent or good, and were used to identify individuals. In total, 43 dolphins were identified based on scars, marks, pigment patterns, and speckling characteristics.

Data analysis

A common issue in many previous studies was that survey efforts were not uniform throughout the study area (Hung and Jefferson 2004, Parra 2006, Rayment et al. 2009). Our research group has conducted projects on the humpback dolphin in Xiamen since 2004. However, we only selected data between June 2007 and July 2010, because of similar survey efforts in all Xiamen waters during this period.

To discriminate residents and transients, we referred to descriptions in Karczmarski (1999), Keith et al. (2002), and Parra et al. (2006), and to Gubbins' (2000) definition of bottlenose dolphins, and put forward 3 criteria to determine residents: 1) the number of sightings was ≥ 10 (Table 1); 2) the maximum interval between re-sightings was < 6 mo (Fig. 2); and 3) the individual was infrequently located near the boundary of the survey area (Fig. 3). In Xiamen, 21 dolphins were identified as residents. While the other dolphins were not, they should not arbitrarily be identified as transients, because they might live outside the study area, e.g., Kinmen waters where we were not permitted to survey. Here, data on those dolphins were not used to estimate range sizes.

Range sizes of 21 dolphins were estimated by the common methods of the fixed kernel method and MCP used in Australia (Parra 2006) and individual dolphins in the PRE (Hung and Jefferson 2004). Here, we estimated the core area using both the 50% and 95% fixed-kernel methods. Moreover, the shortest linear distance between the 2 extreme locations without crossing land was measured.

All determinations of range sizes were performed using GIS, ArcView 3.3 (Environmental Systems Research Institute, Redlands, California, USA), with the Animal Movement Extension. Kernel ranges of 95% and 50% probabilities of occurrence were estimated with smoothing parameters calculated using a cross-validation procedure for the least squares (Seaman et al. 1999, Parra 2006). The area of any landmass in the MCP or kernel range was subtracted out.

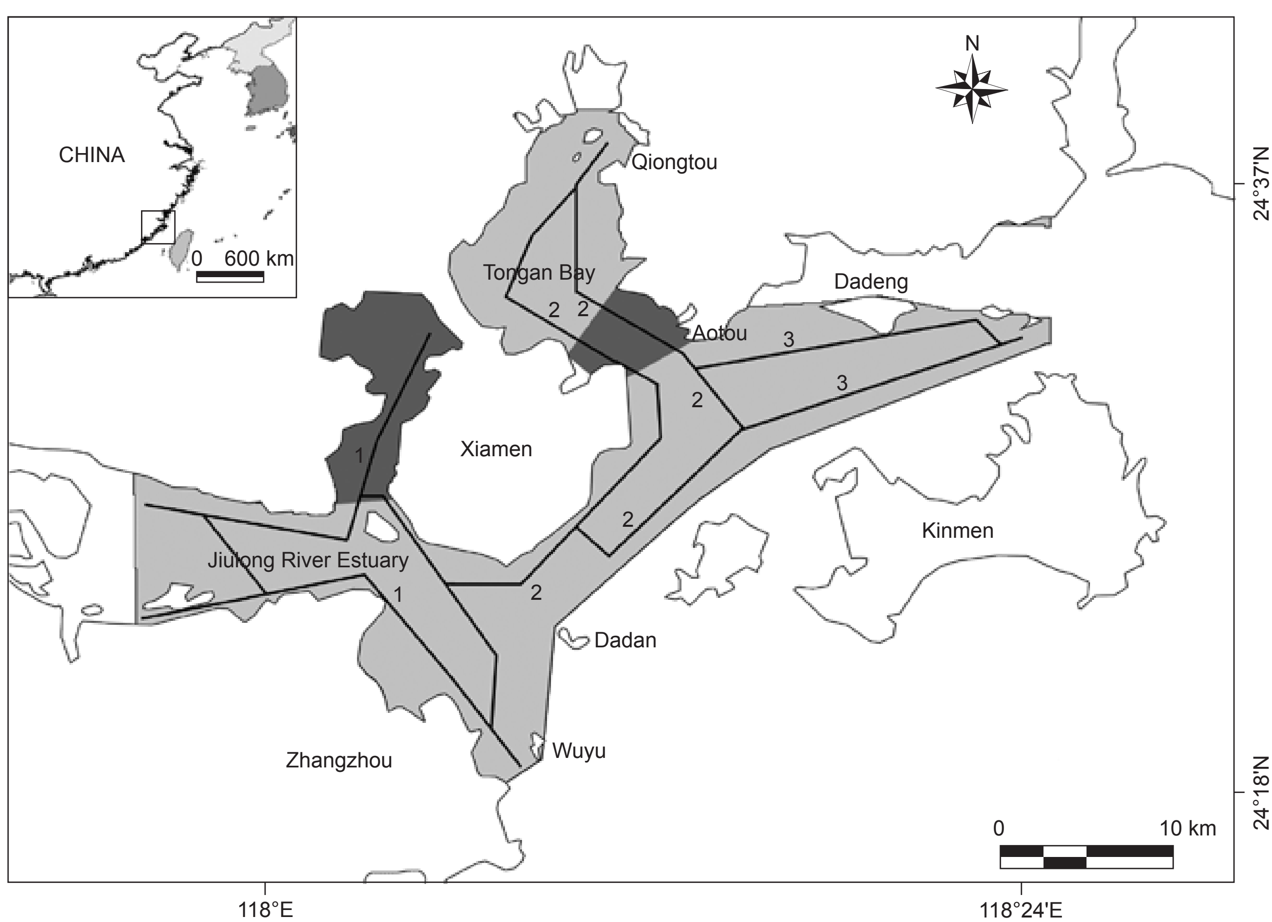

Fig. 1. Map of Xiamen and adjacent waters surveyed in the present study. The survey area included the dark-gray and gray parts. The dark-gray indicates core areas of the Xiamen Nature Reserve established in 1997. Survey lines (number 1, 2, and 3) are shown.

Influencing factors

As mentioned above, paired and unpaired bottlenose dolphins had significantly different range sizes. In order to explore the pairing effect, coefficients of association (COAs), as representative indices of social relationship between a pair of dolphins, were calculated by the most common half-weight index (HWI) (Owen et al. 2002). We used SOCPROG 2.4 (Whitehead 2009) to calculate the HWI for all pairs among the 21 dolphins. We defined "paired" dolphins using revised objective criteria in Owen et al. (2002): (1) minimum COAs of 0.50 (actually > 0.7) with a partner dolphin; and (2) partners were the reciprocally closest associates (preferred association), as measured by COAs. According to this definition, paired dolphins included only

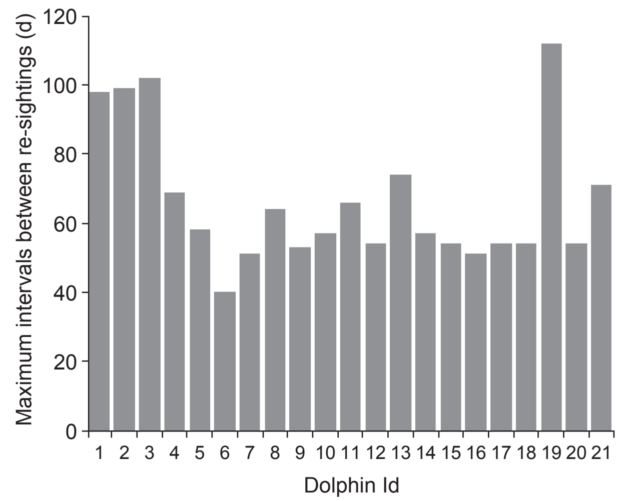

Fig. 2. Maximum intervals between re-sightings of 21 resident dolphins.

Table 1. Range sizes of 21 resident Indo-Pacific humpback dolphins at Xiamen, China with 10 or more sightings each

Individual Id	Sex	Age class	No. of sightings	Range size(in km²)			Linear Distance (in km)
				MCP	Kernel 95%	Kernel 50%	
1	Female	Spotted Adult	19	100.88	275.22	131.84	31.47
2		Mottled Subadult	18	198.58	368.6	39.07	36.2
3		Speckled Subadult	17	44.33	133.89	34.8	13.71
4	Female	Spotted Adult	24	56.65	73.6	8.75	14.28
5	Female	Speckled Subadult	21	148.64	243.44	33.66	33.56
6	Female	Speckled Subadult	27	51.19	77	8.95	13.82
7		Unspotted Adult	10	45.96	91.73	29.15	13.75
8		Unspotted Adult	22	52.05	68.66	16.08	13.94
9	Female	Speckled Subadult	14	29.57	64.84	14.94	14.09
10		Mottled Subadult	17	106.06	207.09	30.95	34.41
11		Mottled Subadult	10	29.1	56.87	13.89	10.21
12		Speckled Subadult	14	98.15	193.1	30.93	18.6
13	Female	Unspotted Adult	14	78.41	223.93	61.92	25.53
14	Female	Spotted Adult	13	72.51	161.88	20.81	21.69
15		Speckled Subadult	15	73.76	126.24	17.81	18.82
16	Female	Mottled Subadult	18	202.06	251.45	36.74	28.32
17		Mottled Subadult	13	79.39	185.95	31.95	18.26
18		Mottled Subadult	12	76.88	140.89	17.02	18.69
19		Grey juvenile	13	76.49	247.07	9.29	22.7
20		Mottled Subadult	15	103.32	126.17	18.97	20.27
21		Grey juvenile	11	41.32	94.49	16.16	13.17
Average			16	84.06	162.48	29.70	20.74

2 individuals. In fact, dolphins associate with multiple partners. Therefore, we calculated the COAs of each dolphin with other dolphins. We tested the difference in the range sizes of dolphins with high COAs (≥ 0.5) and those with low COAs (< 0.5) using the Mann-Whitney *U*-test.

Additionally, the age class and sex were assessed. The age class was defined using the criteria of Jefferson and Leatherwood (1997) (gray juvenile, mottled subadult, speckled subadult, spotted adult, and unspotted adult). Here, only 8 females were identified by the following methods: (1) direct identification by ventral angle photography; (2) a neonatal small calf swimming

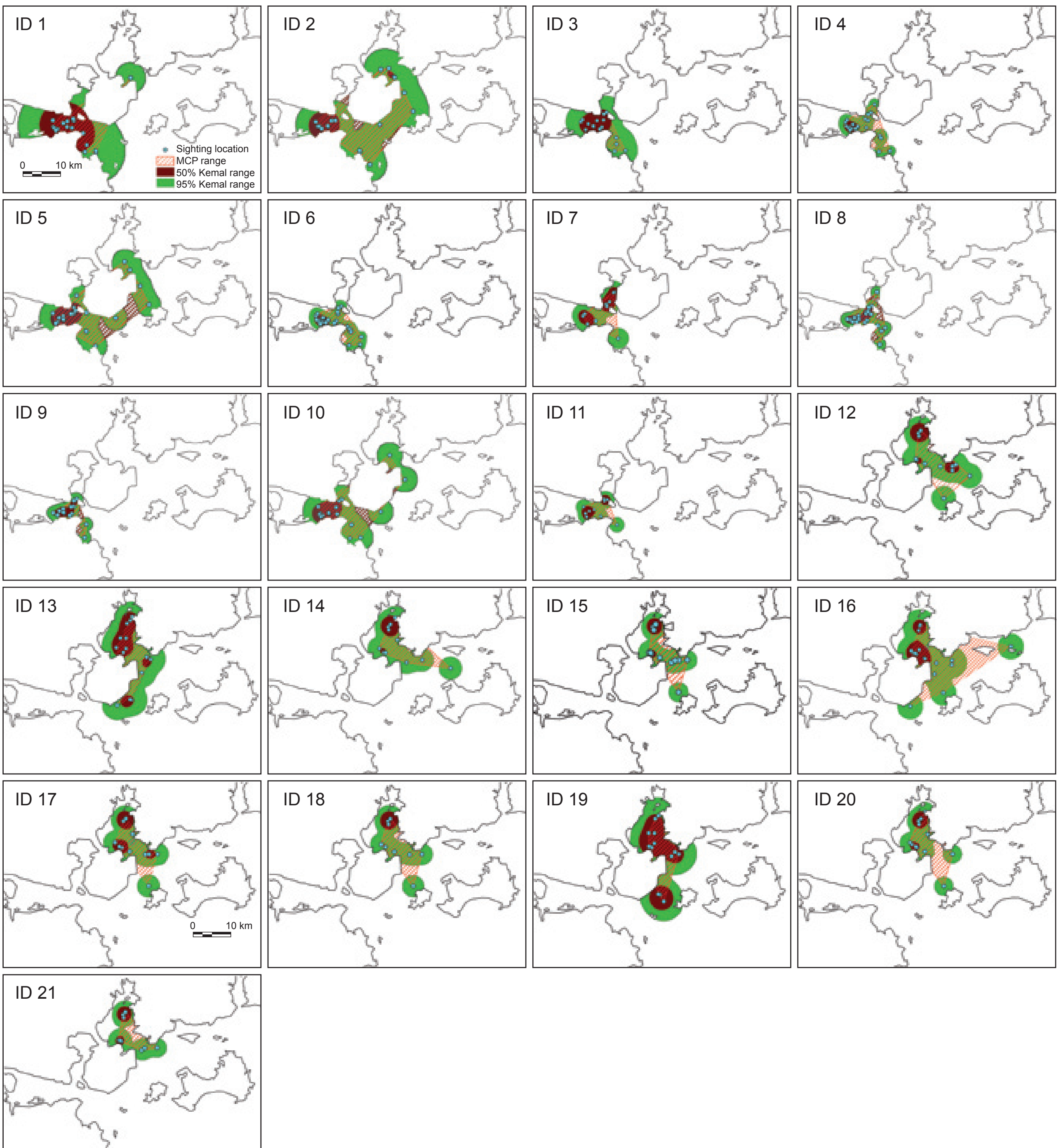

Fig. 3. The minimum complex polygon (MCP), 95% kernel, and 50% kernel range use by 21 resident dolphins at Xiamen, China.

nearby for the majority of the time; and (3) pure mother-calf groups.

The measures of ranges at different levels of influencing factors were compared using SPSS vers. 12.0 (SPSS, Chicago, IL, USA). All tests were non-parametric and two-tailed. All *p* values were considered significant at the 0.05 level.

RESULTS

Range size

The mean range sizes (± standard deviation; SD) of the 21 resident individuals were 162.48 ± 82.91 (range, 56.87-368.6) km^2 based on the 95% kernel method and 84.06 ± 48.29 (range, 29.1-202.06) km^2 based on MCP method (Table 1). The core area (50% kernel) was 29.7 ± 26.72 (range, 8.75-131.84) km^2. The mean linear distance was 20.74 ± 7.92 (range, 10.12-36.2) km.

Most (76.2%) individuals had an MCP range of 51-120 km^2, 90.5% had a 95% kernel range of 51-250 km^2, and 76.2% had a 50% kernel range of 10-40 km^2 (Fig. 4). All dolphins traveled 10-40 km in linear distance.

Space use

The representative range (95% kernel and MCP) analysis distinctly revealed that 10 dolphins (47.6%) (dolphin nos. 12-21) used Tongan Bay as their primary habitat, 7 dolphins (28.6%) (nos. 3, 4, 6, 7, 8, 9, and 11) spent most of their time in the JRE, and 4 dolphins (19%) (nos. 1, 2, 5, and 10) used the entire study area (Fig. 3).

All dolphins were concentrated in two core areas: Tongan Bay (10 dolphins, 47.6%), and the mouth of the JRE (11 dolphins, 52.4%). The mean size of the core area in Tongan Bay (32.9 km^2) was slightly larger than that in the JRE (26.2 km^2).

Range patterns of individual-associated COAs

A cluster analysis based on COAs showed 2 distinct clusters (Fig. 5). Cluster A included

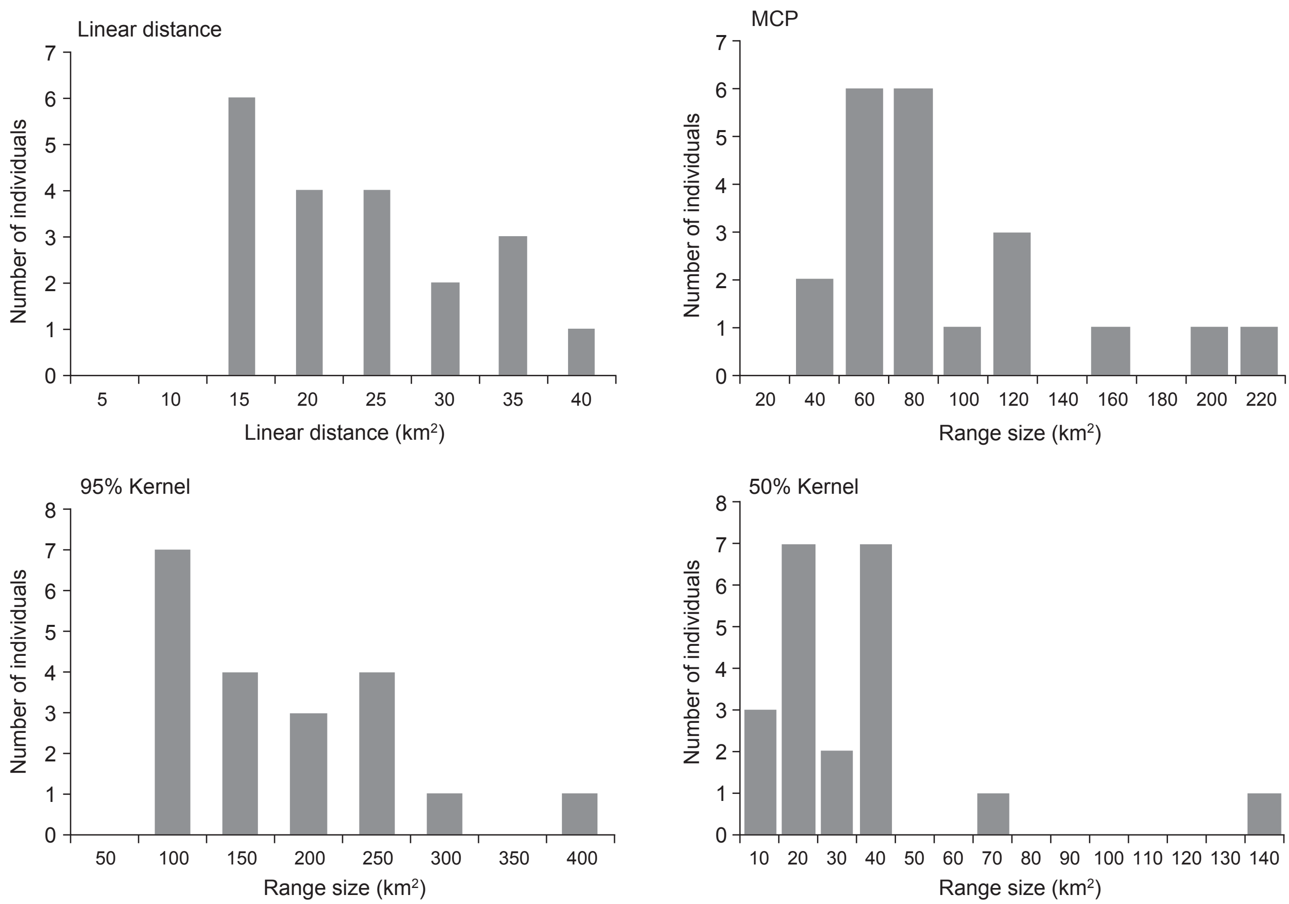

Fig. 4. Size distributions of individual ranges of humpback dolphins at Xiamen, China.

individual nos. 1-11, and cluster B included individual nos. 12-21. No significant differences in the MCP range, 95% and 50% kernel ranges, and linear distance between clusters A and B were found (Mann-Whitney *U*-test, MCP, $U = 40.0$, $p = 0.291$; 95% kernel, $U = 38.0$, $p = 0.231$; 50% kernel, $U = 51.0$, $p = 0.778$; linear distance, $U = 46.0$, $p = 0.557$). Clusters A and B were mainly distributed in western and eastern waters, respectively (Fig. 3). Considerable overlap in space use among the dolphins in the same cluster was found. For example, an MCP range of 46.08 km^2 and a kernel range of 126.92 km^2 overlapped between dolphin nos. 12 and 14.

Using our criteria, we were able to categorize ten (47.6%) of 21 dolphins as paired, i.e., nos. 4 and 6, nos. 8 and 9, nos. 13 and 19, nos. 18 and 20, and nos. 15 and 21 (Fig. 5). Paired dolphins had a significantly smaller average 50% kernel range of 19.0 km^2 than that of unpaired dolphins at 39.4 km^2 (Mann-Whitney *U*-test, $U = 16.0$, $p = 0.005$). Although paired dolphins appeared to have smaller MCP ranges, 95% kernels, and linear distances than unpaired dolphins (Fig. 6), no significant difference was found (Mann-Whitney *U*-test, MCP, $U = 34.0$, $p = 0.152$; 95% kernel, $U = 28.0$, $p = 0.061$; linear distance, $U = 40.0$, $p = 0.291$). Paired dolphins had similar ranges (Fig. 3), and showed considerable range overlap. For example, nos. 4 and 6 had similar range shapes (Fig. 3) and sizes (MCP 56.65 vs. 51.19 km^2; kernel 73.6 vs. 77 km^2, respectively), and considerable range overlap (MCP 48.62 km^2, kernel 68.7 km^2).

Besides the preferred association (paired), dolphins usually had multiple partners. The MCP range size and linear distance of dolphins with mean COAs of ≥ 0.5 were significantly smaller than those with mean COAs of < 0.5 (Mann-Whitney *U*-test, MCP, $U = 23.0$, $p = 0.028$; linear distance, $U = 26.0$, $p = 0.047$; 95% kernel, $U = 28.0$, $p = 0.065$; 50% kernel, $U = 30.0$, $p = 0.088$). Dolphins with more partners (> 10, 52.4%) had significant larger ranges than the individuals with fewer partners (≤ 10, 47.6%) (Mann-Whitney U-test, MCP, $U = 1.0$, $p = 0$; 95% kernel, $U = 13.0$, $p = 0.003$; 50% kernel, $U = 13.0$, $p = 0.003$; linear distance, $U = 10.0$, $p = 0.002$).

Age class and sex

Considering the test demands on the sample size, data of mottled/speckled subadults and spotted/unspotted adults were respectively pooled. The mean representative ranges (MCP and 95% kernel) of subadults were 95.4 and 167.3 km^2, which were larger than the 67.7 and 149.2 km^2 of adults (Fig. 7). The average linear distance of subadults (21.5 km) was slightly larger than that of adults (20.1 km). None of these differences was significant (Mann-Whitney *U*-test, MCP, $U = 29.0$, $p = 0.38$; 95% kernel, $U = 36.0$, $p = 0.792$; linear distance, $U = 37.0$, $p = 0.861$), which is similar to the results of Hung and Jefferson (2004). In contrast, the core area of subadults (25.4 km^2) was slightly smaller than that of adults (44.8 km^2), but the difference was not significant (Mann-Whitney *U*-test, $U = 37.0$, $p = 0.861$).

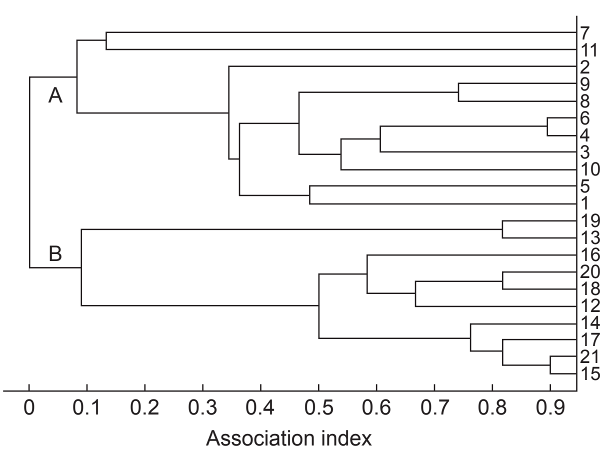

Fig. 5. Cluster analysis for half-weight coefficients of association (COAs) for 21 resident individuals with at least 10 sightings at Xiamen, China.

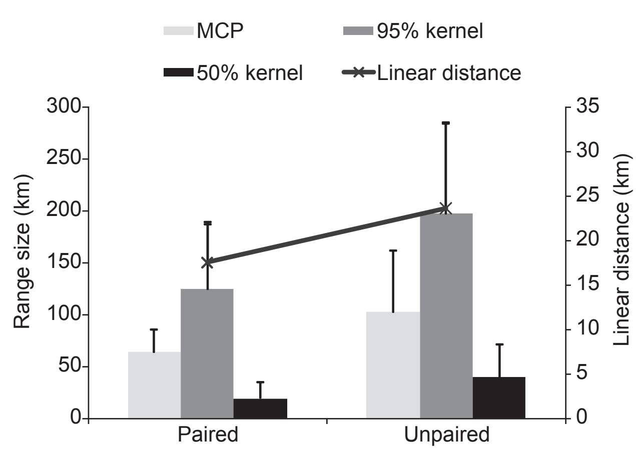

Fig. 6. Comparison of the range sizes of paired and unpaired dolphins (the standard deviation is shown by vertical lines above the bars).

We identified 8 females, among which 7 mother-calf pairs were found. The average range size of a mother-calf pair was slightly larger than those of another 13 dolphins of unidentified sex (MCP 84.5 vs. 78.9 km^2; 95% kernel 161.1 vs. 157 km^2; 50% kernel 40.6 vs. 23.5 km^2; linear distance 21.3 vs. 19.4 km), however it was not significant (Mann-Whitney *U*-test, MCP, $U = 45.0$, $p = 0.968$; 95% kernel, $U = 43.0$, $p = 0.843$; 50% kernel, $U = 44.0$, p =0. 905; linear distance, $U = 34.0$, $p = 0.362$).

DISCUSSION

Comparison between the MCP and kernel estimators

A significant difference between range sizes calculated using the MCP and the 95% kernel methods was found. The MCP estimator completely encloses all data points by connecting the outer locations in such a way as to create a convex polygon (Mohr 1947). The kernel method is suited to the presentation and quantitative determination of activity densities within a range (Worton 1987). Therefore, they are very different measures, and the results cannot be simply compared. In the present study, the MCP and kernel methods were used. The objectives were only to provide a general profile of the range patterns of this species at Xiamen, to gain valuable information, and to be compared with previous and future articles.

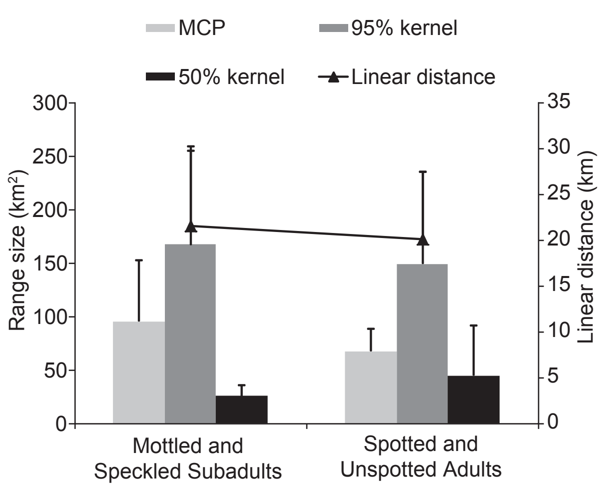

Fig. 7. Average range sizes of different age classes of individual humpback dolphins in the Pearl River Estuary (the standard deviation is shown by vertical lines above the bars).

Space use and potential association with prey

The considerable overlap in space use of either the entire range or core areas in the JRE and Tongan Bay might reflect prey aggregation in these waters. Some studies listed prey of Indo-Pacific humpback dolphins as being *Colllichthys lucidus*, *Nibea albiflora*, *Mugil* sp., *Johnius* spp., *Sardinella* spp., and *Thrissa* spp. (Wang and Sun 1982, Wang et al. 2003, Barros et al. 2004). In the JRE, some natural mangroves exist. Mangroves are key components of very productive ecosystems, which support high concentrations of zooplankton, peracarida, and fish (Nip and Wong 2010, Wang et al. 2010). The frequencies of some prey, i.e., *J. belengerii*, *C. lucidus*, *T. kammalensis*, and *S. aurita* in the JRE are very high (Hong et al. 2004); similarly, *J. belengerii*, *M. ophuyseni*, *Sardinella* spp., and *Clupanodon punctatus* are dominant species in Tongan Bay (Huang et al. 2006). In contrast, only *J. belengerii* is a dominant fish species in the area between Kinmen and Aotou (Huang et al. 2007), which was not a core area for the majority of dolphins.

Range patterns

Unpaired dolphins had a significantly larger range than paired dolphins. This was inconsistent with another study on male bottlenose dolphins (Owen et al. 2002). Dolphins with more partners or low COAs had larger range sizes. This can perhaps be interpreted as unpaired dolphins and those with more partners or low COAs needing to travel farther to meet food demands, reduce conspecific competition, and increase their mating opportunities.

Comparison with populations in other waters

The MCP range size and linear distance of dolphin individuals at Xiamen were similar to those in Hong Kong (84.1 vs. 99.5 km^2, 20.7 vs. tens of kilometers, respectively). The linear distance was significantly shorter than a few hundred kilometers in South Africa (Karczmarski 1996, Keith et al. 2002). Obviously, our results do support the population at Xiamen having a polygonal range than linear range.

We considered that the habitat characteristics such as topography, prey concentration, and proportion of residents and transients might be crucial reasons for whether a dolphin has a linear or polygonal range. Habitats of Algoa Bay, Richards Bay, and the eastern Taiwan Strait have similar characteristics: 1) a relatively straight coastline; 2) a narrow strip of shallow waters along the shoreline; 3) few bays or incisions; and 4) few inshore islands (Karczmarski 1996, Keith et al. 2002, Wang et al. 2007). The dolphins' prey may concentrate along the narrow straight coastline, which would limit dolphins to moving and preying along the shore. The majority were transients (possibly > 80% in Algoa Bay and 86.7% in Richards Bay), which greatly contributed to the populations' linear range patterns. In contrast, Xiamen and the PRE are situated in broad, shallow waters along a convoluted coastline, where many bays/incisions and inshore islands exist (Hung and Jefferson 2004). This enables the dolphins to meet their food and energy requirements in a polygonal area without long-distance travel offshore, and at least 48.8% dolphins (21/43) were identified as residents.

Implications for conservation

In 1997, a nature reserve for the Indo-Pacific humpback dolphins was established at Xiamen. Two protected core areas (Fig. 1) were designated which cover a total of 55 km^2 in area, and other waters were defined as buffer zones. Due to the limits of technology at that time, this open-use protected area was defined with the very preliminary available knowledge on distribution and movements. Based upon distribution data in 2004, Chen et al. (2008) provided a new design for the marine protected area, including the JRE and a small portion of Tongan Bay. This design was supported by the present data of range patterns. In addition, the entire Tongan Bay was identified as a core area instead of just a small portion of it. In fact, since extensive fish mariculture was banned in 2005, the encounter rate (dolphins/km of survey line) of dolphins in Tongan Bay greatly increased to 0.090 in 2009 compared to 0.021 in 2004. By comparing figures 1 and 3, a majority of the polygonal ranges of all dolphins were not within the current protected core areas. So we propose to change the current scale of the protected area, and give priority to the JRE and Tongan Bay for conservation of this species.

It was surprising that the 2 core areas were occupied by 2 different social clusters. In social cluster A of 11 dolphins, some dolphins absolutely utilized the JRE. Although nos. 1, 2, 5, and 10 used eastern waters seasonally, their core areas were still located in the JRE. In social cluster B of the other 10 dolphins, no dolphins used the JRE, and most core areas were located in Tongan Bay. These results indicated that the different social clusters exhibited a certain level of territoriality.

For cluster A, the JRE core area was under busy vessel traffic pressure, e.g., the number of voyages by ships were > 300 per day, while only about 10 or fewer ships per day were counted in Tongan Bay. Two identified dolphins exhibited unmistakable evidence of propeller cuts on their bodies (according to our photo-identification data). Vessel traffic already had negative impacts on animals in the PRE, e.g., vessel collisions (Jefferson 2000) and disruption of behavior (Ng and Leung 2003). For these reasons, it is strongly recommended that the number of vessels be restricted and the travel speed be controlled. In contrast, for cluster B in Tongan Bay, human activity is few. However, some occasional electro-fishing and mud dumping should be eliminated.

Some transitional waters, such as south-eastern waters of Xiamen, might be corridors for communication between these 2 clusters. These areas might be defined as a buffer zone, and should be given a certain conservation status.

Research prospects

As is known, waters around Kinmen (Fig. 1) belong to Taiwan. However, there are no obvious geographic or environmental barriers. We followed dolphins to the borderline, and watched them moving into Kinmen waters several times. Therefore, the range size of some individuals in the present study might have been underestimated. Due to political reasons, Kinmen waters are not available to Chinese researchers. For a better understanding of range patterns of Xiamen's population, it is necessary to cooperate with scientists from Taiwan and other nearby areas along the Chinese coast to seek relationships among the chain of small populations of *S. chinensis*.

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