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Distribution, abundance, and individual movements of Indo-Pacific humpback dolphins (*Sousa chinensis*) in the Pearl River Estuary, China

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Abstract

To obtain critical information on distribution and abundance of Indo-Pacific humpback dolphins (*Sousa chinensis*) residing in the Pearl River Estuary (PRE), systematic line-transect surveys and photo-identification studies were conducted in the eastern and western sections of the estuary in 2005–2006 and 2007–2008, respectively. Dolphins in the eastern section occurred throughout Lingding Bay, whereas their distribution in the western section extended from the mouth of Modaomen to the channel between Shangchuan and Xiachuan islands. Variations in dolphin distribution during the wet and dry seasons were evident and probably associated with movements of their prey species. Photo-identification of individuals confirmed exchange of at least some individuals between the western and eastern sections of PRE, and thus dolphins from both areas almost certainly comprise a single population. Using line-transect analysis, the total population size of the PRE humpback dolphins was estimated to be 2555 during the wet season and 2517 during the dry season. However, these should be considered preliminary as the coefficients of variation in some survey areas were high. Further studies should focus on refining these estimates and working towards understanding the western boundary of the PRE population.

Keywords: abundance; distribution; individual movement; Indo-Pacific humpback dolphin; line-transect survey; Pearl River Estuary; photo-identification.

Introduction

The Indo-Pacific humpback dolphin (*Sousa chinensis*) is widely distributed in the coastal and inshore waters of the Indian and western Pacific oceans (Ross et al. 1994, Jefferson and Karczmarski 2001). It ranges extensively from South Africa in the west, along the coastal rim of the Indian Ocean, through the Indo-Malay Archipelago, along the coast of China in the east, and to northern Australia in the south (Jefferson et al. 2008). Currently, the Indo-Pacific humpback dolphin is listed as a *Near Threatened* species according to the IUCN Red List of Threatened Species (Reeves et al. 2008), and the status of most populations is still poorly known throughout most of its range (Jefferson 2000, Reeves et al. 2008). As they are particularly vulnerable to habitat loss, fragmentation, and degradation, owing to their occurrence close to coasts, improving the understanding of this coastal species has been identified as an urgent task (Reeves et al. 2003, Perrin et al. 2005).

There is very limited information on humpback dolphins in Chinese waters. Jefferson (2000) hypothesized that approximately eight populations occur along the coast of China, including the ones in Beibu Wan, Leizhou Peninsula, Pearl River Estuary (PRE), Shantou, Xiamen, near Min River and Yangtze River, and along the coast of Zhejiang Province. The species was also reported from the Yellow Sea in northern China, but was considered to be an extralimital record (Han et al. 2003). In the past decade or so, focused surveys have been conducted on several populations in Chinese waters, including the ones residing in the PRE (Jefferson and Hung 2004), Xiamen Harbor (Liu and Huang 2000, Chen et al. 2008), Leizhou Bay (Zhou et al. 2007), and along the west coast of Taiwan (Wang et al. 2004, 2007). In China, this species was listed as a Grade One National Key Protected Animal by the State Council, receiving the highest protection status by the authorities. Moreover, humpback dolphins are also fully protected in Hong Kong under the Wild Animals Protection Ordinance that no person is allowed to hunt or willfully disturb them (Jefferson et al. 2009).

The population residing in the PRE [including the waters of the Hong Kong Special Administrative Region (SAR) and Guangdong Province] has been extensively studied since the mid-1990s. In Hong Kong, humpback dolphins mainly occur in western waters, particularly the waters north and west of Lantau Island (Jefferson 2000, Hung 2008). Across the Hong Kong/China territorial boundary, dolphin distribution extends west throughout Lingding Bay (Jia et al. 2000, Jefferson 2000, Qiu and Chen 2001, 2004). Seasonal shifts in dolphin distribution in both Hong Kong and Lingding Bay were evident and probably associated with seasonal movement of their prey, which is influenced by the Pearl River discharge between wet and dry seasons (Parsons 1998a, Jefferson 2000, Qiu and Chen 2001, Hung 2008). Density and abundance of humpback dolphins were estimated for different areas of Hong Kong and Lingding Bay, using both line-transect survey and photo-identification techniques (Jefferson 2000, Jefferson and Hung 2004). In Hong Kong, the most current abundance estimates varied from 103 dolphins in spring to 193 dolphins in autumn (Jefferson 2007). For the entire Lingding Bay including Hong Kong waters, the highest abundance estimate occurred in winter with 1504 animals, but this estimate was considered preliminary as some areas and seasons yielded high coefficients of variation (Jefferson and Hung 2004). Moreover, the same study also suggested that some dolphins moved out of the study area thus it is likely that the entire range of the population was not covered by the Lingding Bay study (Jefferson and Hung 2004). Using photo-identification data, a mark-recapture analysis yielded an estimated population size of 753 dolphins, but this estimate was thought to be an underestimate owing to disproportionate survey effort allocation between Hong Kong and Lingding Bay and a lack of saturation of the discovery curve (Jefferson 2000).

Although extensive surveys have been conducted to study humpback dolphins in Hong Kong and Lingding Bay that are influenced by the eastern four exits of the Pearl River, virtually no information is available on the status of dolphins in the western section of the estuary (Hung 2008). Dolphins have been frequently observed near the southwestern boundaries of the Lingding Bay study area year-round, strongly indicating that dolphin distribution extends west beyond Lingding Bay (Jefferson 2000, Qiu and Chen 2001). Locating the western range of this PRE humpback dolphin population is an important issue for management and conservation actions because the present minimum population abundance estimate of 1500 individuals would be an underestimate if its range extends further west (Jefferson and Hung 2004). Surveys are therefore urgently needed to cover the waters west of Lingding Bay to obtain critical information on distribution and abundance for the entire PRE population.

The main objective of the present study is to gain new information on the population's distribution and generate a preliminary abundance and density for the dolphins residing in the western section of the PRE. Updated information on the status of dolphins from the eastern section of the estuary (i.e., Lingding Bay) is also provided based on recent surveys conducted in 2005–2006. Based on this new information, the status of the entire humpback dolphin population can be better understood, which can guide further conservation actions and decisions in light of increasing threats from infrastructure development projects within the population's range.

Materials and methods

Study area

The Pearl River is the second largest river in China, and drains a vast area of 452,000 km^2 in southern China (Zhao 1990). The PRE has eight outlets, with its eastern four exits (i.e., Humen, Jiaomen, Hongqili, and Hengmen) emptying into Lingding Bay (including the Hong Kong SAR), which is the eastern section of the Pearl River Estuary (EPRE) and extends to the southwest of Macau. The western four exits (i.e., Modaomen, Jitimen, Hutiaomen, and Yamen) empty into Huangmao Sea and the waters around Shangchuan and Xiachuan islands, which are collectively referred as the western section of the Pearl River Estuary (WPRE). The division of PRE into eastern and western sections was arbitrary and mainly as a result of logistical constraints, which led to the inability to cover the western section of PRE until recent years. Moreover, there is a jurisdictional boundary within EPRE that separates Hong Kong territorial waters from the rest of Lingding Bay, hindering surveys to be extended directly across that boundary. The survey areas of EPRE and WPRE encompass 1651 km^2 and 2197 km^2, respectively. The study area is mostly shallow, with the majority of the waters being less than 20 m deep.

For survey purposes, the waters of EPRE and WPRE were divided into six survey areas: North Lingding Bay (NLDB), Central Lingding Bay (CLDB), South Lingding Bay (SLDB), Macau (MA), Huangmao Sea (HMS), and Shangchuan Island (SCI) (Figure 1). A series of parallel transect lines (generally perpendicular to the major coastlines) were placed in each survey area that were 3–4 km apart and extended from the 3-m isobath nearshore to the 20-m isobath offshore (Figure 1). These surveys lines were designed to cover each survey area evenly and provide representative coverage. The total length of transect lines from the six survey areas was 735.5 km.

Line-transect vessel surveys

A set of 12-month line-transect surveys were conducted in EPRE from February 2005 to January 2006, whereas another set of 12-month surveys were conducted in WPRE from August 2007 to July 2008. A 23-m shrimp trawler was used during both sets of surveys, and observations were made from the flying bridge area, which was 4–5 m above sea level. The survey methodology followed standard protocols used for line-transect surveys that were conducted in Hong Kong and Chinese mainland waters in the past (Jefferson 2000, Qiu and Chen 2001, 2004). All surveys were conducted under acceptable weather conditions (sea states 0–5; no heavy rain and visibility $\geq$1200 m). The survey vessel transited different transect lines at a constant speed of 13–15 km/h.

Both sets of surveys were conducted by the same groups of observers from the South China Sea Fisheries Research Institute (SCSFRI) and Hong Kong Cetacean Research Project (HKCRP) to ensure consistency, and all observers were experienced in small cetacean survey techniques and identifying local cetacean species. Beforehand they had participated in at least one at-sea training program provided by the authors. On all surveys, two observers (a data recorder and a primary observer) made up the on-effort survey team. The primary observer searched for cetaceans continuously through a pair of 7×50 marine binoculars, whereas the data recorder searched with unaided eyes and filled out datasheets. Both observers searched the area ahead of the research vessel between 270° and 90° (in relation to the bow, which was defined as 0°). Two to three additional experi-

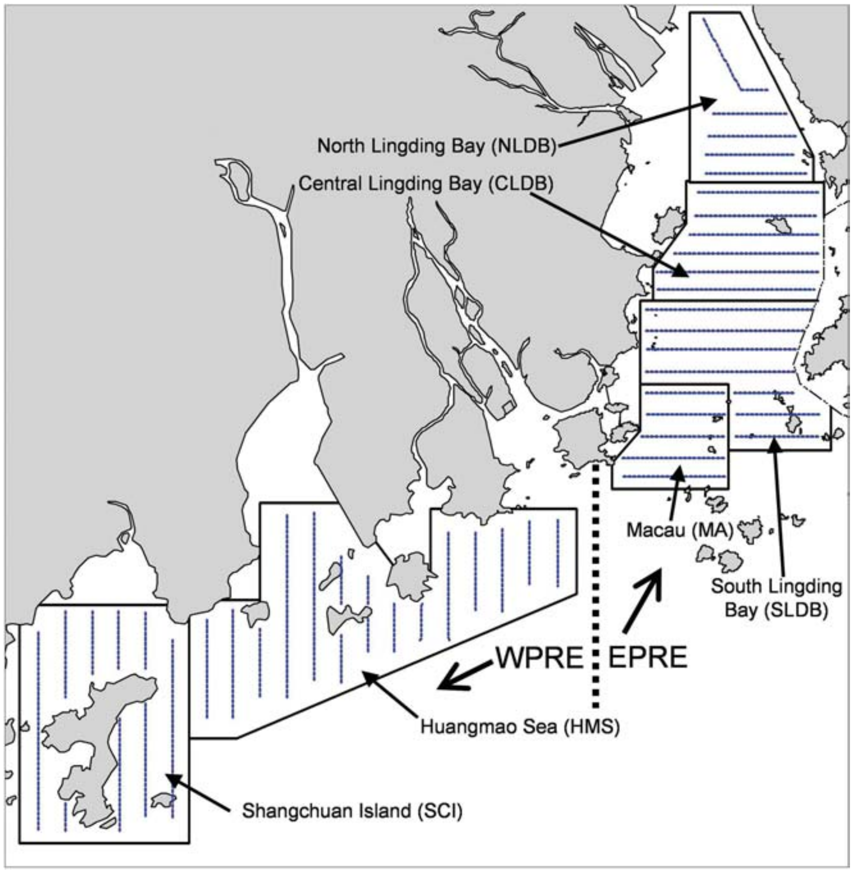

Figure 1 Six survey areas with transect lines in western and eastern sections of the Pearl River Estuary.

enced observers were also available on board to work in shifts (i.e., rotation every 30 min) to minimize fatigue of the survey team members.

During the course of on-effort search, the survey team recorded data that included: time, position (latitude and longitude), vessel speed, sea state, visibility, and amount of survey effort with the assistance of a hand-held Global Positioning System (GPS). When dolphins were sighted, the survey team would end survey effort to immediately record the initial sighting distance (estimated by naked eyes after calibration exercise with laser rangefinder binoculars) and sighting angle (successive compass bearings taken from built-in compass in binoculars) of the group from the survey vessel. Other information, including the sighting number and time, position, environmental conditions, species, group size, group composition, fishing boat association, activity and behavior, were also recorded during the course of a dolphin sighting.

Photo-identification

When a group of humpback dolphins was sighted during line-transect surveys, the survey team would end effort and approach the dolphin group slowly from the side and behind to take photographs of them. An attempt was made to photograph every dolphin in the group, and both sides of each dolphin where possible, as the coloration and markings on different sides are not symmetrical. Digital SLR cameras (Canon, Tokyo, Japan) with long telephoto lenses (100–400 mm zoom) were used by the survey team to take sharp, up-close photographs of dolphins as they surfaced.

All images taken were first examined in the field, and those containing potentially identifiable individuals were sorted out. These photographs were then examined in detail and compared with those in the PRE humpback dolphin photo-identification catalog. Humpback dolphins were identified by their natural markings, such as nicks, cuts, scars, and deformities on their dorsal fin and body (Jefferson and Leatherwood 1997, Jefferson 2000). Their unique spotting patterns were also used as a secondary identifying feature. All photographs of each individual were compiled and arranged in chronological order in a database, with data including the date and location of the initial sighting of the dolphin, re-sightings, associated dolphins, distinctive features, and age classes. Any new individuals were given a new identification number, and their data were also added to the catalog.

Survey data analyses

Distribution Line-transect survey data were integrated with a desktop Geographic Information System (GIS) using ArcView® 3.1 (ESRI, California, USA) to visualize and interpret dolphin distribution in WPRE and EPRE. Location data of dolphin groups (both on-effort and off-effort, collected in all sea states) were plotted on map layers of the

PRE to examine distribution patterns during the entire study period and between the wet and dry seasons. The seasons described in this paper were defined as follows: wet season (April through September), and dry season (October through March). This classification is based on the amount of rainfall in the PRE region, which is directly linked to the volume of freshwater outflow, and levels of water salinity and turbidity. These factors were found by Hung (2008) to be significantly associated with the monthly fluctuations in humpback dolphin densities in this region.

Abundance and density estimation Line-transect analysis methods were used to estimate dolphin abundance and density (Buckland et al. 2001). Survey effort conducted on each survey day was used as the sample, thereby providing some measure of independence even when surveys were conducted on successive days. Only dolphin sightings and effort data collected during sea states 0–3 with good visibility and no heavy rain were used for the abundance and density estimation (Jefferson 2000).

The following formulae were used to estimate density, abundance, and their associated coefficient of variation with the computer program DISTANCE Version 3.5 (Thomas et al. 2010):

$$\hat{D}=\frac{\mathrm{n}\,\hat{f}(0)\hat{E}(s)}{2L\hat{g}(0)}$$

$$\hat{N}=\frac{\mathrm{n}\,\hat{f}(0)\hat{E}(s)\,A}{2L\hat{g}(0)}$$

$$C\hat{V}=\sqrt{\frac{\hat{\mathrm{var}}(\mathrm{n})}{\mathrm{n}^2}+\frac{\hat{\mathrm{var}}[\hat{f}(0)]}{[\hat{f}(0)]^2}+\frac{\hat{\mathrm{var}}[\hat{\mathrm{E}}(s)]}{[\hat{\mathrm{E}}(s)]^2}+\frac{\hat{\mathrm{var}}[\hat{g}(0)]}{[\hat{g}(0)]^2}}$$

where D=density (of individuals), n=number of on-effort sightings, $f(0)$=trackline probability density at zero distance, $E(s)$=unbiased estimate of average group size, L=length of transect-lines surveyed on effort, $g(0)$=trackline detection probability at zero distance, N=abundance, A=size of the survey area, CV=coefficient of variation, and var=variance.

The most distant sightings were truncated to remove outliers and accommodate modeling. Truncation distances for the EPRE and WPRE survey areas were 400 m and 420 m, respectively, which resulted in the lowest variance for the resulting estimate of $f(0)$. Three statistical models, uniform, half-normal, and hazard rate, were used to fit curves to the perpendicular distance data. The model with the lowest value of Akaike's Information Criterion (AIC) was chosen and used in calculation of density and abundance. For most estimates, the hazard rate model with a cosine adjustment was chosen for estimating $f(0)$. The expected value of cluster size was computed by regression of $\log(s(i))$ on $g(x(i))$ unless regression was non-significant compared against a significance level of 0.15. Variance of n was computed by empirical estimation from the sample, and the maximum likelihood estimate (MLE) was used for variance of $f(0)$.

To minimize bias and maximize precision in making the estimates of density and abundance, a strategy of selective pooling and stratification was adopted. For example, the trackline probability density, $f(0)$, can vary between WPRE and EPRE, particularly when the surveys were conducted during different years. And as both areas yielded over 60 dolphin sightings, the minimum sample size for modeling $f(0)$ suggested by Buckland et al. (2001), data from EPRE and WPRE were stratified to estimate different $f(0)$ values for these areas. Finally, based on information about dolphin group dive time and independent observer data from previous Hong Kong surveys (Jefferson 2000), the detection probability ($g(0)$) for the present study was assumed to be 1.0, with all survey techniques held constant.

Individual movements Location data of each individual dolphin in the PRE were obtained from the sighting database and photo-identification catalog to examine individual movements. Individual ranges and movement patterns were examined by plotting all sighting locations of each cataloged individual from 1995 to 2009 on a desktop GIS (ArcView® 3.1), to determine whether individuals were found across different survey areas. Because the current study collected both line-transect surveys and photo-identification data, we were able to examine individual movements within the entire study area, as most of the survey transect lines were drawn in a systematic manner (i.e., the survey teams searched for dolphins throughout the entire study area rather in just the high concentration areas). Thus, the photo-identification data collected during this study should reflect more the actual ranges and movements of individual dolphins in an unbiased manner.

Results

Survey effort and dolphin sightings

From the two sets of 12-month surveys during 2005–2008, a total of 4961 km and 4857 km of line-transect survey effort were conducted in the EPRE and WPRE, respectively. Most of the survey effort (71%) was conducted under favorable sea conditions (sea state 3 or below with good visibility), which were used in the line-transect analysis to estimate density and abundance. From these surveys, 364 groups of humpback dolphins, numbering 1969 individuals, were sighted and the majority of the sightings were made during on-effort search.

Distribution

Dolphins occurred throughout all six survey areas in both wet and dry seasons (Figure 2). Among the four survey areas in EPRE, dolphins were found distributed from Humen in the north, to the coastal waters between Zhuhai and Macau in the west, to Guishan Island in the southeast, and to Hengqin Island in the southwest. Dolphin sightings were generally absent from the very shallow coastal waters near the mouth of Humen, and from Humen to Qiao Island. In WPRE, dol-

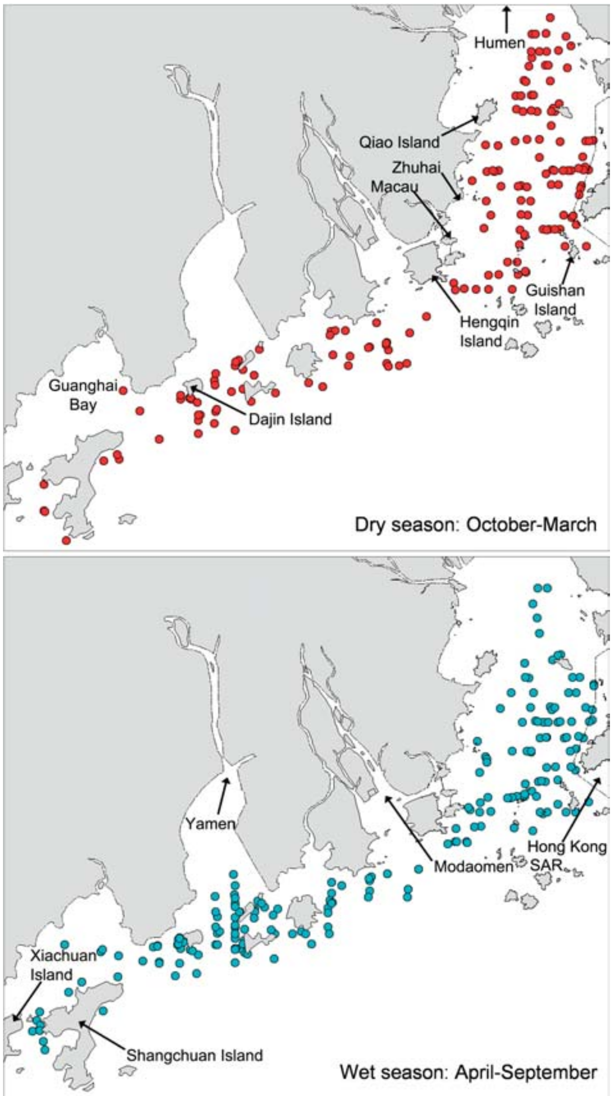

Figure 2 Distribution of humpback dolphin sightings in the Pearl River Estuary during dry season (October–March) and wet season (April–September) in 2005–2008.

phin sightings were made throughout the survey areas of HMS and SCI, extending from the mouth of Modaomen in the east, to the channel between Shangchuan and Xiachuan islands in the west. Notably, dolphins were rarely sighted in the deeper offshore waters (nearly 20 m deep) in the south and the shallow coastal waters near the mouth of Yamen and Modaomen (less than 3 m deep). They also appeared to occur only in estuarine waters that are at least seasonally influenced by discharge from the Pearl River.

A small area between the WPRE and EPRE was not covered during either of the two sets of surveys in 2005–2008. However, humpback dolphins were consistently sighted near the southwest boundary of the MA survey area and the northeast boundary of the HMS survey area, implying that dolphins were most likely to occur in this small area (Figure 2). In addition, several dolphin sightings were made near the western end of the SCI survey area. Therefore, dolphin distribution probably extends west to and beyond the adjacent waters around Xiachuan Island.

Seasonal variations in dolphin distribution in EPRE and WPRE were evident (Figure 2). In EPRE, dolphins were rarely sighted in NLDB during the wet season, when most sightings were made in southern portion of Lingding Bay (i.e., SLDB and MA). Dolphin sightings also appeared to be more evenly spread across EPRE during the dry season. On the contrary, more dolphins were observed in the inshore waters of WPRE in the wet season, whereas dolphins appeared to shift slightly offshore during the dry season. In addition, more dolphins were found in the mouth of Yamen, and the channel between Shangchuan and Xiachuan islands during the wet season.

Abundance and density estimates

Abundance and density estimates of humpback dolphins in EPRE and WPRE were calculated using 7024.7 km of survey effort and 278 on-effort sightings collected during sea states 0–3. These estimates and their associated parameters from the various survey areas for wet and dry seasons are shown in Table 1.

Dolphin densities varied noticeably among different survey areas in EPRE and WPRE. The highest density area in both wet and dry seasons was the MA survey area (111–136 individuals/100 km^2), and both survey areas in HMS and SLDB also recorded relatively high dolphin densities (>60 individuals/100 km^2). In contrast, NLDB survey area recorded the lowest dolphin densities in both wet and dry seasons (22–45 individuals/100 km^2). Abundance and density estimates also varied between the wet and dry seasons among other survey areas. Significant differences in abundance estimates were detected between wet and dry seasons among the survey areas of NLDB, SLDB, and HMS (two-tailed t-test, $p<0.05$) but not for the other three survey areas.

Overall, the total dolphin abundance estimates for the EPRE and WPRE areas were 1052 and 1503 individuals during the wet season, and 1273 and 1244 individuals in the dry season, respectively. Considering the dolphins of EPRE and WPRE to be the same population (see discussion below), the total population size for the PRE would be 2555 in the wet season and 2517 in the dry season. However, it should be noted that only the abundance estimate for the HMS survey area during the wet season had a relatively high level of statistical precision (CV=19%), whereas for other survey areas CVs varied from 28% to 89%.

Individual movements

During the period of 1995–2009, 655 individual humpback dolphins were identified in the PRE, including the waters of Hong Kong SAR. Of these, 211 individuals were first identified in survey areas of EPRE, and another 136 individuals (mostly seen only once or twice) were first identified in survey areas of WPRE. Nearly half of the 655 identified individuals were sighted in the waters of Hong Kong exclusively, probably as a result of the disproportionate amount of survey effort there compared with Chinese mainland waters (Hung

Table 1 Estimates of abundance and associated parameters for humpback dolphins in different survey areas in the Pearl River Estuary.

Survey area	Season	Survey days	*L* (km)	n	*f*(0) (km^{-1})	*E*(*s*)	*D* (100 km^{-2})	*N*	CV (%)
North Lingding Bay									
(403.81 km^2)	Wet	7	349.8	4	7.25	5.25	21.77	88	88.62
	Dry	7	376.1	15	7.25	3.13	45.31	183	39.34
Central Lingding Bay									
(463.74 km^2)	Wet	17	677.5	19	7.25	5.47	55.65	258	33.78
	Dry	15	590.7	19	7.25	4.42	51.56	239	35.54
South Lingding Bay									
(515.68 km^2)	Wet	17	662.5	35	7.25	4.14	79.35	409	30.77
	Dry	18	522.1	29	7.25	4.69	94.44	487	27.56
Macau									
(267.96 km^2)	Wet	7	405.9	19	7.25	6.53	110.76	297	34.63
	Dry	6	216.4	13	7.25	6.23	135.71	364	55.63
Huangmao Sea									
(1335.32 km^2)	Wet	16	1214.9	67	5.46	6.12	92.04	1229	18.78
	Dry	19	823.7	33	5.46	5.73	62.60	836	29.52
Shangchuan Island									
(861.72 km^2)	Wet	12	788.6	17	5.46	5.41	31.83	274	29.19
	Dry	9	396.5	8	5.46	8.60	47.33	408	54.98

Symbols used: *L*, total length of transect surveyed; n, number of on-effort sightings; *f*(0) trackline probability density; *E*(*s*), unbiased mean group size; *D*, individual density; *N*, individual abundance; and CV, coefficient of variation.

and Jefferson 2004, Hung 2008). At least 67 individuals occupied ranges spanning both Lingding Bay and Hong Kong waters, which is evidence of frequent cross-boundary movements of many individuals.

Among the 136 individuals identified in WPRE during the 2007–2008 surveys, three of them were also sighted in survey areas of EPRE. Another 41 individuals also occurred near the boundary line between survey areas of EPRE (i.e., southwestern section of MA) and WPRE (i.e., northeastern section of HMS), providing further evidence that some individuals can regularly move across EPRE to WPRE. Notably, all three individuals that moved between WPRE and EPRE were seen in EPRE at the peak of the wet season (i.e., July), but in WPRE only in the dry season. In addition, the majority of individuals (85%) that occurred near the boundary between WPRE and EPRE were also sighted there during the wet season (mostly from June to August), implying that individuals known from WPRE and EPRE can mostly intermingle during the peak of the wet season.

Discussion

Distribution and population discreteness

The present study is the first to provide important information on distribution and abundance of humpback dolphins residing in WPRE, as well as updated information on dolphins from EPRE. The results confirmed previous speculations that dolphins also occur extensively in WPRE which is influenced by the freshwater discharge from the western four exits of the Pearl River. Although limited, photo-identification data revealed some exchange of individual dolphins between EPRE and WPRE. Because the two areas are connected with no physical barrier to the movement of dolphins, there is no reason to believe that the dolphins are incapable of moving between these areas freely or that the dolphins represent more than one population.

Although the present study suggested a low level of exchange of dolphins from the two areas (with only three individuals sighted in both WPRE and EPRE), this is probably as a result of limited data as well as the two sets of surveys in EPRE and WPRE being conducted in different years. More photo-identification work should be conducted from both areas concurrently, particularly in waters between the boundaries of the MA and HMS survey areas, to determine individual movement patterns in the PRE. If the level of exchange between WPRE and EPRE system is confirmed to be low, it is possible that some structuring within the population could exist. DNA analysis of skin tissues collected from known individuals using biopsy sampling can also be used to examine population structure and level of gene flow between regions (see examples in Hoelzel et al. 1998, Harlin et al. 2003), with minimal intrusiveness to the dolphins when conducted carefully by experienced researchers (Jefferson and Hung 2008).

Results from this study also supported previous findings that PRE humpback dolphins are only distributed in coastal estuarine waters (Jefferson 2000, Hung 2008). Humpback dolphins distributed along the coastal waters of China were often bound to estuarine waters (Zhou et al. 1995, Jefferson and Hung 2004), whereas distribution of the same species in Goa, India, was also either coastal or associated with estuaries (Parsons 1998b). This restricted distribution might be related to the distribution of their prey, as large amounts of prey found in stomach contents in PRE humpback dolphins, including bottom-dwelling species (e.g., Sciaenidae) and typically pelagic fishes (e.g., Engraulidae, Clupeidae), are associated with the productive waters of estuaries (Barros et al. 2004).

Humpback dolphins in both WPRE and EPRE displayed distinct seasonal variations in distribution. It is generally believed that seasonal variations in cetacean distribution is often linked to seasonal availability of their prey (Forcada 2002), and fish distribution in subtropical estuaries can be strongly affected by different environmental parameters such as temperature, salinity, and turbidity (Blaber 1997). In Hong Kong, monthly fluctuations in dolphin densities were significantly associated with several hydrological parameters including temperature, salinity, and water clarity, but their effects appeared secondary to food availability (Hung 2008). Therefore, seasonal shifts in dolphin distribution observed in the present study also probably corresponded with seasonal movements of their prey in the PRE. This relationship can be further examined with collection of additional data on prey resources.

Abundance

In the present study, we provided estimates of dolphin density and abundance in WPRE and EPRE for wet and dry seasons instead of the four solar seasons. Previously, estimates of density and abundance of humpback dolphins were stratified by four seasons (Jefferson 2000, 2007, Jefferson and Hung 2004). However, defining four seasons for this region using climatic parameters such as rainfall and temperature is difficult. Instead, local ecologists consider it more appropriate to divide the year into wet and dry seasons (Dudgeon and Corlett 2004). The present seasonal stratification strategy should better reflect seasonal shifts in different areas within WPRE and EPRE as well as the hydrological characteristics and prey distribution within the PRE system. This is supported by the similar population estimates that were obtained between wet and dry seasons from the overall PRE area. Such stratification into wet and dry seasons should be adopted for future studies on seasonal patterns of distribution and abundance of PRE humpback dolphins.

Notably, this study generated the first preliminary estimate of the dolphin abundance in the PRE region that is influenced by all eight drainages of the Pearl River. This has filled a critical information gap by providing abundance estimate of dolphins residing in WPRE. Although the estimate should still be considered preliminary owing to the relatively low precision (i.e., high coefficients of variation) in some survey areas, the population size of around 2500 dolphins residing in the entire PRE should serve as an important baseline for future estimates of dolphin population abundance. The remarkably similar abundance estimates from both wet and dry seasons also imply that the current study area might have covered most of the entire known range of PRE humpback dolphins, and seasonal shifts out of this study area probably occur at a low level. Future studies should focus on refining this estimate with collection of additional long-term line-transect survey data in both WPRE and EPRE areas, as well as generating estimates from the survey areas in Hong Kong waters during wet and dry (instead of four) seasons.

Although the current study area has extended survey coverage to the large area west of Lingding Bay, several dolphin sightings were made near the western end of the SCI survey area. It appears likely that the western range of the PRE humpback dolphin population extends west of the current WPRE area, although the influence of Pearl River is greatly diminished beyond the waters west of SCI. Anecdotal records suggested that humpback dolphins also occurred around the estuary of Moyangjiang River near Yangjiang City (SCSFRI unpublished data), which is approximately 60 km west of SCI. It is possible that the dolphins reported from this estuary also belong to the same population as the PRE humpback dolphins, or represent another isolated population, as suggested by Jefferson (2000). At present, the eastern boundary of the PRE dolphin population has been clearly defined within Hong Kong waters (Hung 2008). But owing to the uncertainty of the western boundary of the dolphin population, the current abundance estimate should not be treated as the total abundance of the biological population. Future research should include additional line-transect surveys and photo-identification work in the waters west of the current WPRE area, preferably extending to the Moyangjiang River Estuary. This will help to determine the western range and total abundance of the PRE humpback dolphin population. Moreover, some surveys should be conducted in deeper waters beyond the 20-m isobath to examine the possibility of offshore movements of dolphins outside the current study area.

Currently, there is no overall estimate of total abundance of the species (Reeves et al. 2008), and abundance and densities were only estimated in a few places, using either line-transect analysis or mark-recapture analysis of photo-identification data. Abundance estimates have been generated for three other areas in Chinese waters, including Xiamen (67–93 individuals; CVs=25–42%; Chen et al. 2008), Leizhou Bay [237 individuals; 95% confidence intervals (CIs)=189–318; Zhou et al. 2007], and the west coast of Taiwan (99 individuals; CV=52%; Wang et al. 2007). In Australia, abundance estimates were only available in Cleveland Bay (34–54 individuals; CVs=13–27%; Parra et al. 2006) and Moreton Bay, Queensland (119–163 individuals; 95% CIs=81–251; Corkeron et al. 1997). In South African waters, abundance estimates were generated in Algoa Bay region in Eastern Cape coast (450 individuals; 95% CIs=447–485; Karczmarski et al. 1999) and Richard's Bay region on the KwaZulu-Natal coast (170–244 individuals; Atkins and Atkins 2002). Further north, estimates of humpback dolphin abundance were 105 dolphins in Maputo Bay, Mozambique (95% CIs=30–141; Guissamulo and Cockcroft 2004), 58–65 dolphins off Zanzibar (95% CIs=56–102; Stensland et al. 2006), and 131–902 dolphins in the southern and western Arabian Gulf (Preen 2004). When compared with these other populations of humpback dolphins, the PRE population with over 2500 individuals (CVs=19–89%) is by far the largest known population within the species' range. Given the conservation status as a *Near Threatened* species according to the IUCN Red List of Threatened Species (Reeves et al. 2008), the PRE humpback dolphin population certainly deserves important conservation attention, particularly given the increasing industrial development pressures within the population's range. Thus, monitoring the trend in abundance of the PRE population for any decline in dolphin numbers should be a future high priority focus.

Conservation issues

Several threats have been identified for dolphins residing in Hong Kong waters, including water pollution, depletion of food resources, incidental catch, collision with vessel traffic, underwater noise, as well as coastal development activities such as reclamation, dredging and filling, and underwater piling (Leatherwood and Jefferson 1997, Jefferson 2000, Parsons and Jefferson 2000, Würsig et al. 2000, Ng and Leung 2003, Parsons 2004, Jefferson et al. 2006, 2009, Hung 2008). These threats can also be found throughout the Pearl River Delta region, threatening the future survival of the PRE humpback dolphin population.

In the near future, the 35-km long Hong Kong–Zhuhai-Macau Bridge (HZMB) will be built across the central portion of Lingding Bay, or the main distribution area of dolphins residing in EPRE. This infrastructure project, which will involve the construction of a 6-km underwater tunnel, several hundred supporting bridge piles and reclamation of several artificial islands (occupying nearly 4 km^2 of sea area), will undoubtedly exert additional pressure on the survival of the PRE dolphins. Continuous monitoring of the dolphin distribution and abundance before, during, and after the HZMB construction project will be crucial for assessing and understanding the effectiveness of various proposed mitigation measures, and to determine the impact of the bridge construction on the dolphin population. Moreover, the WPRE should also be monitored during the bridge construction, to determine whether dolphins will shift their distribution from EPRE to WPRE during construction and increasing amount of habitat loss and degradation and noise in Lingding Bay.

For the conservation of humpback dolphins, a national marine nature reserve (460 km^2) was established in Lingding Bay in 2003 (Qiu et al. 2009), and another provincial nature reserve (107 km^2) around Dajin Island in HMS was recently created. In Hong Kong, a small marine protected area (the Sha Chau and Lung Kwu Chau Marine Park; 12 km^2) was also established for the protection of dolphin habitats (Hung 2008). The effectiveness of these nature reserves for conserving relatively highly mobile animals such as these dolphins is questionable because the adopted conservation measures for protecting dolphins could still be inadequate (Qiu et al. 2009). There is a clear need to review the performance of these marine protected areas and develop a comprehensive dolphin conservation plan, to cope with the challenges of increasing conflicts between rapid development and dolphin conservation in the Pearl River Delta region.

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