Long-term Monitoring of Population Dynamics of Chinese White Dolphins (*Sousa chinensis*) in Lingding Bay of the Pearl River Delta Region: the Third Stage

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Executive summary

The 2024–25 project, extending the 2017–18 and 2018–19 monitoring programmes for Chinese White Dolphins (CWD; *Sousa chinensis*) in Lingding Bay of the Pearl River Delta region, undertook an one-year vessel-based survey to update population parameters, spatial distribution, and individual ranging patterns. The survey covered four principal strata—Central Lingding Bay (CLDB), South Lingding Bay (SLDB), the Macau sector (MA), and South-west Macau (SWMA)—and combined line-transect sampling with photo-identification to compare the new results with previous cycles and to evaluate changes in habitat use.

Between July 2024 and June 2025, ten systematic line-transect surveys were completed, yielding 3,879.6 km of on-effort coverage—comparable to the effort in 2017–18 (3,882 km) and 2018–19 (3,856 km). A total of 197 dolphin groups (1,019 individuals) and four finless-porpoise groups (12 individuals) were recorded. Abundance was estimated at 640 dolphins, markedly lower than the pandemic-related peak of 1,160 individuals in 2020–21 and the 2017–18 figure of 862 individuals, yet slightly above the 2018–19 estimate of 611. Pronounced spatial heterogeneity was evident: densities were highest in MA (64.31 dolphins 100 km^{-2}) and SLDB (60.27 dolphins 100 km^{-2}) and lowest in CLDB (25.25 dolphins 100 km^{-2}). Such fluctuations appear linked to large-scale climatic variability and shifting anthropogenic pressures (shipping intensity, fishing effort, etc.). The short-lived rebound in dolphin abundance and calf proportion during the 2020–21 COVID-19 shutdown, followed by a rapid decline as human activities resumed, underscores the dolphins' acute sensitivity to short-term environmental change.

Mean group size in 2024–25 was 5.32 ± 5.19 dolphins, marginally higher than in 2018–19 (5.13 ± 4.78), 2017–18 (4.86 ± 4.59) and 2005–06 (4.80 ± 4.91). Calves represented 6.15 % of all individuals—well below both 2018–19 and 2017–18 levels and only half of the 12.36 % recorded in 2005–06—indicating limited recent recruitment. Feeding

and social groups accounted for 38.1 % and 5.7 % of sightings, respectively, considerably lower than the proportions in 2018–19 (52.9 % and 8.6 %) and 2017–18 (74.4 % and 10.1 %), suggesting short-term limitation in prey availability or heightened disturbance in core use areas.

Photo-identification of more than 41,000 images yielded 447 individually recognisable dolphins; approximately 136 of these were resighted on at least two different occasions or in multiple locations, contributing 314 resighting records, whereas the remaining 69.57 % (311 individuals) were photographed only once. These data reveal cross-strata ranging and persistent hotspots. Habitat-use mapping indicates that the western coastal corridor, extending from south-eastern Qi'ao Island to the Qingzhou–Sanjiaoshan Islands, now supports the highest encounter frequencies and densities, whereas the eastern and central bay sectors have declined in importance.

Overall, the project achieved its objectives, providing critical information on abundance dynamics, spatial utilisation and age composition of dolphins in Lingding Bay. Continued monitoring of both the eastern and western Pearl River Estuary, augmented by passive acoustics, prey-resource assessments and a trans-boundary photo-ID database, is essential to understand long-term effects of climate change and human activities on dolphin habitat and recruitment. Enhanced noise management and fisheries regulation in the high-density western corridor, together with rigorous assessment of new offshore developments, are recommended to secure the long-term viability of the CWD population and the sustainable use of its habitat.

Project title and brief description of the Project

Long-term Monitoring of Population Dynamics of Chinese White Dolphins (*Sousa chinensis*) in Lingding Bay of the Pearl River Delta Region: the Third Stage

As a continuation of the Chinese White Dolphins (CWD) monitoring projects conducted during 2017-2018 and 2018-2019, this study aims to conduct another year-long vessel-based dolphin monitoring programme in Lingding Bay (LDB) of the Pearl River Delta region, with the purpose of examining the latest population parameters such as their abundance, distribution pattern and age composition, as a comparison to past monitoring results especially in recent years. Individual ranging patterns will be examined using photo-ID technique based on the combined photo-ID database collected from Lingding Bay. The fine-scale habitat use of CWD in LDB (including temporal changes in recent years) will also be investigated for a better understanding of the important habitats utilized by the dolphins. Appropriate management and conservation strategies could be derived and will be presented to relevant authorities for better implementation of conservation measures for the Pearl River Estuary CWD population.

1 Introduction

The Chinese White Dolphin (CWD; *Sousa chinensis*) is widely distributed along the coasts of the western Pacific and eastern Indian Oceans, yet its largest known population occurs in the Pearl River–Moyang River estuarine system (PRE–MRE) of southern China (Li et al., 2019; Chen et al., 2010). Current records indicate that this population ranges from the waters of North and West Lantau in Hong Kong westward across the Pearl River Estuary to the east coast of Hailing Island at the mouth of the Moyang River, Yangjiang City. Within this continuum, Lingding Bay (LDB)—which spans the territorial waters of Hong Kong and Macao—forms the demographic and ecological core of the population and therefore warrants particular conservation attention.

The LDB, however, adjoins one of the world’s most densely populated coastal corridors. Decades of land reclamation, port expansion, and offshore-wind-farm development have removed or fragmented key near-shore habitats. Additional pressures—including fishing by-catch, ghost gear entanglement, high-speed vessel traffic, underwater noise, and climate-driven changes in prey availability—further erode habitat quality and threaten population viability. Given the scale and persistence of these threats, long-term, spatially explicit monitoring is indispensable for detecting temporal changes in abundance, distribution, and habitat use and for guiding adaptive management of the PRE–MRE CWD population.

Systematic vessel-based surveys of CWD in Lingding Bay have been conducted by the South China Sea Fisheries Research Institute (SCSFRI) since 1997, providing a multi-decadal archive of data on distribution, abundance, individual ranging patterns, and habitat use. Within this long-term programme, two consecutive annual surveys carried out in 2017–18 and 2018–19—funded by the Marine Ecology Enhancement Fund (MEEF)—produced the most recent pre-pandemic assessments and refined knowledge of cross-boundary movements and fine-scale habitat preferences. Analyses of the full time series show substantial inter-annual fluctuations in abundance, with the 2017–19 estimates falling within the mid-range of recorded values. Despite this variability, cumulative anthropogenic pressures—ghost fishing gear, high-speed vessel traffic, underwater noise, coastal development, and climate change—continue to erode habitat quality and may affect prey availability, movement patterns, and home-range size. Consequently, two years of intensified monitoring are inadequate to characterise population dynamics against a backdrop of persistent environmental change; sustained, long-term surveillance remains indispensable.

The 2024–25 project represents a further extension of the 2017–18, 2018–19, and earlier monitoring initiatives. Focusing on the principal distributional strata of CWD in LDB—namely CLDB, SLDB, MA, and SWMA—the project implemented an additional year-long, vessel-based survey programme. Line-transect sampling and photo-identification techniques were employed to collect new data that can be integrated with two decades of historical records, thereby enabling robust assessment of long-term trends in abundance, habitat use, and individual ranging behaviour throughout the PRE region. Ultimately, the findings will inform evidence-based management recommendations for governmental and regulatory bodies.

Objectives of the 2024–25 project

1. **Population dynamics** – Update and compare current distribution, abundance, and age composition of CWD in each survey area with previous monitoring results (2005–06, 2017–18, 2018–19, 2020-21) to evaluate long-term temporal trends.

2. **Individual ranging patterns** – Analyse photo‑identification data to elucidate long‑term movement and home-range characteristics of individual dolphins within LDB.

3. **Fine‑scale habitat use** – Quantify spatial and temporal variation in habitat utilisation, thereby identifying critical areas and shifts in habitat importance.

4. **Management recommendations** – Provide science-based guidance on conservation and management strategies to relevant authorities to enhance protection of the PRE CWD population.

2 Work schedule

The project generally progressed well according to the proposed schedule, with an approved extension for one month for the final report submission, and some necessary adjustments for the field surveys.

Time	Proposed activities	Completed activities
July 2024	Preparation for line-transect vessel surveys	Done accordingly
August 2024	1st line-transect vessel survey, individual identification	Done accordingly
September 2024	2nd line-transect vessel survey, individual identification	Done accordingly
October 2024	3rd line-transect vessel survey, individual identification	Done accordingly

November 2024	**4th line-transect vessel survey; individual identification; submit interim report**	**Sea state unsuitable – survey deferred to Dec 2024. Interim report filed Dec 2024.**
December 2024	**4th line-transect vessel survey; individual identification**	Done accordingly
January 2025	5th line-transect vessel survey; individual identification	Done accordingly
February 2025	6th line-transect vessel survey; individual identification	Done accordingly
March 2025	7th line-transect vessel survey; individual identification	Done accordingly
April 2025	**8th line-transect vessel survey; individual identification submit 1-month no-cost extension request**	**Survey completed. Extension requested Apr 2025.**
May 2025	9th line-transect vessel survey; individual identification.	Done accordingly
June 2025	**10th line-transect vessel survey; begin data collation & statistical analyses (density, abundance, movement, habitat use). Extension approved Jun 2025.**	**10th survey completed 11 Jun 2025; raw data archived; statistical analyses under way; extension approved Jun 2025**
Jul 2025 (extension ends 31 Jul)	**Finalize analyses; draft & submit completion report to MEEF by 31 Jul 2025; address any immediate feedback**	**Completion report submitted 31 Jul 2025**

3 Methodology

3.1 General approach

The systematic line-transect survey data were utilized to calculate the latest abundance estimates and densities of CWD in LDB, which were then compared to the 2017-18, 2018-19 and other monitoring results collected by SCSFRI, to examine any temporal changes in population dynamics.

Photo-identification was carried out concurrently with the line-transect vessel surveys to document individual dolphins and to track their movements within Lingding Bay. For the 2024–25 period, newly acquired images were matched exclusively against a reference catalogue compiled from Lingding Bay surveys conducted over the past decade; no cross-boundary comparison with Hong Kong photo-ID datasets was undertaken. Consequently, the present analysis focuses on intra-bay ranging patterns, while inferences about trans-boundary movements remain based on earlier, inter-annual studies.

Using the analytical method of fine-scale grid analysis, the habitat use of CWD was examined in details, which could establish the importance of dolphin habitats at various locations of Lingding Bay, and identify the critical dolphin habitats with conservation importance.

3.2 Study areas

Lingding Bay in the Pearl River Estuary has been surveyed under a fixed, six-stratum design since 1997, comprising North Lingding Bay (NLDB), Central Lingding Bay (CLDB), South Lingding Bay (SLDB), Macau (MA), Southwest Macau (SWMA), and the western waters to Aizhou Island (AZ). The 2017–18 and 2018–19 monitoring cycles, both supported by MEEF funding, covered all six strata to establish a spatially comprehensive baseline.

For the 2024–25 programme, financial constraints required a reduction in spatial scope. We therefore retained the four strata that historically support the highest densities of CWD—CLDB, SLDB, MA, and SWMA (Figure 1)—while omitting NLDB and AZ, where earlier surveys recorded consistently lower encounter rates. The original transect network was maintained within the remaining strata to preserve methodological continuity and ensure comparability with the historical dataset. Collectively, the four surveyed strata still encompass the core distributional range of the species in Lingding Bay, allowing robust assessment of temporal changes in abundance, habitat use, and ranging behaviour.

3.3 Line-transect vessel surveys

A series of parallel transect lines, perpendicular to the major coastlines in the study area, were placed every ~3 km apart in each survey area. These transect lines are designed to cover the survey area evenly and to provide representative coverage throughout different sections of Lingding Bay. A total of 10 sets of line-transect surveys were completed during the 13-month study period, with one set per month from July 2024 to June 2025.

A shrimp trawler (*Yuezhongyu* 18181) which has an open upper deck with relatively unrestricted visibility was used to conduct all line-transect vessel surveys for the present study. The survey vessel transited through different transect lines at a constant speed of 13–15 km/h. Observations were made from the flying bridge area, which is 4–5 m above sea level, and in acceptable weather condition (Beaufort 0-5, no heavy rain, and visibility >1,200 m). However, only the monitoring data collected in calm conditions of Beaufort 0-3 were included in the line-transect analysis for calculating estimates of dolphin density and abundance as well as examining dolphin encounter rates and their habitat use patterns.

To ensure methodological consistency, the 2024–25 surveys were conducted by the same SCSFRI observer team that carried out the 2017–18 and 2018–19 campaigns. During on-effort operations, a two-person team—comprising a primary observer and a data recorder—searched continuously between 270° and 90° relative to the vessel's bow (0°). The primary observer scanned for marine mammals, chiefly CWD but also Indo-Pacific finless porpoises, using 7 × 50 marine binoculars, while the data recorder searched with the unaided eye and completed the datasheets. Two to three additional observers were available on board to work in rotation; observers switched roles approximately every 30 minutes and were given a break after each hour of effort to minimise fatigue.

Effort data collected during on-effort survey periods included time and position for the start and end of search effort, vessel speed, sea state (in Beaufort scale), visibility, and distance travelled in each series (a continuous period of search effort). When dolphins were sighted, the team went off-effort and the vessel was diverted from its course to approach the dolphin group for group size estimation, assessment of group composition, behavioural observations, and collection of identification photos. Age composition of each dolphin group among different survey area was examined based on their colour patterns. The data recorder filled out a sighting sheet, which includes information on time, initial sighting angle and distance, position of initial sighting, sea state, group size and composition, activities, and behaviour (e.g. response to the survey vessel, any associations with fishing vessels). Position, distance travelled, and vessel speed were obtained from a hand-held GPS.

3.4 Photo-identification and individual ranging patterns

When a group of CWD was sighted during the line-transect survey, the team went off-effort and approached the dolphin group slowly to photograph and identify individuals. Two autofocus digital cameras (Canon 1D and 1DX), each equipped with long telephoto lens (100-400mm zoom) and digital data recorder to record date and time for each frame, were used by the survey team to take sharp, up-close photographs of dolphins as they surface in order to capture their natural markings. Every attempt was made to photograph each dolphin in the group, even those that appeared to have no unique markings. Both the left and right sides of the dolphins were photographed if possible, since the natural markings of the two sides are not symmetrical.

All images containing potentially identifiable individuals were sorted out for photo-identification. 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 was also added to the photo-identification catalogue curated by scsfri the PRE CWD population.

Location data of each individual dolphin identified in the Lingding Bay were obtained from the dolphin sighting database and photo-identification catalogue to examine individual movements and range use. Individual ranges and movement patterns were examined by plotting all sighting locations of each cataloged individual (including the ones identified in the past surveys) on a desktop GIS (ArcView© 3.1), to determine whether any individuals have been found across different survey areas, and to examine individual movements within the entire study area.

3.5 Dolphin distribution pattern

The line-transect survey data were integrated with Geographic Information System (GIS) in order to visualize and interpret different spatial and temporal patterns of dolphin distribution using their sighting positions collected under the present study period. Location data of dolphin group were plotted on map layers of Lingding Bay using a desktop GIS (ArcView© 3.1) to examine their distribution patterns during the entire study period.

3.6 Encounter rate analysis

The encounter rates of CWD (including the number of on-effort sightings per 100 km of survey effort and total number of dolphins per 100 km of survey effort) were calculated in each survey area and during different study periods in relation to the amount of survey effort conducted. The encounter rate can be used as an indicator to determine areas of importance to dolphins within the study area.

3.7 Abundance and density estimation

Density and abundance of CWD were estimated by line-transect analysis using systematic line-transect data collected from the present study. Survey effort conducted on each survey day was used as a single sample, thereby providing some measure of independence even when surveys were conducted on successive days. Estimates were calculated from dolphin sightings and effort data collected during conditions of

Beaufort 0-3 (Jefferson 2000). The following formulae were used to estimate density, abundance, and their associated coefficient of variation with the computer program DISTANCE Version 6.0 (Thomas et al. 2009):

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

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

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

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, Assize of the survey area, CV=coefficient of variation, and var=variance.

3.8 Habitat usage analysis

Quantitative grid analysis of habitat use (see Hung 2008) was conducted using positions of on-effort sightings of CWD and survey effort from the present study. Sighting densities (number of on-effort sightings per km^2) and dolphin densities (total number of dolphins from on-effort sightings per km^2) were then calculated for each 1 km by 1 km grid with the aid of GIS. Sighting density grids and dolphin density grids were further normalized with the amount of survey effort conducted within each grid. The total amounts of survey effort spent on each grid were calculated by examining the survey coverage on each line-transect survey to determine how many times the grid has been surveyed during the study period. For example, when the survey boat traversed through a specific grid 10 times, 10 units of survey effort are counted for that grid. With the amount of survey effort calculated for each grid, the sighting density and dolphin density of each grid were then normalized (i.e. divided by the unit of survey effort).

Two parameters were used to quantify the usage of the habitat. The sighting density was termed SPSE, representing the number of on-effort sightings per 100 units of survey effort. In addition, the dolphin density was termed DPSE, representing the number of dolphins per 100 units of survey effort. Among the 1-km2 grids that are partially covered by land, the percentage of sea area was calculated using GIS tools, and their SPSE and DPSE values were adjusted accordingly. The following formulae were used to estimate SPSE and DPSE in each 1-km2 grid within the study area:

$$SPSE = ((S / E) \times 100) / SA\%$$

$$DPSE = ((D / E) \times 100) / SA\%$$

where S = total number of on-effort sightings

D = total number of dolphins from on-effort sightings

E = total number of units of survey effort

SA% = percentage of sea area

The SPSE/DPSE values for those grids that recorded survey effort were first deduced. For the grids that were not covered by the survey effort (i.e., transect lines have not covered those grids), the densities of those were estimated from the surrounding grids with deduced densities. For instance, if there were only three surrounding grids with known SPSE/DPSE values, then the average would be taken from those three grids. If there were seven surrounding grids, then the average would be taken from those seven grids with known SPSE/DPSE values. The resulting density pattern would provide a continuous gradient based on empirical data, and such pattern would give better resolution of habitat use pattern and allow direct comparison to the one in Hong Kong across the border. On the other hand, if 3×3 km grid (the vessel transects are 3 km apart in Lingding Bay) is adopted, the habitat use pattern would be too coarse and could not provide the necessary resolution to examine any change in habitat use pattern for any particular area of interest.

4 Results and discussions

4.1 Survey effort, dolphin and porpoise sightings

4.1.1 Survey effort and Beaufort sea conditions

From August 2024 to June 2025, ten monthly line-transect vessel surveys were carried out in Lingding Bay, Pearl River Estuary (Tables 1–2). The cumulative on-effort track length for the four survey strata was 3,880 km, closely matching the effort logged in 2017-18 (3,882 km) and 2018-19 (3,856 km). Effort was distributed as follows: CLDB, 1,339 km; SLDB, 1,302 km; MA, 808 km; and SWMA, 431 km. Beaufort sea conditions were highly favourable—94 % of track lines (3,661 km) were completed under Beaufort sea state ≤ 3 with good visibility—ensuring that nearly all observations qualified for inclusion in strip-transect and encounter-rate analyses.

4.1.2 Sightings of CWD

A total of 210 sightings involving 1,117 individual CWD were logged, of which 197 group encounters—comprising 1,019 individuals—were recorded on effort, the remainder being off-effort observations (Table 1). Sightings were unevenly distributed among strata, with the majority occurring in SLDB (86 encounters, 44 %), followed by MA (63, 32 %) and CLDB (46, 23 %); only two encounters were logged in SWMA (Figure 2).

4.1.3 Inter-annual comparison with previous survey cycles

Survey effort has remained effectively constant across monitoring periods, allowing direct comparison of group encounters (Figure 3). Overall, the 2024–25 field period recorded an intermediate total of 197 encounters, lower than the peak values observed in earlier years but higher than some previous troughs.

Patterns among the four survey strata differed markedly. CLDB experienced the greatest variability, peaking at 75 encounters in 2017–18 before dropping substantially to its lowest level (46) in 2024–25. SLDB showed a general increase in encounter numbers over time, reaching its maximum (98) in 2020–21 and remaining relatively high in 2024–25 (86). MA was relatively stable from 2005–06 through 2020–21 (37–49 encounters) but increased sharply to its highest level (63) in 2024–25. By contrast, SWMA consistently exhibited the lowest encounter frequencies, with a brief increase in 2020–21 (12) followed by a drop to just two encounters in 2024–25.

These patterns collectively suggest a gradual redistribution of dolphin use within Lingding Bay. Central areas (CLDB) have become less frequently used, while southern and southwestern areas, particularly SLDB and MA, now support a greater proportion of dolphin encounters. This apparent south-westward shift is likely influenced by a combination of factors, including spatial differences in anthropogenic disturbance, prey availability, and broader hydro-climatic variability, rather than a single driving force. Continued monitoring is essential for understanding the underlying causes of these changes and for informing adaptive conservation strategies.

4.1.4 Incidental records of Indo-Pacific finless porpoises (*Neophocaena phocaenoides*)

Four group encounters (12 individuals) of Indo-Pacific finless porpoises were documented in the south-eastern sector of Lingding Bay (Figure 4). Group sizes ranged from one to four animals. Although incidental to the primary dolphin survey, these observations extend the contemporary distribution records for the species within the estuary and merit targeted follow-up effort.

4.2 Dolphin distribution

4.2.1 Spatial distribution of sightings

Figure 4 depicts the point distribution of all cetacean encounters recorded during the 2024–25 survey cycle in Lingding Bay. CWD were recorded across all four survey strata; however, sightings in SWMA were comparatively rare, indicating markedly lower dolphin activity there than in the rest of Lingding Bay. Instead, sightings were concentrated in four discrete clusters: (i) the north-western waters off Neilingding Island, (ii) along the Hong Kong–Zhuhai–Macau Bridge corridor, (iii) the Datouzhou–

Sanjiashan–Qingzhou Islands—especially within and around the Guishan Offshore Wind Farm, and (iv) the western coast of Lantau Island. All four finless-porpoise encounters occurred at the south-eastern margin of the dolphin distribution, confirming minimal spatial overlap between the two species.

4.2.2 Inter-annual shifts in core areas

When compared with the MEEF-funded surveys conducted in 2017–18 and 2018–19, several notable changes emerge: CLDB recorded fewer dolphin encounters in 2024–25 than in 2018–19 or 2017–18, indicating a continued decline in central usage. Relative to 2005–06, dolphin presence in the waters west of the Sha Chau & Lung Kwu Chau Marine Park and directly west of Chek Lap Kok Airport (at the CLDB–SLDB boundary) has diminished across all three recent cycles (2024–25, 2018–19, and 2017–18). Similarly, waters surrounding Neilingding Island exhibited their lowest encounter frequency on record in 2024–25 (Figure 5).

These spatial shifts indicate that the relative importance of different habitats within Lingding Bay is highly dynamic, likely responding to changing anthropogenic pressures and environmental conditions. A quantitative grid-based analysis, presented in Section 4.8, further assesses the relative significance of each sub-region by estimating distributional density metrics.

4.3 Encounter rates

Using only on-effort data collected in Beaufort sea states 0–3, we quantified dolphin encounter rates for each monthly survey in the four strata (Figure. 6) and then calculated stratum-wide means to compare their relative importance (Figure. 7). The MA yielded the highest mean encounter rate 8.25 groups per 100 km—followed by SLDB, 6.91 groups per 100 km and CLDB, 3.52 groups per 100 km. Dolphins were observed only infrequently in the SWMA.

Between 2018-19 and 2024-25, encounter rates in CLDB declined by 18 % for groups and 8 % for individuals. Declines in SWMA were considerably larger—75 % for groups and 81 % for individuals. In contrast, both SLDB and MA exhibited increases in group- and individual-based encounter rates relative to both 2018-19 and 2017-18. Over the past decade, dolphin habitat use has contracted in CLDB and SWMA, but expanded markedly in SLDB and MA. Collectively, SLDB and MA now account for approximately 77 % of all individual encounters, underscoring their emerging status as the principal dolphin habitats within Lingding Bay.

4.4 Density and abundance

Using the line-transect analysis method, and following the protocols applied during previous monitoring periods in Lingding Bay, we estimated the density and abundance of CWD across the four survey strata (CLDB, SLDB, MA, and SWMA). Only data collected under Beaufort sea states ≤ 3 were used for the analysis. Based on 3,661 km of on-effort survey effort and 194 dolphin group sightings, dolphin abundance and density were calculated for each stratum (Table 3).

Model selection using the Akaike Information Criterion (AIC) identified a hazard-rate detection function with cosine adjustment as the best fit, yielding an effective strip width (ESW) of 316 m. Dolphin densities varied markedly among strata, with MA and SLDB exhibiting the highest densities (64.3 and 60.3 dolphins per 100 km^2, respectively), while CLDB had the lowest density (25.3 dolphins per 100 km^2). For the 2024–25 monitoring period, the estimated total abundance across all strata was 640 dolphins. Precision was moderate for CLDB, SLDB, and MA (coefficient of variation, CV = 19.66–26.73 %), suggesting relatively robust estimates, whereas SWMA showed a lower precision (CV = 52.11 %) due to the limited number of sightings.

4.4.1 Interannual Comparison of Abundance

The temporal analysis of abundance across the four strata (Fig. 8) indicates distinct regional trends:

CLDB: A pronounced decline since the 2017–18 peak, with only a short-lived rebound in 2020–21. The renewed decrease in 2024–25 suggests persistent stressors such as underwater noise or reduced prey availability.

SLDB: Relatively stable between 2017–18 and 2018–19, followed by a substantial peak in 2020–21. Although abundance dropped sharply by 2024–25, it remained slightly higher than in 2017–18, with its share of total abundance increasing from 35 % to 49 %, indicating a growing ecological importance.

MA: Initially declined, peaked in 2020–21, and decreased again by 2024–25. Despite the drop, abundance remained higher than in 2018–19, underscoring the continuing value of this habitat.

SWMA: Fluctuations were observed, but overall contributions to total abundance remain low (< 7 %).

4.4.2 Total Abundance Trends

2017–18 → 2018–19: A sharp of 29 % decline was recorded across all strata, particularly in CLDB and MA.

2018–19 → 2020–21: Total abundance surged by 83 %, driven largely by sharp increases in SLDB and CLDB. This spike coincided with the COVID-19 pandemic, during which ferry operations and cargo traffic were drastically reduced, and fishing activities nearly ceased. The resulting reduction in anthropogenic disturbance and potential prey replenishment likely contributed to this temporary boom.

2020–21 → 2024–25: Abundance decreased by 43 %, partially offsetting the prior increase, and positioning the current population between the previous low (2018–19) and the peak (2020–21).

4.4.3 Interpretation and Implications

The "decline–increase–decline" pattern from 2017–18 to 2024–25 reflects the combined effects of natural interannual variability and anthropogenic pressures. The 2020–21 peak serves as a natural experiment, demonstrating the immediate positive impacts of reduced vessel traffic and fishing pressure on dolphin abundance. Large-scale hydrological data provide a plausible environmental context for the reduced number of CWD recorded in Lingding Bay (LDB) during the 2024–25 field period. Run-off in 2024 rose well above the decadal mean at all three major Pearl-River control stations—+13 % at Gaoyao on the Xijiang River, +38 % at Shijiao on the Beijiang River and +59 % at Boluo on the Dongjiang River—indicating a basin-wide year of exceptionally high freshwater discharge (http://www.mwr.gov.cn/sj/tjgb/zghlnsgb/). According to Chen et al. (2010), pulses of freshwater during the wet season expand the low-salinity plume in LDB and are typically accompanied by an east-to-west shift in dolphin distribution: animals follow their prey towards the western estuary while local conditions in LDB become more turbid and energetically costly for foraging.

In 2024 this “wet-season effect” was probably intensified and prolonged by the unusually heavy precipitation, resulting in a greater portion of the dolphin population spending time outside the four LDB strata covered by the present survey. The apparent decline in encounter numbers therefore need not reflect a true decrease in regional abundance, but rather a hydro-driven redistribution of dolphins—and their prey—beyond the survey area. Continued integration of discharge records, salinity monitoring and dolphin sighting data will be essential for disentangling hydrological forcing from genuine demographic change.

4.4.4 Interpretation, drivers, and management implications

The 2024-25 estimate (~640 dolphins) represents a ~43 % decrease from the pandemic related peak in 2020-21 (~1,160), while remaining slightly above 2018-19 (~611). Together with the stratum-specific patterns (Section 4.4.1) and hydrological context (Section 4.4.3), this "increase—decrease" sequence is best explained by (i) a pandemic "quiet ocean" pulse followed by a rapid rebound of human activities (Jalkanen et al., 2022; Robinson et al., 2023; Erbe et al., 2019), (ii) an exceptionally wet hydrological year in 2024 that redistributed animals and prey outside the four Lingding Bay strata;

and (iii) slow life-history compensation in a species with a **3-5-yr calving interval**, making short-term pressures quickly visible as reduced calf proportion and recruitment (NOAA, 2021).

A. Human-activity signal: the "anthropause" and its post-pandemic rebound

Pandemic pulse (2020-21). Independent AIS-based modelling and ocean-acoustic observations show that global shipping noise source energy **declined by ~6 % in 2020 relative to 2019**, and deep-ocean ambient noise levels dropped across multiple basins -conditions expected to enhance cetacean communication/foraging and to increase local occurrence and detectability, consistent with the 2020-21 spike in abundance (Jalkanen et al., 2022; Robinson et al., 2023).

Rebound (2022+). As shipping, fisheries, and coastal construction resumed, underwater noise and ship density increased, raising risks of acoustic masking, behavioral disruption, vessel strikes, and by-catch-mechanisms repeatedly documented to depress foraging efficiency, social cohesion, and survival, and to reduce recruitment over one to two reproductive windows (Erbe et al., 2019).

B. Hydrology-driven redistribution in 2024

Hydrological records indicate above-average freshwater discharge in 2024 across the Pearl River system-e.g. +13 % at Gaoyao (Xijiang River), +38 % at Shijiao (Beijiang River) and +59 % at Boluo (Dongjiang River) pointing to a basin-wide wet year (MWR, 2025). Such pulses typically expand the low-salinity plume in Lingding Bay, increase turbidity and stratification, and redistribute dolphins westward as they track prey, thereby depressing encounter rates inside the four LDB strata without implying a true regional decline (Chen et al., 2010; AFCD, 2019). This hydro-driven redistribution hypothesis is further consistent with multi-decadal deoxygenation and summertime hypoxia expansion in the Pearl River Estuary, which can alter prey fields used by lactating females and calves (Hu et al., 2021). Continued integration of discharge/salinity/turbidity with dolphin sighting data is therefore essential to disentangle hydrological forcing from genuine demographic change (MWR, 2025; Chen et al., 2010; AFCD, 2019; Hu et al., 2021).

C. Warming-driven prey shifts

A substantial body of work shows that rising sea temperature drives poleward and depthward shifts in coastal and estuarine fishes, and alters phenology and nursery use, reorganizing nearshore assemblages and prey pulses. Classic analyses found most North Atlantic fishes moved latitude and/or depth as waters warmed, while global syntheses report consistent temperature-tracking across marine taxa (Perry et al., 2005; Poloczanska et al., 2013; Pecl et al., 2017). For China's seas, ensemble projections indicate major redistributions of marine fishes and biodiversity under continued warming, implying turnover of nearshore communities and potential loss or displacement of estuarine nursery functions critical to top predators (Hu et al., 2022; Liang et al., 2018). In the Pearl River Estuary, prey fields are further modulated by hydro-climate forcing (freshwater plume, turbidity/stratification) and long-term deoxygenation, which together shift prey availability in space and time (Chen et al., 2010; Hu et al.. 2021).

D. Life-history and detectability considerations

Indo-Pacific humpback dolphins reproduce slowly: females start breeding late and give birth only every 3-5 years (NOAA, 2021). This means even a small rise in adult female deaths or more disturbance to mother-calf pairs-can lower the calf proportion for several years, as seen in our 2024-25 value of 6.15%. Moreover, quieter conditions and reduced vessel wakes during 2020-21 likely increased detectability in line-transect surveys; as conditions normalized, detectability may have declined, reinforcing the apparent abundance drop. Both effects argue for modelling perception/availability covariates (sea state, traffic intensity, sound levels) in density estimation.

E. Long-term decline signal (population-wide context)

Beyond short-term redistribution and detectability effects (A-D), the largest known population of Indo-Pacific humpback dolphins appears to be on a long-term declining trend. A demographic analysis reported an average annual decrease of 2.46% (Huang et al., 2012). Using a regional baseline of 2,500-2,600 individuals in 2014-15 (Li et al., 2019), propagating that rate over 10 years to 2024-25 gives:

$N_{2024/25} = N_{2014/15} \times (1-0.0246)^{10} \rightarrow$ 1,950-2,030 individuals (midpoint ≈ 1,990).

This calculation refers to the regional population, not just LDB, and is therefore not directly comparable to our LDB-only abundance (~640). Nevertheless, it provides important context: the fluctuations we observe in LDB (redistribution + detectability) are likely occurring on top of an underlying gradual regional decline. This strengthens the rationale for management aimed at achieving $\lambda \geq 1$, prioritizing adult-female survival and calf recruitment.

Management implications

Raise the long-term growth rate (λ) to $\geqslant 1$ by improving (i) adult female survival and (ii) calf recruitment—the two most elasticity-sensitive parameters for this species.

1. Shipping management and noise reduction (highest priority).

Implement speed limits ($\leqslant$ 10 kn) and lane offsets/separation across core corridors in CLDB-SLDB-MA; apply seasonal slow-downs/closures in calving/early-rearing months. Routine propeller/engine maintenance and speed reduction measurably reduce low-frequency noise and collision risk (Erbe et al., 2019; Leaper, 2019; Conn & Silber, 2013). Pair with passive acoustic monitoring (PAM) to set adaptive thresholds; note that the pandemic provided an empirical "quiet-ocean" benchmark with global ship-noise source energy reductions and deep-ocean ambient noise drops (Jalkanen et al., 2022; Robinson et al., 2023).

2. Construction "time-windowing" and noise abatement.

For pile-driving/blasting, require soft-starts, bubble curtains, shutdown radii, and real-time acoustic/visual monitoring, with no-work windows during peak calving/early-rearing (e.g..May-Aug). Apply cumulative-effects (CIA) assessments not just project-by-project reviews given the clustering of bridges, reclamation, and offshore wind. Technical exposure thresholds and mitigation should reference NMFS/NOAA acoustic guidance; bubble curtains are demonstrated to attenuate pile-driving noise and reduce risk for odontocetes (NOAA,2018/2024; Dähne et al., 2017; Erbe et al., 2019).

3. Fisheries and by-catch risk reduction.

In SLDB and MA core areas, prohibit high-risk gillnets and encircling gears; pilot acoustic pingers/visualized nets, and institutionalize a rapid report-response-necropsy chain for entanglements/ship-strike cases to quantify hidden mortality and improve SS and SJ (Carretta et al., 2008; Moan et al., 2023).

4.5 Group size

During the 2024–25 survey period, group sizes of CWD in Lingding Bay ranged from single individuals to 28 animals, with a mean (± SD) of 5.32 ± 5.19 dolphins per group. Small aggregations predominated: 37.6 % of groups comprised one or two individuals, and 72.4 % contained fewer than six (Figure 9). Only 12.9 % of the 210 observed groups (n = 27) exceeded ten dolphins—slightly above the proportions recorded in previous years. The mean group size was marginally higher than those reported for 2018–19 (5.13 ± 4.78), 2017–18 (4.86 ± 4.59) and 2005–06 (4.80 ± 4.91). The overall distribution of group sizes was broadly comparable across all three monitoring cycles (Fig. 10), suggesting that dolphin social structure in Lingding Bay has remained largely stable over the past decade.

During 2024–25, large groups (> 10 individuals) were documented in each of the four survey strata (Figure 11). The exception was the SWMA, where only three such groups were detected. The locations in which dolphins formed large aggregations have shifted over time (Figure 11); nonetheless, in the present study these sizeable groups were again most frequently encountered around the Datouzhou–Sanjiaoshan–Qingzhou island complex, which hosts the Guishan offshore wind farm. Compared with earlier years, the distribution of large groups was more strongly skewed toward the western coastal sector of Lingding Bay. Such spatial clustering of sizeable groups may reflect locally enhanced prey availability, affording dolphins greater foraging opportunities and facilitating the formation of larger social units (see further discussion in Section 4.8).

4.6 Calf occurrence

4.6.1 Current survey results

During the 2024–25 monitoring period, 210 dolphin groups were recorded in Lingding Bay. Of these, 12 groups contained unspotted calves (UCs) and 40 groups contained either UCs or unspotted juveniles (UJs). In total, 12 UCs and 43 UJs were identified, representing 6.15 % of all dolphins for which coloration stage could be determined.

4.6.2 Spatial distribution

Dolphin calves (including UCs and UJs) were encountered throughout the study area, mirroring the general distribution of dolphins. Compared with previous surveys, however, their overall spatial pattern shifted slightly toward the western coastal sector of Lingding Bay (Figure 12).

4.6.3 Regional encounter rates

Calf-specific encounter rates (UCs + UJs) generally mirrored overall dolphin patterns, reaching 2.30 groups per 100 km in the MA, followed by 1.00 in SLDB, 0.46 inCLDB, and just 0.24 in SWMA. These figures indicate that MA currently serves as the principal nursery habitat in Lingding Bay, whereas SWMA supports very few calves.

4.6.4 Temporal trends and conservation implications

Figure 14 shows that the proportion of young calves (UC + UJ) has fluctuated rather than declined monotonically over the past two decades:

The data illustrate three distinct phases.

（1）**Long-term decline** (**2005–06 → 2017–18**): calf proportion fell by one-third, mirroring the broader decrease in total abundance documented during this interval.

（2）**Short-term rebound** (**2017–18 → 2020–21**): a modest stabilisation in 2018–19 was followed by a sharp rise to 11.88 % in 2020–21—the highest value since 2005–06. This rebound coincided with the COVID-19 slowdown, when vessel traffic and fishing effort were greatly reduced, suggesting that temporary relief from anthropogenic disturbance may enhance calf survival and/or detectability.

（3）**Renewed decline (2020–21 → 2024–25):** calf proportion dropped to 6.15 %, the lowest on record, as maritime and fishing activities returned to pre-pandemic levels.

Figure 15 reveals that the percentage of sightings containing young animals fluctuates in tandem with the calf-to-individual ratios described earlier. Sightings that included unspotted calves plus unspotted juveniles (UC + UJ) peaked in 2020-21 (36.2 %), after a gradual decline from 2005-06 (34.5 %) through 2017-18 (27.0 %) and 2018-19 (28.9 %); the value then dropped to its lowest level in 2024-25 (19.0 %). The trend for unspotted calves alone (UC) shows a similar pattern—highest in 2005-06 (12.9 %), lower but stable from 2017-18 through 2020-21 (8.9–7.2 %), and reaching a minimum in 2024-25 (5.7 %). These parallel fluctuations indicate that year-to-year changes in the proportion of calf-bearing groups closely track variations in the overall calf contribution to the population, underscoring the rapid responsiveness of calf production and survival to short-term shifts in environmental conditions and human disturbance.

Because calf production and survival underpin long-term population viability, the recent downturn warrants concern. Continued, fine-scale monitoring of calf metrics—ideally integrated with acoustic records, prey surveys and disturbance indices—is essential for detecting future fluctuations and for designing adaptive conservation measures for the Pearl River Estuary humpback-dolphin population.

4.7 Behavioral states and association with fishing vessels

4.7.1 Behavioural composition

Activity states were recorded for every on-effort sighting to identify key areas used for feeding, socializing, travelling, and resting. During 2024–25, 80 of the 210 groups (38.1 %) were observed feeding and 12 groups (5.7 %) were engaged in social interactions. An additional 9 groups were travelling and 5 groups were milling or resting. The proportion of feeding and social groups was markedly lower than in 2018–19 (52.9 % feeding; 8.6 % social) and 2017–18 (74.4 % feeding; 10.1 % social), suggesting either a continuing downward trend or short-term fluctuation in these activities.

4.7.2 Spatial patterns of feeding and social behaviour

Feeding groups were distributed throughout the study area in all three recent survey cycles (Fig. 16). While the overall pattern changed little between cycles, feeding activity in 2024–25 was displaced slightly westward toward the coastal sector of Lingding Bay. Social groups exhibited a similar coastward shift, but their numbers declined in both CLDB and SLDB when compared with 2018–19 and 2017–18 (Fig. 17).

4.7.3 Encounters linked to active fishing vessels

Only 14 groups (6.7 % of all sightings) were recorded in association with operating fishing vessels during 2024–25. These encounters involved six gill-netters, four purse-seiners, three single trawlers, and one pair-trawl (hang trawl) vessel. Vessel-associated groups occurred in every survey stratum and mirrored the general dolphin distribution (Fig. 18). The 2024–25 figure is lower than the 9.7 % recorded in both 2018–19 and 2017–18, and substantially below the 15.0 % reported in 2005–06.

The pronounced decline in vessel-related encounters over the past two decades likely reflects the progressive reduction of trawling effort inside Lingding Bay, attributable to enforcement of the bottom-trawl ban, intensified anti-poaching surveillance, and possible displacement of fishing fleets to more distant grounds as local resources have dwindled. Concurrently, the reduced fraction of feeding groups—particularly those foraging in trawler wake—may indicate a decreasing reliance on fishery-associated foraging opportunities. Dolphins may therefore be investing greater time and energy in locating natural prey patches, a behavioural shift with potential energetic and demographic consequences. Continued monitoring of both activity states and fishery interactions is essential to assess how evolving fisheries management and prey availability influence the foraging ecology and long-term viability of the Pearl River Estuary humpback dolphin population.

4.8 Habitat use

4.8.1 Methodological overview

Spatial patterns of CWD activity were quantified by calculating sighting-based (SPSE: sightings per 100 units of survey effort per km²) and individual-based (DPSE: dolphins per 100 units of survey effort per km²) indices for every 1 × 1 km grid cell within the four survey strata (Fig. 19).

4.8.2 Fine-scale distribution in 2024–25

High-density clusters. Cells with SPSE > 20 and DPSE > 100 formed a contiguous west-coast to central LDB corridor extending from south-eastern Qiao Island, past the western artificial island of the Hong Kong–Zhuhai–Macau Bridge (HZMB), to the Qingzhou–Sanjiaoshan island complex. These grids hosted both frequent encounters and large groups, identifying them as the principal feeding and social hubs in Lingding Bay.

Functional attributes of hotspots. Most high-density grids were adjacent to islands, bridge piers, or monopile turbines of the Guishan offshore wind farm. Such physical structures generate localised turbulence during tidal exchange, aggregating prey and thereby attracting dolphins (Scheidat et al., 2011; Lindeboom et al., 2011).

Low-density zones. Conversely, SPSE < 5 and DPSE < 20 predominated in the eastern LDB—from north-eastern Qiao Island to the waters north of Guishan Island—indicating limited current attractiveness, likely owing to intensive vessel traffic, elevated noise levels, or lower prey availability.

4.8.3 Inter-annual shifts in core habitats (2017–18 → 2024–25)

The progressive contraction from a multi-corridor (2017–18) to a single west-coast corridor (2024–25) indicates that CWDs now rely disproportionately on a narrower swath of habitat（Figure 20）. Central LDB cells between Neilingding Island and Lung Kwu Chau, once prominent, now show markedly reduced DPSE values.

Quantitative grid analysis reveals that core dolphin habitat has contracted toward he western near-shore (Zhuhai-Macau shoreline) and become more concentrated over the past decade. This spatial shift may be linked to concurrent changes in human activity and prey distribution within Lingding Bay, highlighting the importance of flexible, spatially explicit conservation strategies that can adapt to environmental and anthropogenic dynamics.

4.9 Photo-identification，Ranging Patterns, and Movements

Between August 2024 and June 2025, line-transect surveys in Lingding Bay yielded > 41,000 photographs, from which 447 individually recognisable Indo-Pacific humpback dolphins were identified. Photo-identification (photo-ID) analysis documented 314 resighting events, whereas 69.57 % of dolphins were photographed only once. For movement analyses, a subset of 180 dolphins—each sighted in 2024–25 and on at least two earlier occasions—provided sufficient temporal depth.

4.9.1 Intra-estuarine range variation

Photo-ID data reveal pronounced inter-individual differences in space use. Some dolphins maintained localised home ranges centred in the north LDB (Figure 21) or south LDB (Figure 22), whereas others ranged widely across multiple strata within the Eastern Pearl River Estuary (EPRE), traversing the entire survey area (Figure 23). These broad-scale movers highlight functional connectivity among LDB habitats.

4.9.2 Cross-boundary movements

Historical analyses—most notably in 2018–19—show frequent movements between Hong Kong and Guangdong waters. Dolphins from the northern Lantau social cluster (North Lantau) were repeatedly photographed in north LDB, whereas the southern cluster (West/South-west Lantau) appeared mainly in south LDB, with occasional excursions into the North Lingding substratum (NLDB). At least 17 western-Lantau individuals extended their ranges 10–15 km into upper LDB or NLDB, and six were photographed in the Modaomen (MA) sector, demonstrating estuary-wide activity radii. Four dolphins absent from Hong Kong for ≥ 2 yr were resighted in LDB during 2018–19, indicating permanent or semi-permanent relocation and potential consequences for Hong Kong's CWD.

4.9.3 Data gaps and risks in 2024–25

The 2024–25 programme did not include a systematic cross-boundary match against the Hong Kong catalogue, generating three critical uncertainties:

1) Undetected route shifts—large-scale projects (e.g., the third runway, major reclamations) may alter movement corridors, but changes cannot be tracked without updated matching.

2) Management disconnect—lack of shared evidence hinders coordinated regulation between Guangdong and Hong Kong.

4.9.4 Recommendations

Re-establish a routine cross-boundary photo-ID database and batch-match all

2024–25 images to the Hong Kong catalogue.

Implement a joint annual workflow—SCSFRI and Hong Kong teams should harmonise photo standards, naming conventions, and data-sharing protocols for near-real-time exchange.

Targeted long-term monitoring—deploy fixed photographic or acoustic stations at the Hong Kong–Zhuhai–Macau Bridge, the Guishan offshore wind farm, and the airport expansion area to track post-construction effects.

Integrate cross-boundary findings into risk assessment—combine updated photo-ID outputs with dynamic DPSE/SPSE hotspot mapping to quantify infrastructure and fisheries impacts on individual movements and inform adaptive-management thresholds.

4.9.5 Concluding remarks

Systematic, cross-boundary photo-identification is indispensable for elucidating the spatial ecology and connectivity of Chinese white dolphins in the Pearl River Estuary. Completing the 2024–25 cross-match will verify whether the broad movement patterns documented in 2018–19 persist, intensify, or shift under emerging anthropogenic pressures. Such individual-level evidence is essential for synchronised conservation planning across Guangdong and Hong Kong and for safeguarding the long-term viability of this trans-boundary dolphin population.

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5 Summary and way forward

Abundance in 2024-25 is ~640 individuals a marked decline from the 2020-21 peak (~1,160) but slightly above 2018-19 (~611). The most plausible drivers are: (i) a post-pandemic rebound of shipping, fisheries and coastal construction that elevated underwater noise and risks of collision and by-catch; (ii) an exceptionally wet hydrological year that expanded the low-salinity plume and likely redistributed dolphins and their prey westward, beyond the four LDB strata; and (iii) slow life-history

(3-5-yr calving interval), which makes such pressures quickly visible as a reduced calf proportion (6.15%) (Jalkanen et al., 2022; Robinson et al., 2023; Erbe et al., 2019; MWR, 2025:Chen et al., 2010; AFCD, 2019; Hu et al., 2021; NOAA, 2021). In addition, warming-driven shifts in coastal/estuarine fishes including poleward/depthward movements and altered phenology/nursery use-are expected to reorganize prey fields in China's seas and within the Pearl River Estuary, increasing the risk of spatio-temporal mismatch for CWD (Perry et al., 2005;Poloczanska et al., 2013; Pecl et al., 2017; Hu et al., 2022; Liang et al., 2018).

Spatial analyses reveal an ongoing contraction and westward displacement of core habitat. A multi-corridor distribution documented in 2017-18 fragmented by 2018-19, and by 2024-25 high-density cells had merged into a single corridor extending from south-eastern Qiao Island to the Zhuhai–Macau artificial island and Qingzhou/Sanjiaoshan area. Eastern and central sectors of the LDB now contribute little to overall habitat use. Photo-identification efforts have catalogued 447 dolphins and yielded 314 resightings, furnishing a robust baseline for evaluating individual movements and range dynamics.

Long-term monitoring is therefore essential. A permanent, multi-year surveillance network covering the full Pearl River–Moyang River estuary should integrate vessel line-transects, passive acoustics, unmanned aerial systems and satellite remote sensing to track temporal shifts in abundance, distribution and calf ratios. Such a framework will provide the statistical power needed to detect subtle demographic or spatial changes.

Cross-boundary collaboration must also be strengthened. Re-establishing a Guangdong–Hong Kong photo-ID database with harmonised protocols will facilitate the quantification of transboundary movements and enable coordinated enforcement and risk assessment. Complementary hotspot protection measures—designating the continuous western corridor (Qiao–Guishan–Qingzhou) as a priority conservation zone, imposing vessel speed restrictions, scheduling construction quiet periods and expanding seasonal fishery closures—are recommended. Targeted noise audits and prey-restoration pilots in declining areas such as CLDB should be implemented to test adaptive-management interventions.

Finally, **mechanistic research** is needed to link anthropogenic drivers with dolphin ecology. Before-and-after acoustic monitoring and prey-resource surveys will quantify the effects of noise reduction, fisheries pressure and coastal engineering on density and behaviour, yielding thresholds to guide policy. Concurrent public and policy engagement—via academic meetings, outreach exhibitions and media communication—will ensure that scientific findings inform provincial marine-ecological plans, fisheries management and infrastructure impact assessments.

By coupling continued data collection with adaptive, evidence-based management, the project aims to secure the long-term viability of the Pearl River Estuary dolphin population and to provide a transferable model for reconciling coastal development with ecological conservation.

6 Evaluation and benefits

As a direct extension of the 2017-18 and 2018-19 programmes, the 2024-25 project fully met its stated objectives. On the basis of 3,662 km of on-effort transects and extensive sighting records, we updated density and abundance estimates for CWD in the four principal sectors of Lingding Bay, deriving a total population of approximately 640 individuals. Movement analyses of 180 repeatedly sighted dolphins revealed marked inter-individual variation, while SPSE/DPSE grid mapping showed that the former multi-corridor distribution has contracted into a single, west-coast corridor. The surge in abundance observed during the COVID-19 lockdown of 2020-21—when vessel traffic and fishing effort were greatly reduced—provided a valuable “natural experiment”, confirming the dolphins’ acute sensitivity to short-term anthropogenic disturbance.

These findings supply a robust scientific foundation for regional conservation and management. We recommend designating the west-coast corridor as a priority monitoring zone and reinstating a Hong Kong–Guangdong cross-boundary photo-identification database to support joint enforcement and risk assessment. Project results will be disseminated at academic conferences and through outreach channels to inform government agencies, industry stakeholders and the wider public.

Looking ahead, the project envisages routine cross-boundary matching, deployment of fixed acoustic arrays and fish-sonar surveys in identified hotspots, and the continued application of adaptive-management principles. Ongoing data accumulation and targeted mitigation are expected to enhance the long-term viability of the Pearl River Estuary dolphin population and to provide a transferable model for ecological protection in the context of large-scale coastal infrastructure and fisheries management.

7 Disclaimer

Any opinions, findings, conclusions or recommendations expressed in this report do not necessarily reflect the views of the Marine Ecology Enhancement Fund or the Trustee.

8 Declaration

I hereby irrevocably declare to the MEEF Management Committee and the Steering Committee of the relevant Funds including the Top-up Fund, that all the dataset and information included in the completion report has been properly referenced, and necessary authorisation has been obtained in respect of information owned by third parties.

Signature:

Project Leader, Prof. Chen Tao

Date: 2025.7.31

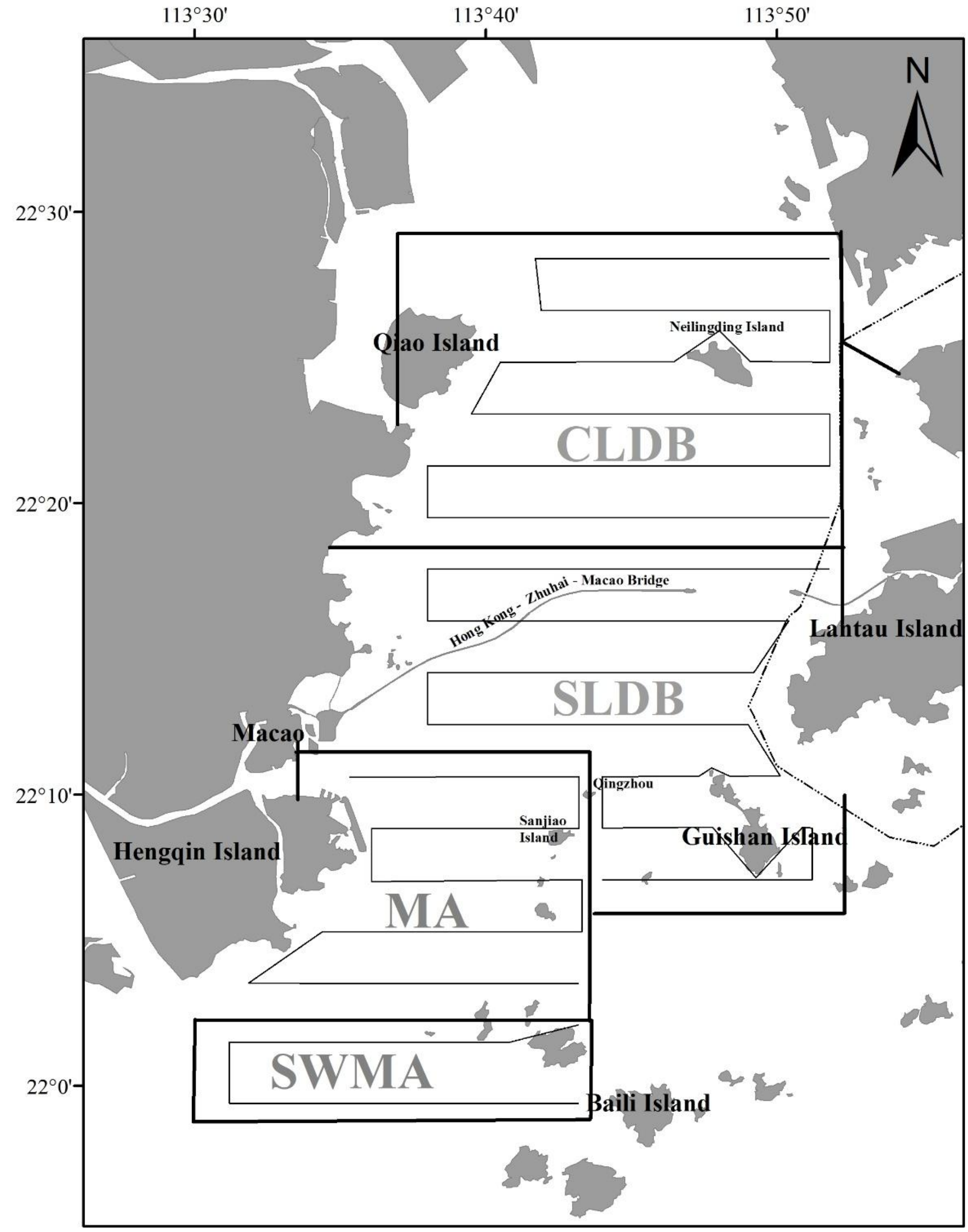


Figure 1. Survey areas and transect lines in Lingding Bay (2024-25)

CLDB, Central Lingding Bay; SLDB, South Lingding Bay; MA, Waters surround Macau; SWMA, Southwest waters to Macau

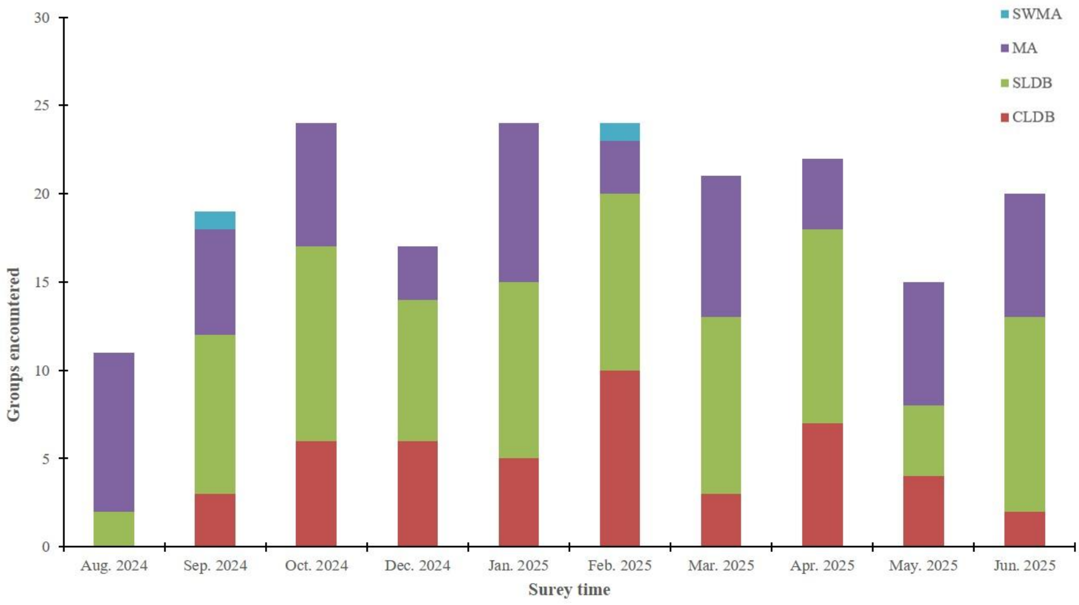


Figure 2. Monthly on-effort sightings of Chinese White Dolphin groups in the four survey areas in Lingding Bay (2024-25)

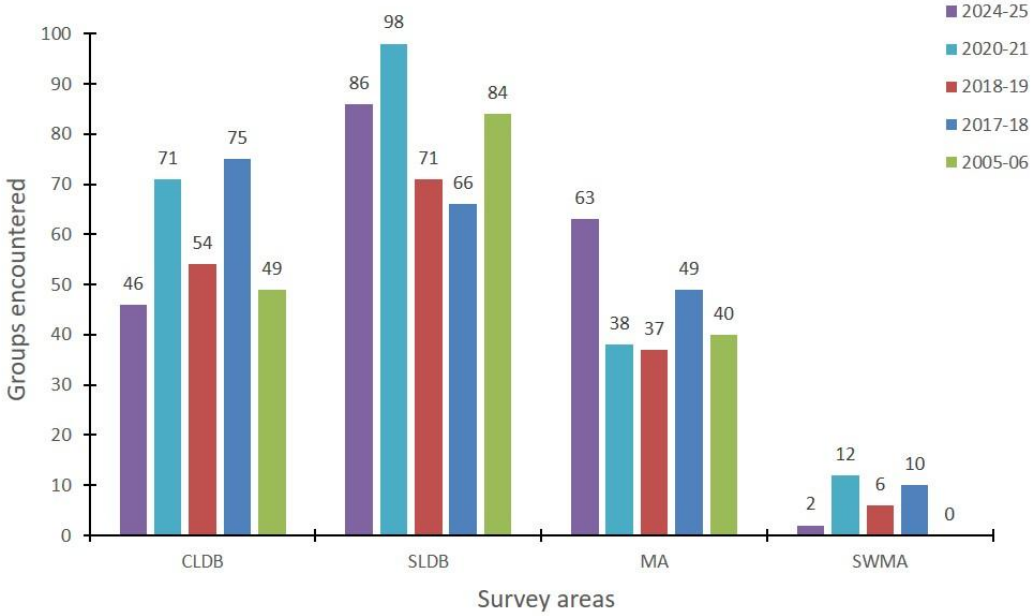


Figure 3. Comparison of the on-effort sightings of Chinese White Dolphin groups in the four survey areas in Lingding Bay between 2024-25, 2020-21, 2018-19, 2017-18 and 2005-06 monitoring periods

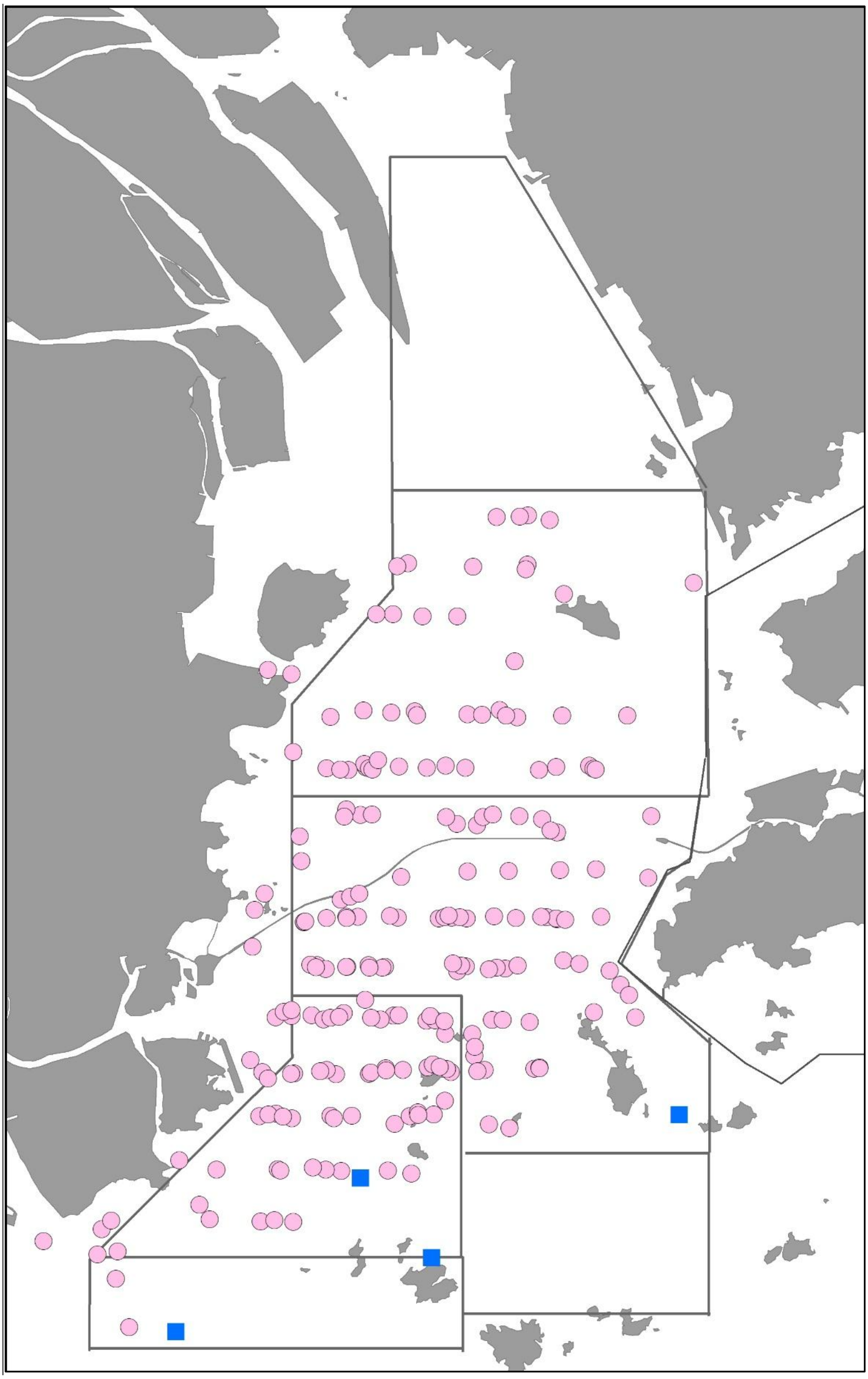


Figure 4. Distribution of Chinese White Dolphin (red dots) and Indo-Pacific finless porpoise (blue square) sightings in Lingding Bay (2024-25)

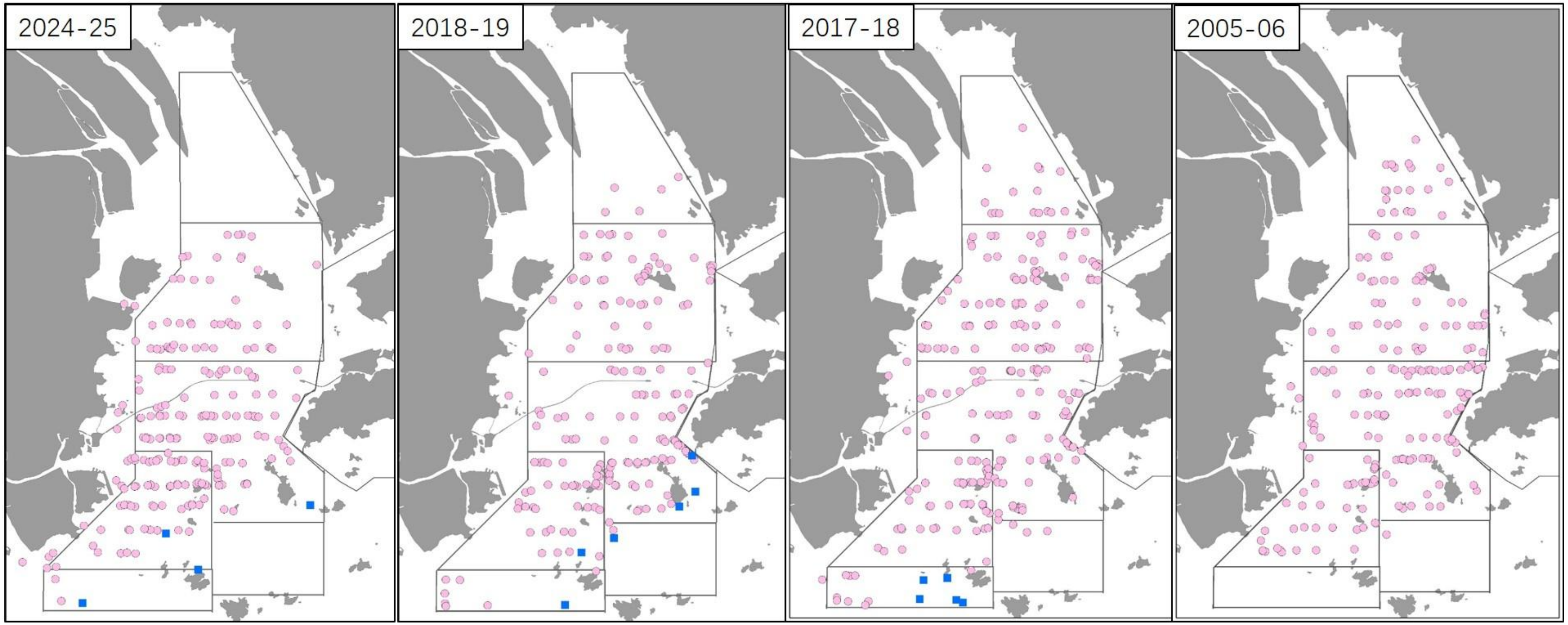


Figure 5. Comparison of Chinese White-Dolphin distribution patterns in Lingding Bay during the 2005–06, 2017–18, 2018–19, and 2024–25 monitoring periods (note: the SWMA stratum was not surveyed in 2005–06; the NLDB stratum was not surveyed in 2024–25; and the AZ stratum was also excluded from the 2024–25 survey).

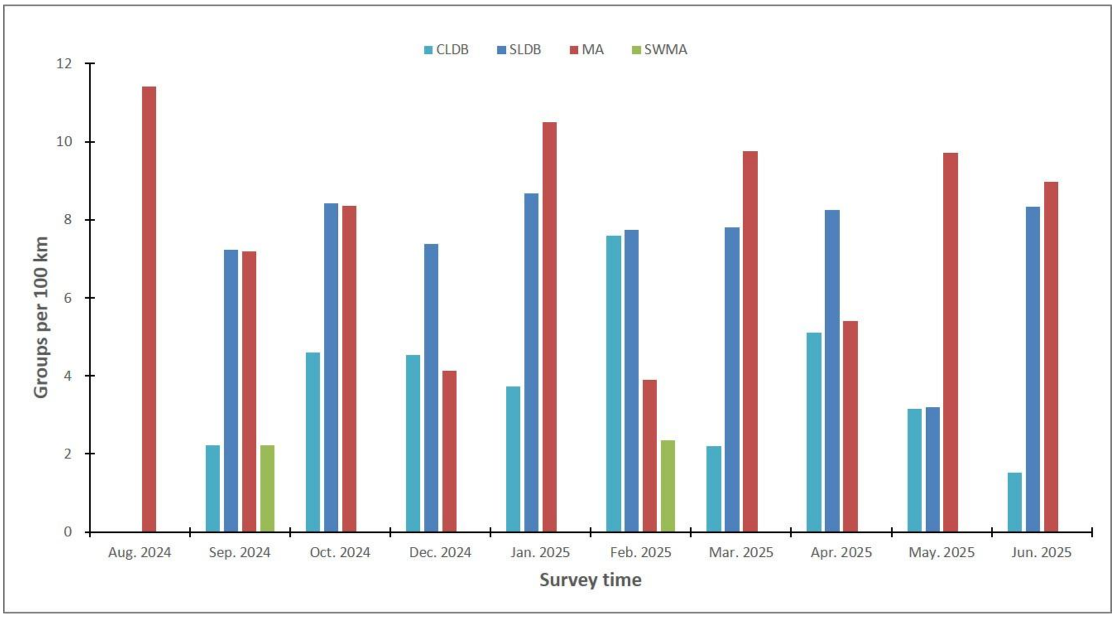


Figure 6. Monthly encounter rates of Chinese White Dolphin groups in the four survey areas in Lingding Bay (2024-25)

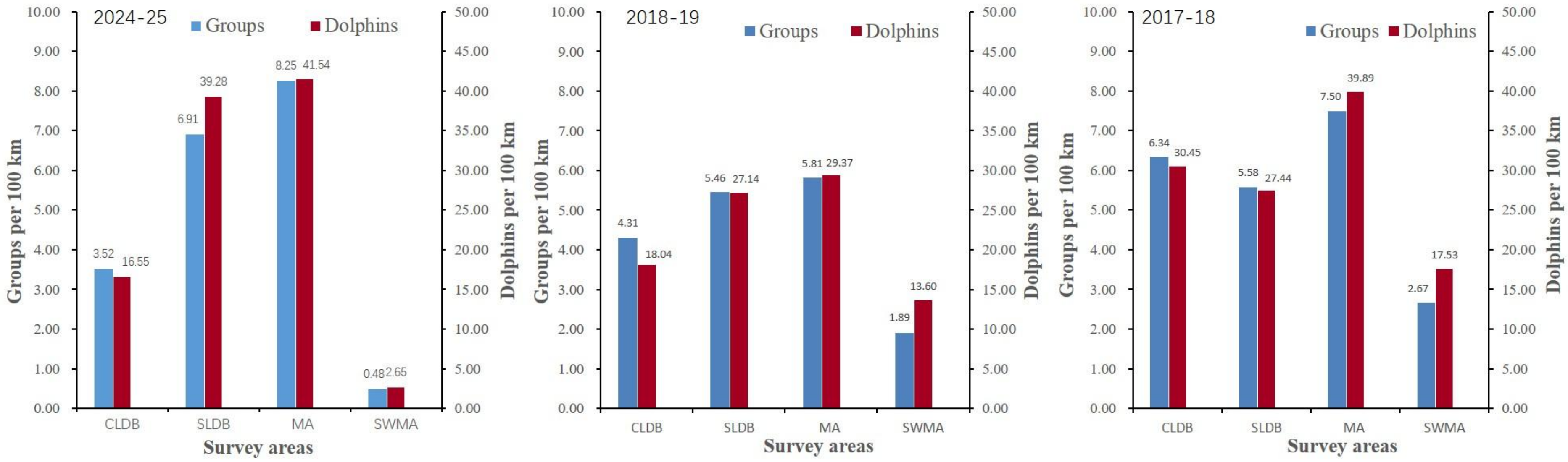


Figure 7. Comparison of combined encounter rates across the four survey areas in Lingding Bay during three survey cycles (2024 – 25, 2018 – 19, and 2017 – 18).

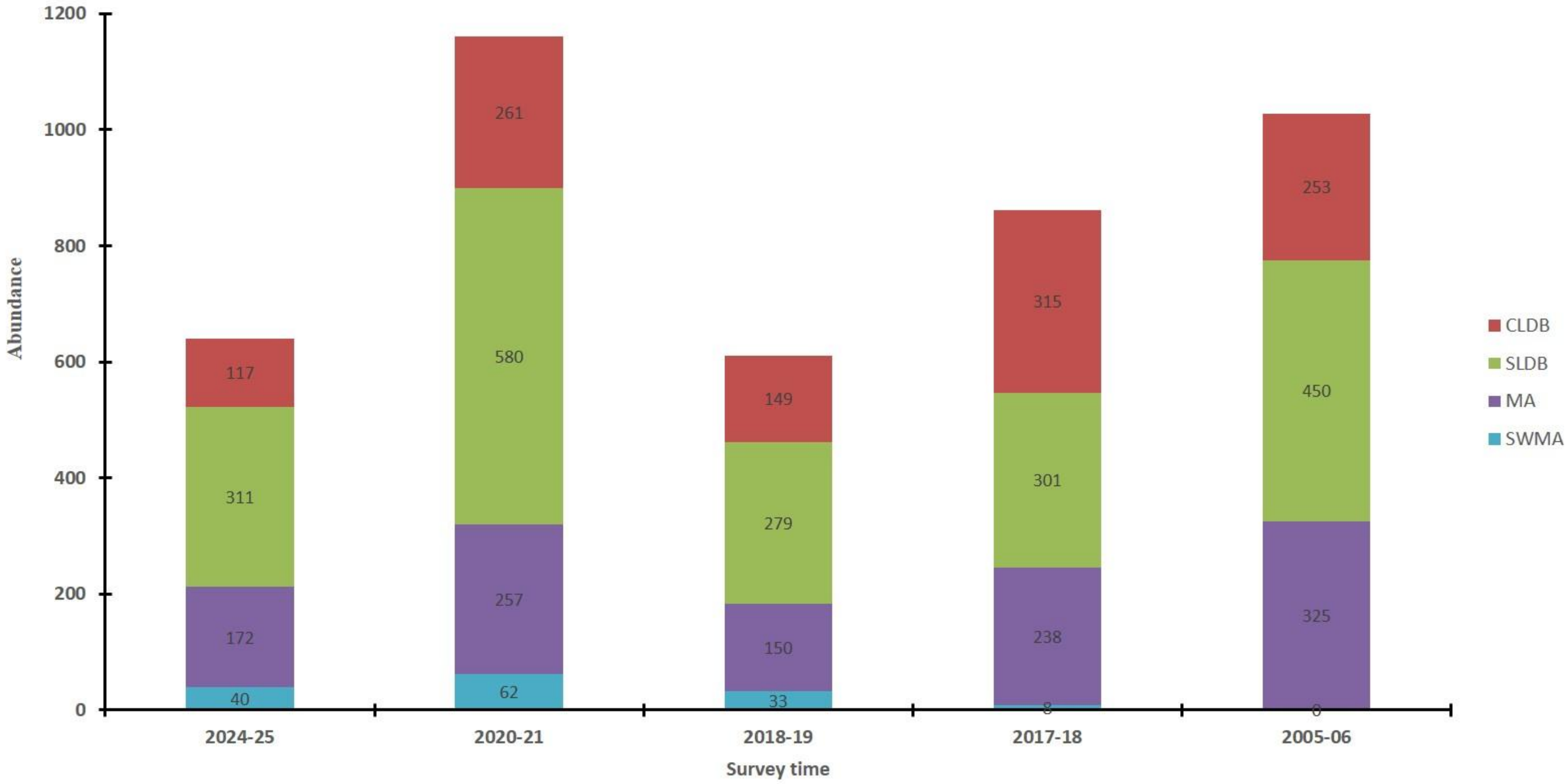


Figure 8. Comparison of abundance across the four survey areas of Lingding Bay during four survey cycles: 2024 – 25, 2020 – 21, 2018 – 19, 2017-18, and 2005 – 06 (note: the SWMA stratum was not surveyed in 2005 – 06).

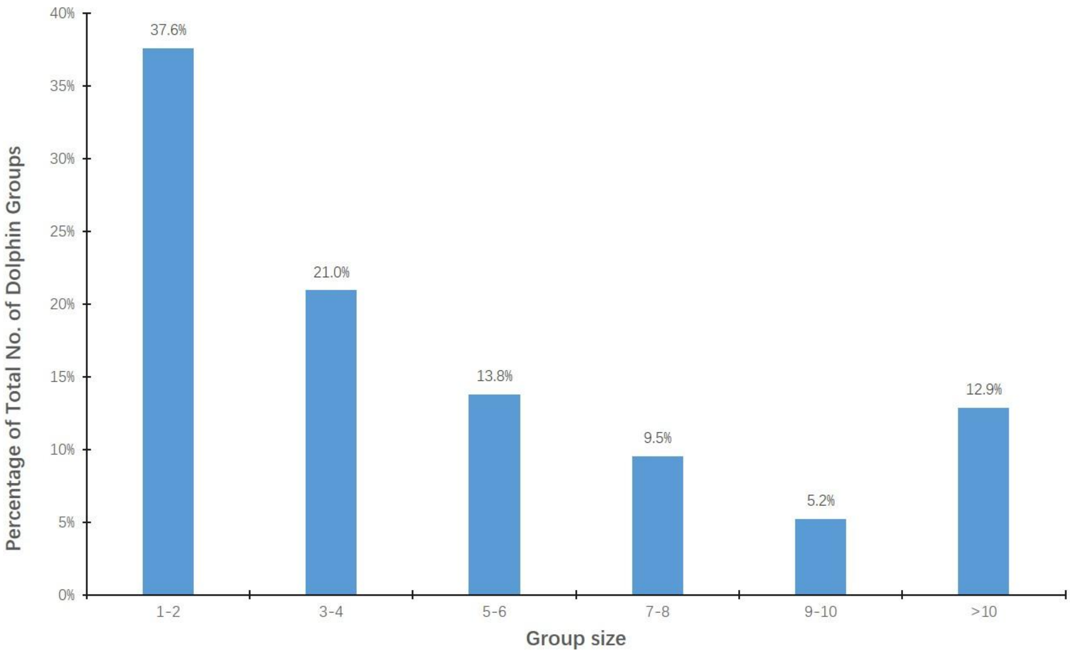
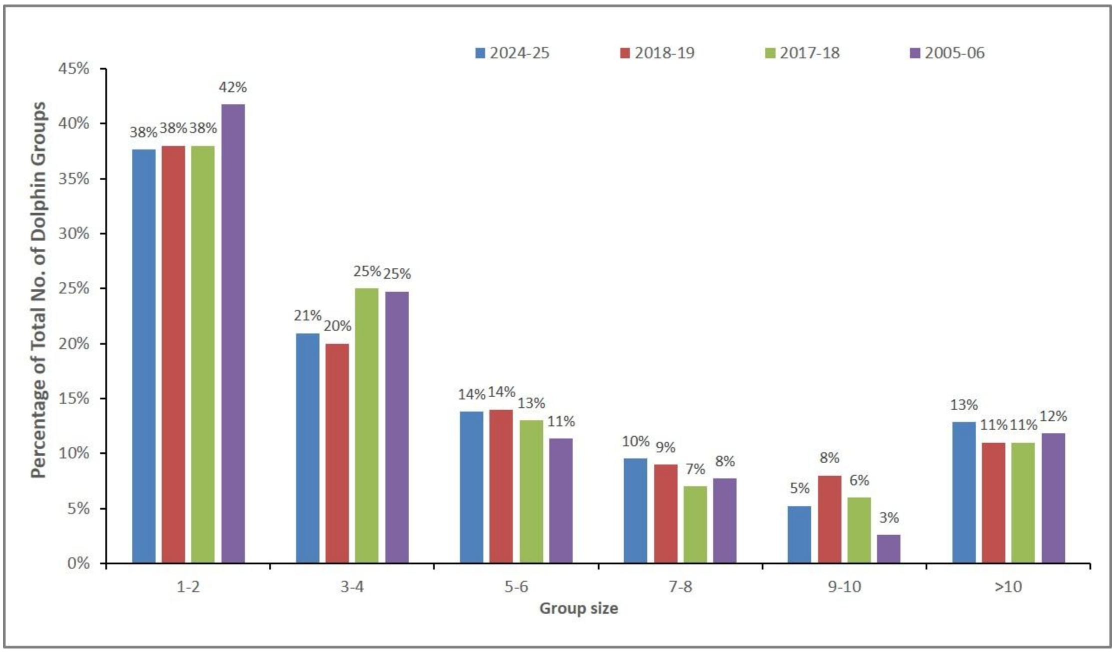


Figure 9. Percentages of different group sizes of Chinese White Dolphins in Lingding Bay (2024-25)



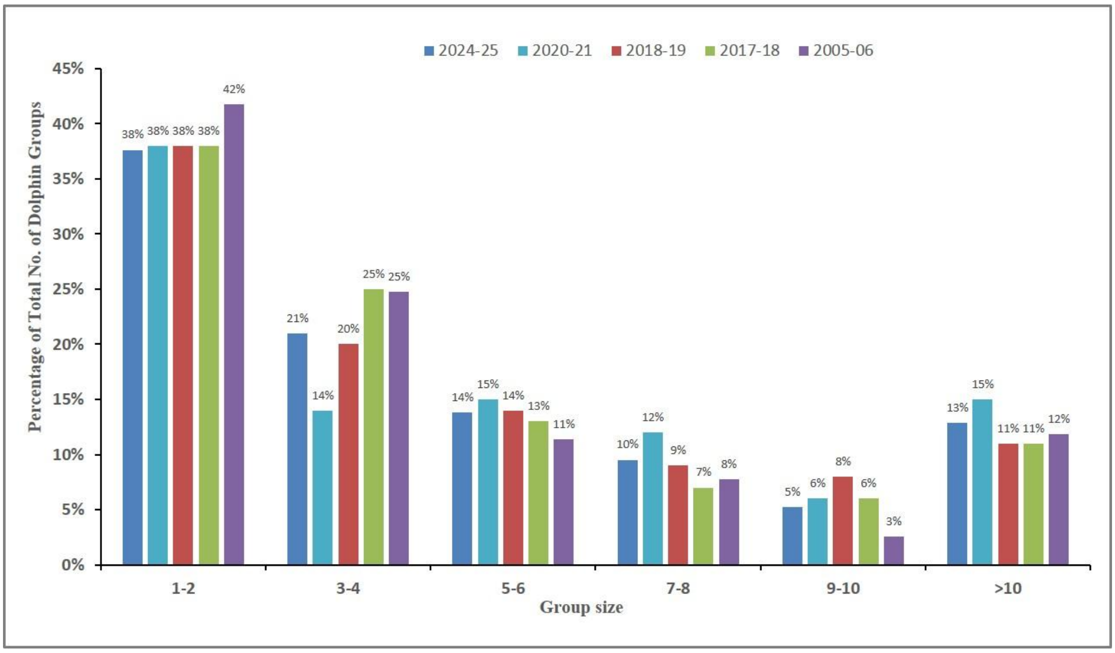


Figure 10. Composition of group size of Chinese White Dolphins in Lingding Bay during 2024-25, 2020-21, 2018-19, 2017-18 and 2005-06 monitoring periods

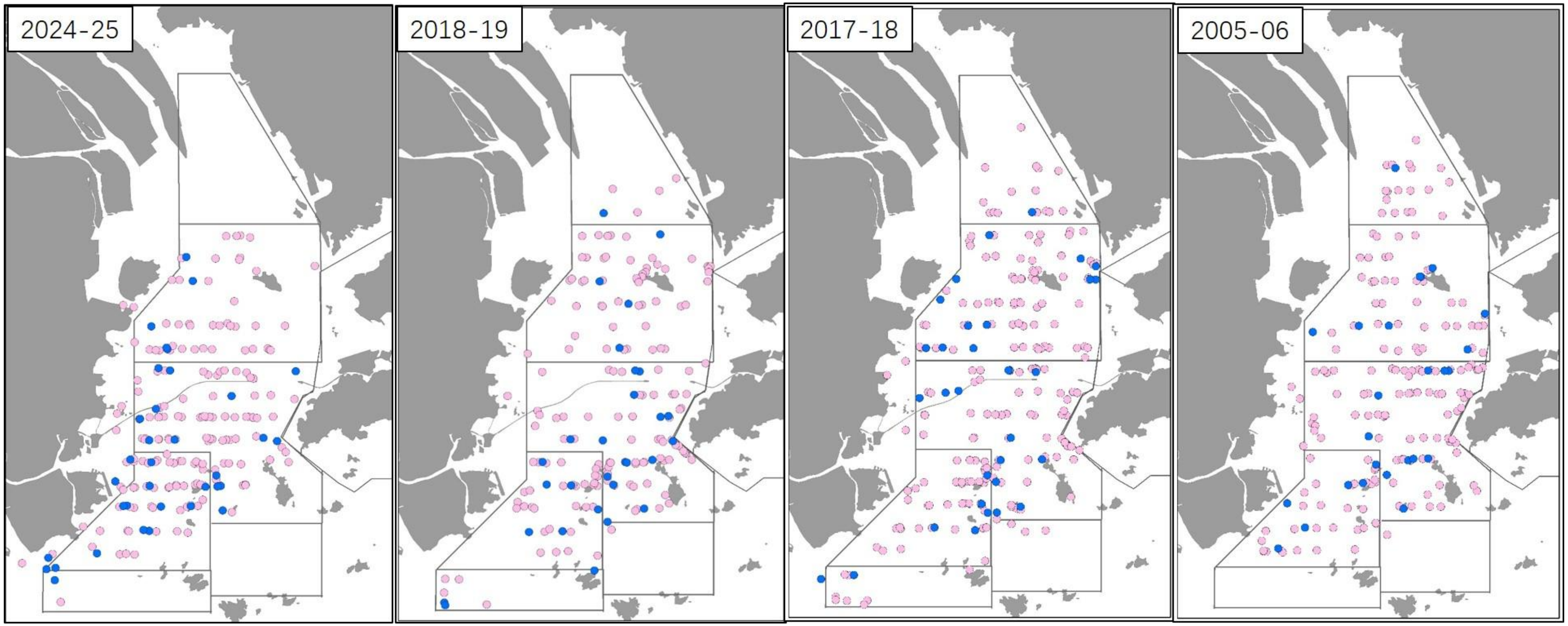


Figure 11. Distribution of dolphin sightings of large groups with more than 10 individuals (blue dots) in Lingding Bay during 2024-25, 2018-19, 2017-18 and 2005-06 monitoring periods (note: the North Lingding Bay [NLDB] stratum was not surveyed in 2024–25)

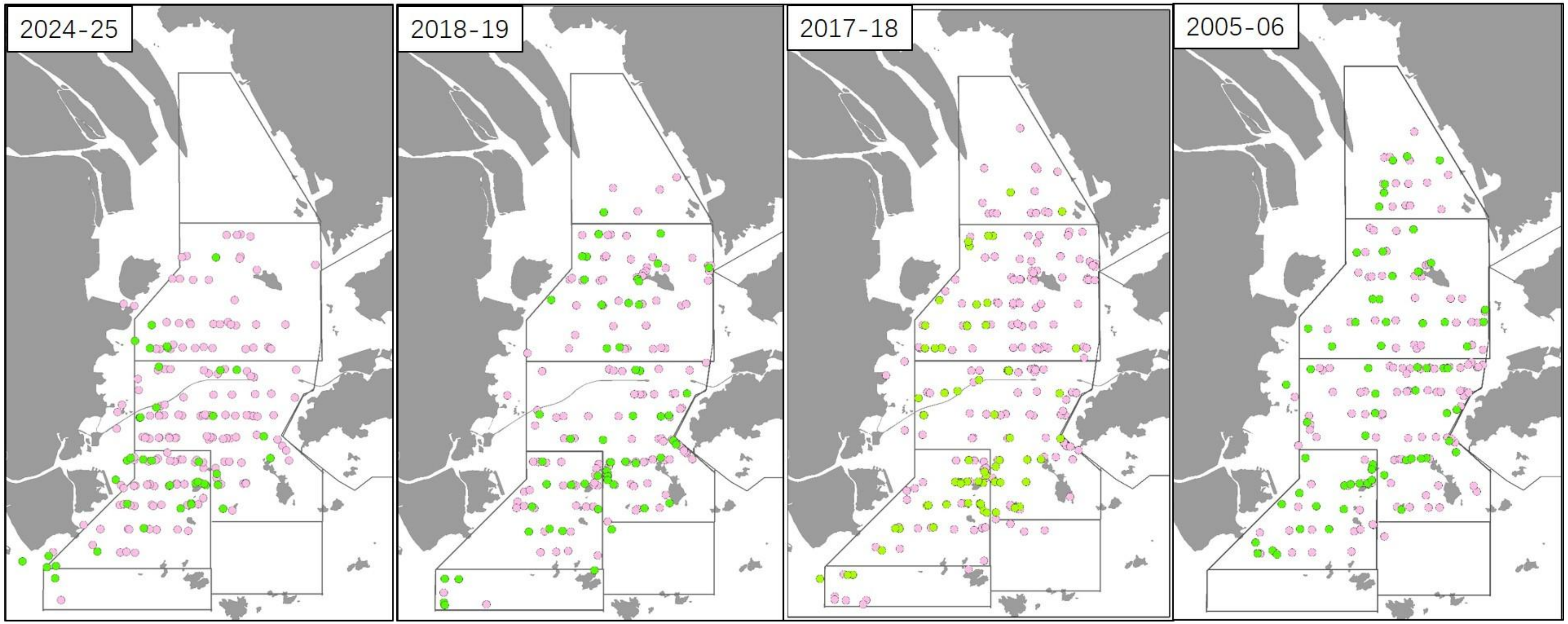


Figure 12. Distribution of young calves (Unspotted Calves and Unspotted Juveniles, green dots) distribution in Lingding Bay during 2024-25, 2018-19, 2017-18 and 2005-06 monitoring periods (note: the North Lingding Bay [NLDB] stratum was not surveyed in 2024–25)

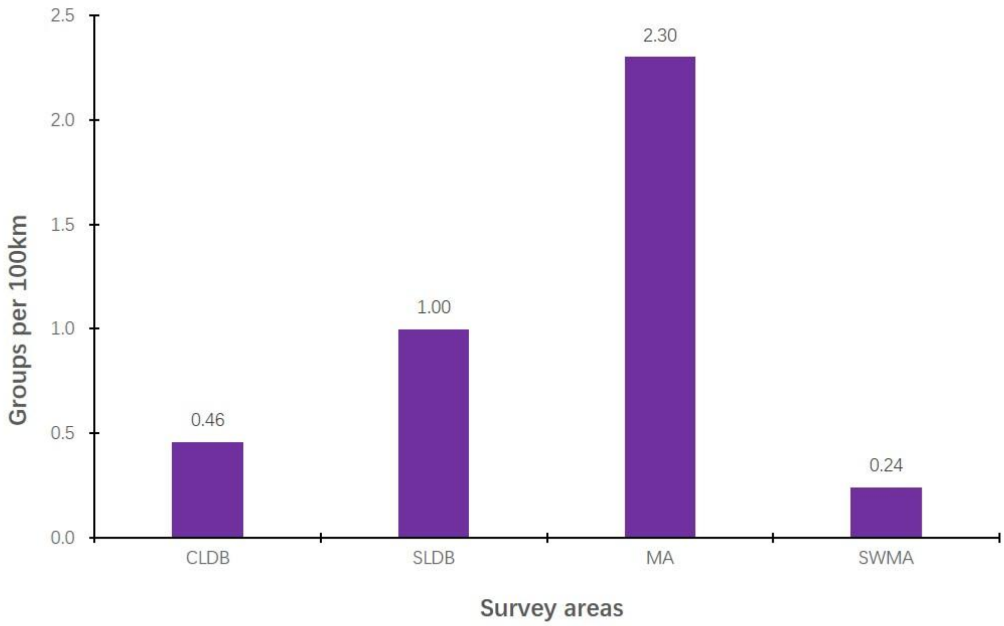


Figure 13. Encounter rates of young calves (Unspotted Calves and Unspotted Juveniles) in the four survey areas in Lingding Bay (2024-25)

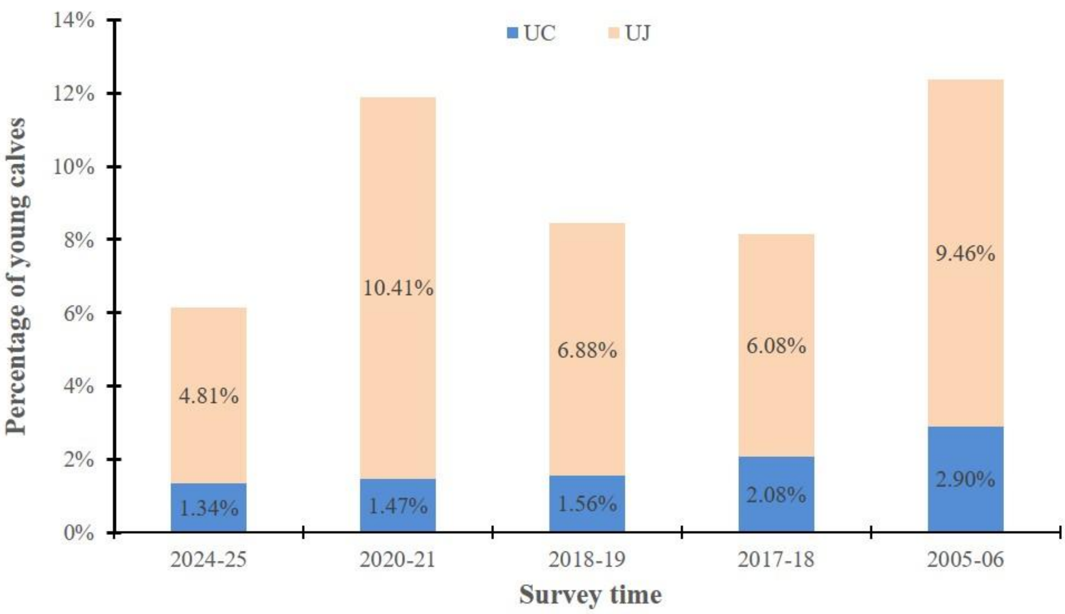


Figure 14. Percentages of young calves (Unspotted Calves and Unspotted Juveniles) among all dolphin groups in Lingding Bay during2024-25, 2020-21, 2018-19, 2017-18 and 2005-06 monitoring periods

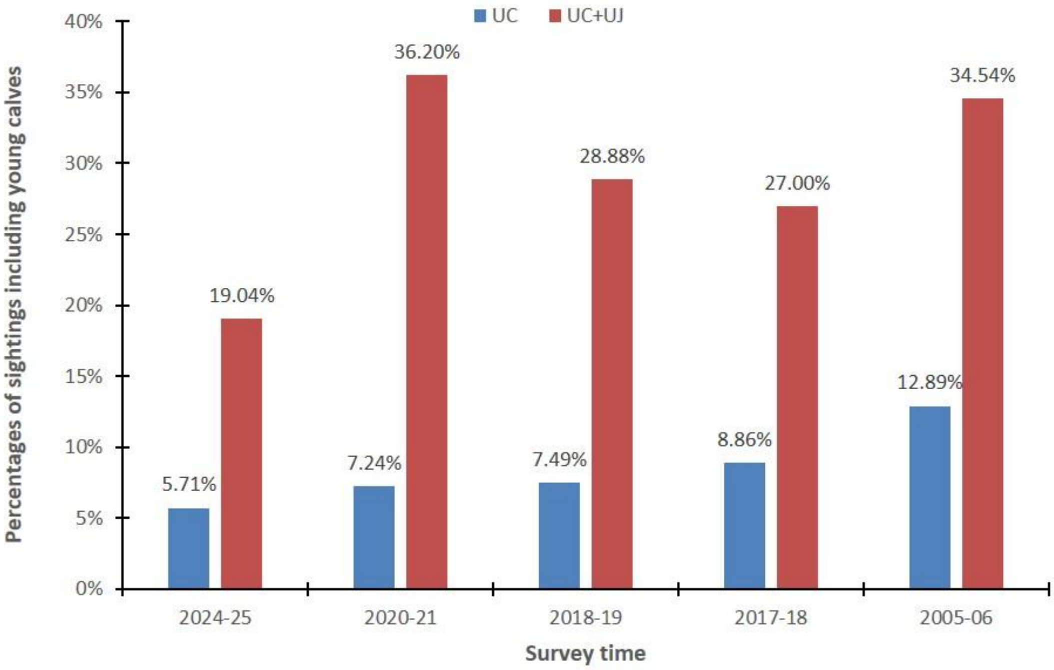


Figure 15. Percentages of sightings including young calves (Unspotted Calves and Unspotted Juveniles) in Lingding Bay during 2024-25, 2020-21, 2018-19, 2017-18 and 2005-06 monitoring periods

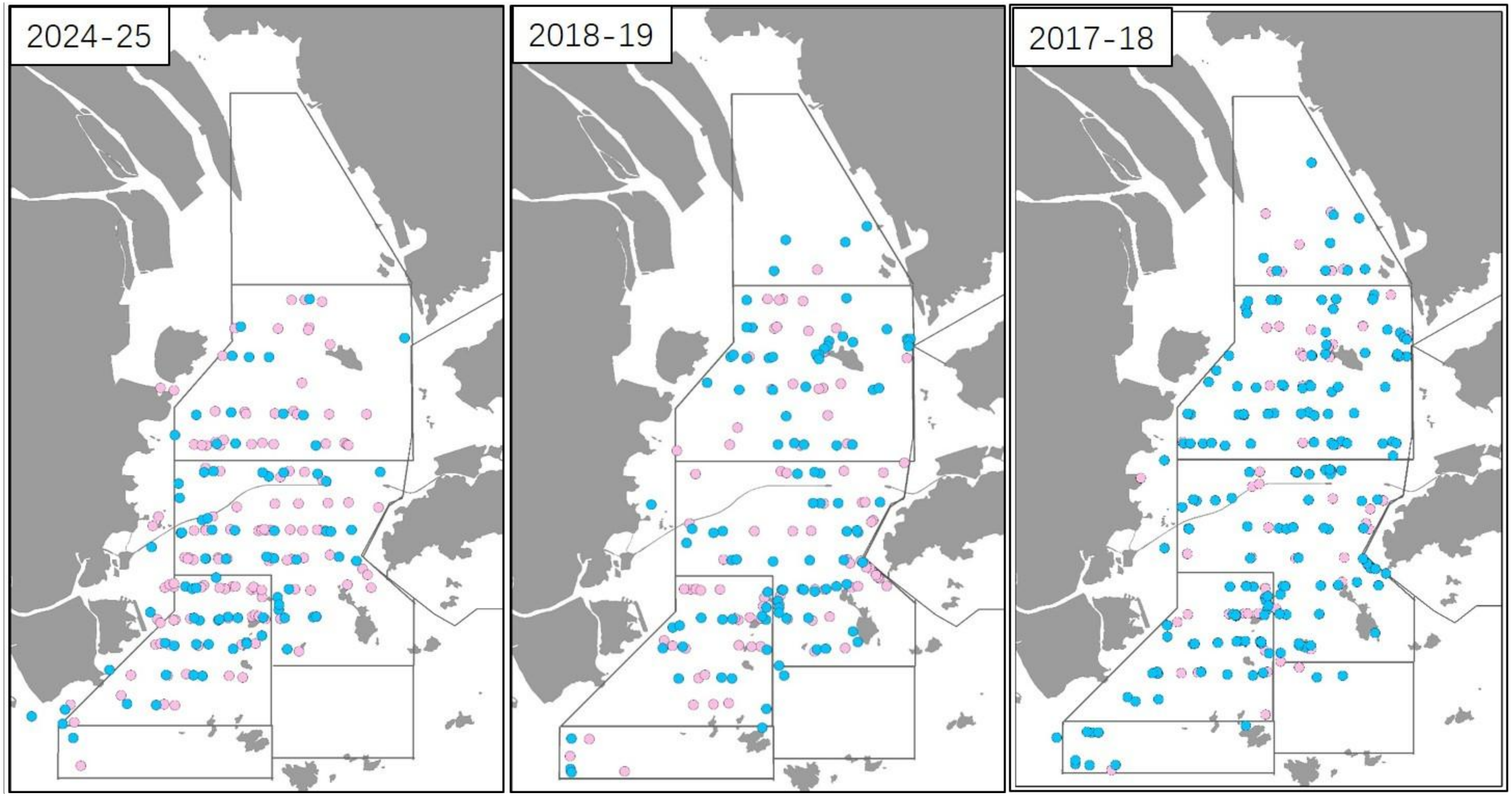


Figure 16. Distribution of Chinese White Dolphins engaged in feeding activities (cyan dots) in Lingding Bay during 2024-25, 2018-19 and 2017-18 monitoring period (note: the North Lingding Bay [NLDB] stratum was not surveyed in 2024–25)

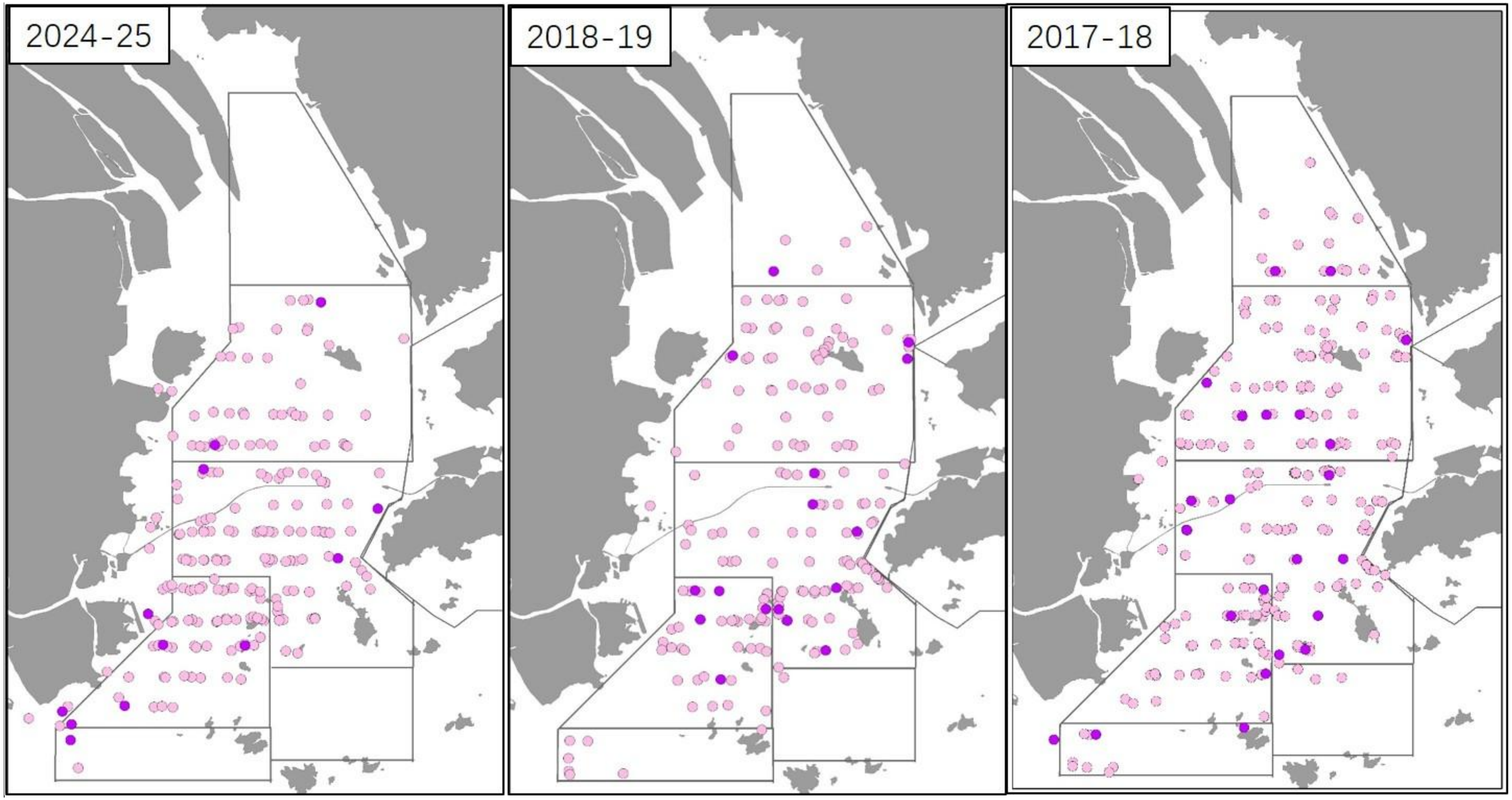


Figure 17. Distribution of Chinese White Dolphins engaged in socializing activities (purple dots) in Lingding Bay during2024-25, 2018-19 and 2017-18 monitoring period (note: the North Lingding Bay [NLDB] stratum was not surveyed in 2024–25)

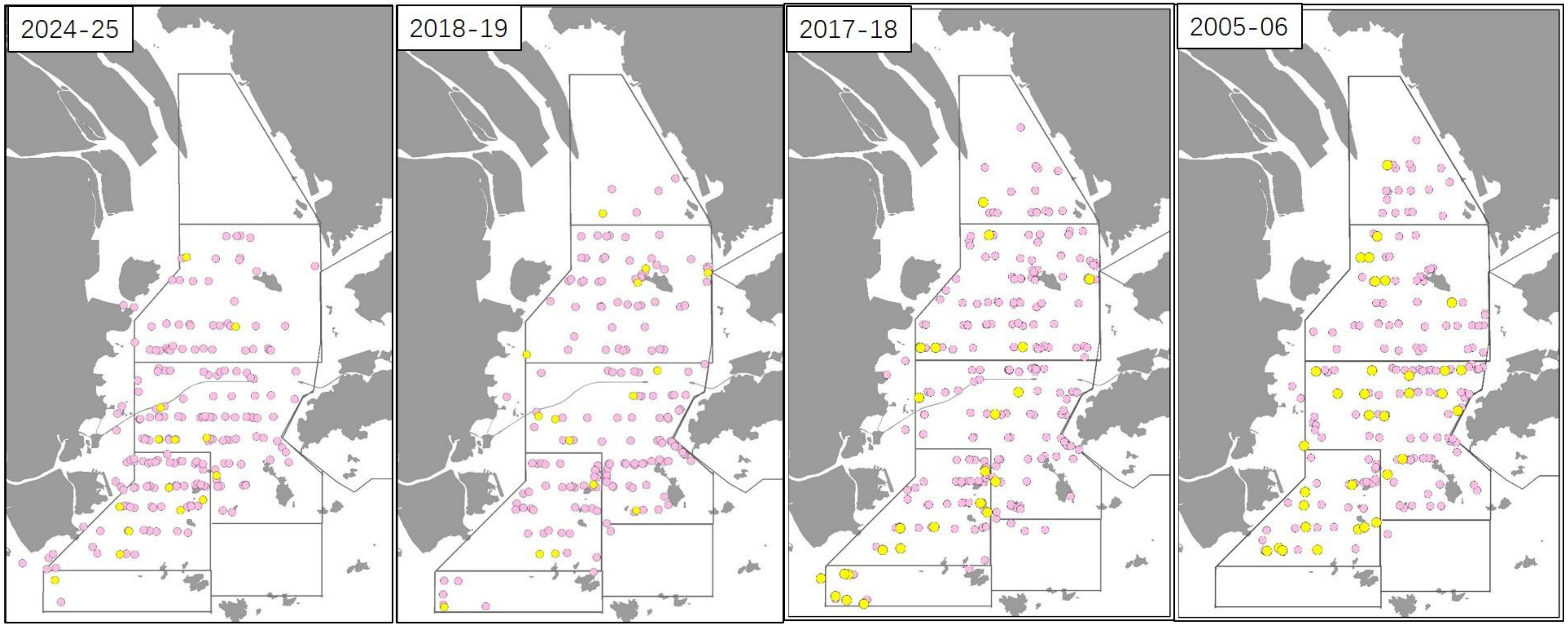


Figure 18. Distribution of dolphin sightings associations with fishing boats in Lingding Bay during 2024-25, 2018-19, 2017-18 and 2005-06 monitoring periods (note: the North Lingding Bay [NLDB] stratum was not surveyed in 2024–25)

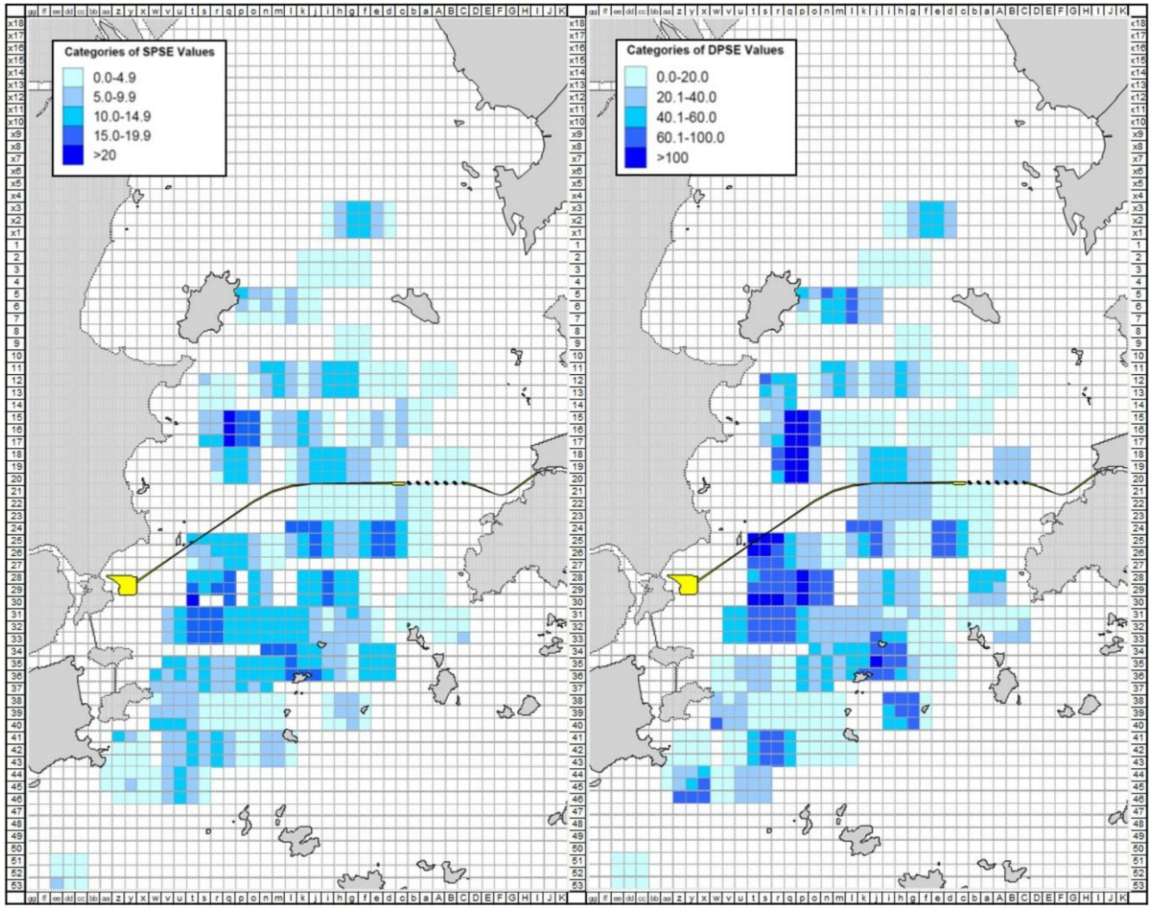


Figure 19. Sighting (left, SPSE) and individual (right, DPSE) densities of Chinese white dolphins in the Pearl River Estuary during 2024–2025, based on on-effort survey data and corrected for survey effort per km². SPSE and DPSE values represent the number of sightings or dolphins per 100 units of survey effort, respectively

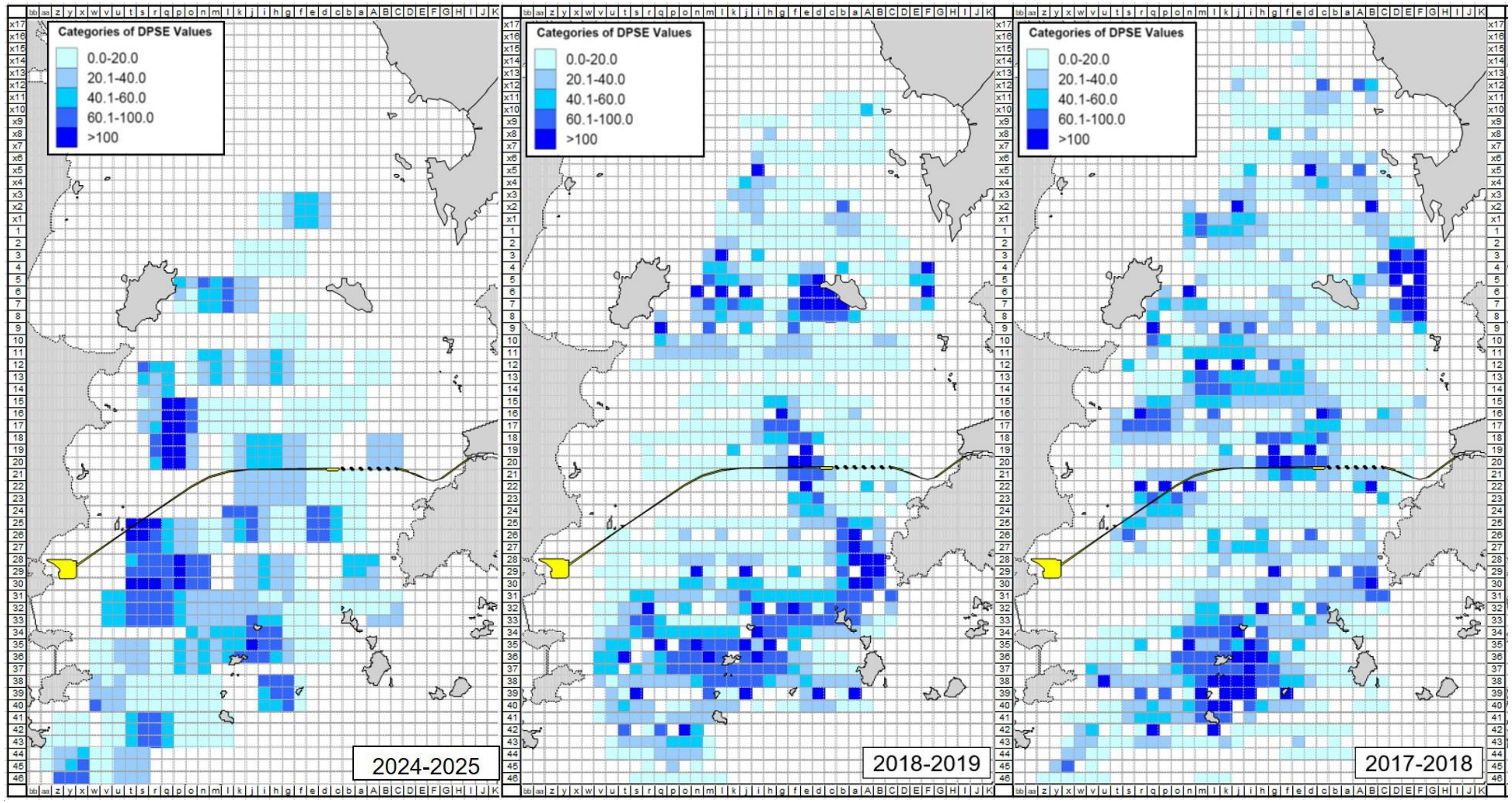


Figure 20. Comparison of Chinese white dolphin (CWD) densities in Lingding Bay during the 2024–2025, 2018–2019, and 2017–2018 monitoring periods, corrected for survey effort (DPSE: number of dolphins per 100 units of survey effort per km²; values shown within each grid)

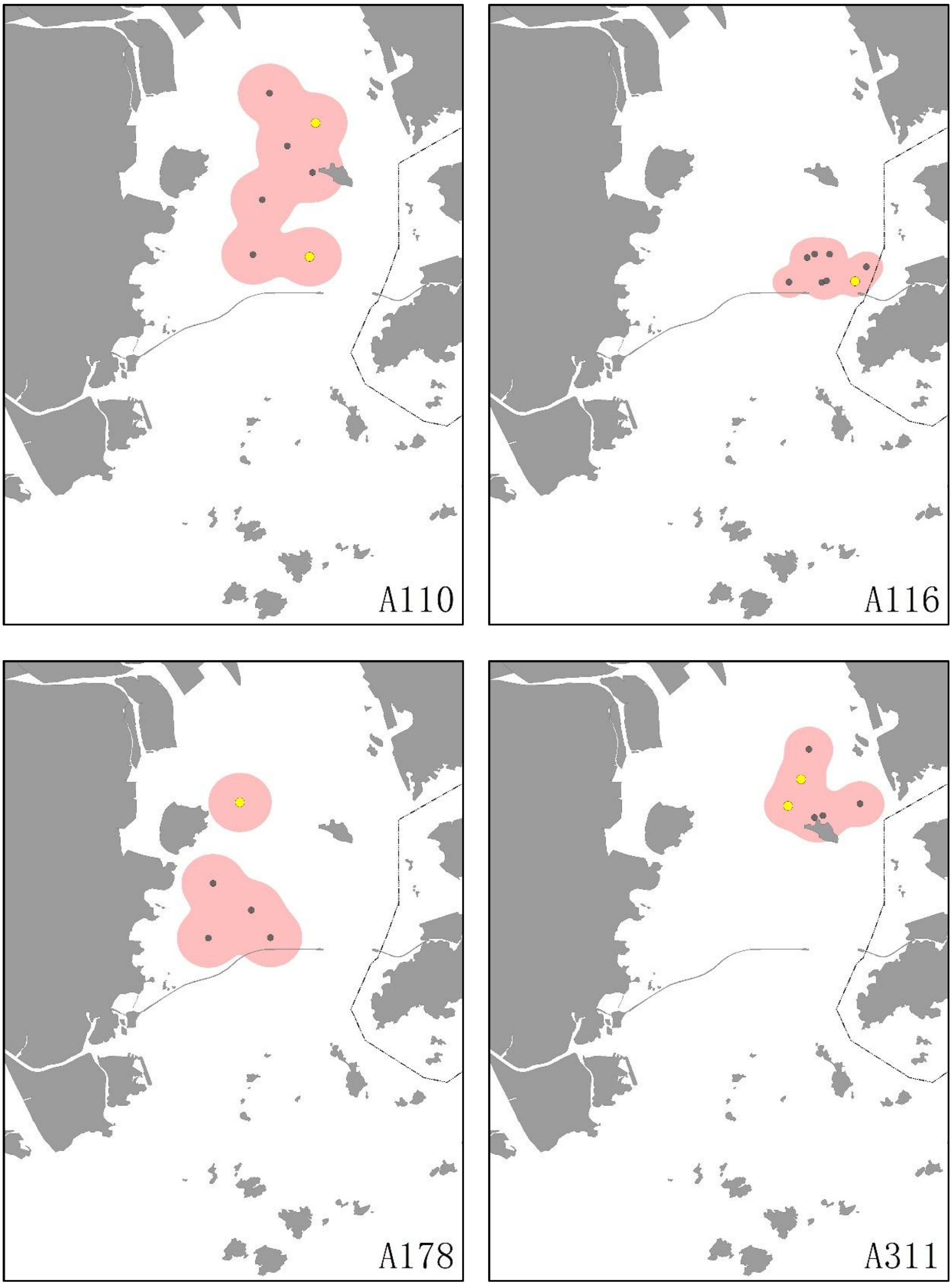


Figure 21. Examples of four individuals sighted during the 2024-25surveys in Lingding Bay that have ranged mostly in central part of Lingding Bay (yellow dots: sightings made in July 2024-June 2025)

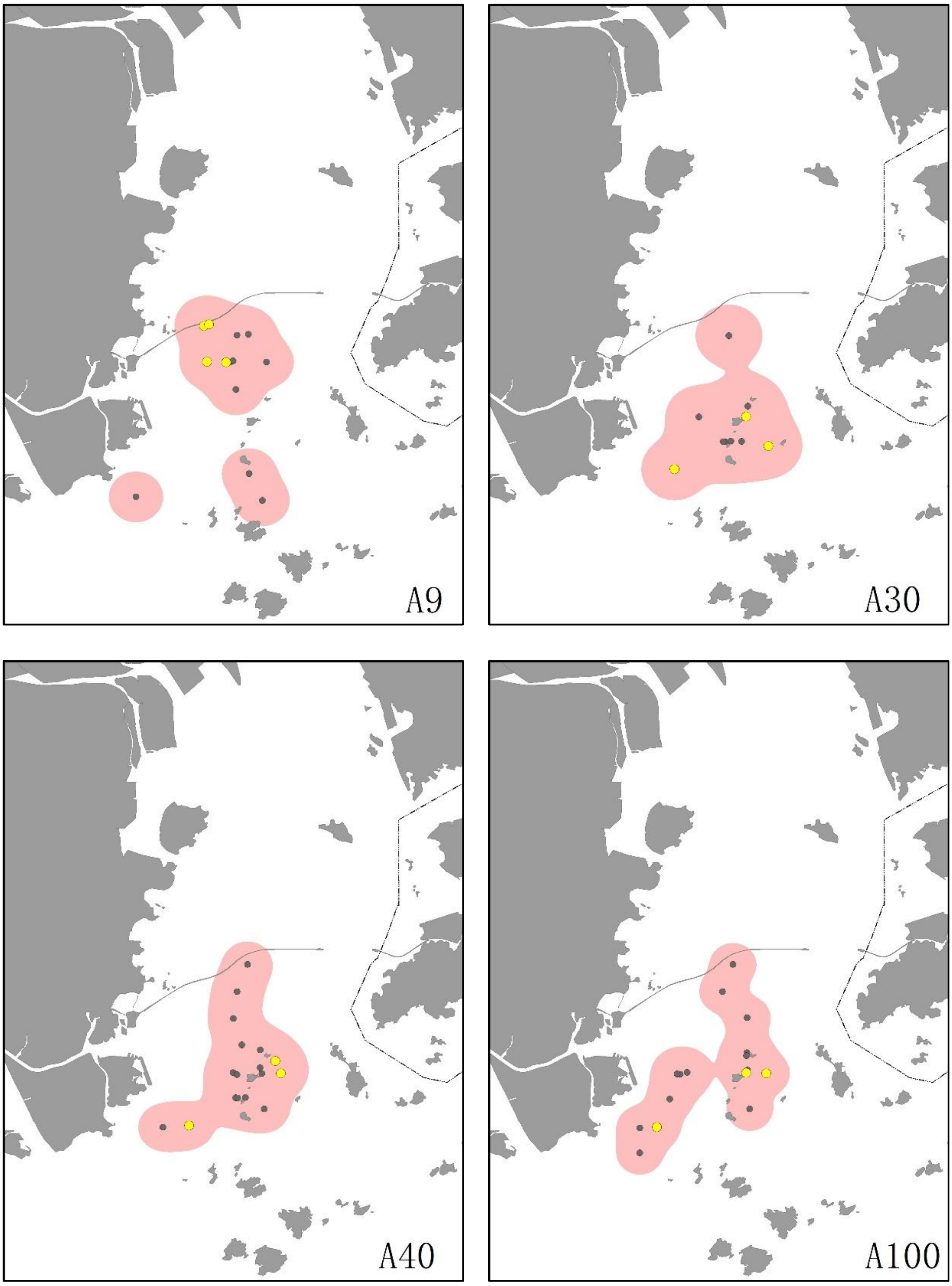


Figure 22. Examples of four individuals sighted during the 2024-25 surveys in Lingding Bay that have ranged mostly in southern part of Lingding Bay (yellow dots: sightings made in July 2024-June 2025)

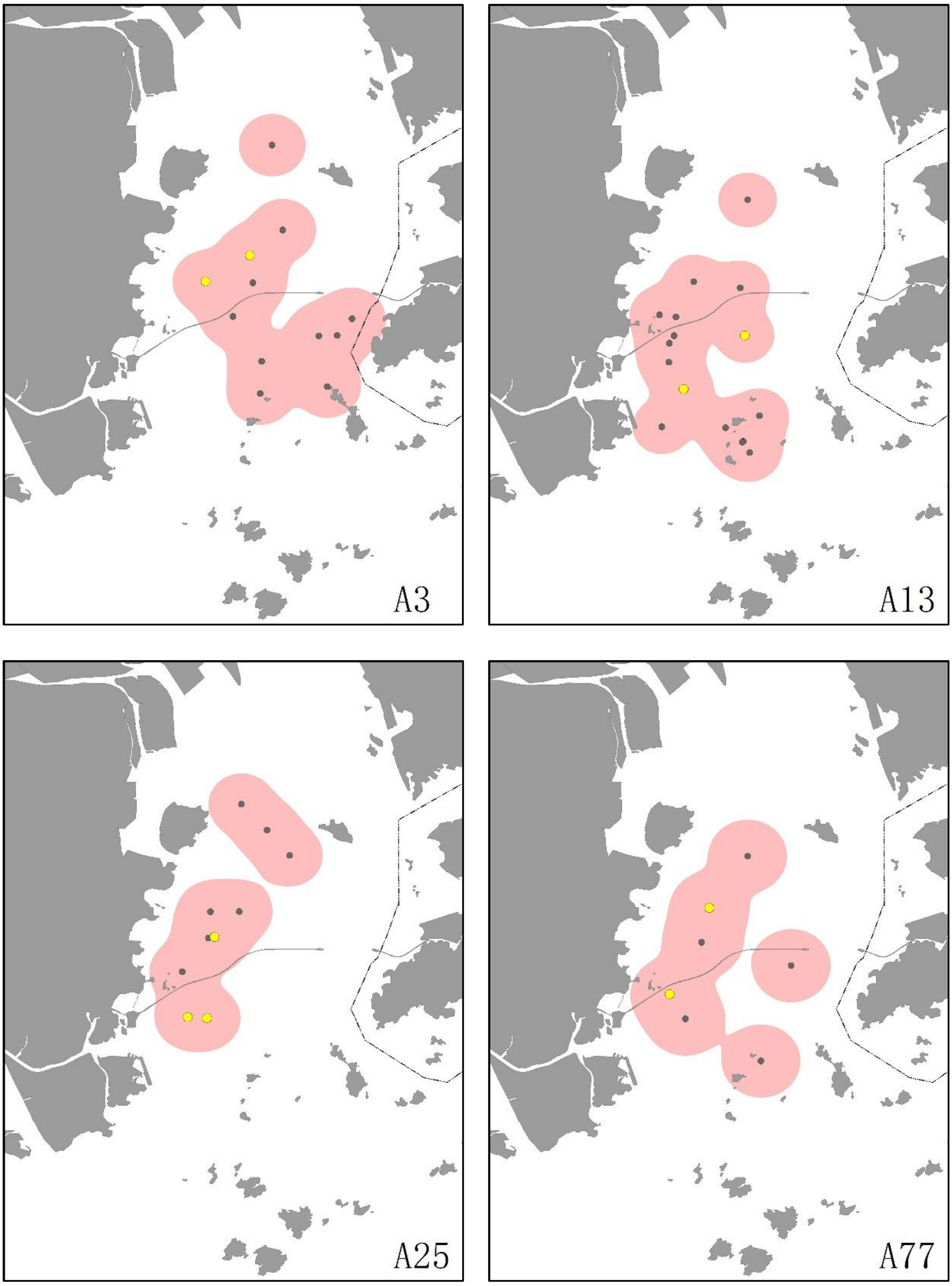


Figure 23. Examples of four individuals sighted during the 2024-25surveys in Lingding Bay that have spanned across different parts of Lingding Bay (yellow dots: sightings made in July 2024-June 2025)

Table 1. Survey effort and sightings of Chinese White Dolphins in Lingding Bay (July 2024-June 2025)

Surveys	Length of transect-lines (km)	Encounter groups	Encounter dolphins
Aug.2024	399.1	11	70
Sep.2024	397.8	19	83
Oct.2024	393.1	24	111
Dec.2024	381.6	17	70
Jan.2025	377.3	24	152
Feb.2025	380.7	24	82
Mar.2025	386.5	21	151
Apr.2025	384.7	22	107
May.2025	383.8	15	78
Jun.2025	395	20	115
Total	3879.6	197	1019

Table 2. Survey effort, number of groups and individuals of Chinese White Dolphins in all weather conditions and under calm conditions (Beaufort 0-3) in each of the survey areas in Lingding Bay (July 2024-June 2025)

Survey time	Survey areas	Survey Effort（km）		Encountered groups		Encountered dolphins	
		All states	Beaufort 0-3	All states	Beaufot 0-3	All states	Beaufort 0-3
Aug.2024	CLDB	137.3	109.9	0	0	0	0
	SLDB	138.4	87.0	2	0	4	0
	MA	78.8	78.8	9	9	66	66
	SWMA	44.6	44.6	0	0	0	0
	Total	399.1	320.3	11	9	70	66
Sep.2024	CLDB	135.6	135.6	3	3	24	24

	SLDB	129.0	124.5	9	9	43	43
	MA	88.2	83.4	6	6	15	15
	SWMA	45.0	45.0	1	1	1	1
	Total	397.8	388.5	19	19	83	83
Oct.2024	CLDB	130.3	130.3	6	6	29	29
	SLDB	130.8	130.8	11	11	47	47
	MA	83.7	83.7	7	7	35	35
	SWMA	48.3	48.3	0	0	0	0
	Total	393.1	393.1	24	24	111	111
Dec.2024	CLDB	132.1	132.1	6	6	36	36
	SLDB	119.8	108.4	8	8	31	31
	MA	88.5	24.2	3	1	3	1
	SWMA	41.2	25.6	0	0	0	0
	Total	381.6	290.3	17	15	70	68
Jan.2025	CLDB	134.3	134.3	5	5	16	16
	SLDB	115.3	115.3	10	10	92	92
	MA	85.8	85.8	9	9	44	44
	SWMA	41.9	41.9	0	0	0	0
	Total	377.3	377.3	24	24	152	152
Feb.2025	CLDB	131.9	131.9	10	10	37	37
	SLDB	129.1	129.1	10	10	29	29
	MA	77.0	77.0	3	3	6	6
	SWMA	42.7	42.7	1	1	10	10
	Total	380.7	380.7	24	24	82	82
Mar.2025	CLDB	136.2	136.2	3	3	5	5
	SLDB	128.1	128.1	10	10	72	72
	MA	82.0	82.0	8	8	74	74
	SWMA	40.2	40.2	0	0	0	0
	Total	386.5	386.5	21	21	151	151

Apr.2025	CLDB	137.0	137.0	7	7	35	35
	SLDB	133.3	133.3	11	11	59	59
	MA	74.1	74.1	4	4	13	13
	SWMA	40.3	40.3	0	0	0	0
	Total	384.7	384.7	22	22	107	107
May.2025	CLDB	132.6	126.5	4	4	24	24
	SLDB	140.2	124.9	4	4	25	25
	MA	72.1	72.1	7	7	29	29
	SWMA	38.9	38.9	0	0	0	0
	Total	383.8	362.4	15	15	78	78
Jun.2025	CLDB	131.6	131.6	2	2	10	10
	SLDB	137.9	120.1	11	10	81	74
	MA	78.0	78.0	7	7	24	24
	SWMA	47.5	47.5	0	0	0	0
	Total	395.0	377.2	20	19	115	108

Table 3. Estimates of abundance and associated parameters for Chinese White Dolphins in different survey areas in Lingding Bay (July 2024 - June 2025)

Survey area	***L*** **（km）**	***n***	***f*(0) km^{-1}**	***E*(*s*)**	***D*** **(100 km^{-2})**	***N***	**CV (%)**
CLDB （463.74 km^2）	1305.4	45	3.17	4.62	25.25	117	26.73
SLDB （515.68 km^2）	1201.5	81	3.17	5.64	60.27	311	19.66
MA （267.96 km^2）	739.1	60	3.17	5.00	64.31	172	20.10
SWAM (128.36 km^2)	415.0	8	3.17	10.25	31.31	40	52.11

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

Table 4. Estimates of abundance and associated parameters for Chinese White Dolphins in different survey areas in Lingding Bay (August 2018 - May 2019)

Survey area	***L*** **（km）**	***n***	***f*(0) km^{-1}**	***E*(*s*)**	***D*** **(100 km^{-2})**	***N***	**CV (%)**
CLDB （463.74 km^2）	1114.4	47	3.75	4.06	32.12	149	22.36
SLDB （515.68 km^2）	1263.9	67	3.75	5.45	54.12	279	20.44
MA （267.96 km^2）	619.6	33	3.75	5.61	55.96	150	24.87
SWAM (128.36 km^2)	264.8	5	3.75	7.20	25.48	33	79.11

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

Table 5. Estimates of abundance and associated parameters for Chinese White Dolphins in different survey areas in Lingding Bay (August 2017 - April 2018)

Survey area	*L* (km)	*n*	*f*(0) km^{-1}	*E*(*s*)	*D* (100 km^{-2})	*N*	CV (%)
CLDB (463.74 km^2)	1103.4	70	4.46	4.80	67.89	315	22.06
SLDB (515.68 km^2)	1093.1	59	4.46	4.85	58.33	301	20.34
MA (267.96 km^2)	626.7	47	4.46	5.32	88.93	238	28.66
SWAM (128.36 km^2)	336.8	8	4.46	1.13	6.01	8	70.20

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

Attachments

Attachment 1:

Auditor's Report and Financial Statement of the Project, Staff Record and Receipts are not disclosed due to confidentiality reasons.

Attachment 2:

Financial Position of the Project, Staff Record and Receipts are not disclosed due to confidentiality reasons.

Attachment 3：

Project asset list： No project assets. Photos are not applicable.