Marine Ecology Enhancement Fund (MEEF)

Declaration

To: The Secretariat of the MEEF

Reference No.: MEEF2017015C

Project Title: Conservation Ecology of Chinese White Dolphins across the Pearl River Estuary
Phase 3 (Cont.): Metapopulation Dynamics and Viability Analyses

Name of Project Leader: Dr Leszek Karczmarski

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, Dr Leszek Karczmarski

Date: 30 Sept 2021

(Updated on 30 Oct 2022 and 13 Feb 2023)

Marine Ecology Enhancement Fund (MEEF)

Conservation Ecology of Chinese White Dolphins across the Pearl River Estuary Phase 3 (Cont.): Metapopulation Dynamics and Viability Analyses

MEEF2017015C

Completion Report

30 Sept 2021
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Cetacea Research Institute

Executive summary

This current project represents a continuation of Phase 3 of a multi-year undertaking that over the past years has been gathering a quantitative body of evidence to establish scientifically-verifiable basis for formulating conservation priorities and strategize management recommendations for Chinese white dolphins across the Pearl River Delta (PRD) region. In the prior phases of this project, a great deal of data has been obtained which have advanced our understanding of the population's vital demographic metrics, which in turn provides insights into the processes that determine the population responses to environmental changes and anthropogenic pressure. We are now at the verge of reaching a stage of this multi-year effort where we can quantify with a considerable detail what determines the (meta)population long-term viability, and will soon be able to identify what represents biological management units.

All aspects of the project, including field data collection, analytical treatment and other project-related activities progressed well and on schedule, as per the amended scope and timeframe. The entire body of work advanced along the conceptual framework delineated at the onset of this multi-year undertaking. The current phase of the project maintained low-intensity surveys with a conscious effort to cover the entire geographic range of the Pearl River Delta (PRD) coastal waters with a comparable field effort, from Hong Kong in the east to Shangchuan/Xiachuan Islands at westernmost reaches of the region. Maintaining the photo-ID field effort served the primary purpose of securing the basic continuity of data-flow (which is vital for all intended mark-recapture analyses) and preventing major gaps in incidental but crucial data.

While a dataset from any specific individual phase of this multi-year undertaking is on its own insufficient for inferring any population-level indicators, as part of a larger multi-year work and benefiting from data obtained over the past years, the combined dataset allows to present our main findings in an extent indicative of the population processes and patterns. Based on the most up-to-date dataset, we quantified the dolphins' site fidelity within and between sections of the PRD region, estimated the individual dispersal and ranging patterns, computed the demographic connectivity across the larger coastal system, performed fine-scale assessment of socio-spatial dynamics and population parameters at the easternmost and westernmost reaches of the PRD, and depicted the socio-demographic population structure across the greater PRD region. Subsequently, by applying these population metrics (with the exception of genetic evidence), we have performed population viability analyses (PVA) to project its demographic trajectory.

Advanced movement analyses were performed using the latest synthesised dataset to examine the geographic fidelity and movement of Chinese white dolphins within and across the Pearl River Delta region. Current results indicate that in general the dolphins exhibit a considerable and likely long-term fidelity to spatially limited sections of the PRD coastal habitat, which corresponds with our previous preliminary findings and is consistent with the limited number of re-sightings of individuals between the three sections (Eastern, Middle,

and Western) of the PRD. Movement of individuals seldom exceeds few tens of kilometres, and movement between Eastern, Middle, and Western PRE appears to be sporadic and limited to only a handful of individuals. Throughout the PRD region, all dolphins exhibited the same general non-migratory pattern of ranging and dispersal. In other words, despite the lack of any obvious physical barriers in coastal waters of the PRD, individual dolphins use only a fraction of that region and depend for their daily lives on only a small section of this much larger estuarine habitat.

Our latest multi-state mark-recapture analyses of demographic connectivity indicate that the probabilities of inter-subpopulation transitions of Chinese white dolphins between the three PRD sub-regions are generally low, which is consistent with the cross-referenced photo-ID dataset and our findings from various movement analyses. In overall, the PRD dolphins exhibit high likelihood of staying in the same deltaic sub-region regardless of where the individuals were first identified. The very low yet non-negligible transition rates suggest limited but ongoing movement of a small number of individuals between the putative subpopulations, which appear to represent important vectors in maintaining a broader cohesion of the larger PRD metapopulation. All our latest quantitative evidence points to a complex picture of the PRD dolphins forming spatially distinct (three deltaic sub-regions) but not completely discrete demographic sub-units, with occasional cross-region transition of individuals as vectors that bridge the putative subpopulations, forming a heterogeneous metapopulation across the greater PRD coastal habitat.

In light of the latest multi-faceted assessment of the heterogeneous population structure, further demographic analyses were performed factoring-in the local spatial dynamics in the Eastern PRE. Spatio-demographic models indicate a notable heterogeneity in apparent survival rate estimates across Eastern PRE, where dolphins with spatial preferences to Hong Kong waters had higher survival estimates than those using primarily mainland waters. This fine-scale spatial heterogeneity in survival shows that Chinese white dolphins experience varied region-specific levels of stresses that impacts their survival to a different extent. Such fine-scale heterogeneity in survival rates as that reported here has never been reported elsewhere for Chinese white dolphins nor in any other coastal delphinids. The rarity of such data speaks volumes for the effectiveness of our research design and analytical diligence, as detailed demographic analyses are highly demanding in both data quality and quantity, and are only possible with long-term studies that are appropriately designed and executed. In overall, however, all our estimates of demographic measures indicate that these dolphins are under a tremendous anthropogenic stress.

Using the most up-to-date mark-recapture dataset and multifaceted socio-demographic analyses, we have substantially advanced our understanding of the socio-behavioural and demographic processes that underpin the population ecology of Chinese white dolphins at the westernmost reaches of the PRD region. The dolphin group dynamics appear to be substantially governed by demographic factors; in other words, over long temporal scales, the grouping pattern depends more on the presence (or absence) of individuals rather than social affinity between individuals. The spatial pattern of multiple social clusters in western

PRE illustrates a discernible socio-spatial structure, where individual ranging pattern and spatial preferences to specific foraging locations are the underlying driving force that determines the association patterns and shapes the social structure of this obligatory inshore species. Computational population models indicate that, despite the considerable size and substantial number of young dolphins, the survival rates are lower than the previously estimated threshold for long-term biological persistence of a viable population. Worryingly, these estimates are even lower than that at the easternmost reaches of the PRD, suggesting that the Western PRE dolphins are under substantial level of impacts, possibly combined effects of multiple stressors exerted over space and time.

Advanced social network analyses were performed to quantify the socio-demographic structure of Chinese white dolphins across the spatial scale of the entire PRD region. Eigenvector-based clustering algorithm was applied as it is more appropriate for non-hierarchical cetacean societies. The analytical results are well representative of the overall pattern and provide a far greater detail than ever accomplished in the PRD region (and in fact anywhere else across the geographic range of Chinese white dolphins). At least 25 social units were identified, including dyadic associations of individuals that move occasionally between sub-regions. These individuals are important as they play an major role in population connectivity. Among the identified social units, ten of them constitute a vast majority of individuals ever seen and catalogued during our multi-year field effort, and are likely to be the key population units across the PRD. However, they do not necessarily represent meaningful management units; instead, we anticipate that several of these socio-demographic units likely represent jointly a management unit. Further and more in-depth analyses are needed, however, to address this question conclusively based on well-funded evidence. The refined analytics – once completed with inclusion of genetic data – will be particularly important when applying our long-term findings to delineate management units.

With these most up-to-date population metrics in-hand, we examined the demographic population projections for Chinese white dolphins in coastal habitats of the PRD. At present, however, the analysis can only be presented without any measures of gene flow and sex-specific dispersal (a component that still has to be incorporated, as we have indicated on several previous occasions). Population viability analyses (PVA) were performed adopting the latest quantified metapopulation structure and measures of dispersal between putative subpopulations. All completed PVA model simulations indicate negative population growth rates, with a substantial risk of population fragmentation. In other words, the PRD population is on a steep downward slope in all projected demographic scenarios, where the entire PRD metapopulation and all its three putative subpopulations qualify as Critically Endangered (CR).

Our current results present convincing evidence that the metapopulation structure and the resultant socio-demographic dynamics are critical in modelling and understanding the population persistence. If the current evidence of metapopulation structure and connectivity was overlooked or ignored (i.e., the PRD dolphins be viewed as a homogenous single population without spatial substructure, as it was done in all previous assessments conducted in the region to date), the stochastic rate of population decline worsens to almost double that of the PRD metapopulation. In contrast, the dispersal between subpopulations (through individual movements) has a positive "rescue effect" on the overall persistence of a metapopulation and stabilise the local demographic dynamics. The dolphins travelling between the sub-regions, even if just a handful of individuals, are of paramount importance, not only as vectors of gene flow and to maintain the cohesiveness of the demographic structure, but in fact determining the fate of the larger metapopulation. However, it cannot be overstated that this natural buffering mechanism of metapopulation connectivity cannot be seen as a secure "safety valve", especially as movement between the eastern and western perimeters of the region has never been seen (all transitions take place between dolphins in neighbouring sub-regions only). A local extinction event (of any of the current subpopulation units) could set off a ripple effect leading to population fragmentation. Such turn of events would be of major conservation concern and a real nightmare for management efforts. For this reason alone, we emphasise that current PVA analyses have to be repeated/refined (hopefully in the final concluding phase of this project) once the currently missing genetic data is available.

The results generated by our work are the first of its type and highly significant in quantifying the metapopulation dynamics of the PRD dolphins and understanding their heterogeneous socio-demographic structure, and – importantly – understanding the implications of these newly documented dynamics on fundamental population processes. The metapopulation viability assessment of Chinese white dolphins across the spatial scale of the greater PRD, as per the original framework of this multi-year undertaking, is also the first such assessment anywhere in the species range. Although the PVA has to be repeated once the genetic data become available, it is already indicative of the overall demographic trajectory and should be seen as a cause for concern. The severity of this concern cannot be overstated, which once again underscores major implications of this multi-year project and the critical importance of having it fully completed (a concluding phase of this project is much needed).

Once fully completed, deliverables of this project will be instrumental in the delineation of population management units, which in turn will be highly informative for effective conservation efforts in the PRD region. Given the quality and quantity of our current results, we are confident that once fully completed, this project will provide an evidence-based framework to guide realistic conservation objectives and fine-tune management strategies that could effectively maximise their conservation outcome.

Caveats and disclaimer

Although delivering a considerable detail, this report presents still an interim phase of this multi-year research undertaking and as such – to avoid any potential misinterpretation – it should NOT be used as a scientific reference nor viewed as a research publication, nor used at this current stage for management recommendations. As per the originally envisioned project timeline, the next (final and concluding) phase of this ongoing work has to be completed first, before the pre-final findings presented here can be sufficiently validated and used for the intended purposes as envisioned in the conceptual framework of this project set forth and agreed on with MEEF Management Committee at the onset of this multi-year study.

Brief description of the Project

This current project reported here represents a continuation of Phase 3 of a multi-year undertaking that over the past years has been gathering a quantitative body of evidence to establish scientifically-verifiable basis for formulating conservation priorities and strategize management recommendations for Chinese white dolphins across the Pearl River Delta (PRD) region, from Hong Kong and Lingding Bay in the East to the westernmost reaches of the PRD. In the prior phases of this project, a great deal of data has been obtained which have advanced our perception of the population's vital demographic parameters, structure, and connectivity, which in turn exposes the processes that determine the population responses to environmental changes and anthropogenic pressure. The evidence collected to date indicates a complex metapopulation system which comprises of at least three sub-units (each of them seemingly representing a demographically distinct sub-population) with a dynamic network of interactions that is being currently examined. On a spatial scale (i.e., eastern vs. middle vs. western reaches of the PRD region), the sub-populations – even though socio-demographically distinct – are not entirely discrete and the degree of their connectivity is being currently quantitatively scrutinized by our ongoing work.

As we have discussed in the initial application for the current funding cycle, we are approaching a stage of this multi-year effort where we can quantify in a considerable detail what determines the (meta)population long-term viability and will soon be able to identify what represents biological management units. In other words, the work described in the current project is not simply a continuation of what we did in the 2019/20 but a considerable advancement where we take a next step in quantifying the metapopulation processes and set a ground for subsequent assessment of relevant conservation implications. Our work in 2020/21 differs from that of 2019/20 most notably in that we apply the findings of the prior funding year, especially the metapopulation structure and use them to quantify a region-wide metapopulation dynamics and eco-demographic viability. Quantitative understanding of the metapopulation processes and structure, and verifiable up-to-date population viability analyses (both of which have been identified recently as top priority by IUCN working group), are at the top of our priority list for the project's funding-cycle reported here.

More broadly, this multi-year project aims to assemble a considerable range of quantitative evidence that (i) is fundamental to the understanding of the conservation ecology of Chinese white dolphins, and (ii) will facilitate informed strategizing of evidence-based conservation priorities, as well as (iii) be instrumental in future delineation of scientifically sound management strategy. This type of work has been discussed many times in the past two-and-half decades but never previously undertaken nor even attempted. Once our work is completed as initially planned (a final concluding phase is still pending), the body of verifiable data generated and the overall outcome of this multi-year work will have no precedence anywhere in the species range, setting a benchmark for current and future research and conservation of Chinese white dolphins in the Pearl River Delta region and elsewhere in the Asia-Pacific eco-region.

Objectives of the current phase

- **Metapopulation dynamics, demographic structure, and socio-spatial connectivity of Chinese white dolphins across the PRE/PRD region:** Following up on our recent discovery of the socio-spatial structure of the PRD dolphin population and the presence of apparent subpopulation units (as indicated in the MEEF2017015B completion report), we will further quantify the inter-subpopulation transition rates, determine individual dispersal pattern through continuous space, and model the population's social network to quantify the socio-spatial connectivity between individuals and groups across the seascape of the PRD region. – *As per the adopted framework of this multi-year study, this objective is carried forward from the prior funding cycle of this project*.

- **Metapopulation viability analyses:** With the application of our recently determined (and to be quantified during this current phase) population-specific and sub-population-specific demographic parameters and measures of population structure, we will *(i)* conduct analyses of the metapopulation processes and trend, *(ii)* validate earlier population viability assessment (PVA), this time based on the most recent and – first ever for this species in this region – quantitative population indicators, and *(iii)* deliver population status assessment according to the IUCN criteria based on the most recent quantitative evidence. – *All the above, however, will have to be done without any measures of gene flow and sex-specific dispersal (as we will be lacking the initially intended genetic data). Consequently, albeit informative, the results will not be fully conclusive at this stage and the PVA may have to be refined/revised once the missing genetic component is completed and the relevant data is available. To deliver a fully conclusive assessment of the (meta)population for effective conservation management of Chinese white dolphins in the PRD region, this objective will have to be continued into the next phase of this project.*

Methodology

(a) Study area

Data collection followed the same field protocol as in the prior phases of this ongoing work (e.g. Chan & Karczmarski 2017; Lin *et al*. 2018) and was performed across the Pearl River Delta region (PRD), which refers to coastal waters of the entire estuarine system of the Pearl River, the second largest in China in terms of water discharge. In its lower reaches, the Pearl River branches into eight main outlets, four of which enter into the Lingding Bay (generally known as Pearl River Estuary), while further to the west the other four branches enter the South China Sea through Modao and Yamen Estuary. The project reported here covers the entire greater Pearl River Delta region, from Hong Kong in the east to Jiangmen in the west, including Eastern PRE (Hong Kong waters and Lingding Bay), Middle PRE and Western PRE (Modao Estuary and Yamen Estuary). At this stage of the project, while the fieldwork had to be reduced to low-intensity surveys, the field effort was balanced across the PRD region as much as the sea conditions allowed, in order to secure the data continuity and comparability.

(b) Field data collection

Fieldwork was performed by the means of boat-based photo-ID surveys that follow an internationally accepted field protocol (e.g. Hammond *et al.* 1990), as in similar studies by the PI elsewhere (e.g. Karczmarski 1999, Karczmarski *et al.* 2005). Digital images of dorsal fins were taken using high-speed digital cameras (Canon EOS series) equipped with image-stabilized lens of variable focal length (zoom 100-400mm). Good quality photographs of the upper body and identifiable dorsal fin of a dolphin constitute the marking/recapture event that can be used for subsequent capture-mark-recapture analyses. Individuals were identified by means of assessing various individually characteristic external features (e.g. Hammond *et al*. 1990), primarily pigmentation pattern and distinctive notches on the trailing edge of a dorsal fin and dorsal ridge (e.g. Karczmarski & Cockcroft 1998), as in recent study by Chan & Karczmarski (2017) and following standard laboratory procedures, including assessment of image quality and the distinctiveness of an individual to minimize unequal catchability related biases (e.g. Friday *et al.* 2000; Karczmarski *et al.* 2005).

(c) Analytical techniques

<u>Movement analyses</u>

Using geographically-referenced individual sighting histories, movement of individuals were modelled and compared between the Eastern PRE (EPRE), Middle PRE (MPRE), and Western PRE (WPRE) sub-regions. A suite of movement analyses, including the estimation of lagged identification rates, transition rates between areas, and movements in continuous space, were performed using SOCPROG 2.8 (Whitehead 2009).

<u>Site fidelity</u>

To quantify the site fidelity of individuals in a particular area, single-area lagged identification rates (LIRs) (Whitehead 2001) were calculated for EPRE, MPRE, and WPRE sub-regions separately. The resultant single-area LIRs represent the probability of an individual being re-sighted in the specific sub-region of the PRD a certain time-lag after its first sighting in that sub-region. Movement models were generated and fitted to the data, and the best model(s) were selected based on Akaike Information Criterion (AIC) (or quasi-likelihood AIC, QAIC) (Whitehead 2007). Bootstrap method was used to estimate standard error and 95% confidence interval of the observed data and the movement model projections (Whitehead 2007).

Multiple-area LIRs were also calculated to quantify individual probabilities of being re-sighted in the same area *vs*. any other area over a time lag (Whitehead 2001). Consequently, the multiple-area LIRs reflect the overall site fidelity of individuals within and between the three sub-regions. Subsequently, movement models were fitted to the observed data and the best models were selected in the same manner as above (Whitehead 2007).

Transition rates between areas

To quantify the transition rates between the sub-regions, the parameterised Markov movement models were applied in SOCPROG 2.8 (Whitehead 2009), to estimate the probabilities of individuals moving from one area within the PRD to another over a sampling period (Whitehead 2001), with Poisson approximation to maximise the likelihood (Hilborn 1990). The sampling period were set in years, thereby the resultant transition probabilities were estimated in annual rates. Bootstrapping method with 1000 replications were performed to estimate the standard errors.

Individual movement in continuous space

Diffusion rates depict the rate of spread of individuals through continuous space (across the PRD) under the assumption of uncorrelated random walk and absence of physical barriers. Individual diffusion rates and mean-squared displacements were quantified over time lag in days in SOCPROG 2.8 (Whitehead 2009) using the modified likelihood method developed by Whitehead (2001), which was specifically designed to account for irregular sampling effort in mark-recapture photo-ID studies. Jackknife method was used to estimate the standard errors of the parameters.

Social dynamics

Social analyses were performed using SOCPROG 2.8 (Whitehead 2009). Half-weight association index and relevant statistics (HWI; Cairns and Schwager 1987; Weko 2018) were applied as a measure of association strength between individuals. Permutation tests were performed to examine the significance of long-term social preferences in the observed association pattern in contrast to random associations of individuals (Bejder et al. 1998; Whitehead 2008). The association matrix was repeatedly permuted by inverting rows and columns randomly chosen within the observed matrix of individual associations. Subsequently, the permuted random association matrix was compared with the observed association matrix generated by the field-gathered data. The number of required permutations was determined by increasing the number of permutations until the P-value for the comparison of the standard deviations of the random and observed association matrices has stabilised (Bejder et al. 1998). Higher SD of the observed association matrix than that of the random association matrix with a P-value < 0.05 is indicative of significant long-term preferential grouping pattern (Whitehead 2009).

Socio-spatial structure and connectivity

Group-living animals frequently form social clusters, where associations among individuals in the same cluster are stronger and more frequent than those with individuals from other clusters (Whitehead 2008), which has major consequences for demographic processes and population connectivity (Andrews et al. 2010; Chabanne et al. 2017), and carries significant management implications (e.g. Mills 2007; Blumstein 2010; Snijders et al. 2017). Following the conceptual framework of Whitehead (2008), the clustering of individuals was measured by modularity (Q), which is calculated as the proportion of the total association within clusters minus the expected proportion of random associations (Newman 2004). A Q-value that approximates zero suggests weak clustering pattern, while $Q \geq 0.3$ indicates differentiation between clusters that is likely rooted in the preferential social grouping and may indicate functional social units (Newman 2004). Both agglomerative and eigenvector-based cluster analyses were performed to assess the social structure of the entire PRD metapopulation.

Mark-recapture analyses

Based on our latest findings indicating a metapopulation structure for the dolphins inhabiting the PRD region, a suite of open population mark-recapture models was performed using program MARK (White and Burnham 1999). Sighting histories of naturally-marked distinctive individuals were pooled together by years as annual sampling occasions. Multi-state model (Arnason 1972, 1973; Schwarz et al. 1993) and POPAN formulation of Jolly-Seber model (POPAN model for short; Schwarz and Arnason 1996) were applied to investigate the dolphin (meta-)population dynamics across the greater PRD region.

Goodness-of-fit (GOF) tests for mark-recapture models were performed using program U-CARE to identify the most parameterised general model with adequate fit of data (Choquet et al. 2009; Pradel et al. 2003). Variance inflation factor ($\hat{c}$), as the measure of overdispersion of data, was estimated and incorporated in the selection of candidate models to account for the overdispersion of data ($\hat{c} > 1$).

Multi-state model was applied to estimate the state-specific survival rates (S), recapture probabilities (p) and inter-state transition probabilities (ψ) of the dolphins across the PRD region. In additional to the state effect, other effects were also incorporated to construct a suite of candidate models, including age class effect ('Age'), time-dependent effect ('t'), constant over occasions ('.'), survey intensity ('effort'), and time-since-marking (TSM) effect ('a2') on apparent survival rate (also known as the 'transient effect'). The best candidate models were selected according to the corrected Akaike Information Criterion (AICc) or quasi-likelihood AICc (QAICc).

All sighting histories of naturally-marked, distinctive and individually identifiable dolphins were divided into EPRE, MPRE and WPRE (putative) subpopulations, and POPAN models were applied to estimate the super-population sizes (N). A variety of effects, including age class effect ('Age'), time-dependent effect ('t'), constant over occasions ('.') and survey intensity ('effort'), were incorporated in constructing the candidate models, which were selected based on AICc/QAICc. Subsequently, mark-ID ratio (θ) was estimated to project the total population sizes (N_T): $\widehat{N_T} = \hat{N} / \hat{\theta}$, where the variance of total population size is estimated following Urian *et al.* (2015):

$$var(\widehat{N_T}) = \widehat{N_T}^2 \left(\frac{var(\hat{N})}{\hat{N}^2} + \frac{var(\hat{\theta})}{\hat{\theta}^2} \right)$$

and the lower and upper log-normal 95% confidence intervals are calculated as $\widehat{N_T^{lower}} = \widehat{N_T}/C$ and $\widehat{N_T^{upper}} = \widehat{N_T} \times C$, where $C = \exp\left(1.96\sqrt{\ln\left(1 + \frac{var(\widehat{N_T})}{\widehat{N_T}^2}\right)}\right)$ (Burnham *et al.* 1987).

(Meta-)Population viability

Several years ago, our research team conducted an early-stage (and the only ever done in the region to date) viability analysis on the PRD dolphins based on life-history parameters (see Huang et al. 2012). This analysis, however, although based on the best information that could have been gathered at the time, was quite basic; it did not address any potential population structure and/or connectivity, and much of the demographic parameters used were (i) not up-to-date (as up-to-date data was not available at the time), (ii) spatially biased to Hong Kong/EPRE sub-region, and (iii) several of the parameters had to be adopted from published parameters of other species of similar life history elsewhere as those for Chinese white dolphins and for the PRD region were not available at the time. Currently, thanks to our multi-year research undertaking (largely supported with the MEEF funding) and the pace with which our study accomplished intended targets, much of the population-specific (and/or subpopulation-specific) demographic parameters and measures of population structure are now clearly emerging. With this data in hand, we have re-run and updated the population viability assessment (PVA) based on the most recent demographic indicators. However, this could only be done without any measures of gene flow and sex-specific dispersal (as we were forced to abandon the genetic component of the project, initially intended for this current phase reported here). Consequently, albeit informative, the results are not yet fully conclusive at this stage and the PVA will have to be repeated/ refined once the currently missing genetic data is available.

To project and compare the population trend of the PRD Chinese white dolphins, individual-based PVA models were performed using the program VORTEX (version 10.2.9, Lacy and Pollak 2017). While – according to our current demographic evidence – the metapopulation model delivers the most accurate representation of the population processes in the PRD region, we also ran simulations using our up-to-date mark-recapture estimates for a hypothetical homogeneous PRD population without any subdivisions to demonstrate the differences and biases in the results generated from a much simpler approach (such as that of our earlier attempt ten years earlier; Huang et al. 2012).

For each scenario, 1000 iterations of simulation were run over a time scale of 100 years. From the inputted demographic parameters, generation times and deterministic population growth rates were calculated for each of the putative subpopulations and for the PRD metapopulation as a whole, as well as for the hypothetical PRD homogeneous population. In contrast, stochastic rates of population growth were estimated from the individual-based simulation results which take stochasticity and dispersal into account, and were therefore more realistic in reflecting the changes of the modelled demographic units (Lacy et al. 2017). Extinction was defined as the stage when only one sex remains in the population. Over 1000 iterations of model simulations, the fluctuation of population size and the probability of extinction were projected across time-scale. The percentages of extant population size after three generations were estimated. The risks of extinction were assessed according to the IUCN Red List Categories and Criteria Version 3.1 (Criterion A3, IUCN 2001) (e.g. Currey et al. 2009; Huang et al. 2012).

Completed activities against the proposed work schedule

All photo-ID mark-recapture work progressed as intended, timely and on schedule along the amended timeline of the project.

In the meantime, analyses were performed based on the currently updated and synthesized dataset. Furthermore, recently initiated cross-referencing of the PRD dolphin database with individual-ID datasets elsewhere in China was completed and currently includes fully cross-matching with three other populations of Chinese white dolphins in southern China and one population north of the PRD region. Jointly, this effort represents an important building block within the framework of our larger multi-year undertaking, and an important steppingstone in the application of our data while preparing for an appropriate final phase of this project and its successful conclusion.

Activities completed during the project period reported here are summarised in the following table, and presented in a greater detail further in this report.

Summary table of completed activities:

Categories of activities	**Key-points**
Recruitment of new Senior Researcher	• A new member of a research team was recruited, on a level of Senior Researcher, and the appointment was arranged soon after the confirmation of the Project by MEEF-MC. The new team member is well-familiar with all aspects of our field protocol and is well-versed in socio-behavioural analyses.
Photo-ID field surveys	• Whenever the sea conditions allowed, which was rather infrequent during the project-period reported here as it was already past the main 2020-field survey season, sea-based fieldwork was performed with a conscious effort to cover the entire greater Pearl River Delta region. • A total of 20 boat-based photo-ID surveys were carried out with 81 dolphin groups encountered and 374 individual sighting-records collected.
Photo-ID data processing	• Processing of photo-ID and associated data advanced along the intended timeframe, and rigorous data scrutiny was intensified when field surveys were limited due to unfavourable sea conditions. • The currently applied field and lab protocols test well for the quality control of all collected data and the continuity of data gathering with consistent standards, assuring the comparability (and analytical replicability) of all data collected to date across the entire PRD. • As indicated previously, the processed mark-recapture and spatial data, combined with datasets from prior phases of this MEEF-funded project, represent the backbone quantitative information for the primary analyses, currently performed and forthcoming, within the framework of this multi-year undertaking.
Data synthesizing / modelling	• Cross-referencing of photo-ID data across the greater PRD region has progressed well and timely, as intended. The data synthesizing process is at a very advanced stage that can

	facilitate informative interim analyses. However, as the advancement of the project (including some analytical components, such as genetics) during 2020-2021 has been negatively affected (as indicated above and further in this report), a substantial part of data synthesising process will have to be extended beyond the originally envisioned timeframe. It is highly important to have it completed, however, in order to generate sufficiently conclusive deliverables. • Based on the latest cross-referenced dataset, there is only a small number of individuals (a few tens) that were identified in more than one sector (Eastern *vs.* Middle *vs.* Western) of the PRD, and none was ever recorded moving across the entire PRD coastal region. This is the first ever and an important indication that dolphins in the PRD form spatially distinct but demographically not fully discrete sub-units, and the population structure is likely heterogeneous with dynamic but limited connectivity. It is the extent of these dynamics that is now of crucial importance, as it defines the socio-spatial population structure and, consequently, it is among the primary determinants of population viability. Reliable models and accurate estimates of these dynamics are of paramount importance for the outcome of our work, and among the top priorities of this project. • As part of a recently initiated collaborative effort of cross-referencing dolphin-ID datasets in China, we completed a cross-match of the PRD database with photographic catalogues of Chinese white dolphins collected to date in Leizhou Bay, Sanniang Bay, and off Hainan Island (a total of over 3,000 catalogued individuals) and in coastal waters of Xiamen, and have found no re-sighting of a single individual among the five putative populations.
Data analyses and write up	• Using the most up-to-date synthesized PRD dataset, advanced analyses of individual site fidelity (by computing lagged identification rates) suggest a considerable long-term geographic fidelity of the dolphins to spatially limited sections of the PRD coastal habitat. Although our models factor in the process of emigration and re-immigration of individuals and the impact of dolphin mortality (either natural or anthropogenic), the chance of re-identifying individuals in a different sub-region of the PRD is low and remains so despite increased sample size and larger dataset

	(corresponding to the limited number of individuals seen in multiple sectors). • Dispersal models that project the temporal pattern of dolphin range expansion over a continuous space indicate that all PRD dolphins, regardless of the section of the PRD in which they were seen (or moved between), exhibit a non-migratory and highly limited dispersal pattern. Individual spatial displacement appears to be restricted and notably smaller than the spatial ranges of their respective subpopulations. The magnitude of displacement and the rate of diffusion differ between individuals and between the three sub-regions of the PRD coastal waters. Dolphins seen in more than one sector exhibit the greatest spatial dispersal (as expected), and this limited number of individuals appear to represent the vectors maintaining the metapopulation connectivity. • Multi-state mark-recapture models were performed to provide estimates of transition probabilities of individuals between the putative subpopulations. The probabilities of transition, which are estimated in annual rates, serve as a quantitative measure of inter-subpopulation movements. While most individuals remained within spatially limited sections of the PRD coastal habitat throughout the entire timeframe of the multi-year database, exceptionally low but non-negligible transition rates indicate a limited but ongoing spatial connectivity between the dolphins in the three sectors (Eastern, Middle, and Western) of the PRD. These results, although still interim at the current stage, show great similarities to the estimates generated by the parameterised Markovian movement models. These converging results of a multifaceted approach add to the analytical confidence and thus warrant a successful accomplishment of the intended objectives of this project in its final (currently under preparation) phase. • In light of the latest multi-faceted assessment of the heterogeneous population structure, further mark-recapture analyses were performed to investigate demographic parameters of the Eastern PRE subpopulation, factoring-in local spatial dynamics. Agglomerative hierarchical clustering (AHC) analyses indicated that in Eastern PRE, dolphins display a further heterogeneous regional sub-structure relative to spatial preferences across this coastal habitat. This finding has been factored-in when constructing the

	Cormack-Jolly-Seber (CJS) capture-recapture models, which substantially improved the model performance and its fit to the data gathered in Eastern PRE. • Benefiting from this approach, modelling results indicate a notable difference in survival rates across the HK-China administrative border; dolphins with spatial preferences to Hong Kong waters exhibited notably higher survival rates than those using primarily mainland waters. In overall, however, their survival rates were below the known survival threshold that can ensure their long-term biological persistence, indicating that these dolphins are under a tremendous anthropogenic stress. This once again highlights the critical importance of Hong Kong waters (especially off southwest Lantau) as important habitat refuge (seemingly last such habitat refuge in Hong Kong waters) that plays a critical role in sustaining dolphin's daily needs in the Eastern PRE (and by extension, that of the dolphin metapopulation across the greater PRD). -- It is also worth mentioning that this level of fine-scale heterogeneity in survival rates within a subpopulation has never been reported in elsewhere in other coastal delphinids. Detailed demographic analyses such as ours are only possible thanks to the long-term, well-planned and thoroughly-executed field data collection across a multi-year time-scale. • The latest mark-recapture abundance analyses indicate that the maximum possible number of Chinese white dolphins in Eastern PRE approximates ~900 individuals; but a more conservative (realistic) estimate that factors-in mortality across years, brings this number down to ~700 dolphins. In either case, however, the extant number of dolphins in the Eastern PRE is undisputedly lower than previously suggested, which has seemingly plummeted due to a combined effect of low survival and limited recruitment into the subpopulation in face of the multitude of anthropogenic pressure in the region. • Based on the latest up-to-date and synthesized mark-recapture dataset, we conducted multifaceted socio-demographic analyses of Chinese white dolphins at the westernmost reaches of the PRD, and have quantified the population spatial characteristics and demographic parameters.

	• As often seen in a fission-fusion animal society, the fabric of connections within this subpopulation is generally fluid but non-random. Advanced analyses of group dynamics indicate that the temporal pattern of group formation and individual associations is largely governed by demographic processes. In other words, it first depends on the presence/absence of other dolphins, and then amongst those available potential associates, individuals choose their affiliates based on either inter-individual social affinity or similar spatial preference of foraging locations (the latter appears more likely as a pattern). • The above finding corresponds with the socio-spatial dynamics of the Western PRE dolphins, as depicted by social cluster analyses. Two contrasting techniques were applied, and despite the methodological differences, both provide concurring evidence that there is a well discernible socio-spatial structure comprising of multiple clusters that are socially well inter-connected with varying spatial preferences, albeit with overlapping ranges. • Advanced capture-mark-recapture modelling analyses, with the aid of goodness-of-fit (GOF) tests and likelihood-ratio-tests (LRTs), were performed to provide estimations of the key population parameters. POPAN mark-recapture models suggest that >900 dolphins inhabit the westernmost reaches of the PRD region, with notably more juvenile individuals than that in Eastern PRE. This might suggest a higher reproductive rate as compared to the rest of the PRD system; yet another indicator that the PRD dolphin population is not as homogeneous as previously assumed but rather comprises of spatially differentiated sub-units. • After accounting for any potential bias of transience (less frequently seen individuals), the estimated rate of survival in Western PRE was alarmingly low (even lower than that in Eastern PRE). The low estimates of survival rates came as surprise, as western reaches of the PRD region have long been thought to be under lesser anthropogenic pressure than the heavily urbanised and industrialised Eastern PRE. This seems indicative of a substantial level of threats to these animals, many of them not yet quantified nor even identified, even though coastal waters of Western PRE are vast and seemingly less polluted and more productive in terms of fish resources than Eastern PRE.

	• Adopting the latest quantified metapopulation structure and measures of dispersal between subpopulations, the population viability analyses (PVA) were performed to project the metapopulation trajectory and assess the conservation status of Chinese white dolphins in the PRD region. • All PVA model simulations indicate negative rates of population growth, i.e., the PRD population is on a steep downward slope in all demographic scenarios considered and projected over the next 100 years. However, if the metapopulation structure was to be disregarded (which was the underlying assumption in all previous assessments), it would falsely double the decline rate and substantially inflate the probability of extinction. On the contrary, the dispersal between subpopulations (through individual movements) has a positive "rescue effect" on the overall persistence of the metapopulation. Despite the very limited transitions between subpopulations, the ongoing individual dispersal appears to stabilise (though to a limited extent) the local demographic dynamics. In other words, the dolphins travelling between the sub-regions of the PRD, even if just a handful of individuals, are of paramount importance not only as vectors maintaining the cohesiveness of the demographic structure, but also as a key factor determining the fate of the larger metapopulation. -- It has to be underscored, however, that the positive effect of individual dispersal on the population dynamics is not likely to reverse the fast declining trajectory of the population. In other words, the "rescue effect" of metapopulation dynamics enhances the overall biological viability of the PRD dolphins in face of mounting anthropogenic pressure. It is not a sufficient "safety valve" on its own, however, and will not secure the long-term survival of the PRD dolphins as a viable demographic unit in the absence improved survival rates and greater recruitment into the (meta)population. • While the interim PVA results indicate that all three putative subpopulations are declining, the dolphins in the Middle PRE waters are declining in numbers most rapidly, with a very substantial likelihood of local extirpation. Should this happen, it will have a fundamentally detrimental effect on the PRD dolphins as it will fragment the population and distort the current metapopulation dynamics across the PRD. Currently, the dolphins in Middle PRE play a critical role in

	bridging the Eastern and Western subpopulations. A local extirpation in the Middle reaches of the PRD would likely set off a series of chain reactions: the positive "rescue effect" would be removed as the connectivity across the PRD would be either drastically reduced or (most likely) terminated, and the impact of inbreeding depression may kick in, thus exacerbating the extinction risk for the remaining two isolated populations. • Our current PVA assessment was performed without any measures of gene flow and sex-specific dispersal (as the genetic component envisioned in the original project framework was lacking). Consequently, albeit informative, our current PVA results are not fully conclusive at this stage and the viability analyses will have to be repeated/refined once the missing genetic data is available. • Our current PVA analyses indicate once again that dolphin conservation in the PRD cannot focus only on local dolphin groups or specific core areas, but has to involve a regional maintenance of the metapopulation dynamics. The process of population fragmentation is likely already underway. If it ever occurs, it will be detrimental, likely lethal to the persistence of the PRD (meta)population. In that context, it is hard to overstate how critical is the task undertaken by our project and the importance of having it completed with all initially set goals and objectives.

Images taken during field surveys in the PRD region

The photographs below (Fig. 1–9) provide pictorial illustrations of dolphin encounters, field conditions and fieldwork activities during sea-based photo-identification surveys of Chinese white dolphins conducted across the greater Pearl River Delta region throughout our multi-year undertaking.

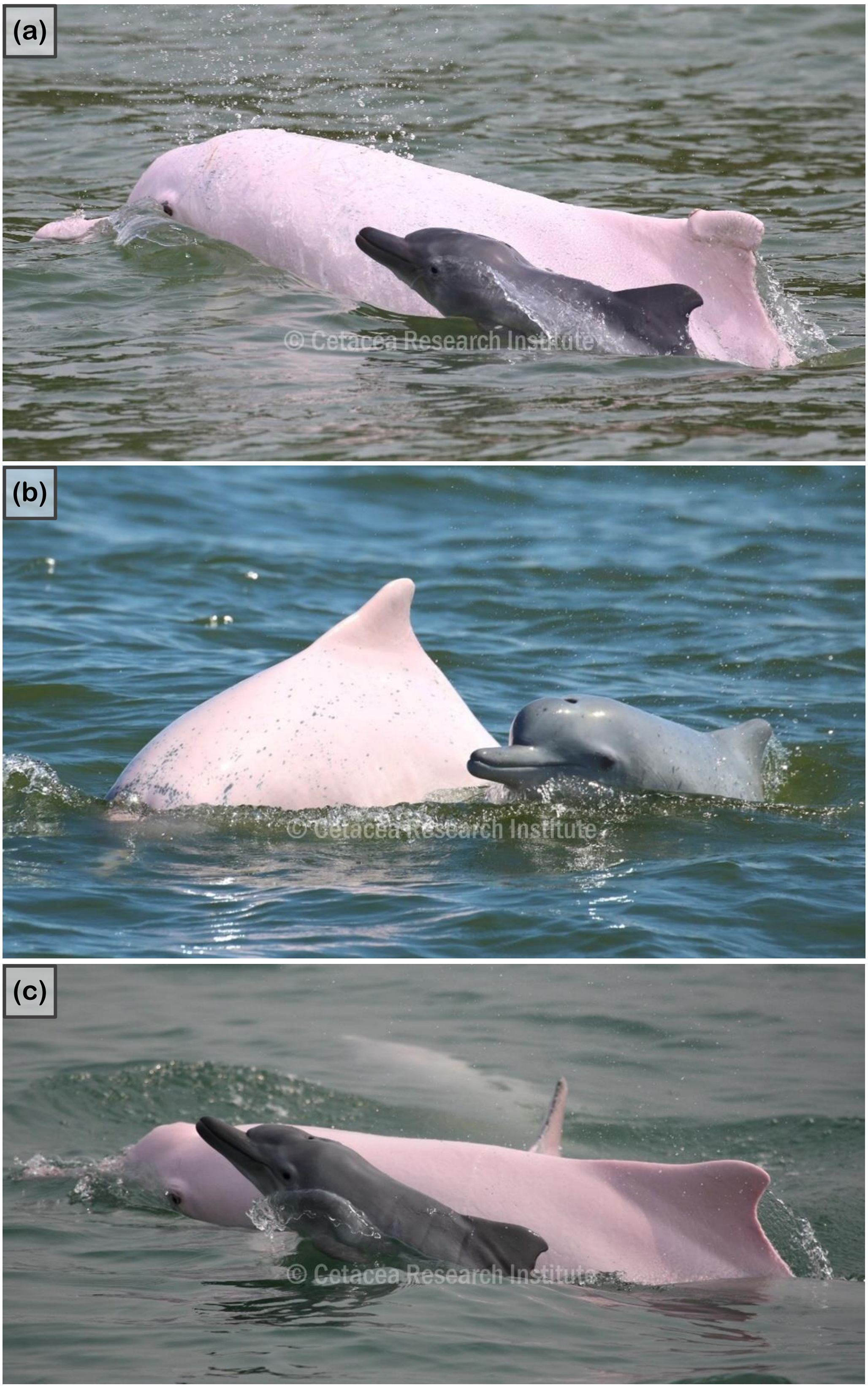


Figure 1. Births, deaths and recruitment to the population.

(a) While newborns are generally unmarked and cannot be individually identified, photographic records of mom-calf associations (with distinctive / re-identifiable moms) constitute the key data for estimating birth rates.

(b) The PRD dolphin metapopulation is a complex, heterogeneous demographic system. Our region-wide photo-ID data indicates that the proportion of young individuals (calves and juveniles) is considerably higher at the westernmost reaches of the PRD region.

(c) In contrast, at the eastern perimeter of the region (between Hong Kong and Zhuhai), the number of newborns is notably low, an alarming indication of low birth rates and/or high mortality rates of young calves.

Figure 1 (*cont.*). Births, deaths and recruitment to the population.

(d & e) Newborns and young calves are most susceptible to the multitude of stressors in the PRD waters. The first-borns to young females are especially vulnerable, due to the transfer of large volumes of accumulated heavy metals and variety of organic pollutants from the mother to calf through lactation.

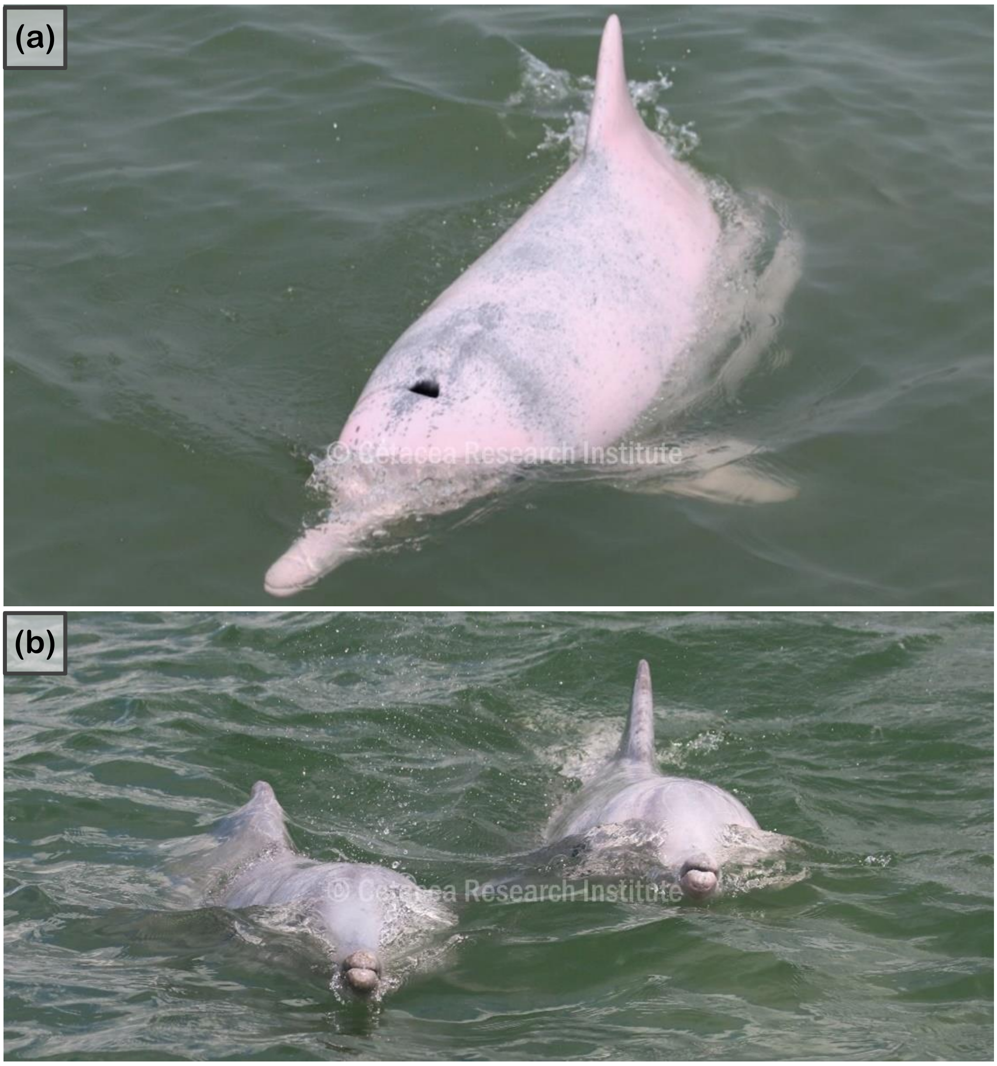


Figure 2. Dolphins approaching research vessels.

(a & b) During our photo-ID field surveys, dolphins often exhibit inquisitive behaviour approaching our research vessel, especially juveniles and young adults. Never any notable boat-avoidance was detected – largely thanks to the manoeuvring skills of our skipper and the understanding of dolphin behaviour. This is of critical importance to ensure equal catchability of all individuals encountered, and thus the quality and comparability of long-term photo-ID data across the region.

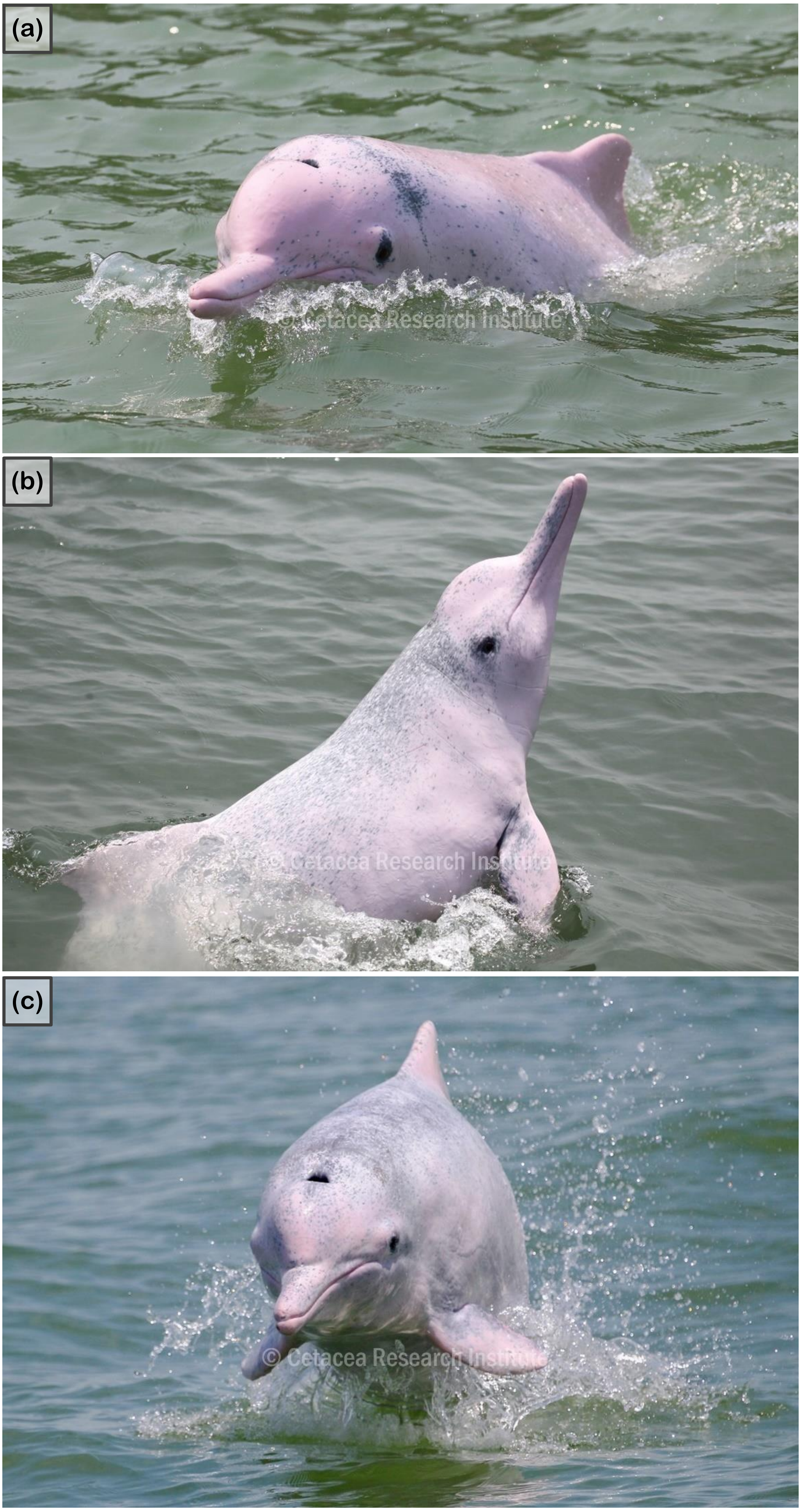


Figure 3. Chinese white dolphins engaging in various behaviours.

(a) An adult dolphin surfacing next to research vessel with no signs of boat avoidance.

(b) While engaging in foraging activities, Chinese white dolphins are often seen performing airborne behavioural displays such as head-slapping (as shown in this example) and breaching.

(c) Although Chinese white dolphins are a relatively slow-moving cetacean (compared to, for example, the more elusive finless porpoises that can also be seen in PRD waters), they are sometimes seen leaping repeatedly (behaviour known as "porpoising") while fast travelling towards foraging sites or evading disturbance.

Figure 3 (*cont.*). Chinese white dolphins engaging in various behaviours.

(d) A young adult dolphin displaying a rare high-leap which is seldom seen in this species. Note that the individual suffered a considerable physical injury at the dorsal fin, likely due to incisions by fishery gear (e.g., fishing lines).

(e) A subadult dolphin performing a lateral leap, an airborne behavioural event associated with foraging and/or socialising.

(f) A fully grown adult, likely 30+ years of age, with an entirely pink/white body and almost no pigmentation.

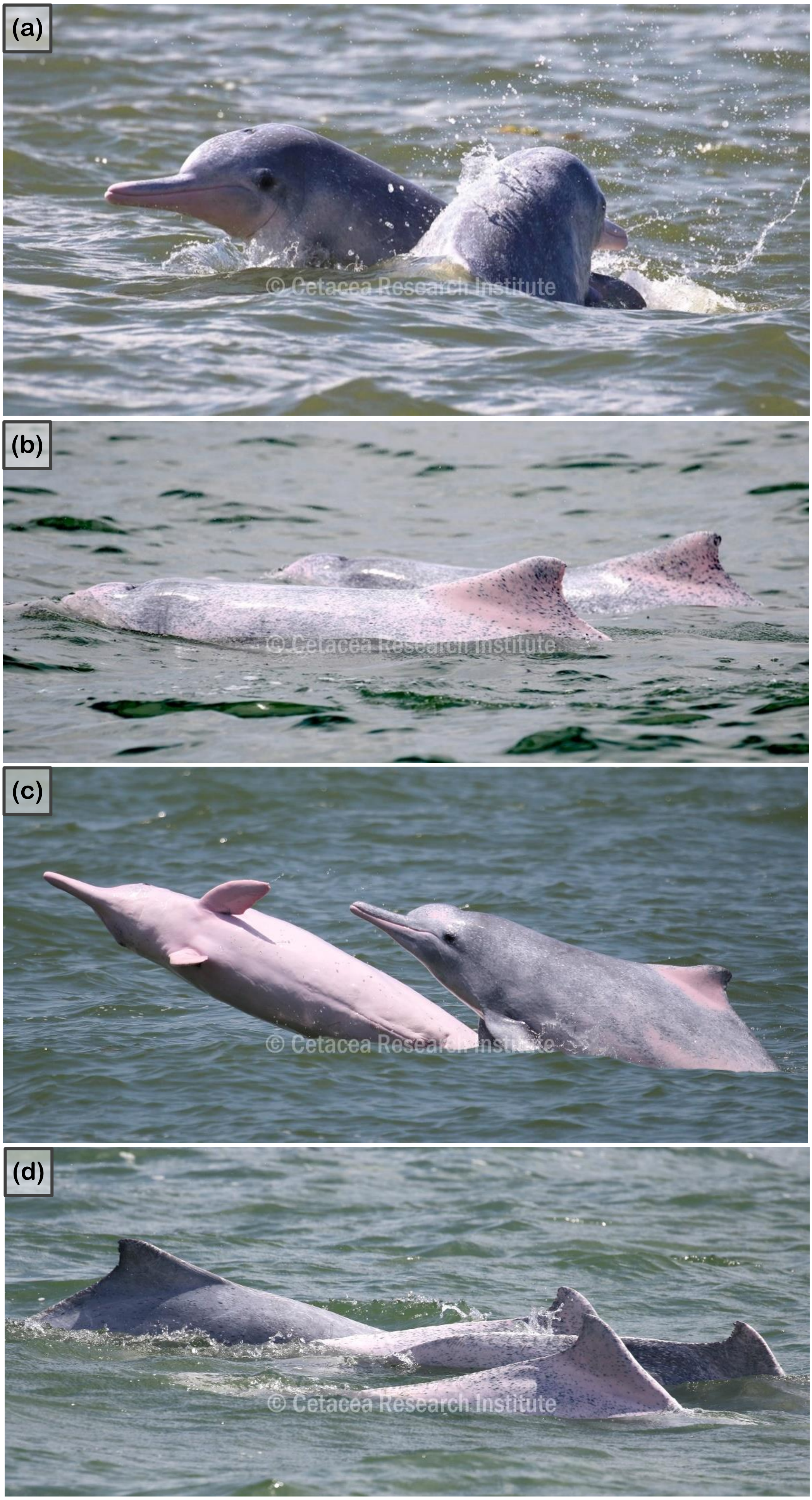


Figure 4. Group dynamics of Chinese white dolphins.

(a) Two juvenile dolphins seen socialising. Chinese white dolphins inhabiting the Pearl River Delta region live in fission-fusion societies, with fluid group dynamics and frequently changing group membership.

(b) A group of two dolphins in close parallel position, providing a good opportunity for photo-capturing both individuals. Photo-ID technique offers a powerful and non-invasive means to collect data on inter-individual associations, which are the fabric forming the socio-demographic structure of the larger metapopulation.

(c) Dolphins in a foraging group. In waters of eastern PRE, the dolphin groups are generally small in size (usually 3-4, and seldom more than 10 individuals). However, substantially larger foraging groups / aggregations are often seen in the western PRE; yet another indication of a heterogenous structure of the PRD dolphin population.

(d) Our long-term photo-ID database and multiple lines of analytical evidence point to a complex heterogenous metapopulation structure, with three socially discernible and spatially distinct communities. See details further in this report.

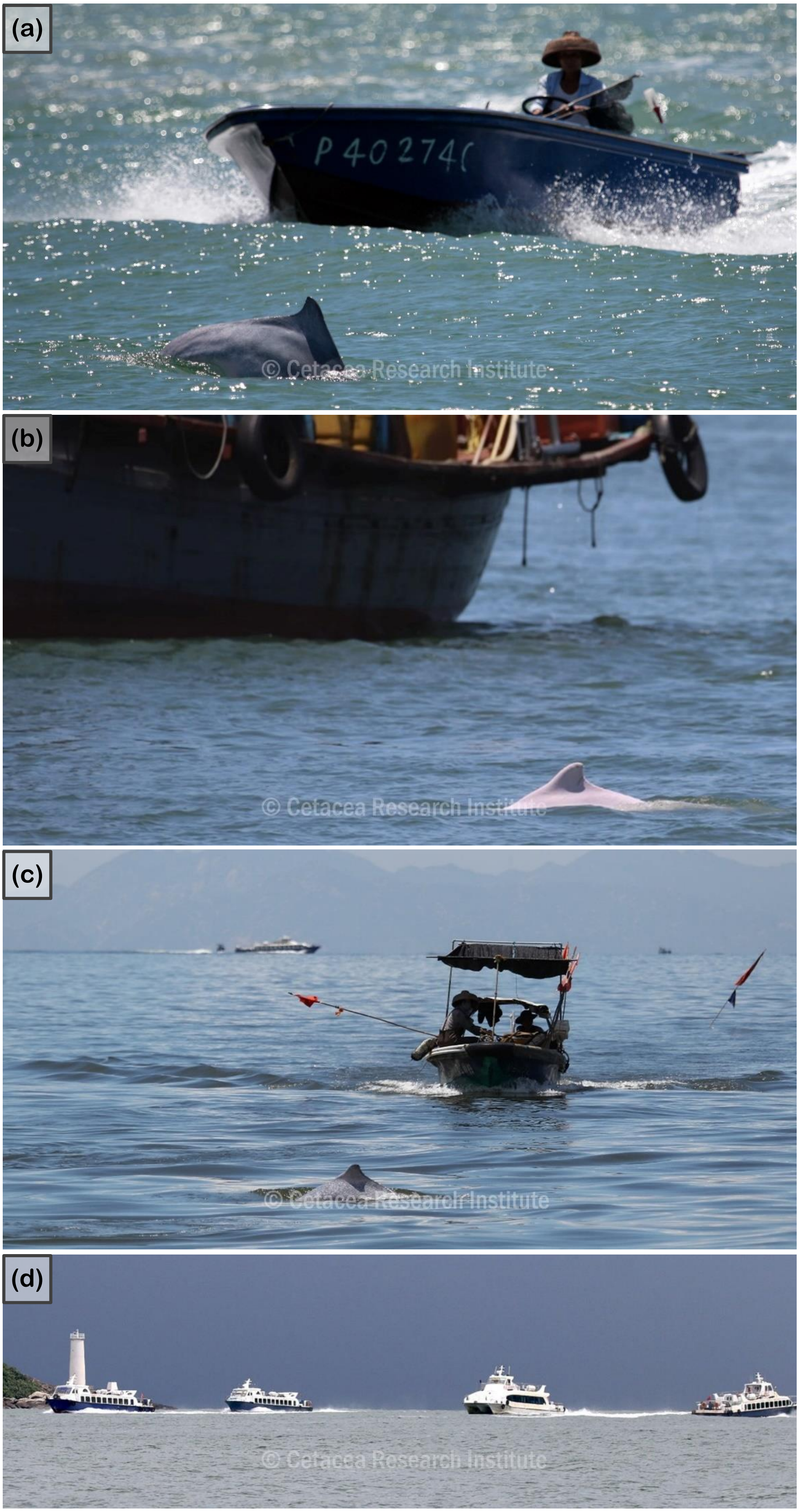


Figure 5. Chinese white dolphins facing heavy sea traffic.

(a) A juvenile dolphin evading the path of high-speed small vessel. Chinese white dolphins in the PRD are often on the collision course of maritime traffic, particularly in the Eastern PRE.

(b) An adult dolphin swimming next to a motorised vessel. Even when cruising at low speed, motor engines introduce underwater noise disturbance to the dolphins as well as distortion of coastal soundscape.

(c) A local fishing boat cruising towards a dolphin without slowing down or changing its course. Even at the westernmost reaches of the PRD region – thought to be less impacted – intensive fishery activities cause a considerable risk of injuries from boat collision.

(d) Intensive traffic of multiple high-speed ferries at the channel between Shangchuan and Xiachuan Islands – one of the dolphin hotspots in Western PRE waters.

Figure 6. Intensive fishery and aquaculture activities in coastal waters of the Pearl River Delta region.

(a & b) Chinese white dolphins foraging near operating fishing vessels, for example **(a)** around seine net vessels and **(b)** behind trawlers. Although trawling has been banned in Hong Kong waters, various types of trawlers are frequently seen operating in mainland waters.

(c) In western PRD, we have witnessed a massive increase in oyster farming and other aquaculture activities, which currently occupy substantial sections of inshore shallow waters, effectively excluding dolphins from accessing these potential foraging habitats.

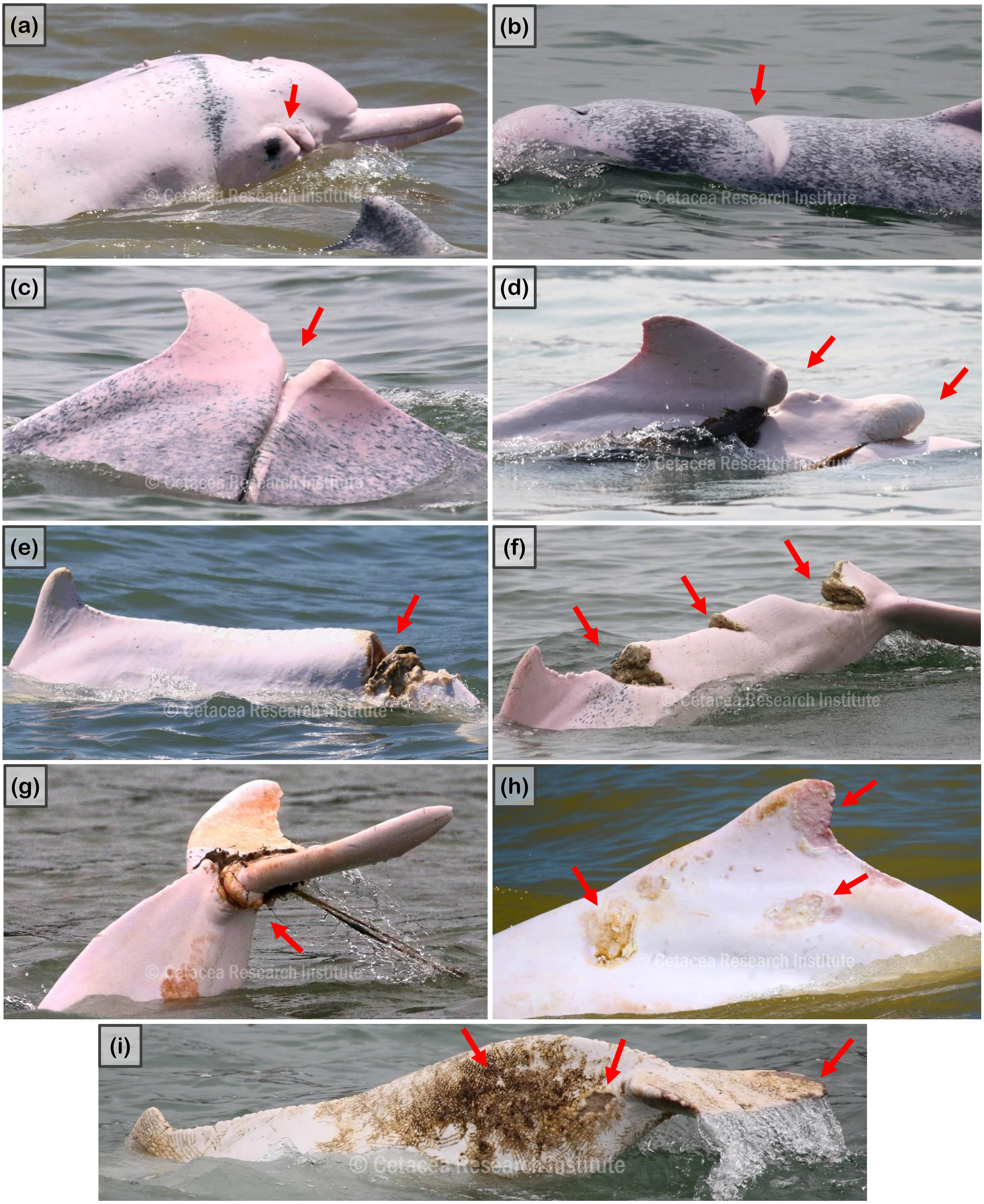


Figure 7. Traumatic injuries and skin lesions of Chinese white dolphins in the PRD region.

In face of the multitude of anthropogenic stressors across the PRD region, a substantial proportion of PRD dolphins suffers from **(a-g)** physical injuries caused by entanglement in fishing gear, boat collisions, and propellor cuts, as well as **(h-i)** various types of lesions and ulcers indicative of compromised health conditions. Refer to Chan and Karczmarski (2019) for further details.

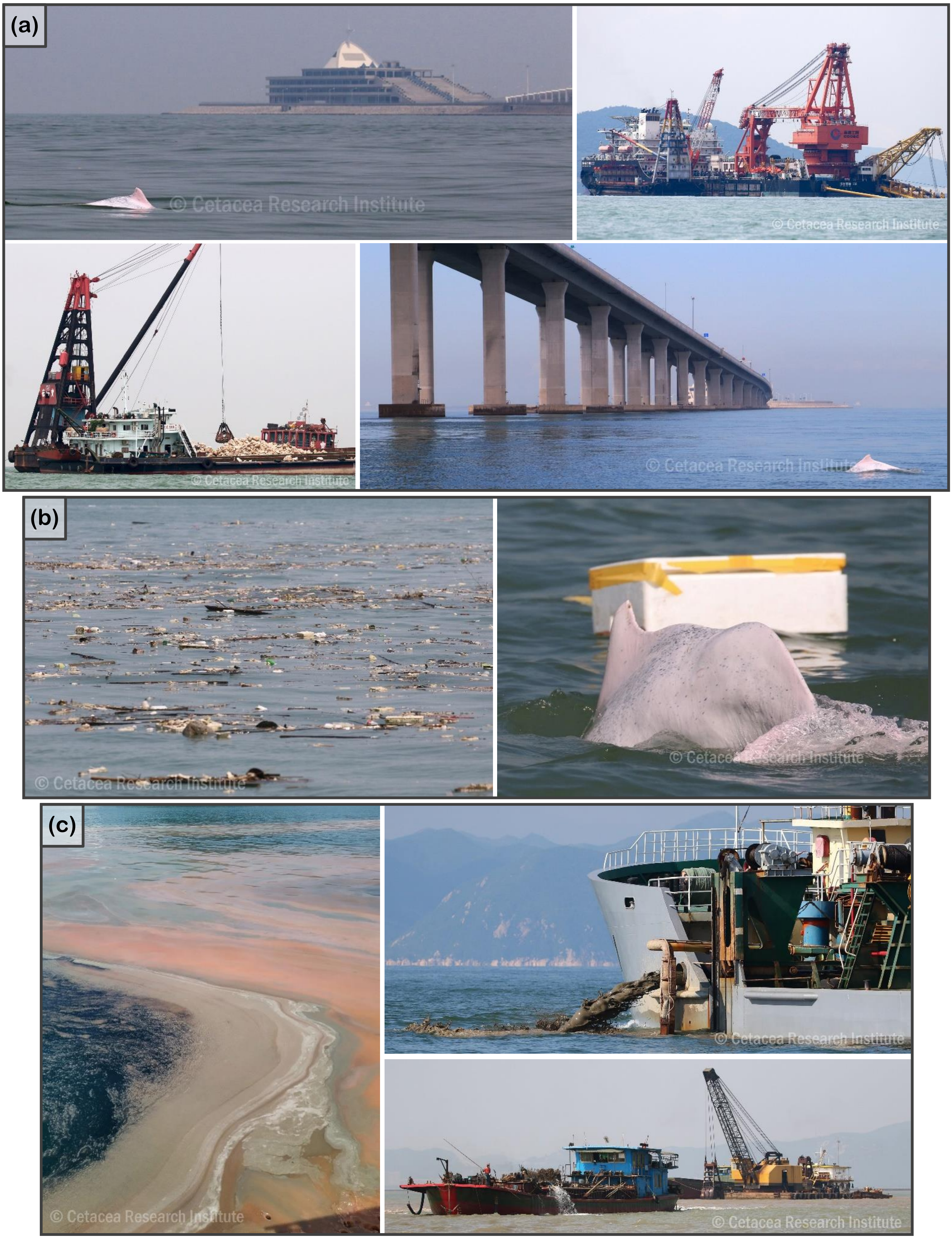


Figure 8. Some of the primary threats to PRD dolphins that were particularly visible during our field surveys, including **(a)** habitat loss and degradation due to many coastal and marine development projects, **(b)** suspended and floating rubbish and plastics of various type and size leading to accidental ingestion, **(c)** pollution, bottom-dredging and sand-mining across PRD waters and coastal habitats.

Figure 9. Photographs of our research team at work, including L. Karczmarski (Project Leader), S.C.Y. Chan (Senior Researcher), and other team members and research assistants – many thanks for their effort and dedication to work long-hours under a highly-fluid and weather-dependent schedule. During this multi-year undertaking, sea-based surveys were conducted across the PRD region, collecting photo-ID data as well as various socio-behavioural and environmental information associated with dolphin sightings.

Results

Field effort

Sightings of Chinese white dolphins (CWDs) recorded during the study period reported here are summarised in Table 1. The geographic distribution of all dolphin encounters and photo-ID records obtained during this time-period is displayed in Figure 10.

Table 1. Summary of survey effort, number of groups, and dolphin sightings during the MEEF2017015C funding cycle.

Area	Month	Number of surveys	Number of groups encountered	Monthly number of dolphins sighted
HK	Oct 2020	1	4	25
	Dec 2020	1	3	10
	Jan 2021	1	4	14
	Mar 2021	2	8	26
	Apr 2021	2	10	39
	May 2021	1	0	0
	Jun 2021	2	5	22
	Total	10	34	136
PRD	Feb 2021	1	4	16
	Mar 2021	2	6	22
	Apr 2021	2	9	43
	May 2021	2	10	51
	Jun 2021	3	18	106
	Total	10	47	238
Overall		**20**	**81**	**374**

Throughout the project, a conscious effort was made to cover the entire geographic range of the Pearl River Delta (PRD) coastal waters with a comparable field effort, from Hong Kong in the east to Shangchuan/Xiachuan Islands at westernmost reaches of the region. However, as the commencement of the fieldwork within the project period reported here had to be postponed, the primary field season of 2020 (the time of year permissible of fieldwork due to conducive weather/sea conditions) was already missed before the field work could be launched. Consequently, we were unable to conduct any fieldwork in the Western PRD up until weather/sea conditions improved

(February 2021). Therefore, as per the amended Objectives, the Project maintained only low-intensity surveys (sea-conditions permitting) and prioritised the two analytical components most relevant to the current phase of our work even though the required field datasets were not yet fully completed.

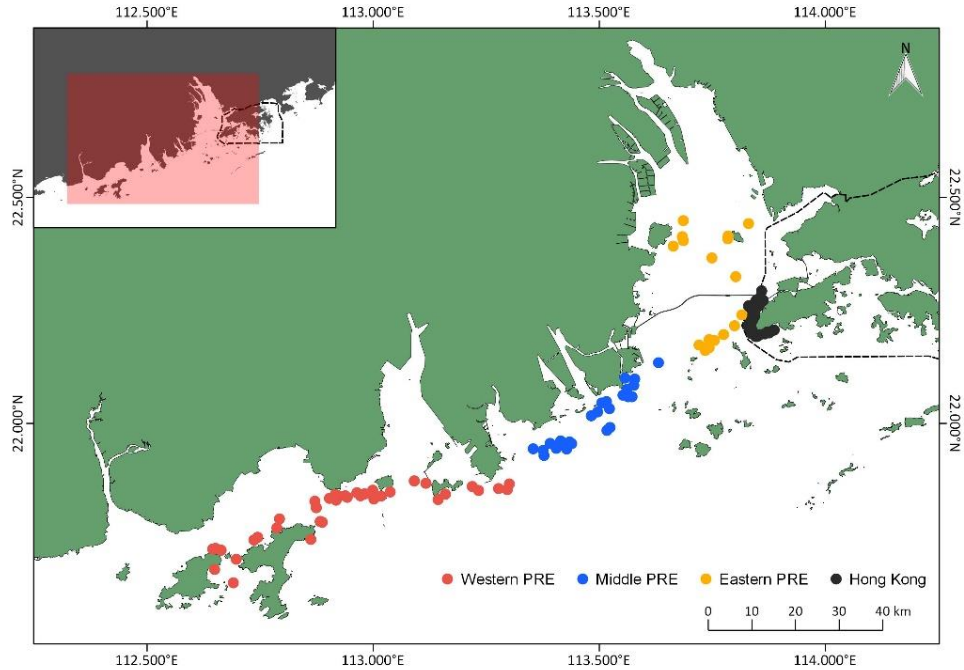


Figure 10. Locations of sighting of Chinese white dolphins across the PRD region where individual ID-data were collected during the MEEF2017015C funding cycle. Different sectors of the PRD estuarine system are indicated by different colours.

Maintaining the photo-ID surveys with at least a minimum level of field effort served the primary purpose of *(i)* securing the basic continuity of data-flow (which is vital for all intended mark-recapture analyses) and *(ii)* preventing major gaps in incidental but crucial data such as individual-ID mark-change, births, injuries, mortality, etc.; all of which was done with the hope of resuming the work meaningfully and with full intensity in the next field season.

Data summary

An integrated summary of a fully updated photo-ID mark-recapture dataset cross-referenced across the entire PRD region is given in Figure 11.

As pointed out in our previous reports, a dataset from any specific individual phase of this multi-year undertaking is on its own insufficient for inferring any population-level indicators. It is especially so in the phase reported here, given that the time-period was even shorter than usual. However, as part of a larger multi-year work and benefiting from data obtained over the past years, the combined dataset allows to present our main findings in an extent indicative of the population processes and patterns. In this report, we summarise our recent findings based on the most up-to-date dataset. We have to underscore, however, that the

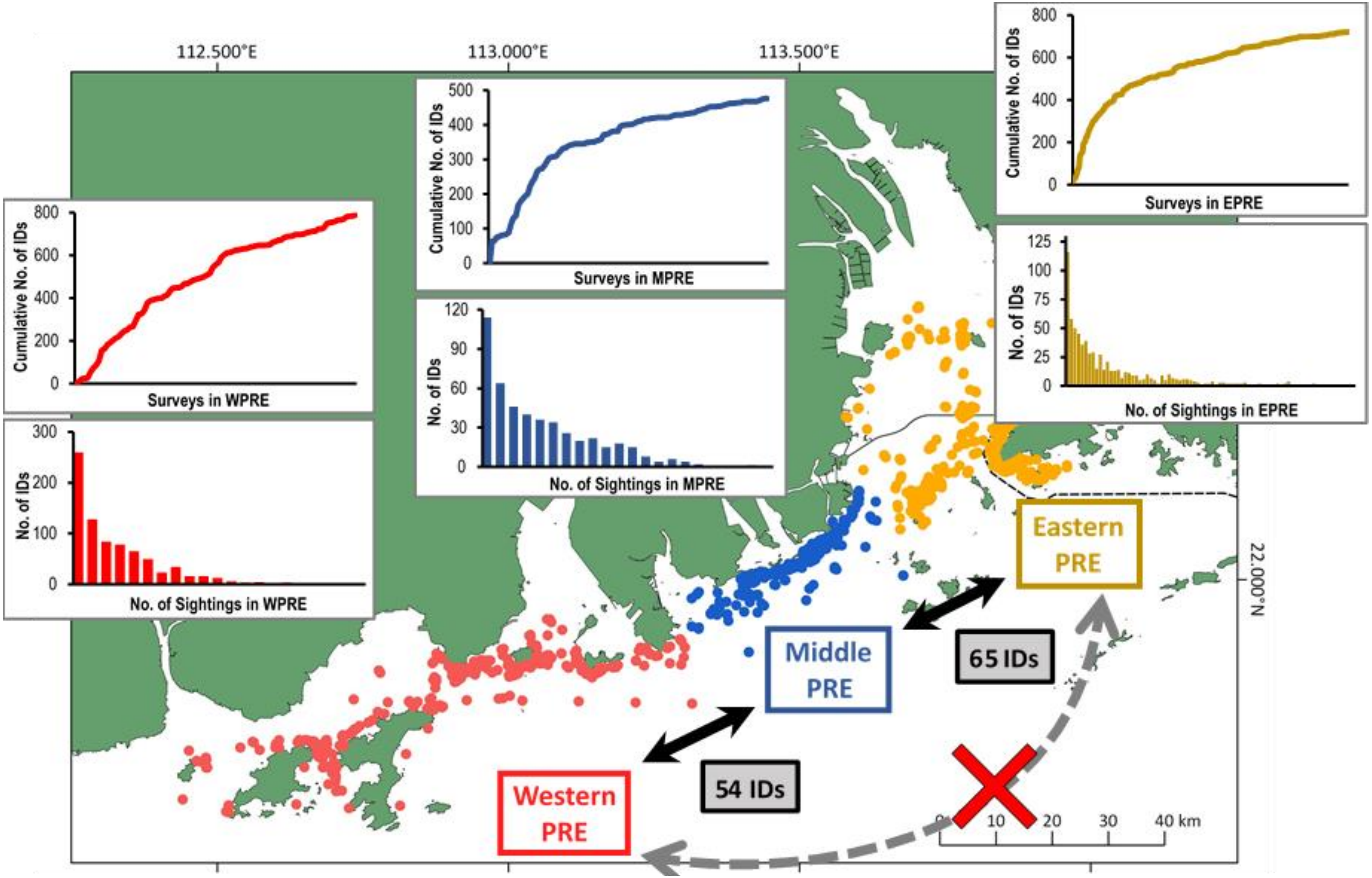


Figure 11. Integrated map illustrating the latest updated summary of photo-ID mark-recapture data processed and synthesized to date. The locations of sightings of Chinese white dolphins across the PRD region are shown in different colours for different sectors. Discovery curves and sighting frequency figures indicate the cumulative number of individuals identified and the number of individual re-sightings per sector, respectively. Based on the currently cross-referenced data, only a small number of individuals (albeit slightly higher than previously reported) were identified in more than one sector of the region. Consistent with previous reports, no individual was seen moving all the way between the eastern and the western reaches of the PRD.

report presented here should not be used as a scientific reference nor as a base for management recommendations as the final phase of this project that can facilitate conclusive recommendations for conservation and management has yet to been performed. As indicated in the original project design, such all-encompassing consolidation and synthesis of all multi-year data collected to date (both MEEF-funded data and that funded by other sources) requires a dedicated concluding phase of this project (an appropriate proposal is currently under development).

Movement and site fidelity

Only a small proportion of identified individuals (a few tens) were photographed in more than one sector of the PRD region (e.g. in Eastern and Middle PRE, or in Middle and Western PRE). Not a single individual was ever seen moving between the eastern and the western sectors of the PRD (see Figure 11). Consistent with previously reported preliminary findings, the limited movement of individuals across the coastal region of the PRD re-affirms that the dolphins exhibit highly restricted geographic ranges. Given that PRD represents a continuum of inshore shallow-water habitats under estuarine influence, the restricted movement pattern of individuals within and between the deltaic sectors is highly unexpected and warrants further analytical investigation (presented in the following two sections below).Based on the most up-to-date dataset, advanced movement analyses were performed using Lagged Identification Rates (LIRs) to examine the geographic fidelity and movement of Chinese white dolphins within and across the Pearl River Delta region. Current results indicate that in general the dolphins exhibit a very considerable and most likely long-term fidelity to their respective sections of the PRD coastal waters, which corresponds with our previous preliminary findings and is consistent with the limited number of re-sightings of individuals between the three sections (Eastern, Middle, and Western) of the PRD region. Modelled movement of individuals seldom exceeds few tens of kilometres, and movement between Eastern, Middle, and Western PRE appears to be sporadic and limited to only a handful of individuals. These observations jointly suggest that the PRD dolphin population has a complex heterogeneous demographic structure, far different from what has been previously thought.

We calculated single-area LIRs individually for Eastern, Middle, and Western PRE (Figure 12), as guided by our earlier findings that delineated these areas as sectors of putative demographic units of the PRD population. These modelling projections represent the probability of any individual to be re-identified in a specific sector of the PRD at a certain time-lag after its first sighting in that sector. Several movement models were generated and projected against the observed temporal pattern. The most parsimonious model that best-explains the observed pattern was subsequently selected based on Akaike Information Criterion (AIC).

(a)

(b)

(c)

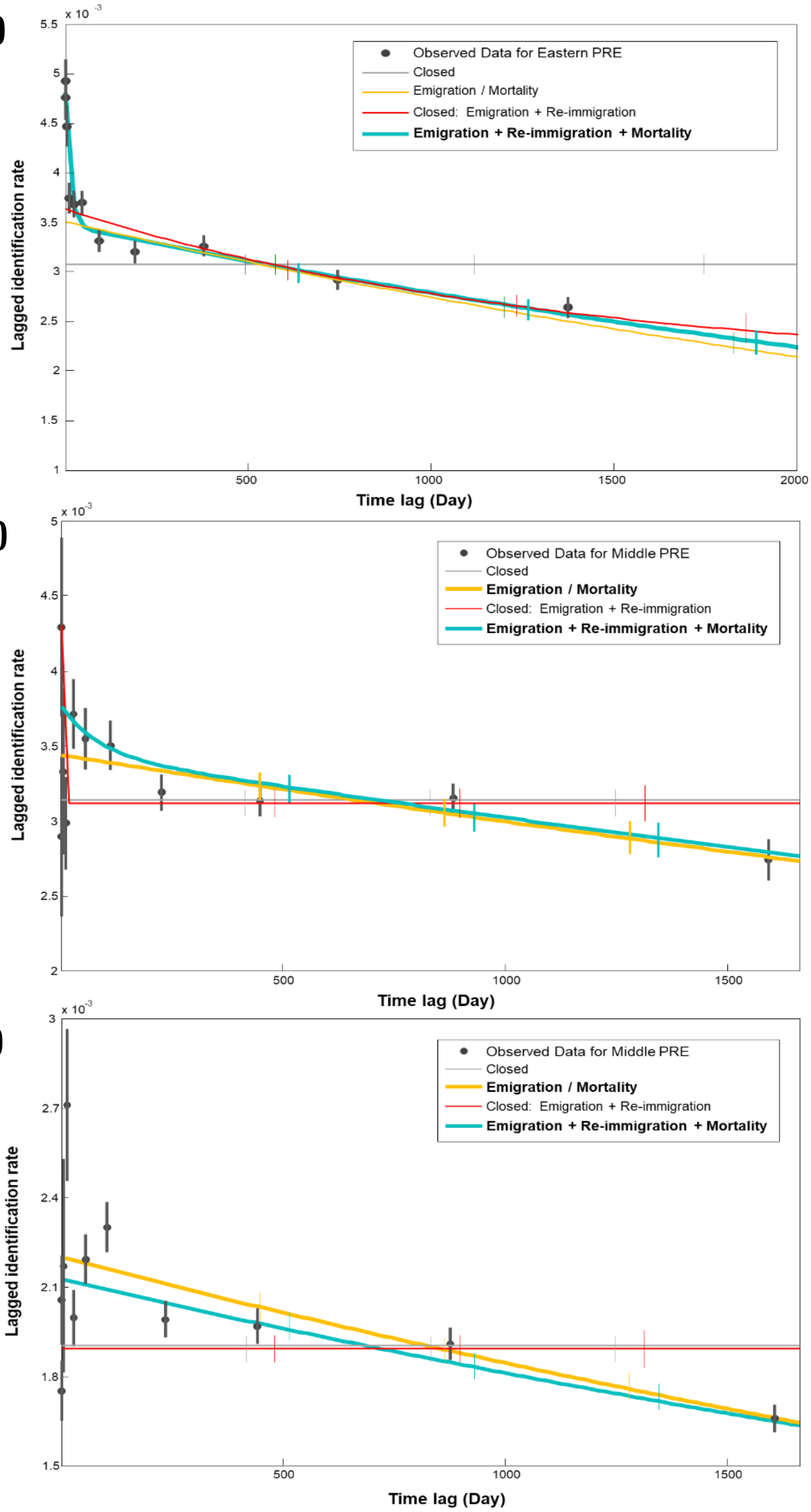


Figure 12. Single-area lagged identification rates (LIRs) of Chinese white dolphins in (a) Eastern PRE, (b) Middle PRE, and (c) Western PRE, with the corresponding most parsimonious movement models that best represent the observed patterns indicated in bold text and thicker lines. Bootstrap SE of the observed data and the movement models are shown as solid error bars.

The single-area LIRs displayed a similar pattern in all three putative sectors of the PRD, declining continuously with a broadly comparable rate across the time lag projection, although there were fine-scale differences in these projections (such as the rate of decline, variation in observed data, and the selected most-parsimonious models) across the PRD. While the LIRs of the observed data declined rapidly over the initial time-lag period in all three putative sectors of the PRD, this decline was most noticeable in the Eastern PRE (Figure 12a) and least so in the Middle PRE (Figure 12b). Throughout the projected time-period, the error bars in the Eastern PRE were the smallest compared to the other two sectors (Figure 12a). In contrast, the LIRs in Middle and Western PRE displayed slower initial drop with visibly more fluctuations throughout the projected period (Figure 12b and 12c; the larger error bars in Middle and Western PRE are due to lower individual sighting frequencies). Consequently, the movement model projection generated for the Middle and Western PRE remains somewhat less definitive (two movement models were similarly supported by AIC selection), although both models are indicative of a very similar pattern (Figure 12b and 12c). The continuous decline in LIRs reflects the discontinuation of sightings/re-sightings of certain individuals, most likely due to mortality as a primary cause (either natural or human-caused), as permanent emigration is unlikely to be a major (if any) factor (Figure 12).

As pointed out in previous reports (and proposals), the moderate level of model uncertainty in Middle and Western PRE serves as explicit indication that more data would strengthen the dataset and would greatly benefit the final outcome of this multi-year project. It is highly regrettable that it was not possible at present.

Multiple-area Lagged Identification Rates (LIRs), presented previously in their preliminary phase (interim reports), were now revised and re-computed using the most up-to-date dataset to examine the movement of dolphins across the entire PRD. Multiple-area LIRs quantify the probabilities of an individual to be present (re-sighted) in the same section of the PRD *versus* any other section of the region over a time-lag period. Consequently, this modelling approach reflects the overall fidelity of individual dolphins to any specific section of the PRD and the overall movement (if any) at the population-level across the estuarine habitat of the region. Movement models were generated and fitted to the observed data and the best-fitted models (those that best describe the observed pattern) were selected based on AIC in similar manner as in the single-area LIRs.

The multiple-area LIR analyses involve integrated modelling of movement *within the same area(s)* and *between different areas* as part of the computational process (Whitehead 2008, 2009). For the PRD dolphins, the observed LIRs *within the same areas* declined continuously across the time lag projection (Figure 13) and both the selection and the projection of the best-fitted model closely resembled the overall pattern of the single-area LIRs (as displayed in Figure 12), further supporting the notion of high (likely long-term) fidelity of the PRD dolphins to their respective sections (likely preferred habitat/foraging areas) within the PRD. On the other hand, the daily LIRs *between different areas* remained almost zero throughout the entire projected period (Figure 13), indicating that movement of individuals across the greater PRD is infrequent and highly limited, with almost complete lack of exchange of individuals between putative sub-regions of the PRD.

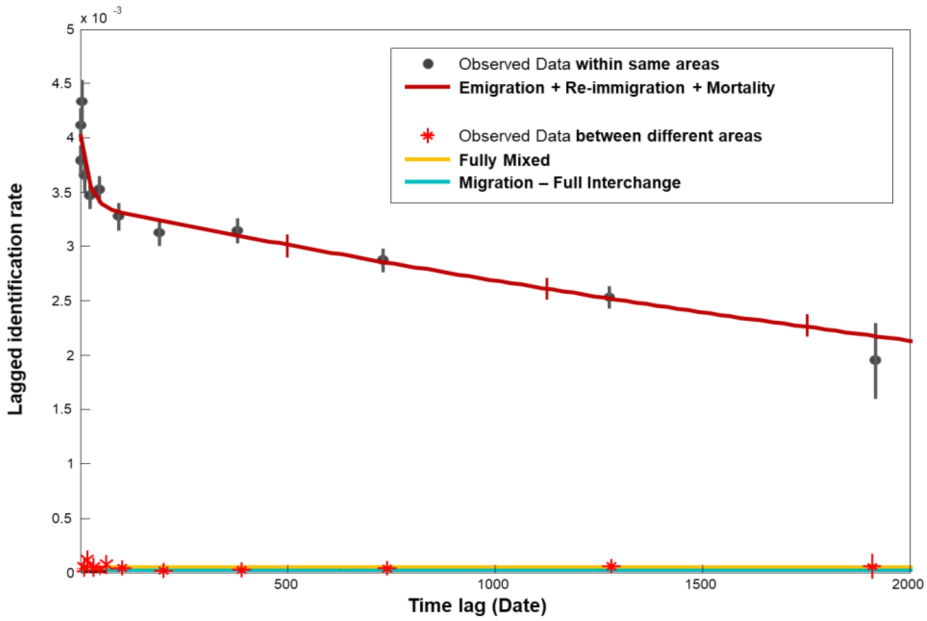


Figure 13. Multiple-area lagged identification rates (LIRs) of Chinese white dolphins re-sighted within the *same* sub-region (grey dots) and in *different* areas (red asterisks) of the PRD, displayed along with the best-fit movement models. Bootstrap SE of the observed data are shown in solid error bars. Note that the models of LIRs between *different* areas, represented by horizontal lines overlaying the x-axis, overlap with one another indicating unarguably that according to all mark-recapture models movement of individual dolphins across the greater PRD region is extremely rare.

The findings summarised above, using the most up-to-date dataset, synthesised and geographically cross-referenced across the entire PRD, with the contrasting LIRs *within* vs. *between* the putative sectors of the PRD and across the putative units of the PRD dolphin population (along with their respective model projections), represent a clear indication that long-range movement across the PRD region is a rare event. Even though the membership of dolphin groups is fluid, individual site fidelity to a specific section (sub-region) of the PRD is high. In other words, despite the lack of any obvious physical barriers in coastal waters of the PRD, individual dolphins use only a fraction of that region and depend for their daily lives on only a small section of this much larger estuarine habitat.

Ranging pattern

Using the most up-to-date mark-recapture dataset, the ranging pattern of Chinese white dolphins was further investigated by applying individual dispersal models. To understand the differences across the PRD region, the dispersal patterns were first projected for dolphin sighting histories within Eastern, Middle, and Western PRE (Figure 14), and subsequently compared across the region (Figure 15).

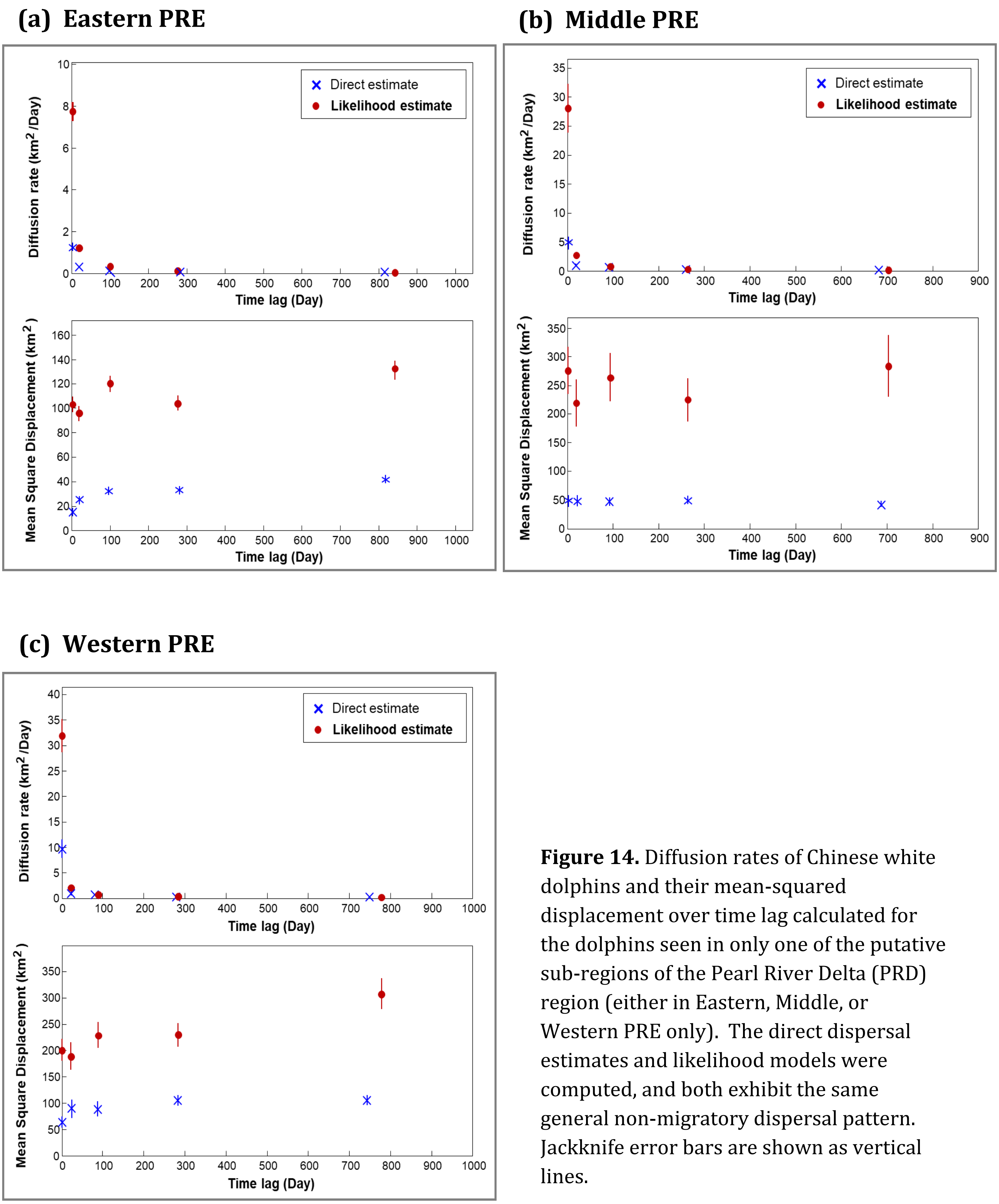


Figure 14. Diffusion rates of Chinese white dolphins and their mean-squared displacement over time lag calculated for the dolphins seen in only one of the putative sub-regions of the Pearl River Delta (PRD) region (either in Eastern, Middle, or Western PRE only). The direct dispersal estimates and likelihood models were computed, and both exhibit the same general non-migratory dispersal pattern. Jackknife error bars are shown as vertical lines.

Throughout the PRD region and regardless of where the individual dolphins were seen, and whether or not they were re-sighted in the neighbouring section of the PRD, all dolphins exhibited the same general non-migratory pattern of ranging and dispersal. The diffusion rates were highest at the initial time-lag interval; while shortly after, within just a few weeks of time lag, the rate of diffusion dropped substantially to a negligible level (Figures 14 and 15). This spatio-temporal pattern was the same for all PRD dolphins and indicates a limited dispersal. Movement was generally limited to the geographic range the dolphins cover within first few weeks since their sighting. A temporal projection of mean-squared displacement shows all individuals displaying large initial displacement area but very little expansion soon thereafter (Figures 14 and 15). While all individuals exhibit the same pattern of dispersal, dolphins identified in more than one sub-region (Figure 15a and 15b) generally travel farther and exhibited greater dispersal than those seen in only one section of the PRD (Figure 14a-c). Among dolphins that were seen in one putative sub-region only, individuals in Middle and Western PRE (Figure 14b and 14c) displayed similarly higher rate of diffusion and greater spatial displacement than those in Eastern PRE (Figure 14a).

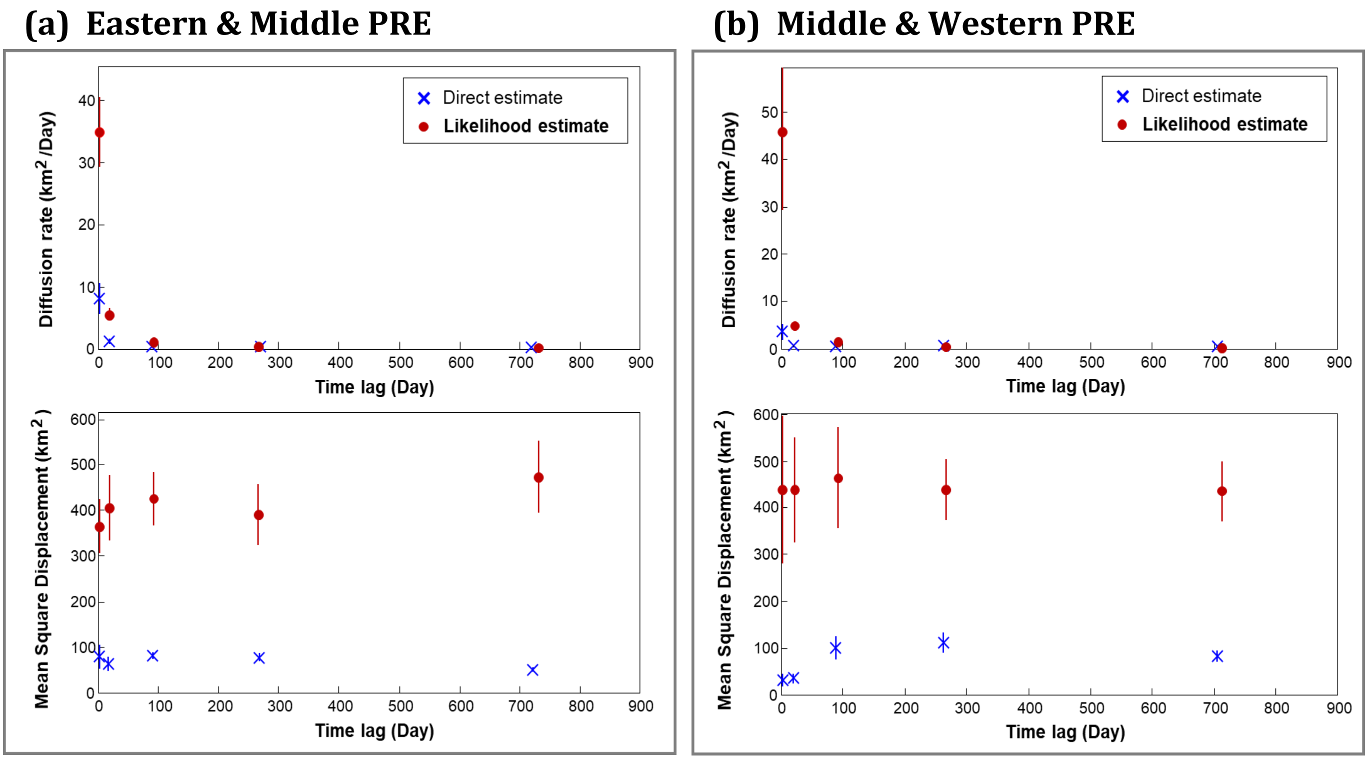


Figure 15. Diffusion rates and mean-squared displacement over time lag computed for Chinese white dolphins that were seen in more than only one putative sub-region of the Pearl River Delta (PRD) coastal system. The direct dispersal estimates and likelihood models were computed, and both exhibit the same general non-migratory dispersal pattern. Jackknife error bars are shown as vertical lines.

Given the above, it is apparent that ranging and spatial dispersal of individual dolphins inhabiting the PRD region occur only within a fraction of their respective subpopulation range. Even though some of the PRD dolphins range across greater distances and move between neighbouring sub-regions of the PRD, seemingly representing the vectors of metapopulation connectivity, these individuals still do not range across the entire PRD coastal region (see also Figure 11). As there are only a handful (a few tens) of these individuals with limited re-sightings (especially in Middle and Western PRE), variations of the estimated dispersal parameters remain (as indicated by error bars in Figures 14 and 15); it is especially so as these type of dispersal analyses are particularly sensitive to sample size and robustness of the dataset. In that context, as pointed out earlier, the level of model uncertainty in Middle and Western PRE points explicitly that more data would strengthen the dataset and greatly benefit the final outcome of this multi-year project. It is highly regrettable that it was not possible at present.

Population connectivity

To advance our understanding of the demographic connectivity of the PRD (meta)population, multi-state mark-recapture models were computed to quantify the rate of transition between the apparent Eastern, Middle, and Western PRE (sub)populations. The data treatment and scrutiny protocols were adopted from the published work by Chan and Karczmarski (2017), with only high-quality images of highly distinctive adult individuals used for analyses, in order to minimize analytical bias that could arise from potential mismatch or misidentification of individuals. In contrast to the movement and dispersal analyses reported above, probabilities of transition between subpopulations were estimated in annual rates across the timeframe of the latest and most up-to-date dataset, thus providing a complementary broader perspective in a demographic time-scale. These estimates, however, as all other estimates reported earlier and above, remain interim at present and should not be referenced until strengthened with further evidence and advanced analytical treatment (as envisioned in the original project design and intended for a closing phase of this multi-year undertaking).

The latest demographic analyses indicate that the probabilities of inter-subpopulation transitions of Chinese white dolphins between the three PRD sub-regions are generally low within the range of 1.9 - 4.4% annually (Table 2), which is once again consistent with the cross-referenced photo-ID dataset (only a handful of individuals was seen moving between deltaic sub-regions) and interim findings of various movement analyses (considerable long-term site fidelity in respective sub-regions of the PRD), as reported above. In overall, the PRD dolphins exhibit high likelihood (~92 - 98% probability) of staying in the same deltaic sub-region regardless of where the individuals were first identified. As the Middle PRE subpopulation neighbours both East and West sub-regions, these dolphins exhibit the highest rates of movement to the other sectors and the lowest probability of remaining in the Middle PRE waters (albeit the differences are small). Current mark-recapture modelling results correspond remarkably close with that of the parameterized Markovian movement model (as reported previously) in both general pattern and estimated parameters of inter-subpopulation/inter-sector transition rates. The consistency of our findings using multifaceted approach adds to the analytical confidence of the emerging population-level pattern where the PRD dolphins form a complex heterogeneous demographic meta-population structure, even though the specific fine-scale dynamics of this structure require further scrupulous examination to be fully understood.

Annual transition probability (SE)		**To subpopulation:**		
		Eastern PRE	Middle PRE	Western PRE
From subpopulation:	Eastern PRE	0.979	0.021 (0.003)	0
	Middle PRE	0.036 (0.007)	0.920	0.044 (0.006)
	Western PRE	0	0.019 (0.005)	0.981

Table 2. Transition probabilities of Chinese white dolphins between Eastern, Middle, and Western PRE estimated with multi-state mark-recapture models. All estimates are in annual rates. Standard errors are given in parentheses.

Corresponding with other analytical results reported above, current results of multi-state mark-recapture models serve as a quantitative measure of the degree of demographic connectivity of Chinese white dolphins across the PRD region. The low yet non-negligible transition rates suggest limited but ongoing movement of a small number of individuals between the putative subpopulations, which appear to represent important vectors in maintaining a boarder cohesion of the larger PRD meta-population, both demographically and presumably genetically as well (though the latter could not be investigated nor verified at present due to previously discussed limitations; but would be highly informative if/when this multi-year project can proceed to the concluding phase). All our latest evidence points to a complex picture of the PRD dolphins forming spatially distinct (three deltaic sub-regions) but not completely discrete demographic sub-units, with occasional cross-region transitions of individuals acting as vectors that bridge the putative subpopulations, forming a heterogeneous metapopulation across the greater PRD coastal habitat.

Spatial structure and demographic parameters in Eastern PRE

In light of the latest multi-dimensional measures of the heterogeneous population structure, further mark-recapture analyses were performed factoring-in the local spatial dynamics in Eastern PRE, to investigate the population parameters of the Eastern PRE subpopulation. As in all demographic models, to ensure accurate estimation of population parameters with minimum potential bias due to field data collection, analytical dataset was constructed with individual sighting records that followed a rigorous data scrutiny protocols of filtering only top-quality images of highly-marked individuals (Chan and Karczmarski 2017). Agglomerative hierarchical clustering (AHC) analyses, based on fully cross-referenced and synthesized dataset spanning Hong Kong and mainland China waters, indicated that dolphins inhabiting this region display heterogeneous spatial preferences across Eastern PRE (Figure 16). Multiple clustering methods were applied and all tests resulted in agglomerative coefficients close to one, indicating a considerable differentiation in individual preferences of choosing their individual range within a broader range of the (sub)population. With the application of fine-scale clustering algorithms, three clusters of individuals were identified with their ranges corresponding to three sub-sections of Eastern PRE waters, namely *(i)* Hong Kong (HK), *(ii)* inner Lingding Bay (iLB) and *(iii)* outer Lingding Bay (oLB) (Figure 16).

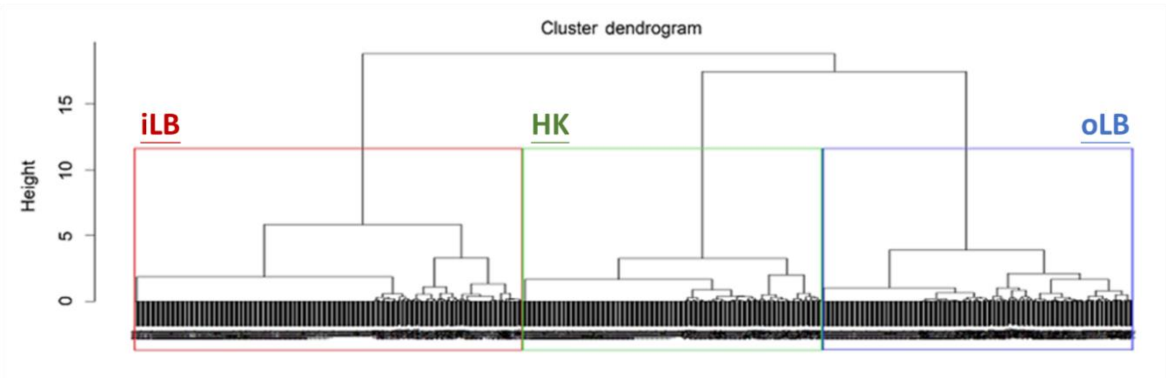


Figure 16. Agglomerative hierarchical clustering (AHC) analyses on the regional preferences of Chinese white dolphins in Eastern PRE estuarine waters. The dendrogram indicates three clusters of individual dolphins identified with their spatial preferences to Hong Kong waters (HK; green), inner Lingding Bay (iLB; red) and outer Lingding Bay (oLB; blue).

Cormack-Jolly-Seber (CJS) capture-recapture models were subsequently applied to quantify the apparent survival rates of the Eastern PRE dolphins. Adopting the factor of individual regional preferences in constructing the CJS models substantially improve the fitness of data structure (Figure 17). In other words, incorporating the regional preference effect helps explaining the pattern of variations in population features among the Eastern PRE individuals. This once again underscores the importance of understanding fine-scale demographic structures in accurate estimation and meaningful interpretation of population parameters.

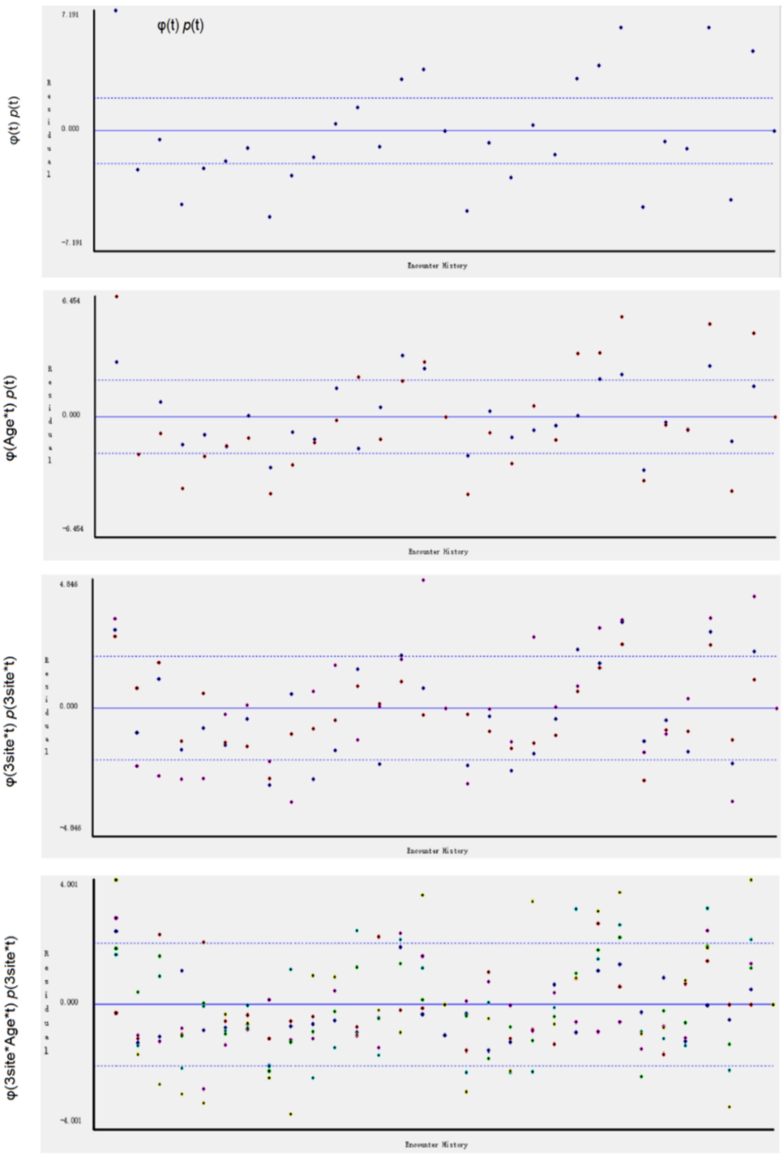


Figure 17. Deviance residual plots of four CJS models used in goodness-of-fit (GOF) tests. Asymmetry in the deviance residuals (greater proportion of negative to positive residuals) of the simplest model (the top graph; without considering any spatial differentiations) suggested that the lack of model fitness was largely due to insufficiently addressed data structure. Incorporating the regional spatial preference effect (together with age-class effect; the bottom graph) substantially improved the goodness-of-fit, with most residues much closer to zero (within the two horizontal dashed lines).

The most parsimonious CJS models (selected based on the corrected Akaike Information Criterion, AICc) indicate a notable heterogeneity in apparent survival rate estimates across Eastern PRE (Table 3). Dolphins with spatial preferences to Hong Kong waters had higher survival estimates than those using primarily mainland waters, while those preferring the inner and outer Lingding Bay in mainland China waters shared the same survival estimates (Table 3). Adult dolphins had higher survival rates than juveniles, which is well-expected given that younger pre-mature animals are generally more susceptible to environmental threats. Notably though, the magnitude of difference between adults and juveniles was considerably larger in mainland waters (iLB and oLB) than in Hong Kong (Table 3). When averaged across Eastern PRE, the adult and juvenile apparent survival rates approximated 0.95 and 0.86, respectively. Both these estimates are below the threshold of non-calf survival rates needed for the dolphin long-term multi-generational persistence as biologically viable population in PRD waters (Karczmarski et al. 2017a).

Table 3. Apparent survival rate estimates of Chinese white dolphins in Eastern PRE generated with the most parsimonious Cormack-Jolly-Seber (CJS) models, with notable variations between age-classes (adults *vs.* juveniles) and among individuals with different spatial preferences (HK *vs.* iLB+oLB).

Regional preferences	**Adult**		**Juvenile**	
	Survival rates	**SE**	**Survival rates**	**SE**
Hong Kong (HK) *= individuals more frequently seen in HK waters than in other parts of Eastern PRE*	0.98	0.007	0.92	0.024
Inner and outer Lingding Bay (iLB+oLB) *= individuals more frequently seen in mainland waters of Lingding Bay than in HK (the estimates did not differ between inner and outer parts of Lingding Bay and are presented here together)*	0.93	0.015	0.74	0.038
Overall *= averaged across Eastern PRE*	0.95	0.009	0.86	0.035

While the overall low survival rates indicate that these dolphins are under a tremendous anthropogenic stress, the fine-scale spatial heterogeneity in survival shows that Chinese white dolphins experience varied region-specific levels of stresses that impacts their survival to a different extent. While anthropogenic impacts vary in intensity across the PRD seascape, limited individual ranges (restricted dispersal) of these coastal dolphins (see above) render them highly susceptible to spatially-differentiated anthropogenic impacts, especially if these impacts are locally intensified and persists over extended time periods. Resource overexploitation by fisheries and habitat degradation by various coastal developments (often involving land reclamation) are among the primary threats to PRD dolphins (Karczmarski et al. 2016; Lin et al. 2021), and are most intensive in the northern and western reaches of Lingding Bay. In comparison, waters off west/southwest Lantau Island in Hong Kong are considerably less affected and have been suggested to represent the last habitat refuge of Chinese white dolphins across the whole of Eastern PRE (Karczmarski et al. 2016; 2017a). This once again highlights the critical importance of Hong Kong waters (especially coastal habitats off Southwest Lantau) in the conservation of this dolphin species in the PRD; not only in Eastern PRE but likely that of the larger metapopulation (see the "rescue effect", further in this report).

The type of fine-scale heterogeneity in survival rates as that reported here for the dolphins in Eastern PRE has never been reported elsewhere nor in other coastal delphinids; and as such it deserves a particular attention. The rarity of such data is primarily because detailed demographic analyses are highly demanding in both data quality and quantity, and are only possible with long-term studies that are appropriately designed and executed with persistence and high intensity of both field effort and mark-recapture coverage. The field component of such studies is particularly challenging, and the work reported here is one of a handful of cases where it was well-planned and successfully accomplished.

Our latest demographic analyses suggest also that, in addition to the low survival rates (i.e., high mortality), limited recruitment likely contributes to a decade-long decline in dolphin abundance in Eastern PRE waters. It may be due to low birth rate or low calf survival (as noted in Jefferson et al. 2011), or – more likely – a joint synergetic effect of both, along with the depletion of prey resource in Eastern PRE waters (especially in Lingding Bay) which has increased the dolphin's nutritional stress (Lin et al. 2021).

The latest POPAN mark-recapture modelling analyses indicate that there are 902 Chinese white dolphins in Eastern PRE waters. However, given the alarmingly low survival rates reported above, this estimate represents an upper estimate as considerable mortality may and likely have occurred during the time of our data collection. In other words, the figure of ~900 dolphins should be seen as the maximum possible number of Chinese white dolphins in Eastern PRE. A more conservative, and likely more realistic abundance estimate (given the natural and human-caused mortality across recent years), brings this number down to ~710 individuals. Nevertheless, even if the more optimistic (though unlikely) estimate was to be considered, the current number of dolphins inhabiting Eastern PRD (which represents the PRE proper) is undoubtedly lower than the previously suggested number (~1,300 dolphins; Chen *et al.* 2010, Hung 2015). Importantly, approximately half of the extant Eastern PRE dolphins rely for their daily lives on western Hong Kong waters (Chan and Karczmarski 2017), which underscores that conserving the integrity and quality of dolphin habitat in Hong Kong waters (which is less degraded in relative terms, despite its small size) is of paramount importance to dolphin long-term survival.

Socio-spatial and demographic parameters in Western PRE

Using the most up-to-date mark-recapture dataset, we carried out multifaceted socio-demographic analyses to quantify population parameters and to advance our understanding of the socio-behavioural and demographic processes that underpin the population ecology of Chinese white dolphins at the westernmost reaches of the PRD region.

As in all our prior and current work, only groups with good photo-coverage (majority of group members photo-identified with high-quality images) were filtered to construct analytical dataset. Although the stability of dolphin groups in PRD is generally weak, with a low mean association index (fluid associations), permutation tests at 1000 permutations with 1000 trials per permutation have shown that the variation (SD) in observed association indices is significantly higher than that of permuted random index, indicating that dolphins in Western PRE display a higher number of preferred associations (and likely also avoided associations) than a random assembly of individuals. Together with the measure of correlation coefficient and social differentiation, these metrices indicate a differentiated social pattern that warrants further investigation.

To quantify the temporal stability of individual associations, we computed Standardised Lagged Association Rates (SLARs), which represent the probability of any two individuals remaining associated at a certain time lag after they were first seen associating, divided by the mean number of associates. A permuted matrix (Standardised Random-data Association Rates; SRARs), a fully randomised matrix (Standardised Null Association Rates; SNARs) and multiple models of social dynamics were constructed and fitted against to the observed SLARs (Figure 18).

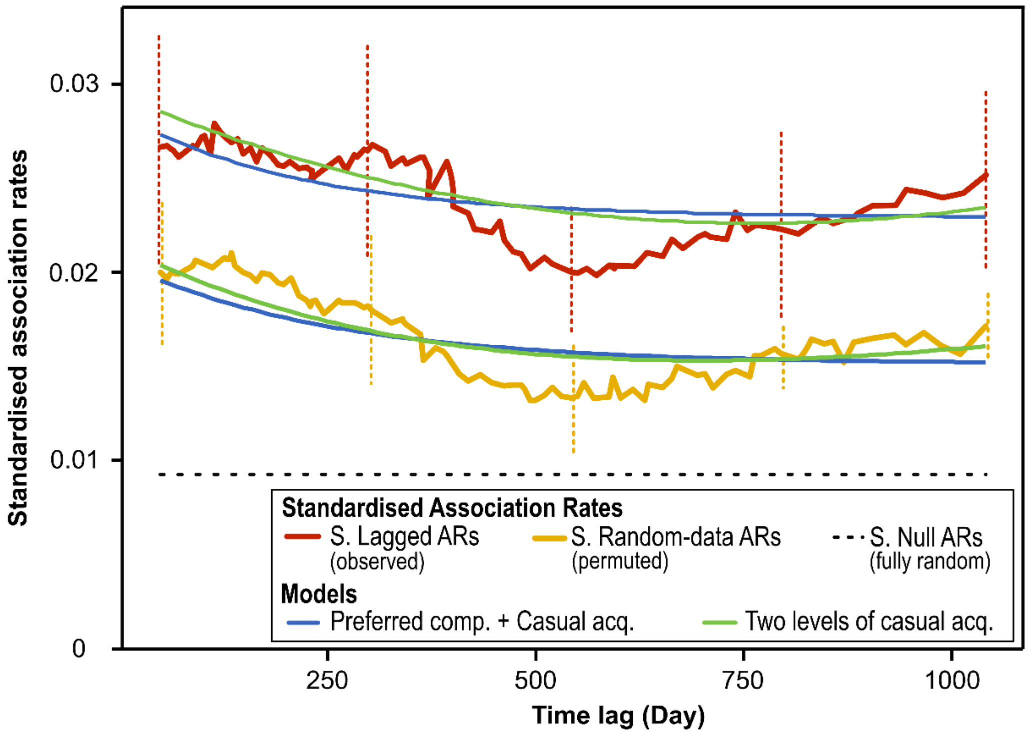


Figure 18. Standardised lagged association rates (SLARs, red), standardised random-data association rates (SRARs, yellow), and standardised null association rates (SNARs, black dashed line), and the two best-fitted models of social dynamics (blue and green) for SLARs and SRARs of Chinese white dolphins in Western PRE. Jackknife error bars are shown as vertical dotted lines.

Despite some oscillations and occasional declines, the observed temporal pattern of associations (SLARs) was relatively stable in the long-term and notably higher than the fully random association rates (SNARs), indicating that associations between individuals were not by chance alone, which is also supported by the selection of best-performing models. SRARs projected from data permuted within sampling period (day) were also higher than the null model (SNARs) but lower than the SLARs, and the temporal pattern mirrored that of SLARs (Figure 18).

The temporal pattern of group dynamics underscores the fluidity of associations which – although non-random (observed SLARs were higher than those of the Random Null Model at all times) – appear to be substantially governed by demographic factors. In other words, over long temporal scales, while the dolphins may have preferred associations, the grouping pattern (fluidity of association) depends more on the presence (or absence) of individuals rather than social affinity between individuals. In yet another words, when groups are formed, the choice of associates depends first on the availability (presence) of other dolphins (determined by individual movement pattern), and then among those available potential associates, individuals may choose their affiliates based on inter-individual social affinity or similar spatial preference of a site where the individuals aggregate (see also further).

The socio-spatial dynamics of dolphins inhabiting Western PRE were further assessed with cluster analyses, to model the pattern of group formation and social structure. As our dataset has grown since our previous such analyses (Chan et al. 2022), two parallel paths of analytical treatment were applied at this stage to examine the current data presented in this report. The reason behind doing so was to compare the differences and all potential pros and cons in the analytical procedures and resulting outcomes, and consider which of the two alternative approaches provide a more informative tool for the formulation of a concluding assessment of dolphin socio-spatial structure in Western PRD (and, in our further analyses, across the greater PRD region).

A non-hierarchical clustering method that uses eigenvector-based algorithm was applied to compute and identify the optimal number of clusters through progressive bifurcations. Six social clusters were identified (Figure 19) and all clusters had higher mean association indices than the overall dataset. The modularity of the social network was ~0.40, indicating an accurate depiction of the differentiation between clusters. The social structure of dolphins inhabiting Western PRE depicted against their geographic range is displayed in Figure 19b-i, where individual sightings of dolphins that formed the same clusters are colour-coded (which corresponds also to the colour of nodes in the network diagram; Figure 19a). Clusters #1 and #2, which occurred primarily off the northern shores of Shangchuan and Xiachuan Islands (westernmost section of the study area; Figure 19c and d), were both socially and spatially most distant from all others, while cluster #6 sited on the opposite end of the social network appeared similarly discrete in the spatial scale with all sightings located in the eastern section of the study area (Figure 19h). The other three clusters were more connected socially and considerably overlapped spatially (mainly around Tonggu and Dajin Island), but appeared to have different centroids in the social network diagram.

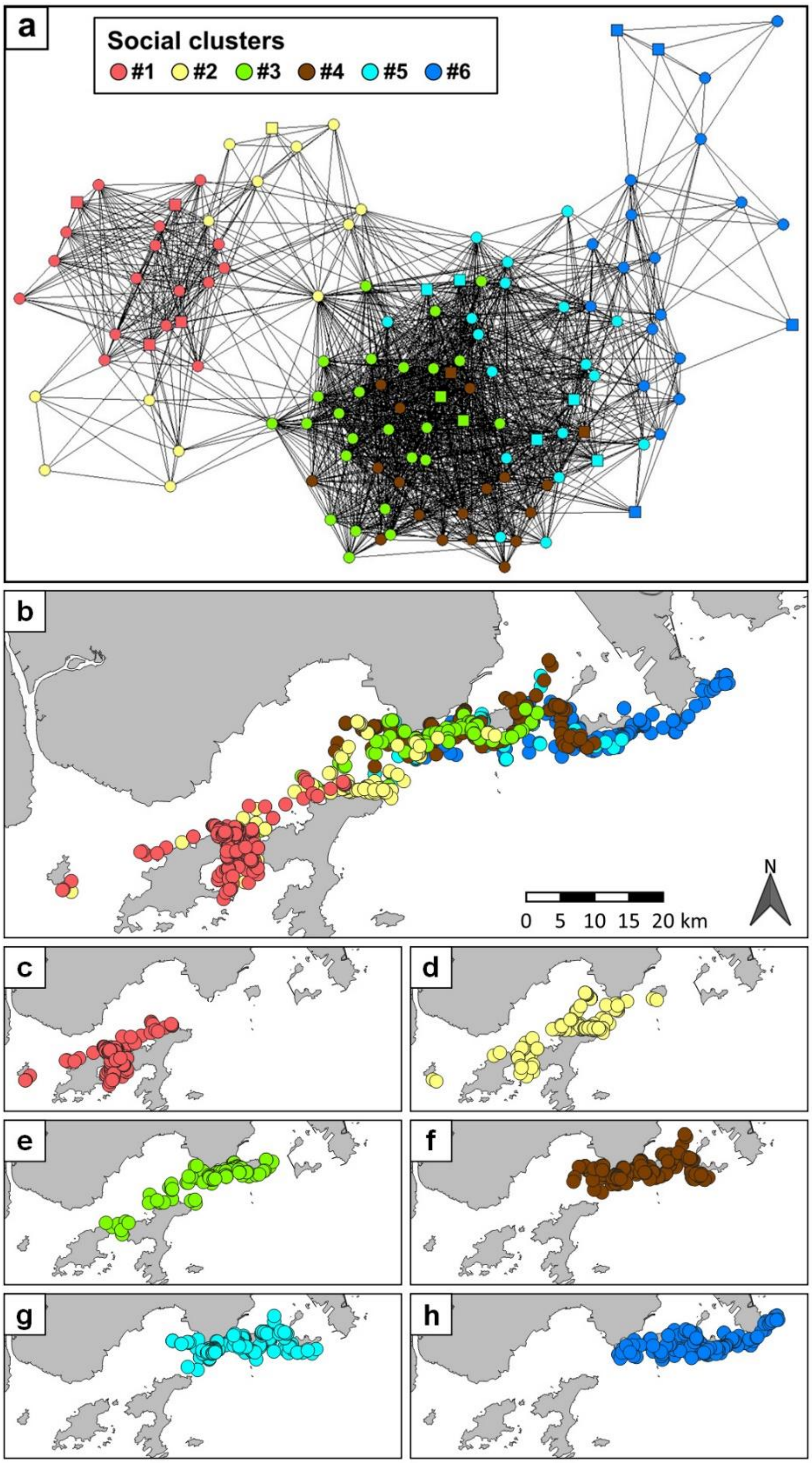


Figure 19. (a) Network diagram of six social clusters of Chinese white dolphins and (b–h) geographic locations of individuals attributed to the social clusters at the western reaches of the Pearl River Delta region. (a) The six social clusters, shown in different colours, were identified at modularity ~0.40, where adults are depicted as circle nodes and juveniles as square nodes, and the distances between nodes are inversely proportional to the strength of associations. The individual sighting locations are displayed (b) together on one chart and (c–h) individually for each cluster to avoid overlapping points.

An average-linkage clustering method that assumes a hierarchical structure among individuals, and where the modularity was maximised by progressively merging potential clusters, was also performed for reasons indicated above. This agglomerative approach identified five hierarchical clusters, and the dendrogram was depicted at a modularity approximating ~0.4 and cophenetic correlation coefficient of ~0.8 (Figure 20), both indicative of a good representation of social differentiation among individual dolphins. Similar to the modelling results of the non-hierarchical algorithm, all identified clusters had association indices higher than the overall average, and the individuals attributed to various hierarchical clusters exhibited different but not completely dissimilar distribution pattern, with overlapping ranges (Figure 20).

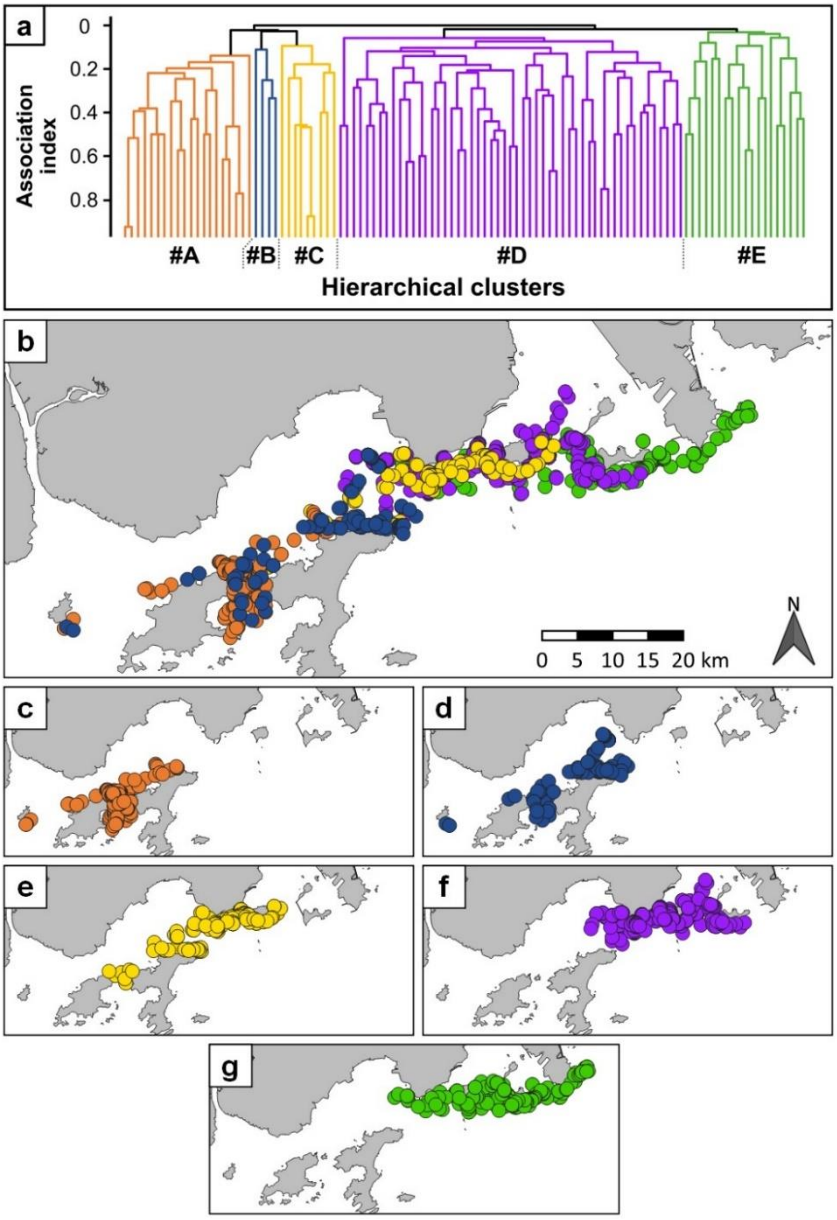


Figure 20. (a) Dendrogram of five hierarchical clusters of Chinese white dolphins and (b-g) geographic locations of sightings of individuals attributed to the hierarchical clusters at the western reaches of the Pearl River Delta region. (a) Cophenetic correlation coefficient was ~0.8 and modularity was ~0.4. The individual sighting locations are displayed (b) together on one chart and (c–g) individually for each cluster to avoid overlapping points.

While the final choice of the analytical clustering technique is open to debates, the results (5 non-hierarchical clusters *vs.* 6 hierarchical clusters) indicate that while there may be some differences in a fine detail, the overall representation of the social structure of Chinese white dolphins at the western reaches of the PRD region is consistent irrespective of the analytical technique applied. Consequently, the non-hierarchical approach that uses eigenvector-based algorithm appears to be a better choice (used also previously in our earlier analyses) as the fission-fusion society of Chinese white dolphins does not appear to have a hierarchical structure.

The spatial pattern of dolphin social clusters in western PRE illustrates the type of dynamics where, despite some tightly interconnected clusters, a discernible socio-spatial structure – given a scrupulous analytical treatment – is evident. Indicative of a fission-fusion society with fluid associations, it appears that individual ranging pattern and spatial preferences are the key factors, if not the only factors that determine their group dynamics. Given that foraging was the most frequently seen behaviour, we believe that the daily association pattern of Chinese white dolphins is largely driven by their individual fidelity to specific foraging locations. In degraded environments with limited food resources, such as the PRD coastal waters (e.g., considerable habitat destruction, overfishing, etc.; Karczmarski et al. 2016), finding food to meet daily nutritional needs can be a major daily challenge (Lin et al. 2021). As such, foraging preferences are likely the underlying driving force that determines the association patterns and shapes the social structure of this obligatory inshore species (as argued also for other taxa by Cantor and Farine 2018; Methion and Díaz López 2020).

Using the most up-to-date mark-recapture dataset and computational program MARK, we performed modelling analyses to estimate key population parameters of dolphins inhabiting the westernmost reaches of the PRD region. Two open population models, Cormack-Jolly-Seber (CJS) and POPAN, were applied as they are complimentary to one another. The CJS model offers the possibility to incorporate and test the time-since-marking (TSM) effect, and was used to estimate apparent survival rates (ϕ) and recapture probabilities (p) for a more thorough model selection and accurate parameter estimation. The POPAN model was used primarily to estimate the super-population size (N), which is unavailable in the CJS model. Candidate models were generated by incorporating different demographic effects on the estimated parameters and subsequently selected based on the AICc or quasi-AICc (QAICc). Goodness-of-fit (GOF) tests were performed to assess the fitness of the general (most parameterised) models, and likelihood-ratio-tests (LRTs) were used to test the various effects between nested candidate models.

With the application of POPAN models, we estimated that 921 Chinese white dolphins use Western PRE waters as their primary habitat (Table 4). Notably, there are more juvenile dolphins in this area, both in number and proportion, than at the eastern reaches of the PRD region.

Table 4. Population size estimate (POPAN mark-recapture parameters) of the Chinese white dolphins inhabiting coastal waters at the westernmost reaches of the PRD region.

POPAN parameters	**Estimate**	**CV**
Size estimates (N)		
= the number of dolphins using Western PRE waters as their primary habitat		
• Adult	723	0.039
• Juvenile	198	0.047
• Total (= Adult + Juvenile)	**921**	0.061

Most of our current understanding of the life history of the PRD dolphins comes from examination of carcasses stranded in Hong Kong and Lingding Bay. In the absence of other data, the life history characteristics were assumed to be similar across the entire region. However, the higher proportion of young individuals at the western reaches of the PRD suggests either a higher reproductive rate, or lower mortality rate of young individuals (or both) as compared to the eastern reaches of the PRD system. Furthermore, the differences in dolphin demographic characteristics echo our other finding that the PRD dolphin population is not as homogeneous as previously assumed but rather a dynamic and spatially differentiated socio-demographic system.

Despite the considerable size and substantial number of young dolphins, Cormack-Jolly-Seber (CJS) modelling (Table 5) indicates generally low survival rates of the Western PRE dolphins, with a prominent heterogeneity between age-classes.

Table 5. Estimates of survival rates and recapture probabilities (Cormack-Jolly-Seber parameters) of the Chinese white dolphins inhabiting coastal waters at the westernmost reaches of the PRD region.

Cormack-Jolly-Seber (CJS) parameters	**Estimate**	**SE**
Annual survival rates (ϕ) = the probability of dolphins surviving from one year to the next = *in other words, the proportion of the Western PRE dolphins surviving per year*		
• Adult	**0.94** (i.e., ~6% mortality of adult dolphins/year)	0.031
• Juvenile	**0.82** (i.e., ~18% mortality of juvenile dolphins/year)	0.075
Annual recapture probabilities (p) = the probability of dolphins being re-identified with high-quality ID-images (i.e., photographically "recaptured") per annum = *in other words, the proportion of the Western PRE dolphins seen and photographed per year*		
• Adult & Juvenile – no differences between age-classes, indicating rigorous field and laboratory protocols in ensuring equal catchability of all dolphins regardless of their features	**0.57 – 0.78** (i.e., >half to >three-quarter of all dolphins were photographically recaptured per year)	0.025 – 0.043

While the estimation of apparent survival rates consider both the true survival of animals and the permanent emigration (movement) of individuals, in long-lived mammals such as Chinese white dolphins, true survival rates are not likely to vary drastically in a short period of time in the absence of catastrophic events. Short-term variations and individual heterogeneity in survival estimates are therefore closely related to patterns of emigration (Pradel et al. 1997; Chan and Karczmarski 2017). When the potential bias of emigration (related to the less frequently seen individuals) is separated from the estimation of parameters, the survival estimates of repeatedly-seen dolphins approximate 0.94 and 0.82 for adults and juveniles, respectively. Both estimates are notably lower than the previously estimated threshold for long-term biological persistence of a viable population (Karczmarski et al. 2017). Worryingly, these estimates are even lower than that at the easternmost reaches of the PRD (see above), although the magnitude of difference between age-classes is similar.

These low estimates of survival rates came as surprise, as western PRD has long been thought to be under lesser anthropogenic pressure than the heavily urbanised and industrialised Lingding Bay and Hong Kong waters at the eastern reaches of the PRD. Water quality in western PRD is reported to be considerably better, with lower pollutant levels than in Lingding Bay which receives wastewater from the most populated part of the heavily urbanised region. Maritime traffic, including cargo ships, tankers, high-speed ferries, and other motorised vessels, is also less intense in the western reaches of the PRD. A newly published study of Chinese white dolphin diet conducted across the PRD region (partially facilitated by our project) indicates a dietary shift in recent years, likely due to declining food resources (Lin et al. 2021); and here too the change in the dietary spectrum was notably more pronounced in the eastern than western PRD (Lin et al. 2021).

Estimates of population parameters and vital rates (such as individual survival, fecundity, fertility) reflect the population status and can be indicative of population-level response to multiple stressors, both natural and anthropogenic (Williams et al. 2002). Monitoring such demographic characteristics offers a window into population processes and may provide an early warning if the population is underperforming, possibly declining, ahead of detectable change in population numbers. The low survival estimates suggest that Chinese white dolphins inhabiting western PRE are under substantial level of impacts, possibly combined effects of multiple stressors exerted over space and time, though largely unquantified and not even sufficiently identified. Given the apparent contradiction between the larger proportion of juvenile dolphins in western PRE and low estimates of current survival rates, it is plausible that the substantial level of environmental stress is due to recent developments (past decade) and largely, perhaps primarily, anthropogenic. This dilemma requires further and very careful consideration. We strongly recommend to have it performed as part of a concluding phase of this multi-year research undertaking.

Socio-demographic structure across the greater PRD region

To quantify the socio-demographic structure of Chinese white dolphins across the spatial scale of the entire PRD region, advanced social network analyses were performed using eigenvector-based clustering algorithm. As pointed out above, this approach is more appropriate for non-hierarchical cetacean societies (and considerably more sophisticated as well), but also highly demanding in terms of data quantity and quality. Robust datasets are therefore a must if the generated results are to be reliable. Currently, we are at the verge of reaching that stage, which speaks volumes for the effectiveness of our research design and analytical diligence, even when faced with unforeseen limitations. The results presented below are well representative of the overall pattern and provide a far greater detail than ever accomplished in the PRD region (and in fact anywhere else across the geographic range of Chinese white dolphins). However, a greater level of detail in defining the population structure can (and should) be still achieved, as indicated below (see the concluding paragraph).

With the latest photo-ID dataset cross-referenced across the entire PRD region and non-hierarchical network analyses with eigenvector-based algorithm, we identified at least 25 social units, including dyadic associations of individuals that move occasionally between sub-regions. These latter individuals, even if infrequently sighted, are important to consider as they play an important role in population connectivity. Excluding these infrequently seen individuals at this stage of the analyses could potentially underrepresent the level of socio-spatial connection across the region.

The 25 identified social units cluster into 10 distinct and more stable units, which we putatively designate as distinct demographic clusters (Figure 21) depicted in Figure 22 against their spatial distribution. These ten demographic clusters constitute a vast majority (>93%) of all catalogued individuals and they are likely the key population units within the PRD dolphin population. However, they do not necessarily represent meaningful management units. We anticipate that several of these socio-demographic units likely represent jointly a management unit. Further and more in-depth analyses are needed, however, including genetic data, to address this question conclusively based on a well-funded evidence.

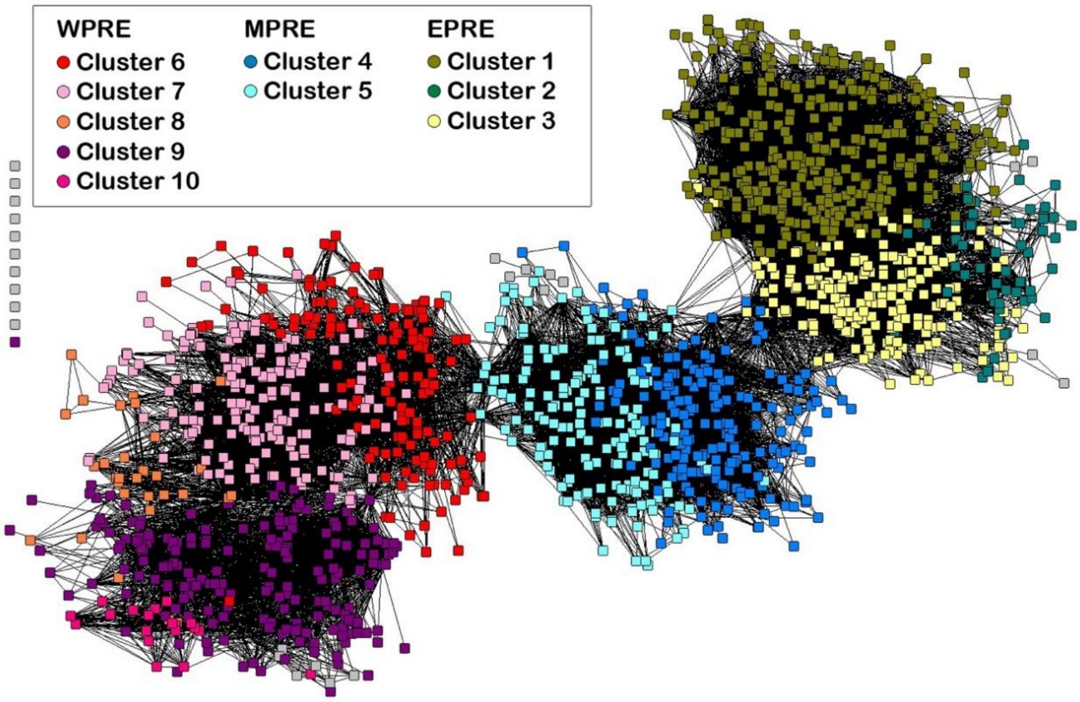


Figure 21. Social network diagram of 25 eigenvector clusters derived from the most up-to-date dataset of Chinese white dolphins seen across the Pearl River Delta (PRD) region. Of those, ten more demographically stable units (depicted above) constitute a vast majority of individuals ever seen and catalogued in coastal habitat across the PRD.

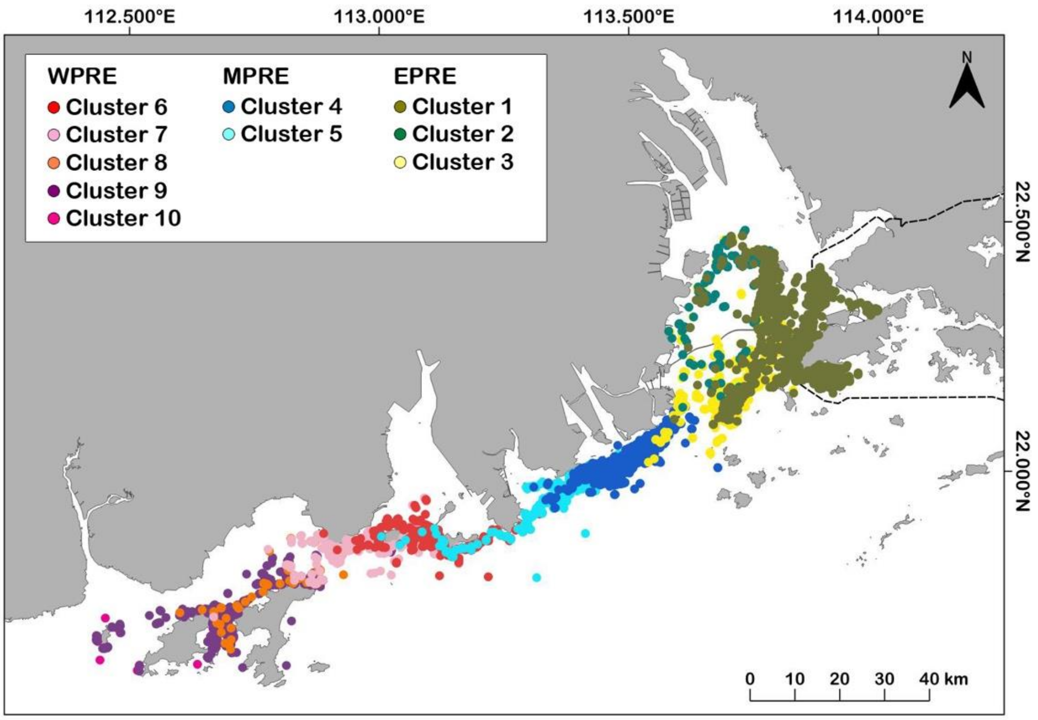


Figure 22. Geographic distribution of 10 clusters putatively designated as main socio-demographic units of Chinese white dolphins in the PRD region (***note:*** the conclusiveness of "main socio-demographic units" requires further analytical scrutiny).

The results presented above are sufficiently representative to depict the general socio-demographic and spatial pattern (e.g. number of units/ communities/ subpopulations, and their specific geographic sub-region). It has to be emphasised, however, that these model projections are still somewhat tentative and require further modelling scrutiny (e.g. the level of connectivity, number of clusters, cluster membership, etc.) with inclusion of supplementary data of considerable importance (e.g., population socio-genetics; as intended in the original project design) and refined analytics, which – once completed – will be particularly important when applying our findings to delineate management units. An appropriate proposal is currently under development and we strongly recommend to have it performed as part of a concluding phase of this multi-year research undertaking.

Viability analyses

As we have advanced our understanding of the population parameters, individual movement and dispersal pattern, socio-spatial dynamics and demographic connectivity of the PRD dolphins, the time is now ripe to apply the most up-to-date population metrics to examine the demographic population projections for Chinese white dolphins in coastal habitat of the PRD. However, we have to reiterate that, this analysis is currently presented without any measures of gene flow and sex-specific dispersal, as we are lacking the genetic component initially envisioned in the original project framework. Consequently, albeit informative and analytically robust, the results are not yet fully conclusive or final and will have to be repeated once the currently missing genetic data is available.

To project the population trajectory, population viability analyses (PVA) were performed adopting the latest quantified metapopulation structure and measures of dispersal between putative subpopulations. To further demonstrate the benefits of taking into account the population heterogeneity and connectivity (contrary to the previous rather simplistic assumption of a single PRD population without spatial substructure), the metapopulation viability assessment was compared against a hypothetical homogenous population scenario. Individual-based stochastic PVA simulations were run to model the fluctuation of population size and the probability of extinction over time, which offers insights into the demographic changes with stochasticity and dispersal taken into consideration.

All completed PVA model simulations indicate negative population growth rates, i.e., the PRD population is on a steep downward slope in all projected demographic scenarios modelled over the next 100 years (Figure 23), which is not surprising given the alarmingly low survival rates that are well below the previously estimated threshold that could secure biological viability (Karczmarski et al. 2017a). However, the rates of decline differ considerably between stochastic and deterministic metrics, and – more importantly – between the more realistic metapopulation scenario and the hypothetical homogeneous population scenario. Under the metapopulation scenario, the overall stochastic population growth rate was estimated at an annual rate of -3.3%, which was substantially higher (less negative) than the deterministic rate (-5.0%) which does not account for demographic stochasticity and dispersal between subpopulations. In contrast, if the current evidence of metapopulation structure was disregarded (under the homogeneous population scenario), the stochastic rate worsened to -6.2% per annum, almost double that of the PRD metapopulation (Figure 23). Translating the projected population trajectories into changes of population size, the entire metapopulation unit was estimated to lose nearly ~86% of the extant individuals after three generations. It was estimated to be even worse for the hypothetical single population, which would lose almost all (over ~97%) individuals. While the metapopulation model projection declined rapidly, the probability of total extinction was not reached in the modelled 100 years. On the other hand, however, if the metapopulation connectivity was to be cut-off, the likelihood of a single population going extinct increases to 48% (Figure 23b).

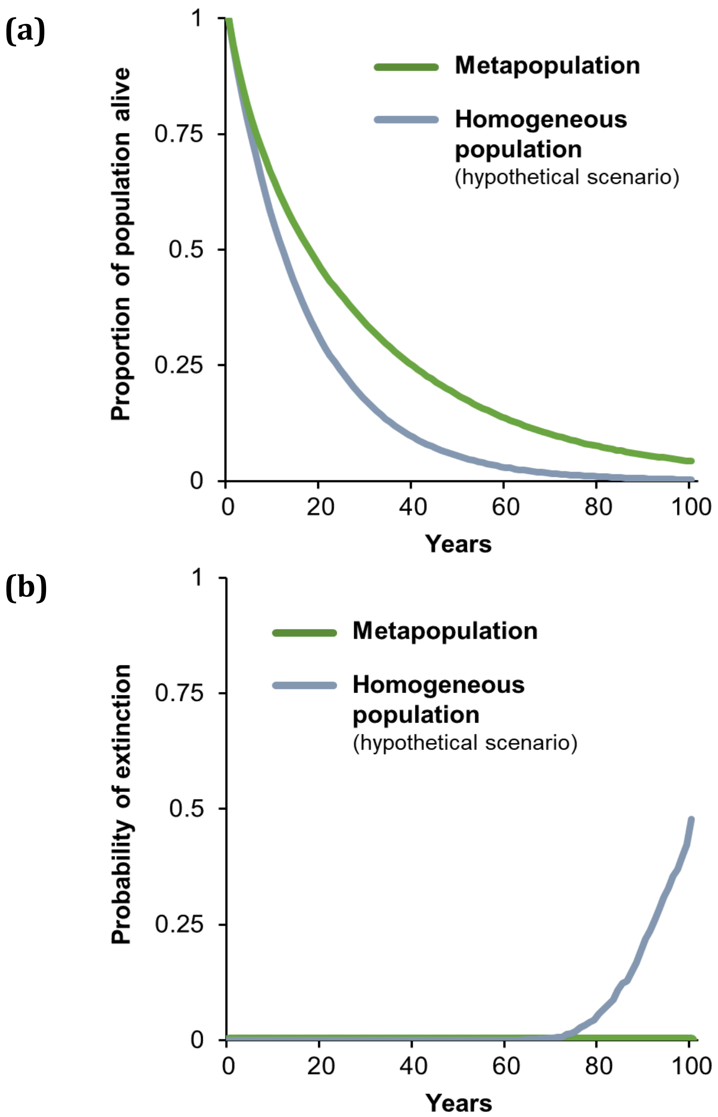
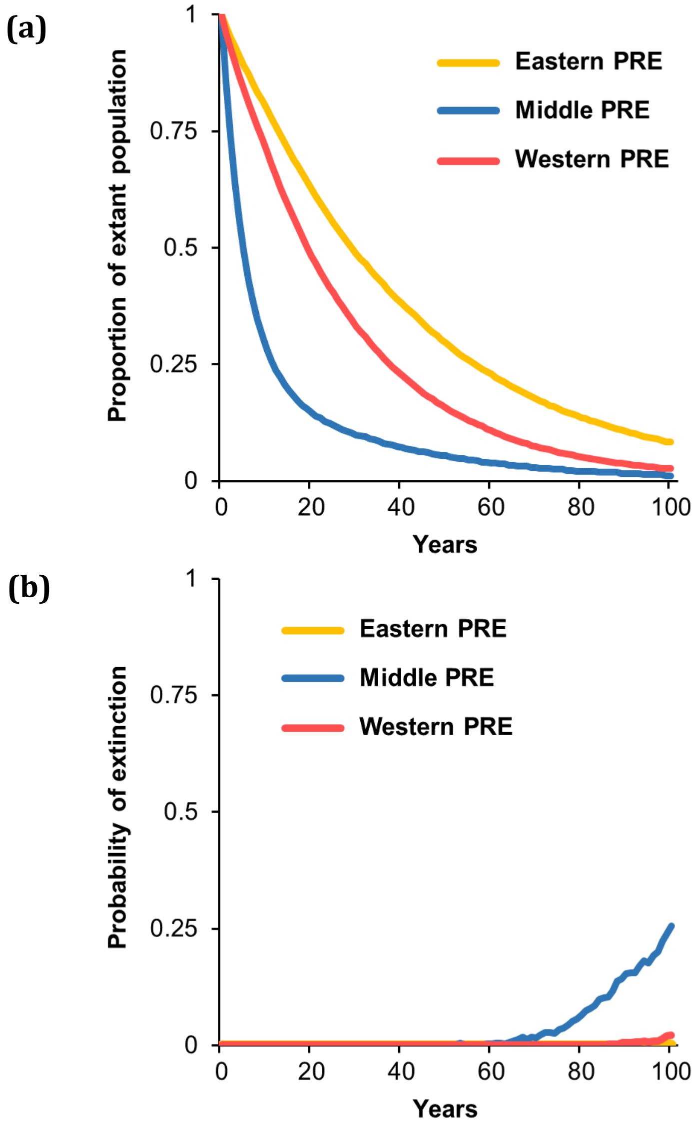


Figure 23. Projections of (a) the proportion of population alive and (b) the probability of extinction of Chinese white dolphins in the greater Pearl River Delta region over the next 100 years, from 1000 iterations of individual-based simulations under the metapopulation scenario (green) and the hypothetical scenario of a single homogeneous population (grey).

PVA model simulation for heterogeneous metapopulation projects all three putative subpopulations to decline continuously over the next 100 years, albeit at different rates (Figure 24a). Simulation models suggest that dolphins in Middle PRE will decline in numbers most rapidly as compared to the two other demographic subunits, with a high likelihood of local extinction (nearly 25% chance of one sex gone extinct in Middle PRE within 100 years; Figure 24b).

Figure 24. Projections of (a) the proportion of population alive, and (b) the probability of extinction of Chinese white dolphins in the Eastern (yellow), Middle (blue) and Western (red) PRE subpopulations over the next 100 years; from 1000 iterations of individual-based simulations under the metapopulation scenario.



Although these PVA models are not yet conclusive given the reasons stated above, our current results present convincing evidence that the metapopulation structure and the resultant socio-demographic dynamics are critical in projecting and understanding the population persistence. It is most apparent when the metapopulation trajectory is contrasted with the simplistic homogeneous PVA model (which has been the underlying assumption for any such analyses in this region in all prior studies), as it falsely doubled the decline rate and substantially escalated the probability of extinction. While in general all stochastic fluctuations exacerbate the risk of extinction for a single population, as in the case of a homogeneous PRD population, the dispersal between subpopulations (through individual movements) has a positive "rescue effect" on the overall persistence of a metapopulation even if the demographic stochasticity remains in effect. This is likely the case in the PRD metapopulation: even though the transition between subpopulations is limited (see results reported above), the ongoing individual dispersals from "better-performing" subpopulations (those with slower rate of decline, i.e., Eastern and Western PRE) supplement those at greater risks (i.e., Middle PRE) and stabilise the local demographic dynamics. In other words, the individuals travelling between the sub-regions, even if just a handful of them, are of paramount importance, not only as vectors of gene flow (and to maintain the cohesiveness of the demographic structure), but more decisively in determining the fate of the larger metapopulation.

However, it cannot be overstated that this natural buffering mechanism of metapopulation connectivity should not been seen as any sorts of "mitigation". It would be fundamentally wrong to bet on having this mechanism reverse the tide of fast declining trend, because in the demographic time-scale it cannot. Even with the dispersal "supplements", the PRD population as a whole is fast declining, with most individuals likely to be lost in just a few decades. Moreover, dolphins in Middle PRE are at a considerable risk of local extirpation, which – if it was to happen – will have a detrimental impact on the larger PRD metapopulation. The connectivity of the PRD metapopulation depends largely, if not entirely, on the transitions of dolphins through the Middle PRE waters. No individuals were ever seen travelling between the outer (eastern and western) perimeters of the PRD; it is always either between Middle and Western PRE or Middle and Eastern PRE. Should a local extinction occur in the mid-region of the PRD, it could terminate the inter-subpopulation connectivity. If this was to happen, the positive "rescue effect" would be removed and the impact of inbreeding depression could kick in, thus exacerbating the extinction risk for the remaining two isolated populations. Therefore, the ripple effect of a local extinction event (of any of the current subpopulation units) could set off a series of chain reactions leading to population fragmentation. Such turn of events would be of major conservation concern and a real nightmare for management efforts.

The above stated concern is also reflected in the interim status assessment of the Chinese white dolphins in the PRD region. Based on the currently gathered information and analytical evidence, all demographic units, including the entire PRD metapopulation and any of its subpopulations, qualify to be listed as Critically Endangered (CR) under the IUCN Criterion A3 (Figure 25). Such assessments are likely to speak louder to the general public as they visualise more explicitly how urgent are the current conservation concerns surrounding Chinese white dolphins in PRD waters. They also underscore the importance of taking this project through to its final concluding phase.

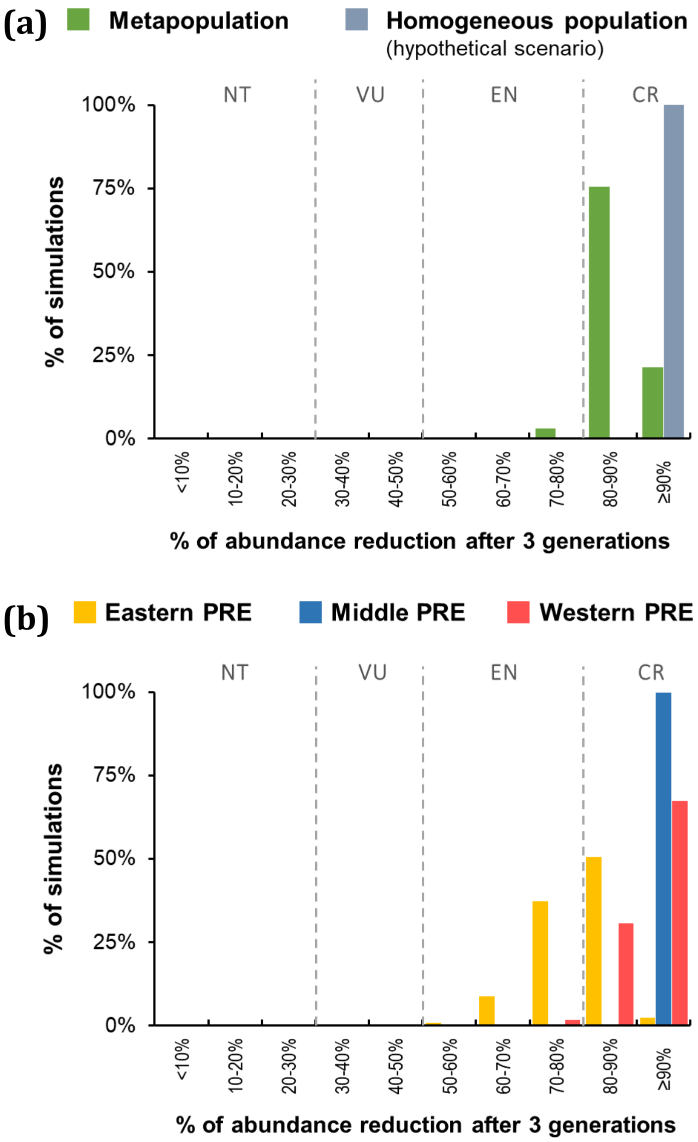


Figure 25. (a) Distribution of the percentage of abundance decline of Chinese white dolphins in the Pearl River Delta region after three generations for 1000 PVA simulations under the metapopulation scenario (green) and hypothetical scenario of a single homogeneous population (grey). (b) For the metapopulation scenario, the decline in abundance of Eastern (yellow), Middle (blue), and Western (red) PRE subpopulations are displayed individually. The thresholds of abundance reduction that meet the classification of Critically Endangered (CR; ≥ 80%), Endangered (EN; ≥ 50%), Vulnerable (VU; ≥ 30%) and Near Threatened (NT; < 30%) under IUCN criterion A3 are also indicated as grey dotted lines.

It has to be once again underscored that the current PVA exercise is not yet final and is given here specifically for reporting purposes, to illustrate the progress of the project and the potential impacts of our work.

Evaluation of the project effectiveness

All aspects of the project – as per its amended scope and timeframe – progressed well and on schedule. The entire body of work advanced along the conceptual framework delineated at the onset of this multi-year undertaking.

As amply indicated in the current and all previous reports, our field survey protocol and analytical techniques have once again tested well for the effectiveness and quality control, and the comparability of all collected data across the greater geographic region. Data processing has also progressed with consistent standards, which facilitated all the analyses presented in this report, all of which are based on the latest and most up-to-date mark-recapture dataset.

As planned in the original project framework and subsequently adjusted in the amended proposal (adjusted to fit the funded scope of work and time-frame), we have performed multifaceted analyses of various aspects on the population dynamics and structure, demographic parameters, individual movement patterns, dispersal and ranging, and socio-demographic connectivity of Chinese white dolphins across the greater PRD region. The results generated by our work are the first of its type and highly significant in quantifying the metapopulation dynamics of the PRD dolphins and understanding their heterogeneous socio-demographic structure, and – importantly – understanding the implications of these newly documented dynamics on fundamental population processes. Based on these latest findings, we have further generated the first metapopulation viability assessment of Chinese white dolphins across the spatial scale of the greater PRD, as per the original framework of this multi-year undertaking. Although at present the PVA remains interim and will need to be repeated once the genetic information becomes available, it is already indicative of the overall demographic trajectory and should be taken as a cause for concern. The severity of this concern cannot be overstated, which once again underscores major implications of this multi-year project and the critical importance of having it fully completed (a concluding phase of this project is much needed).

Deliverables of this project, once finalised, will be instrumental in the delineation of population management units, which in turn will be highly informative for effective conservation efforts in the PRD region. This objective was an integral component of the original project design and in the light of our current findings (especially the PVA assessment) it gained massively in importance. From its very onset, this project represents a carefully-designed research which, if timely and thoroughly executed, is guaranteed (thanks to its structural design, effective field protocol and well-tested quantitative analytical techniques) to carry major implications for the conservation management of Chinese white dolphins in Hong Kong and across the PRD region. This work has been long overdue, as abundantly indicated by our findings and the results detailed in this report. Once fully completed, this work will significantly enhance our understanding of the conservation ecology of the PRD dolphins and offer an opportunity to reconsider (possibly revise) the current approach to their long-term conservation. At this advanced stage (and given the quality and quantity of our current results), we are confident that once fully completed, this project will provide an evidence-based framework to guide realistic conservation objectives and fine-tune management strategies that could effectively maximise their conservation outcome.

Additional current output

As the type of work undertaken in this project depends on large multi-year datasets, publishable results (research articles in peer-reviewed journals) were expected to follow only after the full completion of this multi-year undertaking. Currently, the final concluding phase of this project still needs to be completed.

Meanwhile however, while working on the main body of the intended deliverables (i.e., the key findings, which will be submitted to journals only after the concluding phase of this project is completed), we have already generated and/or facilitated (by joint effort with our collaborators in the Mainland) a number of peer-review papers in international journals that can serve for a measure of the credibility and effectiveness of our ongoing work. Much of the currently published work addresses specifically the PRD dolphins but carries also broader region-wide implications. For example, a comparison of our PRD photo-ID catalogue with photo-IDs of Chinese white dolphins in waters hundreds of kilometres further south along the Chinese coast (over 3,000 individuals) indicated no re-sighting between the regions, which directly supports the population model projections generated with our PRD data. In other words, our findings derived from this MEEF-funded project benefit not only the PRD dolphins and their future conservation, but helps also to understand the population processes of Chinese white dolphins elsewhere in Chinese waters. In that context, their spatial structure and connectivity across larger geographic scales (e.g., the coast of China/SE Asia) should be given further dedicated research attention.

List of research papers in international peer-reviewed journals generated and/or facilitated by this project to date:

Lin W, Chan SCY, Guo L, Ho Y-W, Zheng R, Mo Y, Karczmarski L (In Prep.) Spatial heterogeneity in survival: Indo- Pacific humpback dolphins in world's largest coastal metropolitan region. Unpublished manuscript (currently in a final stage of preparation).

Chan SCY, Karczmarski L, Lin W, Zheng R, Ho Y-W, Guo L, Mo Y, Lee ATL, Or CKM, Wu Y (2022) An unknown component of a well-known population: socio-demographic parameters of Indo-Pacific humpback dolphins (*Sousa chinensis*) at the western reaches of the Pearl River Delta region. *Mammalian Biology* (Special Issue) 102(4): 1149–1171.

Lin W, Karczmarski L, Guo L, Zhou R, Mo Y, Yiu SKF, Ning X, Wai T-C, Wu Y (2021) Prey decline leads to diet shift in the largest population of the Indo-Pacific humpback dolphin? *Integrative Zoology* 16: 548–574.

Tang X, Lin W, Karczmarski L, Lin M, Chan SCY, Liu M, Xue T, Wu Y, Zhang P, Li S (2021). Photo-identification comparison of four Indo-Pacific humpback dolphin populations off southeast China. *Integrative Zoology* 16: 586–593.

Guo L, Lin W, Zeng C, Luo D, Wu Y (2020) Investigating the age composition of Indo-Pacific humpback dolphins in the Pearl River Estuary based on their pigmentation pattern. *Marine Biology* 167: 50.

Chan SCY, Karczmarski L (2019) Epidermal lesions and injuries of coastal dolphins as indicators of ecological health. *EcoHealth* 16: 576–582.

Lin W, Chan SCY, Zhen C, Karczmarski L, Wu Y (2018) Mark-recapture technique for demographic studies of Chinese white dolphins — Applications and suggestions. *Acta Theriologica Sinica* 38: 586-596.

Summary and Way Forward

Our latest analyses, as per the framework delineated at the onset of this multi-year undertaking, have been summarised in this report, delivering advanced assessment of dolphin movement patterns, individual transitions across the region, dispersal and displacement patterns across the spatial scales of the entire PRD, and socio-demographic connectivity of the complex metapopulation. However, it must also be recognised that while the reliable identification of the population structure and accurate quantification of its demographic connectivity represent the primary large body of evidence gathered to date, it is the extent of the intra- and inter-subpopulation dynamics that is now crucially important to quantify, as these socio-spatial and demographic processes are among the key determinants of population long-term viability. What it means is, as shown earlier in this report, that conservation actions cannot focus only on local dolphin groups and specific core areas, but have to adopt a holistic approach to a regional maintenance of the metapopulation dynamics. If these dynamics are not retained, population fragmentation may follow, and each of the fragmented population units will be considerably more susceptible to local pressure and face considerably higher extirpation risk.

Given the apparent fragility of the connectivity vectors within the PRD dolphin population (as our current estimates indicate), such fragmentation process would be highly detrimental, likely lethal to the continuous persistence of the PRD (meta)population. In that context, it is hard to overstate how critical is the task undertaken by our project to the long-term survival and conservation of Chinese white dolphins in the region. Robust models and accurate estimates of the population processes (as indicated above) are of paramount importance for any reliable assessments of population viability and identification of conservation targets that may – if timely implemented – facilitate sustainable survivability of Chinese white dolphins in Hong Kong and across the greater PRD region.

While the overall picture of the metapopulation processes of Chinese white dolphins in the PRD is gradually getting clearer and we have the first glimpse into their long-term viability (or rather in-viability, as our findings indicate), it has to be explicitly pointed out that this type of analyses is particularly sensitive to the robustness of the dataset. With only limited level of data gathering during the phase reported here, many of the results presented, albeit at an advanced stage, are still a step away from being final or conclusive, and should be further validated against data stochasticity as intended and stated in the original proposals. However, the work, even though as promising as we have shown in this and all previous reports, may suffer irreparable damage and so will the intended deliverables and their applicability in future conservation and management efforts. As amply demonstrated above, it is impossible to overstate how fundamental are the issues addressed in our project and how crucially important is to have this multi-year endeavour completed with all initially set goals and objectives.

Given our recent findings, the most important research questions that remain to be addressed (and should be targeted in the next phase of the project) are as follows:

- The overall size of the complex (meta)population and its spatially-distinct sub-units needs to be quantified, along with spatially-differing survival rates, and multi-state transition of individuals within and across the PRD.

- Following up on the work initiated in the prior phase of this project, genetic tools should be applied to estimate the generational scale of population processes, which – once interfaced with our current population models based on mark-recapture data – would greatly enhance the formulation of metapopulation viability models for accurate trend projections.

- Our multi-year individual-based data provides a great opportunity to quantify the reproductive dynamics and estimate most up-to-date population-specific reproductive parameters of the PRD dolphins (e.g., birth rate, calf survivorship, annual recruitment rate), which represent an essential component of species' life history that so far has not been addressed.

- Given our recently discovered spatial heterogeneity in demographic parameters among dolphins of the Eastern and Middle PRD, this spatio-demographic pattern should be examined in a greater detail as it pertains to the most vulnerable population unit in the whole of the PRD.

- Once the above is accomplished, it would allow us to conduct appropriately thorough analyses of the demographic trajectory of the PRD dolphins. With that done, it will be possible to credibly identify management units of the PRD dolphins and priority units for conservation, which could then form a solid basis for evidence-based conservation plan for Chinese White Dolphins in Hong Kong and across the greater PRD region.

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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.

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.

Declaration

I hereby irrevocably declare, warrant and undertake to the MEEF Management Committee and the Steering Committee of the relevant Funds including the Top-up Fund, that I myself, and the Organisation:

1. *do not deal with, and are not in any way associated with, any country or organisation or activity which is or may potentially be relevant to, or targeted by, sanctions administered by the United Nations Security Council, the European Union, Her Majesty's Treasury-United Kingdom, the United States Department of the Treasury's Office of Foreign Assets Control, or the Hong Kong Monetary Authority, or any sanctions law applicable;*
2. *have not used any money obtained from the Marine Ecology Enhancement Fund or the related Top-up Fund (and any derived surplus), in any unlawful manner, whether involving bribery, money-laundering, terrorism or infringement of any international or local law; and*
3. *have used the funds received (and any derived surplus) solely for the studies or projects which further the MEEF Objectives and have not distributed any portion of such funds (including any derived surplus) to members of the recipient organisation or the public.*

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