**Marine Ecology Enhancement Fund (MEEF)**
**Declaration**

To: The Secretariat of the MEEF

**Reference No.:** MEEF2017015B

**Project Title:** Conservation Ecology of Chinese White Dolphins across the Pearl River Estuary Phase 3: Connectivity, Metapopulation Structure and Source-Sink Dynamics

**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: 31 Jul 2020

Marine Ecology Enhancement Fund (MEEF)

# Conservation Ecology of Chinese White Dolphins across the Pearl River Estuary

## Phase 3: Connectivity, Metapopulation Structure and Source-Sink Dynamics

**MEEF2017015B**

**Completion Report**

*31 Jul 2020*

Cetacea Research Institute
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## Executive summary

The project reported here represents an initial stage of Phase 3 of a multi-year undertaking, initiated with a pilot study in 2015. This multi-year research effort aims at developing a sound ecological framework for the conservation of Chinese White Dolphins (CWD) across the greater Pearl River Delta (PRD) region, southeast China. The western reaches of the PRD region (referred here as Western Pearl River Estuary, W-PRE) appear to harbour substantial numbers of CWD, seemingly larger than those in Eastern PRE. The dolphins in Western PRE may in fact be critically important to the continuous long-term survival of CWD anywhere in the greater PRD region. However, with no in-depth research ever done in Western PRE (other than our pilot Phase 1), literally nothing was known about these dolphins prior to the initiation of our project. All aspects of their ecology, socio-demography and population processes investigated in this ongoing multi-year research represent the first ever scientific account of this population.

All photo-ID mark-recapture work, including field data collection, analytical treatment and other project-related activities intended to take place during the time period reported here progressed as planned, timely and on schedule, following closely the originally envisioned framework of the project. The photo-ID data collected across the PRD contributed a very substantial new component to the long-term mark-recapture database, which forms the backbone for all ongoing and all intended research investigations within this multi-year undertaking. Even though there are obvious limits to how much data can possibly be generated in a single year (which is the time-duration of the project reported here) of a field-based study of notoriously cryptic and highly mobile marine vertebrates, in our case, in conjunction with the earlier MEEF-funded phase(s) of this study, the work reported here represents a substantial building block within the framework of the larger multi-year undertaking. A total of 71 surveys were conducted during the project period reported here, resulting with 308 encounters of dolphin groups and cumulative number of 1614 dolphin sighting-records.

Our current analyses, albeit not yet final in the context of the ongoing multi-year work, have delivered interim assessment of individual movement patterns within and between sub-regions of the PRD, quantified the rate of transitions across the region,

estimated the individual dispersal pattern and displacement range respective to the spatial scale of the coastal ecosystem of the PRD, depicted the socio-demographic structure and preliminarily quantified the socio-spatial connectivity within the complex metapopulation dynamics of the PRD dolphins.

Interim movement analyses in all three sectors across the region indicated moderate-to-considerable long-term site fidelity of Chinese white dolphins to their respective sectors of the Pearl River Delta region. While some individuals may temporarily leave their deltaic sub-regions, re-immigration is frequent and in the long-term the dolphins exhibit considerable affinity to relatively restricted geographic ranges. The long-term continuous decline in modelled geographic fidelity is likely (or at least to considerable degree) due to dolphin mortality, which in the context of population modelling results in discontinued re-sightings. The model projection of multiple-area movement analyses also reflects a low number of individuals re-sighted across the three sub-regions of the PRD. Conjointly, these interim findings support that the movement between different sectors of the PRD is limited, although this conclusion has still to be tested in the currently intended next phase of this project.

Parameterised transition models computed based on the current dataset delivered a direct quantitative measure of annual transition of individuals between the three distinct sectors of the PRD (Eastern, Middle, and Western PRE), providing a valuable complementary assessment of dolphin movement patterns. The transition rates, albeit low, were not negligible, suggesting infrequent movement of individuals between the neighbouring sectors of the PRD. This in turn is indicative of spatially distinct but not completely isolated demographic sub-units, where the infrequent transitions play a vital role in bridging the putative subpopulations across the greater PRD region. However, there is currently no evidence for individual movement across the entire PRD region, although this statement cannot yet be conclusive at this stage of the project. Furthermore, our current analyses, which are at an interim stage of data intake and processing, are sensitive to the robustness of dataset and therefore these interim results indicated here have to be further examined against data stochasticity when the full intended dataset is compiled and synthesized at the final stage of this project.

The dispersal patterns of CWDs over continuous space across the greater PRD region were preliminarily quantified and contrasted between the individuals seen in the three deltaic sectors. Irrespective of the demographic sub-units (subpopulations) or geographic sub-regions, all dolphins in the PRD region exhibited a non-migratory dispersal pattern. The expansion of individual ranges was most detectable within a week of the first sighting of an individual, and within a quarter of a year the diffusion rates declined to negligible. In other words, individual displacement areas stabilised within three months. While in all cases the individual displacement areas covered only a portion of their respective subpopulation range, the dynamics of dispersal and the magnitude of displacement differed between subpopulations and sub-regions. This is likely reflective of fine-scale differences in habitat and resources available to the dolphins across the greater PRD region (as indicated by an independent, non-MEEF funded study by our research team, currently in press in peer-reviewed journal). It may also be indicative of socio-behavioural heterogeneity across the region, although this has still to be further tested.

Agglomerative social cluster analyses identified three discernible dolphin communities, corresponding spatially to the three sub-regions, Eastern, Middle, and Western PRE. Although on the intra-community level the individual affiliations are generally fluid and dynamic as in a typical fission-fusion society (which is also commonly seen in other *Sousa* populations), the social units depicted in the PRD are spatially distinct and socially discernible by their grouping and movement patterns. It is apparent that the social dynamics are influenced by ranging patterns of individuals, which are in turn largely shaped by their foraging preferences and choice (and availability) of foraging grounds. While the infrequent movement of a handful of individuals between communities / subpopulations may be insignificant for the social fabric of the dolphin society, it is important in maintaining population connectivity, especially as this connectivity appears to be limited at best. The significance of this socio-demographic connectivity cannot be overstated as it facilitates gene flow and prevents the formation of completely insular/discontinuous (sub-)populations. Given that the key dolphin foraging grounds are under increasing threat of coastal degradation and habitat alteration across the region, and given a recent evidence that the availability of dolphin prey is becoming increasingly limited in the PRD (as shown by our independent non-MEEF funded study; in press), this is of major concern and underscores once again (as indicated by our earlier work and earlier reports) the paramount importance of coastal habitat conservation in areas

frequented by the dolphins. The currently scheduled follow-up phase of this multi-year project intends to address further this issue.

Our current analyses of individual movement pattern, connectivity and socio-demographic structure, although still interim and not yet based on sufficiently robust dataset, indicate that the Chinese white dolphins inhabiting the greater Pearl River Delta region form a complex metapopulation with three socially distinct, demographically discernible, and spatially discrete albeit not discontinuous subpopulations (Eastern, Middle, and Western PRE). This heterogeneous socio-demographic structure is apparently in response to the environmental differences across the region that have likely been amplified in recent years/decades. The possibility of population fragmentation in response to increasingly heterogeneous anthropogenically impacted seascape of the PRD underscores the utmost importance of an accurate identification of the metapopulation structure, which is among the most significant findings of this project to date (albeit it has still to be validated with currently incoming data and further analyses). Of similarly crucial importance is the realisation that the three putative subpopulations represent interconnected but demographically distinct units, which is vastly different from what have been previously thought. These finding are of paramount importance for formulating informed management decisions and strategizing conservation actions. Correct identification and quantification of the metapopulation structure is the first but crucial step that has profound implications on population parameterisation and the understanding of demographic dynamics and population viability, the very work intended for the upcoming and the next follow-up concluding phase of this multiyear undertaking.

As summarised above, our current findings, although not yet final, are all first of its kind never previously delivered nor attempted in the PRD and in fact anywhere in the species range. Our interim analyses affirm the overall framework and direction of this multi-year project, which if continued will deliver results of major conservation significance due to their implications for long-term conservation management strategy of Chinese white dolphins across the PRD; a model system that may be well applicable elsewhere in comparable habitats for similar conservation targets.


## Disclaimer

This report presents interim findings of an ongoing multi-year research undertaking and it should not be referenced as scientific publication or used at this current stage for management recommendations to avoid any potential misinterpretation and to not cause misunderstanding. As per the project timeline, the next stage of the current phase (Phase 3 cont.) of this ongoing work has to be completed first, followed by analysis-intensive concluding phase, before the interim findings presented here can be sufficiently validated and used for the intended purposes as envisioned in the conceptual framework of this project and 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 represents an initial stage of Phase 3 of a multi-year research effort, initiated with funding from Hong Kong Airport Authority (AAHK) in 2015 (Phase 1) and continued with the MEEF funding support (Phase 2, recently completed). The multi-year effort aims at developing a sound ecological framework for the conservation of Chinese White Dolphins (CWD) across the Pearl River Delta (PRD) region, from Hong Kong and Lingding Bay in the East to the westernmost reaches of the PRD.

Our findings during Phase 1 of this multi-year study indicated that waters of Western PRD harbour substantially larger numbers of CWD than Eastern PRE, with larger groups and different age structure, suggesting that the dolphins in Western PRE may be essential to the continuous persistence and long-term biological survival of CWD in the PRD as whole. Consequently, with no other work ever conducted in Western PRE, this current project was developed to quantify population parameters, processes and structure of CWD across the PRD, and to advance, possibly realign the fundamental concepts of CWD conservation in the PRD and elsewhere in the species range. As our findings to date suggest, current management strategies may need to be revised and probably substantially re-focused, and this prospect alone underscores the high importance of the work pursued in this project and the unique potential of generating long-lasting legacy for biological conservation.

A great deal of new data obtained over the past two years have significantly advanced our perception of the vital demographic parameters, connectivity and structure of the dolphin groups inhabiting the PRD coastal region, which in turn exposes the processes that determine the population responses to environmental change. The picture that begins to emerge is of a complex metapopulation with at least three (but possibly more) sub-units (perhaps subpopulations) with a dynamic albeit not yet sufficiently understood network of interactions. On a local spatial scale (i.e. Eastern PRE *vs.* Middle PRE *vs.* Western PRE) the sub-units appear distinct, but not discrete, and as our database increases, the degree of their connectivity is currently being quantitatively examined.

In the project period reported here, we maintained the volume of data gathered in Middle and Western PRE in parallel with increase in the intensity and scope of data

processing and analyses, as we are now approaching the stage where more reliable analyses become possible. Our growing dataset will soon be able to facilitate sufficiently in-depth analyses that can lead to first peer-reviewed publications. In this completion report, which summarises only the initial stage of the Phase 3, we provide first glimpse of the indicators of the population spatial structure of the PRD dolphins and the interim analyses of the newly discovered metapopulation dynamics and the socio-spatial network of interactions across the PRD. In the next stage (Phase 3 cont., intended for 2020/21), we are going to dive deeper into the population processes with further quantification of the currently discovered patterns. The work reported here (completed in the 2019/20 funding cycle) will be further expanded to provide bases for the identification of management units of Chinese White Dolphins in the greater PRD region (intended for the 2020/21 funding cycle), which in turn will facilitate comprehensive assessment of population long-term viability and how the dolphin long-term survival is affected by the currently identified metapopulation structure across the PRD. This will be a major step, never previously done nor attempted, not only in the PRD region but in fact anywhere in the species range. This is going to be a highly significant step in the overall goal of this multi-year project and will facilitate the formulation of management recommendations (the final Concluding Phase of this project) to strategize conservation initiatives and facilitate informed management decisions.

## Methodology

### (a) Study area

Data collection followed the same field protocol as the prior and the currently ongoing work (e.g. Chan & Karczmarski 2017; Lin *et al*. 2018) and was performed across the Pearl River Delta region (PRD), which refers to the 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 and Western PRE

(Modao Estuary and Yamen Estuary). At this stage of the project, the work in Hong Kong was scaled down (as the Hong Kong dataset is already substantial), but not completely suspended so that the intensity of surveys needed to secure the data continuity and comparability was maintained, while the work in the Mainland part of the PRD, especially Western PRE, was scaled up as much as the sea conditions allowed.

**(b) Field data collection**

Field work 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**

*Movement analyses*

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).

*Site fidelity*

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 later after being first sighted in that sub-region. Movement models were 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 models (Whitehead 2007).

Multiple-area LIRs were also calculated to quantify the individual probabilities of being re-sighted in the same area *vs*. any other area over a time lag (Whitehead 2001). Therefore, 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 model were applied in SOCPROG 2.8 (Whitehead 2009), to estimate the probabilities of individuals moving from one area 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 describe the rate of spread of individuals through continuous space under the assumption of uncorrelated random walk. 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 the 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.

## Completed activities against the proposed work schedule

All photo-ID mark-recapture work progressed as intended, timely and on schedule, and along the originally envisioned timeline of the project. Despite a challenging season with unpredictably less favourable sea conditions and COVID-19 outbreak

across a substantial part of the field season, the required sea-based fieldwork was performed during the reported period to ensure the continuity of data gathering. In conjunction with the prior MEEF-funded work, the processed and cross-referenced database represents an important building block within the framework of the larger multi-year undertaking. Interim analyses of the metapopulation dynamics and socio-spatial connectivity of the Chinese white dolphins across the region were performed based on the currently synthesized dataset. Our current findings, albeit not yet final, clearly indicate already major implications for the continuous advancement of our understanding of the PRD dolphin population processes, underscoring the importance of completing this multi-year project with all its consecutive phases as initially envisioned at the onset of this work.

Boat-based photo-ID surveys were carried out in Hong Kong (HK) waters and various sectors of the Pearl River Delta (PRD) region whenever the sea conditions allowed. During the project period reported here, the research team completed a total of 71 surveys and encountered 308 dolphin groups with overall cumulative number of 1614 dolphin sighting-records. The monthly survey efforts and sighting rates are summarized in Table 1. As pointed out in the original proposal and in previous reports, the intensity of field surveys is weather dependent and peaks in summer months, with low-intensity period during winter.

**Figure 1.** Images taken during sea-based photo-identification surveys of Chinese White Dolphins conducted in various sectors of the Pearl River Delta region.

**Figure 1 (*cont.*).** Images taken during sea-based photo-identification surveys of Chinese White Dolphins conducted in various sectors of the Pearl River Delta region.


**Figure 1 (*cont.*).** Images taken during sea-based photo-identification surveys of Chinese White Dolphins conducted in various sectors of the Pearl River Delta region.

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**Table 1.** Summary of survey effort, number of groups, and dolphin sightings during the MEEF2017015B funding cycle.

| Area | Month | Number of surveys | Number of groups encountered | Cumulative number of dolphin sightings |
|---|---|---|---|---|
| HK | July 2019 | 4* | 33 | 131 |
| | Aug 2019 | 3* | 9 | 42 |
| | Sept 2019 | 3* | 8 | 33 |
| | Oct 2019 | 3* | 8 | 23 |
| | Jan 2020 | 2 | 5 | 12 |
| | Feb 2020 | 1 | 5 | 8 |
| | Mar 2020 | 1 | 1 | 4 |
| | Apr 2020 | 2 | 3 | 14 |
| | May 2020 | 2 | 2 | 17 |
| | Jun 2020 | 3 | 12 | 55 |
| | Jul 2020 | 4 | 13 | 38 |
| | Total | 28 | 99 | 377 |
| PRD | July 2019 | 5* | 51 | 352 |
| | Aug 2019 | 7* | 30 | 134 |
| | Sept 2019 | 2 | 12 | 94 |
| | Oct 2019 | 5 | 25 | 208 |
| | Nov 2019 | 4 | 23 | 109 |
| | Dec 2019 | 1 | 3 | 19 |
| | Mar 2020 | 2 | 10 | 37 |
| | Apr 2020 | 3 | 20 | 97 |
| | May 2020 | 3 | 13 | 84 |
| | Jun 2020 | 3 | 2 | 10 |
| | Jul 2020 | 8 | 20 | 93 |
| | Total | 43 | 209 | 1237 |
| Overall | | 71 | 308 | 1614 |

** As the sea conditions of summer 2019 were unpredictably less favourable than usual for an average year, sea-based fieldwork in these summer months ended-up somewhat less intensive than expected. Therefore, the initial surveys (indicated here with *) within the timeframe of the current funding cycle were covered with the funds brought over with the extended project period of the previous MEEF funding cycle (MEEF2017015A). This in turn allowed to scale down a bit the projected budget for the field work expenses in this current (MEEF2017015B) project.*

***Summary table of completed activities:***

| **Categories of activities** | **Key-points** |
|---|---|
| Photo-ID field surveys | • Whenever the sea conditions allowed, sea-based fieldwork was performed across the Pearl River Delta region.<br>• A total of 71 boat-based photo-ID surveys were carried out with 308 dolphin groups encountered and 1614 individuals sighting-records collected. |
| Photo-ID data processing | • Processing of photo-ID data advanced concurrently with field-data gathering during the peak field-season, and it was intensified during winter months when the field survey intensity was lower due to unfavourable sea conditions.<br>• The currently applied field and lab protocols test well for the quality control of collected data and the continuity of data gathering with consistent standards, assuring the comparability of all data collected across the entire PRD region to date.<br>• The processed datasets, combined with data from prior MEEF-funded projects, provide the backbone quantitative information for the intended analyses within the framework of the larger multi-year study. |
| Synthesizing of mark-recapture data | • Cross-referencing of photo-ID data across the greater PRD region has progressed well and timely as intended and it is at an advanced stage that can facilitate informative interim analyses. This is intended to continue and be at its final stage by the end of this currently ongoing Phase 3 of this multi-year project (pending the availability of 2020/21 funding).<br>• Based on the currently cross-referenced dataset, there is only a small number of individuals that were photographed in more than one sector (Eastern *vs.* Middle *vs.* Western) of the PRD region. This is the first |

| | |
|---|---|
| | ever and very important indication that in the PRD the dolphins form demographically distinct but not discrete sub-units, and the population structure is likely heterogeneous with limited connectivity. However, these findings are interim at this current stage and should be treated with caution. Further validation, as per the original project framework is needed before final conclusions are drawn.<br>• Lagged identification rate movement analyses suggest a moderate-to-considerable long-term site fidelity of the dolphins to their respective sectors of the PRD, with occasional emigration, mortality, and frequent re-immigration of individuals. The probability of re-sighting individuals in the neighbouring sub-region is low in a daily rate, echoing the limited number of individuals seen in multiple sectors.<br>• Parameterised Markov models provide the quantitative measure of movements and indicate a very limited but ongoing spatial connectivity between dolphins in the three deltaic sectors of the PRD region. While most individuals stay in their preferred sectors of the PRD, the probability of individuals moving *to* and *from* waters further west is extremely low, suggesting that the current study area adequately covers the range of the PRD metapopulation.<br>• Quantified diffusion analyses indicate that all dolphins in the PRD, regardless of the sectors they remained in or moved to, exhibit a non-migratory dispersal pattern, with restricted individual displacement areas that are notably smaller than the ranges of their respective subpopulations.<br>• Social clustering analyses depict a heterogenous social structure with three discernible communities of dolphins across the greater PRD region. Although living in a fission-fusion society with fluid group dynamics, the communities are clearly socially distinct and spatially discrete, but not completely insular or discontinuous, |

| | |
|---|---|
| | with very low level but ongoing socio-spatial connectivity linking the neighbouring communities. The spatial ranges of these social communities are identical to that of subpopulations, thus the terms 'community' and 'subpopulation' can be used interchangeably (depending on whether they are used in a social or demographic context).<br>• Current interim results of our analyses of individual movement pattern, socio-demographic structure and population connectivity indicate that Chinese white dolphins inhabiting the greater Pearl River Delta region form a complex metapopulation of heterogeneous socio-demographic structure with three discernible communities / subpopulations (in Eastern, Middle, and Western PRE). This represents a very significant step in advancing our understanding of the population processes of these dolphins and reaffirms the sound direction and the well-advancing progress of this multi-year project.<br>• The evidence gathered to date (which is considerable, but not yet final) indicates that the three putative subpopulations should be treated as distinct but interconnect management units, which is vastly different from what has been previously thought. Consequently, all relevant management decisions and conservation actions may have to take these findings very seriously into account if they are to be effective.<br>• Identifying the metapopulation structure (and its subpopulation units) represents a fundamental bedrock for accurate understanding and appropriate parameterisation of population processes that shapes the daily lives of the PRD dolphins, which has profound implications for the accurate assessment of population status and viability. As indicated at the onset of this multi-year project, this is intended as primary tasks in the upcoming next Phase of our multi-year project.<br>• Preliminary comparison of our photo-ID catalogue with photo-IDs of CWDs in waters hundreds of kilometres |

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|---|---|
| | further south along the Chinese coast indicates no re-sightings of identified individuals between the regions, which suggests that the PRD metapopulation is distinct, likely separated from other CWD populations in Chinese waters. The degree of its insularity, and that of the other putative populations should be given further dedicated research attention.<br>• Based on the current data and analyses completed to date, one manuscript has been submitted to peer-reviewed journal and three others are currently in advanced stage of preparation for journal submission. |

## Results

During the time-period reported here, the sighting records of Chinese White Dolphins (CWDs) obtained during the 71 field surveys cover the entire range of the Pearl River Delta (PRD) coastal waters, with Hong Kong and Shangchuan/ Xiachuan Islands at the easternmost and westernmost flanks of the range, respectively. The geographic distribution of all dolphin encounters (and our photo-ID records obtained during this time-period) is displayed below in Fig. 2.

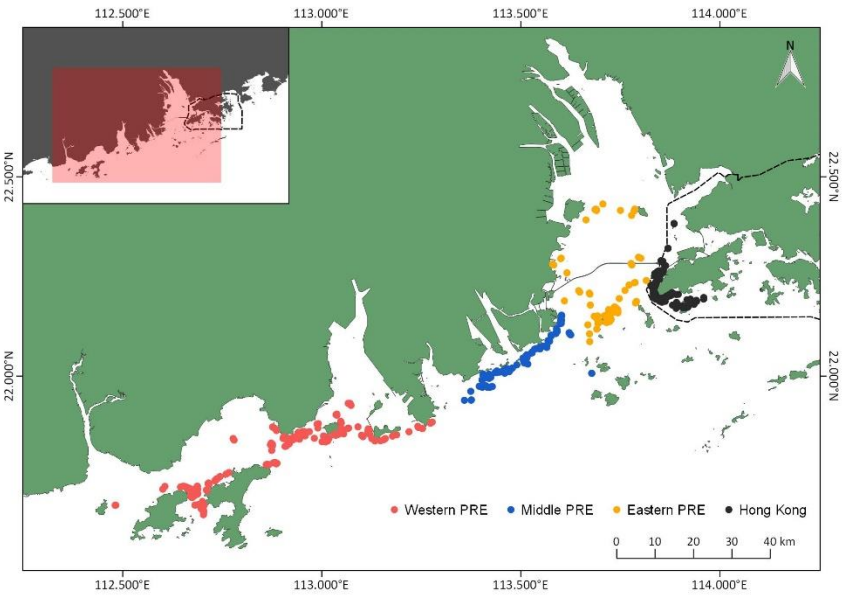


**Figure 2.** The location of sighting records of Chinese white dolphins across the PRD region where individual ID-data were collected during the MEEF2017015B funding cycle. Different sectors of the PRD estuarine system are indicated by different colours.

As pointed out in our previous reports, the dataset from the current Project alone (and any individual sub-component of this multi-year undertaking) is on its own insufficient for inferring any population indicators or to perform any comprehensive analyses. However, as part of a larger multi-year project and benefiting from the data obtained prior to this MEEF-funded work, our combined datasets represent an increasingly robust basis for more sophisticated analyses. At present, we are not yet at a stage of delivering final conclusive results, but we are at the stage of producing interim assessments based on considerable analytical confidence, depicting broader processes and patterns, although specific details require further analytical scrutiny as do some of the currently generated population models which need to be further validated with more data and data-sensitive analyses. Consequently, all current findings and results presented in this report have to be seen as indicative but not yet conclusive or final. They are likely depicting broader processes and patterns quite accurately, but are not yet sufficiently "bullet-proof" to be used for conclusive conservation management recommendations, which is well in-line with the original time-table of this project and its conceptual framework set forth at the onset of this multi-year undertaking.

In the following pages we summarise the most relevant recent findings. We explicitly underscore however, that this report should not be referenced as a scientific publication or used for management recommendations as at this stage it would be premature. The remaining parts of the ongoing work have to be completed first, before the interim findings presented here can be sufficiently validated.

An integrated summary of the currently processed and cross-referenced photo-ID mark-recapture data across the greater PRD region is illustrated in Fig. 3. Only a small number of individuals (a few tens) were identified in more than one sector of the PRD, only in the neighbouring sectors (e.g. in Eastern and Middle PRE, or in Middle and Western PRE) with not a single individual ever re-sighted in eastern and the western sectors of the PRD. Consistent with that of preliminary results in previous reports (and proposals), the limited exchange of individuals between the deltaic sectors serves as the first and important indication that even though the PRD coastal waters seem to represent a continuous stretch of coastal inshore habitats with freshwater discharge from the river outlets, the dolphins appear to have restricted geographic ranges. Such pattern warrants further analytical investigations of the movement patterns of individuals within and between the deltaic sectors.

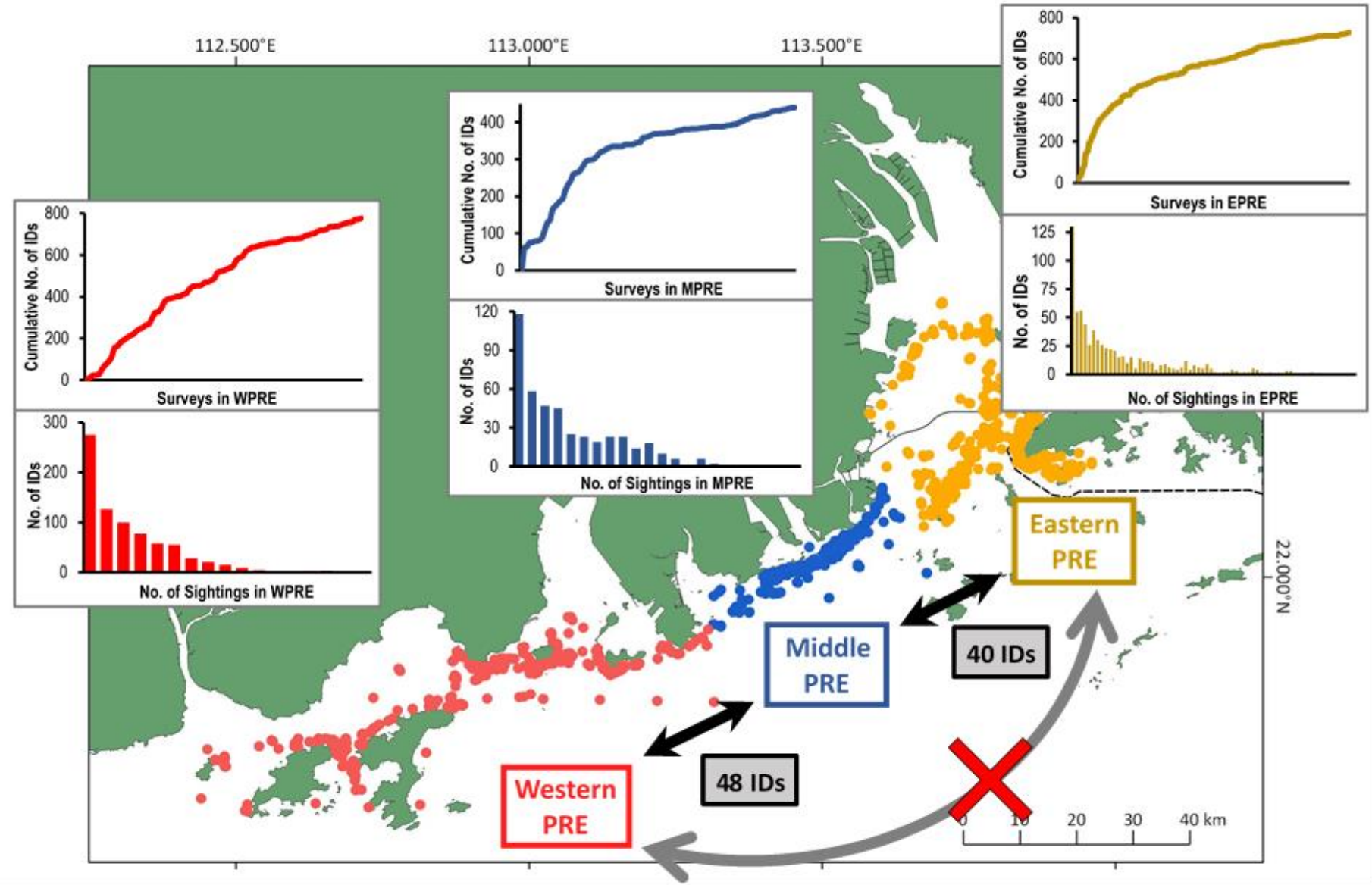


**Figure 3**. Integrated map illustrating the summary of photo-ID mark-recapture data currently processed and synthesized. The locations of sightings of Chinese white dolphins across the PRD region are shown in different colours for different sectors. Discovery curves and sighting frequency figures indicate the cumulative numbers of individuals identified and the numbers of individual re-sightings per sector, respectively. Based on the currently cross-referenced data, only a small number of individuals were identified in more than one sector of the region, and no individuals were seen moving all the way between the eastern and the western reaches of the PRD.

Based on the currently processed mark-recapture database, interim movement analyses were performed to quantify the individual geographic fidelity in the three distinct sectors of the PRD region. Single-area lagged identification rates (LIRs) were calculated for Eastern, Middle, and Western PRE (Fig. 3), representing the probability of any individual to be re-identified (re-sighted) in the specific sector of the PRD at a certain time-lag later after being first sighted in that sector. Movement models were fitted to the data and projected along the observed pattern, and the most parsimonious model that best-explain the pattern was subsequently selected based on Akaike Information Criterion (AIC).

The LIRs in all three sectors of the Pearl River Delta region declined continuously across the time lag projection and with a comparable rate of decline, although the rates of initial decline, size of error bars, and best-fit models differed between sectors. In Eastern PRE, the LIRs exhibited a clear and rapid drop over the initial period, followed by the sharpest change in the decline rate; and throughout the projected time lag period, the error bars were the smallest compared to the other two sectors (Fig. 4a). Differently, the LIRs in Western PRE displayed a slower initial drop with visibly more fluctuations (Fig. 4c); while similar fluctuations and error bars were apparent in Middle PRE, but without an obvious initial rapid drop (Fig. 4b). The larger error bars in Middle and Western PRE, especially for the initial data points, are due to lower individual sighting frequencies in these sectors. Consequently, there was a moderate degree of model uncertainty during the processes of model selection in these two sub-regions (in particular Western PRE); which serves as yet another indication that more work is needed to solidify the dataset and dataset-sensitive analyses, as pointed out in previous reports and proposals.

Nonetheless, the interim analyses of single-area LIRs in all three sectors across the region indicate moderate-to-considerable long-term site fidelity of Chinese white dolphins to their respective sectors of the PRD. While some individuals may temporarily leave their deltaic sub-regions, re-immigration is frequent and in the long-term the dolphins exhibit considerable affinity to relatively restricted geographic ranges (see also further). It should also be noted that across all three sectors, the long-term continuous decline in LIRs, albeit relatively slow, is likely due to dolphin mortality, either natural or human-caused, which in modelling-terms results in discontinuation of re-sightings. In overall, these interim findings support

the earlier notion that the movement between different sectors of the PRD is limited.

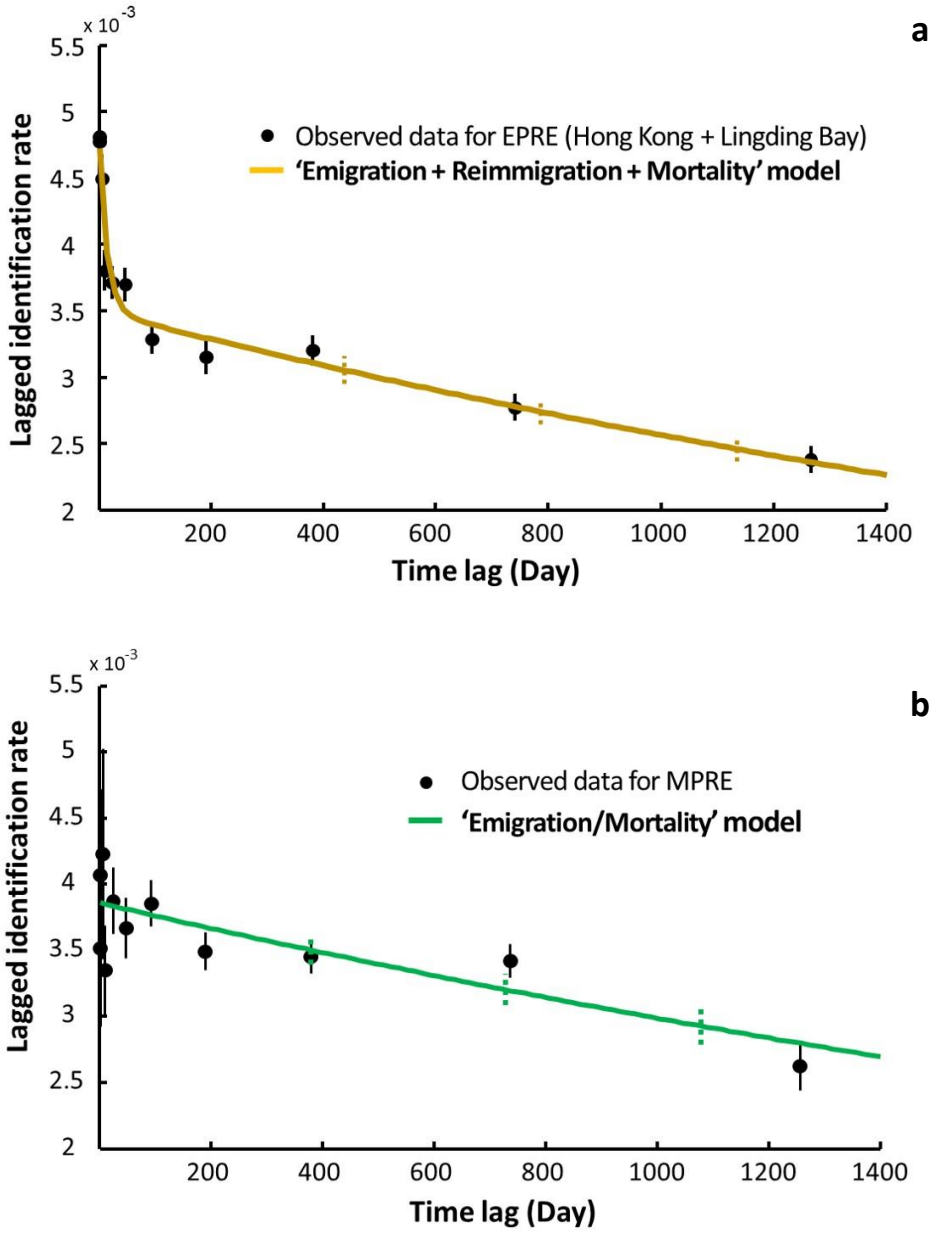


**Figure 4.** Single-area lagged identification rates (LIRs) of Chinese white dolphins in (a) Eastern PRE and (b) Middle PRE, with the corresponding most parsimonious movement models that best fit the observed patterns. Bootstrap SE of the observed data and the movement models are shown in solid and dotted error bars, respectively.

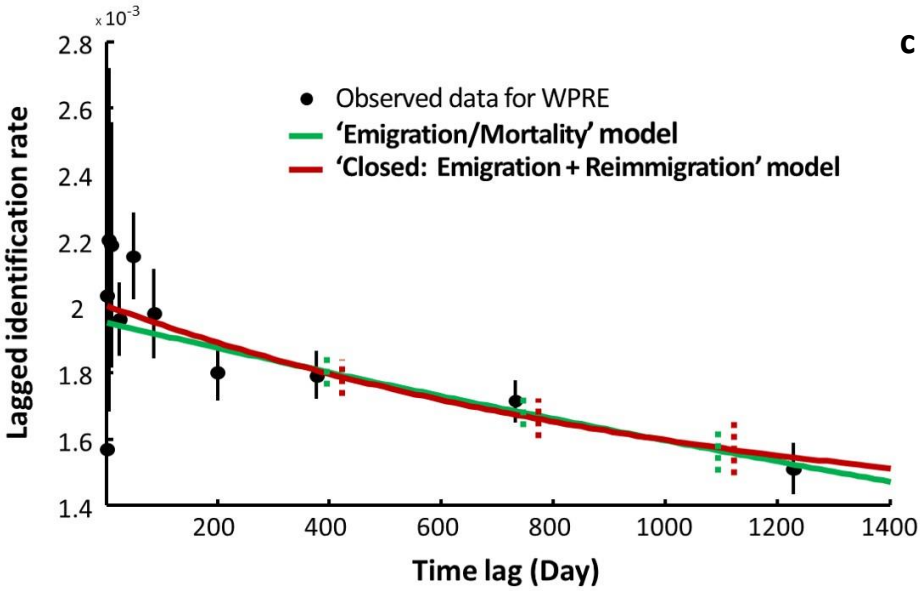


**Figure 4 (*cont.*).** Single-area lagged identification rates (LIRs) of Chinese white dolphins in (c) Western PRE with the corresponding most parsimonious movement models that best fit the observed patterns. Bootstrap SE of the observed data and the movement models are shown in solid and dotted error bars, respectively.

To examine the inter-sector movements, interim analyses of multiple-area lagged identification rates (LIRs) were computed to quantify the probabilities of an individual being re-sighted in the same sub-region in contrast to any other sub-regions of the PRD over a time lag period. Effectively, the multiple-area LIRs reflect the overall site fidelity of individuals within any of the three deltaic sectors, and compare it with the movements between the sub-regions. Specific movement models were fitted to the data and selected based on Akaike Information Criterion (AIC) in similar manner as in the single-area LIRs.

The observed LIRs within the same areas declined continuously across the time lag projection (Fig. 5), of which the pattern closely resembled the overall pattern of the single-area LIRs of Eastern, Middle and Western PRE, thus reaffirming the dolphins' moderate long-term site fidelity to their respective sectors. On the contrary, the LIRs between different areas were close to zero (in a daily rate) throughout the entire time lag period (Fig. 5). The model projections reflect low numbers of individuals re-sighted across the PRD sub-regions. Furthermore, the clear contrast between the

LIRs within *vs*. between the PRD sub-regions is indicative of the infrequent inter-sector movements of individuals, much less than those within the same sector.

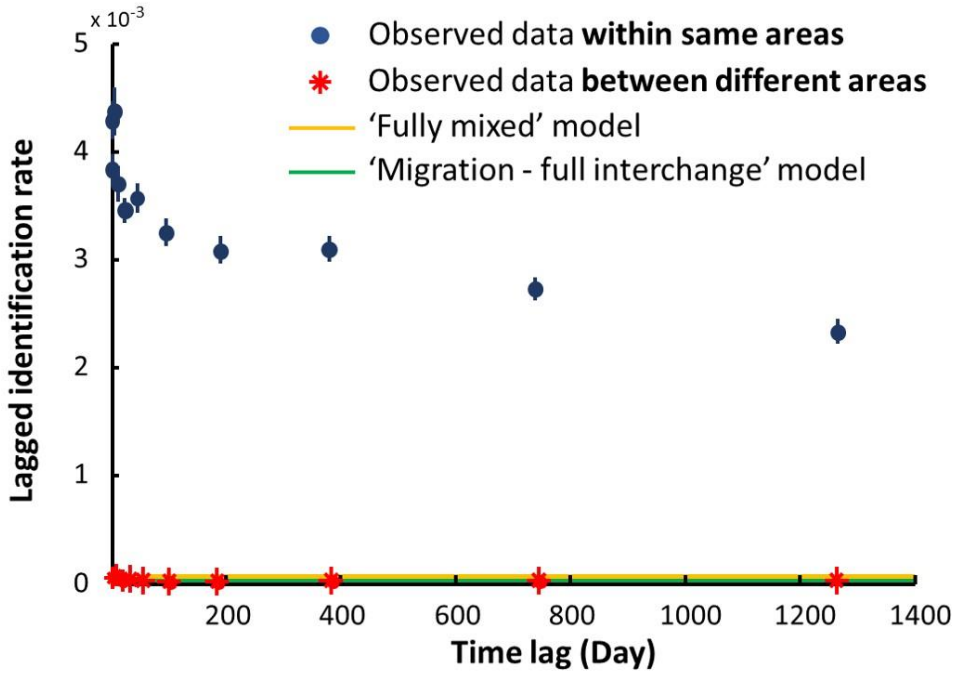


**Figure 5.** Multiple-area lagged identification rates (LIRs) of Chinese white dolphins re-identified within the same sub-region of either Eastern, Middle or Western PRE (blue dots) and in different areas (red asterisks), displayed along with the best-fit movement models. Bootstrap SE of the observed data are shown in solid error bars. Note that the observed LIR between different areas were close to zero for the entire time lag period and therefore both models, overlapping with one another, are represented by horizontal lines overlaying the x-axis with no error bars.

Parameterised Markov models were computed to further quantify the rates of transition between the Eastern, Middle, and Western PRE sub-regions. In contrast to the movement analyses mentioned above, the probabilities of individuals moving from one sector to another were estimated in overall annual rates across the entire projected timeframe, to provide complementary broader perspective.

Based on the currently assembled dataset, the estimated transition probabilities of Chinese white dolphins between the three sub-regions of the greater PRD were generally low, ranging between 1.5% and 3.6% per annum (Table 2). The individuals

identified in either of the deltaic sectors exhibited in overall high probabilities (over 90%) of remaining in the same sectors. In comparison, the dolphins in Middle PRE showed the highest rates of moving to other sub-regions, and the lowest probability of staying in M-PRE waters. To test the western boundary of the PRD population, a 'further west' sector was added to examine the likelihood of westward movements to and from Western PRE beyond the current study area. The resultant westward transition estimates between Western PRE and 'further west' were close to zero.

**Table 2.** Annual transition probabilities of Chinese white dolphins between Eastern, Middle, and Western PRE. To test the western boundary of the PRD population, a '*further west'* sector was added to examine the likelihood of westward movements to and from Western PRE beyond the current study area. Estimated parameters of transition probabilities are listed in bold, and standard errors from bootstrap replicates are given in parentheses.

| **Annual transition probability** (SE) | | **To sector:** | | | |
|---|---|---|---|---|---|
| | | EPRE | MPRE | WPRE | *'Further west'* |
| **From sector:** | EPRE | **0.985** | **0.015** (0.003) | 0 | 0 |
| | MPRE | **0.027** (0.005) | **0.937** | **0.036** (0.005) | 0 |
| | WPRE | 0 | **0.018** (0.003) | **0.9815** | **<0.001** (<0.001) |
| | *'Further west'* | 0 | 0 | **<0.001** (<0.001) | **0.999** |

The parameterised Markov movement model provides a direct quantitative measure of annual transition probabilities between dolphins in the three sectors of the PRD. The transition rates, albeit low, are not negligible, suggesting highly infrequent but ongoing movement of a small number of individuals. This in turn is indicative of spatially distinct but not completely discrete demographic sub-units, where infrequent transitions play a vital role in bridging the putative subpopulations across the greater PRD region. The extremely low likelihood of individuals moving 'further west' of the Western PRE suggests that the currently surveyed area adequately covers the range of the PRD population. Consequently, recent anecdotal suggestions

that the PRD dolphins range further to the west of Western PRE are likely just that, anecdotal, indicative of sporadic rallies at most and unlikely the actual population range; they should be taken very cautiously. On the other hand, however, it should be noted that this type of analysis, which in our project is currently at its interim stage, is sensitive to the robustness of dataset and therefore these results should be further validated with the full intended dataset which, as described in the original proposal, will be synthesized at the final concluding phase of this project. It will be at this stage only that all relevant population models can be reliably tested against data stochasticity and conclusions drawn with sufficient analytical confidence.

To understand the dispersal of Chinese white dolphins across the PRD region, preliminary analyses using SOCPROG's likelihood models (Whitehead 2009) were performed to quantify the patterns of individual movement over continuous space. The dispersal patterns were subsequently compared between individuals seen in the three estuarine sectors of the PRD (Fig. 6 and Fig. 7). As expected, individuals seen in more than one sub-region exhibited generally higher diffusion rates than the dolphins that were seen in only one of the sub-regions. Among the individuals seen only in one sub-regions, the diffusion rates were considerably higher in Middle and Western PRE than that in Eastern PRE.

Regardless of the sectors that the dolphins stayed in or moved between, all individuals exhibited the same general temporal pattern of dispersal. Notably, individual diffusion rates were highest at the initial interval and dropped drastically at the next time interval. Within less than quarter of a year after any individuals' first sighting, the rate of diffusion declined substantially to a level close to zero, indicating very little further movement beyond the spatial scale the individual already covered in the weeks since the initial sighting of that individual (Fig. 6). The temporal pattern of mean-squared displacement corresponded to that of diffusion rates, with all individuals displaying large initial displacement areas but very little expansion thereafter (Fig. 7).

The dolphins seen only in Middle PRE and only in Western PRE displayed similarly higher diffusion rates over time (initial rate = ~30 $km^2$/day) and larger displacements (stabilised at ~300 $km^2$), as compared to those seen only in Eastern PRE (initial diffusion rate = ~8 $km^2$/day; displacement stabilised at ~120 $km^2$). Individuals seen in more than one sector dispersed at higher rates (initial rate = ~40 $km^2$/day) and

over larger areas (stabilised at ~500 $km^2$). However, due to the small number of such individuals in the PRD, with limited re-sightings, the error bars of these estimates were also considerably larger. As such, these results, although indicative, are given here for reporting purposes only to indicate the progress of the project but not yet any final conclusive estimates. Sufficiently conclusive results can only be reached after the remaining phases of the project are successfully completed.

Based on the current initial results, irrespective of the demographic sub-units (subpopulations) or geographic sub-regions, all Chinese white dolphins in the greater Pearl River Delta region exhibited a non-migratory dispersal pattern. In general, the expansion of individual ranges was most detectable within a week of the first sighting of an individual, and within a quarter of a year the diffusion rates declined to negligible while the displacement area stabilised. The individual displacement areas covered only a portion of their respective subpopulation range, although the dolphins that moved between subpopulations (the apparent vectors of socio-spatial connectivity within the PRD metapopulation) ranged across greater distances; but even these individuals did not range across the entire PRD coastal region. Spatio-temporal dynamics of individual dispersal is likely driven by the physio-ecological characteristics of the coastal environment and big part of it rests in the availability of key habitats (Karczmarski *et al.* 2017a).

On the other hand, the dynamics of dispersal and the magnitude of displacement appears to differ between subpopulations / sub-regions, which is likely due to differences in habitat structure across the greater PRD region. The estuarine waters of Eastern PRE are relatively enclosed and semi-sheltered within a large embayment; while Western and Middle PRE are considerably more exposed. The observed heterogeneity of individual dispersal patterns, albeit still rather preliminary at this stage, if confirmed would be indicative of considerable socio-behavioural diversity across the PRD region, and consequently higher susceptibility of local communities to degradation of local habitats (Karczmarski *et al.* 2016; 2017a) and depletion of critical resources such as prey (Lin *et al*., In Press). This corresponds with our other findings (mentioned earlier) and cumulatively points to a complex socio-demographic structure of the PRD dolphin population, where behavioural differences of local communities are likely habitat-driven and differ across the spatial scale of the PRD, a pattern majorly different from anything that have previously been thought about these dolphins.

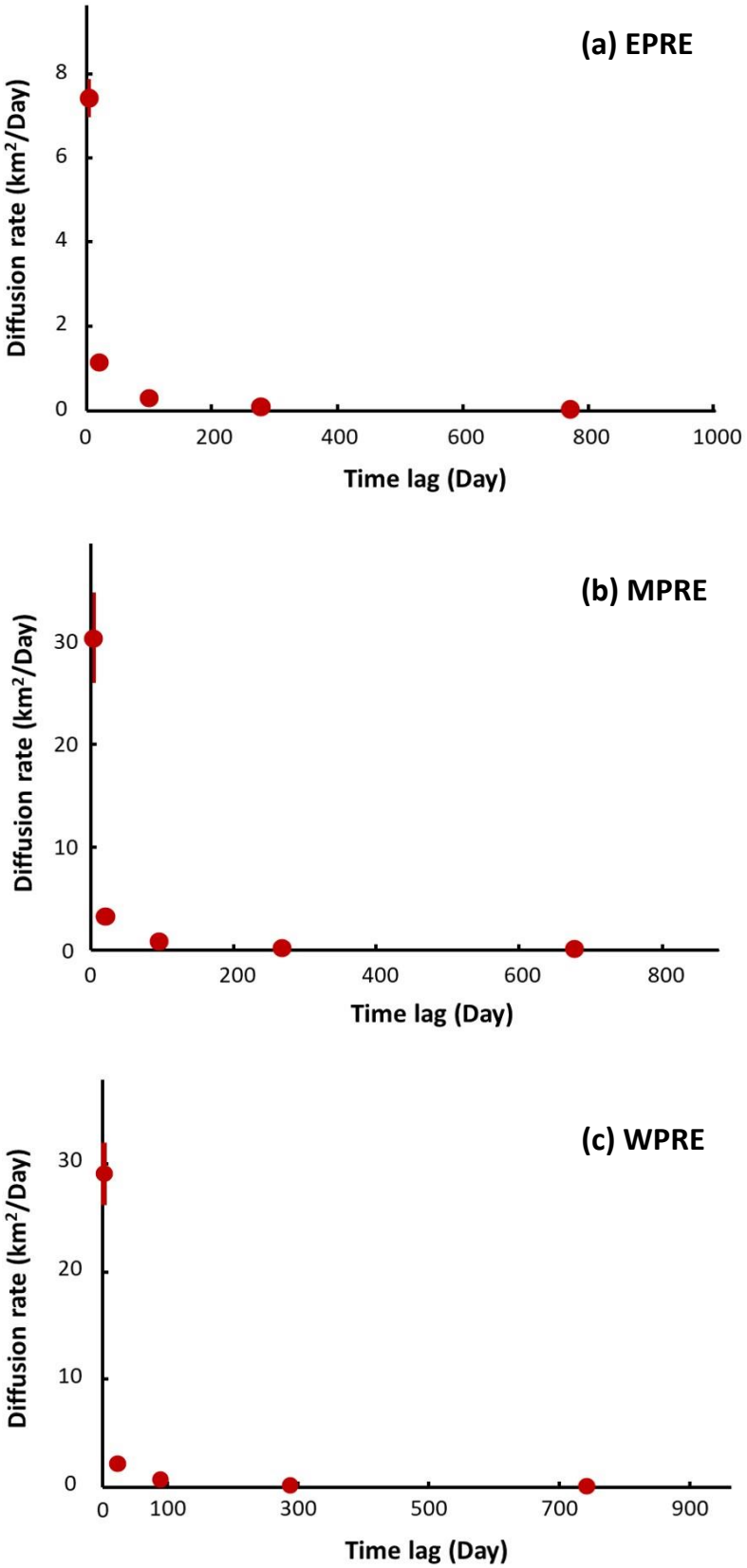


**Figure 6.** Diffusion rates over time lag of Chinese white dolphins seen in only one sub-region (a-c) of the Pearl River Delta (PRD) region. Jackknife error bars are shown as red vertical lines.

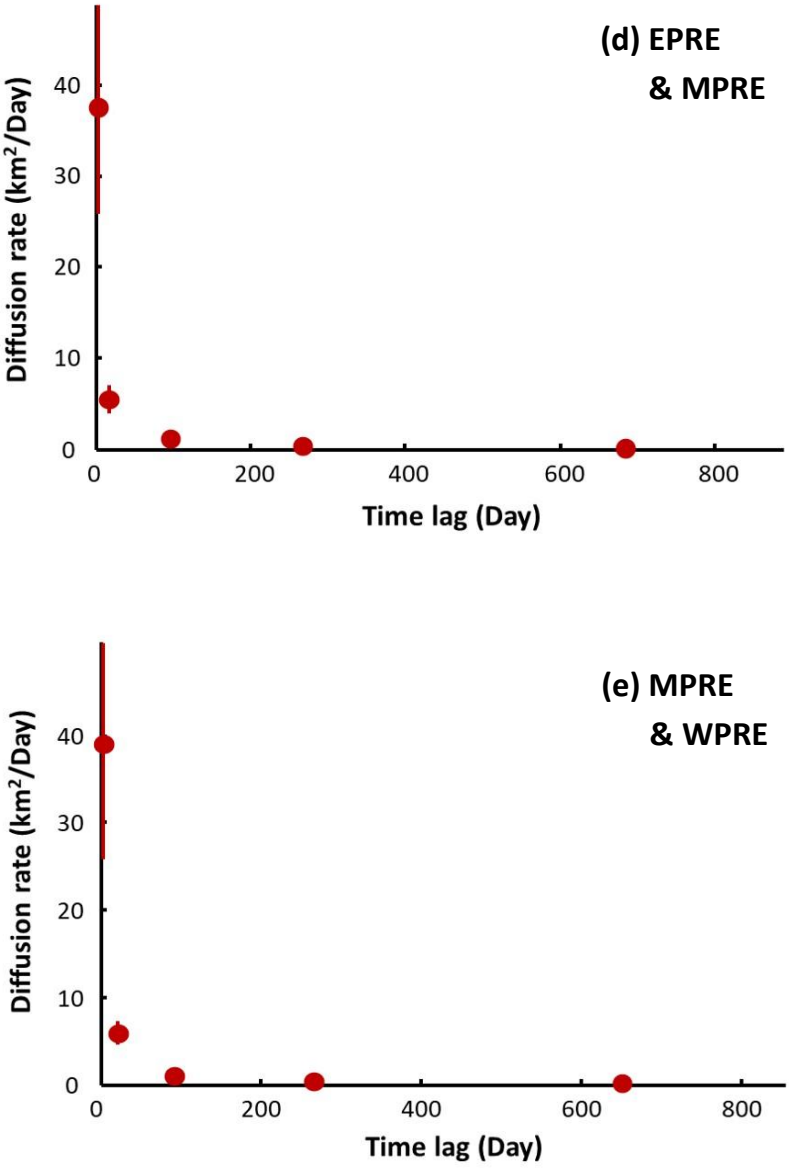


**Figure 6 (*cont.*).** Diffusion rates over time lag of Chinese white dolphins seen in two sub-regions (d-e) of the Pearl River Delta (PRD) region. Jackknife error bars are shown as red vertical lines.

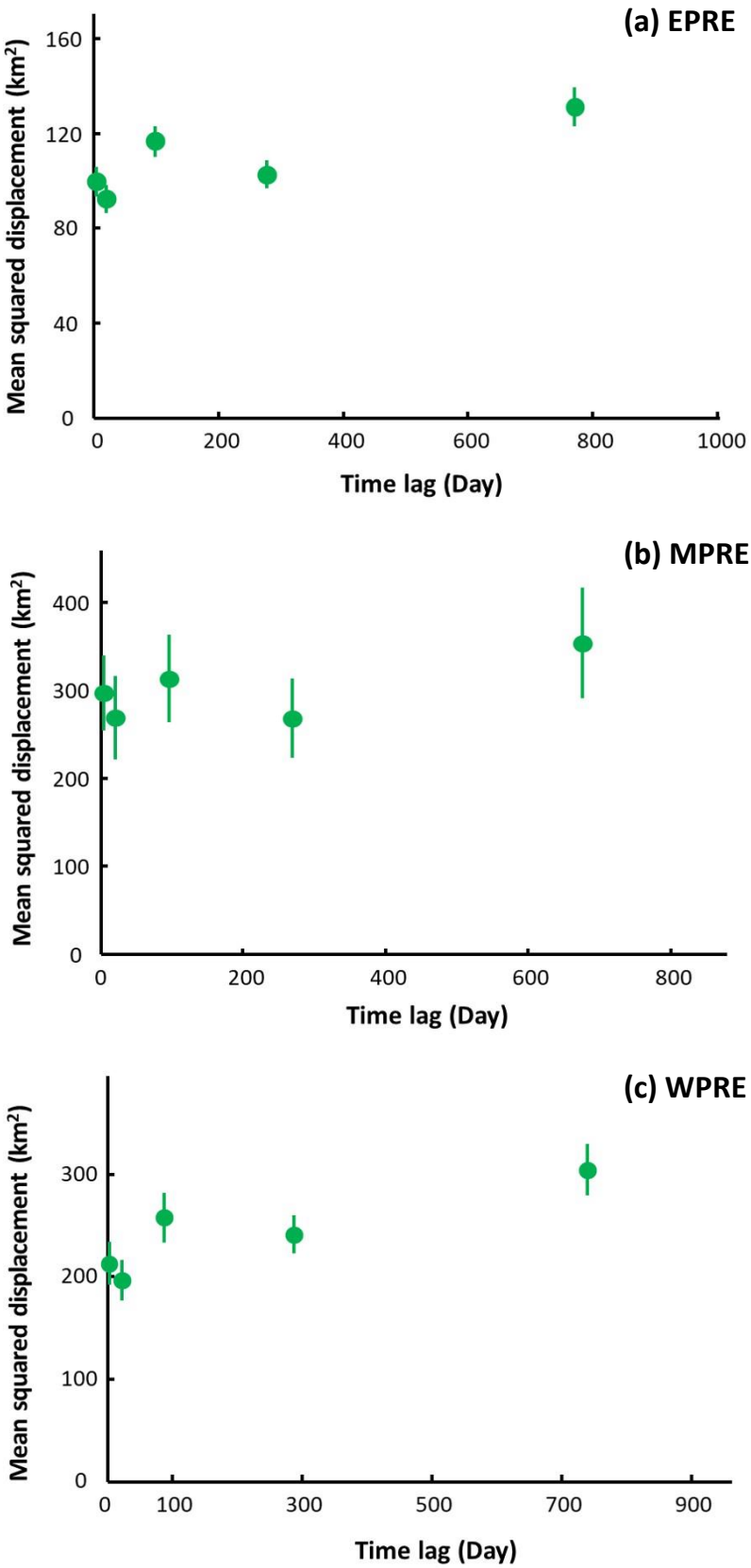


**Figure 7.** Mean-squared displacement over time lag of Chinese white dolphins seen in one sub-region only (a-c) of the Pearl River Delta (PRD) region. Jackknife error bars are shown as green vertical lines.

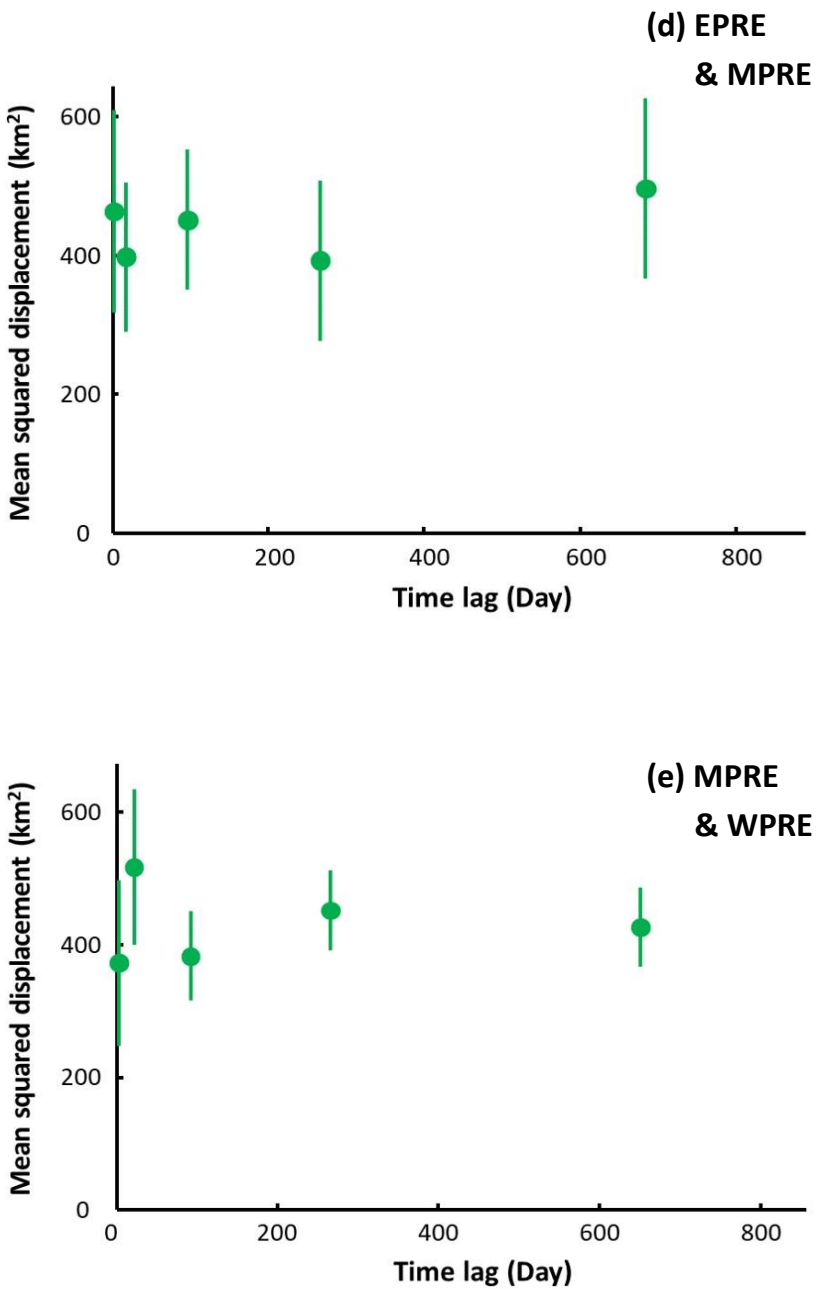


**Figure 7 (*cont.*).** Mean-squared displacement over time lag of Chinese white dolphins seen in two sub-regions (d-e) of the Pearl River Delta (PRD) region. Jackknife error bars are shown as green vertical lines.

Socio-demographic analyses were performed using the currently synthesised mark-recapture dataset across the region. Half-weight association index (HWI), a measure of association strength commonly used in marine mammal studies, was applied to quantify the inter-individual associations. The mean HWI across all individuals was

estimated at 0.013 (SD ± 0.006). The P-value of permutation test stabilised at 1000 permutations with 1000 trials per permutation ($P < 0.001$), where the standard deviation of observed HWI was significantly higher than that of the permuted random HWI, indicating preferred (and potentially some avoided) associations among individual dolphins.

To assess the socio-spatial structure of the PRD dolphins across the entire PRD region, social cluster analyses were performed on a subsampled dataset (excluding seldom seen individuals) to limit any potential bias caused by sporadic sightings when depicting the prevalent social pattern and, consequently, ensure an adequate representation of the prevailing spatial structure (if any) among the PRD dolphins. Using the agglomerative clustering method, five hierarchical clusters of Chinese white dolphins were identified (Fig. 8), with all clusters exhibited higher mean HWI than the overall mean. A dendrogram was constructed to display the connectivity of the five clusters, with the cophenetic correlation coefficient (CCC) of 0.77 and the modularity (Q) above 0.3, the two matrices indicative of the clustering accuracy, both indicating that the clustering result was representative of the social differentiation among individuals but likely limited by the current sample size and/or time duration of the study. To visualise the spatial distribution of the clusters, the sighting locations of individuals attributed to each of the clusters are shown in Fig. 9, depicting distinct spatial pattern with limited overlap of their respective ranges which corresponds to the three sectors of the PRD: clusters 1 and 2 in Eastern PRE, cluster 3 in Middle PRE, and clusters 4 and 5 in Western PRE.

Both the dendrogram (Fig. 8) and the spatial charts of the respective clusters (Fig. 9) indicate a socio-spatial differentiation among the Chinese white dolphins across the greater PRD region. Three discernible dolphin communities can be depicted, corresponding spatially to the three sub-regions, Eastern, Middle, and Western PRE. The cluster analyses reported here are very much in line with the results of our interim movement analyses (reported above), both indicating that the PRD dolphins form a heterogeneous population, or – more accurately – a complex metapopulation with distinct social and spatial subdivision into at least three socio-demographic units. These units should be seen as distinct communities at the least, or – perhaps more likely – sub-populations, which has still to be determined in the course of our further work.

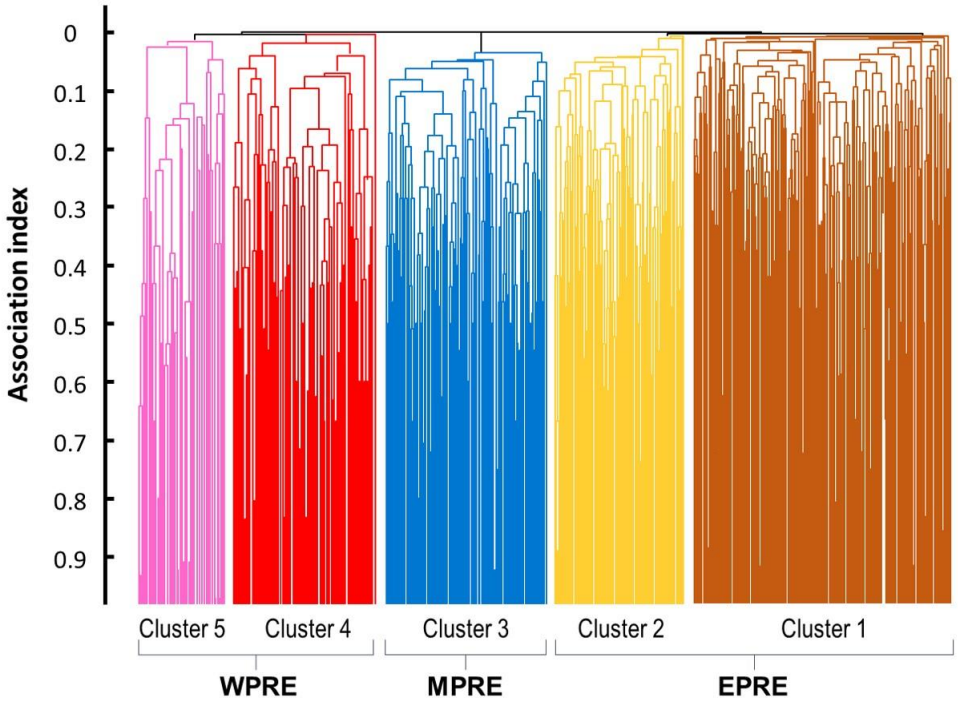


**Figure 8.** Dendrogram of five hierarchical clusters (colour coded) of Chinese white dolphins seen across the Pearl River Delta (PRD) region. Analyses depicted by this dendrogram excluded the most infrequently seen individuals.

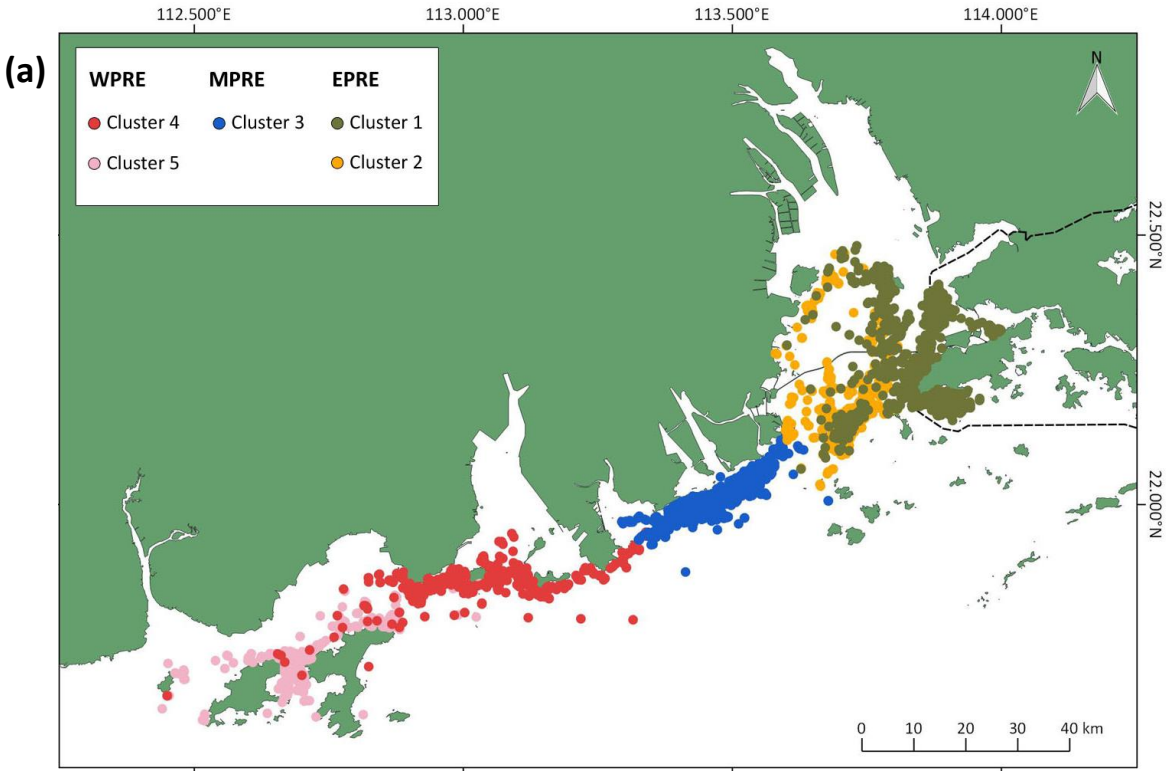


**Figure 9.** Geographic locations of sightings of individuals attributed to five hierarchical clusters (excluding the most infrequently seen individuals) displayed (a) together on one chart and (b-f) individually for each cluster to avoid overlapping points.

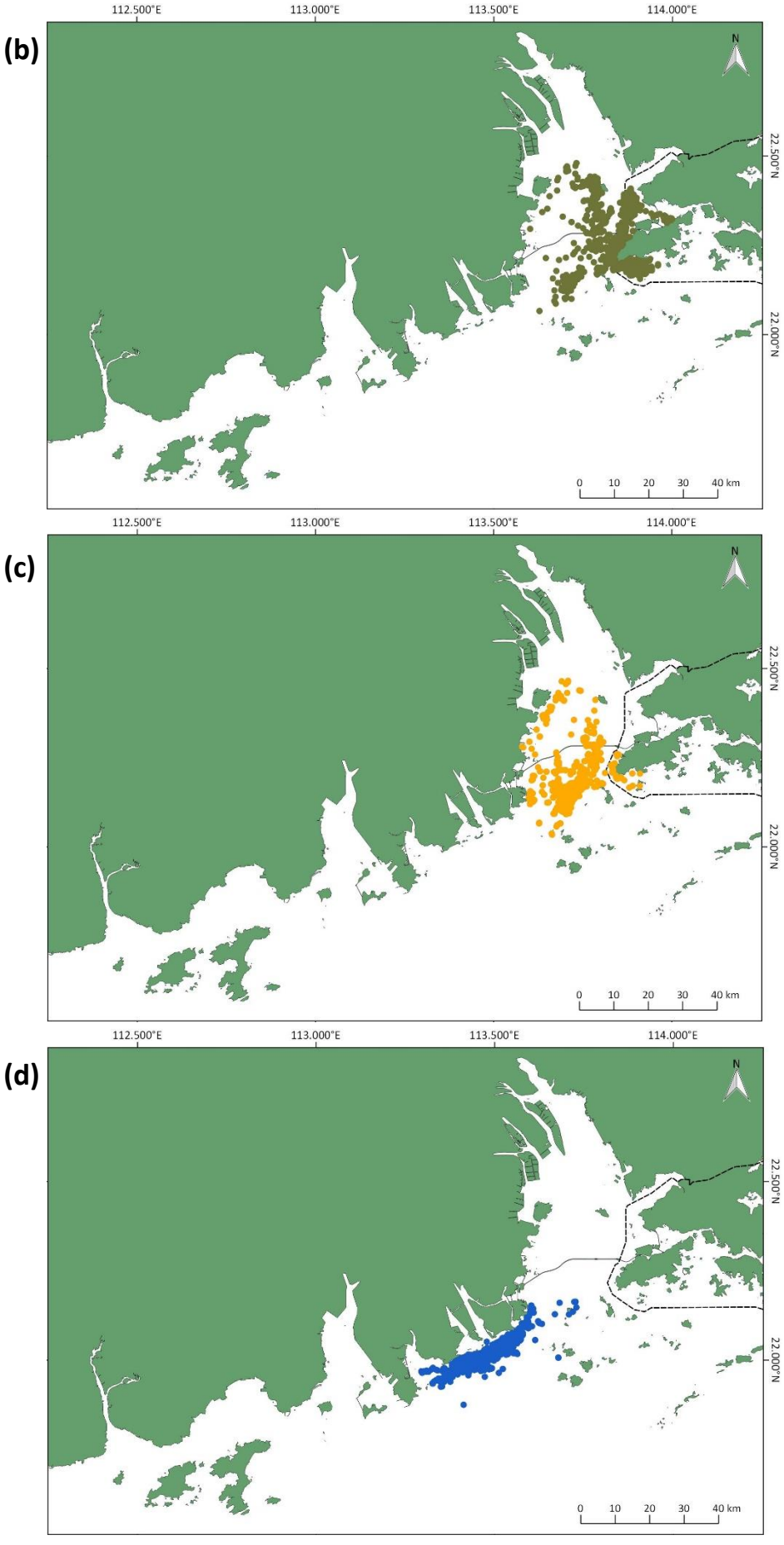


**Figure 9 (*cont.*).** Geographic locations of sightings of individuals attributed to five hierarchical clusters (excluding the most infrequently seen individuals) displayed individually for each cluster to avoid overlapping points.

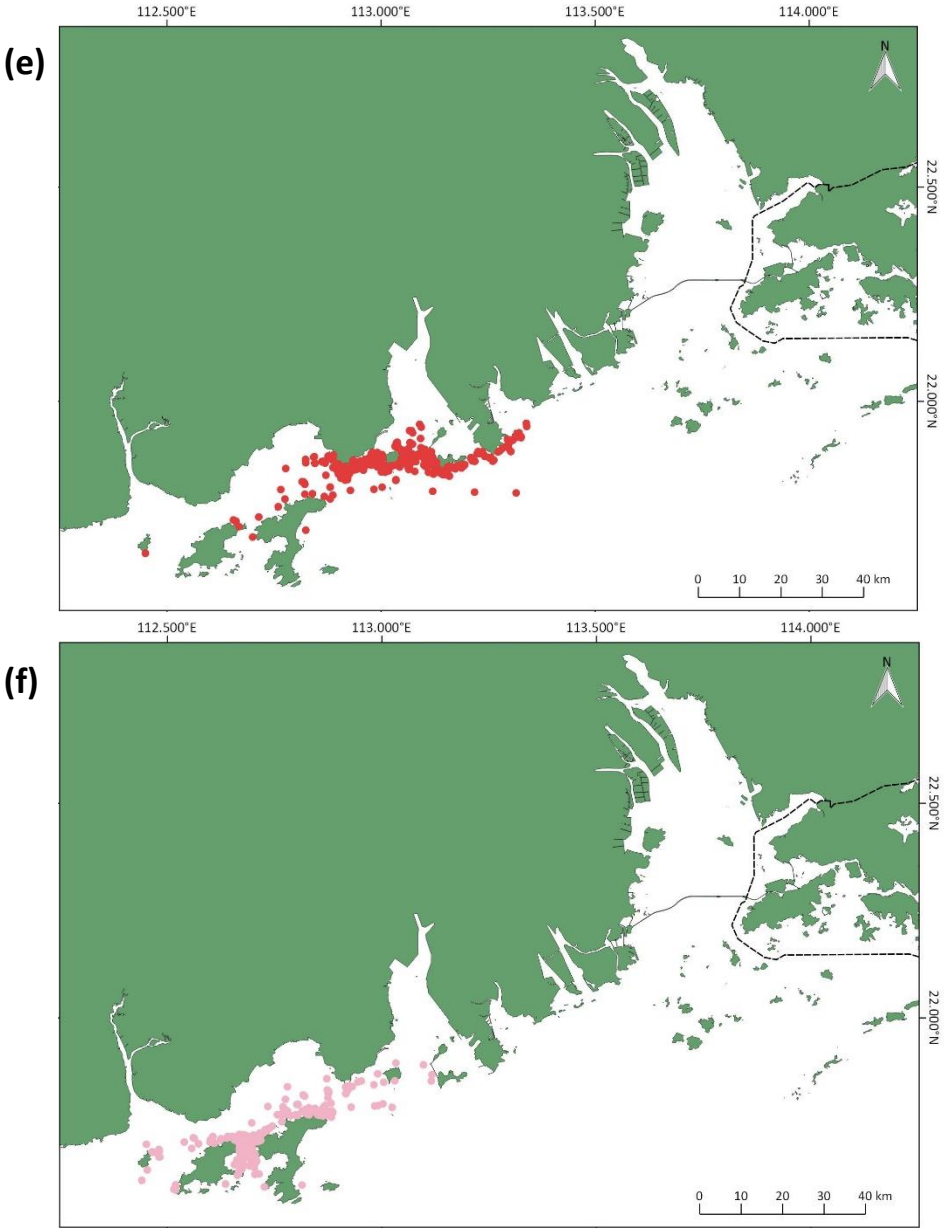


**Figure 9 (*cont.*).** Geographic locations of sightings of individuals attributed to five hierarchical clusters (excluding the most infrequently seen individuals) displayed individually for each cluster to avoid overlapping points.

While the subsampling of the dataset (as described above) advanced the scientific scrutiny of data representativeness, the process also inevitably excluded dyadic associations of individuals that occasionally move between sub-region but were infrequently sighted. Such individuals may play a vital role in the connectivity of socio-demographic clusters and bridging the spatial structure of the population. While excluding the infrequently seen individuals facilitates a clearer representation of the broader spatio-demographic pattern, it may potentially underestimate a low-level connectivity. Therefore, to counter any such potential bias, socio-demographic analyses were also performed on an unrestricted dataset of all catalogued

individuals. This approach resulted in a total of 50 hierarchical clusters depicted using agglomerative clustering method, but despite the high number of identified clusters, five main clusters constituted >95% of all individuals in the unrestricted dataset. The remaining clusters consisted of very few (usually less than three) individuals each (Fig. 10). The overall pattern of social differentiation resembled very closely the socio-demographic structure depicted using the restricted dataset, with three discernible communities across the region. Moreover, the five main clusters were similarly spatially distributed as the clusters generated with the restricted dataset. The only notable difference was a greater spatial overlap between clusters/communities, with more individuals attributed to the corresponding clusters venturing further to the neighbouring sub-regions (Fig. 11). However (and highly importantly), when interpreting the results derived from the unrestricted dataset, the lack of data treatment must be fully acknowledged, as these clustering results cannot be seen as accurate representation of social units due to the bias introduces by sporadically/infrequently seen individuals.

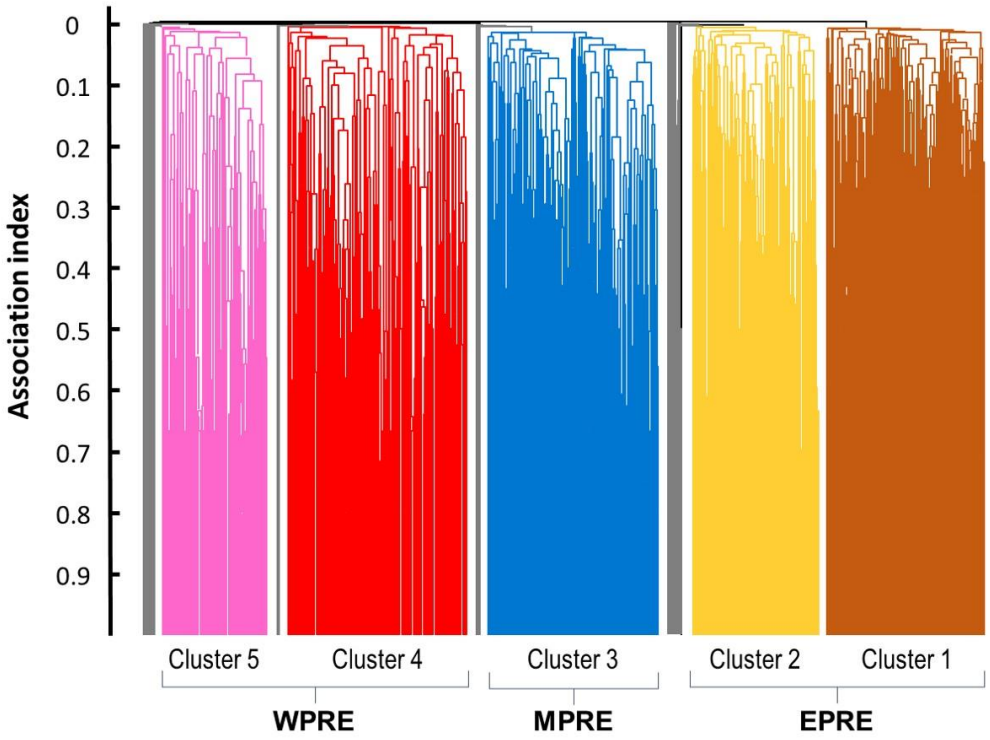


**Figure 10.** Dendrogram of 50 hierarchical clusters derived from the unrestricted dataset of Chinese white dolphins seen across the Pearl River Delta (PRD) region. Despite the considerably high number of identified clusters, five main clusters (colour coded) constituted the vast majority (>95%) of individuals in the dataset. The 45 clusters representing <5% of individuals are shown in dark grey.

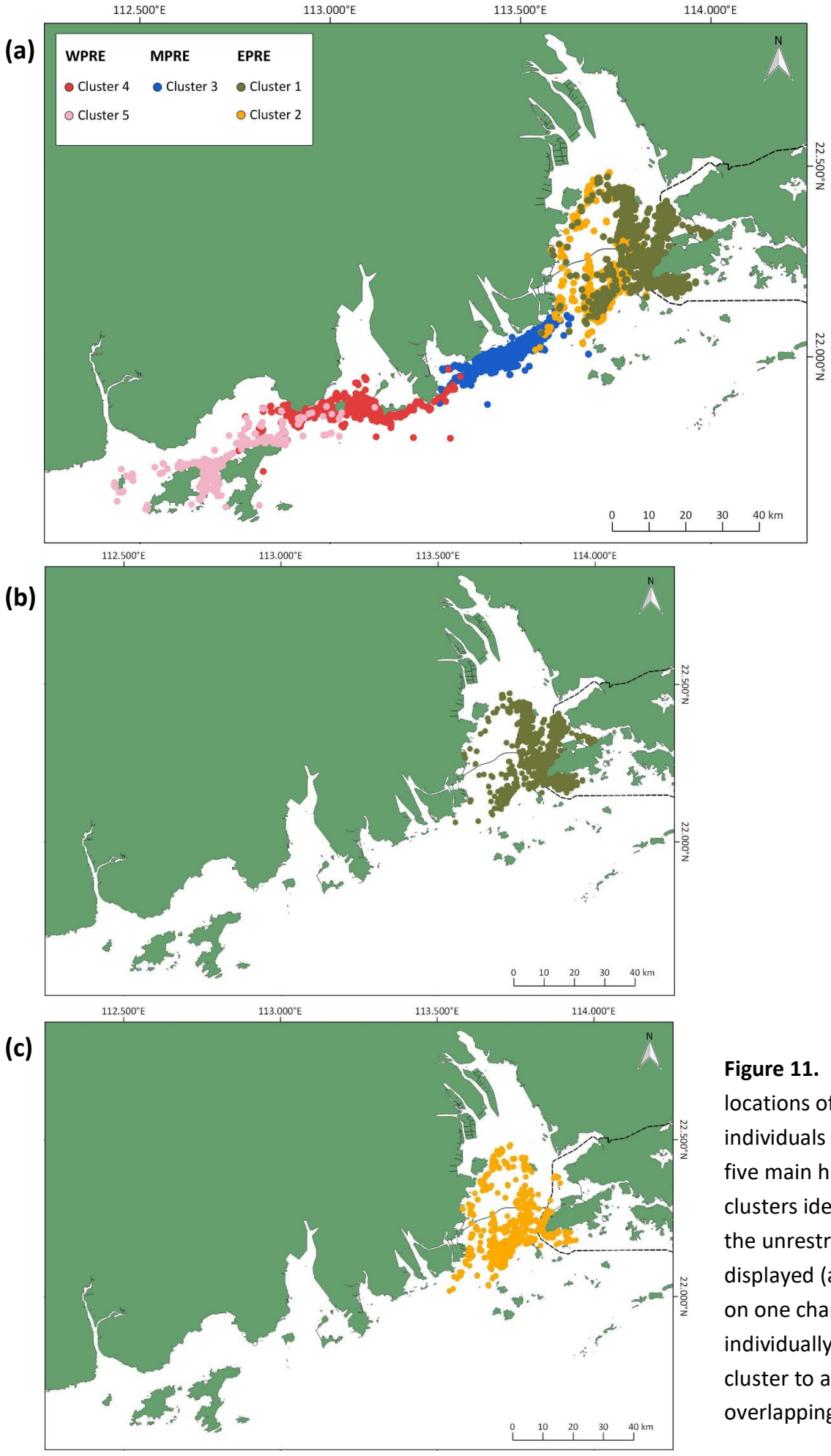


**Figure 11.** Geographic locations of sightings of individuals attributed to five main hierarchical clusters identified from the unrestricted dataset displayed (a) together on one chart and (b-f) individually for each cluster to avoid overlapping points.

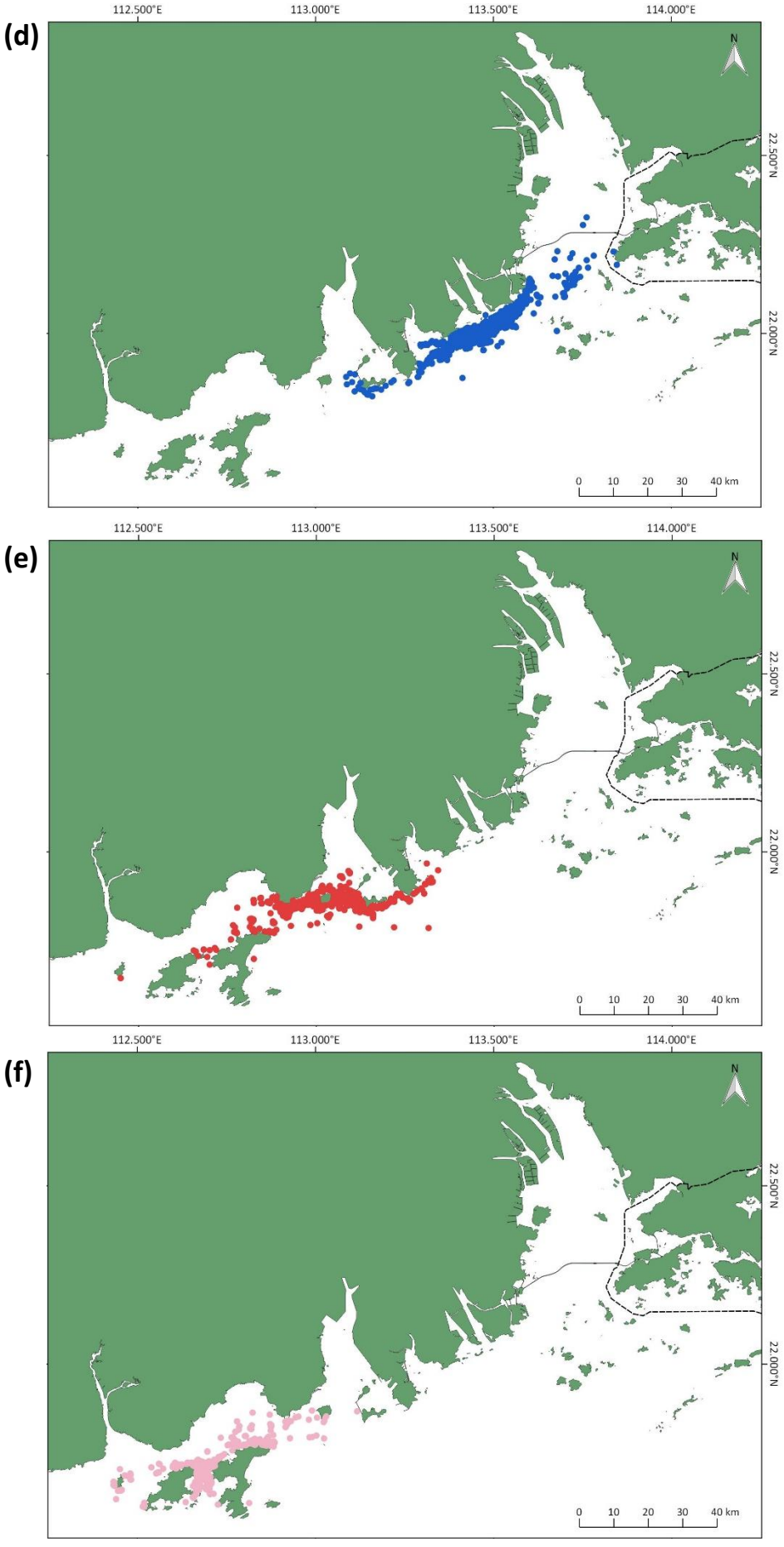


**Figure 11 (*cont.*).** Geographic locations of sightings of individuals attributed to five main hierarchical clusters identified from the unrestricted dataset displayed individually for each cluster to avoid overlapping points.

Apart from the agglomerative clustering method, as summarised above, more complex network analyses were also performed using eigenvector-based clustering algorithm on both the subsampled and unrestricted datasets (see Appendix). Such analyses are considerably more informative and more appropriate for non-hierarchical cetacean societies. However, they are also particularly demanding in terms of data quantity and require robust datasets to be reliable. This is the type of dataset we intend to generate at the completion of this multi-year study. It is not yet the stage we are currently at. Therefore, agglomerative cluster analyses are depicted here, while the preliminary eigenvector-based network analyses are disclosed for the reporting purpose only (see Appendix), not yet suitable for public release.

Based on the current interim analyses of individual movement pattern, socio-spatial structure and socio-demographic connectivity, the picture that is now beginning to emerge is that of a complex metapopulation with heterogeneous socio-demographic structure which is particularly clear when displayed across the PRD spatial scale, with three discernible dolphin communities (possibly subpopulations) in the Eastern, Middle, and Western PRE. Given that the spatial ranges of these social communities are identical to that of subpopulations, the terms 'community' and 'subpopulation' can be used interchangeably, depending on whether they are used in a social or demographic context.

In the social context, although the PRD dolphins exhibit fluid group dynamic with a fission-fusion pattern on the intra-community level, the distinct social clusters are spatially discrete and socially discernible by their grouping and movement patterns. It is plausible, in fact likely, that the predominant pattern of social dynamics is influenced by ranging patterns of individuals, which are in turn largely shaped by their foraging preferences and choice (and availability) of foraging grounds. As foraging is the most frequently observed behaviour (Or 2017; see also the habitat utilization analyses reported in Phase 2 of this multi-year project), it is likely a contributing factor to the restricted movement and ranges of the dolphins.

In a demographic context, although infrequent movement of a handful of individuals between subpopulations may be insignificant for the social fabric of the dolphin society, it is important in maintaining the connectivity (even though limited) between the subpopulations which likely facilitates gene flow and prevents population-level fragmentation and forming of insular/discontinuous subpopulations. As the current

interim results presented here suggested, the Chinese white dolphins in the PRD region form three socially distinct, demographically discernible, and spatially discrete but not discontinuous subpopulations. This is likely in response to environmental differences specific to Eastern, Middle and Western PRE, or possibly just an intrinsic socio-behavioural feature of a complex mammalian society. However, it seems also apparent that environmental differences across the PRD region have been amplified in recent decades (Karczmarski *et al*. 2016; 2017a; Lin *et al*. 2016; In Press; Gui *et al*. 2017) and the present pattern of metapopulation dynamics across the greater PRD region may be as much a product of natural population processes as response to the multitude of anthropogenic impacts. A range of population responses to anthropogenic pressure have been seen in closely related coastal species elsewhere, ranging from the shift in distribution and daily pattern of behaviour (e.g. Karczmarski *et al*. 2000; Koper *et al*. 2016) to population socio-spatial subdivision and fragmentation (e.g. Karczmarski *et al*. 2017b).

The possibility of population fragmentation in the PRD in response to increasingly heterogeneous seascape due to high levels of anthropogenic pressure highlights the importance of identifying the metapopulation structure, which vastly differs from anything previously thought about PRD dolphins. To the best of our current knowledge, the three social communities (and putative subpopulations) identified in the current phase of this project should be treated as interconnected units when strategizing conservation management decisions. The next and much needed step is an accurate quantitative determination of the metapopulation viability based on most up-to-date population parameters, its likelihood of long-term persistence and accurate estimates of the probabilities of local extirpation of any of the three putative subpopulations. As per the framework of this multi-year study, population viability analyses (PVA) are intended in the follow-up phase of this project.

In addition to our PRD-focused work, we have performed preliminary 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. We have compared ID records of over 3,000 individuals and found no re-sighting between the regions. This suggests that the PRD metapopulation is distinct, likely separated from other CWD populations in Chinese waters. The degree of its insularity, and that of the other putative populations should be given further dedicated research attention.

**Another severely (lethally) injured Chinese white dolphin**

During the project period reported here, an adult dolphin was seen in Hong Kong waters with severe injuries by deep propeller cuts at the peduncle. This is the third such documented case of major physical trauma in the past just over 5 years, which should be a cause of concern. The first case, in 2015, ended up with considerable public outcry, confusion among some non-governmental activists, and inaction by management authorities, while the dolphin's health progressively deteriorated and led to its slow and painful death across three weeks since the injury. The second case occurred in 2018 (detailed in reports of the previous phase of this MEEF-funded project), but the fate of the dolphin has a much better ending which can be attributed to far more rational decision by local management authorities and appropriate swift action taken by the response team and veterinarian team of Ocean Park Hong Kong, assisted by our research team. In this current third case, however, the dolphin took a similar path as the first case and was found dead a few days after its first sighting, following several days of challenging weather conditions. To the best of our knowledge, our research team collected the only photographic record of this injured individual, a reproductive female at her prime, when she was still alive.

The injured dolphin was found in mid-June 2020 in waters off south Lantau, had severe incisive trauma with deep wounds that were at least some 10-days old and were evidently deteriorating (Fig. 12). Two deep incisions, apparently propeller cuts, were located at dorsal part of the peduncle, right at the base of the fluke, severely impeding locomotion of the dolphin. Our research team assessed the severity of the injury and the overall health condition of the dolphin, which was clearly critical and required immediate medical intervention. However, in contrast to the successful previous case (the second case mentioned above), no rescue action was executed as the confounding factors of time (late afternoon) and the time required by the response team for preparation, let the Ocean Park's veterinarian team decide against launching an immediate medical response.

In the following day, the weather and sea conditions turned challenging and precluded any field survey, likely making the conditions highly challenging for the injured dolphin as well, especially because of its impaired mobility. As result, the dolphin was not seen alive again. A week later, a substantially deteriorated CWD carcass was reported in eastern Hong Kong waters. Although it was far from the

location of our sighting, our photo-ID data obtained at the time of the sighting and the catalogued ID-record confirmed that it was the same individual.

Vessel collision, propeller cuts and fishing gear entanglement have been the causes of concern to the individual health and overall well-being and the dolphin population in the PRD region for many years. Our earlier work quantified that one in every ten dolphins has physical injuries from various anthropogenic causes (Chan and Karczmarski 2019). However, it was not until the well-documented case from 2015 that dolphin injuries of the level of severity as those three traumatic cases documented by our team have ever been seen and/or reported anywhere in the PRD region. This could be interpreted as apparently growing number of such cases in recent years, likely indicative of the mounting threats of boat collision and propeller cuts to the dolphins, which is not surprising considering the cumulative development in western Hong Kong waters and the intensified maritime activities that followed. Given the high frequency of these recent traumatic injuries, it is likely that similar circumstances will arise again in a near future. Local management authorities should be better prepared with more efficient response and rescue protocol.

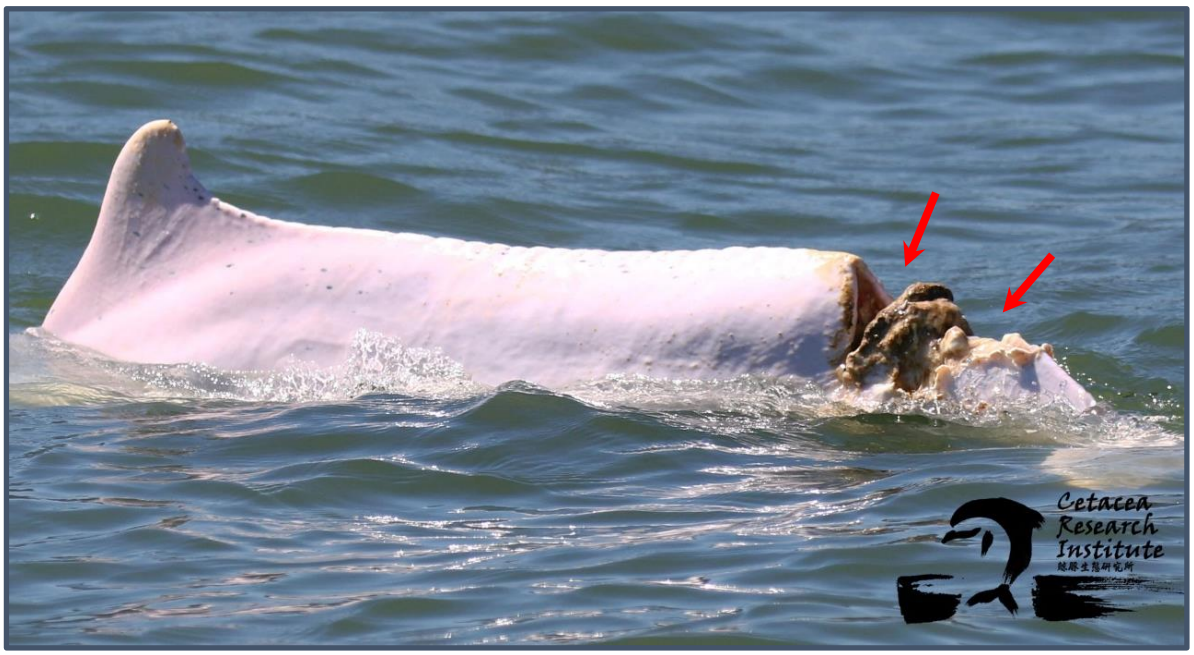


**Figure 12.** An adult female Chinese white dolphin found severely injured in June 2020, with two propeller cuts to its peduncle, at the base of the fluke (red arrows). The wound was clearly deteriorating and severely impeded the dolphin's locomotion.


**Figure 12 (*cont.*).** An adult female Chinese white dolphin found severely injured in June 2020, with two propeller cuts to its peduncle, at the base of the fluke (red arrows). The wound was clearly deteriorating and severely impeded the dolphin's locomotion.

In all three recent cases (recorded the past ~5 years), the injured dolphins were among the most frequently sighted individuals that had numerous entries in our photo-ID catalogue. Both individuals in the most recent two cases were breeding females, with their reproductive history spanning several years in our long-term mark-recapture dataset. In fact, the first and the most recent third case were among our earliest IDs. Cases of such incidental mortality of otherwise perfectly healthy individuals (as confirmed by autopsy of the 1st and 3rd case, performed by Ocean Park veterinarian team), and especially reproductive females (the two most recent incidents) are particularly detrimental given the critical role of reproductive females in maintaining the numbers of this vulnerable species and locally endangered (Karczmarski *et al*. 2014), fast declining population.

On the other hand, these sad cases once again underscore the importance of our multi-year research project in constructing and maintaining a high-quality long-term mark-recapture record and monitoring the demographic performance of the PRD dolphin population.

## Evaluation of the project effectiveness

All photo-ID mark-recapture activities intended for this phase of the project have progressed effectively and timely as planned. Field surveys were optimized to collect field data under safe and workable weather/sea conditions. As stated previously (in the original proposal and previous reports), survey intensity was unavoidably lower in winter months due to highly unfavourable sea conditions typical for local winter weather; but gradually increased as summer approached, which represents the peak field season. All our data collected during this phase of the project contributed very substantially to a comprehensive photo-ID mark-recapture database of Chinese white dolphins across the Pearl River Delta region, which is of major importance if any intended population analyses are to produce scientifically sound results.

The currently applied field and lab protocols have once again tested well for the quality control of collected data and the continuity of data gathering with consistent standards, of which the scientific scrutiny is the key in delivering meaningful analytical results. The processing and synthesising the increasingly larger dataset

have been progressing on schedule and well, which facilitates effective monitoring of the project progress and all the interim analyses presented in this report.

As intended in the original proposals, based on the currently synthesised dataset, including the previous and the currently ongoing MEEF-funded work, we have performed multifaceted, although still interim at this stage, analyses of various aspects on the individual movement patterns, population connectivity and socio-demographic structure of CWD across the greater PRD region, detailed in earlier pages of this report. The results generated are the first of its type and highly significant in quantifying the metapopulation dynamics of the PRD dolphins and depicting the heterogeneous socio-demographic structure across the PRD spatial scale, which will be instrumental in the delineation of management units for effective conservation efforts in the region (intended as part of the upcoming phase of this multi-year project). The current findings not only advance our understanding of the population / metapopulation processes, but also form the basis for further investigation and quantification of the demographic dynamics and population viability of the PRD dolphins, intended as one of the objectives of the next stage of this current Phase-3 of the project.

In overall, the current interim results, albeit not in their final publishable stage, provide the first ever suite of quantitative evidence of a complex metapopulation system of Chinese white dolphins across the greater PRD region, which in itself speaks for the well-thought design, sound implementation and effectiveness of this multi-year project, and its steady advancement in the previously envisioned and set forth direction. The application of metapopulation framework identified in this current phase of this project will facilitate a better understanding of population processes that ultimately determine population long-term viability. Consequently, the project outputs will not only advance our understanding of what determines the daily lives of the PRD dolphins, which in itself has been long-overdue, but also carry considerable implications for revisiting, updating and possibly revising the conservation management strategy for these dolphins in Hong Kong and across the PRD region.

All findings reported here (and in the upcoming future reports) will be published in respected peer-reviewed scientific journals. While several papers are currently in preparation and some have already been submitted, the primary intended output

(and the key papers) require more data and further analytical validation before they can be ready for journal submission.

## Summary and way forward

It cannot be overstated how much the photo-ID data collected across the PRD during the earlier phase of this multi-year project and during the pre-MEEF stage of our research have contributed to the long-term mark-recapture database, which is the backbone of all current, ongoing and intended investigations within the project long-term framework. The latest analyses have been summarised in this report, delivering interim assessment of individual movement patterns within and between sub-regions of the PRD, transitions rates across the region, estimates of individual dispersal pattern and displacement range across the PRD spatial scales, socio-spatial structure and socio-demographic dynamics of the complex metapopulation of the PRD dolphins. These findings, although not yet at their final stage, are all first of its kind never previously obtained nor even attempted in the PRD region, nor anywhere in the species range.

Adequate understanding of the metapopulation structure is the first and most fundamental step in the understanding the demographic dynamics underlying population processes and – importantly for conservation management – population viability, which is the very topic (population viability analyses, PVA) we intend to address in the next phase (currently awaiting funding confirmation) of this project.

Before any PVA can be undertaken, however, the metapopulation spatio-demographic structure has to be validated with more data and more sophisticated socio-spatial analyses. Further to the agglomerative clustering method (summarised earlier in this report), more complex network analyses are needed with application of eigenvector-based clustering algorithm. Such analyses are considerably more informative and far more appropriate for non-hierarchical cetacean societies. However, they are also far more demanding in terms of robustness of datasets. A preliminary attempt has been made (for reporting purposes only, see Appendix), but it has to be validated with a more robust dataset that can withstand strict modelling scrutiny. As envisioned in the conceptual framework set forth at the onset of this

project, we anticipate generating such sufficiently robust dataset at the later stage, close to the completion of this multi-year study.

The spectre of population fragmentation in the PRD in response to increasingly heterogeneous seascape and due to high levels of anthropogenic pressure (as indicated earlier in the results section of this report), should be seen as major conservation concern and potential management dilemma of highest urgency and utmost importance. Validating the currently identified metapopulation structure is at the core of such efforts, especially as it vastly differs from anything previously thought about the PRD dolphins. The next and much needed step is an accurate assessment of the metapopulation viability, with most up-to-date population parameters and in a manner that goes far deeper into the population functional structure than the early work from almost a decade ago (Huang *et al*. 2012). The likelihood of the (meta)population long-term persistence and accurate estimates of the probabilities of extirpation of any of the three regional subpopulations are among the most urgently needed population estimators. They will be instrumental in the establishment of any future management strategy if such strategy is to be effective. These are among the objectives of the intended next phase of this project, as per the framework of this multi-year study set forth at the very onset of this work.

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*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.*

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*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.*