Marine Ecology Enhancement Fund (MEEF) Declaration

To: The Secretariat of the MEEF

Reference No.: MEEF2017015A

Project Title: Conservation Ecology of Chinese White Dolphins across the Pearl River Estuary Phase 2: Population Parameters, Demographic Structure and Habitat Requirements

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 Nov 2019

Marine Ecology Enhancement Fund (MEEF)

Conservation Ecology of Chinese White Dolphins across the Pearl River Estuary

Phase 2: Population Parameters, Demographic Structure and Habitat Requirements

MEEF2017015A

Completion Report

30 Nov 2019

Cetacea Research Institute

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Executive summary

The project reported here represents a continuation of Phase 2 of a multi-year undertaking, initiated with a pilot study in 2015. The multi-year undertaking 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 of this multi-year project), literally nothing is known about these dolphins and all aspects of their ecology and socio-demography investigated in our project represent first ever scientific account of this population.

All work and 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 that is the backbone for the entire multi-year undertaking. Even though there are obvious limits to how much field-collected data can a 1-year project (which is the time-duration of the project reported here) possibly generate, in our case, in conjunction with the earlier phase of this study and the ongoing MEEF-funded Phase-3, the work reported here represents an important building block within the framework of the larger multi-year undertaking. A total of 105 surveys were conducted during the project period reported here, which resulted with 519 encounters of dolphin groups and a cumulative number of 2836 dolphin sighting-records.

Our current analyses, albeit not yet anything final in the context of the multi-year project, have preliminarily quantified individual movement patterns across the PRD, mapped the habitat use pattern and computed the temporal social dynamics of the CWDs in the eastern part of the PRD region, and quantified the population parameters and socio-demographic structure of CWD in the westernmost part of the PRD. Early-stage movement analyses across the region, albeit still preliminary, indicate moderate-to-considerable long-term site fidelity of Chinese white dolphins

in all three sectors of the Pearl River Delta region. Although some individuals may leave their respective sectors of the PRD, re-immigration is frequent and in the long-term the dolphins exhibit considerable affinity to relatively restricted geographic ranges. These early findings suggest that the movement between different sectors of the PRD may be limited, but this can only be confirmed with more in-depth modelling approach after sufficiently beefed-up dataset (which should be achieved after additional 2-years of field work) is fully synthesized and cross-matched across the entire PRD region.

At the eastern reaches of the PRD, areas frequented by CWDs were mapped by constructing advanced habitat utilization models. High-definition "heat-maps" illustrating the area utilization patterns clearly indicate that CWDs have very restricted core areas, centred in inshore shallow waters, especially along the coastlines that remain relatively 'unspoiled' by anthropogenic impacts and with relatively low levels of human disturbance (lower levels than in other sectors of the area); e.g. as Southwest Lantau and Green Island/Sam Kok Shan Island). The foraging core areas are even more restricted, yet closely resemble the overall area use pattern, which reaffirms our earlier observations that the dolphins' nutritional needs and foraging locations determine their overall habitat use pattern in the PRD. Moreover, the current evidence suggests that Hong Kong waters, particularly off west and southwest Lantau Island, represent one of the most important dolphin foraging ground, with the largest continuous patch of relatively unaltered coastal foraging habitat in the entire Eastern PRE.

Based on the latest spatial projection of the area use pattern, finer-scale movement analyses were performed to compute individual site fidelity and movement pattern between foraging core areas across the Eastern PRE waters. The early-stage findings suggest low short-term fidelity of CWDs at the same core areas with frequent movements between areas, but moderate long-term site fidelity with considerable re-immigrations of dolphins back to the same foraging locations. Social dynamics analyses were also performed to examine the temporal stability of associations among individuals in the Eastern PRE. Although their social affiliation was stronger than by chance alone, in other words non-random, inter-individual associations were generally weak and fluid as in a typical fission-fusion mammalian society.

On the other side of the Pearl River Deltaic region, mark-recapture analyses suggest that there are at least 914 dolphins inhabiting the coastal waters of Western PRE, corresponding to our initial supposition that this part of the PRD harbours a substantial number of dolphins, and is therefore of critical importance to the overall persistence of CWD in the PRD. However, the survival rates of the dolphins in the western reaches of the PRD seem surprisingly low, likely below the threshold of long-term persistence. This is a highly unexpected finding, but the estimates are still very much preliminary at this stage and ringing the alarm bell would be premature. However, if this figure is supported by further analyses of a larger sample size, it would indicate that although the coastal waters of Western PRE are vast and seemingly still productive, the dolphins are likely under considerable environmental stress; probably stress of a different type and magnitude compared to that in the eastern part of the region, but larger than one would have expected in the relatively less-impacted western reaches of the PRD, and the population trajectory may be on a downward slope. More data and further analyses are still needed though, before conclusions can be reached. This work is currently underway within the framework of the ongoing MEEF-supported Phase 3 of this project, and this part of our current efforts is of the highest urgency.

Agglomerative cluster analyses identified five hierarchical social clusters in the Western PRE. Although individual affiliations are generally fluid and dynamic, the dolphin social structure is heterogeneous with stronger and more frequent associations among individuals in the same cluster than from other clusters, yet not sufficiently discrete to be considered as separate communities. Individuals attributed to different clusters exhibited different, but not completely dissimilar, distribution pattern, and with considerable overlapping in their ranges. While this is indicative of a discernible social structure among the dolphins, the hierarchy of association modelled using the agglomerative approach may correspond primarily to the spatial segregation of individuals, likely driven by spatial preferences and individual fidelity to foraging areas. As such, non-hierarchical clustering methods will be explored in future analyses to further examine the social structure and inter-individual / inter-group connectivity, and the current findings and interpretations presented in this report should be viewed as preliminary.

In overall, the findings summarized in this report, although still far from final or conclusive, are all first of its kind even after decades of former research effort in the region, underlining the urgent need of such information for effective CWD conservation strategy. Our current findings and initial analyses affirm the overall framework and direction of this multi-year project, which if continued, will deliver results that are of great interest to marine science in general, and of paramount importance locally/regionally due to their major management implications, benefiting the conservation efforts of CWD across the entire PRD region. Further continuous flow of incoming data is therefore much needed (and currently underway thanks to the MEEF-funded Phase-3 of this project). Once sufficiently robust dataset is in place (as intended by the end of this multi-year project), the results of our efforts will carry important implications in advising local authorities on management recommendations based on empirical scientific evidence.

Brief description of the Project

The project reported here is a continuation of Phase 2 of a multi-year project, initiated with a pilot study (Phase 1) supported with the Hong Kong Airport Authority (AAHK) funding in 2015, and currently underway with MEEF funding support. This multi-year undertaking 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. Recent findings of Phase 1 and initial stage of Phase 2 (which lasted only half-a-year) of this project indicate that western waters of the PRD region harbours substantially larger numbers of CWD than Eastern PRE, with larger groups and different age structure. The latest data suggest that the dolphins in Western PRE are essential to the continuous persistence and long-term biological survival of CWD in the PRD.[1]

With no prior research in Western PRE, other than the Phase 1 and initial stage of Phase 2 of our multi-year project reported here, literally nothing is known about these dolphins. However, if the Western PRE population is of the type, size and status as our current data suggest, this could re-shape the fundamental concept of CWD conservation; the management strategies might need to be revised and probably substantially re-focused. This prospect alone underscores the importance and urgency of this ongoing study, part of which is presented in this report. The current phase of this project (reported here) has focused primarily on gathering population-level data on CWD in the Western reaches of the PRD and, along with comparative surveys in Hong Kong and Eastern PRE, it continues to assemble a robust mark-recapture dataset which, in the forthcoming phase of this project will be used to determine what constitutes the CWD population in the complex coastal habitats of the PRD and neighbouring waters.

In a larger-scale of our multi-year undertaking, this study will (i) quantify population parameters, size and sociodemographic structure; (ii) identify spatiotemporal

[1] The PRD region (or simply PRD) refers to the coastal waters of the entire estuarine system of the Pearl River Delta, 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 (PRD) region, from Hong Kong in the east to Jiangmen in the west, with the eastern reaches of the PRD region referred to as Eastern Pearl River Estuary (Eastern PRE) and the western reaches of the region referred to as Western PRE.

patterns of movement, range use and habitat utilization, and functional connectivity of dolphin habitat; (iii) determine the population connectivity and identify meaningful demographic units (management stocks; if any) for conservation; and (iv) will generate spatio-behavioural models of the population responses to anthropogenic change (e.g. habitat loss) and (v) demographic models of the processes that determine the population long term viability. This work, as part of a multi-year research framework, carries an immense potential for contributing to conservation management of CWD across the PRD and future assessments of anthropogenic impacts.

Methodology

(a) Study area

Data collection followed the same field protocol as the prior and the currently ongoing work and was performed across the PRD, including Hong Kong waters, Eastern PRE (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) so that only the intensity of surveys needed to secure the data continuity and comparability was maintained; while the work in the Mainland part of 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

Mark-recapture analyses were applied to construct population models, estimate population parameters, size and structure, and model geographic fidelity and movement patterns. Computer program MARK (Cooch & White 2012) was applied for population modelling and demographic parameters estimation, while program SOCPROG (Whitehead 2009) was used to model movement pattern, socio-behavioural dynamics and population structure.

The procedures of population modelling were based on the recently published multi-model approach by Chan & Karczmarski (2017). To test the fit of the observed data with constructed population models and to offer demographic parameter estimations, individual identification sighting histories were input to program MARK, which provides an analytical platform with various model types, essentially categorized as open, closed, and combined population models. Jolly-Seber open population models (Jolly 1965; Seber 1965) allow free recruitment and deletion of individuals and estimate survival rate and catchability along with the estimate of super-population size and several recruitment factors in various formulations (Burnham 1991, Schwarz & Arnason 1996, Pradel 1996, Link & Barker 2005). On the contrary, closed population capture-recapture models, comprising the full likelihood models (Otis *et al.* 1978) and the conditional likelihood models (Huggins *et al.* 1989), assume no recruitment or deletion during the study period and primarily provide population size, capture and recapture probability estimates. Yet another approach, the Pollock's robust design models (RD models; first described by Pollock and extended by Kendall and others; e.g. Kendall & Pollock 1992) combine the concepts of open and closed population into a single model with two levels of sampling units, making the models more complicated yet closer to the reality. It can therefore concurrently determine survival rates, temporary emigration rates, capture and recapture probability and population size. Best model within each model type was statistically selected based on the Akaike Information Criterion (AIC) and the biological interpretation of selected models was carefully examined.

Furthermore, to quantify the intra- and inter-population connectivity and to construct spatiotemporal models, the probability of transition between locations, the diffusion rates and the displacement of individuals over time (e.g. Whitehead 2001) were calculated with the aid of program SOCPROG (Whitehead 2009). Lagged identification rates, generated with SOCPROG, depict the pattern of site fidelity of individuals, with the AIC techniques applied to select the best fit model of residency. Furthermore, with the computational assistance of program SOCPROG, social structure models were constructed and examined based on mark-recapture data. Lagged association rates, multidimensional scaling and social network analyses in SOCPROG (Whitehead 2009) were applied and tested to compute the dynamics of individual associations, temporal group stability and spatiotemporal pattern of community structure.

Area utilization analyses followed the modelling approach by Or (2017), with kernel density estimation (KDE) and Local Convex Hull (LoCoH) methods, both of which estimate the probability of spatial area use (Worton 1989, Seaman & Powell 1996, Getz & Wilmers 2004, Getz *et al.* 2007), applied to depict the pattern of range use of the population across the PRE and to identify critically important core areas. In home range analysis, the generated 50% isopleths represent the core areas while 95% isopleths indicate the range. Adaptive kernel density estimates with least-squares cross-validation (LSCV) for kernel smoothing were applied using the Home Range Estimate extension tool in ArcGIS (2012) and/or Quantum GIS (2011). To generate isopleths using the LoCoH approach, k-LoCoH were performed in R. The value *k*, which refers to the number of nearest neighbours (geographic coordinates of prior and subsequently seen groups) taken to create the convex hulls was determined by as recommended by Getz *et al.* (2007). The same procedures were applied to geographically referenced data of observed behaviour (focal sampling of behaviour; e.g. Karczmarski & Cockcroft 1999, Mann 1999) to identify key areas for ecologically and socially important behaviours (e.g. Karczmarski *et al*. 2000).

Completed activities against the proposed work schedule

All work progressed as intended, timely and on schedule, and along the envisioned framework of the project. Sea-based fieldwork was performed over the original budgeted 12-month period of this Project to collect data, and – as the required completion date coincided with the busiest time of the year (middle of field season with peak survey-effort) – the project period was extended primarily to perform analyses and to prepare this completion report. However, as the sea conditions of the field season reported here were far more unfavourable than what is typical for an average year, sea-based fieldwork was continued into the extended period to maximise the data output and retain the originally intended project workflow.

Boat-based photo-ID surveys were carried out in Hong Kong (HK) waters and Pearl River Estuary (PRE) whenever the sea conditions allowed. The research team completed a total of 105 surveys during the project period and encountered 519 dolphin groups with a cumulative number of 2836 dolphin sighting-records. The monthly survey efforts and sighting rates are summarized in Table 1. As pointed out in the original proposal and in the Interim Report, the intensity of field surveys is weather dependent, with a peak field-season in summer months and low-intensity period during winter; although this difference was less apparent in this field season.

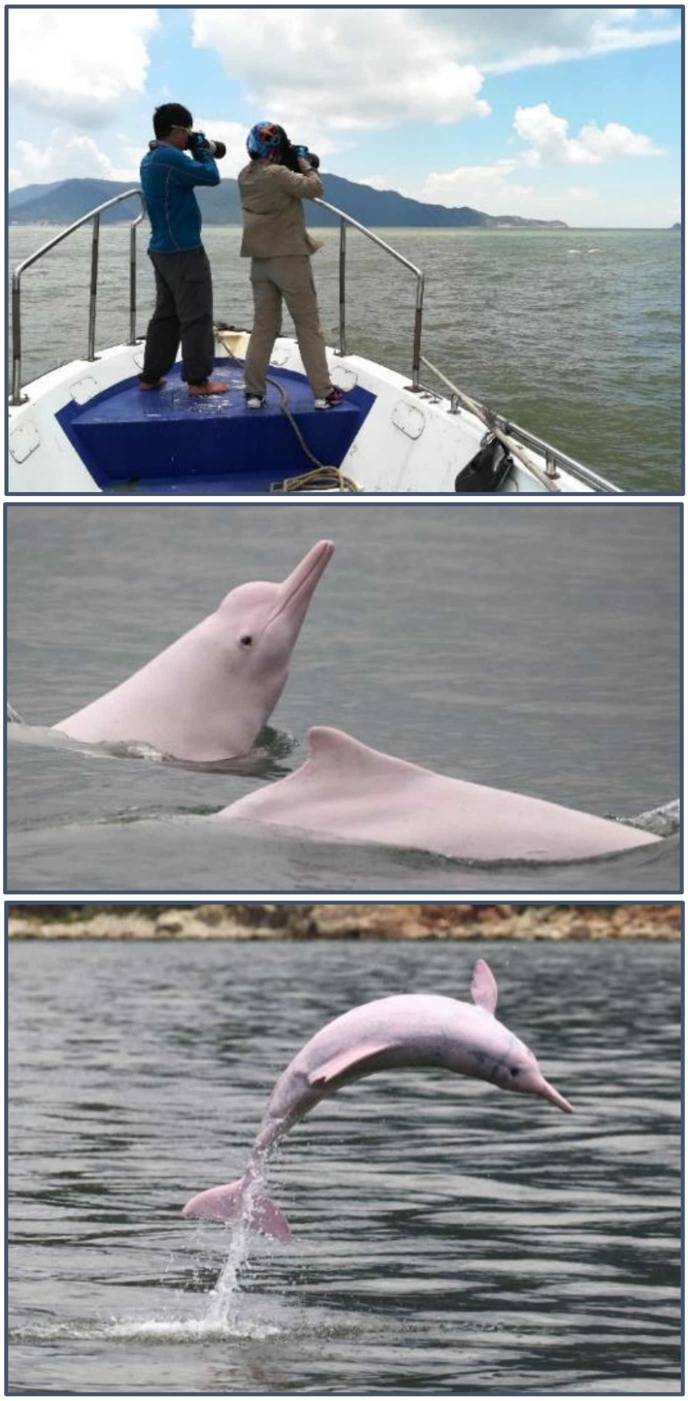


Figure 1. Images illustrating sea-based photo-identification surveys of Chinese White Dolphins in the PRD region.

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

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

Table 1. Summary of survey effort, number of groups, and dolphin sightings

Area	Month	Number of surveys	Number of groups encountered	Cumulative number of dolphin sightings
HK	July 2018	4	17	76
	Aug 2018	9	52	217
	Sept 2018	5	29	133
	Oct 2018	2	1	1
	Nov 2018	2	1	16
	Dec 2018	1	1	8
	Jan 2019	1	5	10
	Feb 2019	2	1	12
	Mar 2019	2	5	19
	Apr 2019	1	3	18
	Jun 2019	4	16	86
	Jul 2019	4	33	131
	Aug 2019	3	9	42
	Sept 2019	3	8	33
	Oct 2019	3	8	23
	Total	46	189	825
PRE	July 2018	7	39	210
	Aug 2018	6	29	145
	Sept 2018	6	68	434
	Oct 2018	4	4	12
	Nov 2018	3	7	23
	Dec 2018	4	18	81
	Jan 2019	1	6	27
	Feb 2019	4	14	95
	Mar 2019	5	30	247
	Apr 2019	2	8	49
	May 2019	3	15	155
	Jun 2019	2	11	47
	Jul 2019	5	51	352
	Aug 2019	7	30	134
	Total	59	330	2011
Overall		105	519	2836

** Three of the four surveys conducted in Hong Kong in July 2018 were covered with the funds from the previous MEEF funding (MEEF2017015).*

Despite unfavourable sea conditions across a substantial part if the field season, ample amount of data was collected, sufficient to secure the continuity of annual data gathering. As such, in conjunction with the prior and the currently ongoing MEEF-funded work, it represents an important building block within the framework of the larger multi-year undertaking, where the continuity of incoming data of the same standard and quality and comparable intensity is of great importance.

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. • A total of 105 boat-based photo-ID surveys were carried out with 519 dolphin groups encountered and 2836 individual 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. • ID-data from Hong Kong and Lingding Bay (mainland waters) have been fully cross-matched (Eastern PRE), which facilitated analyses of socio-spatial dynamics (see further). • As one of the primary focus of this current Phase of the multi-year undertaking, the gathering and processing of data from the Western reaches of the PRD has been intensified and advanced timely. • The currently applied field and lab protocols test well for the quality control of collected data and the continuity of data gathering with consistent standard, assuring the comparability of all data collected across the PRD region to date.

Synthesizing of mark-recapture data	• Cross-referencing of photo-ID data across the greater PRD region has commenced and progressed well as intended, which will continue and is expected to be at its final stages in the next Phase of this project (also currently supported with MEEF funding). • The processed and synthesized mark-recapture datasets provided the backbone quantitative information for socio-demographic analyses on the CWDs inhabiting the Eastern and Western reaches of the PRD region. • Social structure analyses indicate that in Eastern PRE, CWDs live in a highly fluid fission-fusion society with mostly casual associations between individuals. Although there is detectable fine-scale structure (likely driven by individual spatial preferences), the overall pattern indicate one, highly dynamic unit with frequently interacting individuals. • Socio-demographic analyses across the PRD (although still in an early stage), indicate a substantially more complex population structure (as compared to social structure within Eastern PRE), with a substantial number of individuals using the westernmost region of the PRD as their primary habitat. The heterogeneous population structure (with multiple social clusters) and fluid group dynamics appear to be governed by demographic factors and spatial preferences. • Based on the current data and the analyses completed to date, three manuscripts are currently in preparation and intended for peer-reviewed journals. • Benefiting from the mark-recapture photo-ID datasets, the health conditions of free-ranging CWDs in Hong Kong waters were assessed and appear notably compromised, symptomatic of the ecological conditions of coastal waters in the region. This work has been published in the international peer-reviewed scientific journal *EcoHealth* (see Appendix).

Processing of spatial data and movement analyses	• Geographically-referenced data have been gathered and processed alongside the photo-ID mark-recapture work. • The synthesized data facilitated further the spatial analyses of the habitat use pattern of CWDs and contributed a spatial component that is fundamental to the performed socio-demographic analyses. • Preliminary movement analyses were performed to examine the site fidelity of individuals across the PRD region. Early indicators suggest that CWD exhibit considerable affinity to relatively restricted geographic ranges. • Latest habitat utilization analyses identified several core areas (habitat hotspots) in the Eastern PRE, all of which are in inshore waters of relatively lower anthropogenic impact compared to neighbouring areas. Individual movement analyses suggest low short-term fidelity but moderate long-term return rates to this preferred core areas. The current analyses will be further refined (and results updated) during the (currently ongoing) preparation of manuscripts for publication (see further). • Multifaceted analyses indicate that the socio-demographic structure of CWDs at the westernmost region of PRD is likely determined by their individual spatial preferences restricted to certain areas. • Further work is anticipated to advance timely and to be continued in the next Phase of this MEEF-funded project as planned.

Results

During the time-period budgeted for and reported here, the sighting records of Chinese White Dolphins obtained during the 105 surveys cover the entire Pearl River Delta region, with Hong Kong and Shangchuan/Xiachuan Islands at the easternmost and westernmost flanks of the range. The geographic distribution of dolphin encounters (and our photo-ID records) is displayed in Fig. 2.

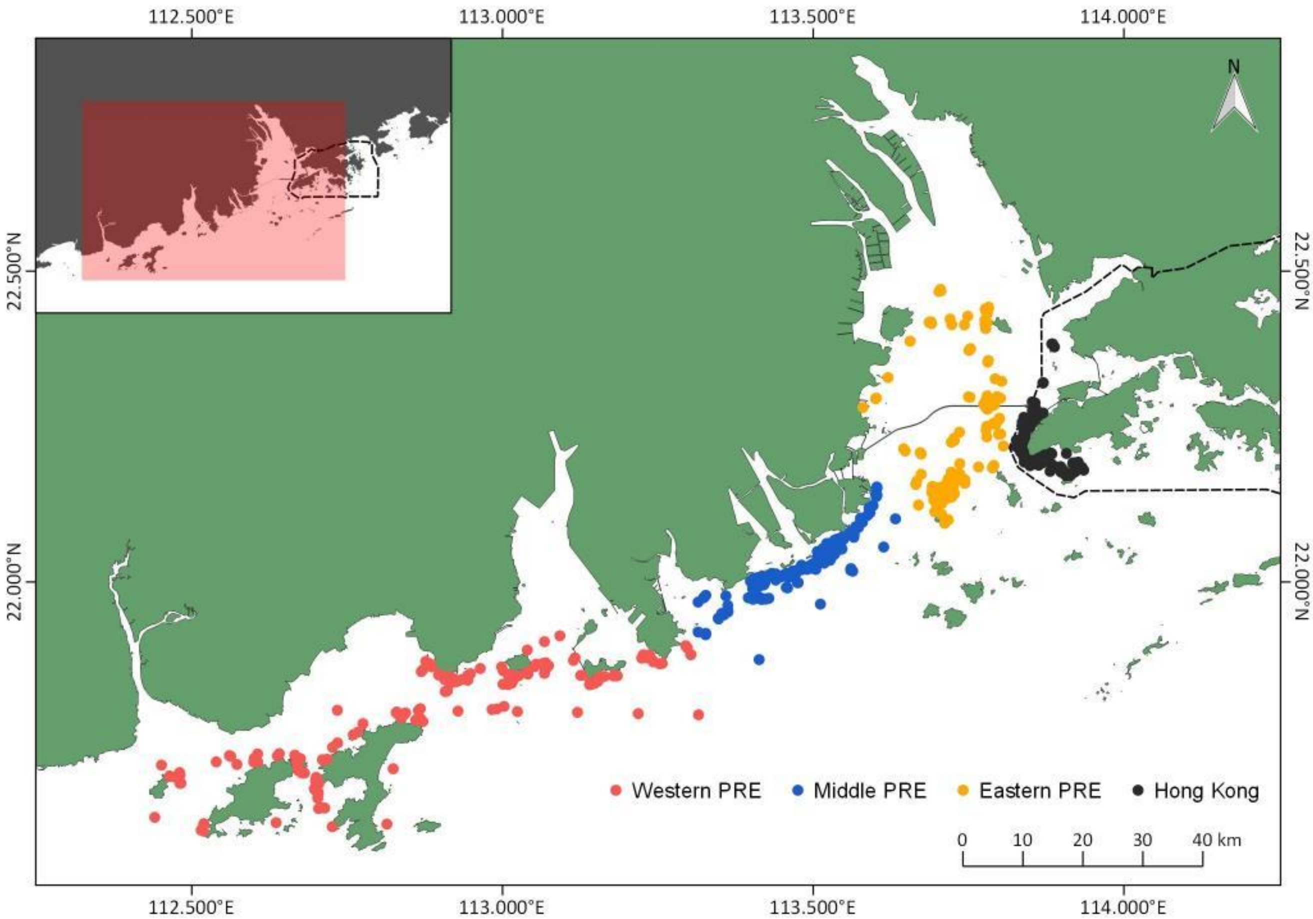
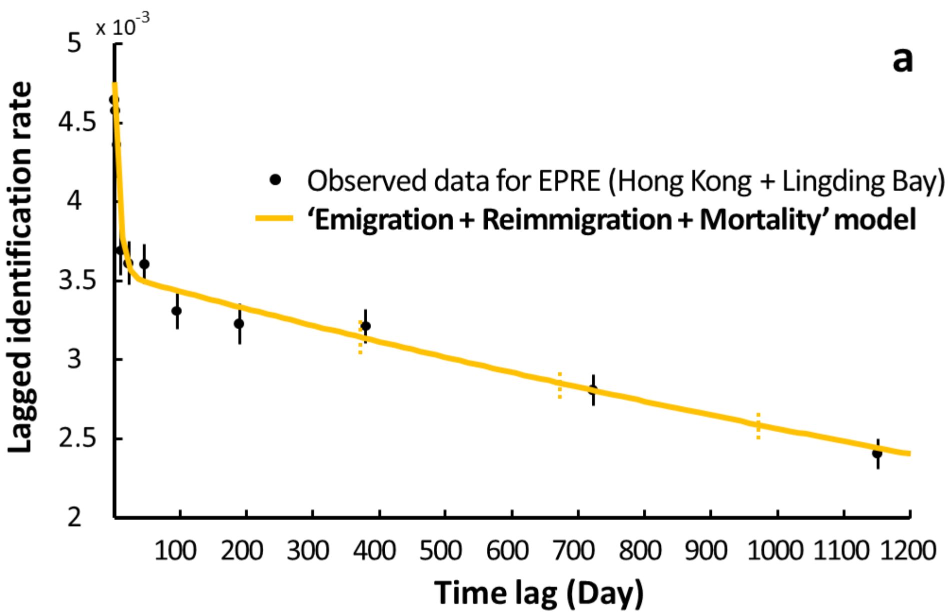


Figure 2. The location of sighting records of Chinese white dolphins across the PRD region where individual ID-data were collected. Different sectors of the deltaic system (e.g. Western, Middle, Eastern PRE) are indicated by different colours.

The dataset from the current Project alone (and from any individual sub-components of the multi-year project) is far from sufficient to perform comprehensive analyses, underlining the importance of the continuity of data collection. The data presented here has to be seen therefore as preliminary and it would be premature to use it for a thorough investigation of the socio-demographic structure and population connectivity of CWD across the entire PRD region. This is anticipated to be achieved in the next (ongoing) Phase-3 of this multi-year MEEF-funded project (as per the timeline in our original proposal). For the purpose of this report, only preliminary analyses were performed to indicate the movement patterns across the greater region. On the other hand, when combined with our earlier obtained data, the overall dataset continues to strengthened and is currently robust enough for reliable analyses on the habitat utilization pattern and socio-spatial dynamics of CWDs in Eastern PRE, as well as the socio-demographic features of individuals inhabiting the western reaches of PRD region. Here we present some of the findings that are currently used for preparation of manuscripts for peer-reviewed journals (albeit the results presented here will likely be further refined at the final stage of journal publication. Therefore, it has to be explicitly pointed out that the estimates and figures presented here are not yet conclusive and should not be referenced as such to avoid misinterpretation and to not cause any misunderstanding among stakeholders. Journal articles with the final estimates will be made available to all interested parties once published.

Based on the currently processed dataset, preliminary movement analyses were performed to quantify the site fidelity of individuals in 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 an individual being 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 the best model was subsequently selected based on Akaike Information Criterion (AIC).



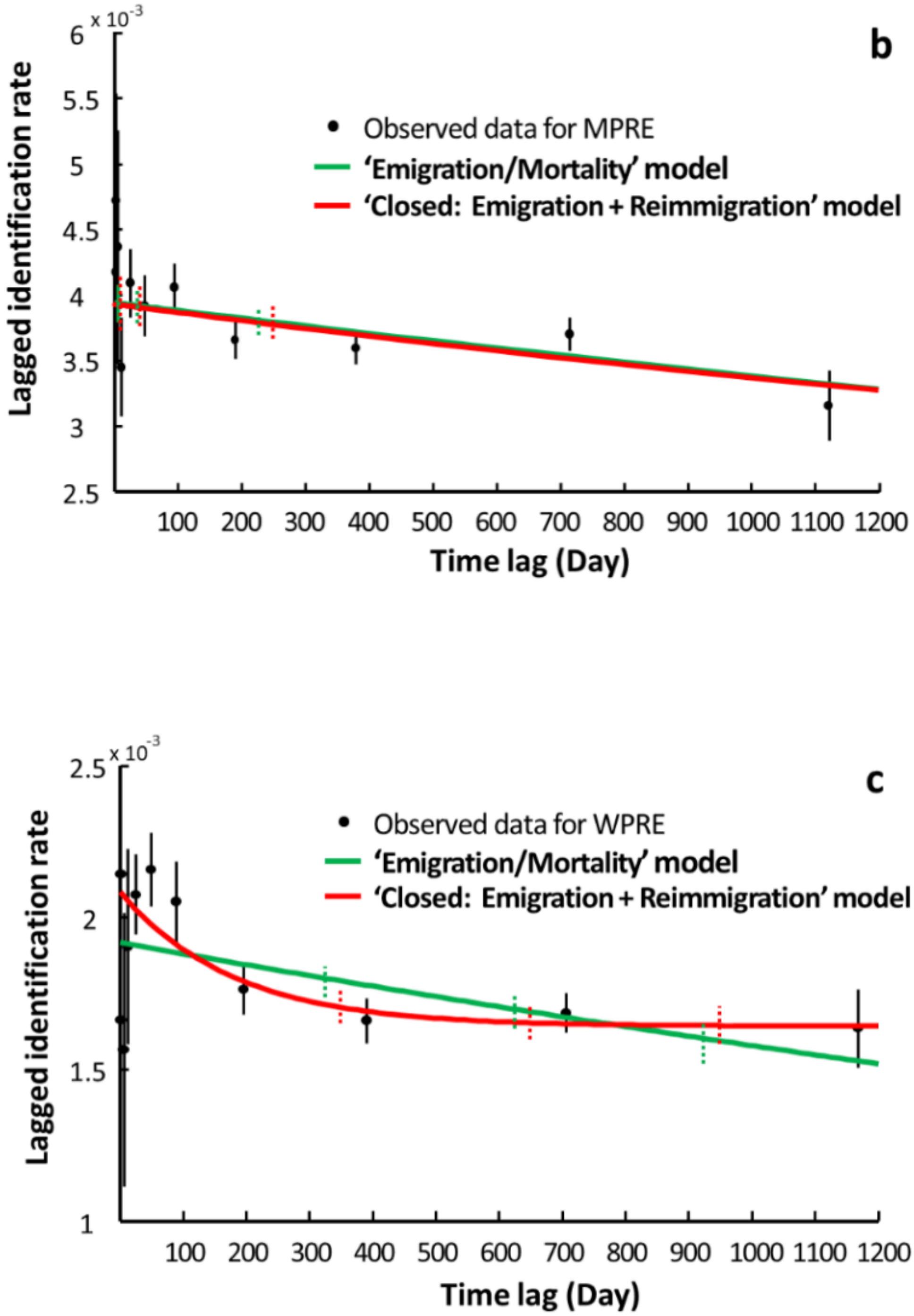


Figure 3. Single-area lagged identification rates (LIRs) of highly distinctive individuals (D ≥ 3) of Chinese white dolphins in (a) Eastern PRE [*displayed on page 18*], (b) Middle PRE, and (c) Western PRE with the corresponding best-fit movement models (ΔQAIC ≤ 2). Bootstrap SE of the observed data and the movement models are shown in solid and dotted error bars, respectively.

The LIRs in all three sectors of the Pearl River Delta region declined continuously across the time lag projection, although the rates of decline, size of error bars, and best-fit models differed between sectors. The LIRs in Eastern PRE exhibited the most rapid drop over the initial period with the smallest error bars, followed by the sharpest change in decline rate (Fig. 3a). In Western PRE, LIRs had larger error bars and displayed a slower initial drop with more fluctuations (Fig. 3c); while similar fluctuations and larger error bars were apparent in Middle PRE, but without an obvious initial rapid drop (Fig. 3b). The larger error bars in Middle and Western PRE for the initial data points were indicative of the lower individual sighting frequencies in these sectors. Consequently, model fitting in these two sub-regions exhibited some uncertainty; yet another indication that more work is still needed particularly for these sectors.

Nevertheless, the early-stage analyses of LIRs across the region indicated moderate-to-considerable long-term site fidelity of Chinese white dolphins in all three sectors of the Pearl River Delta region. Although some individuals may leave their respective sectors of the PRD, re-immigration is frequent and in the long-term the dolphins exhibit considerable affinity to relatively restricted geographic ranges. These early findings suggest that the movement between different sectors of the PRD may be limited. However, this can only be fully examined and confirmed after the dataset is fully synthesized and cross-matched across the PRD, with all relevant movement models performed and tested against stochastic events.

A suite of multi-faceted analyses was performed to investigate the socio-spatial dynamics of CWDs in the Eastern PRE. Advanced habitat utilization models were constructed to identify the dolphin habitat preferences and use pattern, and high-definition “heat-maps” were generated to accurately illustrate the relative frequency of the dolphin area utilization in the region, where areas in red (or warmer colours) represent the most frequently visited areas (critical habitat), and areas in blue (or colder colours) represent areas used less intensively (but still occasionally) by the dolphins. The spatial models generated with all dolphin encounters (all types of behaviour seen) indicate that CWDs activities are highly restricted to inshore shallow waters, especially along the coastlines that are relatively ‘pristine’ with lower level of anthropogenic impact (‘lower’ in region-specific relative terms), such as Southwest Lantau and Green Island/Sam Kok Shan Island (see the red-coloured areas in Fig. 4).

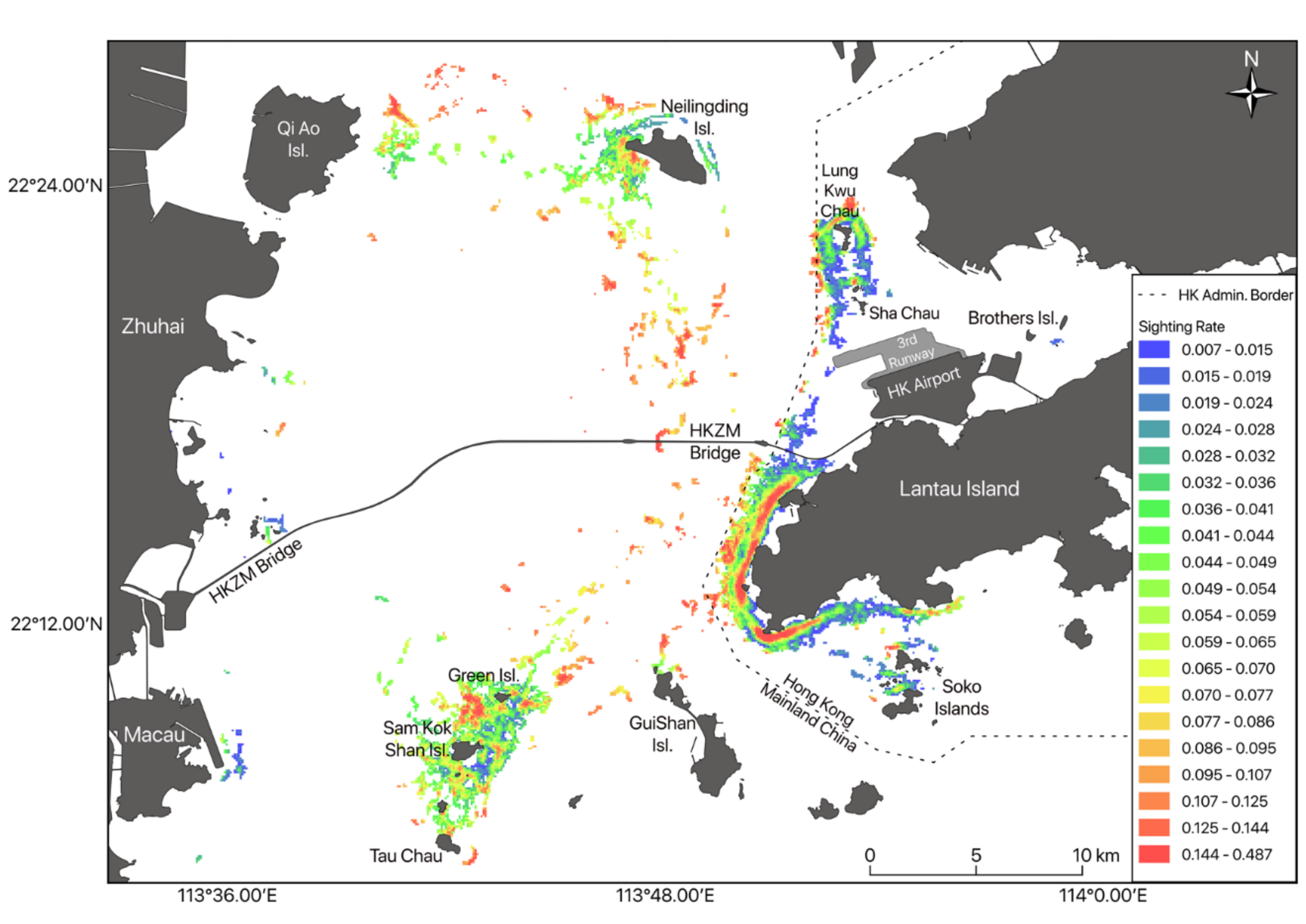


Figure 4. High-definition heatmap of dolphin area utilization pattern across the Eastern Pearl River Estuary (inclusive of Hong Kong). The colour-coded areas represent the rate of dolphin sightings, with warmer colours indicating higher sighting rates. Note that, in contrast to the 'hotspots' (e.g. off Southwest Lantau and Green Island/Sam Kok Shan Island), the fragmented small red patches in the middle of the Estuary without any buffer areas of colder colours are the modelling artefacts resulting from just a handful (small sample size) of dolphin sightings.

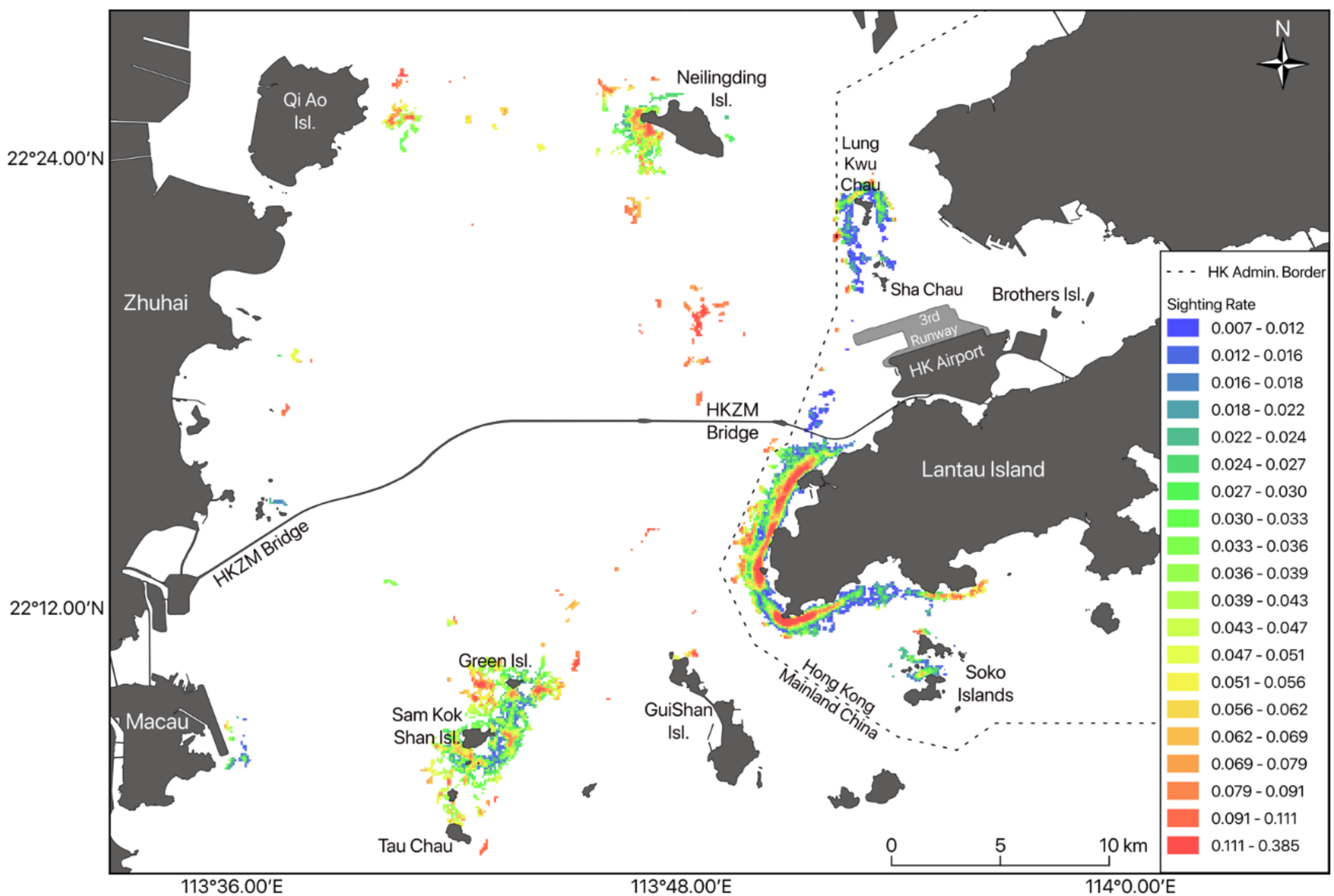


Figure 5. High-definition heatmap of dolphin foraging areas across the Eastern Pearl River Estuary (inclusive of Hong Kong). The colour-coded areas represent the sighting rate of foraging dolphins, with warmer colours indicating higher sighting rates. Note that, in contrast to the 'hotspots' (e.g. off Southwest Lantau and Green Island/Sam Kok Shan Island), the fragmented small red patches in the middle of the Estuary with no cold-coloured buffer zones are the modelling artefacts resulting from just a handful (small sample size) of dolphin sightings.

A high-resolution model of habitat selection specifically for foraging (Fig. 5) identifies a limited number of key foraging sites in the Eastern PRE, which represent areas that provide the critical resources for dolphins daily nutritional needs. In other words, these areas are of paramount importance for the survival of Chinese White Dolphins in the heavily anthropogenically altered habitat of the PRD coastal waters. The foraging area use pattern resembles very closely the overall pattern of range use (Fig. 4), but is even more restricted, indicating that the overall pattern of area utilization by the dolphins is primarily driven by their foraging needs. It has to be explicitly pointed out that waters off southwest Lantau constitute the largest continuous patch of key foraging areas in the entire Eastern PRE, and therefore it is of supreme importance for the conservation of CWD in the region and should be given the utmost priority for protection.

Moreover, it should be noted that the core areas and the overall home range area quantified in these latest spatial analyses (displayed in Fig. 4 and 5) are less inter-connected and spatially more restricted than previously reported (e.g. in the early-stage of this MEEF-funded multi-year study). The reason for it was primarily due to limited at that time survey effort in mainland China waters, which was insufficient to generate accurate model projections and hence, unavoidably, delivered biased estimates even under the best analytical scrutiny. This underlines that great caution must be taken when viewing and interpreting any early results based on short-term studies and/or small sample sizes which, by definition are preliminary and hence not conclusive.

While our current results of spatial analyses remain preliminary at this stage and, even though considerably more advanced than in the earlier reports, they are by no means conclusive. Nevertheless, these early findings reaffirm the reliance of CWD on nearshore coastal habitats for their daily needs and survival. The close spatial resemblance of foraging habitat distribution to the overall area utilization pattern indicates that the dolphins' need of food and foraging locations governs their habitat use patterns. Very importantly, current evidence indicates that Hong Kong waters, particularly west and southwest Lantau Island, represent the most important foraging habitat for the dolphins within the entire Eastern PRE. Such finding corresponds with the high proportion of Eastern PRE dolphins relying on Hong Kong territorial waters, as mentioned in the previous progress reports submitted to MEEF. This pattern seems to be indicative of the level of disturbance and habitat degradation in the mainland waters of Eastern PRE which makes the Hong Kong waters, even though majorly anthropogenically impacted, still degraded less than the coastal habitats across the administrative border.

Based on the updated spatial projection of the dolphins' range use and habitat preferences, four core areas within dolphin range that are of particular importance for foraging have been currently identified (Fig. 6). These are still preliminary considerations, based on preliminary assessment of data that is still being collected and, consequently, these current findings have to be viewed with caution. For example, the area of Sha Chau and Lung Kwu Chau Marine Park (area B in Fig. 6) has been in the past of considerable nutritional importance to Chinese White Dolphins in Hong Kong waters, but in recent years its usage as foraging area (in fact, its overall usage all together) has diminished drastically to a level of hardly any functional importance. In the Fig. 6 (and further in this document) this area is included for its "historic" value and is used for testing purposes only (see further). Given the recent level of major disturbance in neighbouring waters and the substantial decrease in the utilisation by the dolphins in recent years, the functional value of the Sha Chau - Lung Kwu Chau Marine Park to the dolphin's daily needs is debatable at best and as it seems, the previous "hotspot" of dolphin sightings may have to be seen now as "hotspot lost". At the final stage of our analyses, with more rigorous scrutiny (during the final stage of manuscript preparation), the area of Sha Chau - Lung Kwu Chau Marine Park will most likely have to be left out as it does not seem to warrant a priority conservation status anymore. However, more data is needed (at least another two field seasons) so that our conclusions can be based on sufficiently robust factual bases rooted in quantifiable, statistically testable and replicable evidence.

For the need of this report (and ONLY for reporting purposes, to indicate the progress of our work; not drawing any final conclusions) finer-scale analyses of dolphins movement across the Eastern PRE waters, between the tentatively identified four core foraging areas (Fig. 6), has been performed. Multiple-area lagged identification rates (LIRs) were calculated to quantify the individual probabilities of being re-sighted in the same area *vs.* any other area (e.g. between core area A and core area B) over a time lag (Fig. 7), with movement models fitted to the observed multiple-area LIRs and selected based on Akaike Information Criterion (AIC). Consequently, the multiple-area LIRs reflect the site fidelity of individuals within and the movement between the areas considered (the areas considered are those tentatively identified as foraging core areas, A-D in Fig. 6).

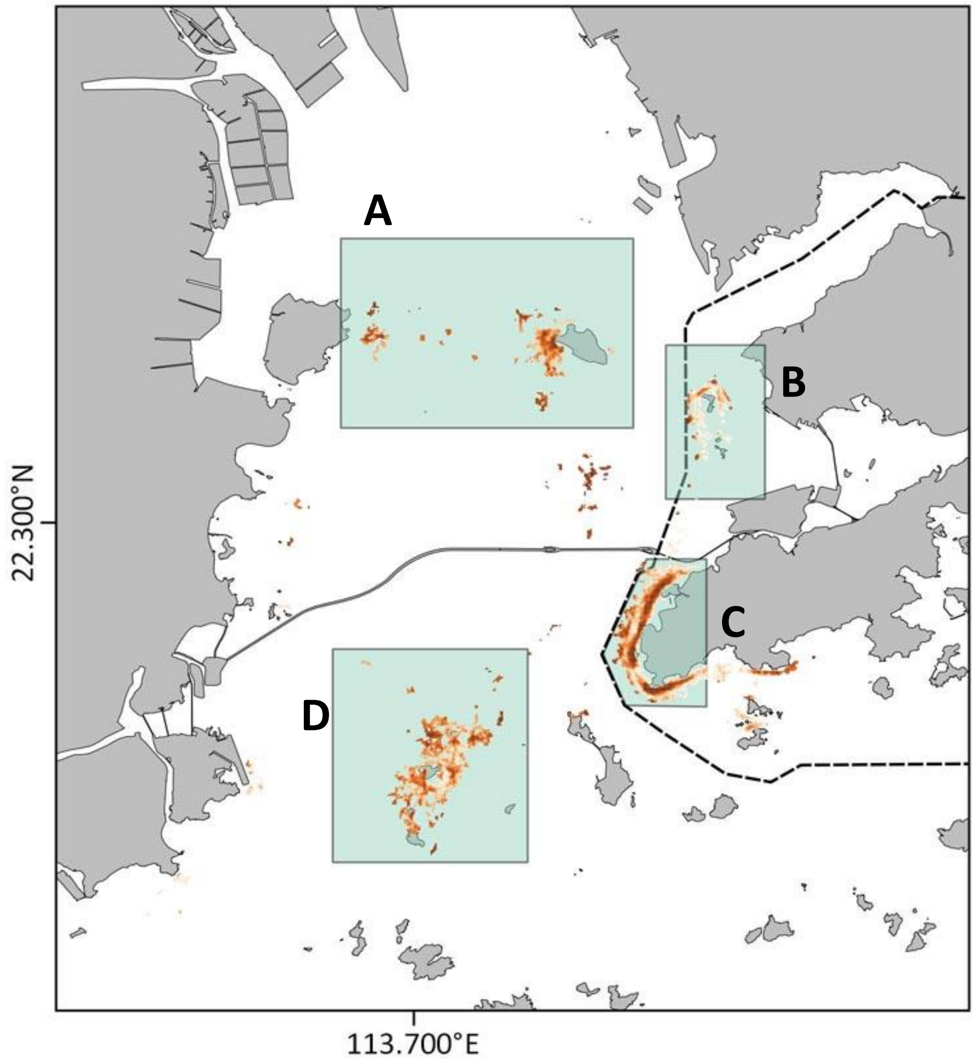


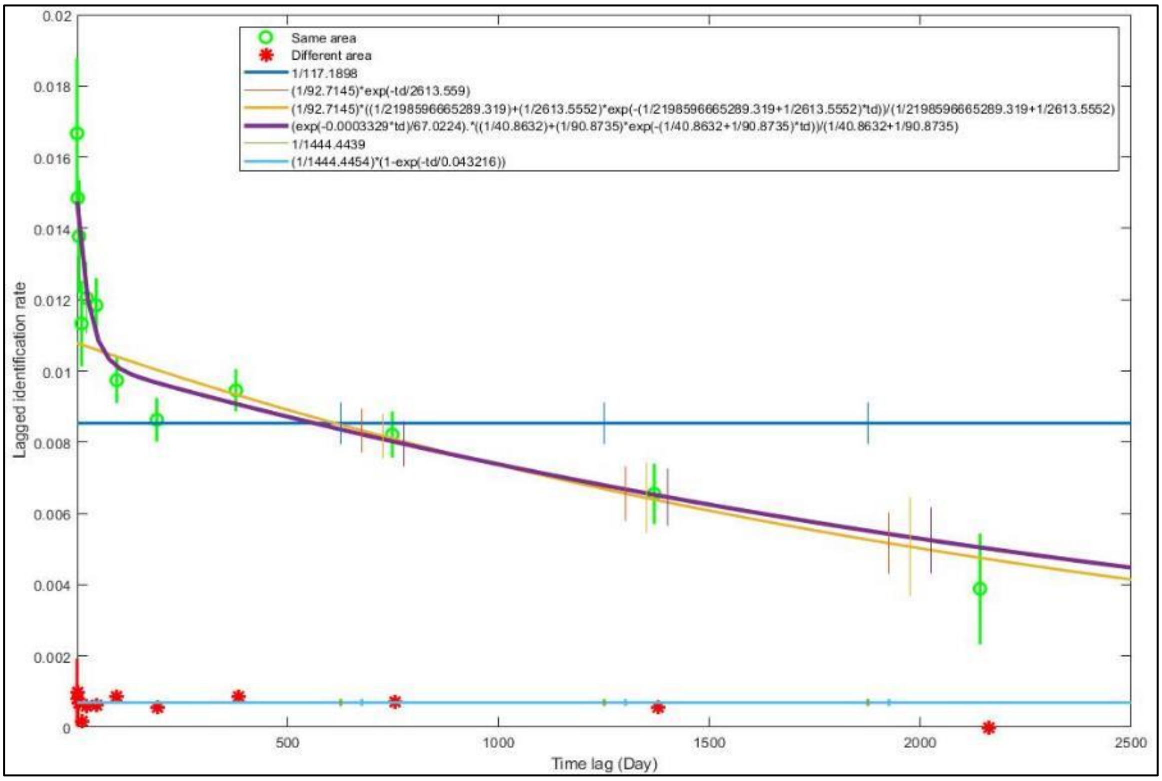
Figure 6. Four foraging core areas of Chinese White Dolphins (referred to as foraging "hotspots" in Fig. 7) preliminarily identified in Eastern Pearl River Estuary (note, the current "hotspots" are subject of further testing and at present have to be viewed with caution). Movement analyses were performed to quantify the patterns of movement between the four tentative "hotspots" (see Fig. 7). However, it has to be explicitly pointed out that the area around Sha Chau and Lung Kwu Chau Marine Park (area B) was only included for its historic functional value to the dolphins, which has diminished drastically in recent years. For the purpose of this report (and only this report), it is used as one of the hotspots for testing purposes. Given the recent level of disturbance in neighbouring waters and the substantial decreases in its usage by the dolphins in these years, this previous "hotspot" of dolphin sightings may have to be seen now as "hotspot lost" and this will have to be addressed with further scrutiny before drawing final conclusions.

In overall, the LIRs within the same area declined continuously across the time lag projection, although the rates of decline, size of error bars, and model fitting differed between areas (Fig. 7). The LIRs within the same area for all areas exhibited the most rapid drop over the initial period, followed by a sharp change in decline rate. In all cases, the best fitted model for LIRs within the same area was 'Emigration + Re-immigration + Mortality'. On the other hand, the LIRs between areas increased very rapidly over the initial period (in a matter of days, almost unnoticeable on the figures presented below) and then stabilized over time lag. The best model fitted for the LIRs between two areas was generally 'Migration - Full interchange', although some level of model uncertainty was noticed during the model fitting.

These current (still preliminary) movement analyses of LIRs between dolphin core areas in Eastern PRE indicates low short-term fidelity of CWDs to any specific core area with frequent movements between areas, but moderate long-term site affinity with considerable re-immigrations of dolphins back to the same foraging locations. In other words, while some individuals may move between different areas in the Eastern PRE (interchange between areas), re-immigration is also frequent and, in the long-term, the dolphins exhibit moderate-to-considerable affinity to their preferred ranges of foraging areas. Once again, however, these early findings have to be viewed cautiously as they will be revised and refined as more data is gathered and more robust dataset is used to run the analyses and generate the spatial representation of dolphin activities. This will require another several months and be done during the final stage of manuscript preparation that is intended to target a high-ranking international ecological peer-reviewed journal.

Social dynamic analyses were performed to examine the temporal stability of associations among individuals in the Eastern Pearl River Estuary (Fig. 8). Standardized lagged association rates, representing the probabilities of any two individuals remaining associated at a certain time lag after they were first seen associating, were computed to quantify the temporal stability of individual associations. Standardised null association rates (SNARs, or null model) were also estimated to represent the pattern when associations are completely random over time lag. Various social dynamic models were fitted to the observed SLAR and selected based on Akaike Information Criterion (AIC). Standard errors of all projected association rates and models were estimated by jackknife procedures.

Between Hotspot A and Hotspot B



Between Hotspot A and Hotspot C

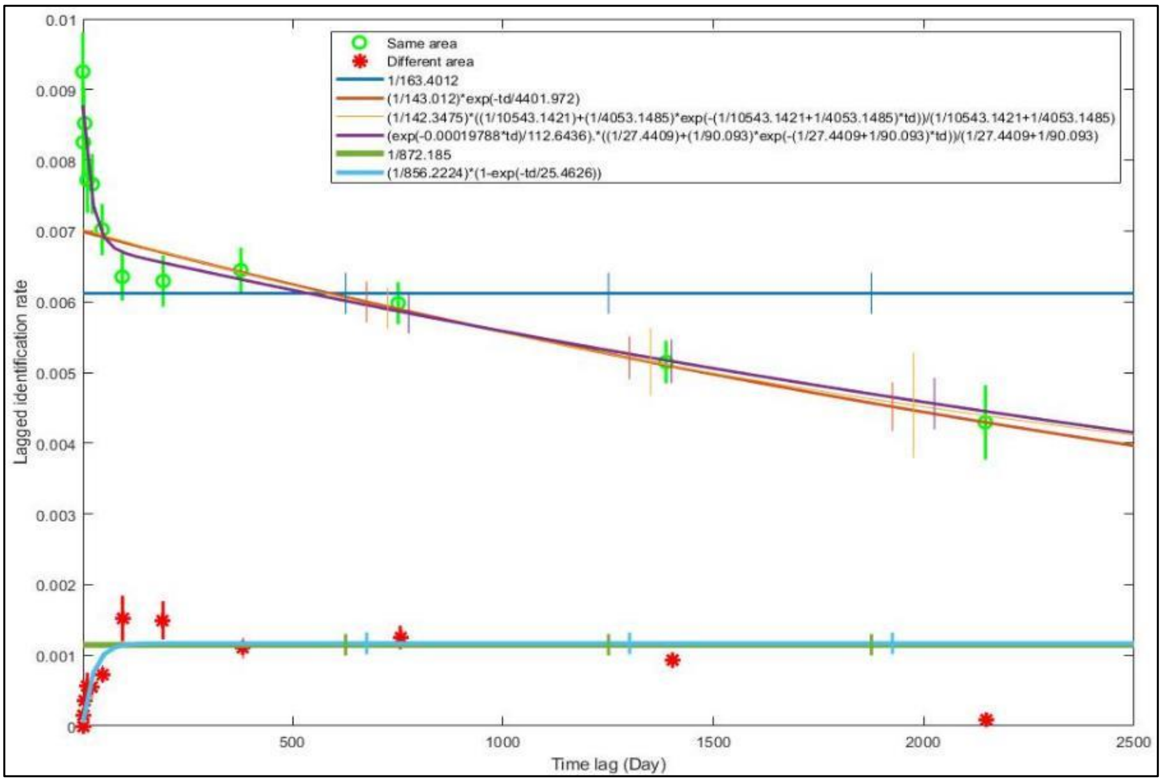
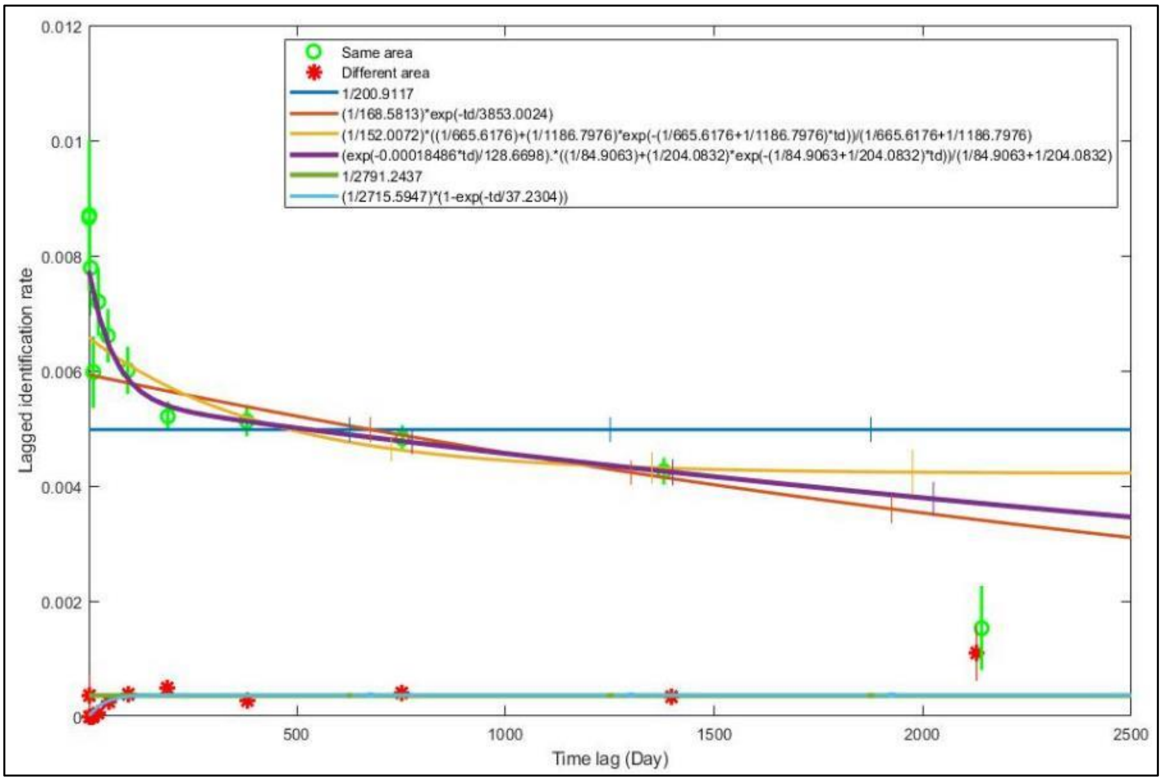


Figure 7. Multiple-area lagged identification rates (LIRs) of highly distinctive individuals of Chinese White Dolphins seen in the four core foraging areas (preliminarily identified here as foraging "hotspots" A through D) in Eastern PRE. Bootstrap SE of the observed data and the movement models are shown in solid and dotted error bars, respectively.

Between Hotspot A and Hotspot D



Between Hotspot B and Hotspot C

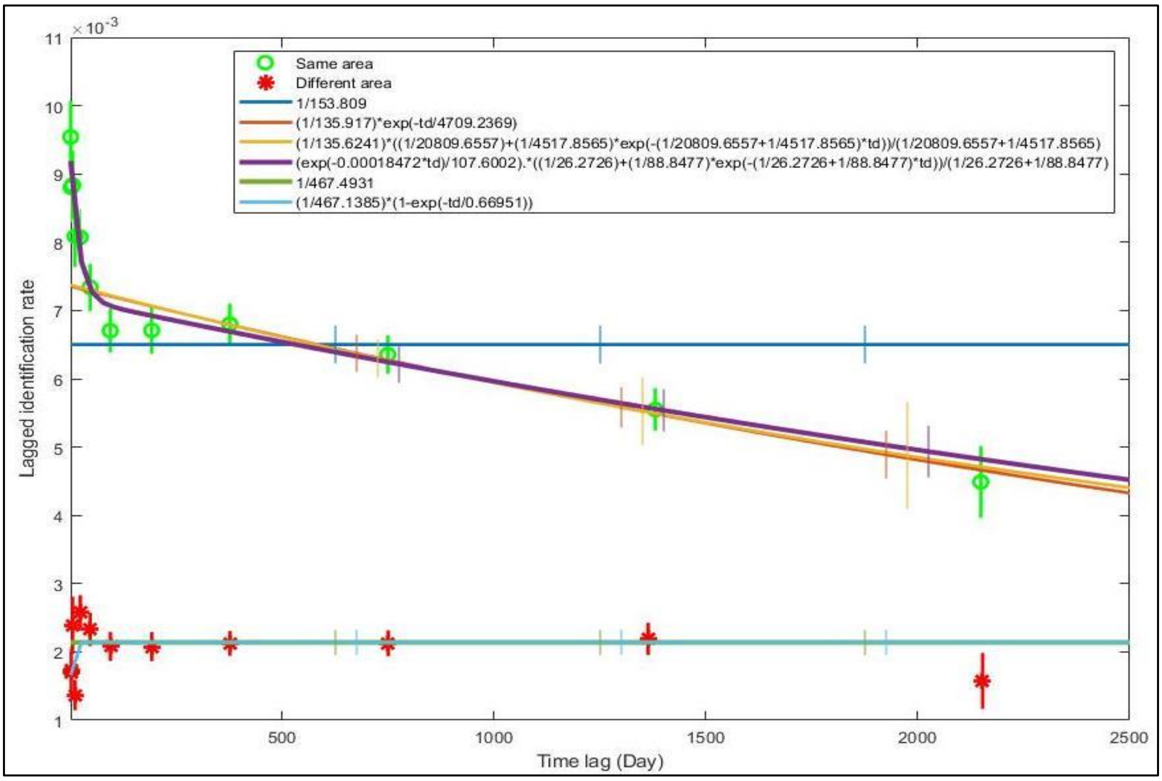
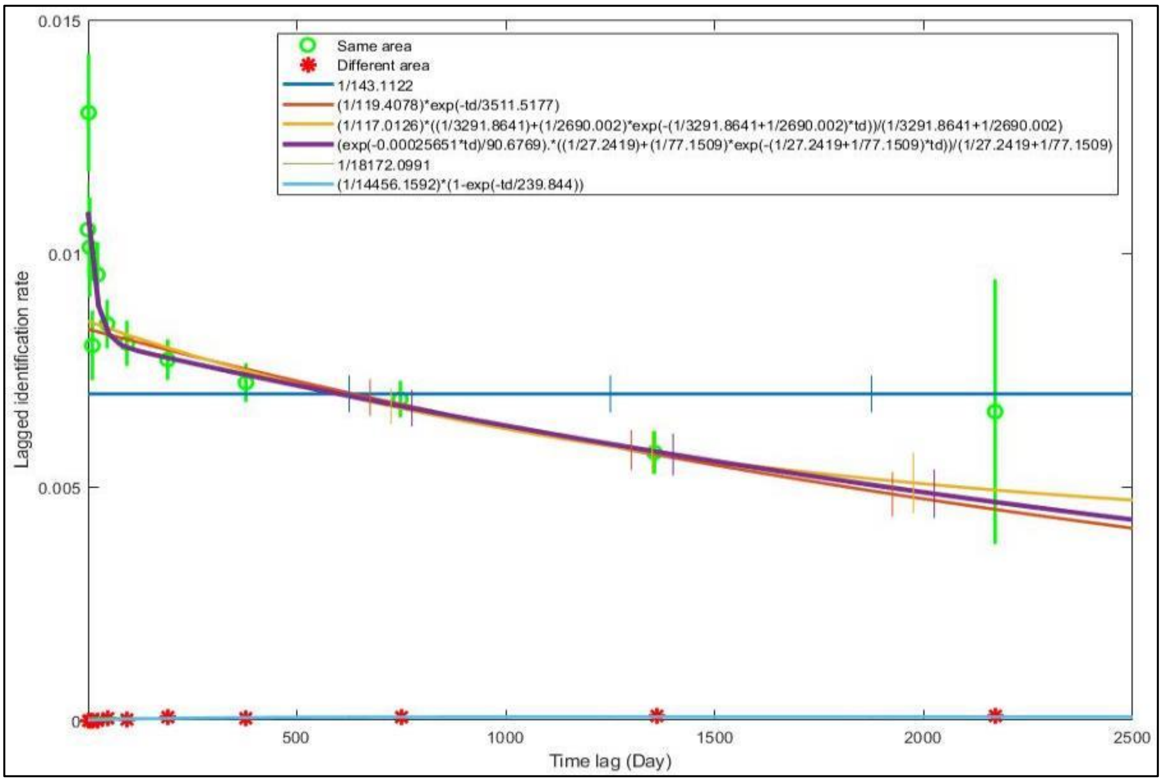


Figure 7 ***(cont.).*** Multiple-area lagged identification rates (LIRs) of highly distinctive individuals of Chinese White Dolphins seen in the four core foraging areas (preliminarily identified here as foraging "hotspots" A through D) in Eastern PRE. Bootstrap SE of the observed data and the movement models are shown in solid and dotted error bars, respectively.

Between Hotspot B and Hotspot D



Between Hotspot C and Hotspot D

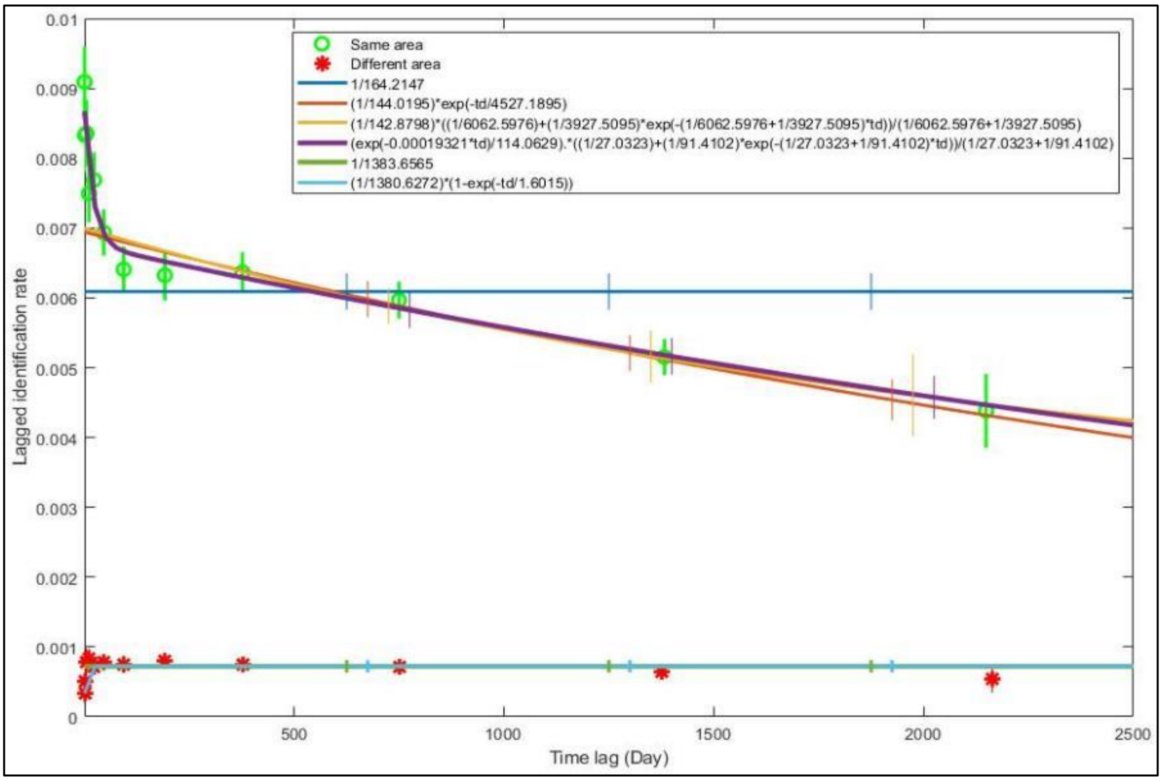


Figure 7 *(cont.).* Multiple-area lagged identification rates (LIRs) of highly distinctive individuals of Chinese White Dolphins seen in the four core foraging areas (preliminarily identified here as foraging "hotspots" A through D) in Eastern PRE. Bootstrap SE of the observed data and the movement models are shown in solid and dotted error bars, respectively.

Benefiting from a long-term dataset (the most robust part of our current dataset with highest survey effort), there was only slight oscillations in SLARs of the dolphins seen in Eastern PRE, which again highlights the critical importance of these type of data to cover long time-periods to be representative. The SLARs were notably higher than the SNARs (the null model), indicating that the associations between individuals were not by chance alone. However, even so, the SLARs declined continuously over the projection of time lag, especially over the initial time period, indicating that individual associations are generally weak and highly fluid as in typical fission-fusion mammalian society. This is further supported by the best-fitted social dynamic model 'two levels of casual acquaintance' which was also projected to decline over time.

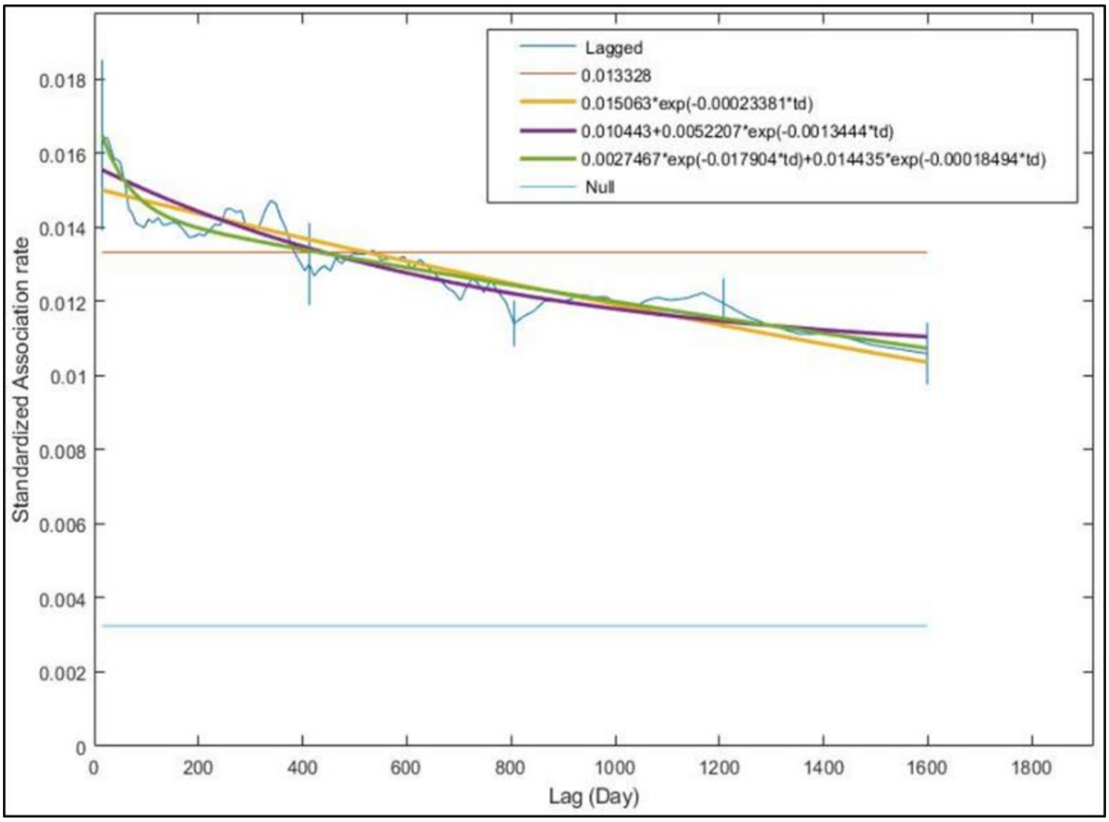


Figure 8. Models of social dynamics fitted to Standardised Lagged Association Rates (SLARs) of Chinese White Dolphins seen in waters of the Eastern Pearl River Estuary ≥ 10 times. Jackknife error bars are shown as vertical solid lines.

With the increasingly robust photo-ID dataset, we were able to carry out preliminary analyses to examine the socio-demographic features of Chinese White Dolphins in the westernmost reaches of the Pearl River Delta region. Mark-recapture analyses were performed to provide early assessments of the population parameters, with the data treatment and analytical protocols adopted from the published work by Chan and Karczmarski (2017), using only the high-quality images of highly distinctive individuals to minimize the analytical biases from any misidentification. The mark-ID ratio, representing the proportion of individuals in the population that are highly marked, was estimated to be 90.2%, which is similar to the ratio estimated in Hong Kong waters (see Chan and Karczmarski 2017). POPAN mark-recapture models suggest that there are at least 914 dolphins inhabiting the coastal Western PRE waters, and this number might still increase, albeit slightly, in the remaining course of our project. This finding corresponds with our original notion that conceived the very framework of this ongoing project, that the Western part of the Pearl River Delta harbours a substantial number of Chinese white dolphins, perhaps more than the numbers known for Eastern PRE waters, and that this part of the deltaic region is of critical importance to the population persistence.

Analyses employing the Cormack-Jolly-Seber (CJS) mark-recapture models suggest that the recapture probabilities of individuals (i.e. the probability of re-sighting of individuals across years) were considerably high, ranging between 0.55 and 0.76. The high recapture rates indicate that the currently applied field and lab protocols are tested well for the quality control of collected data, and the constructed dataset is gradually gaining robustness to deliver unbiased population numbers. However, the CJS population models also estimated that the apparent survival rates of the dolphins in the Western PRE, albeit still preliminary, is likely below 0.955, which is the threshold of long-term biological persistence of CWD in the PRE (Karczmarski *et al.* 2017). This alarming figure indicates that although the coastal waters in Western PRE are vast and seemingly still productive (one of the major fishing grounds in the region), the dolphins are likely under considerable environmental stress, probably of different type and magnitude as compared to that in Eastern PRE, but nevertheless the population trajectory may be on a downward slope. These findings, which effectively quantify population parameters, once refined, will have profound implications not only on our understanding of the well-being of the CWD in the region, but also on our directions for conservation management. Manuscript is currently under preparation and is expected to be submitted for scientific publication in the next Phase of this multi-year project.

To investigate the socio-spatial dynamics of CWDs in the Western PRE, social cluster analyses were performed to model the social connectivity and structure of individuals. Agglomerative cluster analyses using the average-linkage method assume hierarchical structure among individuals and compute the optimal number of clusters through progressively merging potential clusters. Using the currently processed (still not complete) photo-ID dataset, five hierarchical social clusters were apparent under the agglomerative approach. Although the individual associations were generally fluid and dynamic, all identified clusters had higher association indices than the average of the overall dataset, suggesting the associations among individuals in the same cluster are stronger and more frequent than those with individuals from other clusters. Tiered dendrogram displaying the clusters was modelled with modularity (Q) higher than 0.3 and cophenetic correlation coefficient (CCC) close to 0.8 (Fig. 9), indicating that the division of clusters was a good representation of the social matrix among the dolphins.

The spatial distribution of the dolphin social structure in Western PRE is displayed in Fig. 10, where individual sightings of dolphins that formed the same clusters are depicted by the same colour. Based on the hierarchical clustering results, the individuals attributed to different clusters exhibited different but not completely dissimilar distribution pattern, and with considerable overlapping in their ranges. While this is indicative of a discernible social structure among the dolphins, the hierarchy of association shown in the dendrogram (Fig. 9) may correspond primarily to spatial segregation of individuals driven by spatial preferences and individual fidelity to foraging areas (as observed in other parts of the region). As such, at the time when the analyses will be refined, with more robust dataset and further scientific scrutiny, non-hierarchical clustering methods will be explored to further examine the social structure and inter-individual connectivity, and therefore current findings and interpretations (presented in this report) should be viewed as preliminary (for the reasons repeatedly highlighted in the earlier paragraphs). Nevertheless, based on the current information, the social structure among the Chinese White Wolphins in the Western PRE appears heterogeneous with multiple clusters and notable spatial separation between them, but not sufficiently discrete to be considered as separate communities.

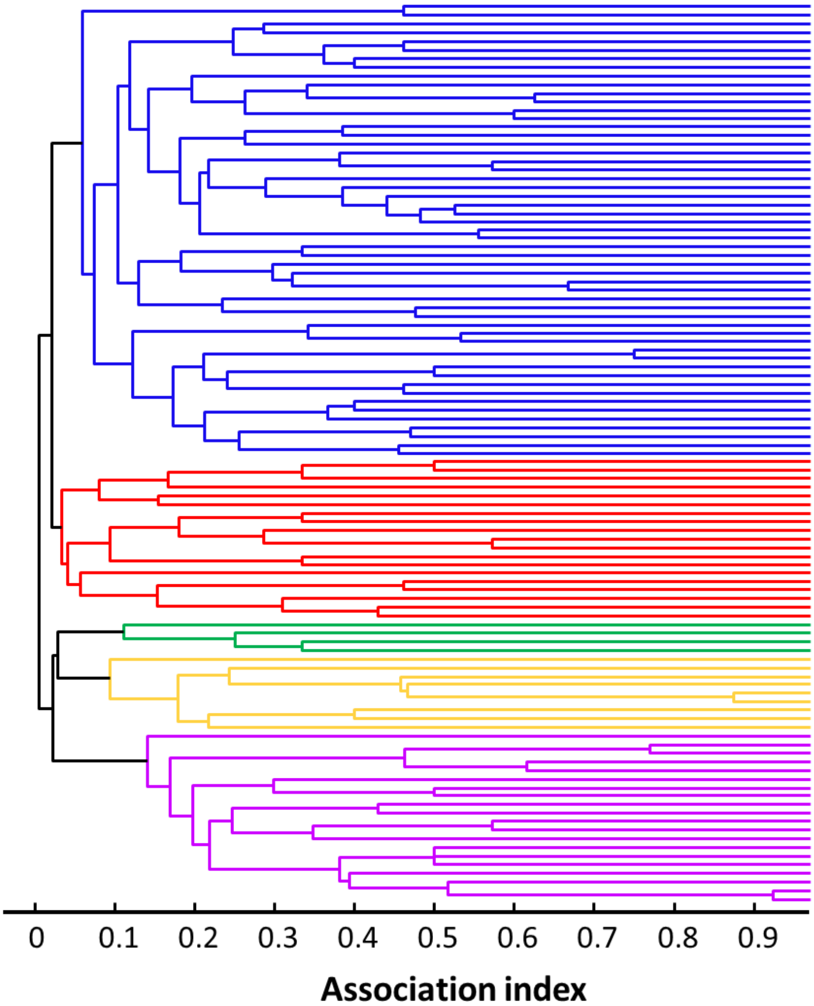


Figure 9. Agglomerative dendrogram showing five hierarchical clusters of Chinese white dolphins seen ≥ 6 times in waters of the Western Pearl River Estuary. The modularity is higher than 0.3 and cophenetic correlation coefficient (CCC) is close to 0.8, indicating that the clustering, even though preliminary, is a reasonably good representation of the dolphin social structure. However, the hierarchy of association may correspond more to spatial segregation of individuals, presumably driven by spatial preferences and individual fidelity to foraging areas (as observed in other parts of the region) then social affiliation. As such, at the time when our analyses will be refined, with more robust dataset and further scientific scrutiny, non-hierarchical clustering methods will be explored to further examine the social structure and inter-individual connectivity. Consequently, the current findings and interpretations (presented here for reporting purposes only) should be viewed as preliminary.

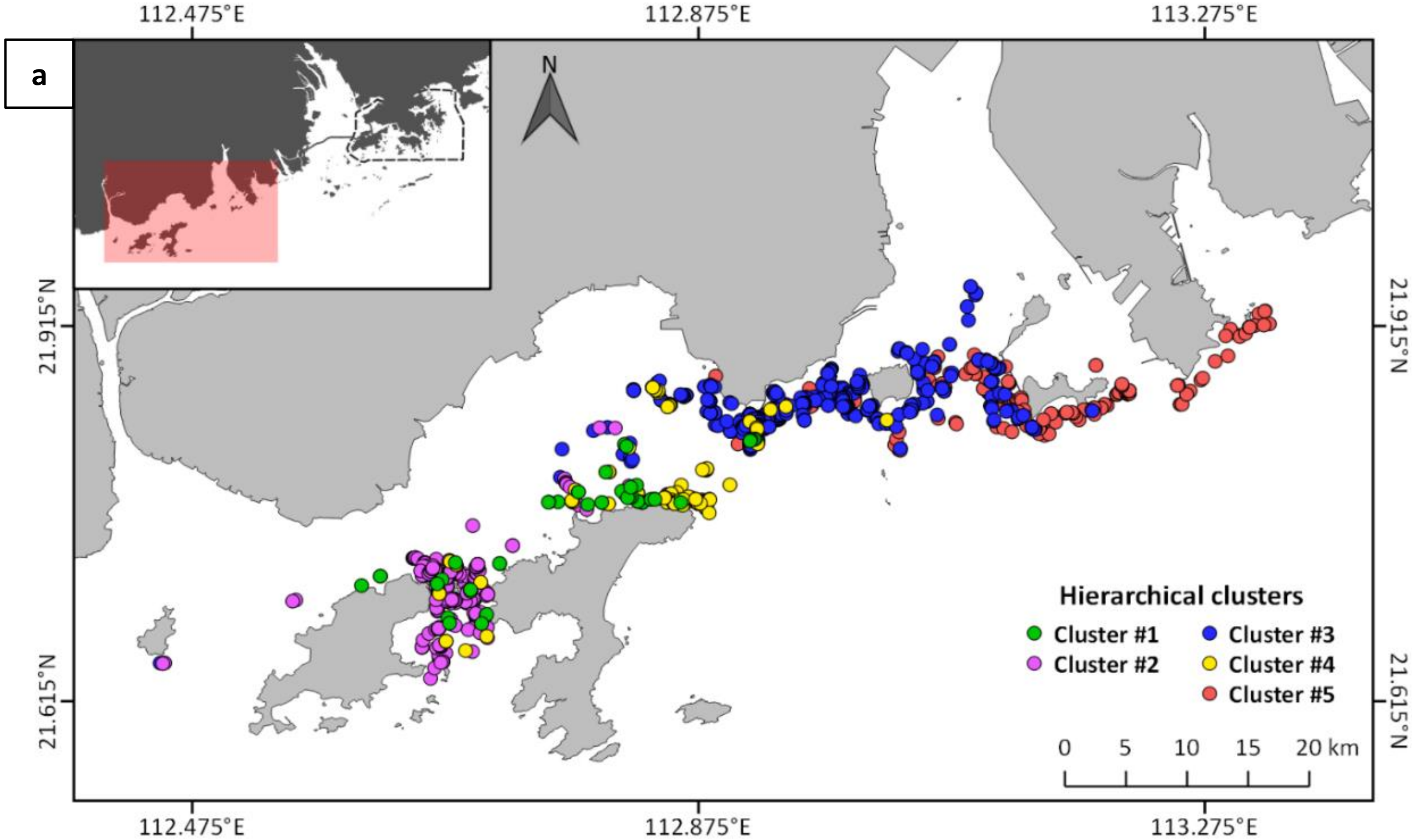


Figure 10. Spatial distribution of individuals attributed to the hierarchical clusters of Chinese White Dolphins seen in Western Pearl River Estuary. The chart above, map (a), displays all currently identified clusters on one chart while charts (b) through (f) (see below) present individually each cluster for better illustration of data points that in chart (a) might be overlapped. The several clusters exhibited different but not completely dissimilar distribution pattern, with a considerable overlap of their ranges.

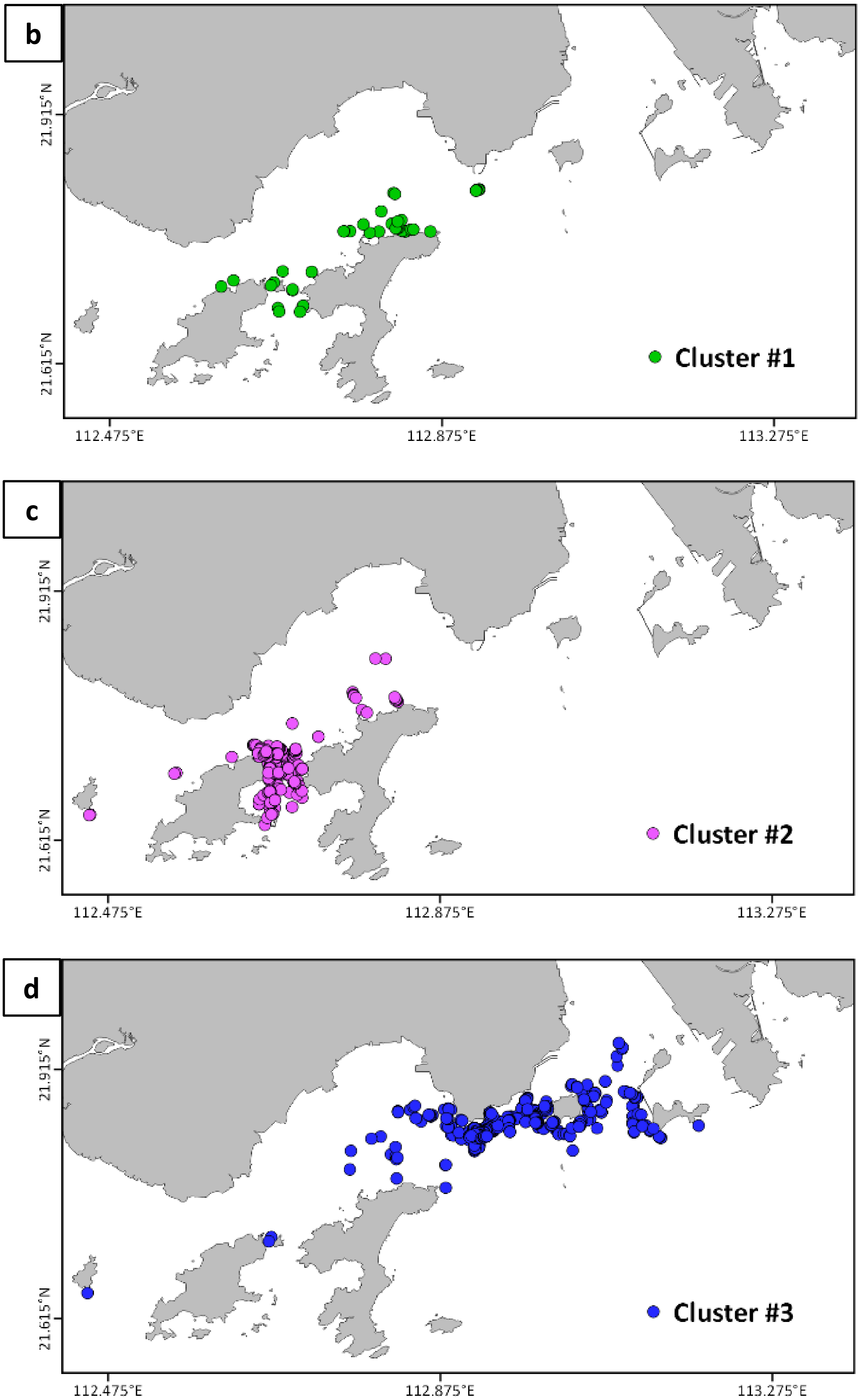


Figure 10 *(cont.)*. Spatial distribution of individuals attributed to five hierarchical clusters of Chinese White Dolphins seen in Western Pearl River Estuary. The charts (b) through (f) display individually each cluster for better illustration of points that might be overlapped in chart (a) as the five clusters exhibited different but not completely discrete distribution pattern, with considerable overlap of their ranges.

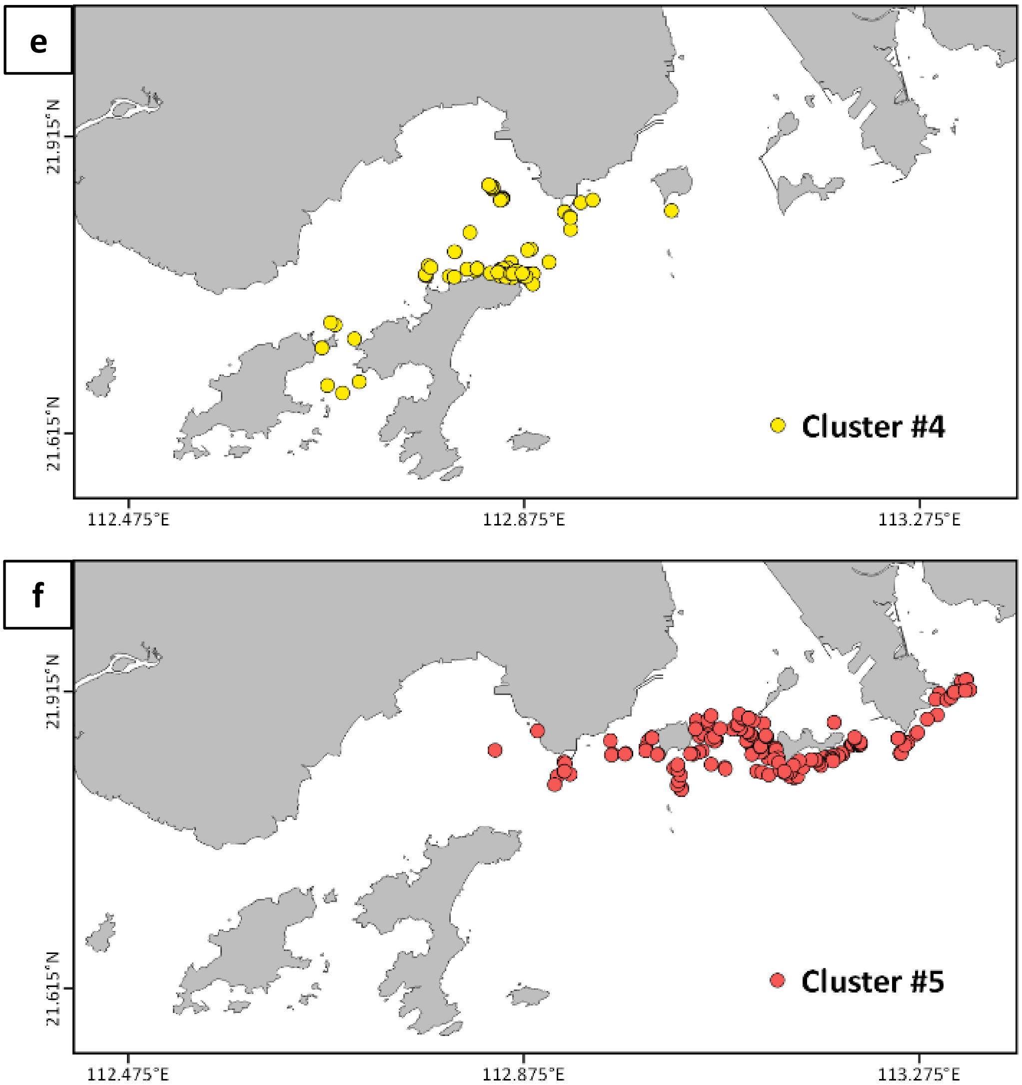


Figure 10 *(cont.)*. Spatial distribution of individuals attributed to five hierarchical clusters of Chinese White Dolphins seen in Western Pearl River Estuary. The charts (b) through (f) display individually each cluster for better illustration of points that might be overlapped in chart (a) as the five clusters exhibited different but not completely discrete distribution pattern, with considerable overlap of their ranges.

Further to the work expected to be completed in this Phase of the MEEF-supported project, and benefiting from the high-quality images collected in our photo-ID surveys, we assessed the health conditions of free-ranging CWDs. Cutaneous lesions and abnormal skin conditions on the dolphin body, which can be observed in the field without physical contact with the animal, are often the first indicators of compromised immune system that are often related to habitat degradation, pollution and eutrophication from anthropogenic sources. In Hong Kong, ~50% of the dolphins suffer from at least one type of epidermal lesions, and one in every ten dolphins has physical injuries indicative of vessel collisions, propeller cuts and fishing-gear entanglements. As top predators with long lifespan, dolphins are good ''barometers'' of marine environment and their compromised health conditions are symptomatic of increasingly degraded ecological conditions of coastal seas, especially in rapidly developing regions of fast-growing economies. This work, indicated in our previous progress report, was further advanced in recent months and has now been published in the peer-reviewed scientific journal *EcoHealth*. See Appendix II for the full text of the published article.

Evaluation of the project effectiveness

All intended activities of the Project have progressed effectively, timely, and in the pace as intended. The chances of surveys were optimized to collect field data under safe and workable weather 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 winter weather; but gradually increased as summer approached, which represents the peak field season. During the project period reported here, the seasonal difference in survey intensity was less apparent than usual as the sea conditions during the peak field season were notably less favourable than usual. Nevertheless, all our data collected during this phase of the project contributed very substantially to a comprehensive photo-ID mark-recapture database of CWD across the PRD region, which is of major importance if any intended population analyses are to produce scientifically sound results.

As stated in the original proposals, comprehensive analyses on the population connectivity and socio-demographic structure of CWD across the greater PRD region will require further research effort for at least two more years (for the obvious reasons that the database is not yet sufficiently robust across the greater region). Nevertheless, 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. The processing and synthesising the increasingly larger dataset have been progressing well and on schedule, which facilitates effective monitoring of the project progress.

Based on the combined dataset, including the previous and the currently ongoing MEEF-funded work, we have performed various initial analyses and delivered indicative (albeit preliminary) results, as detailed in earlier pages of this report. This include movement patterns, spatial pattern of habitat use, socio-spatial dynamics and structure, population parameters, and population health conditions. The latter has furnished a peer-reviewed publication in an international scientific journal, while the others are currently being fine-tuned with further and more rigorous scientific scrutiny. We have no doubts that all findings reported here (and in the upcoming future reports) will be published in respected peer-reviewed scientific journals.

Summary and way forward

In overall, all major tasks for this phase of the multi-year project, from field data collection to data processing and synthesis, to initial analyses and preliminary assessment, and to delineating the research activities for the next phase of this ongoing project have proceeded timely and along the project framework as envisioned in our initial proposal. Photo-ID data collected across the PRD region contributed to the long-term mark-recapture database, which will be the backbone for all ongoing and subsequent investigations. Multi-faceted analyses delivered preliminary assessment of individual movement patterns across the PRD, mapped the habitat use pattern and computed the temporal social dynamics of the CWDs in the eastern part of the PRD region, and quantified the population parameters and socio-demographic structure at the westernmost reaches of the PRD. These findings, although not yet at the final stages, are all first of its kind even after decades of former research effort in the region, underlining the critical urgency and need of such information for effective CWD conservation strategy. Current findings and results affirmed the framework and direction of this multi-year project, which if continued, will deliver results of high scientific value and major management implications, benefiting the conservation efforts of CWD across the entire PRE region. As our current progress has met, and in some ways exceeded our expectations and affirmed the overall direction of this multi-year undertaking, the only way forward is to continue this work in the coming years, as intended and described in our original proposal.

Impact statement (of the multi-year project)

Once our dataset is sufficiently robust, which is projected to happen over the next upcoming phase of this project, our results will carry important implications in advising local authorities on management recommendations based on empirical scientific evidence. The currently projected results will determine and quantify population connectivity, socio-demographic and geographic structure, patterns of range use and habitat utilization, and vital population parameters that determine population viability, and these are just the most obvious among the anticipated outcome of this project, all of which form important building blocks in revealing what constitutes the Chinese white dolphin population in the Pearl River Delta region and what determines its long-term viability and – importantly – what needs to be done to ensure the long-term persistence of this iconic species in the diverse, dynamic and frequently challenging ecological conditions of the PRD. This information, expected to be delivered in the upcoming Phase of the project (the next two years), will not only have major implications for conservation efforts in Hong Kong and the PRD, but also provide a demonstrable conservation framework for other regions in China (and more broadly Southeast Asia) where this species occur but where local knowledge of their conservation ecology is meagre.

The work undertaken in this project has been long-overdue for the region; the data is much needed as the environmental challenges to the Chinese White Dolphins are mounting, with the population in rapid decline (Huang et al. 2012, Karczmarski et al. 2016, 2017) and current management practices apparently insufficient to attain their stated objectives. There is no surprise therefore that there are numerous environmental groups that try to step in and make a positive difference. There have been numerous workshops held in Hong Kong in the past ~3 years that brought in various well-intended stakeholders concerned with the conservation of the local marine environment in general and Chinese White Dolphins in particular. However, in the absence of hard evidence based on robust datasets, even the best of intentions can lead to misrepresentation, sometimes misunderstanding of the limited biological indicators, and subsequently misguided management recommendations. This has to be recognised as, in the absence of good bases for making management recommendations, such actions can (and often do) cause far more harm than good. In the case of species that are long-lived, slow reproducing, highly mobile, socially complex and demographically susceptible to unregulated removal, such as dolphins, the evidence needed for making informed conservation decisions comes only from multi-year studies with large sample sizes painstakingly scrutinised to unravel the underlying pattern of natural dynamics. Only then a scientifically sound conservation management strategy can be evoked, and only then there is a chance that such management strategies can withstand the test of time and be proven effective. This is why this long-term (and long-overdue) project that is currently only about half-way-through the data-gathering process, carries an immense conservation-applicable importance that simply is impossible to overstate.

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Appendix I

Updates on a severely injured Chinese white dolphin

During the project period reported here, an adult dolphin was seen in Hong Kong with severe injuries by multiple propeller cuts at the dorsal ridge and peduncle. Another case of similar major physical trauma, which happened 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 painful death ~3 weeks since the injury. In both cases, the injured dolphins were among the most frequently sighted individuals that had numerous entries in our photo-ID catalogue. This time however, the fate of the dolphin, identified as breeding female, has a much better ending which can be attributed to much more rational decision by local management authorities and appropriate action taken.

By late August 2018, a female dolphin suffered from severe incisive trauma with deep wounds (multiple propeller cuts) that were evidently deteriorating (Fig. A1). Our research team assessed the health condition of the dolphin, which was critical and clearly required immediate medical intervention. This time, following our initial assessment and with an independent monitoring by our research team, an operation team deployed by Hong Kong's Agriculture, Fisheries and Conservation Department (AFCD) and Ocean Park's veterinary department took a swift action and deployed antibiotics (through remotely administered dart injection; Fig. A2) to strengthen the immune system of the injured dolphin.

In late November, our research team re-sighted this dolphin with its wounds considerably healed and in overall a much better condition (Fig. A3). The dolphin was found in a group with 15 other individuals and was actively foraging with frequent leaps above the water surface. Our observation indicated that, despite its major injuries only three months earlier, the dolphin has apparently restored its normal behaviour, including socializing with other individuals and active foraging; and seemingly managed to fulfil its daily nutritional needs as its body conditions did not indicate malnutrition.

More recently, in mid June 2019, ten months after being found injured, the dolphin was again re-sighted and with several close-up tele-photo images taken, it was possible to confirm that its wounds were well-healed with no sign of deterioration or infection (Fig. A3). The dolphin was seen (and photographed) performing high leaps completely out of the water during foraging – an encouraging sign that this animal, although now permanently marked, appears to have recovered its mobility and vitality for survival.

In contrast to the case from 2015 mentioned earlier (male nicknamed "Hope"), when it took the authorities three weeks before any rescue action was taken, this time the swift action of the AFCD and Ocean Park Hong Kong represents a case of successful intervention to treat and remedy severe anthropogenic injury of a coastal dolphin, and to effectively rescue a biologically highly valuable member (a breeding female in her prime age) of this threatened and declining population. This action should be applauded and serve as example of appropriate and effective handling of such cases, would similar circumstances arise ever again.

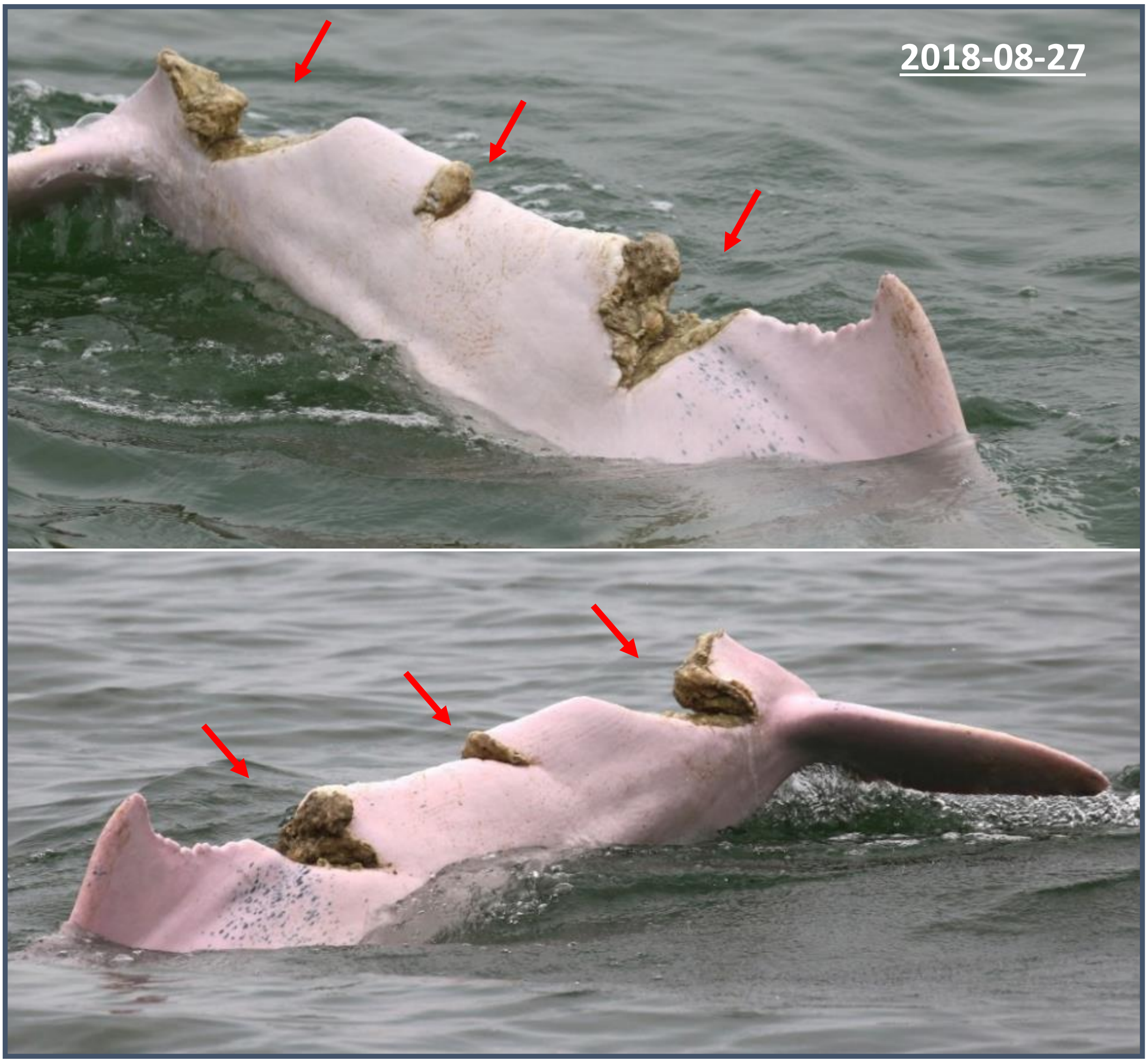

Figure A1. An adult female Chinese white dolphin found severely injured I Aug 2018, with multiple propeller cuts at the dorsal ridge and peduncle (red arrows).

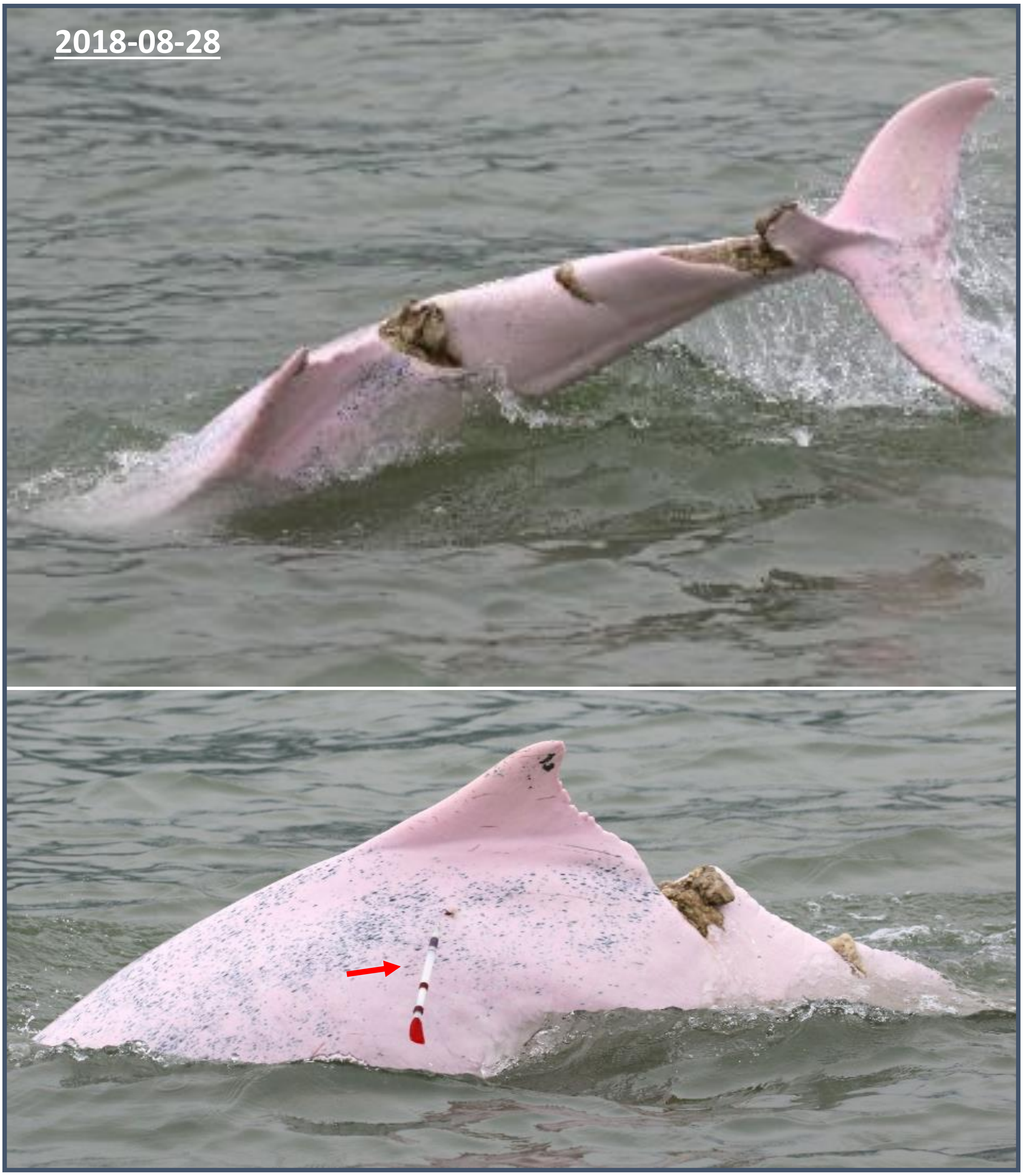

Figure A2. Remotely administered dart injection of antibiotics was delivered to strengthen the injured dolphin's immune system. The operation team was deployed by Hong Kong's Agriculture, Fisheries and Conservation Department (AFCD) and Ocean Park Hong Kong, consisting of the staff from AFCD and experienced wildlife veterinarian from Ocean Park's veterinary department.

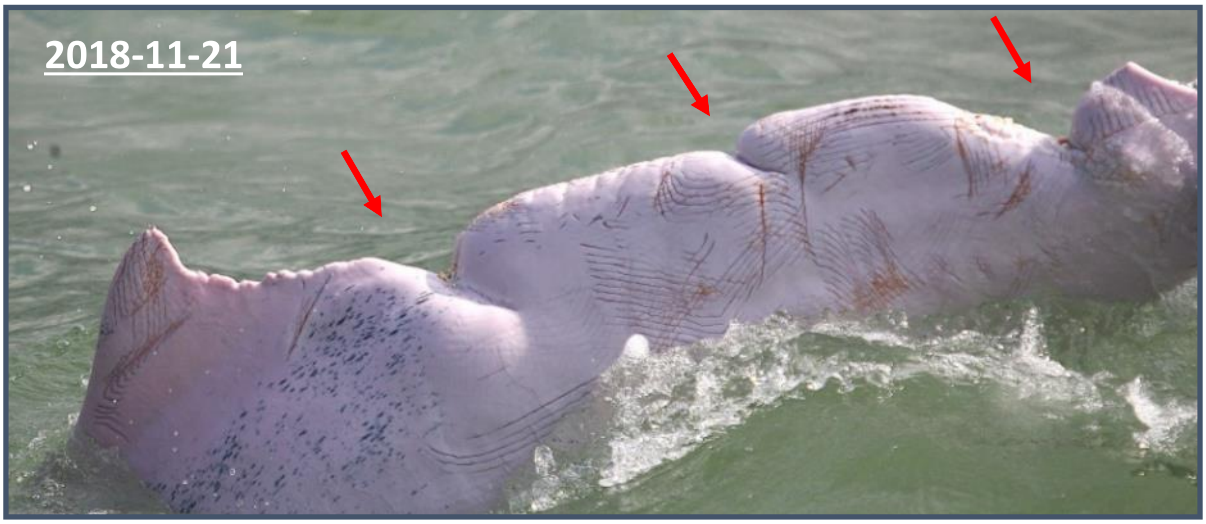

Figure A3. The dolphin was re-sighted three months after it was found severely injured, with its wounds considerably healed and in overall a much better condition.

Figure A4. The dolphin performed high leaps completely out of the water, showing its recovered mobility. Its wounds remained healed with no signs of infection.

Appendix II

Chan, S.C.Y. and Karczmarski, L. (2019). Epidermal lesions and injuries of coastal dolphins as indicators of ecological health. *EcoHealth* 16: 576-582.
https://doi.org/10.1007/s10393-019-01428-0

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ECOHEALTH

Short Communication

Epidermal Lesions and Injuries of Coastal Dolphins as Indicators of Ecological Health

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Abstract: Humpback dolphins (genus *Sousa*), obligatory inshore delphinids, are frequently exposed to adverse effects of many human activities. In Hong Kong, one of the world's most urbanised coastal regions, ~ 50% of the dolphins suffer from at least one type of epidermal lesions, likely related to anthropogenically degraded habitat. Furthermore, one in every ten dolphins has physical injuries indicative of vessel collisions, propeller cuts and fishing-gear entanglements. As top predators with long lifespan, dolphins are good "barometers" of marine environment and their compromised health conditions are symptomatic of increasingly degraded ecological conditions of coastal seas, especially in rapidly developing regions of fast-growing economies.

Keywords: Skin lesions, Physical injuries, Indo-Pacific humpback dolphin *Sousa chinensis*, Ecological health indicators, Anthropogenic pressure, Hong Kong–Pearl River Estuary

As top marine predators with long lifespan, odontocetes are increasingly recognised as sentinels of marine environment's ecological health (Wells et al. 2004; Van Bressem et al. 2009b; Bossart 2011). This is especially so for small coastal cetaceans, as they inhabit areas where much of the effects of human activities concentrate. Among the obligatory coastal species, humpback dolphins (genus *Sousa*) are particularly restricted to inshore shallow waters (e.g. Jefferson 2000; Karczmarski et al. 2000), which exposes them to direct effects of various human activities. In Hong Kong, at the eastern flank of the Pearl River Estuary (PRE), one of the world's most populated and urbanised estuarine system, Indo-Pacific humpback dolphins (*S. chinensis*) are heavily impacted by ongoing anthropogenic habitat degradation due to massive construction projects, pollution, overfishing and intense maritime traffic which have cumulatively raised concerns regarding their health and long-term survival (Karczmarski et al. 2016, 2017). Cutaneous lesions and traumas are often the first indicators of compromised health conditions that can be seen on free-ranging dolphins (Wilson et al. 1997; Van Bressem et al. 2009a, b; Maldini et al. 2010). In this study, with the aid of photo-identification (photo-ID) technique, skin lesions and traumatic deformities were visually assessed and quantified for Indo-Pacific humpback dolphins in Hong Kong waters, which are thought to be among the most anthropogenically impacted dolphins known to science to date (Wilson et al. 2008; Karczmarski et al. 2016).

Boat-based surveys were conducted in Hong Kong waters during 2010–2015, with close-up photographs of the dorsal aspect of dolphins (including dorsal ridge and fin) taken with professional photographic gear. Individual dolphins were subsequently identified and catalogued based

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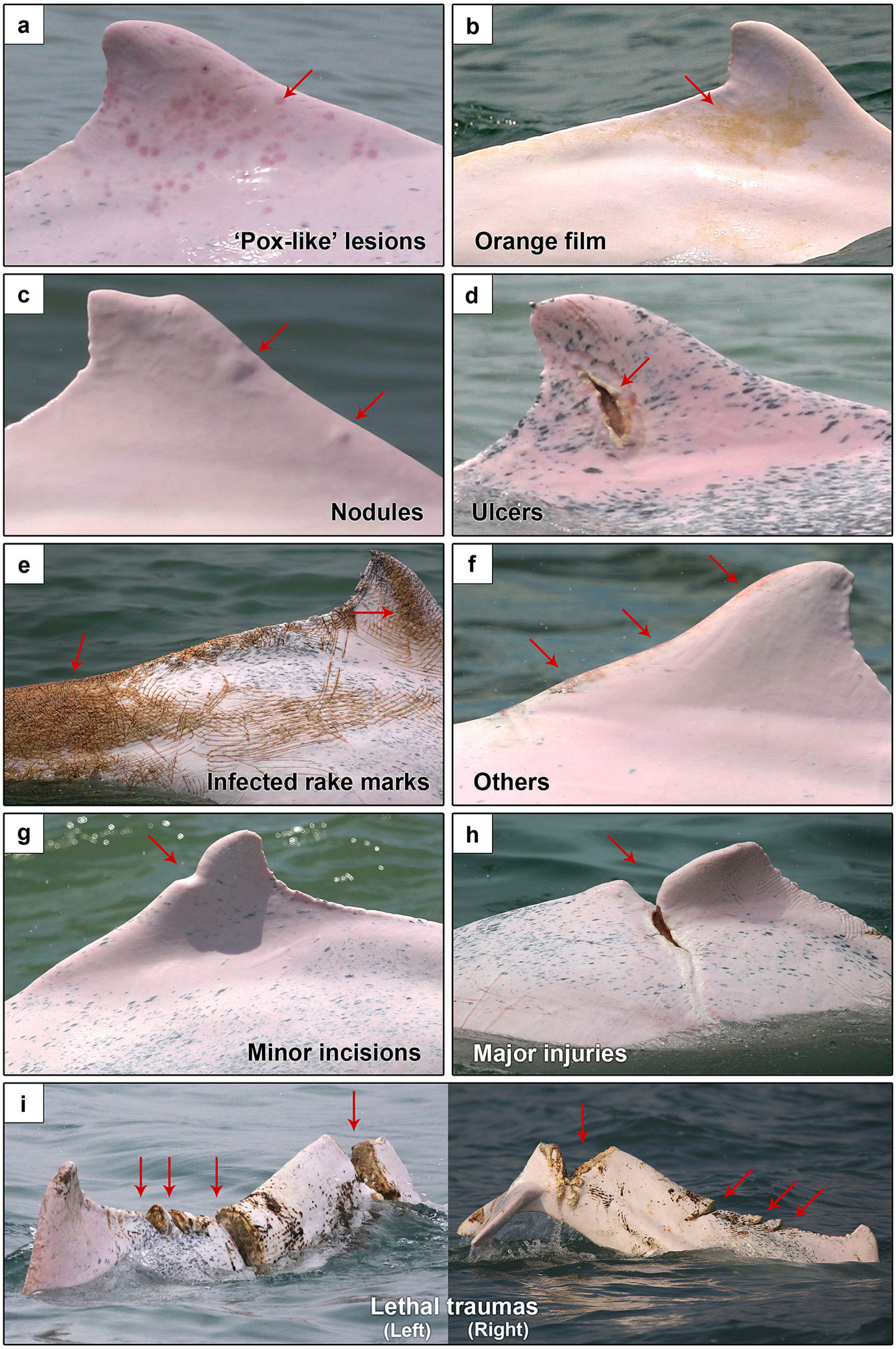

Figure 1. Examples of skin lesions and traumatic deformities seen in Indo-Pacific humpback dolphins in Hong Kong waters during May 2010–December 2015: **a** "pox-like" lesion, **b** orange film, **c** nodules, **d** ulcer, **e** infected rake marks, **f** other lesions, **g** minor incision, **h** major injury, and **i** lethal trauma

on individually distinctive marks and pigmentation (for details see Chan and Karczmarski 2017). Only top-quality images were used in all analyses presented here.

Skin lesions were grouped into six categories (Fig. 1a–f); (I) "*Pox-like" lesions:* ring and tattoo lesions, either ring shaped or clustered as polygons, with slightly darker fringes and dusky centres; morphologically similar to pox disease (Geraci et al. 1979; Van Bressem et al. 1999), although the aetiology of lesions in our study remains unknown. (II) *Orange film:* orange-to-brownish films covering the skin either continuously over large area or in smaller patches (Wilson et al. 1997; Maldini et al. 2010). (III) *Nodules:* circular cutaneous elevations of the skin, occasionally ulcerated (Van Bressem et al. 2014), or dense grape-like nodules associated with rake marks (Van Bressem et al. 2013). (IV) *Ulcers:* disruptions of superficial epithelium exposing deep dermal tissue with seemingly poor healing. (V) *Infected rake marks:* amber-to-brownish tissue spreading over the areas of skin with extensive rake marks. (VI) *Others:* various infrequent lesions not covered by the categories listed above.

The extent of skin lesion coverage was estimated as low, medium, or high ($< 20\%$, 20–50%, and $> 50\%$ of visible epidermis, respectively; after Bearzi et al. 2009). Traumatic deformities, likely anthropogenic, were classified as minor, major, and potentially lethal (Fig. 1g–i). Prevalence of skin lesions and traumatic deformities was estimated as the percentage of affected individuals in the total number of known (individually photo-identified and catalogued) dolphins.

Among the 435 humpback dolphins photo-identified during the study period, over half (n = 220; 50.6%) exhibited at least one type of skin lesion (Table 1). Nearly 60% of the affected dolphins suffered from multiple, up to four, types of skin lesions (Table 2). "Pox-like" lesions, nodules, and orange film were the most common, with comparable prevalence, affecting ~ 1/3 of the identified dolphins (Table 1). Although the extent of lesion coverage on visible epidermis was mostly low, considerable number of affected individuals had high coverage of "pox-like" lesions (16.6%) and orange film (17.3%) (Table 3). There was no indication of lobomycosis-like diseases (LLD). Prevalence of anthropogenic traumatic deformities was alarmingly high (n = 45), averaging one in every ten dolphins having injuries seemingly caused by vessel collisions, propeller cuts or fishing-gear entanglements (Table 1). In one case (Fig. 1i), multiple propeller cuts penetrated deep into the dolphin's body, causing subsequent infection and various progressively developing lesions, and death 24 days later.

The skin lesions and physical injuries documented in this study represent the minimum percentage of affected individuals, as, for consistency, only photographs of dolphins' dorsal body exposed above the water were used (but see Fig. 2). Nevertheless, the prevalence of skin lesions is considerably higher than 37% reported for critically

Table 1. Prevalence of Skin Lesions and Traumatic Deformities Seen in Indo-Pacific Humpback Dolphins in Hong Kong Waters During May 2010–December 2015.

	Number (and percentage) of affected individuals per age class			
	Adult [n = 333]	Juvenile [n = 79]	Calf [n = 23]	Total [n = 435]
Skin lesions				
"Pox-like" lesions	136 (40.8%)	15 (19.0%)	0 (0.0%)	151 (34.7%)
Orange film	110 (33.0%)	0 (0.0%)	0 (0.0%)	110 (25.3%)
Nodules	127 (38.1%)	7 (8.9%)	0 (0.0%)	134 (30.8%)
Ulcers	8 (2.4%)	0 (0.0%)	0 (0.0%)	8 (1.8%)
Infected rake marks	9 (2.7%)	0 (0.0%)	0 (0.0%)	9 (2.1%)
Others	8 (2.4%)	1 (1.3%)	0 (0.0%)	9 (2.1%)
At least one type	202 (60.7%)	18 (22.8%)	0 (0.0%)	220 (50.6%)
Traumatic deformities				
Minor incisions	29 (8.7%)	1 (1.3%)	1 (4.3%)	31 (7.1%)
Major injuries	12 (3.6%)	1 (1.3%)	0 (0.0%)	13 (3.0%)
Lethal traumas	1 (0.3%)	0 (0.0%)	0 (0.0%)	1 (0.2%)
At least one type	42 (12.6%)	2 (2.5%)	1 (4.3%)	45 (10.3%)

Table 2. Proportions of Single and Multiple Types of Skin Lesions Seen on Indo-Pacific Humpback Dolphins in Hong Kong Waters During May 2010–December 2015.

Number of types of skin lesions seen on the same individual	Number of affected individuals	Proportion to the total number of affected individuals (%)
1 type	89	40.5
2 types	70	31.8
3 types	52	23.6
4 types	9	4.1

Table 3. Extent of Coverage of the Six Types of Skin Lesions Seen on Indo-Pacific Humpback Dolphins in Hong Kong Waters During May 2010–December 2015 and the Corresponding Number (and Percentage) of Affected Individuals.

Lesion types	Extent of skin lesion		
	Low	Medium	High
"Pox-like" lesions [n = 151]	95 (62.9%)	31 (20.5%)	25 (16.6%)
Orange film [n = 110]	65 (59.1%)	26 (23.6%)	19 (17.3%)
Nodules [n = 134]	134 (100.0%)	0 (0.0%)	0 (0.0%)
Ulcers [n = 8]	7 (87.5%)	1 (12.5%)	0 (0.0%)
Infected rake marks [n = 9]	4 (44.4%)	5 (55.6%)	0 (0.0%)
Others [n = 9]	9 (100.0%)	0 (0.0%)	0 (0.0%)

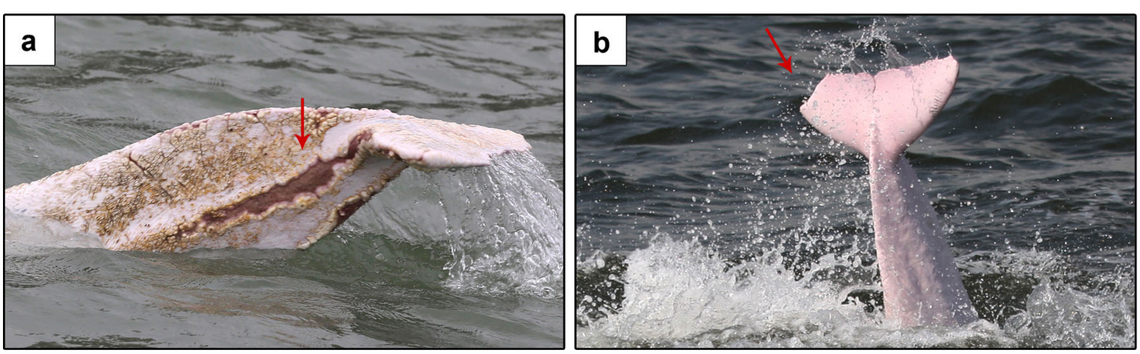

Figure 2. Example of skin lesions and injuries (**a**: large ulcer on peduncle; **b**: cut fluke) that were not included in the analyses reported here as they may go unnoticed for many individuals. As much of dolphin's body remains underwater, only the upper body (dorsal aspect) can be systematically sampled with standard photo-ID techniques. Therefore, the prevalence of skin lesions and traumatic deformities reported here should be seen as minimum estimates

endangered Taiwanese humpback dolphins (*S. chinensis taiwanensis*, Yang et al. 2013), although the opposite is true for anthropogenic injuries (Wang et al. 2017). Furthermore, the estimate of lesions was likely biased downwards by the natural colouration of Indo-Pacific humpback dolphins which changes from dark-grey in calves to pink in mature animals, with mottled/speckled pigmentation of juveniles and young adults masking less conspicuous skin conditions which may have gone unnoticed even on images of the highest quality. Therefore, the percentage of skin lesions presented here (and possibly also that of Yang et al. 2013) is likely an underestimate; which partly explains why it is lower than that reported for some bottlenose dolphin (*Tursiops truncatus*) populations elsewhere (Wilson et al. 1997; Maldini et al. 2010).

Although the epidermal lesions may be non-lethal, the overall large percentage of affected individuals indicates compromised health conditions of the dolphins in Hong Kong waters, likely related to the compromised quality of their habitat (Van Bressem et al. 2009a, b; Mouton and Botha 2012). Although aetiology of the lesions cannot be confirmed at present, studies of other species elsewhere have suggested that causative agents may be bacterial, viral, fungal, diatom-related and parasitic (Wilson et al. 1997; Mouton and Botha 2012). Furthermore, in coastal areas neighbouring large urban centres, such as Hong Kong, besides naturally occurring pathogens, anthropogenic causes like sewage effluent and eutrophication of coastal waters may introduce new pathogenic agents (Wilson et al. 1997; Parsons and Jefferson 2000; Van Bressem et al. 2009b).

Toxicological sensitivity is subject to prevailing local/regional environmental conditions (Tornero et al. 2014) and for long-lived animals such as cetaceans, long-term exposure to environmental pollution has to be recognised as health risk and likely subject to long-term cumulative effects. Similar associations between environmental pollutions and human health are seen throughout the world (e.g. Briggs 2003; Solomon et al. 2016). Although for free-ranging wildlife populations quantitative data are rare, due to often uncertain or unknown levels of exposure and lack of detailed monitoring, the pattern is increasingly evident and the problem increasingly more global (Tornero et al. 2014).

There is mounting evidence linking chemical pollutions to the emergence of several marine mammal diseases, rising their pervasiveness and severity by lowering the population immune response (reviewed by Van Bressem et al. 2009b). Inshore/estuarine species are among the most contaminated, with humpback dolphins reported to have PCB concentrations above the threshold of immune impairment and DDTs concentration and biomagnification among the highest known for delphinids globally (Gui et al. 2014, 2016). The hepatic levels of several heavy metals in PRE humpback dolphins are among the highest reported for cetaceans worldwide, sufficiently high to cause toxicological effects (Gui et al. 2017). This heavy pollutant load, along with long-term environmental degradation and ongoing destruction of dolphin core habitats (Karczmarski et al. 2016; Wong 2017) are likely factors affecting their immune response and increasing chance of infection (as suggested for other coastal dolphins elsewhere, Harzen and Brunnick 1997; Bearzi et al. 2009; Van Bressem et al. 2009a, b), while cutaneous traumas with open wounds likely further exacerbate pathogenesis (Van Bressem et al. 2009a). Moreover, heavy boat traffic and intense fishery activities pose risks of direct injuries (Jefferson 2000; Karczmarski et al. 2016), which can lead to subsequent infections and further aggravate the already compromised health conditions.

The prevalence of traumatic deformities caused by vessels and fishing-gear is high among humpback dolphins in Hong Kong. This is hardly surprising, given the intensity of sea traffic in Hong Kong; other wildlife face similar risk in anthropogenic landscapes, e.g. collision with vehicles when crossing roads (e.g. Bryson-Morrison et al. 2017). In Hong Kong, although the percentage of anthropogenic injuries was not as high as reported for humpback dolphins off Taiwan ($\sim$ 57%, Wang et al. 2017), it was considerably higher than what is known for other coastal dolphins (seldom $>$ 3%, Wells 1993; Van Waerebeek et al. 2007; Bearzi et al. 2009; Bechdel et al. 2009) and notably higher than the 5% reported for Hong Kong dolphins two decades earlier (Jefferson 2000). This apparently increasing trend and the severity of man-caused injuries should be of major concern.

Humpback dolphins are not the only organisms affected by anthropogenic stressors and in Hong Kong/PRE the region's broader biodiversity is at stake (Fu et al. 2003; Lee et al. 2006; Lai et al. 2016). However, as top marine predators with long lifespan and prone to accumulating high pollutant levels, inshore delphinids are especially good indicators of long-term environmental change. Humpback dolphins in Hong Kong represent one such explicit example where the application of quantitative photographic survey techniques for non-invasive monitoring of dolphin health can contribute a valuable component in assessing the environmental burden and overall ecological health of coastal seas.

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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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