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Abundance estimates of three cetacean species in the coastal waters of Matang, Perak, Peninsular Malaysia

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Abstract

1. The paucity of baseline data on coastal cetaceans due to a lack of research in developing countries frequently precludes assessment of their status and informed management actions for conservation.
2. This study provides the first abundance estimates of Indo-Pacific humpback dolphins, Irrawaddy dolphins and Indo-Pacific finless porpoises in the coastal waters of Matang, Peninsular Malaysia.
3. Boat-based surveys covering 1,152 km^2 of coastal waters with 4,108 km of survey effort were conducted between 2013 and 2016 to collect data for line transect analysis of Irrawaddy dolphins and finless porpoises. Photo-identification data of humpback dolphins were concurrently collected for mark-recapture analysis.
4. Estimates of abundance from four sampling strata totalled 763 Irrawaddy dolphins (CV = 13%; 95% CI = 588-990) and 600 Indo-Pacific finless porpoises (CV = 27%, 95% CI = 354-1,016).
5. The annual abundance estimates of humpback dolphins ranged between 171 (95% CI = 148-208) in 2014-2015 and 81 (95% CI = 67-98) in 2015-2016, likely due to the presence of offshore individuals that moved in and out of the study area. The estuarine strata were inhabited by 68 (95% CI = 63-73) inshore humpback dolphins in 2013-2014 to 87 (95% CI = 78-97) dolphins in 2014-2015.
6. As an IUCN Important Marine Mammal Area, the productive coastal waters of Matang are shown to support high density of small coastal cetaceans, and the results serve as

an important baseline for future studies to identify population trends for conservation management plans.

KEYWORDS

conservation, Important Marine Mammal Area, Indo-Pacific finless porpoise, Indo-Pacific humpback dolphin, Irrawaddy dolphin, line-transects, mark-recapture

1 | INTRODUCTION

Abundance estimates form an essential component of baseline information for effective species protection and habitat management, especially for coastal species living in close proximity to anthropogenic activities that pose increasing threats to their welfare and survival (Avila, Kaschner & Dormann, 2018; de Vere, Lilley & Frick, 2018). The lack of capacity and resources in developing countries often precludes assessments needed to highlight the most threatened populations and to inform conservation and management actions (Hines et al., 2015a). Studying coastal cetaceans is particularly challenging due to their evasive behaviour, elusiveness in nature and unpredictable surfacing patterns (Minton et al., 2013).

In the coastal waters of Matang, on the west coast of Peninsular Malaysia, at least three species of small coastal cetaceans have been recorded: Indo-Pacific humpback dolphin (*Sousa chinensis* Osbeck, 1765), Irrawaddy dolphin (*Orcaella brevirostris* Owen in Gray, 1866) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides* Cuvier, 1829) (Kuit et al., 2019a). The Irrawaddy dolphin is listed as ‘Endangered’ (Minton et al., 2017), whereas the humpback dolphin and finless porpoise are listed as ‘Vulnerable’ (Jefferson et al., 2017; Wang & Reeves, 2017) on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. In Malaysia, all three species are fully protected by law and are listed as marine endangered species. Kuit et al. (2019a) had investigated the distribution and spatial separation of these three species in Matang’s coastal waters. The Matang estuaries were identified as important feeding and nursery grounds for inshore resident humpback dolphins that mainly use areas within 7 km from the shore. The more open offshore waters are important for socializing and mating of offshore humpback dolphins, Irrawaddy dolphins and finless porpoises. These grounds however overlap with intensive fishing zones thereby increasing the bycatch risk of these coastal cetaceans in fishing gears such as gillnets and trawl nets (Kuit & Ponnampalam, 2021).

Within the Southeast Asian region, the study area sizes cetacean abundance studies were conducted varied greatly; most were smaller than 500 km^2, with associated abundance estimates of tens to fewer than 500 individuals for each species (e.g., Cherdsukjai & Kittiwattanawong, 2013; Minton et al., 2013; Hines et al., 2015a; Kreb et al., 2020). Published scientific studies on cetacean abundance in Malaysia are sparse, and have mostly been conducted in east Malaysia (Minton et al., 2013; Teoh, Jaaman & Palaniappan, 2013; Zulkifli Poh et al., 2016; Mahmud et al., 2018). The geographically closest Irrawaddy dolphin study to Matang is on the west side of Penang Island, approximately 80 km north of Matang, whereby 32 to 43 individuals were estimated in a small study area of 80 km^2 (Rodríguez-Vargas et al., 2019).

Abundances of humpback dolphins, Irrawaddy dolphins and finless porpoises in the Southeast Asian region had been estimated using two standard methodologies: surveys using line transect (distance) sampling and mark-recapture analysis of photo-identification data (Buckland & York, 2009; Hammond, 2010, Hammond 2018). Mark-recapture and line-transect distance sampling methods have advantages and disadvantages. Factors influencing the choice of methods may include the aims of the study, the target species (e.g. its behaviour and the distinctiveness of natural marks), distribution patterns, resources available (time, finances and logistics) and the size of the study area (Parra & Corkeron, 2001; Hammond, 2010; Sutaria & Marsh, 2011). This study on abundance estimation of the three species of coastal cetaceans employed different methods; decisions were based on each species' morphology and behaviour.

The objective of this study is to generate the first abundance estimates for Irrawaddy dolphins, finless porpoises and humpback dolphins in the coastal waters of Matang. This three-year study represents the first assessment of its kind for cetaceans in Matang, Peninsular Malaysia. Baseline abundance estimates for these threatened coastal cetaceans are important for informed spatial species conservation and management planning by the local management authorities, in an area with high overlap of anthropogenic activities.

2 | METHODS

2.1 | Study area

The Matang mangroves in the state of Perak are located along the north-western coast of Peninsular Malaysia (Figure 1). The coastline of Matang is crescent-shaped, fringed by extensive mangroves and mudflats and comprises five major inter-connected estuaries. The study area is approximately 1,152 km^2 and stretches 56 km along the coastline from Kuala (= estuary) Gula in the north to Kuala Jarum Mas in the south, and extends up to 24 km from the coast (Figure 1). The Matang mangroves and the adjacent mudflats are important nursery and feeding grounds for marine fish and invertebrates, supporting one of the most important fishing grounds in Malaysia with commercial important species such as John's snapper (*Lutjanus johnii*), banana prawn (*Fenneropenaeus merguiensis*) and mud crabs (*Scylla* spp.) (Tanaka et al., 2011; Chong et al., 2012). The study area was divided into the estuarine and coastal strata, which were further subdivided into the northern and southern survey blocks (Figure 1). The stratification allowed allocation of higher search effort to the estuarine strata, which generally had higher cetacean density based on sightings during reconnaissance trips. Since 2019, Matang's coastal waters spanning 2,386 km^2, which encompasses the study area, have been designated as the Matang Mangroves and Coastal Waters Important Marine Mammal Area (IMMA) by the IUCN (Figure 1).

2.2 | Field data collection

Eleven 10-day line-transect surveys were conducted bimonthly between November 2013 and July 2016, except for months with unfavourable weather. A 10-day reconnaissance survey in September 2013 contributed additional photo-identification data for mark-recapture. The coastal waters of Matang were surveyed for cetaceans on 8 to 10 m long fibreglass-hulled boats that were powered by either a 100 or 115 HP single outboard engine. The design of the transect lines was randomly generated using DISTANCE 6.0 software (Thomas et al., 2010) for a stratified study with transect lines spaced 1.85 km (1 n.m.) apart in the estuarine strata and 3.70 km (2 n.m.) apart in the coastal strata. The estuarine strata were adjusted to exclude areas that were difficult for vessel navigation, such as shallow depths (<0.5 m), narrow waterways and places with dense cockle-farming poles. The transect lines were designed to run approximately 45° to the coast to accommodate cetacean density gradients alongshore and onshore/offshore (Dawson et al., 2008). Two sets of transect lines of the same design were created, and each set of lines was used alternately between surveys (Figure 1).

Distance sampling was chosen for Irrawaddy dolphins because their evasive behaviour often resulted in low quality photographs thus making individual identification difficult. Similarly, distance sampling was also chosen for finless porpoises, as the species lacks a dorsal fin for photo-identification. On-effort search was conducted along the pre-determined transect lines with the research vessel speed maintained at ≤ 15 km h^{-1}. Two experienced primary observers were seated on an elevated platform at a height of 2.5 m above deck level and scanned the area forward of the bow from 10˚ of the port/starboard side to 90˚ of the starboard/port side respectively. Both observers alternated between using unaided eyes and 7 × 50 marine binoculars with built-in compass. The third experienced observer scanned the area forward of the bow to reduce the chance of missing cetaceans on the transect line. Observers were rotated to either rest or take up other positions such as data recording approximately every hour to avoid observation fatigue. Observations were made during daylight hours in workable weather conditions (i.e. no heavy rain, swell height not more than 1 m, sea state less than 4 on the Beaufort scale). Sea state and swell height were logged at the start of each transect line, and whenever the data recorder observed a change in conditions during search effort on the line.

Prior to actual surveys, observers were trained to estimate distances to static objects first on land, then to relatively static objects on the water. The estimations were then compared against the readings taken from rangefinder. This was repeated until the difference between observer estimated distances and rangefinder estimated distances were not more than 5 meters. During actual surveys, when a sighting cue of cetaceans was detected, the research vessel was stopped and the observer immediately recorded the initial bearing to the sighting and the bearing of the transect line from the binocular compass, and estimated the distance of the sighting from the research vessel by eye. A waypoint was immediately marked using a handheld GPS (Garmin GPSMAP 78s; Garmin, Olathe, KS) before the research vessel went off-effort and digressed from the transect line to approach the cetacean group and confirm the sighting. Standard sighting data such as date, time, GPS location, species, estimated group size (minimum, maximum and best estimate), group behaviour, effort level (on-effort or off-effort), sea state (measured on the Beaufort scale) and swell height (m) were recorded for all cetacean sightings. Once all necessary data had been collected from the on-effort sighting, the research vessel navigated back to the sighting waypoint on the transect line from which it had previously digressed to continue on-effort observations on the line, weather, time and fuel permitting.

For humpback dolphins, mark-recapture methods applied to photo-identification data were chosen because individuals of this species were more easily photographed and identified, and the distribution of estuarine humpback dolphins near to river mouths and inside rivers resulted in mostly off-effort sightings, which cannot be included in line transect sampling using distance analysis. This was in in spite of the fact that transect lines were placed within the estuarine strata. Photo-identification data for humpback dolphins were collected during the 12 surveys from on-effort and off-effort sightings. The sighted groups were approached at a slow speed (<5 km h^{-1}) so as to minimize disturbance to their behaviour as much as possible, and the boat was positioned to allow photographs to be taken perpendicular to the animals. Attempts were made to photograph both the left and right sides of the dorsal fins of each dolphin individual in the group, regardless of their distinctiveness and behaviour. Photographs of dorsal fins were taken using digital SLR cameras with 70-300 mm telephoto zoom lenses.

2.3 | Data processing and analysis for line-transect distance sampling

At the end of each survey day, cetacean sighting locations and survey tracks were downloaded and saved using the Garmin MapSource® 6.16.3 software. For on-effort sightings, the perpendicular distance from the cetacean sighting to the transect line was calculated based on the angle to sighting (i.e. angle difference between line bearing and bearing to sighting) and distance to sighting. Survey effort and all associated sightings at Beaufort > 3 were excluded from the analysis (Jefferson et al., 2002). Line-transect data (i.e. perpendicular distance, best estimate of group size, length of transect line and survey block area) of Irrawaddy dolphins and finless porpoises were imported for analysis using program DISTANCE 7.2 (Thomas et al., 2010).

The four survey blocks were used as the stratum definition. Right truncation of perpendicular distances was explored to investigate whether this improved the fit of the detection function. Whether or not to truncate and by how much was assessed using goodness-of-fit tests, visual inspection of QQ plots and, all other things being equal, the CV of estimated abundance. Combinations of key functions and series expansions that were considered to model the detection function were half-normal key with cosine or hermite polynomial adjustment, and hazard rate key with cosine or simple polynomial adjustment. Beaufort scale, swell height and group size were included in detection function models to investigate whether they improved model fit using Multiple Covariate Distance Sampling (MCDS). The best fitting detection function model was selected based on the lowest Akaike's Information Criterion (AIC) score. The natural logarithm of group size was regressed against perpendicular distance to test for group size estimation bias; group size estimated from the regression was used if the slope was significant at the 0.15 probability level (the default in DISTANCE).

2.4 | Photograph processing and mark-recapture analyses

Photographs of the humpback dolphins were sorted into left or right sides of dorsal fins and the best photograph of each individual dolphin in every sighting was cropped around the dorsal fin and entered into a custom-designed Microsoft Access database. Attempts were not made to match the left side of dorsal fins (LDFs) and right side of dorsal fins (RDFs) of individuals. Instead, photographs of LDFs and RDFs were treated as two separate databases. Photographs of dorsal fins were scored for quality, Q and distinctiveness, D on a scale of 1 to 4 (with 4 indicating highest quality or highest distinctiveness and 1 indicating very low photo quality or non-distinct individual with a very clean dorsal fin of a standard size and shape) (Minton et al., 2013). Criteria for photo quality evaluation were sharpness, exposure, angle of the dorsal fin, proportion of the dorsal fin that was visible, and presence of water splashes or glare. All dorsal fin photographs were examined for identifiable features (i.e. pigmentation patterns, nicks, notches, dorsal fin shape, scars and mutilations) and matched by eye on the computer screen. A marked individual that did not have a match with previously catalogued individuals was considered to be a new individual and was assigned a unique identification code. Individuals were also categorized into whether they were seen in the coastal or estuarine strata.

To minimize bias, the sighting histories used for mark-recapture analysis were filtered to only include dorsal fin photographs with a photo quality score of $Q \geq 2$ and distinctiveness score of $D \geq 3$. The side of the dorsal fin with more recaptures was used for analysis. Sighting histories were generated for all marked individuals seen in the coastal or estuarine strata, and for marked individuals seen only in the estuarine strata. Data were analysed using program MARK version 9.0 (White & Burnham, 1999).

Pollock's closed robust design model (Pollock, 1982) was used to estimate the abundance of marked (distinctive) humpback dolphins ($\hat{N}_m$). Each survey period (ca. 10 days) was treated as a secondary sampling occasion. Four consecutive secondary sampling occasions were pooled to form three non-overlapping primary periods corresponding to one year (i.e. 2013-2014, 2014-2015, 2015-2016), within each of which the population was assumed to be closed. Temporary emigration between primary periods (years) was modelled as the probability that an individual would be unavailable for capture during a primary period, given that it was available (γ") or unavailable (γ') in the previous primary period. Three models considering varying temporary emigration models were considered: (1) Markovian movement, (γ" ≠ γ') where the probability of an individual being present in the study is conditional on whether it was present in the study area in the previous primary period; (2) random movement (γ" = γ') where the probability of an individual being present in the study area is not dependent on whether it was present in the study area in the previous primary period; and (3) no movement, (γ" = γ' = 0) where there is no temporary emigration (Kendall, Nichols & Hines, 1997). Annual apparent survival probability was kept constant. Capture and recapture probabilities were assumed equal and were allowed to be either constant within years or time-varying.

The best fitting model was selected based on the lowest score of the small sample size-corrected Akaike's Information Criterion (AICc). If overdispersion in the data was apparent, indicated by the variation inflation factor, Fletcher's $\hat{c} > 1$, $\hat{c}$ was adjusted within program MARK and the best fitting model was chosen based on the lowest corrected quasi-AIC (QAICc). To account for model uncertainty, weighted model averaging of the candidate models, based on their AICc/QAICc weights, was applied to obtain estimates of model parameters, including the estimate of the number of distinctive dolphins ($\hat{N}_m$).

The average proportion of distinctive humpback dolphin individuals (with distinctiveness score of 3 or 4) in the population was estimated using a binomial generalized linear model (GLM) with logit link function fitted in R (R Core Team, 2020) to the number of distinctive and non-distinctive dolphins in each group encountered. Models were fitted with and without primary period as a potential explanatory covariate, and the model with lowest AIC was chosen. This proportion ($\hat{\theta}$) was used as a correction factor to estimate the total population size $\left(\hat{N}_T\right)$ of humpback dolphins occurring in the study area, as follows:

$$\hat{N}_T = \frac{\hat{N}_M}{\hat{\theta}}$$

The standard error (SE) for the total population size $\hat{N}_T$ was derived using the delta method with the following formula (Peng et al., 2020):

$$SE(\hat{N}_T) = \sqrt{{\hat{N}_T}^2\left(\frac{SE(\hat{N}_M)^2}{{\hat{N}_M}^2} + \frac{\mathrm{var}\,(\hat{\theta})}{\hat{\theta}^2}\right)}$$

Log-normal 95% confidence intervals (CI) around total population size were calculated according to Burnham et al. (1987), with the lower limit of $\hat{N}_T^{lower} = \hat{N}_T/C$ and the upper limit of $\hat{N}_T^{upper} = \hat{N}_T \times C$, where:

$$C = \exp\left[1.96\sqrt{ln\left(1+\left(\frac{SE(\hat{N}_T)}{\hat{N}_T}\right)^2\right)}\right]$$

3 | RESULTS

3.1 | Irrawaddy dolphins and Indo-Pacific finless porpoises

Approximately 96% of search effort was conducted in sea states of 3 or less on the Beaufort scale. Over 110 survey days, a total of 284.9 h was spent on effort, which yielded 161 sightings of Irrawaddy dolphins and 71 sightings of finless porpoises (Table 1). The realized transect lines, geographic distribution and group size of on-effort sightings of both species sighted during the study period are presented in Figure 2. No finless porpoises were sighted in the estuarine strata.

The selected detection function model for Irrawaddy dolphins was a half-normal key with no adjustment terms, with right truncation at 350 m (Figure 3a). Inclusion of Beaufort, swell height or group size as covariates did not improve the model fit. The Kolmogorov-Smirnov goodness-of-fit test probability was 0.166, indicating an adequate model fit. Estimated average probability of detection within the truncation distance was 0.476 and the effective strip half-width was 166.7 m (CV = 7%). The best estimate of the average abundance of Irrawaddy dolphins in the entire study area between 2013 and 2016 was 763 individuals (CV = 13.3%; 95% CI = 588-990) (Table 2). The average density of Irrawaddy dolphins in the study area was 0.66 individuals per km^2. The average group size of Irrawaddy dolphins was 6.4 individuals (CV = 6.4%, 95% CI = 5.6-7.2).

The selected detection function model for finless porpoises was a hazard rate key with no adjustment terms, with right truncation at 200 m (Figure 3b). Inclusion of Beaufort, swell height or group size as covariates did not improve the model fit. The Kolmogorov-Smirnov goodness-of-fit test probability was 0.710, indicating a good fit of the model to the data. Estimated average probability of detection within the truncation distance was 0.262 and the effective strip half-width was 52.5 m (CV = 22%) (Figure 3b). The best estimate for finless porpoises was 600 individuals (CV = 27.1%; 95% CI = 354-1,016) (Table 2). The average density of finless porpoises in the study area was 0.71 individuals per km^2. The average group size of finless porpoises was 2.6 individuals (CV = 10.5%, 95% CI = 2.1-3.2).

3.2 | Humpback dolphins

There were 119 sightings of humpback dolphins across 120 survey days, of which 28 sightings were encountered on-effort and 91 sightings were encountered off-effort (Figure 4). The sighting histories that met the filtering criteria represented 406 LDF captures from 148 individuals (Table 3) and 414 RDF captures from 161 individuals. The LDF dataset was therefore used for the mark-recapture analyses due to higher number of individual recaptures. Of these LDF captures, 319 captures were from 76 individuals seen in the estuarine blocks (hereafter inshore individuals) and 87 captures were from 72 individuals seen in the coastal blocks (hereafter offshore individuals). No individuals were seen in both estuarine and coastal blocks. Based on individuals identified using LDF, 60 (83%) of the distinctive offshore individuals and 22 (29%) of the distinctive inshore individuals were sighted in only one out of the 12 surveys. The cumulative number of photo-identified humpback dolphin individuals increased throughout the study period (Figure 5a). Inshore individuals (Figure 5b) were recaptured more than offshore individuals (Figure 5c), which were mostly new individuals that were not subsequently resighted. There were sightings of inshore humpback dolphins in the estuarine strata in all 12 surveys, but there were no sightings in the coastal strata during the last four surveys (Table 3).

Two mark-capture analyses were conducted: (1) for combined offshore and inshore individuals in the coastal and estuarine strata, and (2) for solely inshore individuals in the estuarine strata. The variance inflation factor, $\hat{c}$ values of 3.025 for combined offshore and inshore humpback dolphins data, and 1.373 for inshore–only data were used to correct the degree of overdispersion prior to model selection (Tables 4, 5). The Markovian model could not be fitted for either dataset. The best-fitting model for combined offshore and inshore humpback dolphins included random temporary emigration with time-varying capture/recapture probabilities (Table 4). The weighted average estimates of the annual number of distinctive offshore and inshore humpback dolphins ($\hat{N}_m$) varied between 118 (in 2014-2015) and 56 (in 2015-2016) (Table 6). The proportion of marked individuals in the population modelled without primary period as a covariate had a lower AIC than using primary period as a covariate, and hence the overall average of theta = 0.689 was used as the correction factor to calculate total population size. The total number of humpback dolphins in the study area after correction varied between 171 (in 2014-2015) and 81 (in 2015-2016) (Table 6). Estimated capture/recapture probabilities varied between 0.319 and 0.437. The apparent survival probability was estimated as 0.64 (SE = 0.11, 95% CI = 0.41-0.82).

The best fitting model for only inshore humpback dolphins in the estuarine strata included random temporary emigration with time-varying capture/recapture probabilities (Table 5). The weighted average estimates of the annual number of distinctive inshore humpback dolphins ($\hat{N}_m$) varied between 47 (in 2013-2014) and 60 (in 2014-2015) (Table 6). The proportion of marked inshore individuals in the population modelled without primary period as a covariate had a lower AIC than using primary period as a covariate, and hence the overall average of theta = 0.692 was used as the correction factor to calculate total population size of inshore humpback dolphins. The total number after correction varied between 68 (in 2013-2014) and 87 (in 2014-2015) (Table 6). Estimated capture/recapture probabilities varied between 0.430 and 0.622. The apparent survival probability was estimated as 0.84 (SE = 0.06, 95% CI = 0.67-0.93).

4 | DISCUSSION

To the best of our knowledge, this study provides the first information on the abundance of Irrawaddy dolphins, finless porpoises and humpback dolphins in the coastal waters of Matang, and in Peninsular Malaysia, with the exception of the study on Irrawaddy dolphins by Rodríguez-Vargas et al. (2019) around Penang Island. The estimates of abundance using tailored methods are thus suitable to serve as a baseline for future studies on these three coastal cetacean species within the Matang Mangroves and Coastal Waters IMMA, and also as a useful reference for similar studies elsewhere across the species' ranges in Malaysia and abroad.

4.1 | Line transect abundance estimates of Irrawaddy dolphins and finless porpoises in Matang

The assumptions of line-transect sampling include (1) representative sampling of the study area, (2) detection of all animals that are close to the line, (3) animals are detected prior to their response to the observers, and (4) distances are measured accurately (Buckland et al., 1993). In the present study, the study area was sampled systematically with the design of the transect lines placed in four strata. Given the elusivity of Irrawaddy dolphins and finless porpoises (Minton et al., 2013), detection probability on the transect line is highly likely to be less than one due to availability and perception biases, and thus the estimates are negatively biased to an unknown extent. Availability bias arises when animals on the transect line are submerged and thus unavailable for detection, while perception bias arises when surfaced animals are missed by observers due to factors such as poor weather conditions and observer fatigue. Observers were rotated hourly to minimize fatigue, and only sightings in calm sea states were included in the analyses to minimize perception bias from missing animals in higher sea states, as suggested by Jefferson et al. (2002). It was not possible to determine if Irrawaddy dolphins and finless porpoises reacted to the observers before detection; if they did react by swimming away, this would result in underestimation of abundance. The measurement of angles and the accuracy in naked eye distance estimates of no more than plus/minus 5 m means that any bias from the violation of assumption (4) would be small.

Irrawaddy dolphin was the most commonly encountered and widely distributed species in the study area while finless porpoises were mostly found in the coastal areas (Figure 2). Estimates of the Irrawaddy dolphin were within the range of the finless porpoise estimates, suggesting that the abundance of these two species in the area was similar, but the former abundance estimates had higher precision than the latter. The effective strip half-width of the best model for finless porpoises was smaller than that of Irrawaddy dolphins, similar to the findings of Minton et al. (2013) in Kuching Bay, Sarawak. This may be due to finless porpoises being cryptic animals which make detection difficult except during good sighting conditions (Jefferson & Moore, 2020). Finless porpoises also lack dorsal fins and have inconspicuous surfacing behaviour and a smaller average group size than Irrawaddy dolphins (Kuit et al., 2019a), and thus may be more likely to be missed on the transect line especially when they are farther from the research vessel or in higher sea states or swell heights.

4.2 | Annual mark-recapture abundance estimates of humpback dolphins in Matang

The assumptions of the mark-recapture method related to the data are that (1) marks are unique, correctly recorded and not lost during the study period. For the simplest models, it is assumed that (2) future survival or catchability are not affected by marking, and (3) animals have an equal probability of being captured or recaptured within each sampling occasion (Hammond, 2018). Closed robust design also assumes that (4) the population remains closed within primary periods. For assumption (1), adult humpback dolphins can be reliably marked with the photographic capture of their long-lasting and unique pigmentation patterns of their dorsal fin. For assumption (2), apparent survival and capture probability should not have been affected by marking by photo-identification. However, regarding assumption (3), we do not know whether capture probability varied among individuals within sampling occasions because the data were not sufficiently extensive to allow this to be modelled. If individual heterogeneity were present, this would lead to a negative bias in estimated abundance. For assumption (4), births, deaths and emigration may occur within the primary periods of six months to one year but unlikely to cause more than a small bias.

The estimates of abundance relate to the animals that used the area during the study period. Random temporary emigration out of the area between years was found for the whole study area and the estuarine strata only (Tables 4 and 5). The results indicate the presence of an inshore humpback dolphin group in the estuarine strata that remained relatively stable across the three years, and an offshore group that occasionally traversed the coastal strata; further population structure study is needed to clarify if these groups belong to the same or separate populations. The annual abundances of inshore humpback dolphins in the estuarine strata across the three years were similar at around 68 to 87 individuals, whereas the total number of humpback dolphins in the whole study area ranged between 81 and 171 individuals (Table 6). The apparent survival rate of inshore humpback dolphins in the estuarine strata at 0.84 was also higher than the rate of 0.64 for all humpback dolphins in the whole study area. Both variability in annual estimates and low apparent survival rate for all humpback dolphins in the whole study area is likely a reflection of the occurrence of wide-ranging individuals from outside the study area.

Inshore humpback dolphins regularly moved between the five estuaries of Matang and were defined as residents due to their regular sightings (see Kuit et al., 2019b), but there were no matches of individuals between the estuarine and coastal strata. This may be linked to the preference of inshore individuals for estuarine prey that are more abundant in the estuaries relative to the coastal waters, which in turn translates to stable use of the estuaries as feeding grounds by the inshore individuals that have higher site fidelity and fewer movements in and out of the study area (Kuit et al., 2019b). In contrast, the offshore individuals appear to range more widely beyond the study area along the wider coastline. The general lack of resightings of individuals from offshore groups, coupled with zero sightings of such groups from 2015-2016, suggest that those individuals are likely to be occasional visitors to the coastal study area.

Although Matang is a fairly large study area for Indo-Pacific humpback dolphins, the present results highlight the challenge of sampling highly mobile offshore individuals that may travel extensively over wide areas, and emphasizes the importance of inter-state conservation and management strategies. Efforts to match their photo-identifications with those in Langkawi Island and Perlis (approximately 200 km north of Matang) are ongoing (LP, KSH) to investigate whether they belong to the same population in the west coast of Peninsular Malaysia, which appears to harbour significant populations of the species (Ponnampalam, 2012). Further studies are also needed to investigate the factors affecting movement patterns of humpback dolphins in the Strait of Malacca, for better understanding of their population dynamics.

4.3 | Comparison with other studies

The abundance of Irrawaddy dolphins estimated from this study appears to be the largest abundance estimated for the species in the Southeast Asian region, and second only to the largest estimates in Bangladesh in a huge study area that is 14.6 times larger than Matang (Smith et al., 2008). Other abundance studies on Irrawaddy dolphin and finless porpoises that utilized the same line-transect methods and expended similar extensive survey effort include the two-year survey in

Kuching Bay, Sarawak by Minton et al. (2013), and the five-year survey in the Trat Province, Gulf of Thailand by Hines et al. (2015b). However, the size of the survey area in Matang is approximately 2.5 to 2.7 times larger than those two other sites. The approximate density (derived from abundance over survey area size) of 0.66 Irrawaddy dolphin individuals per km^2 in Matang was lower than the approximate density in Trat Province, Gulf of Thailand of 0.98 individuals per km^2, but higher than the estimates in Kuching Bay which were 0.32 to 0.50 individuals per km^2. Direct comparisons of abundance estimates and densities across different study sites must be made with caution because of variations in the methodology used, study area size and survey effort (Haughey et al., 2020).

In comparison to humpback dolphins and Irrawaddy dolphins, studies of finless porpoise abundance are relatively few in the Southeast Asian region. The density of finless porpoises in Bangladesh of 0.08 individuals per km^2 was lower than Matang at 0.52 individuals per km^2 (Table 3). The finless porpoises in Matang also had a higher density than Sarawak (Minton et al., 2013) and Hong Kong (Jefferson & Moore, 2020). The distribution of finless porpoises in Matang on the western edge of the study area suggests that the present study area did not encompass the entire range of the studied animals and that the offshore waters of Matang, beyond the boundaries of our study site, may support higher numbers of finless porpoises (Kuit et al., 2019a).

The largest estimates of humpback dolphins in the Pearl River Estuary, China (Chen et al., 2010) appeared to have a homogeneous distribution in the estuarine waters, hence line-transect distance sampling was a suitable method for abundance estimation there. However, mark-recapture may provide abundance estimates that have a much higher precision than line-transect estimates for study sites with less than 100 humpback dolphins (Wang et al., 2012). With the lack of on-effort sightings of humpback dolphins in Matang throughout the survey area, the mark-recapture method was chosen as the most suitable approach taken in this study for the species.

4.4 | Future research and recommendations

Given that coastal cetaceans in Matang live in close proximity to human activities, future monitoring surveys should be conducted to identify trends in abundance within the study site to help assess whether their survival or reproduction is being negatively impacted by those activities. As photo-identification of Irrawaddy dolphins is challenging and finless porpoises could not be photo-identified, annual line transect surveys for Irrawaddy dolphins and finless porpoises in

Matang are recommended for monitoring of these species, where resources permit. Future studies of finless porpoises should be extended westward of the present study area's boundary to investigate the extent of their offshore range and provide more comprehensive estimates of abundance.

Continuous multi-year monitoring of humpback dolphins in the estuarine and coastal strata through photo-identification will allow better estimation of survival rates (Silva et al., 2009) and could provide better understanding of the ranging patterns of inshore humpback dolphins within the estuaries, and the offshore humpback dolphins in the Strait of Malacca. Long-term monitoring via photo identification surveys would also allow determination of dolphin birth rates and calf survival rates (Henderson et al., 2014; Chang et al., 2016). More photo-identification surveys should be conducted in the offshore waters and could be expanded southwards to photo-identify more individuals that may move in and out of the study area in order to establish the extent of the size and range of resident and offshore humpback dolphin populations in Matang.

In areas with multiple species of interest, approaches to abundance estimation should be adaptive to circumstances as demonstrated by the present study. In the present study, the line-transect method was employed for species that have a relatively homogenous distribution throughout the study area but are difficult to be photographed and identified individually. Such was the case for Irrawaddy dolphins and finless porpoises in Matang due to both species' typically elusive and evasive nature which made individual photo-matching to be very challenging. We thus recommend that when resources are limited for a species that requires high effort for photo-identification, but have a homogenous distribution in the large study area, then the line-transect distance sampling method should be prioritized for the target species. However, the mark-recapture method was chosen to estimate the population size of humpback dolphins in Matang because of the geographic location of estuarine humpback dolphins that drove off-effort sightings and thus precluded the use of distance sampling for humpback dolphins in the estuarine strata. Additionally, unlike Irrawaddy dolphins, the humpback dolphins' dorsal fins have pink areas that have lost skin pigmentation, patterns which result in light/pink patches that are easily distinguishable and thus ideal for photo-identification. The matching of the pigmentation patterns and body spots of humpback dolphins can be used to recognize individuals, as changes in their pigmentation patterns over several years are very minimal (Wang et al., 2012).

4.5 | Conservation implications

The Matang waters support notable populations of these three species of globally threatened small cetaceans. Long-term reliance of an apparently small population of resident humpback dolphins in Matang estuaries as feeding and possibly nursery grounds (see also Kuit et al., 2019a) highlights the importance of these estuaries and nearshore waters as the species' critical habitats. Yet these estuarine areas were also observed to be primary gillnetting grounds for local fishermen. In 2017, a pregnant resident humpback dolphin (LDF 039) with a history of 13 resightings between 2013 and 2016, was found dead at Kuala Sangga. While the dolphin's cause of death was inconclusive, a data check on her ranging patterns showed that she mainly occupied the estuaries of Kuala Gula and Kuala Sangga, where gillnets and bag nets are incredibly common (Kuit, unpublished data), suggesting that she could have been a victim of net entanglement. Meanwhile, the coastal waters of Matang host sizable numbers of Irrawaddy dolphins and finless porpoises, which, based on field observations, are also intensive trawl fishery grounds; the scenario is thus of major conservation concern. During this study, we encountered seven small cetacean carcasses, of which two finless porpoises were bycatch in trawl nets; one carcass was a pregnant individual which was brought to the jetty by the trawl fishers whose net in which it was bycaught, while the other carcass bore scratch marks on its head and body (Kuit & Ponnampalam, personal observations), suggesting that those scars were obtained from having been pushed up against the inside of a trawl net as it dragged along the seabed. Establishing baseline information for these understudied species is a critical first step to serve as a useful reference point for future monitoring to detect population trends and to evaluate if the local populations are sustainable.

Presence of skin diseases, injuries from fisheries interactions and mortalities of cetaceans that were recorded every year during the surveys are a cause of great concern for their long-term survival. Future monitoring surveys should employ similar methodology and coverage of the study area to allow for meaningful comparisons and detection of trends in cetacean abundance in the coastal waters of Matang. Where resources permit, the study should be expanded to adjacent areas to improve coverage of each species' distribution and abundance within the larger Matang Mangroves and Coastal Waters IMMA. While an IMMA is not a marine protected area, the abundance estimates of the three coastal cetacean species, along with the IMMA designation are good grounds upon which to promote and encourage the relevant authorities to take proactive legislative action to conserve the animals and their habitats (see Hoyt & Notarbartolo di Sciara, 2021). To have the latter actions realised would be well in line with the goals laid out in Malaysia's National Policy on Biological Diversity 2016 – 2025. With fewer than 100 humpback dolphins estimated in the estuarine strata of Matang (Table 6), there is an urgent need both to improve understanding of their population dynamics, including estimation of rates of birth, death and migration, and for prompt management action, including exploring the use of low-cost cetacean bycatch mitigation methods, and regulating dolphin-watching tourism particularly in the Sangga Besar River (see Kuit et al. (2019a) for the whole list of recommended conservation actions). We acknowledge that achieving and operationalising conservation action is a long and complex process involving simultaneous aspects such as regulatory procedures, political will, and socio-cultural and socio-economic factors (Kareiva & Marvier, 2012; Bennett et al., 2017). In the event that additional protection for the small cetaceans in Matang is not forthcoming, there is a risk of local species population decline, a shift in site occupancies, or even extirpation. As a signatory of the Convention on Biological Diversity (CBD), Malaysia as a country, is obligated to protect its wildlife species from declining. Research and monitoring efforts should be continued, alongside with legislative lobbying efforts and public outreach activities using information derived from the said scientific studies.

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TABLE 1 Survey effort and on-effort sightings in Beaufort 3 or less for Irrawaddy dolphins and finless porpoises during 11 line-transect surveys between November 2013 and July 2016

Survey period	**Effort (km)**	**Effort (h)**	**On-effort sightings in Beaufort scale ≤ 3**	
			Irrawaddy dolphin	**Finless porpoise**
8-17 Nov 2013	386.1	27.8	14	3
19-28 Jan 2014	396.7	27.8	15	10
6-15 Mar 2014	377.1	26.9	12	3
2-11 Jul 2014	377.7	24.1	15	6
9-18 Sep 2014	377.3	25.9	20	3
3-12 Mar 2015	364.8	25.6	9	8
8-17 May 2015	380.4	25.4	7	5
30 Jun-9 Jul 2015	380.8	28.2	17	6
12-21 Sep 2015	352.5	24.5	22	7
12-21 Jan 2016	349.9	23.0	6	9
22-31 Jul 2016	364.3	25.8	24	11
Total	4107.6	284.9	161	71

TABLE 2 Abundance estimates for Irrawaddy dolphins and finless porpoises for each survey block. The overall total for each species differs from the sum of the blocks because of rounding error. *N* = estimated abundance, %CV = percent coefficient of variation, 95% CI = 95% confidence interval.

Species	**Survey block**	**Area (km^2)**	**Density (per km^2)**	***N***	**% CV**	**95% CI**
Irrawaddy dolphins	North Estuarine	167.42	0.38	64	24.1	40-102
	North Coastal	423.71	0.56	238	18.2	167-340
	South Estuarine	136.85	0.52	72	22.8	46-112
	South Coastal	423.74	0.92	390	16.7	281-540
	Total	1151.72	0.66	763	13.3	588-990
Finless porpoises	North Coastal	423.71	0.60	253	30.9	140-462
	South Coastal	423.74	0.82	346	29.2	197-608
	Total	847.45	0.71	600	27.1	354-1016

TABLE 3 Total number of humpback dolphin sightings, total number of distinct (D ≥ 3 and Q ≥ 2) individuals, distinct inshore individuals and offshore individuals photo-identified from the left side of dorsal fins (LDFs) during three primary periods used in robust design analysis in MARK

Primary period (P)	Secondary period	Days	Total number of humpback dolphin sightings	Total distinct individuals identified (LDF)	Distinct inshore individuals identified (LDF)	Distinct offshore individuals identified (LDF)
P1 (2013-2014)	18-27 Sep 2013	10	20	52	28	24
	8-17 Nov 2013	10	10	35	28	7
	19-28 Jan 2014	10	13	37	32	5
	6-15 Mar 2014	10	10	31	30	1
	P1 Total	**40**	**53**	**85**	**47**	**38**
P2 (2014-2015)	2-11 Jul 2014	10	6	27	24	3
	9-18 Sep 2014	10	7	10	7	3
	3-12 Mar 2015	10	9	28	28	0
	8-17 May 2015	10	14	84	44	40
	P2 Total	**40**	**36**	**101**	**56**	**45**
P3 (2015-2016)	30 Jun-9 Jul 2015	10	6	16	16	0
	12-21 Sep 2015	10	7	26	26	0
	12-21 Jan 2016	10	6	27	27	0
	22-31 Jul 2016	10	11	27	27	0
	P3 Total	**40**	**30**	**51**	**51**	**0**
Total for 2013-2016		**120**	**119**	**148**	**76**	**72**

TABLE 4 Pollock's robust design candidate models for abundance estimation of marked humpback dolphins in the coastal and estuarine strata of Matang arranged in corrected quasi Akaike's Information Criterion ($QAIC_c$) values, with the lowest $QAIC_c$ value representing the most parsimonious model. Model notation: *S*: apparent survival probability; *p*: probability of capture; *c*: probability of recapture; (.): constant parameter; (*t*): parameter varies with time. Variance inflation factor, $\hat{c} = 3.025$.

#	Model	QAICc	Delta QAICc	QAICc weight	Model likelihood	No. of parameters	QDeviance
1	{*S*(.)*p*(*t*)=*c*(*t*)random(*t*)}	-53.74	0	0.907	1.000	18	114.62
2	{*S*(.)*p*(t)=*c*(t)no-movement(*t*)}	-49.19	4.5491	0.093	0.103	19	116.97
3	{*S*(.)*p*(.)=*c*(.)random(*t*)}	-27.87	25.8652	0.000	0.000	9	159.80
4	{*S*(.)*p*(.)=*c*(.)random(.)}	-26.52	27.214	0.000	0.000	8	163.24

TABLE 5 Pollock's robust design candidate models for abundance estimation of marked humpback dolphins in the estuarine strata of Matang arranged in corrected Akaike's Information Criterion ($QAIC_c$) values, with the lowest $QAIC_c$ value representing the most parsimonious model. Model notation: *S*: apparent survival probability; *p*: probability of capture; *c*: probability of recapture; (.): constant parameter; (*t*): parameter varies with time. Variance inflation factor, $\hat{c} = 1.373$.

#	Model	QAICc	Delta QAICc	QAICc weight	Model likelihood	No. of parameters	QDeviance
1	{*S*(.)*p*(*t*)=*c*(*t*)random(*t*)}	18.36	0.00	0.823	1.000	18	205.47
2	{*S*(.)*p*(t)=*c*(t)no-movement(*t*)}	21.42	3.07	0.177	0.216	19	206.27
3	{*S*(.)*p*(.)=*c*(.)random(.)}	40.60	22.24	0.000	0.000	8	249.53
4	{*S*(.)*p*(.)=*c*(.)random(*t*)}	41.77	23.41	0.000	0.000	9	248.58

TABLE 6 Weighted average estimates of abundance of marked inshore humpback dolphins ($\hat{N}_m$) in the coastal and estuarine strata, and estuarine strata only of Matang based on the four candidate models, and the estimates of total population ($\hat{N}_T$) within survey interval year, corrected by the proportion of marked inshore individuals ($\hat{\theta}$) in the population from 2013-2016 photo-identification data. Coefficient of variation (CV), lower and upper log-normal 95% confidence interval (CI) of the estimates are also shown.

Strata	Survey interval	Robust Design abundance estimates			Proportion of marked humpback dolphins		Corrected abundance estimates		
		$\hat{N}_m$	CV ($\hat{N}_m$)	95% CI ($\hat{N}_m$)	$\hat{\theta}$	SE ($\hat{\theta}$)	$\hat{N}_T$	CV $(\hat{N}_T)$	95% CI $(\hat{N}_T)$
Coastal and estuarine	2013-2014	95	0.079	80-110	0.689	0.016	138	0.082	118-162
	2014-2015	118	0.098	96-141			171	0.101	148-208
	2015-2016	56	0.095	45-66			81	0.098	67-98
Estuarine only	2013-2014	47	0.027	45-50	0.692	0.018	68	0.038	63-73
	2014-2015	60	0.052	54-66			87	0.058	78-97
	2015-2016	56	0.064	49-63			81	0.069	71-93

FIGURE 1 The study area encompassing the Matang mangroves and adjacent coastal waters, and the boundaries of the IUCN Important Marine Mammal Area (IMMA), along with the two sets of line-transects that were alternated between surveys

FIGURE 2 The survey effort tracks and group size of Irrawaddy dolphin and finless porpoise on-effort sightings in the north coastal (NC), north estuarine (NE), south coastal (SC) and south estuarine (SE) survey blocks during line-transect surveys between November 2013 and July 2016

FIGURE 3 Detection probability fitted to the perpendicular distance of (a) Irrawaddy dolphin sightings (n = 149) truncated to 350 m and (b) finless porpoise sightings (n = 67) truncated to 200 m

FIGURE 4 The survey effort tracks and group size of humpback dolphin on-effort and off-effort sightings in the north coastal (NC), north estuarine (NE), south coastal (SC) and south estuarine (SE) survey blocks during line-transect surveys between November 2013 and July 2016

FIGURE 5 Discovery curves of the cumulative number of distinctive humpback dolphin individuals identified against the cumulative number of identifications using LDFs between September 2013 and July 2016 for (a) all individuals, (b) inshore individuals only and (c) offshore individuals only

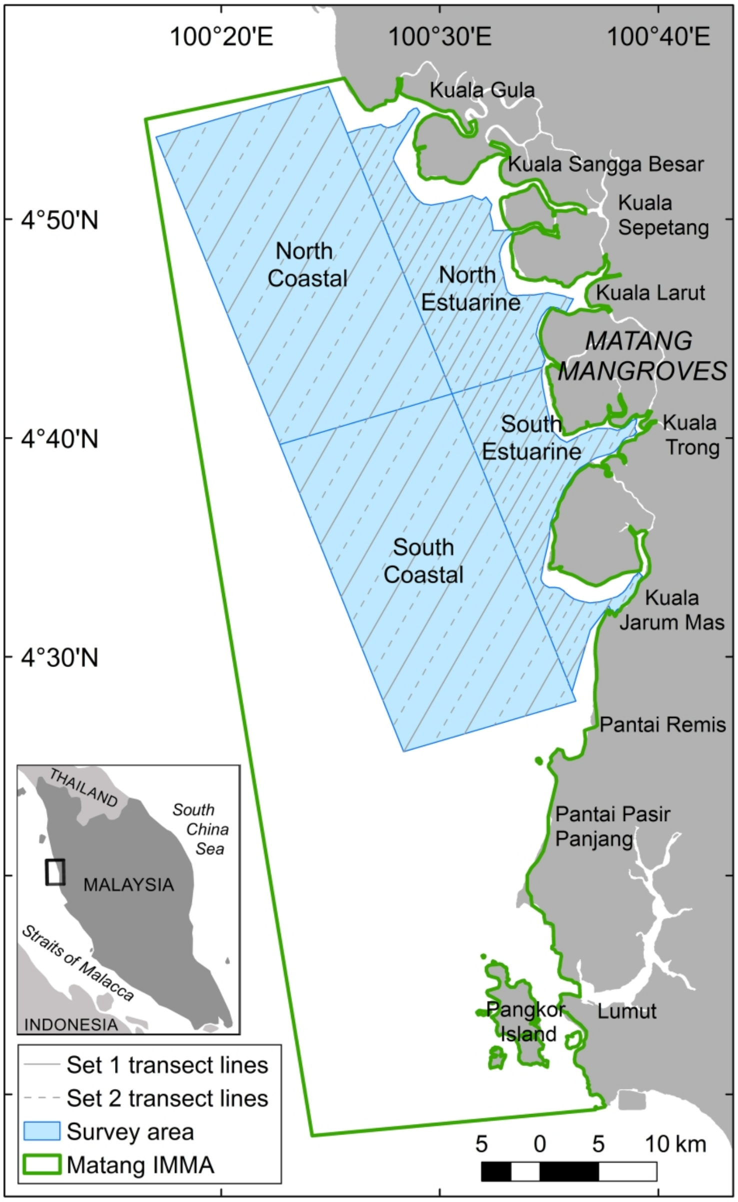

FIGURE 1 The study area encompassing the Matang mangroves and adjacent coastal waters, and the boundaries of the IUCN Important Marine Mammal Area (IMMA), along with the two sets of line-transects that were alternated between surveys

199x324mm (300 x 300 DPI)

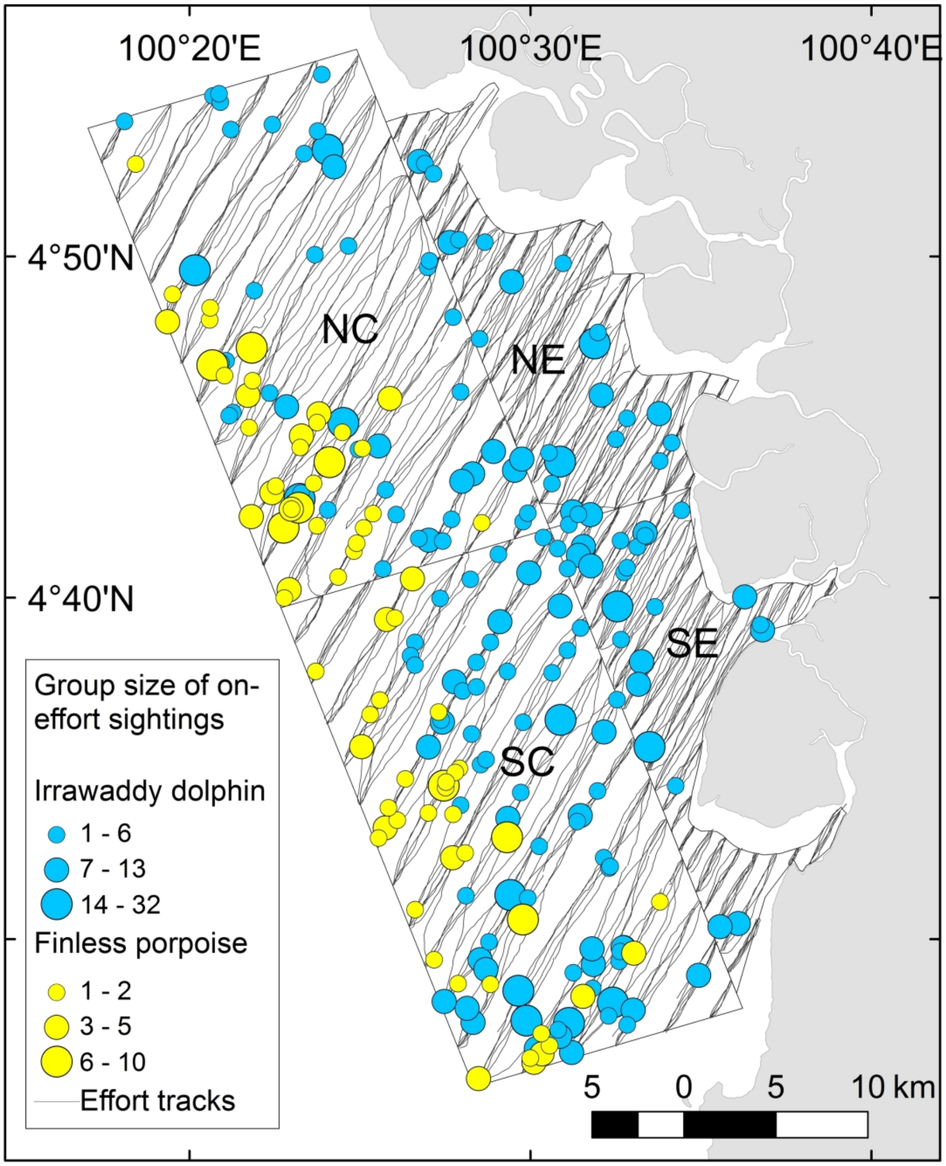

FIGURE 2 The survey effort tracks and group size of Irrawaddy dolphin and finless porpoise on-effort sightings in the north coastal (NC), north estuarine (NE), south coastal (SC) and south estuarine (SE) survey blocks during line-transect surveys between November 2013 and July 2016

210x258mm (300 x 300 DPI)

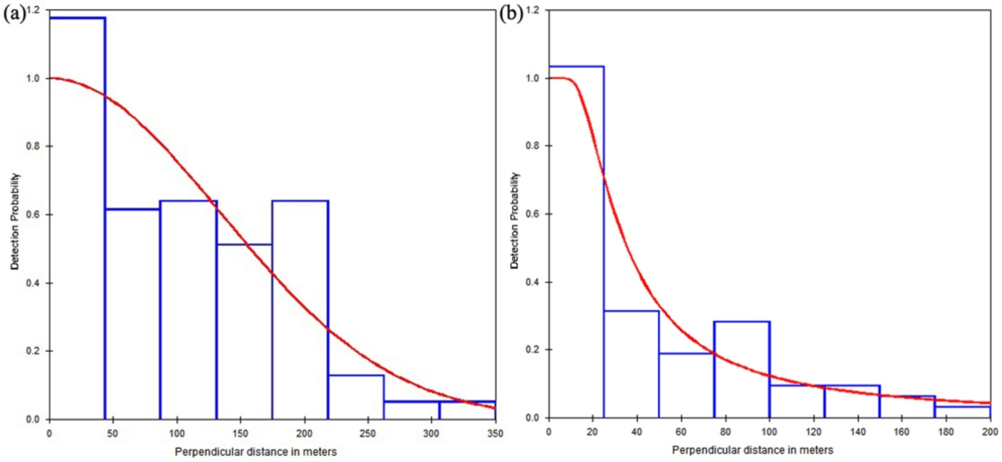

FIGURE 3 Detection probability fitted to the perpendicular distance of (a) Irrawaddy dolphin sightings (n = 149) truncated to 350 m and (b) finless porpoise sightings (n = 67) truncated to 200 m

299x138mm (300 x 300 DPI)

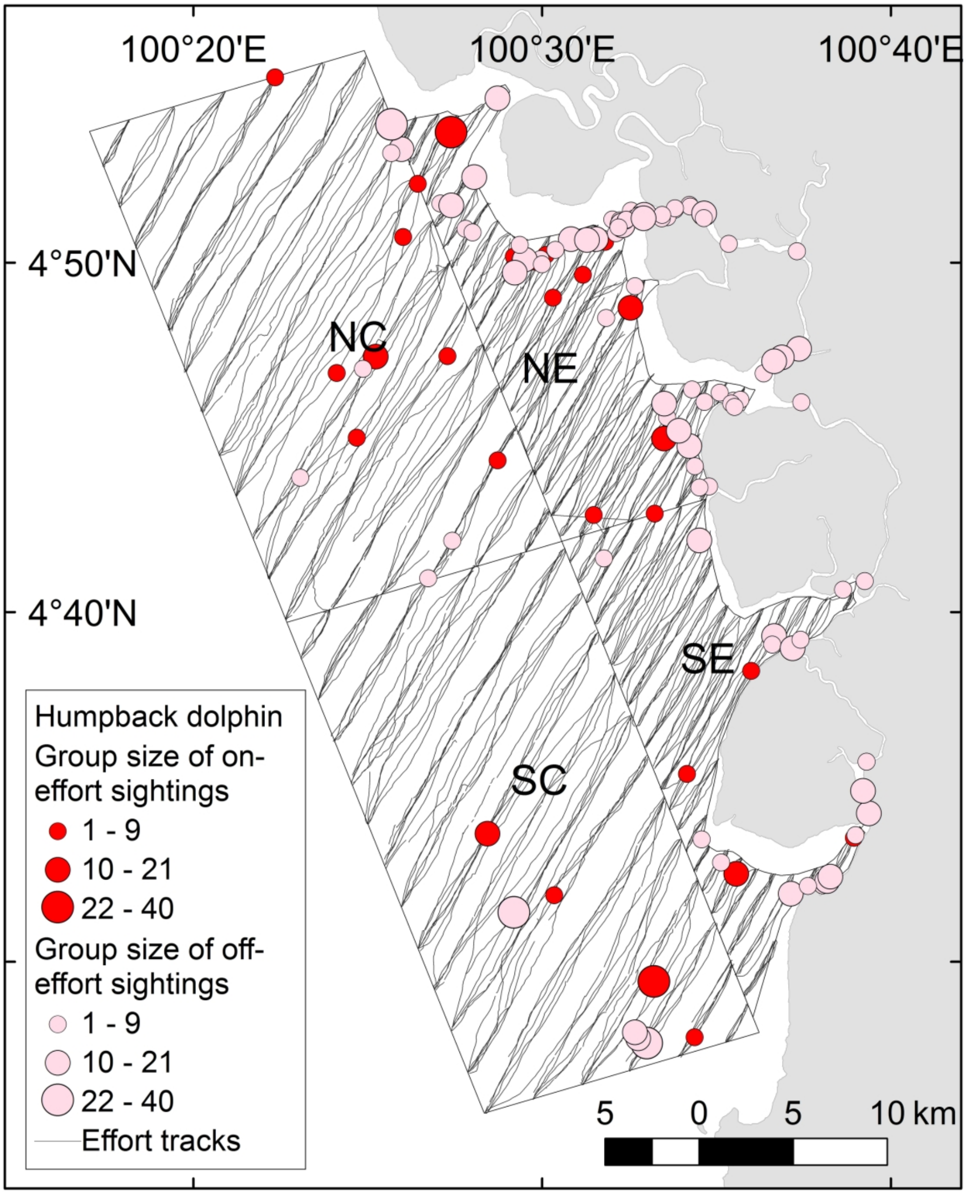

FIGURE 4 The survey effort tracks and group size of humpback dolphin on-effort and off-effort sightings in the north coastal (NC), north estuarine (NE), south coastal (SC) and south estuarine (SE) survey blocks during line-transect surveys between November 2013 and July 2016

205x252mm (300 x 300 DPI)

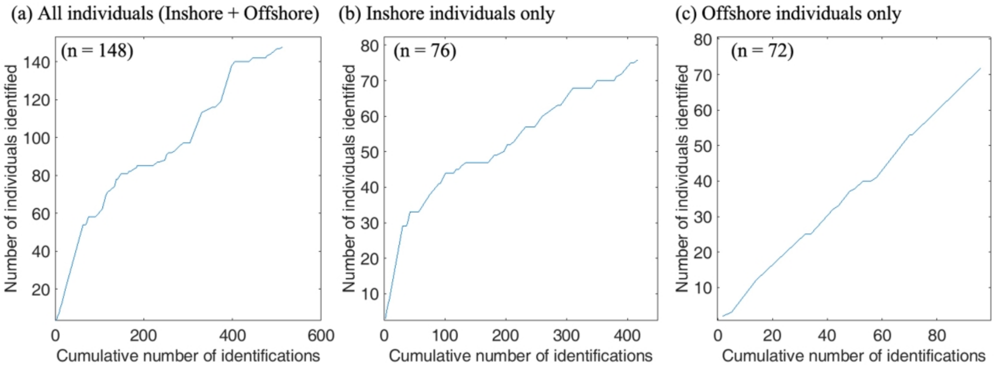

FIGURE 5 Discovery curves of the cumulative number of distinctive humpback dolphin individuals identified against the cumulative number of identifications using LDFs between September 2013 and July 2016 for (a) all individuals, (b) inshore individuals only and (c) offshore individuals only

430x161mm (300 x 300 DPI)