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POPULATION ESTIMATES AND DISTRIBUTION PATTERNS OF IRRAWADDY DOLPHINS (*ORCAELLA BREVIROSTRIS*) AND INDO-PACIFIC FINLESS PORPOISES (*NEOPHOCAENA PHOCAENOIDES*) IN THE KUCHING BAY, SARAWAK

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ABSTRACT. — Small boat surveys were conducted in the Kuching Bay area of Sarawak, East Malaysia, in order to determine the distribution and abundance of coastal cetaceans. Photographic data collected from Jul.2007 through Oct.2010 was used to generate mark-recapture abundance estimates of Irrawaddy dolphins in the study area, and provided insights into ranging patterns and site fidelity. Between Apr.2010 and Oct.2011, line transect surveys were conducted, and abundance estimates for Irrawaddy dolphins and Indo-Pacific finless porpoises were generated using distance sampling.

The best mark-recapture estimate for Irrawaddy dolphins based on a weighted mean of estimates derived from photographs of left sides and right sides of dorsal fins was 233 (CV = 22.5%, 95% CI 151–360). Re-sighted individuals showed a high degree of site-fidelity, with less than 10 km between sighting locations over a period of four years for some individuals. A smaller proportion of re-sighted individuals ranged further—with a maximum straight-line distance of 26 km between sighting locations.

The best line-transect estimate for Irrawaddy dolphins was 149 individuals (CV = 28%, 95% confidence interval 87–255). The line-transect estimate for finless porpoises was 135 individuals (CV = 31%, 95% confidence interval 74–246). Finless porpoise abundance varied seasonally, with higher densities observed between Mar. and May, coinciding with the occurrence of larger groups with very small calves. The line transect and mark-recapture derived estimates for Irrawaddy dolphins are compared, and viewed in the context of mapped relative densities that reveal key areas of habitat for the species. These abundance estimates provide a critical step toward the assessment of both species' local conservation status and can be used in the design of effective management strategies.

KEY WORDS. — Malaysia, Sarawak, South China Sea, marine mammals, conservation, distribution, habitat, Irrawaddy dolphin, Indo-Pacific finless porpoise

INTRODUCTION

The Kuching Bay in Sarawak, East Malaysia, is known to host at least four species of coastal cetaceans including the Irrawaddy dolphin (*Orcaella brevirostris* Owen in Gray), Indo-Pacific finless porpoise (*Neophocaena phocaenoides* Cuvier), Indo-Pacific bottlenose dolphin (*Tursiops aduncus* Ehrenberg) and Indo-Pacific humpback dolphin (*Sousa chinensis* Osbeck) (e.g., Beasley & Jefferson, 1997; Minton et al., 2011). Previous studies showed that Irrawaddy dolphins and Indo-Pacific finless porpoises were the two most frequently-encountered species in the area, and generated relative abundance estimates, but were not able to provide absolute abundance estimates for either population (Minton et al., 2011).

The IUCN Red List of Endangered Species classifies both Irrawaddy dolphins and Indo-Pacific finless porpoises as "Vulnerable" (IUCN, 2008; Wang & Jefferson, 2011). These two species both have known affiliations with riverine, estuarine or nearshore waters (e.g., Amano, 2009; Smith, 2009) and threats to them include fisheries bycatch (Smith & Jefferson, 2002; Smith et al., 2004; Reeves et al., 2008; Jaaman et al., 2009) as well as coastal development and habitat degradation (Smith & Jefferson, 2002; Kannan et al., 2005; Smith, 2007; Smith et al., 2007; Jefferson et al., 2009). The intense pressures on these two species, whose range is limited to localised areas within the Indo-Pacific region, cause them to be of high concern for global conservation efforts (e.g., Smith & Jefferson, 2002; Reeves et al., 2003; Smith, 2007). Five populations of Irrawaddy dolphins in Southeast Asia have been listed as "Critically Endangered" (Reeves et al., 2008).

The river networks, coast and estuaries of the Kuching Bay area host an active artisanal gillnet fishing industry, increasing aquaculture initiatives, a number of new coastal resorts and housing developments, and a planned flood mitigation channel that will divert millions of cubic meters of silt-laden fresh water from the city of Kuching into the Salak estuary. All of these activities have been demonstrated to present clear conservation threats to coastal cetaceans (Kemper et al., 2005; Read et al., 2006; Smith et al., 2007; Adams et al., 2008; Jefferson et al., 2009).

Although the precautionary principle should dictate that urgent conservation measures be implemented for these vulnerable species throughout their range, managers and developers are often unwilling to put measures in place without concrete evidence of a population's precarious conservation status. As such, scientists are under a great deal of pressure to answer the question "how many". The data presented here address this question, but also place the answer in context of "where", as both types of information are critical for the development of effective management strategies. Small boat surveys using both line-transect and photo-identification methodology are used to generate abundance estimates for Irrawaddy dolphins and finless porpoises in the Kuching Bay, and relative abundance is mapped to show areas of high encounter rates that are likely to be of higher conservation priority.

MATERIAL AND METHODS

Survey area. — The survey area, defined as the "Kuching Bay" for its proximity to the city of Kuching, the capital of Sarawak, East Malaysia, comprises three components or strata, including the Salak-Santubong Bay (329 km^2), the Bako-Buntal Bay (119 km^2), and interconnecting portions of the Telaga Air and Salak River, as well as the Santubong and Buntal rivers (with a combined area of 20.09 km^2, see Fig 1). The southern part of the study area comprises of a series of interconnecting rivers and mangrove channels, as well as sandy and rocky coastlines. While portions of the rivers reach maximum depths of 11–12 m, both of the major bays are shallow, not exceeding 10 m in depth as far as 15 km from shore. The substrate throughout the study area is predominantly fine silt and sand and the waters range from brackish (approx. 28 ppt in rivers and estuaries to saline [32 ppt] in the most offshore areas of the area; data held by authors).

The study area includes portions of the Kuching Wetlands National Park on the west side, the Talang-Satang Island Marine sanctuary approximately 10 km offshore and the terrestrial Bako National Park on the east. The area includes five big resorts, four homestay facilities for tourists, and tourist accommodation in Bako National Park. There are also 10 fishing villages bordering the study area, six commercial shrimp ponds (located within tributaries of the Sibu Laut, Rambungan and Santubong rivers) and 17 small fish cage farms located along Santubong river.

Data collection. — Line-transect surveys were conducted on an almost monthly basis from Mar. through Oct. in 2008, 2009, 2010 and 2011. Rough sea conditions and rain during the monsoon season prevented effective surveys between the months of Nov. and Feb. In 2008 and 2009 surveys were conducted with the aim of assessing relative abundance only, and are described in more detail in Minton et al. (2011). Only photographic data from these surveys are included in the analysis presented here.

Surveys conducted from Apr.2010 onward were designed with the aim of estimating absolute abundance using line transect sampling within the analytical framework of the program DISTANCE (Thomas et al., 2010). As such, survey protocols were modified from those used in 2008–2009. Transects extended up to 15 km offshore and were systematically orientated at 45° angles to the primary coastline to ensure they were independent of habitat features and environmental gradients, and to allow for detection of cetacean density gradients alongshore as well as onshore/offshore (Dawson et al., 2008). The survey design function in DISTANCE (Thomas et al., 2010) was used to compare the coverage probability and proportion of survey time spent in transit between transects when transects were separated by 2, 3, 4, 5 and 6 km. A transect separation of 4 km was selected, as this allowed a compromise between intense survey coverage and a realistic amount of survey effort over each 4-day survey period. For the Kuching area, the 4 km spacing allowed a projected 74% of survey time to be spent on effort, with an estimated coverage probability (total length of trackline divided by the total survey area, assuming a nominal strip width of 1km) of 34.1%.

The starting points of the transects originally designed in 2008 were selected randomly, and as such, meet the requirement for randomised distribution of survey effort. However, this aspect of survey design was further enhanced in the 2011 season by the introduction of three alternate sets of parallel transects, placed at roughly equal intervals between the first. At the start of each 4-day survey period, the random number generator function of Microsoft Excel® was used to determine which set of four transects would be followed for that survey. Rivers included in the transects were never more than 450 m wide and were navigated down the center line because a design using diagonal parallel tracks or zigzags, as suggested in Dawson et al. (2008), was unfeasible logistically and would not have given a representative coverage because the lengths of each transect would have been too short relative to the distance able to be searched abeam. Observers felt that they could effectively search from the center to the river banks (although the data and analyses showed that this might not always have been the case).

The survey vessel was a 10 m-long fiberglass-hulled open-decked boat with two 150hp four-stroke outboard engines. A specially designed platform allowed a minimum of two observers to sit approximately 3.5 m above water level. Observers alternated searching with the naked eye and 7×50 binoculars with a built-in compass, with each observer scanning arcs of approximately 100° from just past the center line to 90° to port and starboard (e.g., Buckland et al., 2001; Parra et al., 2006). Emphasis was placed on covering the area immediately in front of the boat in order to reduce the chances of missing animals directly on the transect line, which would violate a key assumption of line-transect methodology. Prior to participating in surveys, all observers underwent shore-based training sessions on line-transect methodology, including practice in distance estimation using a laser range finder. These sessions were repeated by the team members regularly throughout the survey period.

Transects were navigated at 15 km per hour (8 kt) and observers rotated through different positions on the boat at the end of each transect line (roughly half-hour intervals) to avoid fatigue. Effort was recorded to the nearest minute throughout each survey day in order to distinguish between time spent actively searching (from here on referred to as "on effort"), fast transits to or from the start and end points of transect lines, working with cetacean groups, or simply off survey effort. Beaufort scale (as an indicator of sea conditions), swell height, and visibility were recorded on

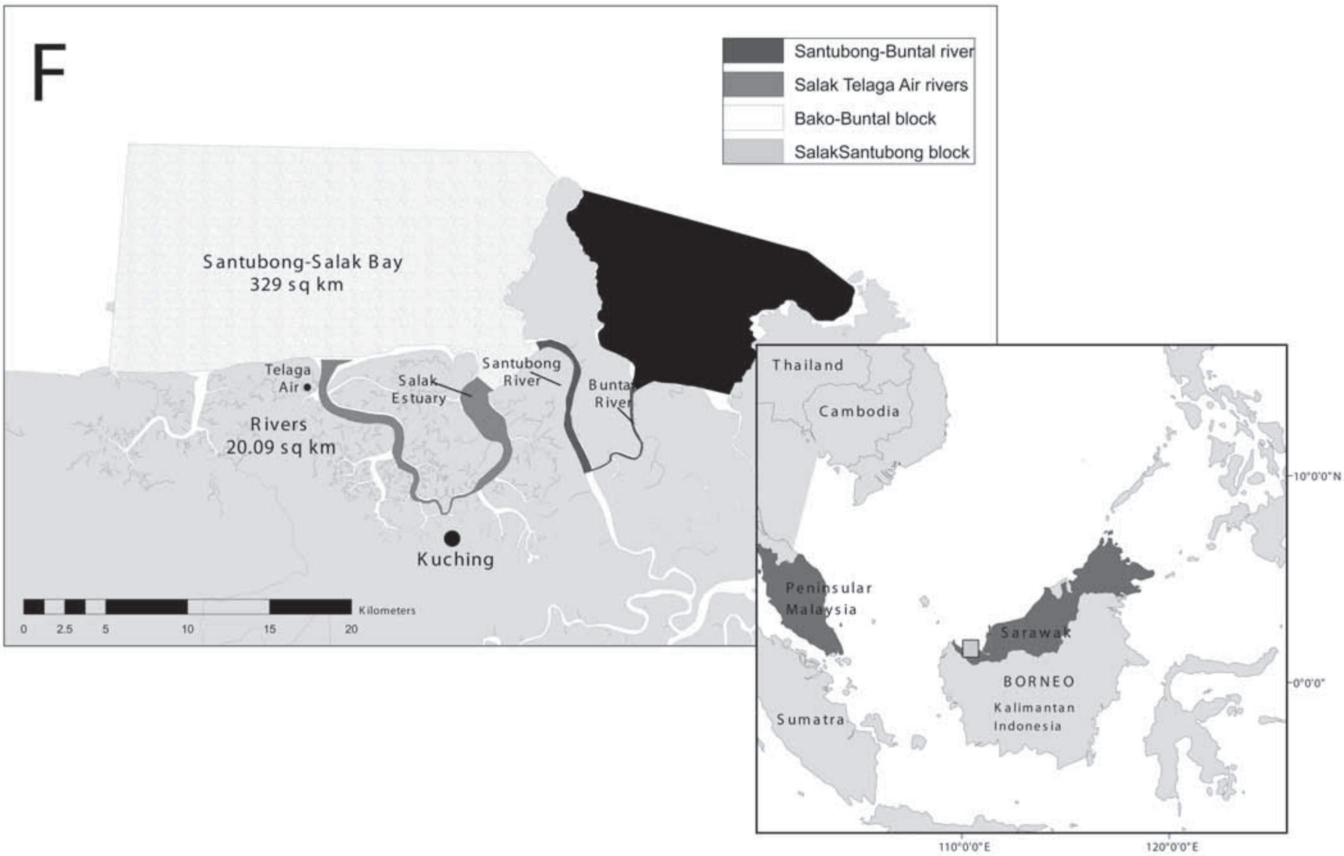


Fig. 1. Kuching area survey "strata". Shapes for areas were created in Google Earth, creating slight mis-match with the base maps used in ArcGIS.

each transect leg and at the time of each sighting, or upon noticeable change. Positional data for both survey tracks and sightings were collected using a handheld GPS unit. The trip odometer function of the GPS was used to record the distance covered on each transect and between each change in observer activity. Search effort was suspended during heavy rain and/or Beaufort scale of 4 or higher.

When cetaceans were detected, search effort was suspended. Data on the transect bearing (based on the GPS heading) was recorded, and the bearing to the sighted cetacean group was measured through the compass binoculars, both to the nearest degree. The observer that first made the sighting estimated the distance from the boat to the animals to the nearest meter, and the boat then left the transect to approach the group and collect data on the group composition, group size and behaviour following standardised data collection methods (e.g., Jefferson, 2000; Parra, 2006).

Behaviour was classified into standardised categories of travelling, feeding (direct feeding observed), probable feeding (dive patterns consistent with feeding activity or fish observed at the surface near dolphins), resting/milling, socialising, or undetermined (e.g., Jefferson, 2000; Lusseau, 2006; Parra et al., 2006). Depth was recorded using a hand-held depth sounder (prior to Jun.2011) or a Garmin GPS 521s fishfinder and GPS (from Jun.2011 onwards).

Photographs were taken using digital SLR cameras with 70–300 mm zoom lenses. Attempts were made to approach the animals as closely as possible without disturbing their natural behaviour and to position the boat so that photos of the left or right sides of dorsal fins could be taken from a perpendicular angle to the animal. Following Würsig & Jefferson (1990: 47), we attempted to "take at random as many photos as possible of members of the group within constraints of time and budget". Generally approaches were made to within a minimum of 10 m, although most groups of Irrawaddy dolphins kept a distance of more than 20 m during encounters.

Data analysis (line transect). — Survey tracks and sighting locations were downloaded at the end of each day using DNR Garmin® software and later processed in ArcMap®. Sighting details were entered into a custom-designed Microsoft Access® database, and line transect data, including line length and associated sightings data were entered into an Excel spreadsheet with custom-designed formulas to calculate the perpendicular distance from the transect line to the cetacean group using the observer's estimated distance and bearings of the transect and sightings.

Line transect data were imported into DISTANCE® (Thomas et al., 2010) and examined for consistency and quality. Data were filtered by species, and detection functions were fitted separately for Irrawaddy dolphins and Indo-Pacific finless porpoises. Different functional forms and adjustment terms for the detection function were tested, including the hazard rate and half normal, with cosine, simple polynomial and hermite polynomial expansions. A number of covariates were available to try and improve the model fit, including group size, Beaufort scale, swell height and observer. The best-fitting detection function was selected based on its Akaike Information Criterion (AIC) score, with the lowest scoring model considered the best fit to the data. Once a detection function was selected, it was applied to all the strata combined, and to generate separate estimates for each of the three components or strata of the survey area (Salak-Santubong Bay, Bako-Buntal Bay and the river networks).

The data were also examined for possible seasonal differences in encounter rates by grouping survey data into 3-month periods (March–May, June–August, and September–November) and dividing the total number of sightings of each species in that period by the distance searched during that time. As this yielded obvious differences for Indo-Pacific finless porpoises, "season" was introduced as a stratum for this species, and the best-fitting detection function was used to generate different densities and abundance estimates for each season.

Distribution of sightings in relation to survey effort. — Tracks were edited to eliminate all portions that were not spent on effort searching for cetaceans on the transect lines. On-effort portions of tracks from 2008 through 2011 were imported into ArcMap 9.3® and overlaid with a 2 × 2 km grid. Grid size was chosen as a compromise between being able to portray finer scale habitat preferences, and a size that would allow sufficient sample sizes of survey effort and sightings to show differences from one cell to the next (smaller cells might only contain one sighting each and not reveal any trends). The number of on-effort Irrawaddy dolphin or finless porpoise sightings in each grid cell was divided by the cumulative survey effort within each grid cell to generate a cell encounter rate. Cells were then colour-shaded to provide a graphic visualisation of high and low density areas.

Data analysis (photo-identification). — Photographs showing left or right sides of dorsal fins were cropped and digitally enhanced and entered into a custom-designed Microsoft Access® database which allowed for storage of sighting information as well as on-screen comparison of photographs. Left and right dorsal fin photos were treated as two separate datasets. Photographs were assigned separate scores of 1–4 for both overall quality and distinctiveness following the protocols described by Friday et al. (2000) and Read et al. (2003) with a score of 4 indicating excellent quality or a high level of distinctiveness, and a score of 1 indicating very poor quality or lack of distinguishing features on the dorsal fin area.

Distinctiveness scores of 1 or 2 were assigned to individuals that had no distinguishing marks, or only superficial scarring or pigmentation that could fade or change over time. Distinctiveness scores of 3 or 4 were assigned to individuals that had lasting damage to the leading or trailing edge of the dorsal fin. Matching of photographs was conducted by eye on-screen, and included photographs of every score in both the quality and distinctiveness categories. Unique ID numbers were assigned to each new individual dolphin after attempting to match to all previously collected photographs.

Sighting histories were generated for all of the individuals in the database (including photos of all quality and distinctiveness), and positions of sighting locations were plotted in ArcMap for individuals that had been sighted on more than one occasion.

In preparation for mark-recapture analysis, to minimise heterogeneity of capture probabilities and to reduce the possible bias from missed matches of individuals that were not recognised due to poor quality photos or non-distinct markings, sighting histories were filtered to include only individuals represented by photographs of a quality 2 or higher, and a distinctiveness score of 3 or higher (e.g., Wilson et al., 1999; Read et al., 2003). Because resulting mark-recapture estimates would not account for the portion of the population without distinctive markings, it was necessary to determine what proportion of the total population would be represented by individuals with a distinctiveness score of 3 or higher and use this proportion as a correction factor for mark-recapture estimates.

Analysis of photographs revealed that within each sighting event, even individuals with distinctiveness scores of 2 or lower could be distinguished from other members of the group due to small superficial markings or dorsal fin shapes. While these markings would not necessarily last long enough to allow recognition of these individuals over a period of months or years, they allowed us to determine for each group how many individuals were photographed in total, and what proportion of them had a distinctiveness score of 3 or higher (e.g., Wilson et al., 1999).

The proportion of distinctive individuals (Score 3 or 4) in all distinctive and non-distinctive individuals (scores 1–4) for each sighting event was averaged across all sighting events, and this mean proportion, p, was used as a correction factor for mark-recapture estimates, $N_{mark\text{–}recapture}$, that only used sighting histories of distinctive individuals.

Thus, the corrected estimate was:

$$N_{corrected} = \frac{N_{mark\text{–}recapture}}{p}$$

The coefficient variation (CV) of the correction factor was calculated using the "delta method":

$$CV^2 N_{corrected} = CV^2 N_{mark\text{–}recapture} + CV^2 p$$

Confidence intervals were calculated assuming estimates were log-normally distributed so that the lower and upper 95% confidence limits were $N_{corrected} / c$ and $N_{corrected} \times c$, respectively, where:

$$c = e^{1.96\sqrt{\ln(1 + CV2Ncorrected)}}$$

The selected sighting histories were consolidated by year to create a total of four "capture occasions". Animals sighted twice in the same year were only counted once in that year. These selected sighting histories were entered into the programme MARK (Cooch & White, 2008) and a number of different models were constructed. These ranged from the most basic model where capture probabilities and recapture probabilities are presumed to be the same and constant over time (equivalent to model M(o) in programme CAPTURE), to models that assume differing capture and recapture probabilities (equivalent to model M(b) in programme CAPTURE), capture probabilities that change over time (i.e., with capture occasion, equivalent to model M(t) in programme CAPTURE), and models that assume different capture probabilities for different classes of animals (referred to as heterogeneity in programme CAPTURE models, formulated as a Pledger mixture model in programme MARK). Although births and deaths were obviously occurring in the population over the 4-year time scale of this study, the time span and sample size was not sufficient to apply open population models to the data. The size of the bias introduced by fitting a closed model to this open population depends on recruitment/survival rates. These are unknown for Irrawaddy dolphins, but based on knowledge of small cetacean birth rates, recruitment rate to the marked population is likely low enough for the bias to be relatively low over the 3-year study period. Akaike's Information Criterion (AIC) values were used to determine which model best fitted the data. Those models that fell within 2 AIC points of the lowest scoring models were considered to have equal support from the data.

RESULTS

Abundance estimates generated from line transect analysis. — Over 48 days of survey effort between Apr.2010 and Oct.2011, a total of 74 Irrawaddy dolphin, 38 Indo-Pacific finless porpoise, and 11 Indo-Pacific humpback dolphin sightings were made, with 55, 33 and 5 of these being on-effort for each species, respectively. The number of on-effort Indo-Pacific humpback dolphin sightings was considered too

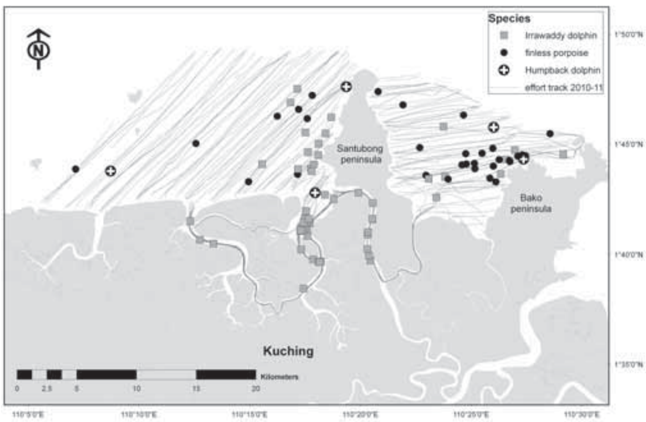


Fig. 2. Distribution of on-effort sightings made during 2010–2011 DISTANCE surveys of the Kuching area. Sea conditions and logistical constraints limited survey coverage of the upper Northwestern most corner of the Santubong-Salak block.

Table 1. Timings and encounter rates for surveys conducted in 2010–2011 using line transect survey methodology.

Dates surveyed	Distance on effort (km)	Irrawaddy dolphin			Indo-Pacific finless porpoise		
		Sightings on effort	Encounters per hour	Encounters per km	Sightings on effort	Encounters per hour	Encounters per km
15–19 Apr.2010	235.89	6	0.381	0.025	9	0.571	0.038
13–16 Jul.2010	223.77	5	0.329	0.022	2	0.160	0.009
24–27 Aug.2010	190.90	3	0.235	0.016	0	0.000	0.000
28 Sep. – 1 Oct.2010	182.17	5	0.407	0.027	1	0.081	0.005
22–25 Mar.2011	191.17	4	0.308	0.021	7	0.538	0.037
26–29 Apr.2011	173.85	1	0.082	0.006	1	0.082	0.006
10–13 May 2011	188.25	6	0.444	0.032	1	0.074	0.005
13–16 Jun.2011	181.59	3	0.237	0.017	5	0.370	0.028
19–22 Jul.2011	207.15	8	0.559	0.039	1	0.070	0.005
9–12 Aug.2011	203.92	4	0.299	0.020	1	0.075	0.005
13–16 Sep.2011	203.98	5	0.331	0.025	1	0.066	0.005
18–21 Oct.2011	207.83	3	0.211	0.014	3	0.211	0.014
Total	**2390.47**	**55**	**0.196**	**0.021**	**33**	**0.118**	**0.013**

Table 2. Abundance estimates for Irrawaddy dolphins and Indo-Pacific finless porpoises in the Kuching Bay derived from line-transect methods. Stratum = Salak-Santubong (SS), Bako-Buntal (BB), and River (see Fig. 1). N = the estimated number of animals in the study area.

	Model	Strata	Density (per km^2)	N	%CV	Lower 95% CI	Upper 95% CI
Irrawaddy dolphins	Unstratified		0.443	208	29.1	118	364
	Stratified by region	SS	0.312	103	38.1	50	212
		BB	0.245	29	43.4	13	67
		River	0.828	17	31.7	9	31
		Total		149	27.9	87	255
Indo-Pacific finless porpoises	Unstratified		0.275	129	38.6	62	269
	Stratified by region	SS	0.141	47	47.8	19	114
		BB	0.730	88	40.6	40	190
		Total		135	31.3	74	246
	Stratified by season	Mar–May	0.61	275	47.2	113	669
		Jun–Aug	0.30	137	45.3	58	322
		Sep–Nov	0.20	91	57.0	32	263

small for analysis and photographs of this species are the subject of a separate study. Table 1 contains details of the timing, distances covered, on-effort sightings, and encounter rates for each survey.

For both Irrawaddy dolphins and finless porpoises, the best fitting detection function was the Hazard rate with a maximum of two adjustments. Models using this detection function for both species fitted well: Kolmogorov-Smirnov goodness of fit test p = 0.997 for Irrawaddy dolphin and p = 0.812 for Indo-Pacific finless porpoise. Effective strip half width was estimated as 104.4 m (CV = 22%) for Irrawaddy dolphins and 87.4 m (CV = 26%) for finless porpoises giving average detection probability of 0.385 and 0.226 within the maximum strip of 271 m and 387 m, respectively.

Inclusion of Beaufort scale or swell height as covariates did not improve the model fit. Introducing group size as a covariate yielded a detection function that came to within less than 2 AIC points of the simpler model without covariates, and yielded a lower CV of 26%. However, this model did not allow for post-stratification by region. As such, only estimates generated from the more parsimonious model without covariates and allowing for stratification are presented here.

Table 2 shows the abundance estimates derived from the best-fitting detection functions chosen in DISTANCE for Irrawaddy dolphin and Indo-Pacific finless porpoises. For Irrawaddy dolphins the unstratified estimate of abundance was 208 individuals (95% CI 118–364), with a CV of 29.1%. The estimates stratified by region show that while the highest density of dolphins was found in the "River" stratum, the highest number of animals was found in the "Salak-Santubong" stratum. Due to the restricted area of the river stratum, realised coverage in the river was higher than in the other survey areas, resulting in a likely overestimate when data were not stratified by region. Given this, the best total estimate is the sum of the stratified estimates; 149 (CV = 27.9%; 95% CI 87–255).

For finless porpoises the selected detection function generated an unstratified estimate of 129 individuals (CV = 38.6%; 95% CI 62–269). Stratifying by region showed that the highest densities by far occurred in the Bako-Buntal Bay. Although the sum of the estimates stratified by region is similar to the unstratified estimate, the former has a lower CV and so the best total estimate is the sum of the stratified estimates 135 (CV = 31.3%; 95% CI 87–255). Stratifying by season showed a much higher density in March–May. The high CVs of these seasonal estimates make them less reliable.

Population estimates generated by mark-recapture analysis. — In general, Irrawaddy dolphins, with their small group sizes and unpredictable surfacing patterns proved difficult to photograph. Only a small percentage of photos taken at each sighting were suitable for use in photo-identification and an even smaller percentage met the filtering criteria (photo quality 2 or higher, individual distinctiveness of 3 or higher) for use in mark-recapture analysis. For this filtered dataset of photographs of the right sides of animals, 55 "captures" were made of 48 separate individuals. Of these, 42 were captured in one year only, five twice, and one individual was photographed in three separate years. The filtered sighting histories of left sides of dorsal fins included 62 captures in total of 54 individuals with 47 seen in one year only, six in two separate years, and one individual across three separate years.

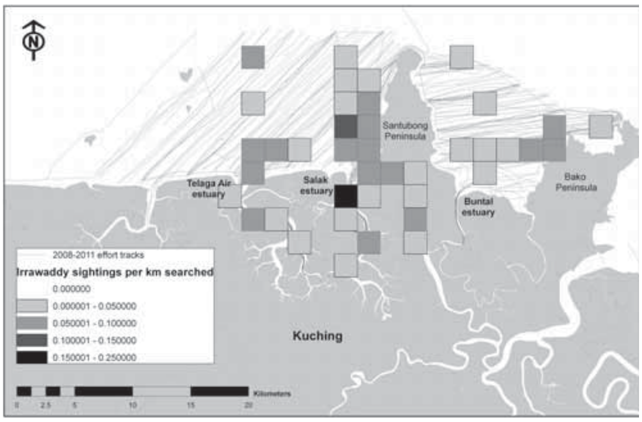
The mark-recapture models that fitted the data best (left and right side photographs) included capture probabilities that varied with time. The model in which capture probability did not vary at all and the mixture model to account for heterogeneity of capture probabilities did not perform as well as the best-fitting model, but they both yielded similar results for both the right- and left-side datasets. Other models performed poorly. Table 3 shows the results of the best fitting mark-recapture model run on the Irrawaddy dolphin sighting histories when filtered for quality (score of 2 or higher) and distinctiveness (score of 3 or higher).

The population estimate generated from photos of left sides of dorsal fins (LDFs) was 149 individuals (CV 29%, 95% CI 95–276). The estimate from photos of right sides (RDFs) was 136 (CV 31%, 95% CI 84–264). Estimates of the proportion of distinctive individuals in the population were 0.705 (CV = 8.3%) for LDFs and 0.524 (CV = 12%) for RDFs. Population estimates corrected for these proportions were 211 (CV = 30%, 95% CI 119–377) and 260 (CV = 33%, 95% CI 137–490), respectively. The mean of these estimates for left and right side photos, weighted by inverse CV-squared, was 233 (CV = 22.5%, 95% CI 151–360); this is our best estimate of Irrawaddy dolphin population size from the photo-identification data.

Distribution of sightings and apparent "core" habitat. — Fig. 3a, b portray relative densities of Irrawaddy dolphins and Indo-Pacific finless porpoises. Each 2 × 2 km cell is shaded to represent the number of sightings per kilometer searched, with darker shading indicating a higher encounter rate. These figures show the highest relative density of Irrawaddy dolphins to occur in the 2 × 2 km cell located in the mouth of the Salak River, with high densities also occurring in the wider Salak-Santubong and Telaga Air estuaries and off the west coasts of both the Santubong and Bako peninsulas. Encounter rates were highest for Indo-Pacific finless porpoises on the west coast of the Bako peninsula, demonstrating an area of overlap of key habitat between the two species.

Movement of individually identified Irrawaddy dolphins. — Fig. 4 shows the locations of sightings of a selection of individual Irrawaddy dolphins that were recognised by photographs of the right sides of their dorsal fins, and that were observed on at least two separate occasions. The minimum distance between multiple re-sights is less than 10 km, as displayed by individual KCH08-RDF-036, which was observed on three separate occasions between Nov.2008 and

a



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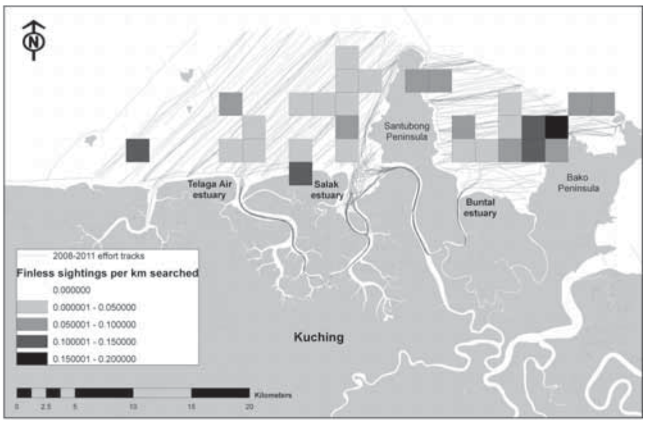

Fig. 3. Relative densities for Irrawaddy dolphins (a) and finless porpoises (b). Densities are represented as the number of sightings per km searched in 2 × 2 km grid cells. This includes all on-effort sightings and all effort tracks from the start of the project in Jun.2008 through Oct. 2011.

Table 3. Abundance estimates (N) of Irrawaddy dolphins in the Kuching Bay calculated using mark-recapture methods and corrected for the proportion of marked animals in the population. Estimates include photographs of quality 2 and above and animals of distinctiveness 3 and 4. For both left and right side dorsal fin photograph datasets, the model chosen was that which assumed equal capture and recapture probabilities, but allowed capture probabilities to vary over time with each capture occasion. See text for explanation of proportion marked and corrected estimates.

Side dorsal fin photographed	Model	N (mark-recapture)	CV (%)	95% CI	Proportion marked (CV %)	N (corrected) (CV %)	Corrected 95% CI
Left	Capture probability varying with time	149	29	95–276	0.705 (8.3)	211 (32)	114–390
Right	Capture probability varying with time	136	31	84–264	0.524 (12)	260 (32)	142–474

Apr.2010 in the Salak River mouth. The maximum distance between re-sights of an individual is a straight-line distance of 26 km as displayed by KCH09-RDF-020, which was observed on the western side of the Salak-Santubong estuary in Aug.2009, and on the eastern side of the Bako-Buntal bay in May 2010. The actual route taken to navigate between these two positions would be over 35 km, either around the Santubong peninsula or through the Santubong and Buntal rivers. In general, site-fidelity appears to be higher in the Santubong-Salak estuary with a higher number of re-sightings occurring in this area.

In the overall matching effort including photographs of all quality and distinctiveness scores, and including within-year re-sightings, based on right sides of dorsal fins, 12 individuals were seen on two occasions and two individuals were seen on three occasions. One of these individuals (KCH07-RDF-007) was seen again twice in 2011 (included in Fig 4 despite being beyond the time frame of most other data presented here). Based on the dataset of left sides of dorsal fins, a total of eight individuals were seen twice, and four individuals were observed three times.

DISCUSSION

Possible violations and sources of bias. — The line transect surveys were designed as far as possible to minimise violation of the assumptions of the method (Buckland et al., 2001). However, our estimates of both Indo-Pacific finless porpoises and Irrawaddy dolphins are likely to be negatively biased by detection probability ($g_{(0)}$) being less than 1 on the transect line because of animals being beneath the surface much of the time, as well as the inconspicuous surfacing behaviour and small group size of both species. Some studies have used data collected on species-specific dive times to generate alternative values of $g_{(0)}$ as a correction factor for inconspicuous or long diving species (e.g., Marsh & Sinclair, 1989; Jefferson et al., 2002). Our methods did not allow for accurate collection of data on the species' "availability bias", and using data from other studies would not be justifiable because the so-called perception bias component of a $g_{(0)}$ correction is survey dependent, generally requiring double platform surveys

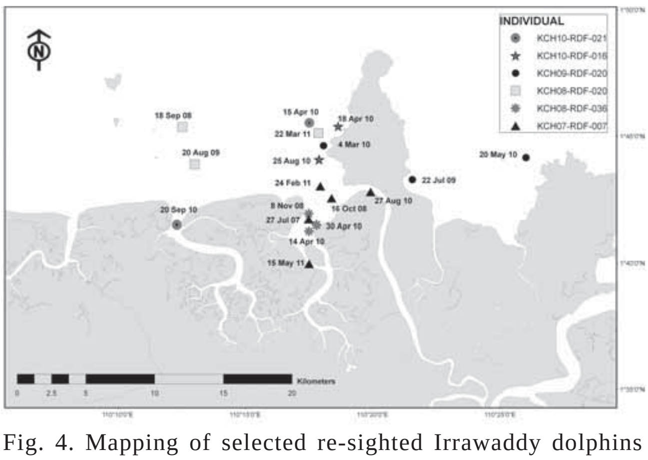

Fig. 4. Mapping of selected re-sighted Irrawaddy dolphins represented by photographs of the right sides of their dorsal fins in the Kuching Bay area.

(Hammond, 2010). The extent of any negative bias in our line transect estimates is therefore unknown.

Line transect estimates may be further biased by the approach to river transects, which was to navigate down the middle of each river or mangrove channel. Where channels were less than 200 m in width, this may have been a valid approach, allowing equal coverage of all habitat types within the channel, but on the portions of rivers that were wider (maximum 450 m), the results of the line transect analysis show that our effective half-strip width was only 104 m for Irrawaddy dolphins and 87 m for finless porpoises. As such, it is likely that the areas near the riverbanks were not effectively covered. Given the high densities of Irrawaddy dolphins in the river stratum, future surveys should strive to achieve more systematic and representative coverage of wider stretches of river (e.g., Dawson et al., 2008; Williams & Thomas, 2009).

Yet another possible source of bias in line transect surveys can result from animal attraction to, or avoidance of survey vessels. In our study systematic data on animal movement with respect to the vessel was only collected in the 2011 survey season, so could not be analysed for the entire survey period. However, in 2011, the vast majority of groups sighted were considered to be moving neither towards nor away from the vessel. As such, we do not believe this was a significant source of bias in our estimates.

Our assumption of closure is violated by births and deaths in the population over the four years of the study and may also be violated by emigration or immigration from outside the study area. Two 3-day surveys of the Muara Tebas area (east of the Bako peninsula) in 2009 and 2010 yielded a small number of Irrawaddy dolphin sightings. Although there were no photographic matches between those animals and the ones sighted within our core study area, it is possible that there is some movement and mixing around the Bako Peninsula. On the other hand, the lack of sightings of Irrawaddy dolphins in the far western portion of the Salak-Santubong Bay indicates that large numbers of animals are unlikely to be entering the population from that side. The relatively high number of re-sightings and high level of site-fidelity implied by the photo-identification data (Fig. 4) also indicate a population for which the bias from emigration or immigration is likely to be low. These observations imply that the animals in this area can reasonably be considered as a resident population.

Mark-recapture estimates are often subject to downward bias due to heterogeneity in capture probabilities (Hammond, 1990, 2010). However, in our study the models incorporating heterogeneity performed poorly. One reason for this could be that the systematic sampling of a relatively large survey area may have helped to reduce any heterogeneity in the data caused by preferences of individuals for particular areas.

Comparison of line transect and mark-recapture results. — For Irrawaddy dolphins, line transect models generate slightly lower estimates of abundance than the mark-recapture method, however the 95% confidence intervals of the estimates from each method show a high degree of overlap, and can certainly be considered to be "in the same ballpark". The CVs for both methods are also comparable, falling between 20% and 30% for different models. The slightly lower estimate derived from line-transect sampling is expected and logical, as this method estimates the average density within the boundaries of the study area over the study period, while mark-recapture methods estimate the total number of individuals using the area over the time period. Because we suspect that our target population ranges beyond the limits of our study area, we would expect (if all assumptions are met) mark-recapture estimates to be larger than line transect estimates. Our line transect estimates are uncorrected for animals missed on the transect line (see above), but the correction would need to be substantial for the total line transect estimate to become larger than the mark-recapture estimate.

In the Mahakam River, Kreb (2004) also found that line-transect estimates generated slightly lower abundance estimates for Irrawaddy dolphins than those obtained using mark-recapture, but with overlapping confidence intervals. Similarly, in the Mekong River, Beasley (2007) obtained marginally lower estimates from line-transect methods than from mark recapture, but again, with overlapping 95% confidence intervals. In this case, mark-recapture estimates offered a much higher level of precision with CVs of only 7%.

While mark-recapture methods have frequently been used with Irrawaddy dolphins and other coastal species demonstrating a high degree of site-fidelity or residency within a study area (see Smith, 2009), they can obviously only be used with species and/or populations that are not overly not boat-shy and have distinctive features (Wursig & Jefferson, 1990). Our project initially had difficulty obtaining sufficient numbers of photographs of suitable quality for this population which displays particularly elusive and unpredictable surfacing patterns. Using line transect methods in parallel with photo-identification and mark-recapture methods over a 2-year period allowed a higher likelihood of obtaining reliable population estimates, and also ensured a systematic coverage of our entire survey area to minimise bias from heterogeneity in mark-recapture. The fact that both methods yielded comparable results through completely different means, gives us confidence and lends more credibility to the estimates that have been generated. As such, for management purposes, it is probably most practical to assume a population between 100–300 individuals for Irrawaddy dolphins, and a similar number for Indo-Pacific finless porpoises, with an understanding that the latter are likely to fluctuate seasonally.

Conservation implications. — These estimates are important for a number of reasons. Firstly, they represent some of the first reliable population estimates for coastal as opposed to riverine populations of Irrawaddy dolphins. The only other published estimates for coastal Irrawaddy populations to date are from line-transect surveys that yielded abundance estimates of 77 dolphins (CV = 27.4%) in the Malampaya Sound, Philippines (Smith et al., 2004) and 5,383 individuals

(CV = 39.5%) in the nearshore waters of Bay of Bengal, Bangladesh (Smith et al., 2008).

Freshwater populations that have been studied appear to be much smaller, with mark-recapture estimates of only 48–55 individuals the Mahakam River, Indonesia (CV = 6–15%) (Kreb, 2004) and 127 (CV = 7%; 95% CI = 108–146) in the Mekong River (Beasley, 2007). Sutaria & Marsh (2011) applied a closed population model to obtain an estimate of 107 individuals (CV = 8%) and an open population model to obtain an estimate of 109 individuals (CV = 7%) in Chilika Lagoon, India.

While estimates for a few populations of the narrow-ridged finless porpoise (*N. asiaeorientalis*) have been made predominantly off the coasts of Japan and Korea (e.g., Shirakihara et al., 2007) ours represent the only abundance estimates for Indo-Pacific finless porpoises apart from those for Hong Kong, where the most recent estimate is at least 217 (CV 21–150%) (Jefferson et al., 2002) and Bangladesh, with an estimated population of 1,382 (CV 55%) (Smith et al., 2008). As in this study, densities of Indo-Pacific finless porpoise in Hong Kong, Pakistan, and Iran were also found to fluctuate seasonally, with the highest densities occurring in the spring and an apparent movement offshore in the summer and autumn (Pilleri & Gihr, 1975; Jefferson et al., 2002; Braulik et al., 2010).

Our abundance estimates for both Irrawaddy dolphins and Indo-Pacific finless porpoises are relatively small, and indicate a cause for concern. Given both species' vulnerable conservation status globally, there is an urgent need to better understand how these abundance estimates, which focus on a very small geographic area, relate to threats in the region, and to establish whether these small populations are genetically isolated or still in breeding contact with other neighbouring populations in Sarawak or beyond.

The relatively small population estimates, coupled with the clear identification of small areas of preferred habitat in river mouths and along the west coasts of the two prominent peninsulas in the study area, should help to focus conservation efforts for both species. Fishing effort, using drift nets from small fiberglass fishing boats is also concentrated in these areas, and working with fishermen will be crucial in managing the threat posed by gillnet entanglement. Preliminary results of a detailed interview-based fisheries study that is currently underway indicate that entanglement of Irrawaddy dolphins occurs throughout the year. The gear most often involved appears to be triple layer drift gill nets, but because these are usually attended during soaking, fishermen are often able to free and release animals. The survival rate of freed animals, some of which were reported to be very weak upon release, is unknown. Further analysis of the interview data upon completion of the study, together with direct observations of fishing effort during line transect surveys should help to shed light on the scope and scale of the threat presented by coastal fisheries.

Additional threats in the Kuching Bay are posed by increasing aquaculture ventures, with dozens of shrimp and fish farms (Ling et al., 2010) recently being constructed in the estuarine portions of the Santubong River (see Fig. 1) and mangrove channels between the Santubong and Salak rivers. The clearing of mangrove and nipah palm groves and filling in of wetlands for the development of low-cost housing estates along the Santubong River, as well as the regular harvest of mangrove wood for charcoal throughout the area is another source of concern, as these activities reduce the water quality of estuarine habitat. Perhaps the most pressing concern in the Kuching Bay is the ongoing construction of a major flood-mitigation channel that will divert millions of cubic meters of fresh silt-laden water into the Salak River (e.g., http://thestar.com.my/metro/story.asp?file=/2009/5/15/southneast/3888219&sec=southneast).

Recommendations. — While these abundance estimates represent an important step toward the assessment of the conservation status of two coastal cetacean species with restricted distributions, this is only the beginning of working toward concrete and effective conservation measures. We recommend long-term monitoring, using the same techniques used for this study, modified, as appropriate, to address issues relating to line transect sampling, to allow detection of trends in population numbers and/or shifts in geographical distribution in the face of ongoing and planned coastal developments. For example, a longer-term mark-recapture study using open population models may help to reveal whether there is a trend toward increase or decrease in this population, and may also yield more accurate information about ranging patterns within the population. We also recommend the use of passive acoustic monitoring to understand distribution and habitat use of these two species on a finer scale, especially in seasons and at times of day when visual surveys are not practical. Finally expanded survey effort into neighbouring regions of Sarawak's coastline, as well as the introduction of genetic studies (through the use of biopsy sampling) are essential to determine the full range of each species' distribution along the coast and to define effective management units.

Researchers will need to work closely with government authorities, developers, fishing communities and other relevant stakeholders to apply these findings to the development of appropriate measures to mitigate the impacts of fisheries and coastal development.

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