RAFFLES BULLETIN OF ZOOLOGY **67**: 671–683
Date of publication: 26 November 2019
DOI: 10.26107/RBZ-2019-0048
http://zoobank.org/urn:lsid:zoobank.org:pub:114BB16C-37B4-4063-AC59-8453A944039F

Population size, distribution and daylight behaviour of Irrawaddy dolphins (*Orcaella brevirostris*) in Penang Island, Malaysia

L.H. Rodríguez-Vargas[1,2], L. Rajamani[1*], L. Dolar[3] & L. Porter[4]

Abstract. The Irrawaddy dolphin (*Orcaella brevirostris*) is endemic to South and Southeast Asia and occurs in shallow coastal waters, associated with freshwater input, coastal lagoons and in three rivers. The status of all except the riverine populations is poorly understood, however, the proximity of all populations to areas of intense coastal development led to the 2017 IUCN classification of 'Endangered'. This is the first description of a coastal estuarine Irrawaddy dolphin population in Penang Island, Malaysia, and provides baseline information on population size, distribution, group structure, and daylight behaviour. Vessel-based observations were conducted throughout 2013 and mark-recapture analysis of the photo-identification data was used to estimate population size. Thirty individuals were identified from 28 unique left and 26 unique right dorsal fins. Closed and open models were used to estimate a population size of 32 ± 3 (SE) and 43 ± 12 (SE) individuals, respectively. Sightings of Irrawaddy dolphins were recorded throughout the study area in the estuary of Balik Pulau (west Penang), mostly between Sungai [=River] Pinang and Sungai [=River] Burung, usually during high tide and close to shore. The mean group size was 5 ± 0.5 (SE). Juveniles (n=26) were sighted throughout the year. Mother-calf pair (n=16) sightings peaked in May. During the surveys, feeding was the most commonly observed behaviour (60%) followed by milling (16%), travelling (14%), and socialising (2%). Groups of dolphins were observed moving in a circular pattern creating loops while feeding, and returning to the point where the activity started. This appears to be the first documentation of dolphins following prey in large circles over several hundreds of metres. As this population occurs within a restricted habitat, the impact of fishing and other anthropogenic activities in the area is high. As coastal development continues to increase, there is an urgent need to develop a management plan to better protect this critical habitat and the dolphins that live within.

Key words. marine mammal, Cetacea, Delphinidae, Irrawaddy dolphin

INTRODUCTION

The Irrawaddy dolphin (*Orcaella brevirostris*) occurs in estuarine areas, rivers, and semi-enclosed lagoons (Minton et al., 2017). In South and Southeast Asia, however, these habitats are highly polluted and are becoming increasingly degraded (Dudgeon, 1992; Islam & Tanaka, 2004). Several populations of this species have been documented in coastal areas; Malampaya Sound, Palawan, Philippines (Dolar et al., 2002; Smith et al., 2004), Sundarbans, Bangladesh (Smith et al., 2006; Smith et al., 2008), Kuching Bay, Sarawak, Malaysia (Minton et al., 2013), Sandakan Bay, Sabah, Malaysia (Dolar et al., 1997), the Gulf of Thailand, Thailand (Hines et al., 2015), and Iloilo Strait, Philippines (Dolar, 2010). There are five freshwater populations; the Mekong River, spanning Laos, Cambodia, and Vietnam (Beasley et al., 2002; Beasley, 2007), the Mahakam River, Indonesia (Kreb et al., 2007), Chilika Lake, India (Sutaria & Marsh, 2011), Songkhla Lake, Thailand (Beasley et al., 2002), and the Ayeyarwaddy River, Myanmar (Smith & Mya, 2007).

These populations inhabit the waters of some of the world's fastest developing countries, where wildlife conservation is often outweighed by the importance of economic growth (Sodhi et al., 2004; Sodhi et al., 2010). As such, Irrawaddy dolphin populations are subject to the various threats associated with economic growth, such as habitat loss and fragmentation and pollution in addition to the persistent threat of interactions with fisheries. Irrawaddy dolphin populations are small and mortality related to anthropogenic activities can have a profound impact (Beasley et al., 2002; Smith et al., 2004; Kreb et al., 2007; Smith & Mya, 2007; Beasley et al., 2013, Minton et al., 2017). As a result of these myriad threats, coastal populations of Irrawaddy dolphin were recently upgraded from "Vulnerable" to "Endangered" on the IUCN Red List of Threatened species and the five riverine populations remain listed as "Critically Endangered" (Minton et al., 2017).

[1]Centre for Marine and Coastal Studies, Universiti Sains Malaysia 11800 USM, Penang, Malaysia; Email: leelarajamani@usm.my (*corresponding author)

[2]Inter-American Convention for the Protection and Conservation of Sea Turtles, Leesburg Pike, Falls Church, Virginia 22041-3803, USA

[3]Institute for Environmental and Marine Studies (IEMS), Silliman University, Bantayan, Dumaguete City, 6200, Philippines

[4]The University of St. Andrews, College Gate, St. Andrews, Scotland, Fife KY16 9A, UK

ISSN 2345-7600 (electronic) | ISSN 0217-2445 (print)

In Malaysia, Irrawaddy dolphin populations have been recorded in the east in Sandakan and Kuching Bays (Dolar et al., 1997; Minton et al., 2013) and around Penang Island, Peninsular Malaysia (Rajamani et al., 2018). Penang is undergoing rapid coastal change with many ongoing and proposed infrastructure development and land reclamation projects (Chee et al., 2017). As the dolphin population is endangered as listed in the IUCN Red list of Threatened Species and occurs in a rapidly degrading habitat, this research provides baseline information on population size, distribution, structure and movement patterns and it is hoped that this new information will be useful for the development of management plans aimed at conserving Penang coastal habitats and the species that dwell therein.

MATERIAL AND METHODS

Study site. Penang Island is located in Peninsular Malaysia (05°08′0″N to 05°35′0″N and 100°08′0″E to 100°32′0″E) and covers an area of about 293 km^2 (Ismail et al., 2002) (Fig. 1). West Penang consists of a small estuarine area, approximately 80 km^2 comprises some 14 km of mangrove coastline and is a shallow, microtidal habitat with freshwater input from six different rivers, including Sungai Pinang and Sungai Burung. The estuarine area extends approximately 2 km seawards and is on average 2 m in depth (Horton et al., 2008; Rosli & Yahya, 2013).

Distribution, population size and movement patterns. In 2013, thirty-eight boat surveys were conducted in the months of February, March, May, July, September, October, and November, and environmental parameters were recorded once a month for seven months of the study period. Boat surveys commenced in the morning (from 0730–0900 hours) and were usually completed within six hours. The surveys were conducted from a small fishing vessel (7.6 m) which travelled a pre-determined route that covered all accessible habitat (approximately 80 km^2; Fig. 1). The surveys were conducted by two experienced observers.

Whenever a cetacean was sighted, the geographic location was recorded using a GPS unit, as well as the time, species, group size, group composition (e.g. number of calves, juveniles, and adults), and observed behaviour. Considerable time was spent with each group to ensure that all individuals in the group were photographed and to facilitate sufficient observations of behaviour and group dynamics. A sighting ended after all individuals had been photographed or when 15 minutes had elapsed since the last surface.

Photographs were taken using a DSLR camera Nikon D3200, with a 70–300mm lens. Calves were distinguished as animals smaller than 2/3 the length of an adult, regularly accompanying a larger animal presumed to be the mother. Juveniles were defined as individuals approximately 2 m in length that swam independently from larger dolphins, and adults were defined as those approximately 2.5 m length, and more robust in form than smaller individuals (Parra et al., 2006).

After taking photos of the individuals observed, the behaviour was determined according to previously published behavioural states for coastal cetacean species, i.e. feeding, travelling, socialising, milling and undetermined (Shane et al., 1986; Karczmarski et al., 1999; Parra, 2006) with modifications based on personal observations (See supplementary material for definition of behaviour in this study). When multiple behaviours were observed, the predominant behaviour was used for analyses.

Population size was determined using the mark-recapture method and photo-identification techniques (Hammond, 2009). In this method, an individual dolphin is identified based on the shape and pigmentation of the dorsal fin, scratches, and wounds on the upper body and most importantly, marks that were most likely to be discernable throughout the duration of the study, e.g., deep scars and deformities (Würsig & Jefferson, 1990).

Habitat. During the surveys, environmental parameters were also measured. Measurements were made every 20 minutes and immediately after dolphin sightings. Sea surface temperature (SST) (°C) and salinity (expressed in Practical Salinity Unit or PSU) were measured using a CastAway® CTD; whereas turbidity (expressed in Nephelometric Turbidity Units or NTU), was measured using a Hach® 2100P turbidity meter, and depth (meters) was measured using a HawkEye® handheld depth finder. The geographical position was recorded using a GPS Garmin 76csx. Sea state was determined according to the Beaufort scale, and surveys were generally conducted during Beaufort $\leq$ 3. The tide level (m) was estimated from the Tide Table for Penang (National Hydrographic Centre, 2013). The mean sea level (MSL) in Penang as defined by the Malaysia National Hydrographic Centre is 1.7 m (National Hydrographic Centre, 2013). All the values above the MSL were recorded as high tide, whereas all those equal or below the MSL were recorded as low tide.

Analysis. Photo-identification and population size. Images taken during the surveys were graded according to their quality and only those of sufficient quality were used to identify individual dolphins (Urian et al., 2015). Individuals with insufficient markings to classify them as unique were also noted. The photo ID catalogue comprised three sets, leftside dorsal fins (LDF) only, rightside dorsal fins (RDF) only and all fins (OBP). A discovery curve was plotted for all three sets. Each catalogue set, LDF, RDF, and OBP was grouped into five sampling occasions of two months each.

Population size was estimated using mark-recapture analyses using the program MARK® (Cooch & White, 2018). This software has been successfully used in several studies to estimate the Irrawaddy dolphin population size (Parra et al., 2006; Minton et al., 2013). In MARK, both closed and open population models were explored. In general, closed population models are considered more robust because of model precision, however, it is assumed that there is little change from births, deaths, immigration or emigration during the study period (Hammond, 2009). As this assumption is almost never fully met, certain closed models are more

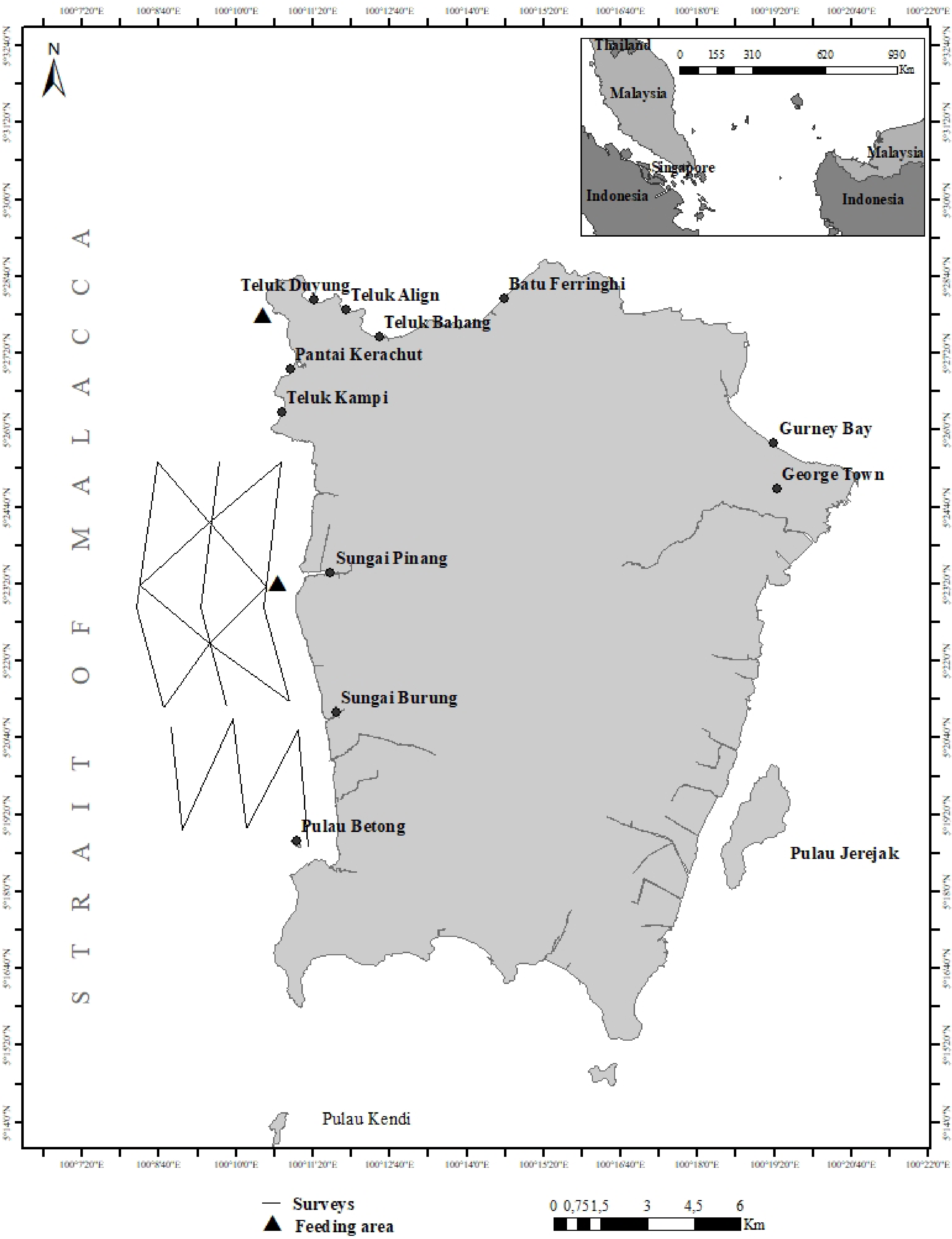

Fig. 1. Penang Island. Shown are the survey trackline west of island and fishing villages.

Table 1. Environmental parameters collected during the study and during boat survey sighting events.

Parameter		Parameters of the study area (no sightings)	Parameters during sightings
Depth (m)	Mean	4.68	4.39
	Range	1.20–11.30	1.2–11.30
Salinity (psu)	Mean	30.94	30.57
	Range	29.06–32.97	28.57–32.37
Turbidity (ntu)	Mean	25.04	25.07
	Range	7.13–92.00	7.13–70.2
Sea surface temperature (°C)	Mean	30.86	30.71
	Range	29.29–32.08	29.12–32.08

flexible and allow for heterogeneity in capture probability with fewer limitations than open population models (Otis et al., 1978; Wilson et al., 1999; Lettink & Armstrong, 2003). Four different models for closed populations were tested to determine which one was the most parsimonious for population size estimates: Mth (time dependent and a heterogeneous probability of detection), Mb (behaviour dependent), Mt (time-dependent), and Mo (constant) (Otis et al., 1978).

Open population models consider variation in population size during the study period, so, when assumptions of closure may not be met, it can be useful to compare estimates of both open and closed models (Sutaria & Marsh, 2011). The models with the lowest Akaike Information Criterion (AIC) were used to determine the best model for each data set. The POPAN formulation for Jolly-Seber was used to compare four different models (Table 2) for open populations, where p = capture probabilities; ϕ = survival probabilities, and *PENT* = a probability of entrance of other individuals in the parameterisation, as a function of time (Cooch & White, 2018). Since MARK only estimates the number of marked animals, a correction factor that includes the unmarked animals was used in order to calculate the total population size (Minton et al., 2013).

Distribution and movement patterns. Distribution was determined by plotting the location of sightings using ArcMAP 10.1. This plot was also used to determine where the dolphins were found at different tidal levels. Locations of each photo-identified dolphin were also mapped using the same software. A grid with squares of 1 km × 1 km was used to estimate the distance between sightings of each identified individual, thus mapping movement patterns during the period of this research (Minton et al., 2011). Two periods of the day, 1000 to 1200 hours (morning) and 1200 to 1400 hours (afternoon), were compared by the number of sightings per timeframe of day where the survey effort was the same.

Environmental parameters. The Statistical Package for the Social Sciences (SPSS 15.0) was used to determine the mean, standard error, and maximum and minimum values of each parameter. A binary logistic regression was run using a forced entry method to predict the absence or presence of the dolphins according to the environmental variables measured during the sightings, i.e. sea surface temperature, salinity, turbidity, depth, and tide height. Also, to model the parameters in the area at the moment of sampling, the GPS positions were plotted in ArcMAP 10.1 along with an interpolation of the measurements using the Kriging tool, in which the function error is calculated automatically.

Behavioural studies. Behavioural information was organised in an Excel database. To establish the frequency in which each type of behaviour was observed throughout the study, an analysis of the frequency distribution of behaviours was generated using Statistical Package for Social Science program (SPSS) 15.0.

RESULTS

Sightings occurred on 25 out of 38 days. A total of 43 sightings of Irrawaddy dolphins were recorded, with an encounter rate of 0.25 sightings per hour, and 1.13 sightings per day. Sightings lasted from 15 to 143 minutes, with a mean sighting duration of 45.35 ± 5.29 (SE) minutes. Most of the sightings (81%) were recorded within 2 km of Sungai Pinang and Sungai Burung river mouths. Only one opportunistic sighting was recorded in Teluk [=Bay] Duyung (on the northwest coast and ~ 9 km from the survey site) adding a new point to Irrawaddy dolphin distribution limits, thus expanding the known distributional limit. This indicates that the range is probably further than previously thought of as the areas between Sungai Pinang and Teluk Kampi. The mean values of sea surface temperature, salinity, and turbidity during sightings were 30.71 ± 0.12 (SE) °C, 30.57 ± 0.13 (SE) PSU, and 25.07 ± 2.96 (SE) NTU, respectively (Table 1). There was no significant difference in the water depths between areas where there were dolphins and areas where there were no dolphins. Dolphins were recorded in waters between 1.2 and 11.3 m depth, with a mean of 4.39 ± 0.26 m. Tidal height during sightings ranged from 0.9 m to 2.7 m. Values of turbidity varied between samples (min 7.13–max 70.2 NTU) but sightings were mostly recorded in spots with turbidity of >20 NTU.

Table 2. Most parsimonious closed and open population models used to estimate abundance using individuals identified separately by marks in their right (RDF) or left (LDF) dorsal fin, and jointly regardless of the side of the mark (OBP). Mt = Model of capture probabilities varying with time; p = capture probability; ϕ = survival probability; (·) constant variable; (t) time-dependent variable; n = number of individuals identified, $\hat{N}$ = population size estimate of marked individuals only; SE = Standard Error; θ = Proportion of marked individuals; Ntotal = Total population size estimate; CV = Coefficient of variation; 95% CI = Confidence Interval.

	Model	n	$\hat{N}$	SE	CV	95% CI	θ	Ntotal	SETotal	CV	95% CI
Closed Population Models											
LDF	Mt	23	29	4	0.15	22–39	0.90	32	6	0.18	23–45
RDF	Mt	25	35	7	0.20	24–52	0.84	42	6	0.15	31–57
OBP	Mt	26	28	2	0.07	24–32	0.87	32	3.1	0.18	23–45
Open Population Models											
LDF	p(t), ϕ (·)	23	36	11	0.30	21–64	0.90	40	13	0.32	22–75
RDF	p(t), ϕ (·)	25	43	10	0.24	27–68	0.84	51	13	0.26	31–84
OBP	p(·), ϕ (·)	26	37	9	0.25	23–60	0.87	43	12	0.28	25–73

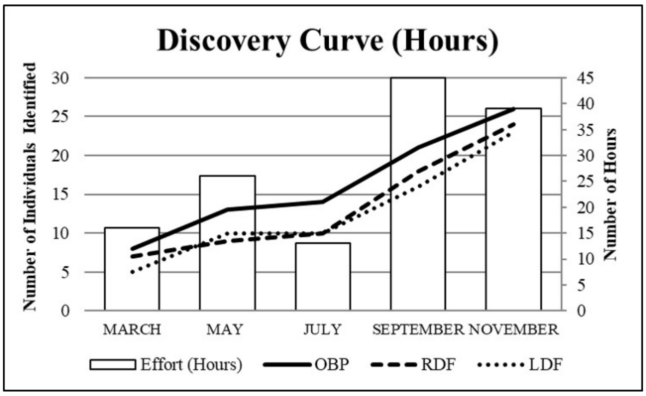

Fig. 2. Discovery curve showing the accumulation of new individuals identified during the period of study, related to the effort in hours per month when sighting were recorded. LDF = Left dorsal fin; RDF = Right dorsal fin; OBP = regardless of side.

There was no significant difference in the environmental parameters of the study area when dolphins were observed and not observed (Table 1). The logistic regression analysis showed to be most suitable when $\chi^2 > 0.05$ (Table 1), and none of the parameters values was significant to predict the absence/presence of the dolphins.

Photo-identification. Thirty (30) individual Irrawaddy dolphins were identified combining all photo-identification data; twenty-eight (28) individuals were identified by their left dorsal fin (LDF) only, and 26 by their right dorsal fin (RDF) only. The discovery curve (Fig. 2) did not plateau indicating that all individuals within the population had not yet been photographed and that more effort is required (Karczmarski et al., 1999; Parra et al., 2006).

Population size. The Irrawaddy dolphins' population size was estimated using OBP, LDF, and RDF datasets (Table 2). The closed population time dependent model (Mt) values of dispersion were the closest to real circumstances in all three cases. Total closed population estimates from the time dependent model (Mt) were between 32 and 42 individuals (Table 2). Open population POPAN formulation for Jolly-Seber showed that for both LDF and OBP estimates, the model p (t), ϕ (.), *PENT* (t) was the most parsimonious, whereas for RDF it was p (.), ϕ (.), and *PENT* (t). Total open population estimates were between 40 and 51 individuals (Table 2).

Distribution patterns. Dolphins were sighted between 0.6 and 5 km from shore. Sightings occurred frequently between Sungai Pinang and Sungai Burung river mouths, and most often at the Sungai Pinang river mouth (Fig. 3). The most northern sighting was recorded opportunistically at Teluk Duyung (05°28′13″N–100°11′22″E) and the most southern sighting was recorded during low tide near Pulau [=Island] Betong (05°18′51″N–100°11′2″E). Thirty-one sightings (72%) occurred during high tide and 12 sightings (28%) during low tide. Two sightings recorded at approximately five kilometres from shore occurred during low tide, whereas the majority of sightings were recorded closer to shore during high tide periods (Fig. 3B).

Four of the most frequently sighted dolphins (OBP006, OBP0010, OBP1004, and OBP007) provided an indication of the spatial range of individuals during the study period (Fig. 3A). Both OBP006 and OBP0010, sighted on four and six different days, respectively, had distances between sightings as long as 16 km. This is the furthest apart Irrawaddy dolphins were noted during this study period. OBP004 was sighted on four different days, the largest distance between sightings of this individual was 14 km, and OBP007 was sighted on seven occasions, and the largest distance between sightings of this individual was 6 km. Other individuals that were recorded on more than three occasions were within the same small bay.

Group composition. Mean group size was 5 ± 0.5 (SE) individuals, with a maximum of 15 individuals and a minimum of two; the mode of the group size was three individuals. From the 43 sightings, 7% were single individuals and 93% were groups. Juveniles were observed in 47% of these group sightings, and calves were observed in 33%.

Average group size was highest in February and lowest in March 2013 (Table 3). From the total number of Irrawaddy

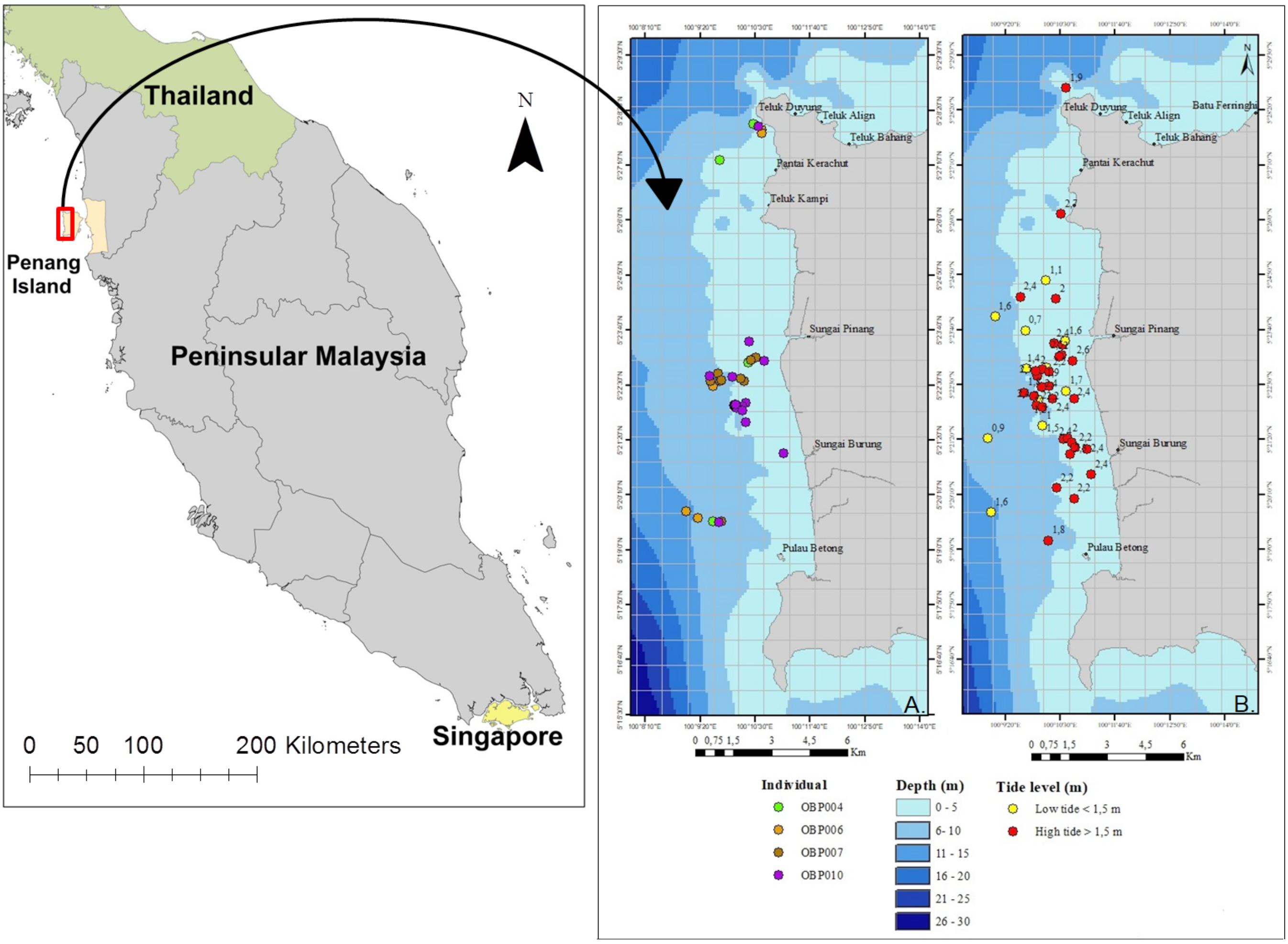

Fig. 3. A, individuals with the widest range of distribution during the time of the study; B, distribution of the sightings with the tide level (m) recorded for each sighting.

Table 3. Mean group size, range, number of groups and total individuals in relation to the proportion of juveniles and calves found during the study. SE = Standard Error. A = Adults; J = Juveniles; C = Calves.

Month	Group Size		Number of Groups	Total Individuals Counted	A	J	C	Proportion of Juveniles (%)	Proportion of Calves (%)
	Mean ± SE	Range							
February	8 ± 2	6–10	2	16	15	1	0	6	0
March	3 ± 1	1–7	6	21	20	1	0	5	0
May	6 ± 2	1–15	8	59	43	10	6	17	10
July	6 ± 4	2–9	2	11	7	3	1	27	9
September	5 ± 1	2–8	10	47	39	4	4	9	9
October	4 ± 1	2–6	6	24	17	3	4	13	17
November	5 ± 1	3–9	6	30	25	4	1	13	3
Total			40	208	166	26	16	13	8

dolphins counted on the study sighted (n=208), 13% (n=26) were juveniles and 8% (n=16) were calves. Mother-calf pairs were observed in 14 (32%) of the 43 sightings, mostly in May (n=5; 12%) and September (n=4; 9%), followed by October (n=3; 7%), July (n=1; 2%) and November 2013 (n=1; 2%). Groups including juveniles and calves had six to fifteen individuals. The biggest group of Irrawaddy dolphins (n=15) which included two calves and one juvenile was recorded in October 2013.

Two mother-calf pairs were recorded in May and in October 2013, confirming the presence of at least two females throughout the study period. These pairs were seen in groups of three to eight individuals. At least two observations of mothers and calves included the presence of a third individual in close proximity.

Dolphin occurrence and behaviour. Out of the 43 sightings, 31 (72%) sightings were recorded between 1000 and 1400 hours. Most of the sightings (53%; n=23) were observed in the morning between 1000 to 1200 hours, and 9% (n=8) in the afternoon between 1200 to 1400 hours. Feeding was the behaviour most commonly observed (60%), followed by milling (16%), travelling (14%) and socialising (2%). Feeding was concentrated between Sungai Pinang and Sungai Burung river mouths (Fig. 4).

Groups feeding (60%) were observed moving in a circular pattern, creating loops and returning to the point where the activity started (Fig. 5) with synchronised diving of two to three individuals occurring often, including mothers and juveniles. Also, individuals feeding would pause before diving to presumably hunt and produced loud sounds when exhaling. Leaps were observed but only in two sightings and aggregations were considered as a socialising behaviour. While travelling the groups displayed one-direction swimming with regular surface intervals, and milling was the very opposite of this, with less movement and irregular surfacing.

DISCUSSION

The size of the population of Irrawaddy dolphins in West Penang was estimated from closed population models, to be 32 to 42 individuals, and from open population models, to be 40 to 51 individuals. This small population size is similar to other areas where there are concerns for their survival (Smith et al., 2004; Kreb et al., 2007; Sutaria & Marsh, 2011; Beasley et al., 2013). Except for an estimated population size of 423 individuals in the east Gulf of Thailand (Hines et al., 2015), all known coastal populations of Irrawaddy dolphins do not exceed 100 individuals (Smith et al., 2004). The size of other coastal populations of Irrawaddy dolphins range from 31 in Cowie Bay (Malaysia); <50 individuals in IloIlo strait (Philippines) 75 in the Bay of Bengal to 233 individuals in Kuching Bay (Malaysia) (Smith et al, 2008; Dolar, 2010; Minton et al., 2013; Shu et al., 2013). As in other coastal areas, Irrawaddy dolphin group size off Penang Island is small, characteristic of cetacean species feeding in coastal areas where prey is distributed unevenly (Smith et al., 2004; Jaaman, 2006; Beasley, 2007; Smith et al., 2008; Ballance, 2009).

The distribution of Irrawaddy dolphins appears restricted to a small area, between Sungai Pinang and Sungai Burung river mouths. This is similar at Cowie Bay, Sarawak, Malaysia IloIlo strait (Philippines), and the Bay of Bengal (Smith et al., 2008; Dolar, 2010; Shu et al., 2013). Therefore it is important these small critical habitats be conserved appropriately. It is clear that the full extent of west Penang population size and range is still unknown as the discovery of new individuals has yet to plateau, hence the need to test both closed and open population models during this study. Further research covering a larger area at the continental shoreline would help provide more information. The most northern sighting of Irrawaddy dolphins occurred 16 km apart from the most southern sighting recorded near Sungai Burung river mouth. (Fig. 3A). Approximately 18 km northeast from where the most northern sighting was recorded is Kuala Muda, another estuary with mangrove forest and with the potential to be an area used by Irrawaddy dolphins. Studies have shown that populations of Irrawaddy dolphins can travel in ranges up to 30 to 40 km apart in Kuching Bay (Peter, 2012), and similar observations have been recorded for individuals seen in different islands in the Philippines (personal observation, M.L. Dolar) suggesting that this species is capable of moving across different coastal ecosystems.

In this study, all sightings occurred within the 6 m depth contour and there was no indication that any depth was preferred within this range. In other areas, Irrawaddy dolphins are often associated with high or rising tide (Jaaman, 2006; de la Paz, 2012; Peter, 2012) and other species of estuarine dolphins show similar high tide related movement patterns representing an opportunity to increase access to the prey while reducing the risk of stranding in shallow areas (Santos et al., 2010; Fury & Harrison, 2011; Prado et al., 2013). Habitat use is determined by a combination of variables both physical and biological, including conditions typical of tropical estuaries such as a patchy distribution of high phytoplankton abundance that in turn is associated with tidal variation and changes between water masses (Forney, 2009).

None of the variables evaluated (i.e., sea surface temperature, salinity, tide), were statistically significant predictors of the presence of the dolphins, as it has been similarly observed in other studies of the association of multiple environmental parameters with the presence of Irrawaddy dolphins (Peter, 2012). However, waters less than 6 m depth seem to be adequate for main activities such as feeding in this area. Perhaps more sightings at greater distances from the shore would provide data that could show significant differences in environmental parameters according to the presence or absence of dolphins.

Similar to what was observed by Minton et al. (2011) in Sarawak waters (Borneo), the occurrence of mother-calf pairs in Penang´s study site suggests that reproduction is taking place and that this particular area is used as a nursing

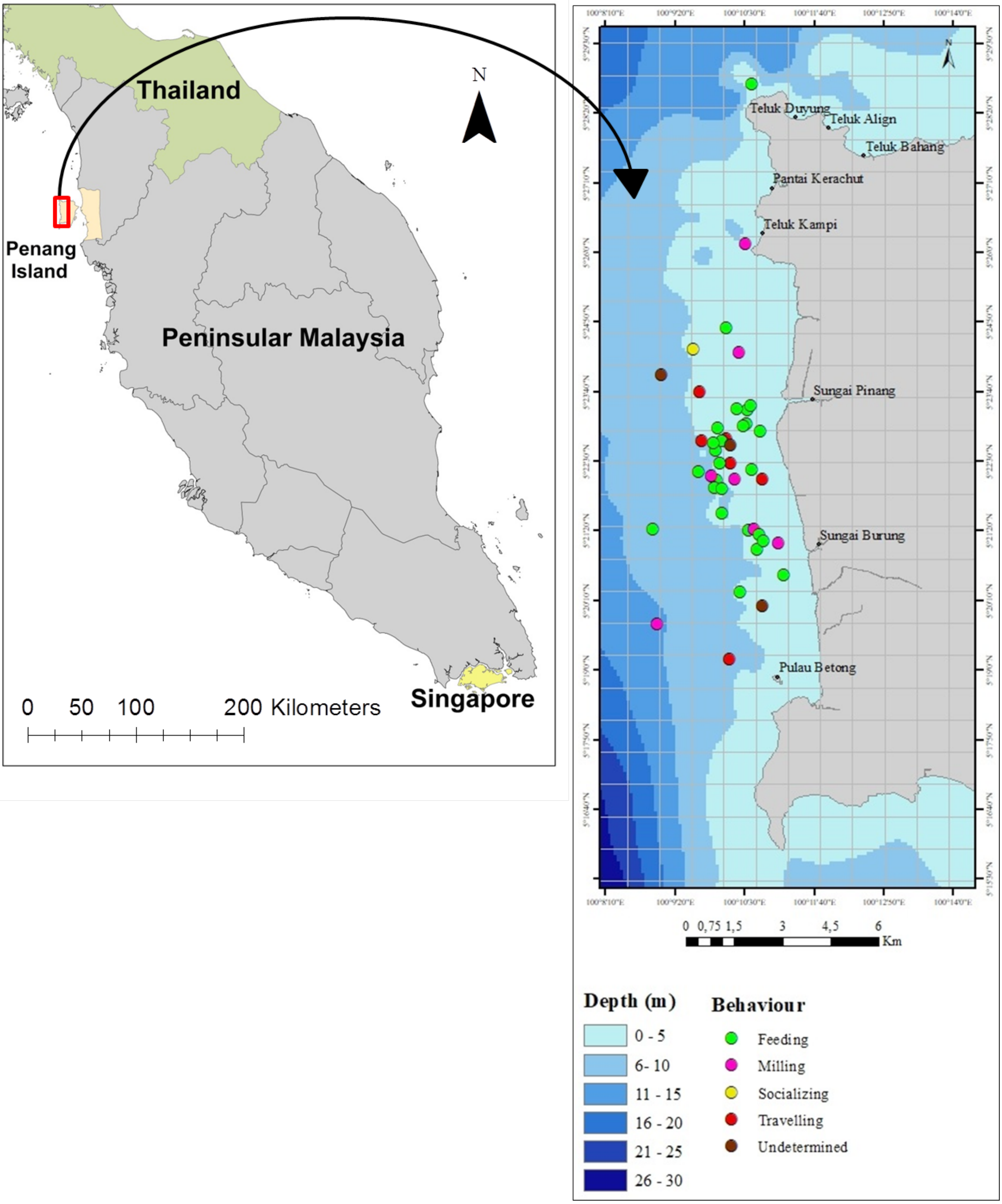

Fig. 4. Distribution of sightings based on behavioural observations recorded in west Penang throughout the period of the study.

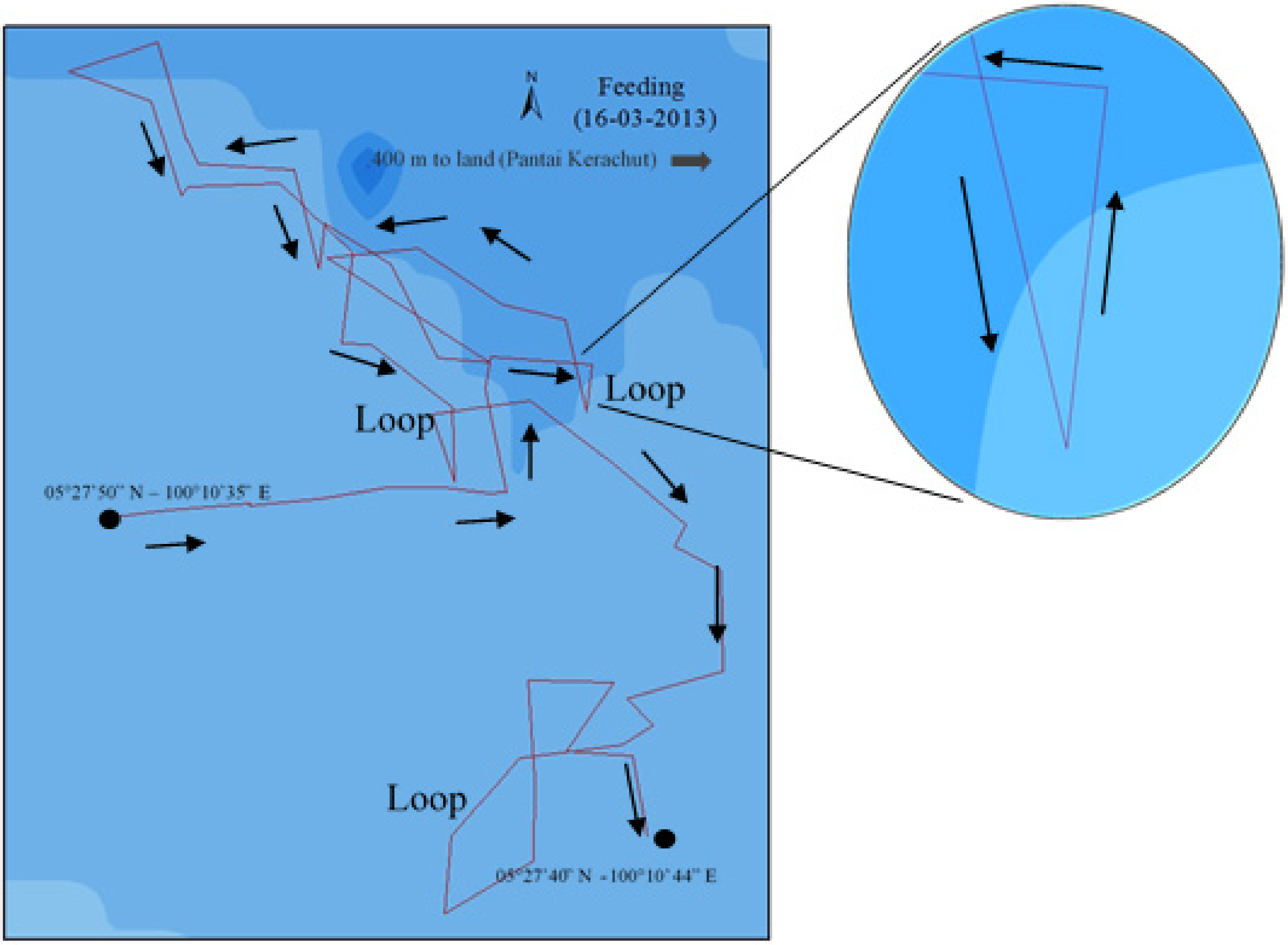

Fig. 5. The pattern of movement tracked when the Irrawaddy dolphins were feeding. The actual track is that of the boat following the dolphins. Some loops have been tagged as an example of what they look like (see inset). The movement was recorded 400 m from Pantai Kerachut while following a group of dolphins outside the survey path, west Penang.

ground as it has been determined in other sites (Sonntag et al., 1999) where small cetaceans calves are being observed year round.

Mean group size of 5 ± 0.5 (SE) individuals is comparable to what has been reported in other Irrawaddy dolphin populations in Southeast Asia and South Asia. In an earlier study by Stacey & Hvenegaard (2002) in the Mekong River of Laos, group sizes ranged from 1–7 with a mean of 3.02. A high of 17 individuals was recorded which is comparable to a high of 15 animals recorded in Penang. Similarly, in the Mekong river, the average group size during the dry season was 6.8 dolphins ± 0.2 (SE) and during the wet season was 5.7 dolphins ± 0.4 (SE) (Beasley, 2007). Although average group size was highest in February and lowest in March there is not enough evidence to back up the assumption that group size is affected by the time of the year. Group size could change by the availability of prey with animals spreading out in smaller groups when resources are scarce to reduce intraspecific competition for food, and aggregating when resources are abundant (Parra et al., 2011).

Behavioural observations made between 1000 and 1400 hours were similar to those in Negros Occidental in the Philippines (de la Paz, 2012), where the levels of activity of Irrawaddy dolphins were higher in the morning and decreased during the day. The dolphins were mainly observed between 1000 and 1400 hours, but after 1200 hours the sightings became fewer. However this is not conclusive for this study as activity after 1400 hours was not consistently recorded. The dolphins were easier to see before noon, which suggests that the detection could be better during morning hours if further research is carried out in the area with a standardised survey effort. In other areas such as the Mekong river and Negros Occidental (Philippines), the levels of activity of Irrawaddy dolphins seem to be higher early morning and decreases during the day as well (Stacey & Hvenegaard, 2002; de la Paz, 2012). The main activity of feeding in Penang was distinctive due to the circular movements to apparently herd the prey and included previously described observations of animals spitting water or throwing fish as a strategy to disorient the prey or as a sign of social interactions (Stacey & Hvenegaard, 2002). The observance of the groups moving around in large circles in search of prey over several kilometres has not been documented before in currently available literature.

As observed during this study, the behaviour of pausing before diving when individuals are feeding was also described by Jaaman (2006), including the loud puffing sounds produced when breathing. Leaps are uncommon in this species, but it seems to be displayed in the presence of disturbances or when the individuals are travelling against strong currents (Beasley, 2007; Smith, 2009). Socialising has been described as aggregations of several individuals in a herding type of behaviour (Jaaman, 2006; Beasley, 2007; Sutaria, 2009; de la Paz, 2012) which coincide with this research observations, it also has shown to have a positive correlation with feeding presumably as part of the cooperation strategy (Kamaruzzan et al., 2011). Indeed, feeding was the predominant behaviour, and similar to what was observed by Sutaria (2009), and the area where these dolphins are foraging appears a critical habitat for their survival.

These results are the first description of a population of Irrawaddy dolphins in Penang Island and the west of Peninsular Malaysia. It remains unclear if this is an open or a closed population probably because the sampling effort was not enough to determine it, and maybe because the distribution of the population is much wider than the study area. These dolphins inhabit an area that remains relatively less developed as compared with the east of Penang Island. We have observed that reproduction, nursing and feeding are evident here, therefore this is an area of importance for this endangered species requiring management actions.

The relatively small size of the population is of concern, considering annual birth rates of Irrawaddy dolphins in other areas such as Chilika Lake and the Mekong River of one calf per year and one calf every three years, respectively (Beasley, 2007; Sarkar, 2011), and the threats observed in Penang such as fishing nets, high-speed boats and the rivers' polluted waters, which are similar to those in the forenamed areas.

The resulting information of this study represents the baseline to conduct further research on the range and dynamics of the population, including more detailed behavioural observations, measuring the levels of interaction with fishing activities and impact of water pollution. Also, in comparison with other areas where populations have been depleted mainly due to the interaction with fishing gears (Beasley et al., 2013) and assuming by how easy it is to detect the individuals that the population is in a good condition, the results herein serve as evidence to follow precautionary principles (United Nations, 1992) such as the development of a management plan through a participative process involving fishing communities to avoid potentially serious or irreversible harm to this or any other population of cetaceans occurring in the island (Rodríguez-Vargas, 2015).

Considering the aforementioned threats, conservation measures should target minimising the interaction with fishing nets, assessing the impacts of the interaction with boats, and studying the levels of pollution. Some of the specific activities in the action plan could include developing a protocol for annual biological monitoring to establish mortality rates using the catalogue of individuals identified in this research, determining the viability of the population, and studying the impact of human activities such as boat traffic and fishing. Establishing a co-managed marine protected area and the implementation of good practices through a community-based monitoring network in the island is also recommended (Rodríguez-Vargas, 2015). This would include training in the release of live animals caught in fishing gears, and reports of stranding (dead or alive) based on the positive and collaborative response of the community to this type of research (Rodríguez-Vargas, 2015) which was of great importance to conclude this study.

ACKNOWLEDGEMENTS

This research was funded by the Universiti Sains Malaysia short term grant, (304/PPANTAI/6311103) and Rodríguez-Vargas was funded by Colfuturo scholarship. We also would like to thank the Centre for Marine and Coastal Studies (CEMACS) staff and volunteers, and the local communities from Teluk Bahang, Sungai Pinang and Sungai Burung fishing villages. Special appreciation goes to our boatman Pak Rahman, for sharing his experience and enthusiasm looking for dolphins.

LITERATURE CITED

Ballance LT (2009) Cetacean Ecology. In: Perrin WF, Würsig B & Thewissen JG (eds.) Encyclopedia of Marine Mammals. Second Edition. Academic Press, London. Pp. 196–201.

Beasley I (2007) Conservation of the Irrawaddy Dolphin, *Orcaella brevirostris* (Owen in Gray, 1866) in the Mekong River: Biological and Social Considerations Influencing Management. Unpublished PhD Thesis, James Cook University, Australia, 340 pp.

Beasley I, Chooruk S & Piwpong N (2002) The status of the Irrawaddy dolphin, *Orcaella brevirostris*, in Songkhla Lake, southern Thailand. Raffles Bulletin of Zoology, Supplement 10: 75–83.

Beasley I, Pollock K, Jefferson TA, Arnold P, Morse L, Yim S, Lor KS & Marsh H (2013) Likely future extirpation of another Asian river dolphin: The critically endangered population of the Irrawaddy dolphin in the Mekong River is small and declining. Marine Mammal Science, 29(3): E226–E252.

Chee SY, Othman AG, Sim YK, Adam ANM & Firth LB (2017) Land reclamation and artificial islands: Walking the tightrope between development and conservation. Global Ecology and Conservation, 12: 80–95.

Cooch E & White GC (2018) Program MARK: A Gentle Introduction. Eighteenth Edition, 1151 pp. http://www.phidot.org/software/mark/docs/book/ (Accessed 6 September 2018).

de la Paz ME (2012) Behaviour and Area Use of Irrawaddy Dolphins (*Orcaella brevirostris)* in the Coastal Waters of Bago and Pulupandan, Negros Occidental, Philippines. Unpublished MSc Thesis. Institute of Environmental and Marine Sciences, Silliman University, Philippines, 62 pp.

Dudgeon D (1992) Endangered Ecosystems: A review of the conservation status of tropical Asian rivers. Hydrobiologia, 248: 167–191.

Dolar ML (2010) Survey and conservation of the Irrawaddy dolphin *Orcaella brevirostris*, in the Visayas, Philippines. Final Report Submitted to the Ocean Park Conservation Foundation, Hong Kong (OPCFHK) by the Marine Research for Conservation (TMRC). LLC, San Diego, California, United States, 46 pp.

Dolar ML, Perrin WF, Yaptinchay AA, Jaaman SA, Santos MD, Alava MN & Suliansa MS (1997) Preliminary investigation of marine mammal distribution, abundance, and interactions with humans in the southern Sulu Sea. Asian Marine Biology, 14: 61–81.

Dolar ML, Perrin WF, Gaudiano JP, Yaptinchay AA & Tan JM (2002) Preliminary report on a small estuarine population of Irrawaddy dolphins *Orcaella brevirostris* in the Philippines. Raffles Bulletin of Zoology, 50: 155–160.

Forney KA (2009) Surveys. In: Perrin WF, Würsig B & Thewissen JG (eds.) Encyclopedia of Marine Mammals. Second Edition. Academic Press, London. Pp. 1129–1131.

Fury CA & Harrison PL (2011) Impact of flood events on dolphin occupancy patterns. Marine Mammal Science, 27(3): E185–E205.

Hammond PS (2009) Mark-recapture. In: Perrin WF, Würsig B & Thewissen JG (eds.) Encyclopedia of Marine Mammals. Second Edition. Academic Press, London. Pp. 705–709.

Hines EM, Strindberg S, Junchumpoo C, Ponnampalam LS, Ilangakoon A, Jackson-Ricketts J & Monanunsap S (2015) Line transect estimates of Irrawaddy dolphin abundance along the eastern Gulf Coast of Thailand. Frontiers in Marine Science, 2: 63. doi:10.3389/fmars.2015.00063.

Horton B, Bird M, Birkland T, Cowie S, Eong OJ, Hawkes A, Khoon GW, Law L, Macgregor C, Shau-Hwai AT, Sa TT & Yasin Z (2008) Environmental and socioeconomic dynamics of the Indian Ocean tsunami in Penang, Malaysia. Singapore Journal of Tropical Geography, 29: 307–324.

Ismail I, Ramli S, Chee PE, Shahunthala D, Kamal Z, Devakie N & Sallehudin J (2002) Overview: The geography, ecology and coastal activities of the south-west district of Penang Island. In: Choo PS, Ismail I, Chee PE & Chuah TT (eds.) Workshop on the Impact of Development on the Coastal Fisheries off South-west Penang Island 7–8 June 2001. Fisheries Research Institute, Batu Maung, Penang, Malaysia. P. 112.

Islam MS & Tanaka M (2004) Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. Marine Pollution Bulletin, 48: 624–649.

Jaaman SA (2006) Marine Mammal Distribution and Interactions with Fisheries in east Malaysia. PhD Thesis, University of Aberdeen, UK, 277 pp.

Kamaruzzan AS, Jaaman SA & Saleh E (2011) Effect of water parameters on the behaviour of Indo-Pacific humpback and Irrawaddy dolphins in Cowie Bay, Sabah, Malaysia. Borneo Science, 28: 1–7.

Karczmarski L, Winter PED, Cockcroft VG & McLachlan A (1999) Population analyses of Indo-Pacific humpback dolphins *Sousa chinensis* in Algoa Bay, Eastern Cape, South Africa. Marine Mammal Science, 15(4): 1115–1123.

Kreb D, Budiono & Syachraini (2007) Review of status and conservation of Irrawaddy dolphins *Orcaella brevirostris* in the Mahakam River of East Kalimantan, Indonesia. In: Smith BD, Shore RG & Lopez A (eds.) Status and Conservation of Freshwater Populations of Irrawaddy Dolphins. Pp. 53–66.

Lettink M & Armstrong DP (2003) An introduction to using mark-recapture analysis for monitoring threatened species. In: Using Mark-recapture Analysis for Monitoring Threatened Species: Introduction and Case Study. Department of Conservation Technical Series, 28. Pp. 5–32.

Minton G, Peter C, Poh AN, Ngeian J, Braulik G, Hammond PS & Tuen AA (2013) Population estimates and distribution patterns of Irrawaddy dolphins (*Orcaella brevirostris*) and Indo-Pacific finless porpoises (*Neophocaena phocaenoides*) in the Kuching Bay, Sarawak. Raffles Bulletin of Zoology, 61(2): 877–888.

Minton G, Peter C & Tuen AA (2011) Distribution of small cetaceans in the nearshore waters of Sarawak, East Malaysia. Raffles Bulletin of Zoology, 59(1): 91–100.

Minton G, Smith BD, Braulik GT, Kreb D, Sutaria D & Reeves R (2017) *Orcaella brevirostris*. The IUCN Red List of Threatened Species 2017: e.T15419A50367860. http://www.iucnredlist.org/details/15419/0 (Accessed 12 December 2017).

National Hydrographic Centre (2013) Jadual Pasang Surut Malaysia (Malaysia Tide Tables) 2013. National Hydrographic Centre, Selangor, Malaysia, 408 pp.

Otis DL, Burnham KP, White GC & Anderson DR (1978) Statistical inference from capture data on closed animal populations. Wildlife Monographs, 62: 3–153.

Parra GJ (2006) Resource partitioning in sympatric delphinids: Space use and habitat preferences of Australian snubfin and Indo-Pacific humpback dolphins. Journal of Animal Ecology, 75: 862–874.

Parra GJ, Corkeron PJ & Arnold P (2011) Grouping and fission-fusion dynamics in Australian snubfin and Indo-Pacific humpback dolphins. Animal Behaviour, 82: 1423–1433.

Parra GJ, Corkeron PJ & Marsh H (2006) Population sizes, site fidelity and residence patterns of Australian snubfin and Indo-Pacific humpback dolphins: Implications for conservation. Biological Conservation, 129: 167–180.

Peter C (2012) Distribution Patterns, Habitat Characteristics and Population Estimates of Irrawaddy Dolphins (*Orcaella brevirostris*) in Kuching Bay, Sarawak. Unpublished MSc Thesis. Institute of Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak, Malaysia, 104 pp.

Prado JH, Secchi ER, & Kinas PG (2013) Mark-recapture of the endangered franciscana dolphin (*Pontoporia blainvillei*) killed in gillnet fisheries to estimate past bycatch from time series of stranded carcasses in southern Brazil. Ecological Indicators, 32: 35–41.

Rajamani L, Porter L, Dolar L, Rodríguez-Vargas LH & Yobe M (2018) Marine mammals of coastal Penang Island, Malaysia. Aquatic Mammals, 44(3): 319–327.

Rodríguez-Vargas LH (2015) The Distribution of Aquatic Mammals in the Waters of Penang Island, Malaysia, with a Focus on the Ecology and Conservation of the Irrawaddy Dolphin *Orcaella brevirostris* (Owen in Grey, 1866). Unpublished MSc. Thesis. University Sains Malaysia, Malaysia, 179 pp.

Rosli NR & Yahya K (2013) Trends of sediment loading in catchment areas of Pinang River in Malaysia. APCBEE Procedia, 5: 128–133.

Santos UA, Alvarez MR, Schilling AC, Strenzel GM & Pendu YL (2010) Spatial distribution and activities of the estuarine dolphin *Sotalia guianensis* (van Bénéden, 1864) (Cetacea: Delphinidae) in Pontal Bay, Ilhéus, Bahia, Brazil. Biota Neotropica, 10: 67–73.

Sarkar SK (2011) Dolphins in Chilika Lake – Endangered due to tourist activities. In: Culik B (ed.) Odontocetes the Toothed Whales. UNEP/CMS/ASCOBANS Technical Series No.24, Bonn. Pp. 141–144.

Shane SH, Wells RS & Würsig B (1986) Ecology, behaviour and social organization of the bottlenose dolphin: A review. Marine Mammal Science, 2: 34–63.

Shu WT, Jaaman SA & Palaniappan PM (2013) A preliminary study of population size of Irrawaddy dolphins (*Orcaella brevirostris*) in Cowie Bay, Sabah, Malaysia. Journal of Tropical Biology and Conservation, 10: 23–26.

Smith BD (2009) Irrawaddy dolphin: *Orcaella brevirostris*. In: Perrin WF, Würsig B & Thewissen JG (eds.) Encyclopedia of Marine Mammals. Second Edition. Academic Press, London. Pp. 638–642.

Smith BD, Ahmed B, Mowgli RM & Strindberg S (2008) Species occurrence and distributional ecology of nearshore cetaceans in the Bay of Bengal, Bangladesh, with abundance estimates for Irrawaddy dolphins *Orcaella brevirostris* and finless porpoises

Neophocaena phocaenoides. Journal of Cetacean Research and Management, 10: 45–58.

Smith BD, Beasley I, Buccat M, Calderon V, Evina R, De Valle JL, Cadigal A, Tura E & Visitacion Z (2004) Status, ecology and conservation of Irrawaddy dolphins (*Orcaella brevirostris*) in Malampaya Sound, Palawan, Philippines. Journal of Cetacean Research and Management, 6: 41–52.

Smith BD, Braulik G, Strindberg S, Ahmed B & Mansur RM (2006) Abundance of Irrawaddy dolphins (*Orcaella brevirostris*) and Ganges river dolphins (*Platanista gangetica gangetica*) estimated using concurrent counts made by independent teams in waterways of the Sundarbans mangrove forest in Bangladesh. Marine Mammal Science, 22(3): 527–547.

Smith BD & Mya TT (2007) Review of the status and conservation of Irrawaddy dolphins *Orcaella brevirostris* in the Ayeyarwady River of Myanmar. In: Smith BD, Shore RG & Lopez A (eds.) Status and Conservation of Freshwater Populations of Irrawaddy Dolphins. Pp. 21–39.

Sodhi NS, Lian PK, Brook BW & Ng PKL (2004) Southeast Asian biodiversity: An impending disaster. Trends in Ecology and Evolution, 19: 12.

Sodhi NS, Posa MRC, Tien ML, Brickford D, Lian PK & Brook BW (2010) The state and conservation of Southeast Asian biodiversity. Biodiversity Conservation, 19: 317–328.

Sonntag RP, Benke H, Hiby AR, Lick R & Adelung D (1999) Identification of the first harbour porpoise (*Phocoena phocoena*) calving ground in the North Sea. Journal of Sea Research, 41(3): 225–232.

Stacey PJ & Hvenegaard GT (2002) Habitat use and behaviour of Irrawaddy dolphins (*Orcaella brevirostris*) in the Mekong River of Laos. Aquatic Mammals, 28: 1–13.

Sutaria D (2009) Species Conservation in a Complex Socio-ecological System: Irrawaddy Dolphins, *Orcaella brevirostris* in Chilika Lagoon, India. Unpublished PhD Thesis. James Cook University, Australia, 275 pp.

Sutaria D & Marsh H (2011) Abundance estimates of Irrawaddy dolphins in Chilika Lagoon, India, using photo-identification based mark-recapture methods. Marine Mammal Science, 27: E338–E348.

United Nations (1992) Rio declaration on environment and development. In: Report of the United Nations Conference on Environment and Development. Rio de Janeiro, Brazil. Pp. 3–14.

Urian K, Gorgone A, Read A, Balmer B, Wells RS, Berggren P, Durban J, Eguchi T, Rayment W & Hammond PS (2015) Recommendation for photo-identification methods used in capture-recapture models with cetaceans. Marine Mammal Science, 31(1): 298–321.

Wilson B, Hammond PS & Thompson PM (1999) Estimating size and assessing trends in a coastal bottlenose dolphin population. Ecological Applications, 9: 288–300.

Würsig B & Jefferson TA (1990) Methods of photo-identification for small cetaceans. Reports of the International Whaling Commission, 12: 43–52.

SUPPLEMENTARY MATERIAL

Description of behavioural states for coastal cetacean dolphins based on Shane et al. (1986), Karczmarski et al. (1999), Parra (2006), and consistent personal observations.

Feeding – Swimming slowly making circles around a specific area. All individuals display a characteristic movement starting with momentary pause before showing a vertical submersion usually exposing the tail, and long dives. Individuals are seen going different directions or making circles as groups, and re-surfacing is unpredictable. In one occasion one individual was observed spitting water, and another one was seen flapping a fish up using its tail.

Travelling – Groups swimming relatively fast, in the same direction. Individuals show short dives and predictable re-surfacing. Full body and half body leaping was observed in a few occasions .

Milling – Slow swimming around the same area, with smooth and short dives and long surfacing. No evidence of vertical diving.

Socialising – Group swimming slow within a small area, keeping the cohesion, rubbing against and on each other. Individuals rolling on their ventral axis exposing ventral area and pectoral fins. Superficial dives and frequent breaths.

Undetermined – An individual was only sighted for a very short instance, which didn't allow enough time to determine the behaviour.