Identifying Habitat Characteristics and Critical Areas for Irrawaddy Dolphin, *Orcaella brevirostris*: Implications for Conservation

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Abstract Irrawaddy dolphins, *Orcaella brevirostris*, in the Kuching Bay, Sarawak, Malaysia have been subjected to pressure from cetacean-fisheries interactions, dolphin watching tourism and coastal development. However, very little information is known about their ecology and factors driving their habitat preferences. To obtain critical information on the distribution, habitat preference and range pattern of Irrawaddy dolphins in Kuching Bay, Sarawak, systematic boat-based surveys were conducted between June 2008 and October 2012. The results showed a statistically significant relationship between Irrawaddy dolphins' distribution and different categories of salinity, tide levels and distance to river mouths. Kruskal-Wallis tests confirmed that the presence of Irrawaddy dolphins in Kuching Bay had statistically significant relationships to habitat parameters of salinity (chi-square = 4.694, $p=0.03$). Fisher's exact test indicated that Irrawaddy dolphins were statistically more likely to be present in waters within a 6 km radius of river mouths. The distribution of dolphins was also affected by tide levels as Mann-Whitney *U*-tests proved a statistically significant difference in dolphin distribution between tide levels lower than 2.0 m and tide levels higher than 2.0 m ($p=3.153\times10^{-11}$). The representative range and core area of photo-identified Irrawaddy dolphins estimated using fixed kernel range was 246.42 km^2 and 37.22 km^2, respectively, with core area located in the Salak Estuary. The results obtained in this study reflect dry season distribution only, and may differ during the wet season. Nonetheless, these results highlight the

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importance of shallow coastal waters and the overlap of Irrawaddy dolphin critical habitat with that of human activities in Kuching Bay. Conservation efforts are required to minimise the effects of the pressures exerted on these animals and their habitats.

1 Introduction

Baseline data on animal distribution, habitat preference and range patterns are critical for effective conservation and management, providing answers to the basic questions of "where do they occur?" and consequently "which areas require protection?". This is particularly important in areas where coastal development is taking place or is planned in the near future. The monitoring of distribution, habitat use and abundance before, during and after development can help scientists and managers to quantify the impacts of these anthropogenic activities to the animal populations (e.g., Dähne et al. 2013).

The Kuching Bay in Sarawak, East Malaysia is home to at least four cetacean species including the Irrawaddy dolphin (*Orcaella brevirostris* Owen in Gray 1866), Indo-Pacific finless porpoise (*Neophocaena phocaenoides* Cuvier 1829), Indo-Pacific humpback dolphin (*Sousa chinensis* Osbeck 1765) and Indo-Pacific bottlenose dolphin (*Tursiops aduncus* Ehrenberg 1833) (Minton et al. 2011, 2013). The mangrove forest, river networks, and coastal area surrounding the Kuching Bay are of economic importance, supporting activities such as gillnet fishing, aquaculture and tourism (including dolphin watching) (Ling et al. 2010; O'Connor et al. 2009). Major development taking place includes an 8 km long flood mitigation channel, currently under construction and scheduled to be operational by 2015. The channel is designed to direct floodwater from the city of Kuching into the Salak River, therefore alleviating the flooding problems during monsoon (Mah et al. 2012), but also introducing enormous quantities of freshwater possibly tainted by urban waste and discharge into core dolphin habitat. Gillnet fishing, aquaculture, dolphin watching, freshwater influxes and coastal runoff/pollution have all been identified as threats to estuarine and coastal cetacean populations worldwide (DeMaster et al. 2001; Bejder et al. 2006; Currey et al. 2009; Fury and Harrison 2011).

Boat-based surveys conducted from 2008 onward have provided baseline information on the distribution of small cetaceans (Minton et al. 2011) and population estimates for the Irrawaddy dolphin and finless porpoise (Minton et al. 2013) in the Kuching Bay. However, to accurately manage and protect this population there is a need to fully understand the factors that influence their habitat requirements on a finer scale. This paper aims (1) identify critical areas of Irrawaddy dolphin habitat in Kuching Bay by calculating the core area and representative ranges using fixed kernel method, and (2) better to understand the factors driving these habitat preferences.

2 Methods

2.1 *Study Area*

The survey area, defined as the "Kuching Bay" due to its proximity to the city of Kuching, the capital of Sarawak, East Malaysia, actually includes a wide area ranging from the Bako Peninsula on the east to Rambungan River on the west and extending up to 15 km north to include Satang Island (Fig. 1). Major rivers flowing into the bay include the Bako River, Buntal River, Santubong River, Salak River, Sibu Laut River and Rambungan River. The bay is generally shallow with a maximum depth of 10 m as far as 15 km from shore, while some river channels are more than 10 m deep with a maximum depth of 23 m recorded at Telaga Air during high tide. Salinity in the study area ranges from approximately 27 PSU in rivers and estuaries to 33 PSU in the offshore areas, while pH ranges from 7.4 to 8.8.

One of the main beaches in Kuching Bay is half way along the west coast of the Santubong Peninsula, a hotspot for both locals and tourists. There are five resorts located along the beach as well as homestay facilities in some of the fishing villages and a golf course. The study area includes portions of the Kuching Wetlands

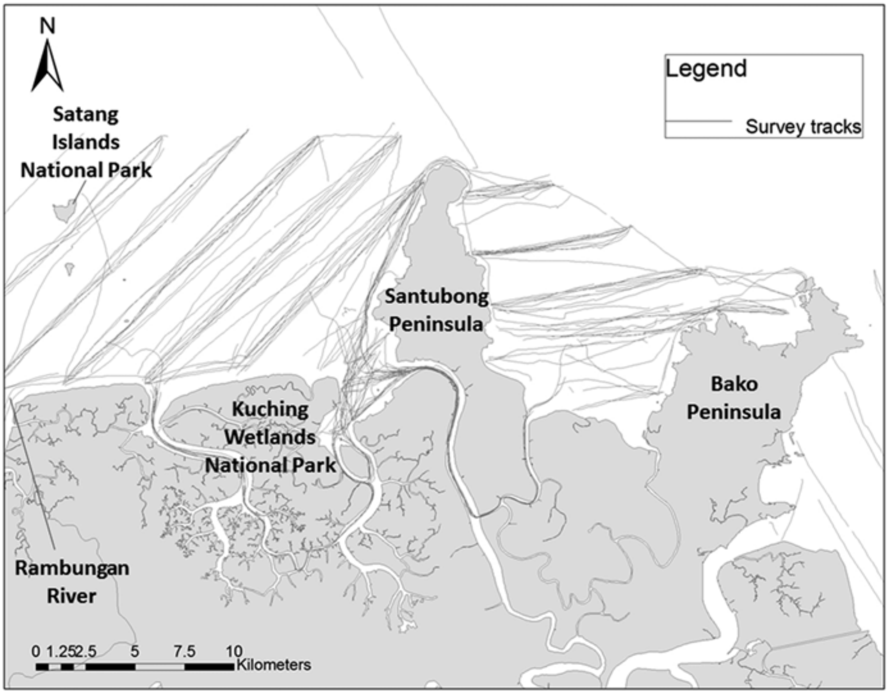

Fig. 1 Study area in Kuching Bay, showing the boat-based survey transects (on-effort portion), running ca. 45° parallel to the nearest coastline

National Park on the west side, the Talang-Satang Marine National Park approximately 10 km offshore and Bako National Park on the east. Mount Santubong National Park is located on the Santubong Peninsula.

2.2 Data Collection

Line transect surveys were conducted from March–October in 2009–2012. Surveys were conducted using open decked, fiberglass-hulled boats that ranged from 7 to 10 m-long, with double outboard engines ranging from 90 to 115 hp. Surveys followed pre-determined parallel transects in the areas along the coasts of the Santubong and Bako peninsulas with occasional surveys along the coast of Kuala Rambungan (Fig. 1). Transects extended up to 15 km offshore with a distance of 4 km between the consecutive transects. Line transects were designed to run approximately at 45° to the coast. This design allows for detection of cetacean density gradients along-shore as well as onshore/offshore (Dawson et al. 2008). Surveys were also carried out in the rivers and channels that were interconnected during all tidal states. Boats were navigated down the centre of the river.

Transects were navigated at a steady speed of 15 km per hour (eight knots). At least two experienced observers were always onboard, while supporting observers had varying degrees of experience. 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 centre line to 90° to starboard and port (e.g., Buckland et al. 2001; Parra et al. 2006). The eye-height of the observers to the water line was between 2.5 and 3.5 m.

Positional data for survey tracks and dolphin sightings were collected using a handheld GPS unit. Effort was recorded to the nearest minute to distinguish between time spent searching (on-effort), fast transits to or from the start and end points of transect lines, working with cetacean groups, fueling or meal breaks (all off-effort). Beaufort scale (as an indicator of sea conditions), swell height and visibility were recorded on each transect leg and at the end of each sighting, or upon noticeable change. Search effort was suspended during heavy rain and/or when the Beaufort scale reached 4 or higher.

Whenever splashes, blows or dark figures similar to dorsal fins or backs were spotted, search effort was suspended and observers went off-effort to confirm the sightings. Once a sighting was confirmed, the boat then left the transect to approach the sighted group and collect data on group composition, group size and behaviour following standardized data collection methods (e.g., Jefferson 2000; Parra 2006).

Water parameters were sampled at the start, midpoint and end of each transect leg. Readings of water temperature, pH, salinity and turbidity were taken using a YSI 6820V2 meter. Readings were also taken at the location of each dolphin sighting. Photographs of the dolphins' dorsal fins 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 of right sides of dorsal fins could be taken from a perpendicular angle to the animal. Following Wursig and Jefferson (1990), we attempted to "take at random as many photos as possible of members of the group within constraints of time and budget". The photographs taken were not only used for range pattern analysis, the photographs were also used to estimate the population of Irrawaddy dolphins in Kuching Bay as described in Minton et al. (2013).

2.3 Data Analyses

2.3.1 Habitat Characteristics

Although boat surveys were conducted between 2008 and 2012, the habitat characteristics analysis of Irrawaddy dolphins in this paper was only carried out for the data collected from 2009 to 2010, whereas the range patterns analysis were only carried out for the data collected from 2008 to 2012.

The GPS locations of observed dolphin groups were downloaded at the end of each day using DNR Garmin® and plotted in ArcMap®. All the water sampling stations were compiled and overlaid with on-effort sightings on ArcMap®. Readings taken at all water sampling station during start, midpoint and end of each transect as well as locations of dolphin sightings while on effort were included in the analysis. Only on-effort sightings were used to avoid the bias that might be introduced by including sightings made while speeding close to shore to the start and endpoints of the transects. Each water sampling station was assigned a value of "Presence" or "Absence". A station was assigned presence (value of 1) when an Irrawaddy dolphin sighting fell within a 600 m radius of the recorded location on the same day that sampling took place. Otherwise it was assigned absence (value 0). This radius was chosen based on field experience. When working with a group of dolphins, the maximum distance they traveled during an encounter was generally 500–600 m from the original location where they were first sighted.

Values for physical characteristics like depth, distance to river mouth and distance to land were assigned to each of the sampling stations ex situ. Depth values were obtained from ArcGIS compatible rasters of British Admiralty charts purchased from and issued by Seazone®. Digitized bathymetry points were generated by manually assigning depth values to each depth point on the chart, and various functions were tested to determine the "best fit" model for interpolating depths in the study area between the known depth values of the chart. The function chosen was Inverse Distance Weighted (IDW) with 1 km grid size.

These interpolated values were used to assign depth values to all water sampling stations since a depth sounder was initially not available on the research vessel. In some instances where the depth was less than 7 m, the depth could be recorded in situ because the YSI meter, which has a maximum cable length of 7 m and had depth sensors on the instrument would reach the sea floor. Distance to river mouth was measured using Google Earth by creating a fixed mid-point in the line connecting two corners of a river mouth and measuring the distance of the sampling stations to

Table 1 Results of Kruskal-Wallis testing for the statistical significance on different parameters for stations with Irrawaddy dolphin present vs absent

Parameters	Chi-square	p-value	df
Temperature	1.077	0.299	1
pH	1.107	0.293	1
Depth	0.513	0.474	1
Distance to land	1.861	0.173	1
Salinity	4.694	0.03	1
Distance to river mouth	5.060	0.02	1

Table 2 Results of Fisher's exact testing for the statistical significance of the stratification range in depth, salinity and distance to river mouth with the distribution of presence or absence of Irrawaddy dolphins

Parameter	Bin stratifications	Number of present	Number of absent	P value of Fisher's exact test
Depth (m)	0–2.99	13	92	0.105
	3–5.99	11	53	
	6–8.99	5	1	
	9–14.6	40	42	
Salinity (PSU)	25–27.99	2	8	0.066
	28–30.99	15	70	
	31–33.99	9	80	
	34–35.99	4	69	
Salinity (PSU)	25–30.99	17	78	0.026
	31–35.99	13	149	
Distance to river mouth (km)	0	5	26	0.033
	0.036–2.99	9	59	
	3–5.99	9	40	
	6–8.99	5	32	
	9–14.32	2	70	
Distance to river mouth (km)	0.00–5.99	23	125	0.033
	6.00–14.32	7	102	

this midpoint. Sampling locations upriver were assigned a value of "0". All the physical and water characteristics parameters were stratified into bins of three units (e.g. 0–2.99 m, 3.00–5.99 m for depth; 25–27.99 PSU, 28–30.99 PSU for salinity, 0.1–2.99 km, 3.0–5.99 km for distance to river mouth) (Table 2).

The dataset of all parameters in Table 1 were tested for normality using Shapiro-Wilks test. The test showed a non-normal distribution for all habitat parameters for both presence and absence grouping, therefore the non-parametric Kruskal-Wallis tests were used to determine which parameters would be statistically significant in relation to the presence or absence of dolphins. The Fisher's exact test was then used to pinpoint the range of values of the parameters that affect the distribution of presence or absence of the dolphins.

Following the statistical analysis, the effects of tidal movement and currents on dolphins' distribution were investigated by plotting the distribution of sightings according to the tidal state at the time of sighting. The Shapiro-Wilks test showed that the sightings were not normally distributed in relation to the tide levels at tide levels of 2.0 m or lower and higher than 2.0 m. Hence the non-parametric Mann-Whitney *U* test was used to test whether the tide levels affect dolphin distribution.

2.3.2 Range Pattern

The term 'range pattern' was used instead of 'home range' due to the fact that the sightings data are only restricted to the study area and dolphins may have ranged outside of the study area. Range pattern was determined using fixed kernel estimation. Fixed kernel produces a probability distribution that describes an animal's home range based on the distribution of its observed locations (Worton 1989) and can also be used at the population level to determine critical areas or areas of high use (e.g., Ingram and Rogan 2002; Parra 2006). Sighting locations for groups of Irrawaddy dolphins were used to determine their ranging pattern. Whenever the same group of dolphins were encountered and photographed more than once in the same survey day, only the first sighting point was taken into account in order to minimize statistical dependence among sighting points.

A shape file (.shp) containing sighting data points was created and the range pattern for the Irrawaddy dolphins with the fixed kernel estimation method was calculated using Geospatial Modelling Environment (GME) version 0.7.2.1 (Beyer 2012). The least-squares cross-validation (LSCV) soothing parameter was chosen because it focuses on the area with the greatest intensity of use, therefore producing a more realistic contour (Worton 1989). Isopleths or utilization distribution (UD) contours of 95 % and 50 % of the ranges calculated were generated using the command '*isopleth*' in GME. The 95 % UD is considered to be the representative range of the species within the study area while the 50 % UD is identified as the core area. As dolphins clearly do not use land, any landmasses included in the kernel estimation were eliminated using the '*erase*' function in ArcMap.

3 Results and Discussion

3.1 Habitat Characteristics

Water samples were collected on 257 occasions, of which 30 had dolphins present and 227 absent. The mean and standard deviation readings for all the parameters from 30 stations of dolphins' present category were as follows: temperature 30.42 ± 0.61 °C (mean ± SD), salinity 31.19 ± 2.26 PSU, pH 8.11 ± 0.19, depth 4.17 ± 2.40 m, distance to river mouth 3.74 ± 3.42 km and distance to land 1.76 ± 1.95 km. Kruskal-Wallis tests confirmed that the presence of Irrawaddy dol-

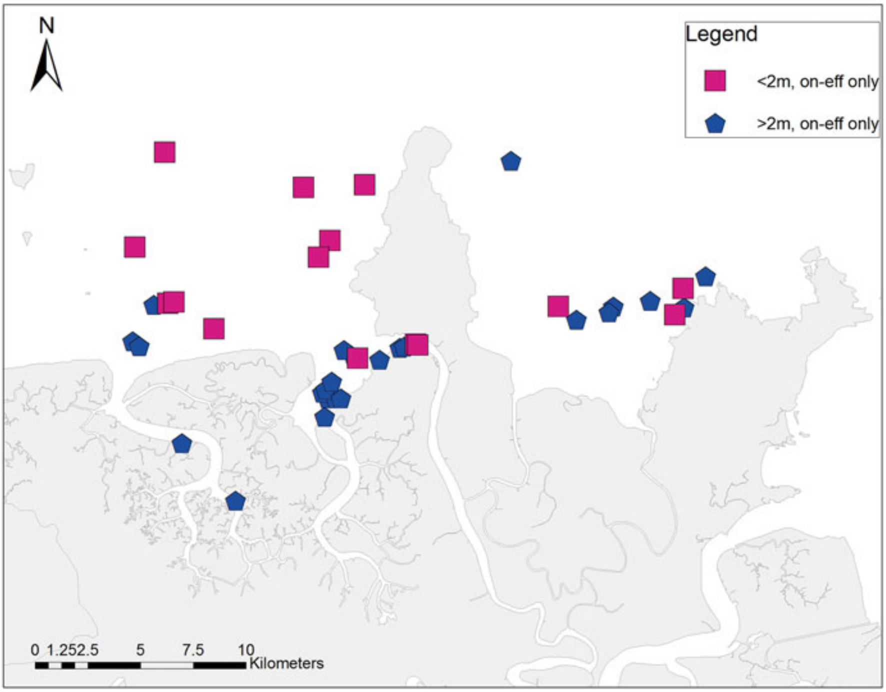

Fig. 2 On-effort sightings of Irrawaddy dolphins with in tidal states higher than 2.0 m vs. lower than 2.0 m. Note that this represents sightings made during 2009–2010

phins in Kuching Bay had statistically significant relationships to habitat parameters of salinity and distance to river-mouth, with chi-square = 4.694 and p-value = 0.03 (Table 1).

Conversely, Fisher's exact test on salinity revealed that the categories approached significance (p = 0.066) whereas for distance to river mouth there was a significant difference (p = 0.033). When distance to river mouth was re-stratified into two equal bins of 0–5.99 km and 6.00–14.39 km, Fisher's exact test yielded a significant result (p = 0.03), indicating that Irrawaddy dolphins are statistically more likely to be present in waters within a 6 km radius from river mouths than beyond that radius. Similarly, when salinity was restratified into two bins of 25–30.99 PSU and 31–35.99 PSU, the p-value of Fisher's exact test is 0.026.

There were 15 on-effort sightings of Irrawaddy dolphins made when the tide levels were 2.0 m or lower and 26 on-effort sightings at tide levels higher than 2.0 m (Fig. 2). In the Salak-Santubong bay, sightings that occurred in tidal states of less than 2.0 m were distributed predominantly in the nearshore areas and in the river mouth while sightings at tide level higher than 2.0 m occurred primarily in the river mouth and upriver. In the Bako-Buntal bay, sightings in both tidal states occurred almost exclusively near the Bako National Park except one sighting that occurred nearer to the tip of the Santubong peninsula. The on-effort sighting locations for tide level less than 2.0 m and more than 2.0 m were tested for normality using Shapiro-Wilks normality test. The test result indicated that the sighting locations were not normally distributed in relation to the tide levels. Hence the non-parametric Mann-Whitney *U* test was used to test whether the tide levels affect dolphin distribution. Irrawaddy dolphin distribution was found to be statistically significant between tide levels lower than 2.0 m and tide levels higher than 2.0 ($p = 3.153 \times 10^{-11}$).

The habitat characteristics selected by Irrawaddy dolphins in Kuching Bay reported here are similar to descriptions from other populations in the region that are known to occur in shallow waters of low salinity and high turbidity (Dolar et al. 1997; Smith et al. 2006, 2008). Whilst similar, this adds to the pool of knowledge specifically for this population of Irrawaddy dolphins in this particular region. The physical characteristic which appears to be the driving factor of the dolphins' habitat choice is distance to river mouth with 76 % of the dolphins' distribution occurring within 6 km of the river mouth and the 50 % core area delineated around the Salak river-mouth. Irrawaddy dolphins as well as other coastal cetaceans such as humpback dolphins (e.g., Lin et al. 2013), harbour porpoises (e.g., Embling et al. 2010; Booth et al. 2013) and common bottlenose dolphins (e.g., Mendes et al. 2002) are known to move in relation to tidal states. Tidal state also links the dolphins' distribution with their surroundings, as they seem to follow the interface between riverine and saline coastal waters, occurring inshore during high tides and further offshore during lower tides. This shows that the river mouth affiliation could be driven more by water flow and tidal currents and its possible effects on prey abundance than salinity or depth.

It is widely believed that prey availability is the main factor driving habitat choice of cetaceans (Baumgartner et al. 2001; Hastie et al. 2005). An ongoing study in Kuching Bay involving interviews with fishermen indicates that they prefer to set their nets on an outgoing tide to catch fish being swept out with the current. It is therefore possible that the dolphins, so often observed in association with this fishing effort, are using the same strategy. Irrawaddy dolphins in the mangrove forests of the Sundarbans and in the Mahakam River, Indonesia have an affinity for deep confluence areas as these areas have high fish abundance and the counter-currents from converging waters provide hydraulic refuge from fluvial and tidal currents (Kreb and Budiono 2005; Smith et al. 2006, 2008).

3.2 Range Pattern

Using kernel density estimation, the representative range (95 % UD) and core area (50 % UD) of Irrawaddy dolphins were estimated to be 246.42 and 37.22 km^2, respectively (Fig. 3). The core area was concentrated in the Salak-Santubong estuary (Fig. 3).

Only one previously published study provided information on ranging patterns of Irrawaddy dolphins using kernel density estimation (Sutaria 2009). The kernel density estimates of 246.62 and 37.22 km^2 in Kuching Bay are smaller than those

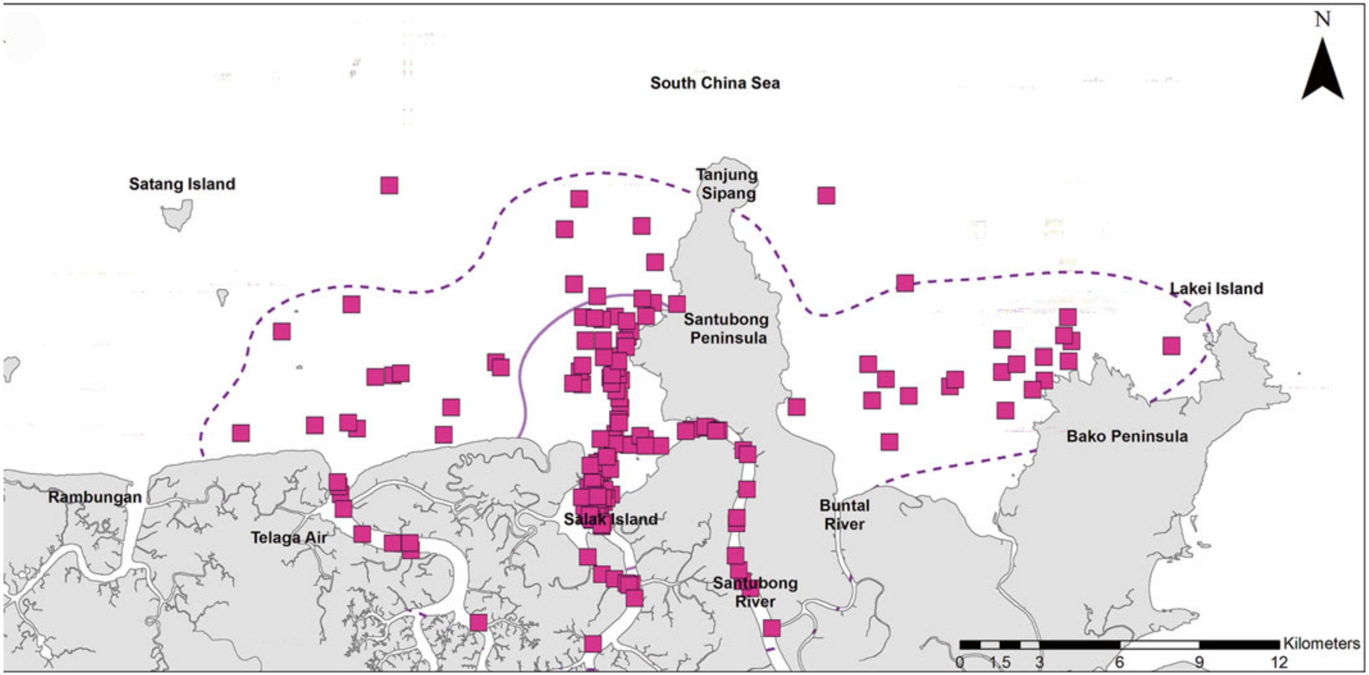

Fig. 3 Core areas (defined by *solid line*) and representative ranges (delineated by *broken line*) of Irrawaddy dolphins estimated using fixed kernel. Sighting data points represent the initial sighting location of dolphin groups representing on-effort sightings made between 2008 and 2012

reported in the Chilika Lagoon, India. Sutaria (2009) reported representative and core areas of 280 km^2 and 61 km^2, respectively, divided into two separate areas of the Outer Channel and South-Central Sector of Chilika Lagoon.

The representative range calculated in this study does not cover areas offshore from Tanjung Sipang (see Fig. 3). Movements of photographically identified Irrawaddy dolphins between the two bays of Salak-Santubong and Bako-Buntal are known to occur (Minton et al. 2013). As such, Irrawaddy dolphins would have to navigate either through the Santubong and Buntal rivers or around the point of the Santubong peninsula to move between the bays. However, since there were no records of sightings along Buntal River or Tanjung Sipang, further investigations are required to determine which route is actually more frequently used.

The association between river mouth distance, salinity, tidal height, critical areas and dolphins' distribution will help land use planners and developers as well as conservation managers to understand the types of habitats which need to be protected in order to conserve Irrawaddy dolphin populations in Sarawak. The habitat preference information is also critical for scientists as it will enable identification of potentially important Irrawaddy dolphin habitat in other parts of Sarawak that have not yet been surveyed and/or to inform Environmental Impact assessments in those areas.

3.3 Implications for Conservation

One of the major obstacles to wildlife conservation and management is the lack of adequate knowledge about species-habitat relationships. Most conservation strategies rely on protecting critical habitats from disturbances or threats to the target species (e.g., Saunders et al. 2002; Geldmann et al. 2013). As such, defining critical habitats, and understanding what role these habitats play in the species' survival is essential for conservation management.

The information presented here on the ranging patterns will help researchers and managers in assessing the target species' overlap with human activities. One of the biggest concerns is the location of the Irrawaddy dolphin core area. Located at the Salak river mouth, this area is also a targeted area for fishing, mostly using gillnets and trammel nets set from small fiberglass boats. Dolphin-watching also takes place in the Irrawaddy dolphin core area, offered by at least six tour operators (O'Connor et al. 2009) as well as a number of local fishers as an extra source of income. Therefore, these animals are at risk to entanglement in fishing gear and possible repeated noise pollution and disruption of feeding and resting activities from unregulated dolphin-watching (e.g., Bejder et al. 2006; Steckenreuter et al. 2012). An additional threat to the Irrawaddy dolphin population is the on-going construction of flood mitigation channel (Mah et al. 2012), designed to direct floodwater into the Salak River which is the core area of Irrawaddy dolphin habitat. Impacts associated with high input of fresh water into an estuarine system have been documented in Australia and New Zealand, these include higher rates of calf mortality

(Currey et al. 2009), incidence of skin disease (Rowe et al. 2010) and changes in habitat use (Fury and Harrison 2011). Without a management plan or mitigation measures in place, abrupt changes in salinity and turbidity might prove to be harmful to the population.

In light of the rapid coastal development taking place in the area, there is a need for continuous monitoring of the target species' distribution, habitat use and abundance. Long term monitoring is crucial to detect possible changes associated with the advent of the flood mitigation channel. This can be done with the already established and ongoing line-transect surveys and photo-identification studies as well as the use of passive acoustic monitoring (PAM). As larger datasets become available for line transect and photo-identification analyses, more robust estimates of abundance and ranging patterns as well as new parameters such as population trends, survival rates, individual ranging patterns and social structure can be obtained. Additionally, these data should also be tailored inform the IUCN Red List of Threatened Species criteria (IUCN 2012a, b) so that status assessment of Irrawaddy dolphin population in Kuching Bay could be performed.

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