**BIODIVERSITAS**
Volume 23, Number 12, December 2022
Pages: 6106-6113

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d231203

# Identifying the hotspot area of Indo-Pacific humpback (*Sousa chinensis*) and Irrawaddy (*Orcaella brevirostris*) dolphins in Matang waters, Perak, Malaysia

**MUHAMMAD FADHLI MAT SOBRI[1], SAIFULLAH ARIFIN JAAMAN[1,♥], ZULQARNAIN MOHAMED[2], AZMI MARZUKI MUDA[1], MUHAMMAD AMIRUL SIDDIQ ABD RASHID[3], XUELEI ZHANG[4]**

[1]Marine Endangered Species Program, Institute of Oceanography and Environment, Universiti Malaysia Terengganu. 21030 Kuala Nerus, Terengganu, Malaysia. Tel.: +60-9-6683947, Fax.: +60-9-6683195, ♥email: saifullahaj@umt.edu.my
[2]Faculty of Science, Universiti Malaya. 50603 Kuala Lumpur, Malaysia
[3]FRI Rantau Abang / Pusat Penyu dan Ekosistem Marin Rantau Abang, 23050 Kuala Dungun, Terengganu, Malaysia
[4]Key Laboratory of Marine Eco-Environmental Science and Technology, First Institute of Oceanography. Ministry of Natural Resources, Qingdao, China

Manuscript received: 13 September 2022. Revision accepted: 28 November 2022.

**Abstract.** *Sobri MF, Jaaman SA, Mohamed Z, Muda AM, Rashid MASA, Zhang X. 2022. Identifying the hotspot area of Indo-Pacific humpback (*Sousa chinensis*) and Irrawaddy (*Orcaella brevirostris*) dolphins in Matang waters, Perak, Malaysia. Biodiversitas 23: 6106-6113.* The Indo-Pacific humpback (*Sousa chinensis*) and Irrawaddy (*Orcaella brevirostris*) dolphins are commonly found in Matang waters, Perak, Malaysia. The area, filled with healthy mangrove forest cover and many estuaries, is not only frequented by the dolphins for its daily activities but also extensively used by locals for artisanal fishing, charcoal production and organizing ecotourism activities. There could be a high risk of human-dolphin interactions, hence determining habitat use and identifying critical habitats or "hot spots" for the dolphins in the area is important. In this study, a series of dedicated boat sighting surveys were conducted from March 2019 to January 2021 between Kuala Gula and Kuala Jarum Mas. The total survey effort was 3325.76 km, 44 days and 239.38 hours. A total of 69 dolphin sightings were made, consisting of 40 Indo-Pacific humpback dolphins and 29 Irrawaddy dolphin observations, respectively. During each sighting, every dolphin's behaviors were categorized as: foraging, socializing, evasive, and travelling, and the survey area was classified into four blocks. The results indicated that different dolphin species have different hotspot areas. For Indo-Pacific humpback dolphins, the hotspot area was Kuala Sangga, while the Irrawaddy dolphin's hotspot area was outside Kuala Larut, and there was a small overlap between the two dolphins' hotspots. Among the recorded behaviors (n: 281) for both dolphins, the most dominant was foraging (72.24%), followed by socializing (17%), evasive (7%), and travelling (4%). The sighted foraging behavior for both dolphin populations was dominant, indicating the hot spots were major foraging grounds for the two dolphin populations. This study shows the importance of Matang waters as a conservation area for the species and warrants further studies of dolphin population ecology to be conducted.

**Keywords:** Cetacean, dolphin behavior, Getis-ord-Gi, Matang Mangrove Forest Reserve, Peninsular Malaysia

## INTRODUCTION

Malaysia is a tropical county with about 329,847 km² landmasses consisting of Peninsular Malaysia, Sabah, and Sarawak (Sarkar et al. 2014; FAO 2020). Malaysia has 4800 kilometers of coastline with different physical properties such as sandy beaches and mudflats (Sarkar et al. 2014). Mudflats consist of mangrove forest areas with high productivity. About 27 marine mammal species have been sighted in Malaysia's water from stranding, sighting, and traveling marine mammal data. To date, 23 species are confirmed to reside or transit in Malaysia territory and Exclusive Economic Zone (EEZ) waters (Jaaman 2010). Kuit et al. (2019) stated that Matang Mangrove Forest Reserve is known to reside in both species of Indo-Pacific humpback dolphin *Sousa chinensis* (Osbek 1765) and Irrawaddy dolphin *Orcaella brevirostris* (Owen in Gray 1866).

The Indo-Pacific humpback dolphin (Figure 5) is an inshore cetacean that can be found in warm-temperate water, including coastal lagoons, rocky reefs, mangrove swamps, estuaries areas, and sandbanks with mudbanks. The distributions of Indo-Pacific humpback dolphins are fragmented as the species live near coastal areas from the east China sea, the gulf of Thailand, and across South East Asia, including Malaysia (Jefferson and Smith 2016; Harahap 2022). The dolphin occurrence ranges from inshore to open sea is large, but they won't go deeper than 30 meters (Jefferson and Smith 2016). Indo-Pacific humpback dolphin documentation in Malaysia is still deficient, but there are studies about the species in certain places in Malaysia (Kuit et al. 2014; Hoffman et al. 2015).

Irrawaddy dolphins (Figure 6) have a euryhaline ability that can adapt to a wide range of salinity which can be seen recorded in East Sabah, Brunei Bay, and West Peninsular Malaysia (Kuit et al. 2014). The ability can be seen in the recent report of a sighting of Irrawaddy dolphins swimming upstream in the river 30 km from estuaries with five ppt salinity (Bali et al. 2017). The Irrawaddy dolphin is the most common dolphin found in Sarawak water that is recognized as an important flagship species (Minton et al. 2011). The Irrawaddy dolphin found in Malaysian water is

on International Union for Conservation of Nature(IUCN) Red List, classified as endangered species because the population trend keeps on decreasing (Minton et al. 2011).

Matang Mangrove Forest Reserve (MMFR) resides in Malaysia Peninsular, that had systematic management since 1902, and is considered the best-managed mangrove forest in the world (Goessens et al. 2014). MMFR also resides among local people who exploited mangrove forest benefits with aquaculture, shrimp harvest, cockles rearing, timber harvesting, and non-timber harvesting. This shows that MMFS is filled with human activities (Ahmad 2009). Even there it is filled with human activities, the occurrence of cetaceans still occurs in Matang waters because of its shallow waters of less than 50 meters and high prey productivity, which become an ideal place for cetaceans to reside (Jefferson and Smith 2016). The high number of fisheries activities in Matang waters leads to heavy vessel traffic, causing the Indo-pacific humpback to have a higher pitch sound than its species in Langkawi (Hoffman et al. 2015).

The occurrence of cetaceans becomes important for the Matang people's socio-economy with the attraction of dolphin watch (Kuit et al. 2014). Previous studies have shown that dolphin distribution still occurs near land, even with many human anthropogenic activities in that area (Kuit et al. 2019). Even with current studies showing the distribution of both dolphins in Matang waters, the hot spot areas for both species still lack data. The identification of the hotspot area in Matang waters gave an opportunity for future studies and increased the conservation importance in that area.

## MATERIALS AND METHODS

### Study area

The study was conducted on the west coast of Malaysia Peninsular (Figure 1). Matang waters have a reserve mangrove forest of 40,288 hectares (400 km²) size with plenty of rivers that have a high amount of biodiversity in the area and one of its residents is cetaceans (Kuit et al. 2014). The rivers inside the Matang waters are Kuala Gula, Kuala Larut, Sungai Sangga Besar, Sungai Selinsing, Sungai Sepetang, Sungai Sangga Kechil, Sungai Trong and Kuala Jarum Mas. The area was in Perak state called Matang waters and the approximate surveyed area was around 680 km² of open sea area and a total river length of 122 km. Matang waters were also filled with human activities such as charcoal production, fisheries, and aquaculture because of many types of natural resources (Ahmad 2009). With high numbers of human activities, the water quality of Matang rivers was still acceptable, and a sufficient number of Dissolved Oxygens (DO) on surface water indicates the water is healthy (Zaidin et al. 2015). Matang waters area is a mudflat area which resides bountiful fish resources and Perak state had the highest landing of marine fish in Malaysia (Department of fisheries 2017).

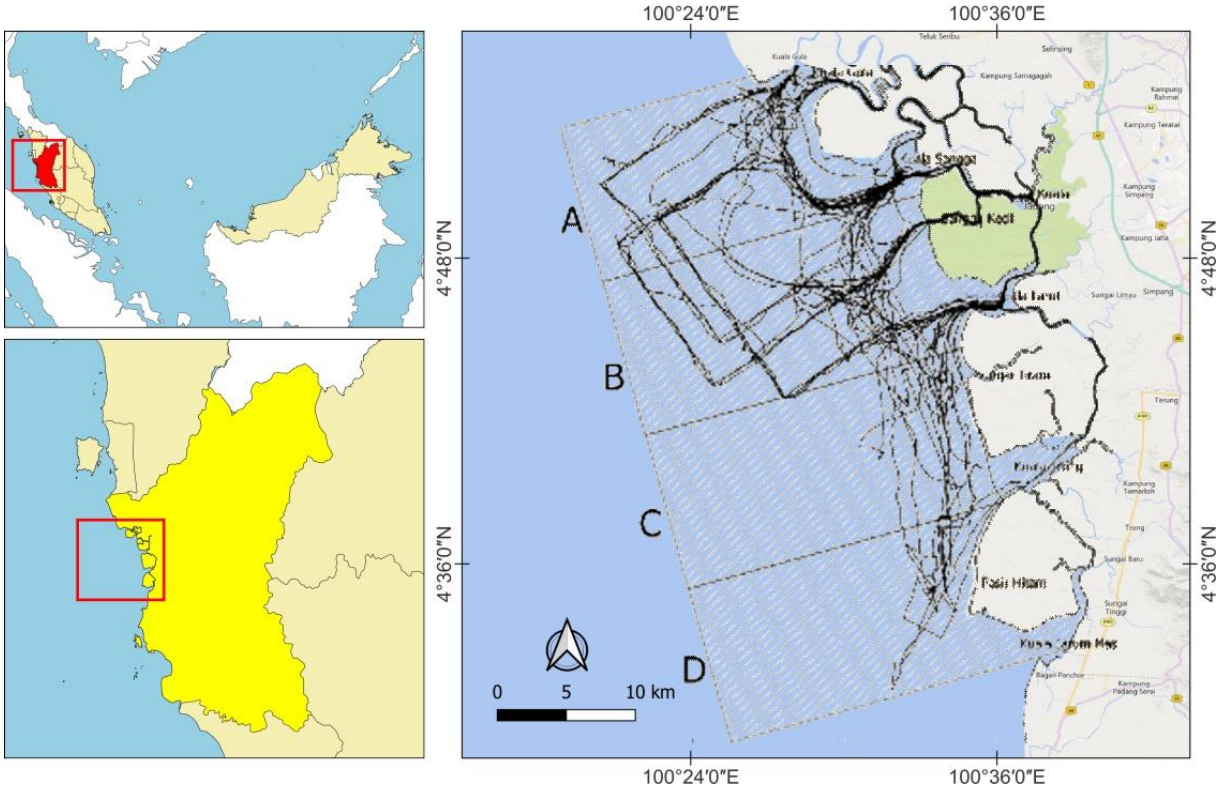


**Figure 1.** Map of survey track in Matang water, Perak and Peninsular Malaysia (smaller picture). The survey area were categorized into area A, B, C, and D

**Procedures**

*Data collection*

The survey was conducted between March 2019 to January 2021, which is 44 days in total. 10 meters wooden boat was used to survey the area with an average speed of 15 km/h. The survey time started from 8.00 morning until 5.00 evening and was only conducted during neap tide. Every survey for searching dolphins started in Kuala Sepetang (4.8384° N, 100.6309° E) and moved to different targeted locations, and went back to Kuala Sepetang from different routes to avoid finding the same dolphin group. Parra (2005) suggest that the range of dolphin between 100 meters are defined as spatial cohesion and may come from the same group. When encountering a dolphin group, the boat will stop, GPS location using GARMIN GPSMAP 64s was recorded and the boat approached slowly to the dolphin group without disturbing them to catalog the behavior data. The behaviors data were categorized as: foraging (dolphins finding food behavior); socializing (dolphins interaction with each other behavior); evasive (dolphins evading interaction with survey boat) and travelling (dolphins moving together to a certain area) (Tyack 2018; Piwetz 2019). Every behavior was taken for 10 minutes, and if the dolphins disappeared before 10 minutes, that observation was discarded. Whenever there are mixed behaviors, only the most dominant will be recorded.

**Data analysis**

The GPS data point were extracted from Garmin into Microsoft Excel. The GPS Data were sorted and converted to CSV files for conversion into QGIS software for Hotspot Analysis (Getis and Ord 1992; Oxoli et al. 2016). The Hotspot Analysis was based on the Getis-ord Gi statistic calculation. To avoid bias in Hotspot analysis, every sighting data point was weighted based on sighting efforts that were standardized as Catch Per Unit Effort (CPUE) (Jaaman 2010). The analysis area was made of 1 km by 1 $km^2$ to increase the precision of the Hotspot Analysis. The Getis-ord Gi statistic was used to calculate the number of Z-scores and P-value in the plot of 1 $km^2$. The hotspot area of the dolphin with a 99% confidence level was accepted to be identified as the hotspot area. With Z-score exceeding 2.58 and a P-value number below 0.01, the Getis-ord Gi analysis had 99% confidence leveled to identify the hotspot area. Only the highest confidence level (99%) was used to pinpoint the hotspot area. The Matang water areas were split into four coded areas A,B,C, and D. Pearson's Chi-Squared test was used to analyze the significance of an area with behaviors of both dolphins.

## RESULTS AND DISCUSSION

**Survey effort and sighting**

A survey in Matang waters was conducted between March 2019 to January 2021, which the total number of days surveyed was 44 days. The total survey covers around 3325.76 km in length and 239.38 hours were spent during these surveys. The total number of sightings for both species was 69, whereas the Indo-Pacific humpback dolphin was 40 and the Irrawaddy dolphin was 29. The total number of both dolphins' behavior was 281. The sighting rate of both dolphins can be observed in (Table 1).

**Identified dolphin hotspot**

To identify the hotspot QGIS Hotspot analysis plugin with the Getis-ord-gi analysis was used to show the hotspot area for both Indo-Pacific humpback and Irrawaddy dolphin. Indo-Pacific humpback dolphin has 33 hotspot area plots (Figure 3). The Z-score for Indo-Pacific humpback dolphins varied from 2.6257 to 8.8975 (mean: 4.9151, SD: 1.9186). The p-value for the Indo-Pacific humpback dolphin varied from 0 to 0.0086 (mean: 0.0007, SD: 0.0018). Irrawaddy dolphin has 45 hotspot area plots (Figure 4.). The Z-score for the Irrawaddy dolphin varied from 2.6537 to 6.5571 (mean: 3.8732, SD: 1.1884). The p-value for the Irrawaddy dolphin varied from 0 to 0.008 (mean: 0.0023, SD: 0.0031).

There is also a significant difference when using Chi-Square of independence between dolphin sightings (Figure 2) with each area ($x^2$: 20.48, df: 3, p-value: 0.0001). The Indo-pacific humpback was more inclined to be sighted most in Area A. For the Irrawaddy dolphin, the sighting was more spread towards the south, which is areas B, C, and D.

**Dolphin behaviors**

Total both dolphin behavior recorded was (n: 281). The behavior was categorized into four segments socializing, foraging, travelling, and evasive. The highest behavior recorded was foraging, which is 72% (n: 203), followed by socializing at 17% (n: 48), evasive 7% (n: 20) and travelling 4% (n: 10). There is a significant difference between the behavior of both dolphins with A, B, C, and D areas ($x^2$: 41.35, df: 9, p-value: 0.000004). The dolphins were likely to forage in Area A and Area B. They also tend to socialize in Areas A and B. For Evasive behavior, they tend to Evade in areas B, C, and D. They tend to travel in Area C.

**Table 1.** The sighting rate (100 km.hrs) of both Indo-Pacific humpback (*Sousa chinensis*) and Irrawaddy (*Orcaella brevirostris*) dolphin during the survey started on March 2019 to January 2021

| Survey month | Date survey | Day survey | Distance (km) | Time (hrs) | Total survey efforts (km.hrs) | No. of sighting (Indo-Pacific humpback dolphin) | No. of sighting (Irrawaddy dolphin) | Sighting rate (100 km.hrs) (Indo-Pacific humpback dolphin) | Sighting rate (100 km.hrs) (Irrawaddy dolphin) |
|---|---|---|---|---|---|---|---|---|---|
| March 2019 | (12/3/2019 - 17/3/2019) | 6 | 557.8 | 41.63 | 3876 | 2 | 5 | 0.05 | 0.13 |
| June 2019 | (12/6/2019 -17/6/2019) | 6 | 366.7 | 27.06 | 1957.12 | 3 | 0 | 0.15 | 0.00 |
| August 2019 | (22/8/2019 - 28/8/2019) | 6 | 506.36 | 38.06 | 3328.978 | 9 | 3 | 0.27 | 0.09 |
| November 2019 | (27/11/2019 - 1/12/2019) | 5 | 384.7 | 27.83 | 2178.63 | 5 | 4 | 0.23 | 0.18 |
| January 2020 | (14/1/2020 - 19/1/2020) | 6 | 454 | 27.33 | 2142.298 | 6 | 9 | 0.28 | 0.42 |
| June 2020 | (22/7/2020 - 27/7/2020) | 5 | 367.1 | 24.9 | 1828.999 | 7 | 0 | 0.38 | 0.00 |
| October 2020 | (8/10/2020 - 12/10/2020) | 5 | 309.7 | 22.61 | 1482.455 | 5 | 1 | 0.34 | 0.07 |
| January 2021 | (4/1/2021 - 8/1/2021) | 5 | 379.4 | 29.96 | 2283.621 | 3 | 7 | 0.13 | 0.31 |
| | **Total** | **44** | **3325.76** | **239.38** | **19078.10** | **40** | **29** | **0.21** | **0.15** |

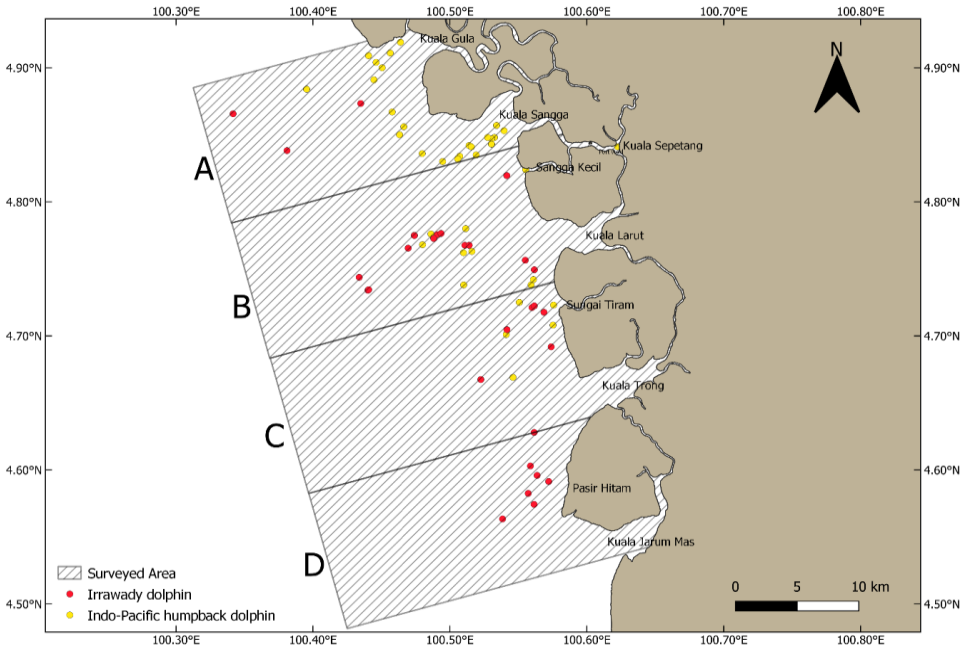


**Figure 2.** The sighting point of both dolphin Indo-Pacific humpback (40 sighting points) and Irrawaddy (29 sighting points) dolphin

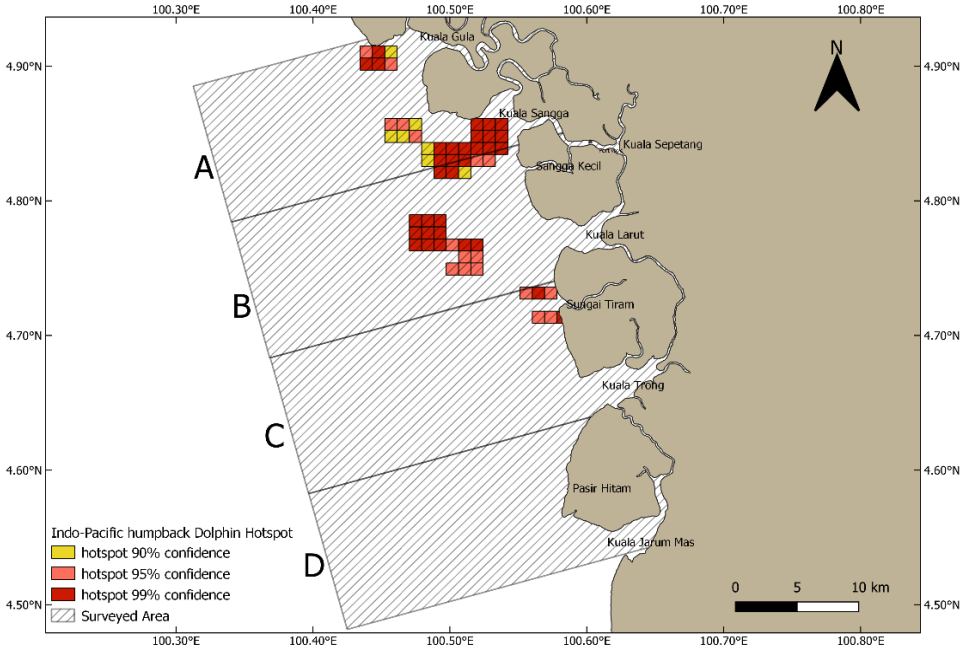


**Figure 4.** There were 45, 1 km x 1 km square hotspot plots with a 99% confidence level for Irrawaddy dolphin. Area B has the highest number of Hotspot plots which is 28, followed by Area C, which is 14 and area D, which is 3

**Table 2.** Pearson's chi-squared test result of the behavior of both Indo-pacific humpback and Irrawaddy dolphin at different areas

| Area | No. of Foraging | No. of Socializing | No. of Evasive | No. of Travelling | Chi-Square Pearson Goodness-of-fit Test | | |
|---|---|---|---|---|---|---|---|
| | | | | | $X^2$ | Degree of freedom (d.f) | p-value |
| Area A | 30 | 17 | 1 | 0 | 41.35061 | 9 | 0.000 |
| Area B | 98 | 64 | 24 | 17 | | | |
| Area C | 1 | 3 | 6 | 0 | | | |
| Area D | 3 | 10 | 4 | 3 | | | |

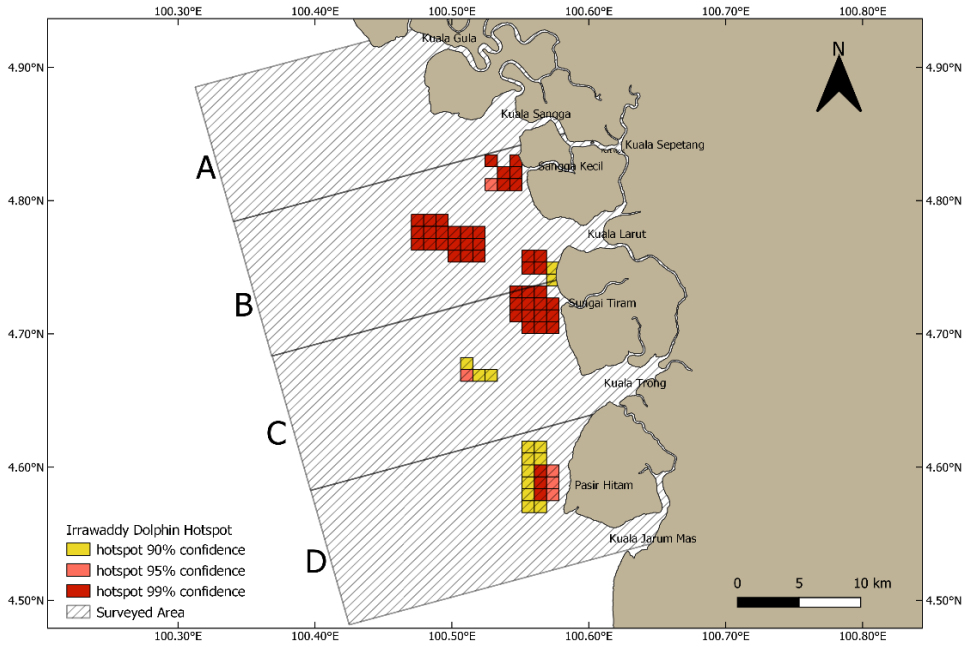


**Figure 5**. Picture of adult Indo-pacific humpback dolphin (*Sousa chinensis*) in Matang waters

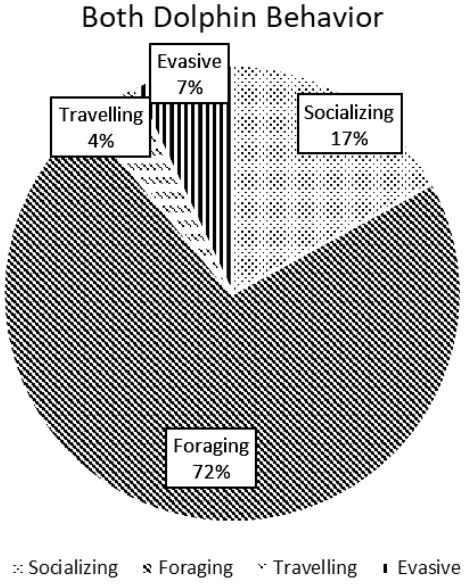


**Figure 6**. Picture of adult Irrawaddy dolphin (*Orcaella brevirostris*) in Matang waters

## Discussion

*Dolphin hotspot*

During the survey in Matang waters, the sighting of the dolphins can be observed distinctly between two species. The Indo-Pacific humpback (*Sousa chinensis*) was more likely to be sighted in Kuala Sangga (area A), which is further north than the Irrawaddy dolphin (*Orcaella brevirostris*). On the other hand, the Irrawaddy dolphins were observed more frequently in Kuala Larut (Area B), which is southern than the Indo-Pacific humpback dolphin hotspot area. The area of the hotspot precision was 1km x 1km was used is this study because the area movement of cetaceans was large and they depend on the area of their prey (Becker et al. 2018).

Even Area A is congested with moving ships, the Indo-Pacific humpback dolphin was not affected. They tend to ignore the moving ship area and forage the area exclusively. During the survey, only these dolphin species were found deep inside the Matang river area near Kuala Sepetang, where there is a local settlement full of moving ships and human activities. The behaviors of the Indo-Pacific humpback dolphin with the survey boat were keen to be friendlier than the Irrawaddy dolphin due to their disregard for the survey ship moving closer.

Irrawaddy dolphins were easily frightened by the survey boat and tried to avoid it by staying 100 meters distance, and when they felt threatened, they tended to avoid it more rapidly and move faster away from the ship. The Irrawaddy dolphin tends to forage in the more untouched area or with less human interaction. Based on a recent study by Pazi et al. (2021), one of the areas that had the least human disturbance were Area B, C, and D. This may be one of the reasons the hotspot area for Irrawaddy dolphins were lower south than Indo-pacific humpback. The Indo-pacific humpback tends to be calm or ignore the surrounding boat and people. The Irrawaddy was more perceptive toward surrounding boats and people (Jiang et al. 2019). It shows that both species have different types of preferences for their habitat and reaction toward human anthropogenic activities.

The mangrove forest was well known for having indirect or direct effects on the livelihood of megafauna (Sievers et al. 2019). The hotspot area for both dolphins tends to have the same type of mangrove area that

discharge nutrient from land to ocean. Matang waters reside in the Matang Mangrove Forest Reserve, which has a high number of nutrient discharges that support primary production for the fish that eventually become prey for the dolphins (Chew et al. 2012). This shows the hotspot area is a vital foraging area for the dolphins because the most dominant behavior in this survey is foraging.

The study of the hotspot area in Matang Waters shows that the Matang Mangrove Forest Reserve plays a bigger role in providing a habitat for this large megafauna (Chew et al. 2012). It is also important for sustaining the Mangrove Forest with adequate information to enhance the management practice and legislative role (Ibharim et al. 2015). Matang Mangrove Forest Reserve also has another important habitat for other species, such as migratory birds, porpoises, and other flora and fauna (Azimah and Tarmiji 2018; Muhd-Ekhzarizal et al. 2018; Kuit et al. 2019).

*Dolphin behavior*

The significance of Indo-pacific humpback and Irrawaddy dolphin behaviors can be seen in (Table 2). Both dolphins tend to have a higher number of foraging behavior and can be seen clearly in Areas A and B. It also showed the number of behaviors is the highest in Area B. There are different reactions and behaviors of both species in the Matang waters area. The behaviors of Indo-pacific humpback and Irrawaddy dolphins are quite different from the dolphin in Cowie Bay, Sabah. There is plenty of trawling boats around 20 km from the coast, but there is no sign of dolphin following them like in Cowie Bay, Sabah as reported by Hashim and Jaaman (2011). Nevertheless, dolphin such as the Indo-Pacific humpback was well known to correspond with local adaptation and varying environmental conditions (Wang et al. 2015).

The category of socializing was based on the dolphin behavior when the observation started. Socializing is when the dolphin observed behave like playing with each other with high-speed movement in the water and frequent direction changes (Bijukumar and Smrith 2012; Tubbs et al. 2020). The Indo-Pacific humpback in Matang waters was seen socializing with breaching, bow riding, upside-down swimming and rough playing with each other. The Irrawaddy dolphin tends to group together and stay close until they touch each other. They also tended to spy-hopping when the survey boat was present. As for traveling behavior, the dolphins tend to move in one direction and synchronize swimming (Tubbs et al. 2020). The Irrawaddy dolphin has been seen traveling northern from Kuala Larut (Area B) when there were trawling trails left by trawlers.

Indo-Pacific humpback dolphins were not affected by surrounding boats even though area A was congested with the local boat moving in and out from the estuaries. They also ignored the moving boat when they were foraging. The dolphins were frequently seen foraging in gill net areas and near coastal areas. One of the foraging indicators is the presence of fish heads floating around the dolphin-sighted area (Kuit et al. 2019). The dolphins were also eating cautiously because they only consume the tail part of the fish and avoid the head and dorsal spine of the fish. There was a sighting of both species group in Matang waters (Area B) that happened twice, but there were no mixing of species in one group. They only stayed with their own species group and distanced themselves.

The interaction of Evading behaviors was used to identify the interaction of both dolphins with the survey boat. During the survey, Irrawaddy dolphins were more evasive than Indo-Pacific humpback dolphins because of their shy and elusive behavior (Jaaman 2010). Our survey covered the coastal area only and missed the open ocean area. In March 2019, June 2019, and August 2019, we went to the open ocean in areas A and B as a preliminary study, but the dolphins tend to be sighted more in coastal areas, so we changed the survey route to coastal areas and abandoned the open ocean area. This also gave us an opportunity to survey the coastal area from Kuala Gula to Kuala Jarum Mas.

The studies of dolphins in Matang waters were still new and started since 2012 and there is plenty of studies that can be done. This study may lead to another question such as how human anthropogenic activities will affect the habitat of this megafauna, will lead to a change into another hotspot area and the social structure of the dolphins in the area. With limitations such as the daytime-only survey and only survey during tide to avoid increasing the chance of encountering the dolphins. Other studies of genetic trees and stable isotopes for the dolphin were also needed to understand more about them. Nevertheless, Matang waters or Matang Mangrove Forest Reserve area was an important source for future study and conservation.

## ACKNOWLEDGEMENTS

This research was jointly supported by the Universiti Malaya project titled "Identifying the hotspot area of Indo-Pacific humpback (*Sousa chinensis*) and Irrawaddy (*Orcaella brevirostris*) dolphins in Matang waters, Perak, Malaysia." (GPF014B-2018), China-ASEAN Maritime Cooperation Fund through the First Institute of Oceanography, China and Universiti Malaysia Terengganu project titled "Joint Surveys for Marine Endangered Species (MES) in Malaysian Waters" (INOS TRUST FUND: 53338)". We would like to thank the local people in Kuala Sepetang, The boatman Hanif and Leman, and The Caifu Homestay for their great hospitality.

## REFERENCE

Ahmad S. 2009. Recreational values of mangrove forest in Larut Matang, Perak. J Trop For Sci 21 (2): 81-87.

Azimah A, Tarmiji M. 2018. Habitat requirements of migratory birds in the Matang Mangrove Forest Reserve, Perak. J Trop For Sci 30 (3): 304-311. DOI: 10.26525/jtfs2018.30.3.304311.

Bali J, Jaaman S, Saleh, Ejria, Munsang T, Tisen O, Ganyai T. 2017. Distribution, abundance and density of Irrawaddy Dolphin (*Orcaella brevirostris*) in Rajang River of Sarawak, East Malaysia. Malays Appl Biol 46: 105-114.

Becker EA, Forney KA, Redfern JV, Barlow J, Jacox MG, Roberts JJ, Palacios DM. 2018. Predicting cetacean abundance and distribution in a changing climate. Divers Distrib 25 (4): 626-643. DOI: 10.1111/ddi.12867.

Bijukumar A, Smrithy R. 2012. Behaviour of Indo-Pacific humpback dolphin, *Sousa chinensis* (Osbeck) in the Ashtamudi estuary, southwest coast of India. J Mar Biol Assoc India 54 (2): 5-10. DOI: 10.6024/jmbai.2012.54.2.

Chew LL, Chong VC, Tanaka K, Sasekumar A. 2012. Phytoplankton fuel the energy flow from zooplankton to small nekton in turbid mangrove waters. Mar Ecol Prog Ser 469: 7-24. DOI: 10.3354/meps09997.

Department of Fisheries Malaysia. 2017. Annual Fisheries Statistics 2017. https://www.dof.gov.my/dof2/resources/user_29/Documents/Perangkaan%20Perikanan/2017%20Jilid%201/Jadual_Pendaratan.pdf.

FAO 2020. Global Forest Resources Assessment 2020 Report: Malaysia. Food and Agriculture Organization, https://www.fao.org/3/cb0033en/cb0033en.pdf.

Getis A, Ord JK. 1992. The analysis of spatial association by use of distance statistics. Geogr Anal 24: 189-206. DOI: 10.1111/j.1538-4632.1992.tb00261.x.

Goessens A, Satyanarayana B, Van-Der ST, Zuniga MQ, Mohd-Lokman H, Sulong I, Dahdouh-Guebas F. 2014. Is Matang Mangrove Forest in Malaysia sustainably rejuvenating after more than a century of conservation and harvesting management? Plos One: 9 (8): e105069. DOI: 10.1371/journal.pone.0105069.

Harahap ZA. 2022. Diversity and distribution of dolphin in Langkat Water, North Sumatera. Jece J Empowerment Commun Educ 1 (3): 235-242.

Hoffman JM, Ponnampalam LS, Araújo CC, Wang JY, Kuit SH, Hung SK. 2015. Comparison of Indo-Pacific humpback dolphin (*Sousa chinensis*) whistles from two areas of western Peninsular Malaysia. J Acoust Soc Am 138 (5): 2829-2835. DOI: 10.1121/1.4934254.

Ibharim NA, Mustapha M, Lihan T, Mazlan AG. 2015. Mapping mangrove changes in the Matang Mangrove Forest using multi temporal satellite imageries. Ocean Coast Manag 114: 64-76. DOI: 10.1016/j.ocecoaman.2015.06.005.

Jaaman SA. 2010. Marine Mammals in East Malaysia: Distribution and Interactions with Fisheries. VDM Verlag Dr. Muller Aktiengesellschaft & Co. KG., Saarbrucken, Germany.

Jefferson TA, Smith BD. 2016. Re-assessment of the conservation status of the Indo-Pacific Humpback Dolphin (*Sousa chinensis*) using the IUCN Red List criteria. Adv Mar Biol 73: 1-26. DOI: 10.1016/bs.amb.2015.04.002.

Jiang Y, Zhang XL, Yang ZG, Jaaman SA, Xu QZ, Muda AM, Muhamad HM. 2019. The preliminary analysis of echolocation signals produced by fleeing Irrawaddy dolphin *(Orcaella brevirostris).* Acta Oceanol Sin 38 (1): 85-89. DOI: 10.1007/s13131-019-1373-y.

Kuit SH, Ponnampalam LS, Fairul-Izmal JH, Chong VC. 2014. Cetacean research and a precautionary approach in developing dolphin-watching tourism in the coastal waters of the Matang mangroves. Proceedings of Matang Mangrove Forest Management Conference 2014. Perak Darul Ridzwan, 24-26 November 2014. [English]

Kuit SH, Ponnampalam LS, Jol EN, Ving CC, Amy T. 2019. Distribution and habitat characteristics of three sympatric cetacean species in the coastal waters of Matang, Perak, Peninsular Malaysia. Aquat Conserv Mar Freshw Ecosyst 29: 1681-1696. DOI: 10.1002/aqc.3121.

Muhd-Ekhzarizal MM, Hasmadi I, Hamdan O, Roslan M, Shaila S. 2018. Estimation of aboveground biomass in mangrove forests using vegetation indices from spot-5 image. J Trop For Sci 30 (2): 224-233. DOI: 10.26525/jtfs2018.30.2.224233.

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

Pazi AM, Khan WR, Nuruddin AA, Adam MB, Gandaseca S. 2021. Development of mangrove sediment quality index in Matang Mangrove Forest Reserve, Malaysia: A synergetic approach. Forests 12 (9): 1279. DOI: 10.3390/f12091279.

Hashim NA, Jaaman SA. 2011. Boat effects on the behavior of Indo-Pacific Humpback (*Sousa chinensis*) and Irrawaddy (*Orcaella brevirostris*) dolphins in Cowie Bay, Sabah, Malaysia. Sains Malaysiana 40 (12): 1383-1392.

Oxoli D, Zurbarán M, Shaji S, Muthusamy AK. 2016. Hotspot Analysis: A First Prototype Python Plugin Enabling Exploratory Spatial Data Analysis Into QGIS. Open Source Geospatial Research & Education Symposium (OGRS2016). Peer J Inc. San Francisco, USA.

Parra GJ. 2005. Behavioural Ecology of Irrawaddy, *Orcaella brevirostris* (Owen in Gray, 1866), and Indo-Pacific Humpback Dolphins, *Sousa chinensis* (Osbeck, 1765), in Northeast Queensland, Australia: A Comparative Study. [Dissertation]. James Cook University, Australia.

Piwetz S. 2019. Common bottlenose dolphin (*Tursiops truncatus*) behavior in an active narrow seaport. Plos One 14 (2): e0211971. DOI: 10.1371/journal.pone.0211971.

Sarkar M, Kabir S, Begum RA, Pereira JJ, Jaafar AH, Saari MY. 2014. Impacts of and adaptations to sea level rise in Malaysia. Asian J Water Environ Pollut 11 (2): 29-36.

Sievers M, Brown CJ, Tulloch VJ, Pearson RM, Haig JA, Turschwell MP, Connolly RM. 2019. The role of vegetated coastal wetlands for marine megafauna conservation. Trends Ecol Evol 34 (9): 807-817. DOI: 10.1016/j.tree.2019.04.004.

Tubbs SE, Keen E, Jones A, Thap R. 2020. On the distribution, behaviour and seasonal variation of Irrawaddy Dolphins (*Orcaella brevirostris*) in the Kep Archipelago, Cambodia. Raffles Bull Zool 68: 137-149. DOI: 10.26107/RBZ-2020-0015.

Tyack P. 2018. Behavior, overview. In: Perrin WF, Würsig B, Thewissen JGM (eds). Encyclopedia of Marine Mammals, 3rd Edn. Academic Press, San Diego.

Wang X, Wu F, Turvey ST, Rosso M, Tao C, Ding X, Zhu Q. 2015. Social organization and distribution patterns inform conservation management of a threatened Indo-Pacific humpback dolphin population. J Mammal 96 (5): 964-971. DOI: 10.1093/jmammal/gyv097.

Zaidin NHARN, Nurhidayu S, Shafuan MFA, Gandaseca S, Kasim MRM, Malek IAA. 2015. Water quality characteristics in different mangrove disturbance levels, Matang Mangrove Forest Reserve, Peninsular Malaysia. 3rd International Conference on Water Resources (ICWR-2015). Bayview Hotel, Langkawi, Kedah, 24-25 November 2015.