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Cetacean diversity, distribution, and population estimation of *Stenella* dolphins in Pieh Marine Protected Area and the surrounding seas, West Sumatra Province

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Abstract. Cetacean studies in Indonesia are rare, especially those pertaining to population abundance. This is in spite of the fact that cetaceans are considered priority biodiversity by the Ministry of Marine Affairs and Fisheries that must be protected and managed sustainably. The purpose of this study was to examine the species and habitat characteristics of cetacean species within the Pieh Marine Protected Area and the surrounding seas, West Sumatra Province and provide recommendations for their management. 25 days of non-consecutive vessel-based surveys were conducted between 2019 and 2022, covering a total distance of 1,567 km. Species diversity, spatial distribution, frequency of occurrence of less frequently observed species, population abundance for species with highest occurrences, and environmental parameters were analysed. Eight species of cetaceans were identified during on-effort surveys in decreasing order of encounter frequency: *Stenella longirostris longirostris* (Gray's spinner dolphin; 44 encounters), *Stenella longirostris roseiventris* (dwarf spinner dolphin; seven encounters), *Stenella attenuata* (pantropical spotted dolphin; seven encounters), *Tursiops aduncus* (Indo-Pacific bottlenose dolphin; six encounters), *Balaenoptera omurai* (Omura's whale; five encounters (three on-effort and two off-effort)), *Grampus griseus* (Risso's dolphin; two encounters), *Lagenodelphis hosei* (Fraser's dolphin; one encounter), and *Peponocephala electra* (melon-headed whale; one encounter). Cetaceans were found in the waters around four islands, namely Bando, Pieh, Pandan, and Toran Islands with water temperatures ranging between 28.0–31.8°C and a depth of 5–360 m. No significant differences in temperature and depth preferences were found between cetacean species inside the MPA but all species except for Omura's whale were encountered at lower mean depth than other studies in the region or elsewhere. The first abundance and density estimates for populations of *Stenella* dolphins in Indonesia were obtained from this study in Pieh Marine Protected Area and the surrounding seas, covering an area of 399.2 km², with 2,997 individuals and 3.8 individuals/km² (CV = 25.2%). The highest density of *S. l. longirostris* was 2.4 individuals/km² with a total population estimate of 1,921 individuals (CV = 30.2%). This baseline information about cetaceans is relevant in the management of Pieh Marine Protected Area and the surrounding seas. The methods used in this study may be replicated in other marine protected areas as part of routine patrols by trained observers to conduct marine mammal studies to narrow the knowledge gap regarding cetacean diversity, distribution and relative abundance in the vast marine environment of Indonesian waters. The high density of spinner dolphins, the presence of calves, the near year-round presence of cetaceans, frequent occurrence of Omura's whales, and the observation of two near-threatened species (*T. aduncus* and *P. electra*), identifies the area as an important habitat for at least eight cetacean species on the west coast of Sumatra and qualifies a nomination of the Pieh Marine Protected Area as an Important Marine Mammal Area.

Key words. spinner dolphins, Indonesia, population, density and abundance, marine mammal conservation, Important Marine Mammal Area (IMMA)

INTRODUCTION

Indonesia is considered the second largest megabiodiverse country in the world, after Brazil (Sabarno, 2002). Its rich species diversity includes cetaceans, as Indonesian marine waters are habitats and migration routes for at least 34 species of cetaceans—around one-third of all cetaceans in the world (MMAF, 2018). In West Sumatra Province, the waters of Pieh Marine Protected Area (MPA) and the surrounding seas are important habitat for cetaceans such as dolphins and whales, which have been observed during field monitoring surveys conducted by the local management unit of the Directorate General of Marine Spatial Management (LKKPN Pekanbaru, 2018).

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Table 1. Data used in the population estimation analysis of *Stenella* taxa.

Date	Number of survey days	Transect length (km)	Number of transect lines surveyed	Cetacean species
15 April–14 December 2019	6	342	11	*Stenella longirostris longirostris*, *Stenella longirostris roseiventris*, *Stenella attenuata*
25 February–23 September 2020	9	562	15	*Stenella longirostris longirostris*, *Stenella attenuata*
16 March–8 July 2021	5	236	5	*Stenella longirostris longirostris*, *Stenella longirostris roseiventris*, *Stenella attenuata*
2 March–21 September 2022	5	427	10	*Stenella longirostris longirostris*, *Stenella longirostris roseiventris*
Total	25	1,567	41	

Pieh MPA and the surrounding seas received its protected status through a ministerial decree from the Ministry of Marine Affairs and Fisheries (MMAF, 2022), becoming one of 11 national MPAs. This area, 399.2 km² in size, is located on the west coast of Sumatra and has a variety of marine biological resources that have important ecological value and/or potential value for sustainable development use. Pieh MPA and the surrounding seas also contains much important biodiversity beside cetaceans, including coral reefs with a rich diversity of 114 species of coral fish (Director General for Marine Spatial Management, 2023). The same decree mentions that sea turtles, namely the green turtle (*Chelonia mydas*) and hawksbill turtle (*Eretmochelys imbricata*) are found almost all-year round on Pandan and Bando Island, which are nesting sites for both species.

All species of marine mammals in Indonesian waters are protected species (Minister of Environment and Forestry, 2018). Protection is also mandated under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Based on the level of threat potentially stemming from its international use or trade, cetaceans are included in the CITES Appendix I and II categories. Meanwhile, cetaceans in Pieh MPA and the surrounding seas are also classified as Near Threatened, Least Concern, or Data Deficient according to the IUCN Red List (https://www.iucnredlist.org/).

Cetaceans are considered priority biodiversity, as identified by the Ministry of Marine Affairs and Fisheries whose management direction is contained in the Decree of the Minister of Marine Affairs and Fisheries Number 79/KEPMEN-KP/2018 concerning the National Action Plan (RAN) for Marine Mammal Conservation for 2018–2022. Therefore, cetacean management is required to ensure that cetacean species, their habitat, and fish resources are optimally protected and can be utilised sustainably.

The presence of cetaceans in any given area is used as an indicator to assess the level of the health of the sea (Bik et al., 2016). As such, the distribution and population abundance of cetaceans needs to be identified and estimated for sustainable cetacean management efforts (Hemami et al., 2018). Having a baseline population abundance estimate provides a reference for future monitoring, analyses on population trends, assessing the quality of the animals' habitat, and identifying threats (Purba et al., 2020). However, apart from encounter rates for some cetacean species (Kreb & Budiono, 2005; Borsa & Nugroho, 2011; Ender et al., 2014), relatively few studies have been conducted in Indonesia and published to provide robust population abundance estimates for coastal cetacean populations (e.g., Kreb et al., 2020; Mustika et al., 2021).

The goals of this study were to assess cetacean species diversity, density and abundance for the most abundant species, encounter rates for less abundant species, distribution, and environmental parameters associated with species presence in Pieh MPA. The findings will help reduce the knowledge gap on cetacean species occurrence in the western waters of Indonesia and contribute to the sustainable management of marine biodiversity in Pieh MPA and the surrounding seas.

MATERIAL AND METHODS

The study was conducted in the waters of Pieh National Marine Protected Area and the surrounding seas, West Sumatra Province (Fig. 1). This research study covers the waters around small islands, including Bando, Pieh, Air, Pandan, and Toran Islands. Primary data for cetacean spatial distribution and density analysis were collected through direct observation from systematic vessel-based surveys during ten survey periods, each lasting 2.5 days on average and 25 days in total from 2019 to 2022 (Table 1). The boat cruised along two transect lines that were laid out perpendicular to the depth gradient and provided representative survey area coverage including different depth contours and distances from islands (Fig. 1). The lines were set out to be able to cover both the northern- and southern-most part of the Pieh MPA within one day based on the time and distance limitations set by the park management authority. The transect at the western part of the park had a length of 40 km, while

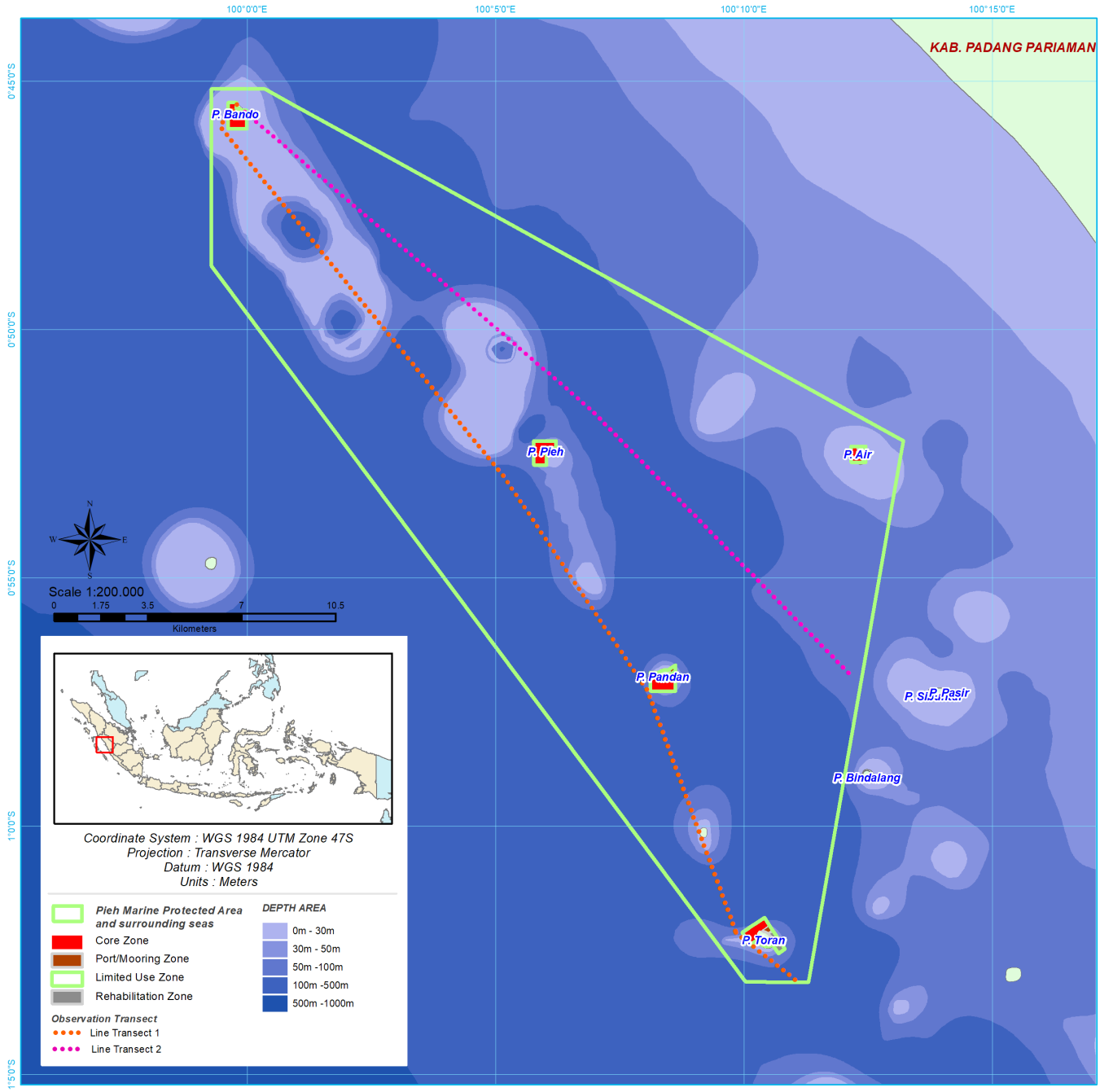

Fig. 1. Survey line transects in the Pieh Marine Protected Area.

the transect to the east was 31 km. Within each of the ten survey periods, each transect was repeated on another day in the reverse direction to minimise bias and ensure coverage during different tidal states.

The average daily total transect length completed was 63 km involving two transect lines. The survey vessel was 12 m in length and had an observer platform on the deck 2.2 m above the sea surface. The vessel moved at an average speed of 8–10 knots. The daily average transect path length was 38.24 km and all tracks were recorded on a GPS unit (Garmin AP 78s). The survey team consisted of four persons who rotated task positions every 30 minutes: 1) data recorder who recorded survey effort every 30 minutes, or earlier if sea or weather conditions changed (survey track, speed and environmental data such as Beaufort sea state, cloud cover, weather (rain/fog) and sun glare conditions and the resulting visibility class: good, medium, or poor), group encounters, and GPS coordinate data; 2) one observer who searched for cetaceans with the naked eye ahead of the bow of the vessel; 3) two observers who searched for cetaceans in the 90° angle range on the port and starboard sides of the vessel at 3.7 m eye-height above sea level with binoculars (Nikon Aculon A211 10–22 × 50 zoom).

Upon sighting of a cetacean, bearing to the animal and boat (using a compass) to obtain the sighting angle as well as distance to the cetacean were immediately recorded, while environmental data relevant to visibility including the Beaufort sea state was also immediately recorded. Observers practiced distance estimations throughout and prior to the survey by estimating and reading the distance to

fixed objects from a laser range finder (maximum range of 1.2 km) and GPS to measure greater distances by checking boat positions towards fixed positions already marked on the GPS unit such as islands or large buoys. Having an observer guarding the track line, assessing distance and sighting angles upon initial sighting, and using tools to increase precision helped in meeting the following three assumptions laid out by Buckland & York (2009) when performing estimations of animal population sizes using Distance Sampling: a) All animals on the survey transect line are detected; b) Animals are detected in their initial position, not affected by the observer's movement or speed; and c) Estimates of distance, angle and group size are accurate.

After the distance data were obtained, the vessel left the survey track to approach the cetaceans for species identification, group size estimation (best, minimum, and maximum), and to take the geographic coordinates of the cetaceans' actual location. In estimating group size, groups were defined as all cetaceans that are within a radius of 100 m, moving in the same direction and, but not always, performing the same activity (Wells et al., 1987; Shane, 1990). The number of juveniles (defined as individuals measuring about ¾ of adult size) and calves (defined as measuring about ½ of adult size) were estimated per group following Kreb et al. (2020). Photographs for species identification were made using a Nikon D7200 DSLR camera with a Nikkor zoom lens of 18–140 mm and also using Nikon Coolpix P1000 cameras with a zoom lens equivalent to 24–3000 mm in 35 mm format.

After group sizes and composition were confirmed, oceanographic data related to sea surface water temperature (SST) obtained directly in the field at each cetacean group location (for the years 2021–2022) and monthly through Aqua MODIS imagery for all years (2019–2022). In-situ SST measurements were taken with an analogue thermometer while measurements were repeated three times. The Aqua MODIS imagery used were Terra MODIS level 3 imagery with a resolution of four km. This Aqua MODIS Terra Imagery data was obtained from the NASA website (http://oceancolor.gsfc.nasa.gov). Meanwhile, depth at cetacean locations for all years were obtained using Geospatial Information Agency Bathymetry data (https://sibatnas.big.go.id/).

Data Analysis. Species were identified based on sight and/or photographic or video field documentation showing clear features used for identifying species, and then compared to the species photos and identification keys from Jefferson et al. (2018). In addition, for identification of Omura's whales, photographic images were compared for diagnostic pigmentation and external physical characteristics as first described by Cerchio et al. (2015) and verified by the same author directly based on field images provided.

All on-effort cetacean sighting locations were plotted on a map, which excluded sightings of the same group encountered again on the same transect line per survey day, providing a proxy of species' relative frequency of occurrence in the study area throughout the study period.

Analysis of cetacean species distribution was based on temperature data obtained from the field (only for 2021–2022) and satellite image data Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) available for all years. Because Aqua MODIS did not provide results for all sightings during the four survey years, the primary and secondary data from Aqua MODIS imagery for SST were combined to fill in the lack of primary data for the years 2019–2020. Prior to doing so, in-situ temperature values and Aqua-MODIS derived temperature values were first tested using a Z-test to compare the average of the temperatures obtained for those sightings with both in-situ and Aqua MODIS-derived data. The Z-test analysis showed no significant differences between the averages of primary temperature (measured in-situ) and SST for 2019–2022 obtained from Aqua MODIS imagery with a value of $Z=1.189$; P-value = 0.234. Environmental/habitat preferences of cetacean species based on SST and depth parameters, based on Geospatial Information Agency Bathymetry, were assessed by using the following tests: Firstly, the Kolmogorov-Smirnov test of normality was performed to determine if the data were normally distributed. Based on these results, the one-way ANOVA test for independent measures and the post-hoc Tukey test was performed for normal distributed data while for the data that were not normally distributed, the Kruskall-Wallis test for independent measures was performed. Depth distribution was analysed by overlaying depth data with the location data of the cetacean groups.

Density analysis and population estimates of *Stenella* species and subspecies (hereafter referred collectively as *Stenella* taxa in Pieh MPA were based on 58 group encounter data of *Stenella* taxa from 25 surveys (six surveys in 2019, nine surveys in 2020, five surveys in 2021, and five surveys in 2022), covering 41 transects. DISTANCE 7.5 was used to estimate the density and abundance of *Stenella* taxa in the Pieh MPA. The DISTANCE software uses information on the survey effort and the distribution of perpendicular distances of sighted objects to estimate density and abundance (Buckland et al., 1993; Buckland et al., 2001; Thomas et al., 2010). Distance analyses were only performed for *Stenella* taxa because the other cetaceans did not meet the recommended number of 60–80 on-effort observations required to obtain robust density estimates (Buckland et al., 2001). All *Stenella* taxa distance data were pooled for all years (2019–2022) to calculate the density function with enough observations ($n = 58$) to increase precision. Prior to pooling of all three taxa data for calculating the density function of *Stenella* taxa, a Kolmogorov-Smirnov test of normality was performed that indicated that the data were not normally distributed ($D = 0.188$; $p = 0.028$). Based on this result, a Kruskal-Wallis test for independent measures was performed to see if there were any significant differences in means of perpendicular sighting distances (PSD) of different taxa. Because the means for *S. l. longirostris* (405 m), *S. l. roseiventris* (417 m), and *S. attenuata* (456 m) were not significantly different (H

(2, N = 58) = 0.096; p = 0.953), pooling of PSDs from all three taxa for density modelling was considered appropriate. Pooling of data for species of similar length or surfacing behaviour has been done in numerous cetacean studies in different parts of the world (Dolar et al., 2006; Becker et al., 2017; Mustika et al., 2021), as well as pooling of years (Dolar et al., 2006; Gómez et al., 2007; Campbell et al., 2015). Besides obtaining density and total population size estimates for all *Stenella* taxa combined, post-stratification was done to calculate separate densities and estimates for each of the three *Stenella* taxa, i.e., *S. l. longirostris, S. l. roseiventris*, and *S. attenuata.*

Population estimation of *Stenella* taxa was done by modelling the detection function through comparison of several key-function models and data truncation scenarios by looking at variables to determine the best fit model. Four combinations of key-functions and adjustment terms were considered, i.e., half-normal + cosine, half-normal + hermite polynomial, uniform + cosine, and hazard rate + simple polynomial. The determination of the best fit model was carried out through an approach using the Akaike Information Criterion (AIC) assessment of the DISTANCE program run (Akaike, 1973; Buckland et al., 2001) within each truncation scenario. The population estimation models selected were those with the lowest AIC value or a difference in values not exceeding >2, selected among key-function models per type of data truncation scenario of perpendicular distance from cetacean encounters. Data truncation is done to reduce data bias (Thomas et al., 2010). After selecting the models with the lowest AIC values within each truncation scenario, final selection in determining the best fitting model was done through comparison of the selected models from different truncation scenarios while also considering Q-Q plot results, Kolmogorov-Smirnov, Cramer-von Misses Family and greater Chi-square value (GOF) test. For these last three tests, a high likelihood (close to 1) meant that the detection function model fit well. Final selection of models among different truncation scenarios with similar best model fit also considered coefficient of variance (CV) values where low CV values indicated low variance and low bias or a more precise estimate (Miller et al., 2019), as the AIC cannot be used to compare among truncation scenarios. Group size biases were incorporated by using a size-bias regression model if a significant alpha level of 0.15 was returned. If there was no significant size bias detected, then the group mean size was used. We performed additional multiple covariates distance sampling (MCDS) with Beaufort sea states covariates both as factor and non-factor to assess how they influenced the detection function model. Beaufort sea states were post-stratified for scales 0–3 (no sightings were made beyond). For these analyses, all observation data were grouped from all years and *Stenella* taxa because the purpose was to see how the shape or scale of the detection curve changed. If the analyses proved to improve model fit, the covariates would be applied to the final models.

RESULTS

Cetacean species detected. During systematic vessel-based surveys between 2019 and 2022, a total survey transect line length of 1,567 km was completed and 75 groups of cetaceans were sighted. Seven species in the sub-infraorder Odontoceti, family Delphinidae were identified: *Stenella longirostris longirostris* (Gray's spinner dolphin, hereafter named spinner dolphin), *Stenella longirostris roseiventris* (dwarf spinner dolphin), *Stenella attenuata* (pantropical spotted dolphin), *Tursiops aduncus* (Indo-Pacific bottlenose dolphin), *Grampus griseus* (Risso's dolphin), *Lagenodelphis hosei (*Fraser's dolphin), and *Peponocephala electra* (melon-headed whale). One species of the sub-infraorder Mysticeti was encountered: *Balaenoptera omurai* (Omura's whale) (Fig. 2). On two occasions, dolphin species remained unidentified due to the distance to the group being too far and the dolphins being fast moving.

Cetacean temporal and spatial occurrence. The most frequently sighted cetacean in Pieh MPA during the study period was the spinner dolphin with 44 sightings (60%), and the least frequently seen species were Fraser's dolphin and melon-headed whale with one sighting each (1%) (Table 2). Similarly, the cetacean species with the highest individual encounter rate was the spinner dolphin at 2.96 sightings per km, and the lowest encounter rate was Fraser's dolphin at 0.001 individuals per km. The fewest cetacean encounters occurred in 2021 with only seven sightings. This is because of the lower survey effort compared to the other three years. The frequency of occurrence of cetaceans is presented in Table 2.

Cetaceans in Pieh MPA were observed throughout most of the survey months in the 2019–2022 observation years except in January and November when there was zero or limited observations (Table 3). The only month which was surveyed in all four years was July, during which six species of cetaceans were observed. Five species were observed in December, but only in 2019, because no surveys were conducted in other years in that month. Four species were observed in the months of March (three years of survey effort) and May (two years of survey effort). Overall, cetaceans in Pieh MPA and the surrounding seas were observed in all survey years with a fluctuating species diversity that was not consistent with the survey effort per year: seven species in 2019 (343 km), three species in 2020 (561 km) and 2021 (236 km), and five species in 2022 (427 km) (Table 3). The spinner dolphin was the only species recorded in each survey year. Conversely, Fraser's dolphins and melon-headed whales were only seen once, each in different years. Cetaceans were found across a range of latitudes and depths throughout Pieh MPA (Fig. 3).

Cetacean distribution based on temperature and depth. There was no significant difference in the SST where all *Stenella* taxa and Omura's whale occurred in Pieh MPA (Kolmogorov-Smirnov (K-S) test: D = 0.369, p < 0.00001); Kruskal-Wallis (K-W) test: H (3, *N* = 73) = 4.6394, p = 0.200. The mean temperature at all sighting locations of

Table 2. Frequency of on-effort* cetacean encounters in Pieh MPA and individual encounter rates in decreasing order.

No.	Species	Number of Sightings				Total sightings (n)	Mean (min–max) group size (G)	Encounter rate (n.G/km)	Percentage of sightings (%)
		2019	2020	2021	2022				
	Survey days	**6**	**9**	**5**	**5**				
Sub-infraorder Odontoceti									
1.	*Stenella longirostris longirostris*	8	17	4	15	44	105 (2–300)	2.947	60
2.	*Stenella longirostris roseiventris*	4	–	1	2	7	60 (20–125)	0.268	10
3.	*Stenella attenuata*	2	4	1	–	7	69 (10–125)	0.308	10
4.	*Tursiops aduncus*	5	–	1	–	6	13 (4–20)	0.050	8
5.	*Grampus griseus*	1	–	–	1	2	6 (5–7)	0.008	3
6.	*Lagenodelphis hosei*	1	–	–	–	1	2	0.001	1
7.	Unidentified dolphin	–	1	–	1	2	4 (1–7)	0.005	3
8.	*Peponocephala electra*	–	1	–	–	1	4	0.003	1
Sub-infraorder Mysticeti									
9.	*Balaenoptera omurai*	1	–	–	4*	3	1 (1–2)	0.002	4
	Total	**22**	**23**	**7**	**23**	**73**			

NB: *Two Omura's whale sightings were made off-effort and excluded from the encounter rates

Fig. 2. Species of cetaceans in the Pieh MPA and the surrounding seas. From top left to below: spinner dolphin, dwarf spinner dolphin, pantropical spotted dolphin, Indo-Pacific bottlenose dolphin, Risso's dolphin, melon-headed whale, Omura's whale, Fraser's dolphin.

Table 3. Species occurrence and survey effort per month for the years 2019–2022.

Identified Species	Month												Years observed
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
Sub-infraorder Odontoceti													
Stenella longirostris longirostris		2020	2021; 2022	2019	2022	2020; 2022	2019; 2020; 2021; 2022	2020	2020; 2022			2019	4
Stenella longirostris roseiventris			2022	2019	2022		2019; 2021					2019	3
Stenella attenuata			2020				2020	2020				2019	2
Tursiops aduncus				2019	2021					2019			2
Grampus griseus					2022		2019						2
Lagenodelphis hosei												2019	1
Unidentified dolphin			2020			2022							2
Peponocephala electra							2020						1
Sub-infraorder Mysticeti													
Balaenoptera omurai							2022		2022			2019	2
Years observed	–	1	3	1	2	2	4	1	2	1	–	1	
Number of species	–	1	4	3	4	2	6	2	2	1	–	5	
Survey months & on-effort km searched (km)													**Total km**
2019				136			46			43	43	75	343
2020		123	121			26	74	166	51				561
2021			130		55		51						236
2022			82		90	81	85		89				427
Total km	–	123	333	136	145	107	256	166	140	43	43	75	1,567

NB: Grey indicates that there were sightings of the species in that month

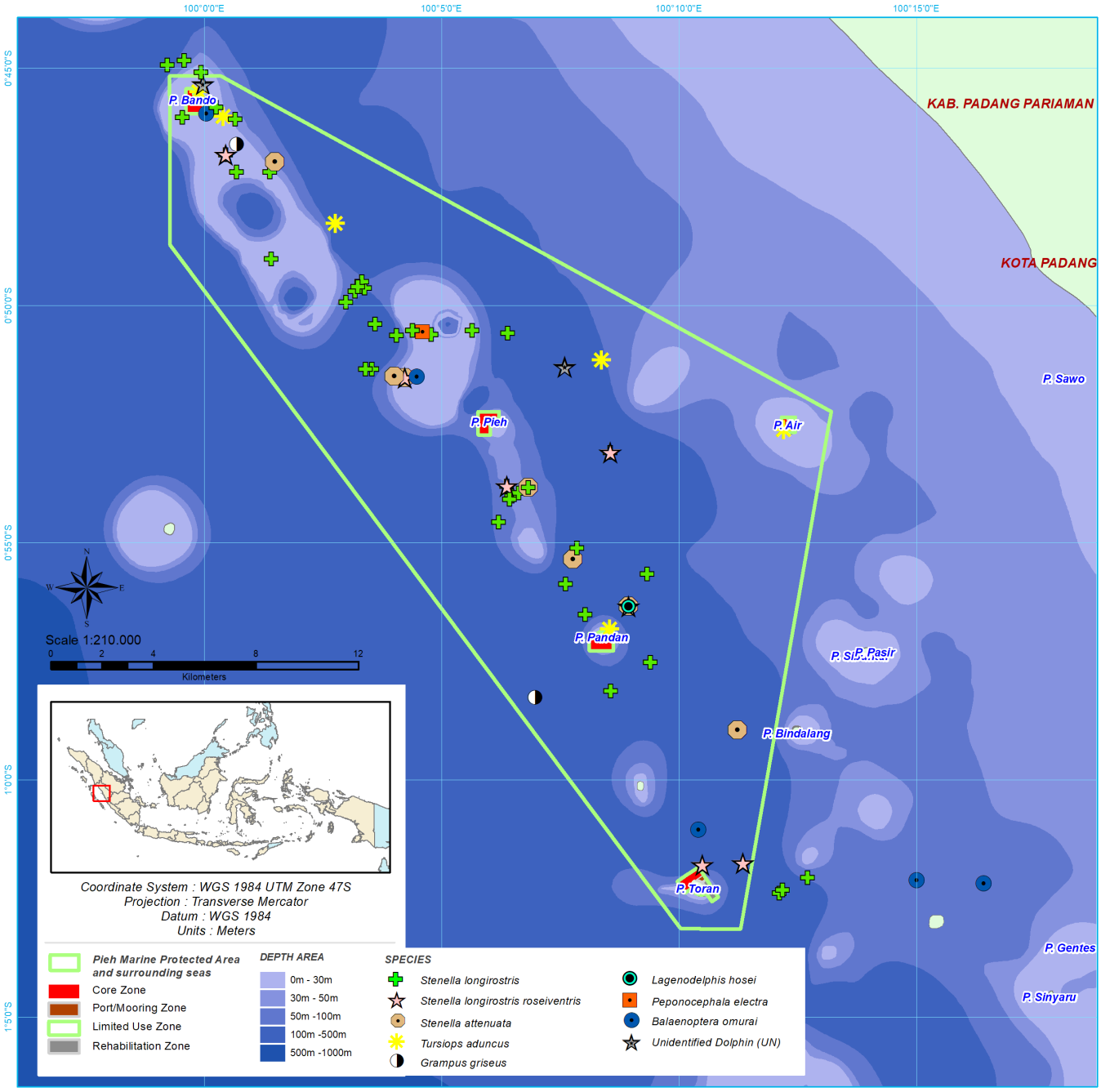

Fig. 3. Distribution of on-effort sightings in Pieh MPA and the surrounding seas from 2019–2022.

cetaceans in Pieh MPA and the surrounding seas in 2019–2022 was 30.3°C with a minimum temperature of 28.0°C and a maximum temperature of 31.8°C. The distribution of cetaceans based on temperature in Pieh MPA and the surrounding seas is summarised in Table 4.

With regards to depth, the results showed that for those species with more than two sightings, including all three *Stenella* taxa, Indo-Pacific bottlenose dolphins, and Omura's whale did not differ significantly in depth-preferences from one another (K-S test (D) = 0.165, p = 0.0305; K-W test: H (4, N = 69) = 3.023; p = 0.554).

The distribution of cetaceans based on depth in Pieh MPA and the surrounding seas obtained through secondary data can be seen in Fig. 3. The average depth at cetacean locations in Pieh MPA was 107.5 m with a minimum depth of 5 m and a maximum depth of 360 m, where the latter was the maximum depth at which Risso's dolphins were observed. The minimum depth for most dolphin species (except for Fraser's dolphin, Risso's dolphin, and the melon-headed whale) and even Omura's whale was very low at only 5 m.

Population estimation. The number of sightings included in the distance analysis varied per truncation scenario were 58 sightings after zero truncation; 56 sightings after 5% truncation; and 50 sightings after a > 900 m truncation scenario. Comparison of model with the lowest AIC values within each truncation scenario and comparison among truncation scenarios based on the outcome of Q-Q plots, and other relevant tests, showed that the best fit to estimate the density and abundance for *Stenella* taxa was the half normal

Table 4. Distribution of cetaceans based on temperature in Pieh MPA.

No.	Species	Number of Samples	Temperature			Number of Samples	Depth		
			Mean	min	max		Mean	min	max
Sub infra-Ordo Odontoceti									
1.	*Stenella longirostris longirostris*	34	30.4	28.0	31.8	44	111	5	280
2.	*Stenella longirostris roseiventris*	7	30.0	29.0	30.9	7	114	5	220
3.	*Stenella attenuata*	5	30.5	29.6	31.1	7	122	5	280
4.	*Tursiops aduncus*	2	31.0	31.0	31.1	6	60	5	180
5.	*Grampus griseus*	2	30.4	30.0	30.9	2	190	20	360
6.	*Lagenodelphis hosei*	1	29.6	29.6	29.6	1	180	180	180
7.	*Unidentified dolphin*	1	30.0	30.0	30.0	2	103	5	200
8.	*Peponocephala electra*	–	–	–	–	1	20	20	20
Sub infra-Ordo Mysticeti									
9.	*Balaenoptera omurai*	5	30.1	29.0	31.0	5	81	15	240

Table 5. Results of the DISTANCE program analysis of *Stenella* taxa population estimation in Pieh MPA and the surrounding seas in 2019–2022.

Post-stratified	AIC	D	N	P	95% CI (LL)	95% CI (UL)	CV N D (%)	K-S Test (p)	Cramer von Mises family-(p) key & adjustment	p of greater chi square value (GOF test)
Key Model: Half normal + cosine (Truncation >900 m) – All *Stenella* taxa combined										
All *Stenella* taxa (n=50)	662.7	3.756	2,997	0.417	1,836	4,895	25.18	0.255	0.5–0.6 0.3–0.4	0.872
Key Model: Half normal + cosine (Truncation >900 m) - *Stenella* taxa post-stratification										
Stenella longirostris longirostris (n = 39)	662.7	3.200	2,553	0.417	1,521	4.287	26.64	0.2551	0.5–0.6 0.3–0.4	0.872
Stenella longirostris roseiventris (n = 6)	662.7	0.197	157	0.417	52	472	55.80	0.2551	0.5–0.6 0.3–0.4	0.872
Stenella attenuata (n = 5)	662.7	0.263	210	0.417	72	612	55.66	0.2551	0.5–0.6 0.3–0.4	0.872
Key Model: Half normal + cosine (Truncation >900 m) - with Beaufort Sea States – All *Stenella* taxa combined										
Beaufort covariate (non-factor) (n=50)	666.2	2.894	2,309	0.547	499	1,510	28.27	0.087	0.1–0.015 0.05–0.1	0.144
Beaufort covariate (factor) (n=50)	667.1	3.101	2,475	0.535	1,411	4,339	28.9	0.097	0.1–0.15 0.05–0.1	0.104

AIC = Akaike Information Criterion; D = density (number of individuals/km²; N = best population size estimate; P = detection probability; CI = Confidence Interval; LL = Lower Limit; UL = Upper Limit; CV = Coefficient of Variation.

+ cosine combination model with a truncation scenario, which excluded sightings > 900 m and excluded Beaufort sea states (Table 5). This final selected model has a population estimate for *Stenella* taxa of *N* = 2,997 individuals (95% confidence interval (CI) = 1,836–4,895) and a density estimate (D) of 3.756 individuals/km² (CV (N, D) = 25.18%.

Post-stratification per taxa led to the following abundance and density estimates for the Pieh MPA with highest estimates for the spinner dolphins of 2,553 individuals (95% CI = 1,521–4,287) and 3.2 individuals/km² (CV (N, D) = 26.64%, followed by pantropical spotted dolphins (N = 210 individuals; 95% CI = 72–612; D = 0.263 individuals/ km²; CV (N, D) = 55.66%) and dwarf spinner dolphins (N = 157

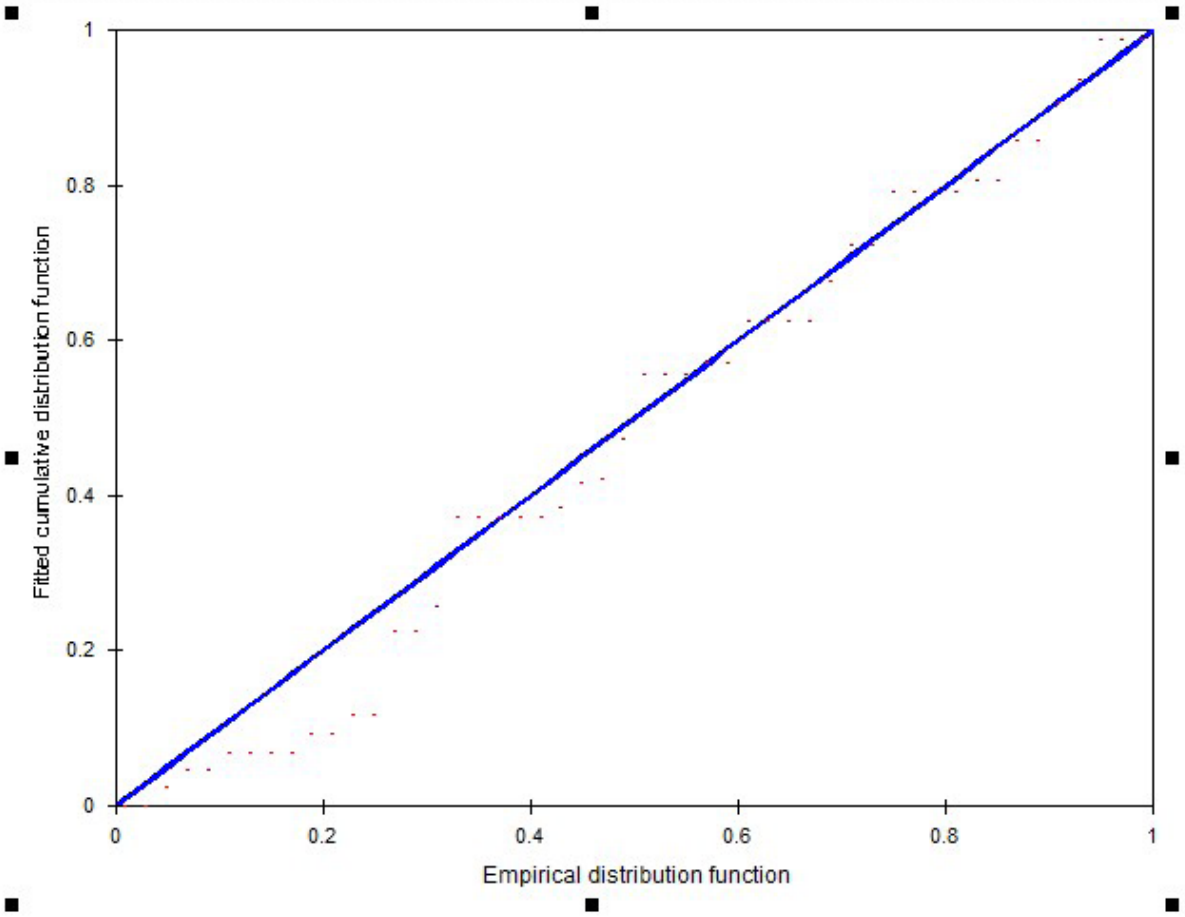

Fig. 4. Q-Q Plot of the best fitted model i.e., Model half normal + cosine (Truncation > 900 m).

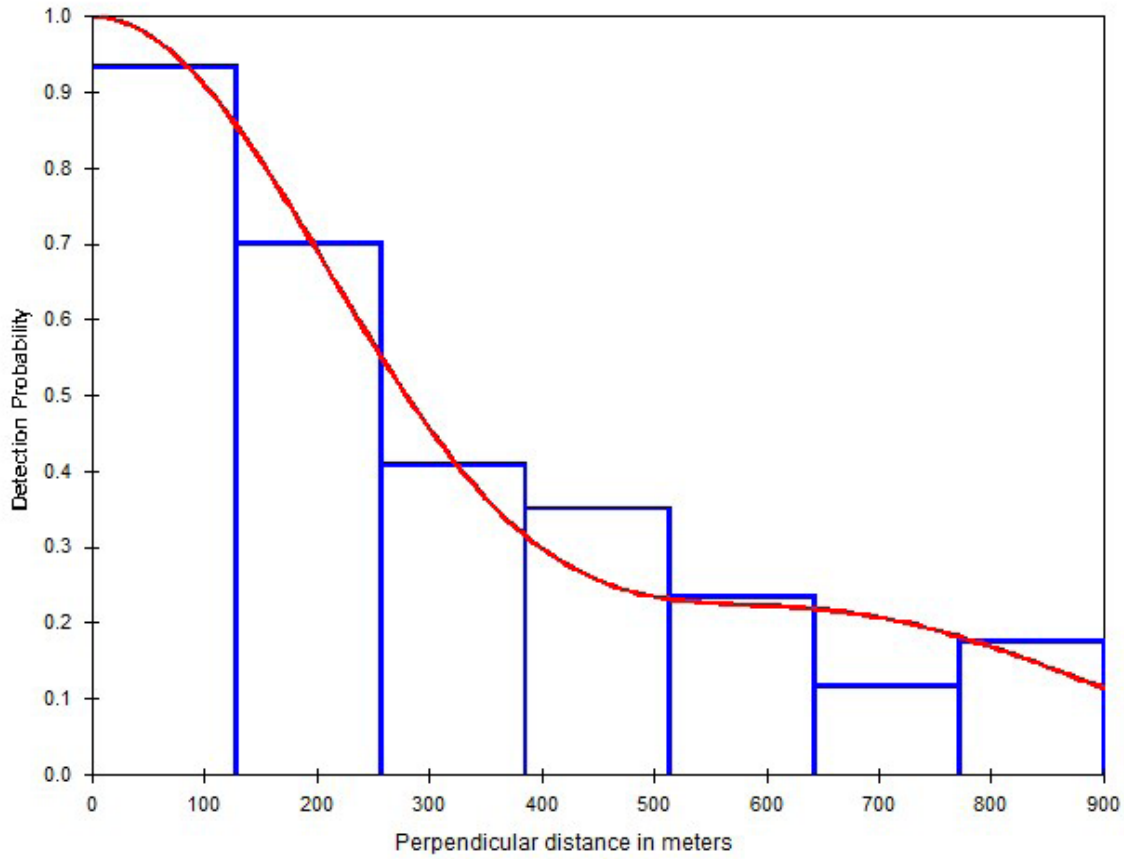

Fig. 5. Detection probability function fitted to the perpendicular distance of observation of groups of *Stenella* taxa best fitted detection function for years 2019–2022 with pooled survey stratum and years providing the probability of greater Chi-square value, p = 0.87. Data were grouped using > 900 m distance truncation.

individuals; 95% CI = 52–472; D = 0.13 individuals/ km^2; CV (N, D) = 48.3%.

The results showed that the inclusion of the Beaufort sea states as covariates increased the detection probability (P = 0.535–0.547) compared to the selected model without inclusion of Beaufort sea states (P = 0.41). However, the detection function-model was not improved by including Beaufort sea states as a factor or non-factor- covariate based on multiple covariates distance sampling (MCDS) and had higher AIC values for the same sample size than the selected conventional distance sampling (CDS) model without Beaufort sea state inclusion. The MCDS model with Beaufort sea state inclusion also performed less well in the Kolmogorov-Smirnov test, Cramer von Mises and GOF test while the normality of the CDS model is shown through the results of the Q-Q plot where the points are spread very close to the diagonal line (Fig. 4). Considering all statistical test variables outcomes, the half-normal + cosine with > 900 m truncation showed the best fitted detection curve (Fig. 5).

DISCUSSION

Species diversity and interspecies interaction. Eight species of cetaceans found in the Pieh MPA and the surrounding seas were identified, with the spinner dolphin being the species most often observed. According to Perrin (2018), spinner dolphins have varied school sizes, from just a few dolphins to a thousand or more. The mean group size of 105 (2–300) spinner dolphins in Pieh MPA, was similar to spinner dolphin group sizes in East Kalimantan, Indonesia (Kreb & Budiono, 2015), with a mean group size of 123 (2–650) individuals. However, Pieh MPA spinner dolphins occurred in larger groups than those observed by Ponnampalam (2012) in Malaysia in the South China Sea, around the Spratly Islands, and the Sulu-Sulawesi Sea with mean group sizes of 27 dolphins. Spinner dolphins in Raja Ampat, West Papua also occurred in lower mean (15–20) and maximum group sizes of 40 dolphins (Borsa & Nugroho, 2011). This would indicate that the Pieh MPA supplies enough fish resources to sustain larger group sizes. Mean depths of 111 m (5–280 m) in Pieh MPA were shallower than those observed in Kalimantan, Indonesia and Malaysia in habitats with respective mean depths of 507 m and 563 m (201–1,575 m) (Ponnampalam, 2012; Kreb & Budiono, 2015). Spinner dolphins in the Halmahera Sea and in the Pacific Ocean of Raja Ampat also occurred at greater depths, i.e., 560 m and 2,310 m (Borsa & Nugroho, 2011). The species often rode the bow of the research vessel after the boat got off the track line. Calves and juveniles were also often found in these groups. This species is most commonly found in tropical pelagic waters (Wursig et al., 2018), with the Pieh MPA and the surrounding seas also being in that category.

The second taxa identified was the dwarf spinner dolphin. Dwarf spinner dolphins are distributed in the shallow waters of inner Southeast Asia, including the Gulf of Thailand, the Timor and Arafura Seas off northern Australia, and other similar areas off Indonesia and Malaysia (Perrin et al., 1999). It is replaced in deeper waters by the larger pelagic spinner dolphin (Perrin et al., 1999). Nevertheless, Kreb & Budiono (2015) stated that dwarf spinner dolphins in East Kalimantan, Indonesia were also observed in deep water with a mean depth of 402 m (5–400 m), but in relatively close proximity to islands (< 10 km), while in Pieh MPA, they occurred at a lower mean depth of 114 m (2–220 m). In East Kalimantan, they were found in groups of 80 (18–170) individuals, more or less similar to group sizes of encountered groups in Pieh MPA, which varied between 60–80 individuals. Out of seven sightings, dwarf spinner dolphins occurred five times alongside groups of spinner dolphins and/or pantropical spotted dolphins.

Pantropical spotted dolphins occurred at an average group size of 69 individuals (10–125), with group sizes inside the Pieh MPA being lower than elsewhere. Ponnampalam (2012) observed these dolphins off Sarawak, Malaysia in mean group sizes of 111 (35–250) individuals and at a greater mean depth of 852 m (108–1,250 m) than the mean depth of 122 m (5–280 m) observed in Pieh MPA. Pantropical spotted dolphins in the Derawan Islands Marine Protected Area (MPA), East Kalimantan, Indonesia also occurred at greater mean depths of 336 m (210–1,015 m). In the Eastern Pacific, pantropical spotted dolphins commonly occur in large multispecies aggregations, including pelagic spinner dolphins and yellowfin tuna (*Thunnus albacares*) (Perrin & Hohn, 1994; Ballance et al., 2006). In four out of seven encounters, pantropical spotted dolphins in the Pieh MPA were observed in the same group with spinner dolphins and in one encounter, with dwarf spinner dolphins.

The average group size of Indo-Pacific bottlenose dolphins at 13 individuals (4–20) per group in Pieh MPA was smaller than that of *Stenella* taxa. As stated by Wang (2018), these dolphins have small group sizes, most commonly between 20 and 50 individuals with calves. An even smaller group of seven individuals was observed by Kreb & Budiono (2005, 2015) at a depth of 350 m inside the Derawan Islands in East Kalimantan, Indonesia, but usual encounters were of groups of 20 (13–29) individuals at a mean depth of 319 m (15–406 m) in the wider MPA of the Derawan Islands. Both of these other locations are in waters deeper than the mean depths of sightings of the species at 60 m (5–180 m) in the coral reef-rich waters of Pieh MPA. Wang (2018) mentioned that waters with rocks and coral reefs, sandy bottoms, or sea grass beds with water less than 100 m deep seem to be the preferred habitat of this species. Minton et al. (2011), observed Indo-Pacific bottlenose dolphins in nearshore waters of Sarawak, East Malaysia, at shallower depths ranging from 3.8 to 24.3 m, with a mean of 9.9 m, while Ponnampalam (2012) observed these dolphins in group sizes between 1 and 75 dolphins at a mean depth of 83 m (32–142 m). The species observed in Pieh MPA tended to be shy, and typically maintained a distance from the research vessel compared to *Stenella* taxa. Hawkins & Gartside (2009) indicated that a relatively small proportion of the Indo-Pacific bottlenose dolphin population at Byron Bay region, northern New South Wales displayed interactive behaviours towards boats, defined as bow-riding, wake-riding, and sustained approaches (22%

of 201 groups observed). Putra et al. (2025) observed a high occurrence of feeding behaviour for this species surrounding a lift-net fishing platform focusing on capturing anchovies in Kaimana, West Papua.

Risso's dolphin was observed in Pieh MPA in 2019 and was recorded again in 2022. At the time of its first encounter in 2019, about six to seven individuals were seen swimming in a straight line, while in 2022, five individuals were accompanied by calves. The depths (20–360 m) at which they occurred in the Pieh MPA is in line with their habitat preferences throughout most of their wide range, namely continental shelf and slope waters instead of oceanic depths (Jefferson et al., 2014). Kreb & Budiono (2015) reported one Risso's dolphin group sighting of eight individuals in the Derawan Islands in East Kalimantan at a depth of 1,015 m, a greater depth than in Pieh MPA, which is consistent with Hartman's (2018) statement that Risso's dolphins tend to inhabit deep, offshore waters (200–1,000 m deep), warmer than 12°C, and in relatively narrow shelf and slope habitat areas. The latter was also indicated by a genetic study where two unique haplotypes of Risso's dolphins were found in the Thai Andaman Sea not shared with other regions of the Pacific Ocean (Piboon et al., 2022). Borsa & Nugroho (2011) observed two groups totalling 15 Risso's dolphins at depths between 485–513 m northwest of Sorong, West Papua. The occurrence of calves of this species in Pieh MPA reinforces the area's qualification for nomination as an Important Marine Mammal Area.

Fraser's dolphin was recorded only once inside the Pieh MPA. Two Fraser's dolphins were identified swimming in a mixed pantropical spotted dolphin and dwarf spinner dolphin group at depths of 180 m and SST of 29.6°C. This cetacean species is often found together with other species such as melon-headed whales, short-finned pilot whales, Risso's dolphins, spinner dolphins, pantropical spotted dolphins, bottlenose dolphins, and sperm whales (Dolar, 2018). Although the species was first discovered in Sarawak, Malaysia (Fraser, 1956), no published studies providing more detailed information on their ecology are available from Southeast Asia except for the Sarawak stranding record. However, four reported sightings of Fraser's dolphin within the Derawan Islands MPA in East Kalimantan, Indonesia were described by Kreb & Budiono (2014). These occurred in mixed-species associations with melon-headed whales in larger group sizes (between 30 and 40 individuals) and greater depths (618–885 m) than the observation in Pieh MPA.

The observation of one group of four melon-headed whales in 20 m deep water inside the Pieh MPA was within the range of the group size but differed in water depth with those observed in the Derawan Islands MPA in East Kalimantan, Indonesia, where groups of 4–105 individuals occurred in deeper waters between 400–885 m (Kreb & Budiono, 2005, 2015). Perryman & Danil (2018) also stated that melon-headed whales occur in deep tropical/subtropical oceanic waters, between 40°N and 35°S. Although considered an offshore pelagic species, there are island-associated populations in some regions and they can be found close to shore associated with oceanic islands and archipelagos (Brownell et al., 2009). This tallies with their occurrence in the Pieh MPA.

Only one baleen whale species was observed both inside and just outside the Pieh MPA, namely Omura's whale. Omura's whale was observed for the first time by the first author in this area during the third quarter of 2018, representing a new record for Sumatra. Three individuals were identified, including a calf, foraging around the waters with mackerel schooling around its surfacing location. During the study period, five more sightings of Omura's whales were made in the months of July, September, and December including observations of calves twice. Omura's whale were identified based on their light chevron and some streaks and blazes, which were clearly visible while the right side of the lower jaw was white and body size not exceeding maximum size of 11.5 m in this species (Wada et al., 2003). The Omura's whale occurrences in Pieh MPA were at an average depth of 81 m and average sea surface temperature of 30.1°C. This is largely consistent with what was stated by Cerchio & Yamada (2019) that sighting locations of Omura's whale in northwest Madagascar during October to December were at an average depth of 52 m and a sea surface temperature ranging from 28°C to 30°C. The occurrence of Omura's whale in shallow nearshore waters is quite common for this species (Jefferson et al., 2015; de Vos, 2017; Cerchio et al., 2019). In other parts of Indonesia such as East Kutai coastal waters, East Kalimantan, Indonesia, during the month of May, four Omura's whales were observed feeding on krill at depths of 60–180 m on a shallow shelf adjacent to a steep slope to deep waters > 1,000 m (Kreb et al., 2012). Similar near shore-feeding was observed in the Derawan Islands MPA during the month of June (pers. obs., Kreb D). Moreover, four observations of Omura's whale at separate locations were made in the months of April and May in Raja Ampat, West Papua, Indonesia at depths of 27 to 180 m (except one sighting in Dampier Strait at 1,200 m) and 2.7 to 12.1 km from the nearest shore (Sahri et al., 2024). Interestingly, Omura's whales seem to occur in the second half of the year in Pieh, West Sumatra, whereas in Raja Ampat and East Kalimantan, they have been observed in the first half of the year only (April to June) in spite of survey efforts in the months of October and November. Other areas where Omura's whale has been observed in Indonesia include the South Java Sea, Bali, Komodo, Solor Archipelago, Seram, Pulau Mansuar, and North Sulawesi (Cerchio et al., 2019; Sahri et al., 2024). Omura's whale also occurs in other parts of Southeast Asia in the waters of Malaysia, Thailand, and the Philippines (Yamada et al., 2006, 2008; Aragones et al., 2010; Ponnampalam, 2012).

In Pieh MPA, it is quite common to find cetacean groups consisting of different species, such as the occurrence of spinner dolphins together with dwarf spinner dolphins, or with pantropical spotted dolphins, and the observation of another mixed-group of dwarf spinner dolphins, pantropical spinner dolphins, and Fraser's dolphins. The occurrence of spinner dolphins and pantropical spotted dolphins in one group throughout the years 2019–2022 was observed five

times in Pieh MPA. As stated by Jefferson & LeDuc (2018), these two species often form interspecific associations in the eastern tropical Pacific, while Ponnampalam (2012) also had two sightings of mixed-groups of spinner and pantropical spotted dolphins off the coast of Sarawak, Malaysia. Kreb & Budiono (2005) also reported on mixed-species associations of spinner dolphins with dwarf spinner dolphins, pantropical spotted dolphins, and Indo-Pacific- and common bottlenose dolphins occurring in similar island-dominated areas in East Kalimantan, Indonesia. In fact, the association between spinner and pantropical spotted dolphin as observed in the Pacific and Indian Oceans are also viewed as an effort to protect themselves from predator attacks (Roman & Estes, 2018). The same authors concluded that in large groups, these dolphins can reduce the risk of becoming prey because there is a collective strength in large numbers, and many eyes are watching the surroundings so that the possibility of a predator attacking one individual is lower and provides security for group members. On the other hand, mixtures between *Stenella* taxa and Fraser's dolphins are rare, since the latter species is most often found in association with melon-headed whales (Tiongson & Sabater, 2013; Kreb & Budiono, 2015). The encounter during which dwarf spinner dolphins, pantropical spotted dolphins, and Fraser's dolphins were observed in co-occurrence in the Pieh MPA was made in relatively deep waters (250–300 m) while the three groups were engaged in playful behaviour. Only two individual Fraser's dolphins were observed mixed with the two larger groups, with best estimates of 125 individuals each.

The fact that cetaceans were observed almost throughout the whole year (ten of the eleven months of a year in which surveys were conducted) in a relatively short period of each survey month highlights the importance of the Pieh MPA for cetaceans. This may be because Pieh MPA has a seabed landscape that includes shallow shelf waters, but also continental slope waters between the five small islands inside the MPA. The landscape is in accordance with what Canadas et al. (2002) named as marine mammal-preferred waters, with static topographic features including continental shelves and slopes since diversity and productivity is determined in part by the slope and depth of seas.

Population estimation. The density of Gray's spinner dolphins in Pieh MPA of 3.2 individuals/km² (CV = 26.64%) is higher compared to similar island-dominated habitats in the Sulu Sea, Philippines, which was 1.37 individuals/km² (CV = 26.6%) and 0.77 individuals/km² (CV = 26.5%) for Tanon Strait (Dolar et al., 2006), as well as for nearshore waters surrounding the main Hawaiian Islands with 0.0443 individuals/km² (CV = 37%) (Mobley et al., 2000). In Indonesia, only estimates in which spinner dolphins and other species (pantropical spotted dolphins, bottlenose dolphins, Fraser's dolphin, Risso's dolphins) density estimates are combined are available for the waters of South Bali that yielded 11 individuals per km² (CV= 39%) (Mustika et al., 2021). In the Bali study, spinner dolphins comprised 56.3% and pantropical spotted dolphins 34.8% of all sightings (together 90%), which justifies the comparison with the *Stenella* taxa estimates of Pieh MPA. Faria et al. (2020) stated that spinner dolphins occur in large, pelagic groups in the Eastern Tropical Pacific, but that elsewhere in the Pacific they are found in small and genetically isolated populations associated with islands, which is similar to the spinner dolphins observed in Pieh MPA. The same authors also stated that spinner dolphins in the Noronha Archipelago of the northeast coast of Brazil formed societies with strong site fidelity mediated by females. Future studies focusing on photo-identification of recognisable dorsal fins in the Pieh MPA may help to determine the level of residency or site fidelity of the *Stenella* populations. Additionally, obtaining samples from stranded animals could facilitate DNA analyses.

Threats. Impact from coastal activities and shipping. Although the impact of coastal development has not been studied by measuring sedimentation, there are no visible signs on the coral reefs that any coastal development has impacted the Pieh MPA ecosystem. The reason for this could be because there are no freshwater rivers discharging into the sea near the park, which would otherwise have the potential to bring sedimentation into the sea during rain (Piccolo, 2021). Given the occurrence of Omura's whales in nearshore waters outside of the MPA as well, which also contain shipping lanes, the species is likely to be vulnerable to ship strikes and noise disturbance (Laist et al., 2001; Jefferson et al., 2015). Plastic waste can be found inside the MPA especially during the rainy season when it washes from the coast (Fig. 7). Omeyer et al. (2023) mentioned that plastic ingestion has been described to have occurred for 13 marine mammal species in Southeast Asia.

Dolphin-watching is an activity allowed inside the park since 2018, following a standard precaution protocol adopted from Commonwealth of Australia (2017), Lewis & Walker (2018), and the NOAA website (www.fisheries.noaa.gov), where boats have to stay at a minimum distance of 50 m for dolphins, 100 m for whales and dolphins with calves, and 300 m for whales with calves. Both rangers and selected tour operators that are allowed to conduct the tours have been made aware of the protocol. Although this activity was allowed in 2018, few tours, if any, have been conducted per year. However, if dolphin-watching tourism increases, it must be well monitored to prevent unsustainable dolphin- or whale-watching such as is the case in Lovina, Bali, and Bocas Del Toro, Panama (Mustika et al, 2015; Soller & Parson, 2019; Westerlaken et al., 2022).

Overfishing and bycatch. As a MPA, the function of Pieh MPA is to protect and preserve various species which provide biological resources and ecosystem services in this area from various direct and indirect threats which are caused by human activities in the form of utilisation without paying attention to conservation principles as set out in Minister of Marine Affairs and Fisheries Regulation Number 31/2020 concerning MPA Management. So far, the survey teams have not observed any instances of bycatch or overfishing in the waters of the Pieh MPA, likely because the area is located far from the mainland and only artisanal fishing is

Fig. 6. Left: Plastic waste observed with the Pieh MPA after heavy rainfall. Right: a dolphin with plastic around its dorsal fin.

done there. Routine patrols, carried out 2–3 times per month, have reported rare incidences of illegal fishing activities. The belief of the fishing community in the Pieh MPA, which the authors were made aware of directly during an encounter with a group of fishermen, is that dolphins bring bad luck, as they will scare the fish away and if entangled, their nets may smell like cetaceans with the same deterring impact on fish.

Area importance. The results of this study illustrate that the potential of cetacean encounters within the Pieh MPA is relatively high with eight cetacean species identified in an area of 399.2 km^2 (0.023 species per km^2). In comparison, the Savu Sea and the surrounding areas in the East Nusa Tenggara Province, which is listed as an Important Marine Mammal Area and encompasses an area 41 times larger (16,512 km^2) than the Pieh MPA includes 24 species of marine mammals (0.0014 species per km^2). The highest frequency of occurrence of all cetacean species occurring in Pieh MPA was the spinner dolphin (60%), which was observed year-round. In other parts of their cosmopolitan distribution, both pelagic and coastal stocks of spinner dolphins have been identified in tropical, sub-tropical, and warm-temperate waters (Perrin, 1998). The Pieh MPA offers a similar habitat to the observed cetaceans in this study as the habitat of island-associated stocks of Hawaiian spinner dolphins, which seek sanctuary in clear, calm and relatively shallow waters with sandy bottoms where they return to certain areas to socialise, rest, and nurture their young (NOAA Fisheries, 2024). During the current study in the Pieh MPA, calves were often observed as well, which may imply a similar habitat function. The existence of eight cetacean species identified in Pieh MPA enriches available information on cetacean diversity in western Indonesian waters, which is currently very lacking, while cetacean density estimates derived from systematic distance sampling are are also very lacking in Indonesia despite the country having the second longest coastline (99,083) km in the world (Kreb et al., 2020, Mustika et al., 2021).

Conservation and management recommendations. The higher density of Pieh spinner dolphins compared to that of spinner dolphins roaming in near-coastal or island habitats in the Philippines and Hawaiian Islands, the presence of calves observed in several species, the near year-round presence of cetaceans, the occurrence of Omura's whales on at least five separate occasions with calves on two occasions over different survey years, and the observation of two IUCN-near-threatened listed species (Indo-Pacific bottlenose dolphin and melon-headed whale) identifies the area as an important cetacean habitat on the west coast of Sumatra and qualifies the Pieh MPA and the surrounding seas to be nominated as an Important Marine Mammal Area.

Although we consider the spatial information obtained from this study to be of great value to local conservation practitioners engaged in place-based marine spatial planning and conservation efforts, we recommend future research to optimise the spatial layout of survey lines to provide a greater survey area coverage.

The density- and population-estimates of *Stenella* taxa represent an important baseline for detecting future trends in abundance during future periodic scientific research of species populations and threats as part of proper evaluation of the MPA in time to come.

The spatial and relative abundance data from this study may be used for comparison with other studies on spinner dolphins where the Pieh MPA is considered a safe habitat for spinner dolphins with very low anthropogenic impacts. Comparisons over time in these spatial and abundance data can indicate where sustainable management of their habitat needs to be strengthened.

For the moment, recommendations for management include frequent patrols inside and in the vicinity of the MPA for illegal fishing activities. During these patrols, outreach may also be conducted by the park rangers with fishermen within or in the vicinity of the MPA to inform them about the danger of ghost nets (derelict fishing gear), which may lead to dolphin entanglement. There could also be a collaborative project to collect these nets, which is similar to an ongoing

project by park authority in which fishermen and divers collaborate in collecting plastic trash, and handing it over to the park authority to obtain some compensation.

Finally, this study shows that routine park monitoring, even on a limited budget, can include cetacean monitoring if done in a systematic manner by marine park rangers trained in cetacean observation techniques. Such an approach can help reduce the knowledge gap on cetacean diversity, distribution, and abundance in the vast marine environment of Indonesian waters.

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