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Habitat preference of two sympatric coastal cetaceans in Langkawi, Malaysia, as determined by passive acoustic monitoring

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ABSTRACT: Little is known about the ecology of the Indo-Pacific finless porpoise *Neophocaena phocaenoides* or the Indo-Pacific humpback dolphin *Sousa chinensis* in Southeast Asia. The present study describes the distribution and habitat preferences of these species around the Langkawi Archipelago of Malaysia. Vessel-based passive acoustic monitoring surveys were conducted 5 times between 2012 and 2013. Both species mainly preferred relatively shallow waters, especially on the east sides of the islands at <15 m depth. However, the species differed in number of detections and spatial distribution, preferred distance from shore, chlorophyll *a* concentration in the water where they resided, and season in which they were detected, indicating that they have different habitat preferences. The best spatial habitat model for the prediction of finless porpoise distribution included bathymetric depth and longitude. The distribution of finless porpoises was relatively stable around the islands and especially in the eastern waters, whereas humpback dolphins may only seasonally visit specific regions of the waters around the islands. Their detection sites were too patchy to enable distribution modeling. The results of this study provide baseline information that can facilitate conservation planning for these species according to their habitat preferences and core areas.

KEY WORDS: Indo-Pacific humpback dolphin · *Sousa chinensis* · Indo-Pacific finless porpoise · *Neophocaena phocaenoides* · Marine mammal · Coastal water · Asia

1. INTRODUCTION

Marine animals in coastal waters require protection, given the high levels of anthropogenic activity in these areas. Small cetaceans occupy large habitats, and novel monitoring technologies such as passive acoustic monitoring help to determine their distributions (Mellinger et al. 2007). Monitoring data may be applied to spatial mapping and habitat modeling approaches (Hooker et al. 2011). In this way, species distributions can be estimated for areas that are unmonitored, and those requiring conservation management can be identified (Fleming et al. 2018).

Malaysia is a 'biodiversity hotspot' with many complex ecosystems and species (Myers et al. 2000, Roberts et al. 2002). However, expanding human activity is accelerating environmental degradation. The Langkawi Archipelago is at the northernmost entrance of the Straits of Malacca in northwestern Peninsular Malaysia (Fig. 1) and has numerous pop-

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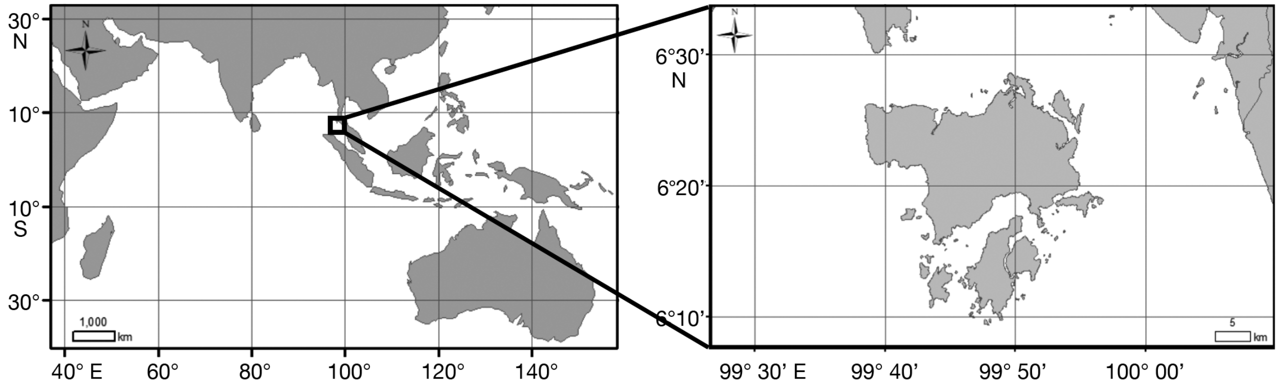

Fig. 1. Location of the Langkawi Archipelago in Malaysia

ular resorts and coastal developments. Although the region is experiencing a growing presence of tourist boat, high-speed ferry, and fishing boat traffic (Marzuki 2008, Shahbudin et al. 2012, Samat & Harun 2013), the waters of Langkawi were collectively recognized by as an Important Marine Mammal Area by the IUCN in 2019.

The waters surrounding the Langkawi Archipelago are populated by small cetaceans, namely the Indo-Pacific finless porpoise *Neophocaena phocaenoides* (hereafter, finless porpoise) and the Indo-Pacific humpback dolphin *Sousa chinensis* (hereafter, humpback dolphin) (Ponnampalam & Jamal Hisne 2011, Ponnampalam 2012, Kimura et al. 2021). Both species are classified as 'Vulnerable' on the IUCN Red List of Threatened Species (Jefferson et al. 2017, Wang & Reeves 2017). They are also protected as endangered marine species in Malaysia under the Fisheries Act 1985 and the Fisheries (Control of Endangered Species of Fish) Regulation 1999. Ecological research has been conducted on finless porpoises and humpback dolphins mainly in Japan, China, and Taiwan (e.g. Akamatsu et al. 2010, Lin et al. 2013, Jefferson & Rosenbaum 2014, Wang et al. 2016, Caruso et al. 2020), but little is known about the ecology of these species in Southeast Asia (Hines et al. 2015).

The aim of this study was to use passive acoustic monitoring to describe the distribution and habitat preferences of finless porpoises and humpback dolphins around the Langkawi Archipelago in Malaysia. We distinguished the species according to their unique acoustic characteristics (Kimura et al. 2021) and compared their distribution and habitats. We also developed a habitat model to quantify the relationships among environmental variables and finless porpoise distribution. By clarifying how these animals are distributed in the study area, we can coordinate conservation and management planning with local authorities and design and perform future investigations into the ecology of these species.

2. MATERIALS AND METHODS

2.1. Field work

Acoustic surveys were conducted in the Langkawi Archipelago, Malaysia (Fig. 1), in September and December 2012 and again in February, May, and October 2013. The sea around the islands was divided into area blocks (see Fig. 2), and the survey lines were oriented at 45° from the shoreline to facilitate the detection of cetacean density gradients offshore and alongshore (Dawson et al. 2008). The lines were spaced at 3.70 km intervals to enable systematic surveying within each area block. Another set of transect lines also spaced at 3.70 km intervals was created and placed between the first set of lines. Both line sets were used alternately across surveys to achieve better coverage (see Fig. 2).

An A-tag — a stereo acoustic data-logger (ML200-AS2; MMT) — was towed by a rope at a speed of ~12 km h^{-1} and 100 m behind the research vessel. A distance of 100 m was used, as it greatly reduces the influences of the presence and cavitation noise of the research vessel on the acoustic detection of porpoises and dolphins. Previous studies have reported that finless porpoises and humpback dolphins may avoid vessels (Ng & Leung 2003, Li et al. 2008, Morimura & Mori 2019, Piwetz et al. 2021). The detection range of the A-tag was ~450 m, based on the sound intensity and propagation of the clicks emitted by dolphins and porpoises (Fisher & Simmons 1977, Li et al. 2009, Fang et al. 2015).

The A-tag records sounds in the 55–235 kHz frequency range as 'events'. This range encompasses the ultrasonic clicks emitted by small cetaceans (Akamatsu et al. 2005). A passive bandpass filter circuit (−3 dB within 55–235 kHz), a high-gain amplifier (+60 dB), a CPU (PIC18F6620; Microchip Technology), a flash memory, and a lithium battery (CR2) were housed in a waterproof aluminum case. Two submersible hydrophones were set 19 cm apart on the exterior of the case. One hydrophone was tuned to 130 kHz, while the other was tuned to 70 kHz. The A-tag does not record frequency or waveform; rather, it records the time the sound was received, the sound pressure of each hydrophone, and the difference in the time at which the sound arrived at each hydrophone.

2.2. Acoustic analysis

The time series analysis software Igor Pro v. 6.3 (WaveMetrics) was used to extract the small cetacean data recorded by the A-tag. Time, sound pressure, sound pressure ratio, sound interval, and relative sound source angles were determined from the sounds recorded by the A-tag with a publicly available program (http://mmtcorp.co.jp/A-tag/). The sound pressure ratio is the ratio of the intensities of the sound pressure recorded using the hydrophones. The relative angle was calculated using the difference between the times at which the sound arrived at the hydrophones.

The sound pressure detection threshold was set to 132.5 dB re 1 µPa. Small cetaceans emit a series of clicks known as a 'click train' (Au 1993). Here, 1 click train comprised inter-click intervals ≤200 ms (Akamatsu et al. 2007). For a series of ≤5 clicks, multiple sounds might have entered at short intervals (Kimura et al. 2010). Therefore, ≥6 clicks constituted a click train, and only those with ≥6 clicks were extracted for analysis.

In A-tag recordings of the sounds of small cetaceans, waves reflected from the water or seafloor can be recorded immediately after the sound waves emitted by the cetaceans. Any sound that followed <0.5 ms after the previous one was deleted, as it was deemed a reflected wave. The sound pressure and click intervals of small cetaceans change in the click train. By contrast, the sound pressure and intervals of artificial noises (e.g. from ships) and natural sounds (e.g. from snapping shrimps and other animals) randomly change (Akamatsu et al. 2008). Thus, only sounds deviating by a range from 1/3 to 3 times of the adjacent sound pressures and intervals were retained (Kimura et al. 2010). Sounds with coefficients of variation in sound spacing <0.8 were extracted within the click train. The coefficient of variation is the standard deviation of the sound intervals in the click train divided by the mean and was used as a sound variability indicator (Kimura et al. 2010). Sound pressure and intervals that changed smoothly were extracted as click trains (Akamatsu et al. 2008, Kimura et al. 2010) by setting the aforementioned filters and visually checking the data using a time series.

The number of small cetaceans was enumerated from acoustic data (recording time, sound pressure, sound pressure ratio, relative angle, and sound interval) collected from all survey lines using Igor Pro software (Kimura et al. 2012). Since the survey vessel was faster than the swimming speed of small cetaceans, it overtook the echolocating cetaceans. The recorded click trains changed from a relative positive to negative orientation corresponding to an individual passing from bow to stern with respect to the A-tag (Akamatsu et al. 2008). When >1 dolphin or porpoise echolocated within the detection range, there were multiple trajectories simultaneously identifiable for ≤5 individuals, which was confirmed by concurrent visual observation (Akamatsu et al. 2008, Kimura et al. 2009). The individual detection time was defined as the time that the click train was nearest 0°, which was the closest point 90° vertically from the survey line (Kimura et al. 2012).

It is comparatively easy to distinguish the clicks of Delphinidae and Phocoenidae even when the sound pressure ratios of their frequency bands alone are used (Kameyama et al. 2014, Kimura et al. 2021. Delphinidae use broadband clicks within the peak range of 20–120 kHz, while Phocoenidae use narrow-band, high-frequency clicks within the peak range of 120–140 kHz and with virtually no components that are <100 kHz (Madsen et al. 2005, Morisaka & Connor 2007, Villadsgaard et al. 2007). Concurrent visual observations and acoustic monitoring in all surveys confirmed the presence of only the 2 species (Kimura et al. 2021). The occurrences of Irrawaddy dolphins *Orcaella brevirostris* and Indo-Pacific bottlenose dolphins *Tursiops aduncus* were rare within the study area (Ponnampalam 2012, L. S. Ponnampalam pers. obs.). Hence, all sounds detected here were attributed exclusively to humpback dolphins and finless porpoises. The sound pressure ratios in the click trains were averaged for each detected individual. The species were discriminated using a sound pressure ratio of 0.68 at the discrimination threshold between humpback dolphins and finless porpoises (Kimura et al. 2021). When the sound pressure ratio was higher or lower than the threshold, we assumed that the click trains were emitted by finless porpoises or humpback dolphins, respectively. Location data obtained with a handheld GPS device and a distribution map were plotted. The survey site was categorized into northeast, southeast, northwest, southwest, and central area blocks based on the survey lines (see Fig. 2), and the distribution bias was determined.

2.3. Comparison with environmental data

Environmental characteristics were compared between the locations at which finless porpoises and humpback dolphins were detected. Depth, slope, distance from shore, chlorophyll *a* (chl *a*) concentration, sea surface temperature (SST), and season were determined.

Data were interpolated into 2 km × 2 km grid cells using the 'IDW' tool of ArcMap v.10.6.1 (ESRI). Depth data were obtained from Navionics H P (https://webapp.navionics.com/). Slope and distance from shore were calculated for each 2 km grid cell using the 'Slope' and the 'Near' tools in ArcMap. Distance from shore was calculated relative to mainland Peninsular Malaysia or the Langkawi Archipelago, whichever was closer. Chl *a* concentrations and SST data were obtained from the NASA Ocean Color Web (https://oceancolor.gsfc.nasa.gov/) from 4 km grid cells for September and December 2012 and for February, May, and October 2013. Environmental data matching the acoustic detection positions of the species were extracted and compared. The southwest monsoon (May–October) was the wet season and the northeast monsoon (November–April) was the dry season (Chenoli et al. 2018). Two and 3 surveys were conducted in the dry and wet seasons, respectively. The average numbers of detections of each species in each season were compared. A Steel-Dwass test was used to compare the numbers of detections per area and per species, and a Mann-Whitney *U*-test was used to compare environmental data between the species.

2.4. Habitat modeling

The software R v.4.0.3 (R Core Team) was used for the statistical analyses. Generalized linear models (GLMs) and generalized additive models (GAMs) were used to analyze the relationships between finless porpoise detections and environmental data. The variance inflation factor (VIF) (Dormann et al. 2013) was calculated using the 'car' package in R (Fox & Weisberg 2019) to evaluate explanatory variable multicollinearity before modeling. As suggested by Zuur et al. (2010), VIF ≥ 3 was set as the threshold to exclude variables, so as to avoid multicollinearity.

The number of finless porpoises detected from acoustic data for each 2 km grid cell was the response variable with a log-linked function. The number of humpback dolphins could not serve as a response variable as the detection site was biased, and the dolphins were detected in only 9 grid cells.

The environmental variables were depth, slope, distance from shore, season, survey date, longitude, and latitude. The presence/absence of humpback dolphins served as an explanatory variable. Chl *a* concentration and SST were not used in the habitat model, as numerous data points were missing, and there was coarse spatiotemporal resolution at monthly intervals.

For the GAMs, 6 degrees of freedom was set for the smoothing function to avoid data overfitting. The 'car' package in R (Fox & Weisberg 2019) was used to construct the GLMs, while the 'MGCV' package (Wood 2018) was used to construct the GAMs. To account for the variations in survey effort per grid cell, the logarithm of distance of each survey line per grid cell was included as an offset term in the model. Poisson and negative binomial distributions were used as candidate distributions for response variables (Wood 2006).

All model combinations ranging from full (all explanatory variables) to null (no explanatory variables) were created with the 'dredge' function in the 'MuMIn' package in R (Barton & Barton 2019). The best model was chosen as the one with the lowest value of Akaike's information criterion (AIC). The predicted relative densities around the Langkawi Archipelago were calculated using the environmental data selected in the best model and compared against actual observations.

3. RESULTS

3.1. Distribution

All 5 surveys recorded both finless porpoises (n = 150) and humpback dolphins (n = 29) (Kimura et al. 2021; Fig. 2, Table 1). The number of porpoises detected did not significantly differ among survey areas (Steel-Dwass test; $p > 0.05$). Nevertheless, there were relatively more individuals in the eastern area than in the other areas (Fig. 2, Table 1). The number of humpback dolphins detected was highest in the northeast and low in the southeast and northwest, and no dolphins were found in the southwest and central areas (Fig. 2, Table 1). However, the differences were not statistically significant (Steel-Dwass test; $p > 0.05$).

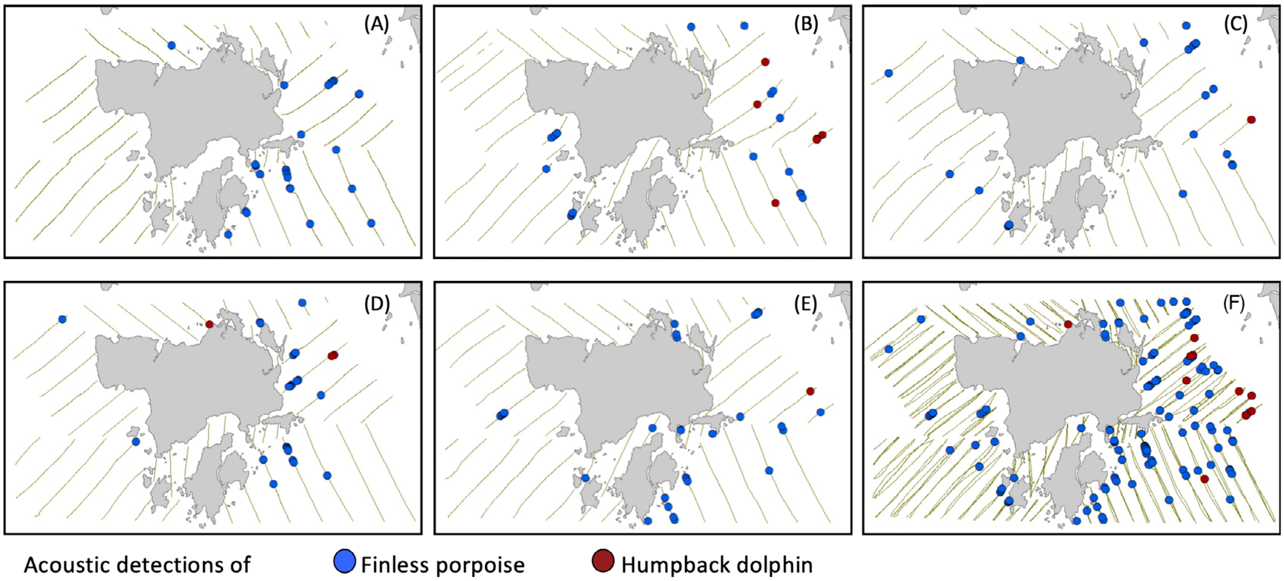

Fig. 2. Survey lines along which finless porpoises (n = 150) and humpback dolphins (n = 29) were detected using passive acoustic monitoring in (A) September 2012 (survey distance: 344.3 km), (B) December 2012 (410.9 km), (C) February 2013 (382.2 km), (D) May 2013 (376.0 km), and (E) October 2013 (399.6 km). (F) Total survey distance was 1913.0 km. Distance between parallel transects was ~3.70 km per line in each survey

Table 1. Number of finless porpoises (*N.p.*) and humpback dolphins (*S.c.*) detected by passive acoustic monitoring surveys in each area and per kilometer of survey line

Area	Acoustic detections		Acoustic detections km^{-1}	
	N.p.	*S.c.*	*N.p.*	*S.c.*
Northeast	56	27	0.132	0.063
Southeast	52	1	0.114	0.002
Northwest	17	1	0.033	0.002
Southwest	16	0	0.044	0
Central	9	0	0.062	0
Total	150	29	0.078	0.015

3.2. Comparison of species distribution and environmental data

Both species were detected mainly in shallow waters, especially at <15 m (Fig. 3). There were no statistically significant differences in depth or slope between the species, although humpback dolphins appeared to prefer shallower waters and gentler slopes (Table 2, Fig. 3). The waters in which humpback dolphins resided were significantly farther from shore and had higher chl *a* concentrations than those occupied by finless porpoises (Table 2, Fig. 3). Preferred SSTs did not significantly differ between the species (Table 2, Fig. 3). The average numbers of finless porpoises detected did not significantly differ between the dry and wet seasons (Table 2, Fig. 3). In contrast, approximately 5 times more humpback dolphins were detected in the dry than in the wet season (Table 2, Fig. 3).

3.3. Finless porpoise habitat model

The model included 1392 grid cells, of which 78 and 9 contained finless porpoises and humpback dolphins, respectively. In the present study, all environmental variables were integrated into the model, as their VIFs were <3 (Table 3).

The GAM with the smallest AIC included depth and longitude (AIC = 745.3). The relationships among explanatory variables, environmental parameters, and the response variable were nonlinear (Fig. 4). Based on the AIC and Q–Q plot, this model was considered best to predict finless porpoise habitat distribution (Table 4), and this did not change even after humpback dolphin presence/absence was included as an explanatory variable. Thus, humpback dolphins were excluded as variables for the best model, although they were included in models with ΔAIC <2 and negative coefficients (Table 4).

Depth was the environmental variable that most strongly influenced the presence of finless porpoises (Tables 4 & 5). Porpoise abundance decreased as water depth increased to >30 m (Fig. 4A). Longitude also affected the presence of porpoises (Tables 4 & 5). Porpoise abundance increased eastwards at 99.8° E

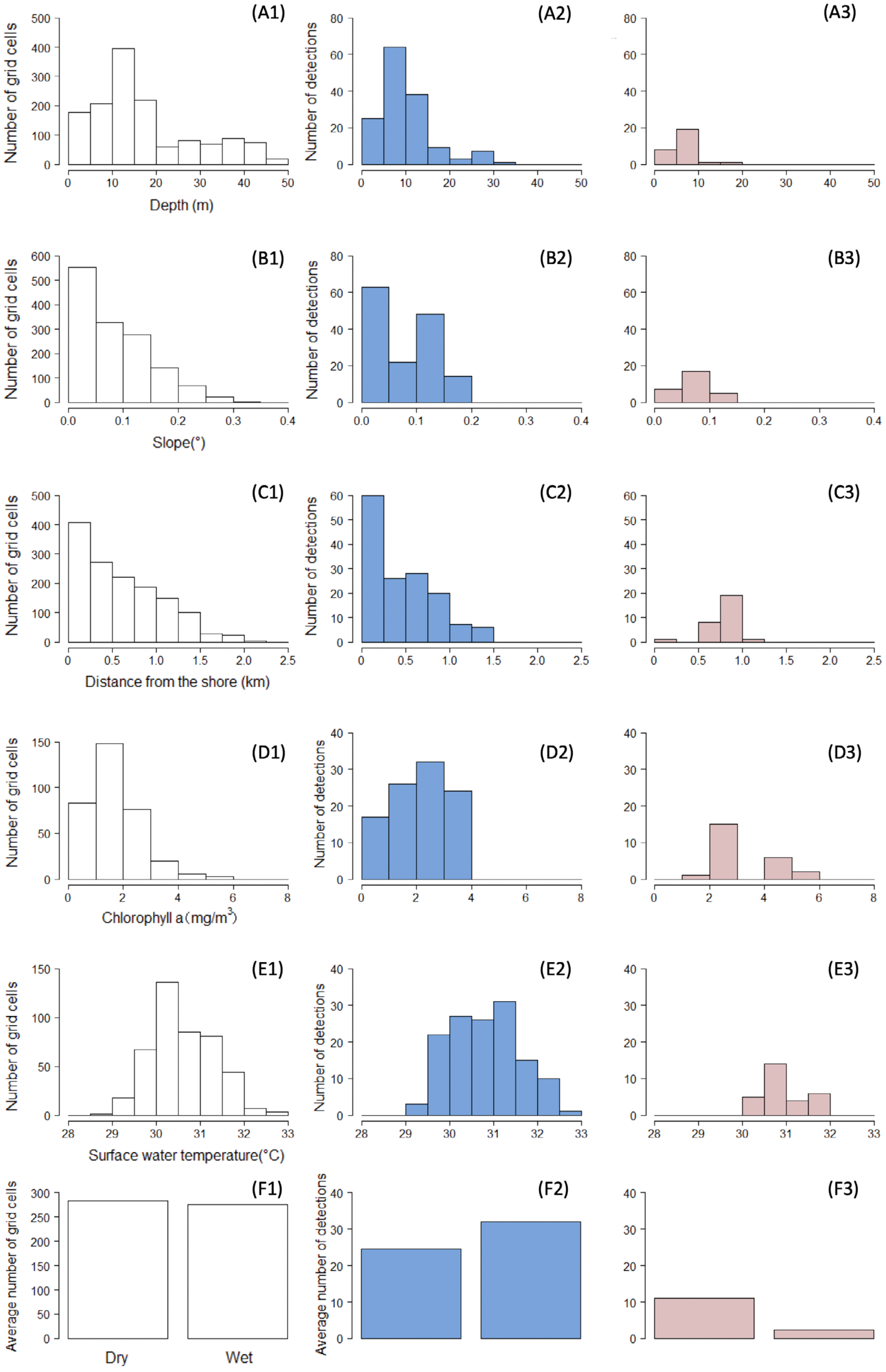

Fig. 3. Number of grid cells (column 1, white), number of finless porpoises (column 2, blue), and number of humpback dolphins (column 3, pink) detected for each environmental variable: (A) depth, (B) slope, (C) distance from shore, (D) chlorophyll *a* concentration, (E) sea surface temperature, and (F) season

Table 2. Environmental data collected at the detection point of finless porpoises and humpback dolphins. A Mann-Whitney *U*-test was used to compare environmental data between the species (*$p < 0.05$; **$p < 0.01$). SST: sea surface temperature

	Finless porpoise				p	Humpback dolphin			
	Minimum	Average	Median	Maximum		Minimum	Average	Median	Maximum
Depth (m)	1.97	8.40	9.90	31.60	0.08	2.30	7.30	8.60	16.90
Slope (°)	0.00	0.07	0.09	0.19	0.08	0.00	0.07	0.08	0.13
Dist. from shore (km)	0.01	4.41	3.10	14.90	**	0.44	8.15	8.00	11.90
SST (°C)	29.41	30.78	30.86	32.89	0.34	30.02	30.89	30.72	31.84
Chl *a* (mg m^{-3})	0.57	2.17	2.17	3.90	*	1.23	3.02	2.18	5.43
		Season					Season		
		Dry	Wet				Dry	Wet	
Total no. ind. detected		49	96				22	7	
Ave. no. ind. detected		24.5	32				11	2.3	

(Fig. 4B). The relative animal densities predicted for the entire area by the best model using environmental data were higher in the northeastern and eastern coastal areas of the Langkawi Archipelago (Fig. 5).

4. DISCUSSION

4.1. Distribution and habitat preferences of finless porpoises and humpback dolphins

To our knowledge, this study is the first effort to model the habitat preferences of 2 sympatric coastal cetacean species within Malaysia and Southeast Asia using passive acoustic monitoring. We compared the habitat preferences of these 2 species and developed spatial habitat models for finless porpoises (Table 4, Fig. 4) to predict their presence outside the surveyed area (Fig. 5). The spatial map could help to inform stakeholders to take appropriate conservation action and protect the species and their environment in a rapidly developing marine region.

Finless porpoises were detected in all areas around the island, whereas the detection sites of hump-

Table 3. Variance inflation factor (VIF) values of explanatory variables in the habitat model. *S.c.*: humpback dolphin

Variable	VIF
Depth	2.03
Slope	1.22
Distance from the coast	2.67
Longitude	2.36
Latitude	1.07
Survey date	1.13
Season	1.13
Presence/absence of *S.c.*	1.00
Abundance of *S.c*	1.00

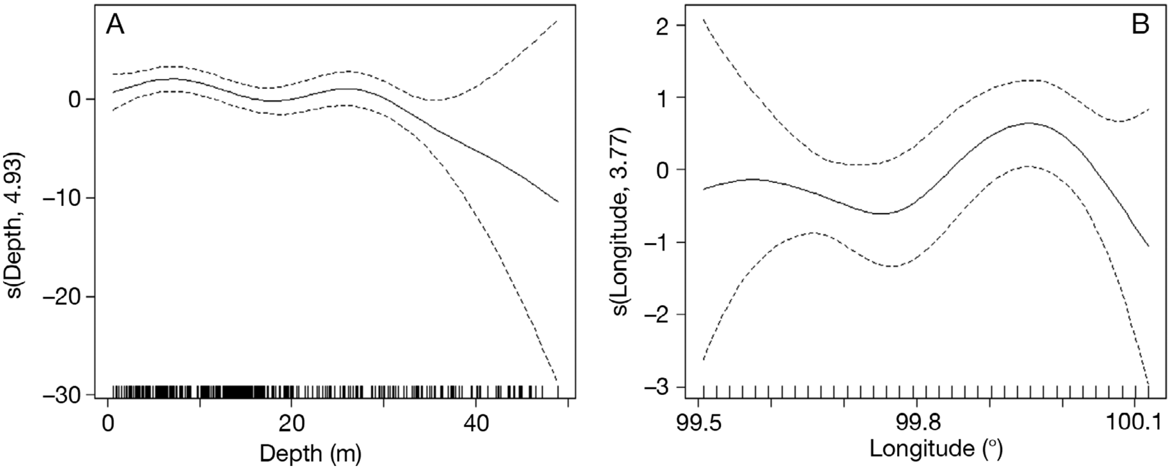

Fig. 4. Smoothing function plots in best model of (A) depth and (B) longitude using the number of finless porpoises as the response variable. Dotted line indicates 95% confidence interval

Table 4. Finless porpoise population models with the lowest value of Akaike's information criterion (highlighted in **bold**) and with <2 units difference in AIC (ΔAIC). Models were created using either a Poisson or a negative binomial distribution and either a generalized linear model (GLM) or a generalized additive model (GAM), and GAMs with negative binomial distributions were selected. Light blue rows indicate models including humpback dolphins (SC). DEP: depth; SLO: slope; DIS: distance from shore; SEA: season; SUR: survey date; LON: longitude; LAT: latitude

Environmental variable	df	Log like.	AIC	ΔAIC
DEP+LON	**12**	**–360.190**	**745.3**	**0.00**
DEP+SC+LON	13	–359.372	745.5	0.16
DEP+SLO+LON	16	–356.652	746.4	1.06
DEP+SLO+SC+LON	17	–355.973	746.6	1.30
DEP+SUR+LON	13	–359.952	746.7	1.34
DEP+DIS+LON	13	–359.968	746.8	1.52
DEP+DIS+SC+LON	14	–359.111	746.9	1.61
DEP+LON+LAT	13	–359.896	747.1	1.74
DEP+SEA+LON	13	–360.289	747.2	1.89
DEP+SC+LON+LAT	14	–359.096	747.2	1.93

Table 5. Degrees of freedom, χ^2, and p of environmental variables selected in the best model with the number of finless porpoises as the response variable. DEP: depth; LON: longitude

Variable	df	χ^2	p
DEP	4.93	25.31	<0.001
LON	3.77	10.48	<0.001

back dolphins were biased (Fig. 2, Table 1). The humpback dolphins detected totaled 29 individuals, but were only present in 9 grid cells. This sample size did not suffice for modeling purposes. The species differed in terms of the number of detections and detection sites, preferred distance from shore, chl *a* concentration in the water where they resided, and season in which they were detected (Table 2, Fig. 3). Hence, both species have different habitat preferences. The number of detections of finless porpoises did not significantly differ between the dry and wet seasons. By contrast, substantially more humpback dolphins were detected in the dry than in the wet season (Fig. 2). Therefore, the porpoises may reside relatively close to Langkawi Island, whereas the humpback dolphins may only seasonally visit specific regions of the waters around the islands. Their actual range may also extend beyond the field of measurement of this study. Recent observations of humpback dolphins around Langkawi indicated that they move between the islands and the coast of Peninsular Malaysia (Teoh 2018). In a study area ~200 km south of Langkawi in Matang, Peninsular Malaysia, the distribution of finless porpoises and humpback dolphins did not overlap (Kuit et al. 2019). Studies in Hong Kong reported that it is uncommon to observe both species in close proximity at the same time, suggesting that the porpoises may avoid the dolphins (Würsig et al. 2016). Further research is required to elucidate the relationship between finless porpoises and humpback dolphins.

Bathymetric depth was the major environmental factor associated with finless porpoise distribution. Thus, it was included into the best model and most others with ΔAIC <2 (Table 4). In these models, porpoise abundance was comparatively higher at depths <30 m (Fig. 4). Humpback dolphins also preferred shallow water (Fig. 3, Table 2). Previous studies of these species reported similar discoveries (Jefferson & Hung 2004, Jefferson & Rosenbaum 2014). In Matang, the average bathymetric depths for finless porpoises and humpback dolphins were 12.3 and 3.6 m, respectively (Kuit et al. 2019). In the Bay of Bengal near Bangladesh, both species preferred shallow water (average depths, 11.0 and 10.6 m, respectively) (Smith et al. 2008). Depth was included in the best models for *Phocoena phocoena* (Booth et al. 2013, Díaz López and Methion 2018), *P. spinipinnis* (Clay et al. 2018), and *P. dalli* (Forney et al. 2012, Becker et al. 2016), species which are in the same family as the finless porpoise. Bathymetric depth is an important environmental factor for coastal small cetacean species including members of the Family Phocoenidae.

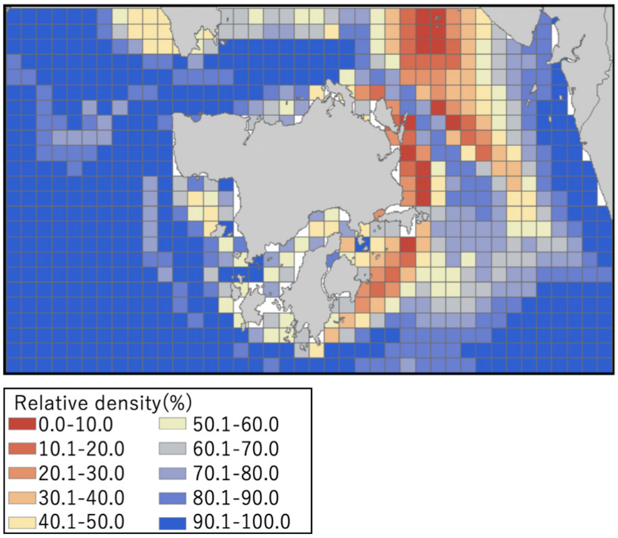

Fig. 5. Relative density of finless porpoises predicted from the best model including depth and longitude

Longitude was also an important predictor of finless porpoise distribution. Peak abundance of this species was established at 99.9–100.0° E in the eastern waters of the Langkawi Archipelago (Fig. 4). Humpback dolphins were also relatively more concentrated in the eastern area of the islands (Fig. 2, Table 1). The latitude and longitude identified herein may indicate that the animals preferred certain areas. However, latitudes and longitudes may also be indirect model variables indicating other environmental parameters that could not be integrated into the analysis (Kanaji et al. 2017). Tidal currents, tides, and ship traffic might also affect the distribution of these species. Nevertheless, we were unable to measure them in this study.

4.2. Limitations

In this study, there were limited environmental data to model, and certain important factors might have been omitted in the models. Three vital environmental factors excluded from this study were prey occurrence, tidal currents, and tides. These parameters may be correlated with the presence of narrow-ridged finless porpoises *Neophocaena asiaeorientalis* and humpback dolphins in different areas (Parsons 1998, Akamatsu et al. 2010, Kimura et al. 2012, Lin et al. 2013, Kuit et al. 2019).

Marine vessels were not integrated into the model but may nonetheless influence the distribution of finless porpoises and humpback dolphins (Dong et al. 2021, Mei et al. 2021). There is a high volume of tourist boat, high-speed ferry, and fishing boat traffic around the Langkawi Archipelago (Ponnampalam & Jamal Hisne 2011, Teoh 2018), and the presence of these vessels may affect the distribution of small cetaceans. However, it was reported that humpback dolphins often approached fishing boats and trawlers (Ng & Leung 2003, Hashim & Jaaman 2011). Moreover, the presence of prey species influences the distribution of finless porpoises and humpback dolphins more strongly than the presence of vessels (Kimura et al. 2012, Pine et al. 2017). In this study, logistical restrictions prevented rigorous recording of vessels and prey. Future research should integrate these factors into the distribution models.

5. CONCLUSIONS

The present study obtained ecological information for finless porpoises and humpback dolphins inhabiting the coastal waters of the Langkawi Archipelago, Malaysia, using passive acoustic monitoring. Both species were distributed mainly in waters of <15 m depth. However, both species differed significantly in terms of numbers and sites detected, preferred distances from shore, and chl *a* concentrations. Finless porpoise distribution was temporally stable especially in the eastern waters around the islands. By contrast, humpback dolphin distribution was seasonal and localized to specific sites within the research area. We propose that each species is influenced by different environmental factors in the waters around the Langkawi Archipelago. Further investigations into the coastal distribution of humpback dolphins may help elucidate their presence and habitat preferences around Langkawi. Long-term sampling, and feeding ecology and prey distribution studies will help clarify the distribution patterns of these species in the area. To our knowledge, this study is the first to model the habitat preferences of 2 sympatric coastal cetacean species within Malaysia and Southeast Asia by passive acoustic monitoring. The conservation and management of finless porpoises and humpback dolphins in the waters around the Langkawi Archipelago may be improved by designing and establishing protected areas customized for each species according to their unique habitat preferences.

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