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Distribution of Three Sympatric Cetacean Species Off the Coast of the Central-Western Gulf of Thailand

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Abstract

Baseline data on the distribution patterns of animals disclose the dynamic function of habitat use as it relates to the accessibility of prey, social interactions, predator-prey interactions, and inter-habitat-patch mobility. Differentiated distribution patterns in sympatric animal species may imply a spatial-partitioning of habitat use. This study used minimum convex polygon and kernel density estimate techniques to measure the extent of occurrence and core habitat of the Indo-Pacific humpback dolphin (*Sousa chinensis*), Irrawaddy dolphin (*Orcaella brevirostris*), and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) in the central-western Gulf of Thailand. For the three cetacean species, their extent of occurrence greatly overlapped, while their core habitats were nearly disjointed, with minor overlap. Principal component analysis and discriminant analysis revealed significant differences in the habitat characteristics inside core habitats, which imply geographic separation of foraging patches between Irrawaddy dolphins, humpback dolphins, and finless porpoises. Based on the core habitat identification, we propose precautionary actions to maintain the habitat condition and integrity inside the core habitats for the three sympatric cetacean species, including revisiting the regulations and mitigation rules for local fisheries and dolphin-watching tourism; re-routing the ferry lanes to avoid the core habitats; and avoiding large-scale coastal modification, such as land reclamation and embankment, in the waters near core habitats.

Key Words: extent of occurrence, core habitat, kernel density estimates, resource partitioning, *Sousa chinensis*, *Orcaella brevirostris*, *Neophocaena phocaenoides*

Introduction

Studies on the distribution patterns of animals disclose the dynamic function of habitat use and selection that relates to the accessibility of prey, social interactions, predator-prey interactions, and inter-habitat mobility (Wilson et al., 1997; Karczmarski et al., 1999; Heithaus, 2001; Davis et al., 2002; Braulik et al., 2012; Wang et al., 2015, 2016). These kinds of studies can provide insights into practical habitat protection and management planning (International Union for Conservation of Nature [IUCN], 2001; Wilson et al., 2004; Cañadas et al., 2005; Garaffo et al., 2011; Zhao et al., 2013; Wang et al., 2016), which can be especially important to identify key habitats and to design sound habitat protection measures for coastal cetacean species that are frequently impacted by proximal anthropogenic activities.

The Indo-Pacific humpback dolphin (*Sousa chinensis*), Irrawaddy dolphin (*Orcaella brevirostris*), and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) exclusively inhabit inshore and coastal waters of China and southeastern Asian countries (Stacey & Arnold, 1999; Jefferson & Karczmarski, 2001; Stacey & Hvenegaard, 2002; Jefferson & Hung, 2004a, 2004b; Jefferson & Rosenbaum, 2014; Jutapruet et al., 2015; Jefferson & Smith, 2016) and mainly feed on coastal prey species (Baird & Mounsouphom, 1997; Jefferson & Karczmarski, 2001; Barros et al., 2002, 2004;

Jefferson & Hung, 2004a, 2004b; Parra & Jedensjö, 2014). Their convergent habitat and prey preferences imply sympatric distribution in a coastal habitat; however, only a few relevant reports are currently available (Chantrapornsyl et al., 1996; Beasley & Davidson, 2007).

The sympatric distribution of different species with similar habitat and prey preferences can be sustained through various mechanisms of resource partitioning (Gowans & Whitehead, 1995; Parra, 2006; Gibbs et al., 2011; Wang et al., 2012; Browning et al., 2014; Ansmann et al., 2015). In pelagic cetacean species, mechanism of resource partitioning can be reached by vertical stratification of different feeding depths (Weir et al., 2009; Wang et al., 2012; Ansmann et al., 2014). For the coastal cetaceans like the Indo-Pacific humpback dolphin, Irrawaddy dolphin, and Indo-Pacific finless porpoise, however, this vertical-stratification mechanism may have insufficient space to evolve because of the shallow water depth in their primary habitats, generally shallower than 30 m. A different mechanism of spatial partitioning, such as geographic separation of foraging patches (Parra, 2006), is more likely.

In the Gulf of Thailand, Beasley & Davidson (2007) qualitatively reported the distribution of Indo-Pacific humpback dolphins, Irrawaddy dolphins, and Indo-Pacific finless porpoises with overlapping depth profiles of distribution in the northeastern Gulf of Thailand along the Cambodian coast. Details of the extent of occurrence and core habitat in these three species, however, were not analyzed. In the central-western Gulf of Thailand, earlier census surveys on the Indo-Pacific humpback dolphins (Jaroensutasinee et al., 2010; Jutapruet et al., 2015) also recorded the occurrence of the Irrawaddy dolphin and Indo-Pacific finless porpoise in the same habitat (S. Jutapruet, unpub. records). Information on the extent of occurrence and core habitat, however, was not analyzed.

Identification of the extent of occurrence and core habitat of a population can provide baselines for precautionary and practical zoning in the design of marine mammal protected areas (Flores & Bazzalo, 2004; Rayment et al., 2009; Silva et al., 2012; Hartel et al., 2015). Currently, only a few habitat protection and management measures designed for these three cetacean species are implemented in the central-western Gulf of Thailand, though anthropogenic activities, including oil and gas transportation, ferry transportation, fishing, and ecotourism, have been increasing (Jutapruet et al., 2015). These anthropogenic impacts likely impact the habitat quality of the Indo-Pacific humpback dolphin, Irrawaddy dolphin, and Indo-Pacific finless porpoise. Identifying key habitats where sound protection actions are immediately needed is an important task to mitigate and minimize likely threats from those anthropogenic impacts.

In this study, the distribution patterns and core habitats of these three cetacean species in the central-western Gulf of Thailand are discussed based on the sighting records from field surveys. The differences of habitat characteristics inside their core habitats are tested, and, upon the identification of core habitat areas for these three cetacean species, the potential habitat protection and management actions are discussed.

Methods

Study Site

The study area included the coastline area (CA) and offshore area (OA) around the small islands near Donsak, Thailand (Figure 1). The habitat types in the CA include rocky shore/cliffs, sand, mud flats, mangroves, and sea-grass seabeds. Anthropogenic activities in the CA habitat include scheduled ferries, small- and industrial-scale fisheries, dolphin-watching boats, and industrial factories along the coast. In the OA habitat, sandy beaches, rocky shores, and rocky cliffs comprise the major habitat features. Small-scale fisheries are the primary anthropogenic activity in this habitat. The northernmost edge of the survey area includes Pa Luai Island within the Ang Thong Marine National Park (established in 1980; 9.517° N, 9.683° E; Figure 1). The rainy season in the study area prevails from mid-May to January, and the summer season spans from mid-February to mid-May.

Field Surveys and Data Collection.

Field surveys were conducted at 0800 to 1400 h from December 2011 to April 2013, 2 or 3 d/mo, using a long-tailed fishing boat with a maximum speed of 15 km/h. All surveys were conducted in conditions of clear weather, 0 to 2 Beaufort Sea State, and at least ~1 km sea surface visibility. At least two surveys were performed each month using opportunistically designed survey tracks to equally cover the entire study area. The survey tracks started from Rat Island to either Ta Rai Island on the east or the Somserm Ferry on the west, then extended to the islands around the OA area as far as Pa Luai Island, and returned to Rat Island each survey day (Figure 1). Each time dolphins or porpoises were sighted, the vessel speed was slowed down, and the following data were recorded: the cetacean species; the GPS position (by Garmin etrex30); and environmental characteristics, including water depth (by Hondex PS-7), turbidity (measured by Secchi disc), pH, sea surface temperature (by Multi-meter: FG2-1 Mettler-Toledo AG), salinity (by Seawater refractometer, HI 96822 HANNA), and distance to mainland shore.

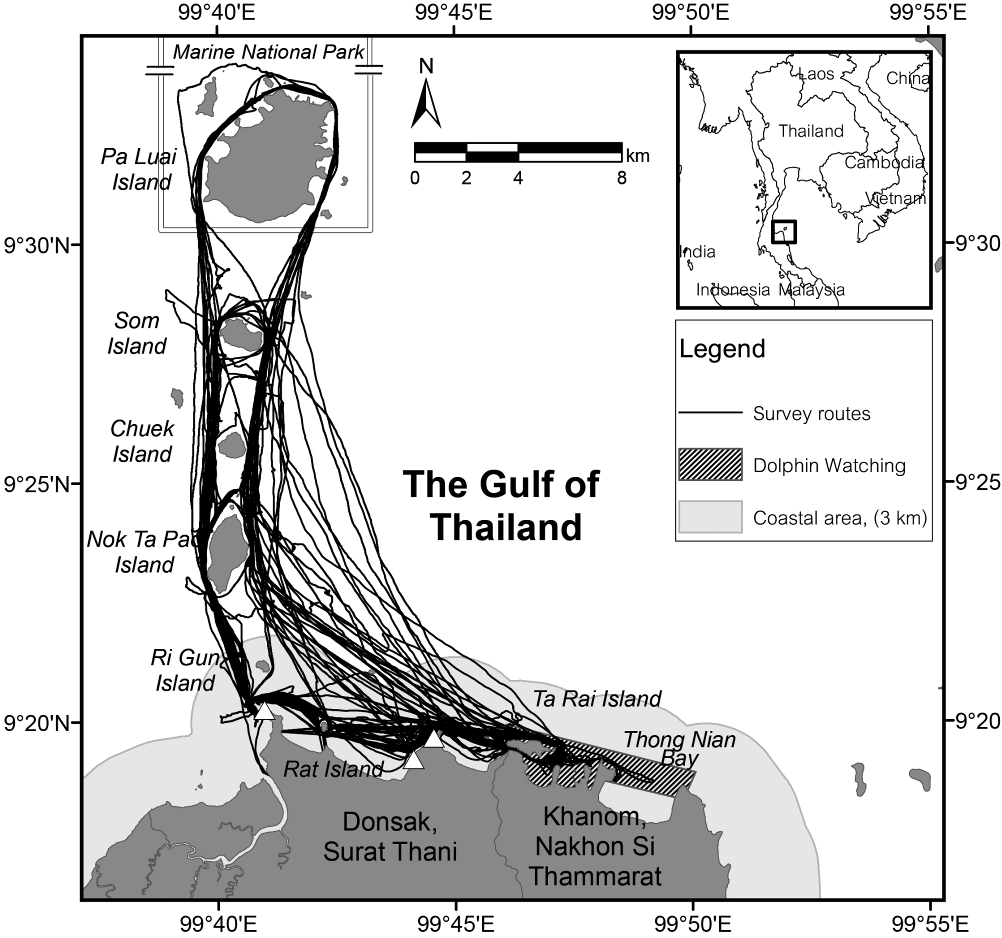

Figure 1. Study site and survey routes for this study in the central-western Gulf of Thailand

Distribution Patterns and Statistics

Distribution patterns of the three cetacean species were measured by the minimum convex polygon (MCP) for the extent of occurrence (IUCN, 2001) and by a 50% kernel density estimate (50% KDE) for identifying the core habitat (Parra, 2006; Keith et al., 2013; Wang et al., 2015, 2016). Sighting data (GPS) of the Indo-Pacific humpback dolphin, Irrawaddy dolphin, and Indo-Pacific finless porpoise were plotted using *ArcMap 9.3* (Environmental Systems Research Institute [ESRI], 2008). Polygons outlining MCP and 50% KDE of the three cetacean species were plotted against their sighting records. Areas of the MCPs and 50% KDEs were measured using *ArcMap 9.3*.

Principal component analysis (PCA) was applied to the habitat characteristics at locations of sightings to transform the dependent characteristics into independent components. Then, discriminant analysis (DA) was applied to the PCA-transformed habitat characteristics within the region of 50% KDE between the three cetacean species and between rainy (between May and October) and dry (from November to April) seasons.

Results

During the 47 boat-survey days covering 2,618.4 km of survey effort, 105 groups of Indo-Pacific humpback dolphins, 40 groups of Irrawaddy dolphins, and 13 groups of Indo-Pacific finless porpoises were recorded. The sighting locations of these cetaceans are shown in Figure 2.

MCPs of these three cetacean species overlapped and varied in size (Figure 2). The Indo-Pacific humpback dolphin had the largest MCP

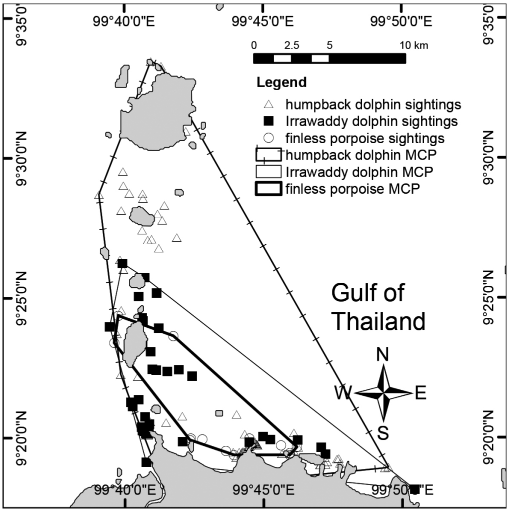

Figure 2. Positions of sightings and extent of occurrence (minimum convex polygon [MCP]) of Indo-Pacific humpback dolphin (*Sousa chinensis*), Irrawaddy dolphin (*Orcaella brevirostris*), and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) near Donsak in the central-western Gulf of Thailand

(280.16 km^2), while the Indo-Pacific finless porpoise had the smallest MCP (44.80 km^2) (Table 1). The core habitats (estimated by 50% KDEs) were found to have only minor overlaps (Figure 3). The Irrawaddy dolphins had the largest core area at 14.71 km^2, while the Indo-Pacific finless porpoise had the smallest core area at 10.06 km^2 (Table 1).

The original six habitat characteristics were transformed into two independent components by PCA, labeled PC1 and PC2 (Table 2). PC1 was primarily affected by distance to mainland shore, water depth, and turbidity, while PC2 was dominated by sea surface temperature, pH, and salinity. Inside the core habitats, discriminant analysis showed a significant difference in the PC1 and PC2 (Figure 4) between the Indo-Pacific humpback dolphin, Irrawaddy dolphin, and Indo-Pacific finless porpoise ($F_{4,156} = 3.233$, $p < 0.05$). The inter-species comparison from discriminant analysis revealed that the habitat characteristics inside the core habitat for Irrawaddy dolphin were significantly different from those of the Indo-Pacific humpback dolphin ($F_{2,78} = 5.309$, $p < 0.01$) and Indo-Pacific finless porpoise ($F_{2,78} = 3.189$, $p < 0.05$), but those differences between the Indo-Pacific finless porpoise and Indo-Pacific humpback dolphin were not significant ($F_{2,78} = 0.869$, $p = 0.484$). Difference of habitat characteristics between rainy and dry seasons was not significant (discriminant analysis, $F_{2,78} = 1.37$, $p = 0.26$). Table 3 summarizes the habitat characteristics inside the core habitats of these three cetacean species.

Discussion

Differences in Distribution and Habitat-Use Patterns

The distribution pattern of a species may change dynamically with the seasonal movements of individual animals within patches (Wilson et al., 1997; Karczmarski et al., 1999; Chen et al., 2010), which affect local abundance, dimensions, and the distribution patterns. In other habitats, both Indo-Pacific humpback dolphins and Irrawaddy dolphins undergo seasonal migration in and out of the studied region (Karczmarski et al., 1999; Stacey & Hvenegaard, 2002; Parra et al., 2006). In the Pearl River Estuary, distribution patterns of the Indo-Pacific humpback dolphin change in concert with the wet and dry seasons (Chen et al., 2010). Similar patterns of seasonality in local abundance and distribution patchiness may also be expected for these three cetacean species in the central-western Gulf of Thailand. Differences in habitat characteristics between dry and wet seasons, however, were not significant in our study region, implying an insignificant seasonality in distribution patchiness. Seasonal change in local abundance is still plausible and requires further exploration.

Jaroensutasinee et al. (2010) report occurrence and abundance estimates of the Indo-Pacific humpback dolphin (total 49 dolphins) near Khanom,

Table 1. Areas (km^2) of the extent of occurrence (estimated by minimum convex polygon [MCP]) and the core habitat (estimated by 50% kernel density estimate [50% KDE]) for the Indo-Pacific humpback dolphin (*Sousa chinensis*), Irrawaddy dolphin (*Orcaella brevirostris*), and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) off Donsak in the central-western Gulf of Thailand

Species	MCP (km^2)	50% KDE (km^2)
Indo-Pacific humpback dolphin	280.159	13.053
Irrawaddy dolphin	125.165	14.714
Indo-Pacific finless porpoise	44.800	10.057

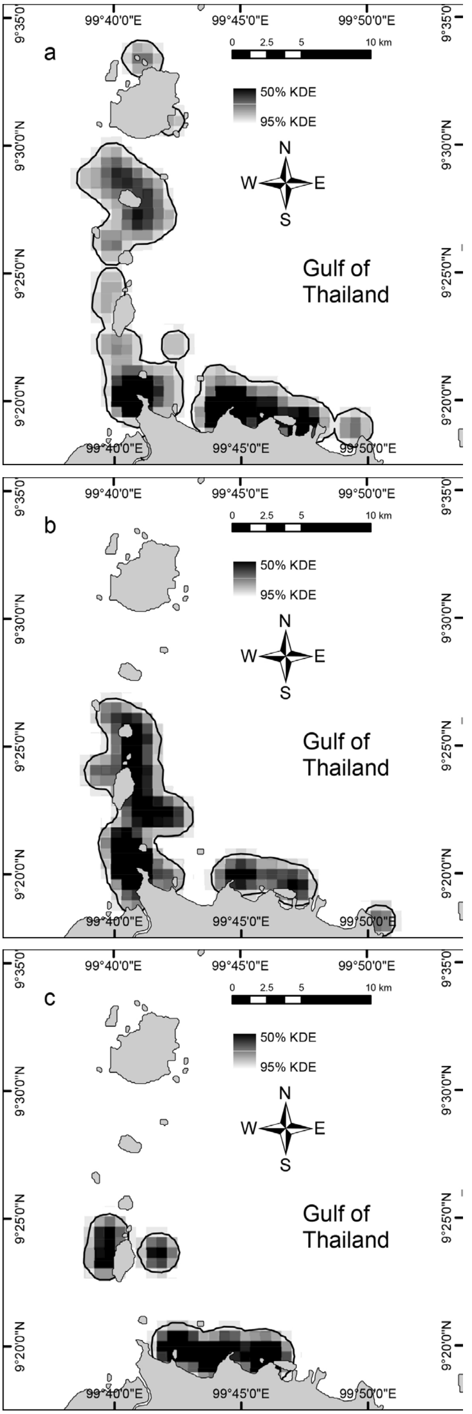

Figure 3. Kernel density estimates (KDEs) with contours outlining 95% KDE boundary based on sighting points of the (a) Indo-Pacific humpback dolphin, (b) Irrawaddy dolphin, and (c) Indo-Pacific finless porpoise near Donsak in the central-western Gulf of Thailand

Table 2. Principal component analysis (PCA) of habitat characteristics at sighting locations of the Indo-Pacific humpback dolphin, Irrawaddy dolphin, and Indo-Pacific finless porpoise. Two dominant principal components were identified, PC1 and PC2, that explain 57.29% total variance. DS = distance to mainland shoreline (km), WD = water depth (m), SED = Secchi depth (m), SST = sea surface temperature (°C), and Sal = salinity (PSU).

	PC1	PC2
DS (km)	0.8678	-0.1302
WD (m)	0.8129	-0.0363
SED (m)	0.8431	0.2740
SST (°C)	0.2388	0.6528
pH	0.0096	0.6148
Sal (PSU)	0.1511	-0.5793
Eigenvalues	2.2046	1.2330
Variance explained	36.74%	20.55%

Nakhon Si Thammarat Province, east of Donsak (Figure 1). In that study, Irrawaddy dolphins and Indo-Pacific finless porpoises were also frequently sighted but not formally recorded (S. Jutapruet, pers. comm.). Some of the Indo-Pacific humpback dolphins (total 15 dolphins) observed off Donsak were also sighted in the waters off Khanom (Jutapruet et al., 2015), indicating that the actual habitat area and, hence, the distribution range, at least for the Indo-Pacific humpback dolphins, might extend eastward. Thus, the geographical range of this study merely covered a part of the natural distribution of the dolphins and porpoises in this area. The MCP and 50% KDE reported in this study, therefore, should not be literally interpreted as the "home range" of these animals. Successive surveys over a broader spatial scale, including Donsak-Khanom waters and the waters west of Donsak, are needed to provide a more comprehensive view of the distribution and the habitat-use patterns of these three cetacean species in the central-western Gulf of Thailand.

Differences in distribution patterns among species might not necessarily result from mechanisms of resource partitioning if the species are ecologically adapted to different habitats as exemplified by the difference between pelagic and coastal cetacean species (Kaschner et al., 2006; Garaffo et al., 2011; Mèndez-Fernandez et al., 2012). In this study, however, MCPs of the Indo-Pacific humpback dolphin, Irrawaddy dolphin, and Indo-Pacific finless porpoise greatly overlapped, implying convergent needs for similar habitat and environmental features. The differences in the sites of

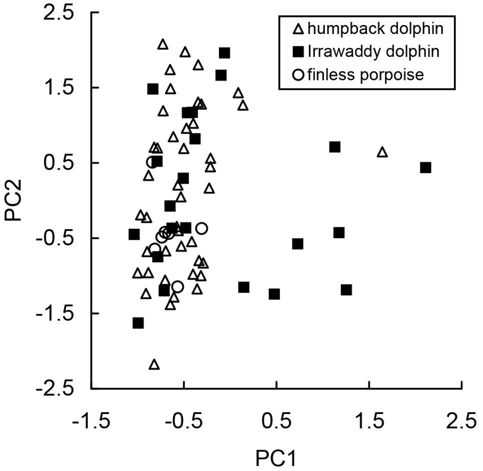

Figure 4. Scatter plot of the PCA-transformed habitat characteristics (PC1 and PC2) inside the core habitat (50% KDE) of the Indo-Pacific humpback dolphin, Irrawaddy dolphin, and Indo-Pacific finless porpoise

core habitats and the habitat characteristics inside the core habitats strongly indicate a spatial partitioning in habitat use relative to shallow waters. Similar patterns of spatial differentiation have also been reported between the humpback dolphin and snubfin dolphin (*Orcaella heinsohni*) in Australian waters (Parra, 2006).

For cetaceans, one of the principal functions of core habitats is the provision of foraging (Hastie et al., 2004; Keith et al., 2013; Wang et al., 2016). Although direct evidence from comparative diet-composition analysis for these three species (e.g., Wang et al., 2012; Parra & Jedensjö, 2014) still does not exist for the Gulf of Thailand, analyses from other habitats and taxonomically relevant species may corroborate the connection between spatial partitioning and differentiation of diet preference (Barros et al., 2004; Jefferson & Hung, 2004a, 2004b; Parra & Jedensjö, 2014). In Australian waters, humpback dolphins and Australian snubfin, a species taxonomically close and ecologically analogous to Irrawaddy dolphin, feed on a similar prey composition, although the number of collected specimens seems insufficient for robust conclusions (Parra & Jedensjö, 2014). Spatially, these two species utilize the same space by partitioning their core habitats (Parra, 2006), which is similar with this study. This similarity may result from a mechanism to utilize similar prey resources through differentiated core habitats.

The number of sightings of the finless porpoise in this study was low, which might lead some to conclude that the estimation of its core habitat, and, hence, the spatial partitioning, is statistically neither representative nor robustly inferred. However, distributions of the Indo-Pacific finless porpoise and Indo-Pacific humpback dolphins in Hong Kong waters, reported with large sample sizes, reveal that these two species spatially utilize different parts of Hong Kong waters with different oceanographic features (Jefferson & Leatherwood, 1997; Jefferson et al., 2002; Hung, 2008), which is consistent with our observations in the Gulf of Thailand. Further, stomach content analyses of finless porpoises and humpback

Table 3. Habitat characteristics (mean ± SD, range) inside the core habitats (50% KDE) of the Indo-Pacific humpback dolphin, Irrawaddy dolphin, and Indo-Pacific finless porpoise. DS = distance to mainland shoreline (km), WD = water depth (m), SED = Secchi disk (m), SST = sea surface temperature (°C), and Sal = salinity (PSU).

Mean	Indo-Pacific humpback dolphin	Irrawaddy dolphin	Indo-Pacific finless porpoise
DS (km)	0.22 ± 0.23	2.34 ± 3.01	0.75 ± 0.38
	(0.01-0.93)	(0.10-10.11)	(0.25-1.23)
WD (m)	3.90 ± 1.46	5.39 ± 3.07	2.69 ± 0.36
	(1.70-9.80)	(1.90-13.40)	(2.10-3.00)
SED (m)	1.05 ± 0.38	1.21 ± 0.56	0.94 ± 0.20
	(0.50-3.00)	(0.50-3.00)	(0.50-1.10)
SST (°C)	29.71 ± 1.41	29.52 ± 1.28	29.6 ± 0.86
	(26.6-32.6)	(27.3-32.1)	(28.80-30.90)
pH	8.21 ± 0.33	8.28 ± 0.36	8.07 ± 0.04
	(7.15-9.06)	(7.98-9.06)	(8.03-8.12)
Sal (PSU)	30.38 ± 1.98	30.55 ± 2.26	31.43 ± 2.51
	(25.0-35.0)	(25.0-36.0)	(28.00-34.00)

dolphins in Hong Kong waters showed different prey composition (Baird & Mounsouphom, 1997; Barros et al., 2002, 2004; Jefferson & Hung, 2004a, 2004b), suggesting different diet niches between the Indo-Pacific humpback dolphin and Indo-Pacific finless porpoise. With potentially different diet niches, these two cetacean species might concurrently inhabit overlapping regions as implied in this study.

Recommendations in Habitat Management and Protection

Precautionary habitat management and protection plans can be designed based on the largest MCP estimate that concurrently protects other marine species and maintains biodiversity integrity. The current boundaries of Ang Thong Marine National Park (www.angthongmarinepark.com/map-of-angthong-marine-park) do not include the MCPs of the Indo-Pacific humpback dolphin, Irrawaddy dolphin, or Indo-Pacific finless porpoise. Protection measures are few (Jutapruet et al., 2015) and are mainly restricted to commercial fishing in inshore waters. The overlap between anthropogenic activities and cetacean distribution can be quantified based on the core habitats (50% KDEs) of these three cetacean species. This quantification may help to guide regulations and mitigation efforts to cope with increasing anthropogenic activities. We propose here to revise the established marine national park boundaries or enact a new marine national park to cover the potential habitats of the Indo-Pacific humpback dolphin that has the widest MCP in this region.

Further restrictions on commercial fishing and coastline development may confer some benefits to these cetacean populations. For fishery activities, the number of vessels, zoning of fishing, and gill-netting regulations inside the core habitats should be revisited to avoid or minimize negative impacts on the cetaceans (Jutapruet et al., 2015). For the dolphin-watching tourism trade that offers routine visits to the core habitats, the number of vessels entering these habitats and the behavior of the vessels should be assessed to minimize the likely impact from spatial competition and behavioral disturbance on the targeted cetaceans. For ferries routinely passing through the core habitats, measures such as re-routing ferry lanes may need to be considered to minimize behavioral and acoustic disturbance (Pirotta et al., 2015). Finally, as the core habitats are all located near the coastline, large-scale coastal modification activities that permanently alter the structure and nature of the coast, such as land reclamation and embankment, should be avoided (Azevedo et al., 2007; Wedekin et al., 2010).

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