Marine Mammal Science

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ARTICLE

Preliminary Investigation of the Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) Around the Taiwan Strait

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ABSTRACT

The bottlenose dolphin is one of the most extensively distributed cetaceans, yet research in Asia, particularly in China, remains limited, leaving an information gap on the species' distribution and population abundance. From 2019 to 2022, surveys were conducted in the surrounding waters of the Nan Peng Archipelago waters, during which 14 groups of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) were recorded across 15 survey trips. A total of 205 marked individuals were cataloged through photo-identification. The likelihood of re-sighting individuals across years was low (3.41%), and the cumulative individual identification curve remains in the growth phase, indicating that many individuals are likely yet to be identified. Additionally, species distribution models (SDMs) were used to predict the potential distribution of bottlenose dolphins around the Taiwan Strait, and the results indicated that this region may be identified as a distributional hotspot of this species. Our study underscores the importance of the Taiwan Strait as a critical habitat for Indo-Pacific bottlenose dolphins.

1 | Introduction

Indo-Pacific bottlenose dolphin (*Tursiops aduncus*, hereafter the IPBD) are cosmopolitan animals found in tropical and temperate oceans around the world. They are also among the most thoroughly studied cetaceans, with extensive research in areas such as biology (Cockcroft et al. 1989; Cockcroft and Ross 1990), population genetics (Natoli et al. 2008), population ecology (Kogi et al. 2004), and behavior (Christiansen et al. 2010). In particular, long-term monitoring and research in Australia and Japan have uncovered numerous unique behaviors and intricate social networks within IPBD populations (Connor et al. 2019). However, the socio-ecology and living habits of bottlenose dolphins vary depending on the geographical location of their habitat, oceanic conditions, and human impact, making the knowledge gained from studying one area potentially unsuitable for describing populations in other regions (Fury and Harrison 2008) Moreover, research

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efforts to explore the ecological diversity and human-wildlife interaction in coastal cetaceans where data are deficient will help to fill the knowledge gaps regarding coastal biodiversity conservation.

IPBD inhabit a variety of marine environments, particularly in coastal regions such as shallow seas, lagoons, and estuaries (Fury and Harrison 2008). They have a discontinuous distribution in the Indian and Pacific Oceans. In the Indian Ocean, they are located at the southern tip of Africa and along the northern margins of the Indian Ocean, including the Red Sea, Arabian Gulf, and Indo-Malay Archipelago (Christiansen et al. 2010; Connor et al. 2019; Cribb et al. 2013; Fury and Harrison 2008; Stensland and Berggren 2007). On the western coast of the Pacific Ocean, the southern half of Japan and the northern coast of Australia are key habitats (Cribb et al. 2013; Fury et al. 2013; Mansur et al. 2012) Furthermore, records of IPBD occurrence have been documented along the coasts of both East and Southeast Asia. For instance, considerable populations are also found in the Philippines and along the coast of Bangladesh (Mansur et al. 2012; Tiongson and Karczmarski 2016). However, many key habitats for this species remain unexplored or have had only preliminary studies conducted. For example, one such region is the East China Sea, which forms a significant part of the western Pacific. Research on IPBD in the area dates back to the last century. Using molecular techniques, Wang et al. (1999) identified the IPBD as the dominant cetacean species in the Taiwan Strait. Previous line-transect surveys documented the nearshore distribution of IPBD (Yang et al. 1997), while opportunistic sightings reported by John and Yang (2009) indicate that discrete populations may also exist throughout the East China Sea. However, IPBD populations in this region have received little conservation awareness or research efforts, especially with regard to their population dynamics or conservation status. As a result, aside from sporadic reports of strandings and bycatch, critical information regarding their population size, distribution, and population structure remains largely unknown.

Compared with other marine species with greater accessibility, exploring migratory species in large-scale habitats poses significant challenges, due to the substantial logistical, financial, and technical support required (El-Gabbas et al. 2021). In recent years, conducting sampling surveys in small-scale areas and then extrapolating the findings to larger scales for such species has been used and proven efficient (Möller et al. 2006). Species Distribution Modeling (SDM), also referred to as habitat modeling, is a reliable and robust tool for this purpose (Cianfrani et al. 2018; Marcer et al. 2013). SDM is used to analyze the relationship between species distributions (e.g., occurrences) and environmental variables that influence habitat selection, and to predict the potential distribution of species in unexplored regions. Various algorithms are introduced for SDM, including the maximum entropy model (Maxent), artificial neural networks (ANN), and generalized linear models (GLM). However, the complex and often nonlinear relationships between species and environmental variables can result in different algorithms producing inconsistent predictions. To address this challenge, the use of ensemble modeling frameworks is recommended to generate more reliable and robust estimates of potential species distributions. Ensemble models can systematically evaluate and compare the performance of multiple SDMs and identify the most appropriate model for a given species-environment context, and are therefore regarded as the most effective approach (Dai et al. 2025; Li and Wang 2013). Consequently, ensemble modeling is gaining increasing traction (Breiner et al. 2015; Hao et al. 2020; Kindt 2018).

Sustained coastal surveys of cetacean populations in the Taiwan Strait region, with a primary focus on the Indo-Pacific humpback dolphin (*Sousa chinensis*) and the Indo-Pacific finless porpoise (*Neophocaena phocaenoides*), were carried out over the course of several years. During these surveys, we also opportunistically recorded the presence of IPBD. Building on this, a wider study to gather fundamental information on the population of IPBD in the Taiwan Strait was conducted, aiming to deepen scientific understanding of the species. Specifically, a 4-year marine survey of IPBD in Nan Peng Archipelago Waters (NPAW), as a subregion of the Taiwan Strait, was conducted with the following objectives:

1. to establish a photo-identification database for the local population to gather basic information such as abundance and distribution;
2. to develop a Species Distribution Model (SDM) to identify key influencing factors; and
3. to use the SDM to predict the potential distribution of IPDB in the Taiwan Strait.

2 | Materials and Methods

2.1 | Field Effort

This study forms part of the broader project "Coastal Cetacean Survey in the Taiwan Strait," which aims to carry out comprehensive surveys of cetacean species throughout the Taiwan Strait. However, due to constraints related to logistical, financial, and technical support, long-term monitoring efforts have been limited to a number of key regions, including the waters of Quanzhou, Xiamen, Zhangzhou, and NPAW (Table S1, Figure 1). Among these, NPAW represents the focal area of the present study. Vessel-based line-transect surveys targeting Indo-Pacific bottlenose dolphins (IPBD) were conducted in NPAW, covering an area of 112.85 km^2 (Figure 1). The region is frequently affected by tropical cyclones and coastal winds, resulting in generally poor sea conditions throughout the year (Ding 1992; Lin et al. 2012; Zhao et al. 2009). Favorable observation conditions—defined as wind speeds below 6 km/h, sea state ≤ 2 in the Beaufort scale and visibility ≥ 1 km, are typically only present during the warm season (April–July). Consequently, no fewer than three complete field surveys were conducted each year from 2019 to 2022 during the favorable observation conditions of the warm season: June 2019, April and July 2020, May 2021, and June 2022 (Table 1, Figure S1).

Field surveys were conducted using a 9-m speedboat powered by a 160 HP outboard engine. At least two observers, using the naked eye or 7×50 handheld binoculars, searched for dolphins (Mansur et al. 2012). Upon spotting dolphins, their

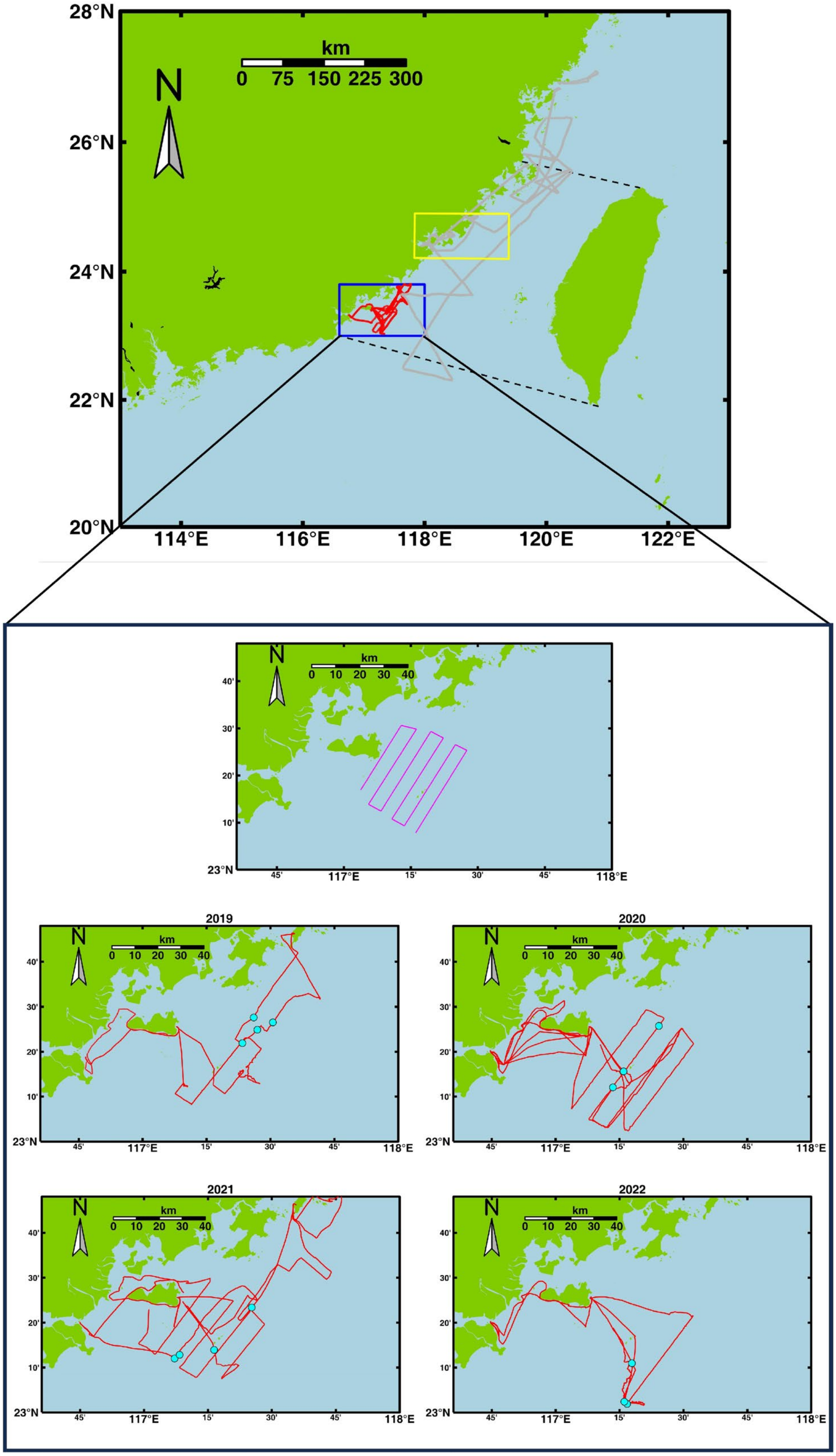

FIGURE 1 | Map of the research area. The upper panel shows the Taiwan Strait, outlined with dashed lines. Within this, long-term monitoring areas are marked by rectangular boxes: NPAW in blue, and Quanzhou, Xiamen, and Zhangzhou waters in yellow. Survey tracks represent field effort throughout the Taiwan Strait, with those inside NPAW specifically highlighted in red. The lower panel zooms into the NPAW subregion. It presents the line-transect survey design in a separate inset, and illustrates field survey efforts by year, with cyan points indicating IPBD encounter locations.

TABLE 1 | A summary of marine surveys conducted in the Nan Peng Archipelago Waters (NPAW) region.

Year	Date	Group number	Identifiable individuals
2019	June 5	—	—
2019	June 6	4	41
2019	June 7	—	—
2020	April 16	1	8
2020	April 17	—	—
2020	April 18	—	—
2020	July 21	2	38
2020	July 22	—	—
2021	May 14	2	42
2021	May 15	1	38
2021	May 16	1	6
2021	May 17	—	—
2022	June 26	2	20
2022	June 27	1	12
2022	June 28	—	—

Note: The symbol "—" denotes unavailable data.

location was recorded with GPS (Garmin 63sc). Once the boat approached the dolphins, efforts were made to photograph both sides of each individual's dorsal fin and intentionally observe the dolphins' bellies to identify the species (Haughey et al. 2021; Mansur et al. 2012). All photographs were taken with digital SLR cameras (Canon 1DX Mark II) equipped with 100–400 mm lens.

2.2 | Photo Identification Analysis

The photo identification of bottlenose dolphins depends on matching unique features of their dorsal fins, such as notches and nicks on the trailing and leading edges, as well as the fin tip (Kogi et al. 2004; Mansur et al. 2012; Reisinger and Karczmarski 2010). The method described by Reisinger and Karczmarski (2010) for photograph processing were adopted: Adobe Lightroom Classic 13.1 is used to assess the photographic quality, by evaluating factors like the focus of the dorsal fin, exposure, contrast of the dorsal fin against the water, the angle of the dorsal fin relative to the photo frame, and the visible portion of the fin. Photos were graded as excellent, average, or poor. Only those graded as excellent—defined by being fully focused, free from glare, having good contrast, an angle of less than 10°, and a fin ratio greater than 80%—are included in the analysis, while average and poor-quality photos are discarded. Photos are systematically cross-checked to create a master catalog of marked individuals and to determine the number of resightings. Individuals that do not match previously recorded animals are assigned a unique identification number and added to the catalog.

2.3 | Build Models

2.3.1 | Presence–Absence Data

To ensure data independence, only the initial encounter locations with IPBD groups were included in the analysis as presence data, totaling 14 presence points. The available data reflect only the presence of the species. An increasing number of studies have demonstrated that including information on species absence can significantly enhance model performance (El-Gabbas et al. 2021), even when using inferred absence data, also known as pseudo-absence (Haughey et al. 2021; Hunt et al. 2007). Therefore, this study also generated pseudo-absence data to enhance model performance.

To ensure that pseudo-absences approximate true absence, pseudo-absence points were sampled from long-term monitoring areas rather than selected through completely random sampling. Long-term monitoring areas were defined as regions with more than three independent survey events, including the Quanzhou Waters, Xiamen Waters, Zhangzhou Waters, and the NPAW (Table 1, Figure 1). Fifty pseudo-absence points were placed at intervals greater than 0.1° to minimize spatial sampling bias. What is more, we generated the same number of pseudo-presence points, resulting in equal weighting for modeling. This sampling strategy has demonstrated strong performance in SDM algorithms (Haughey et al. 2021).

2.3.2 | Environmental Data

Initially, 18 environmental variables were identified as potential predictors (Table 2), based on the physical and ecological characteristics of the Taiwan Strait and with reference to previous SDM studies on marine mammals (Beaumont et al. 2016; Hao et al. 2019; Haughey et al. 2021). All variables, except offshore distance—which was calculated as the Euclidean distance from each point to the nearest coastline—were obtained from the Global Ocean Reanalysis product GLORYS2V4 (CMEMS 2023) and the European Space Agency Ocean Color Dataset (ESAOC; Sathyendranath et al. 2021). For each variable, the mean value during the warm season (April–July) over the period 2019–2022 was computed to align with the survey period and reduce the influence of seasonal variability. To mitigate the negative effects of predictor collinearity and model over-parameterization, employed a correlation coefficient matrix was employed to select a subset of variables: when the Pearson correlation coefficient between two variables exceeded 0.80, the variable with greater ecological relevance was retained.

2.3.3 | Model Sets

To model the distribution of IPBD using the selected environmental predictors, we employed an ensemble modeling framework implemented via the BioMod2 package in RStudio (Thuiller et al. 2009). BioMod2 offers more than 10 modeling algorithms, from which seven presence–absence approaches were selected: Artificial Neural Network (ANN), Classification Tree Analysis (CTA), Flexible Discriminant Analysis (FDA), Generalized Linear Model (GLM), Multiple Adaptive Regression Splines

TABLE 2 | Environmental variables.

Code	Name	Unit	Type	Retained or not	Source
distance	Offshore distance	km	Physical	Yes	Calculation
so	Sea water salinity	10^{-3}	Physical	Not	GLORYS2V4
thetao	Sea water potential temperature	°C	Physical	Yes	GLORYS2V4
uo	Eastward sea water velocity	m/s	Physical	Not	GLORYS2V4
vo	Northward sea water velocity	m/s	Physical	Not	GLORYS2V4
mlotst	Ocean mixed layer thickness defined	m	Physical	Not	GLORYS2V4
depth	Sea water depth	m	Physical	Not	ESAOC
adg_665	Volume absorption coefficient of radiative flux	m^{-1}	Physical	Yes	ESAOC
kd_490	Volume attenuation coefficient of radiative flux	m^{-1}	Physical	Not	ESAOC
chl	Mass concentration of chlorophyll a in sea water	mg/m^3	Ecological	Yes	GLORYS2V4
fe	Mole concentration of dissolved iron in sea water	$mmol/m^3$	Ecological	Yes	GLORYS2V4
no3	Mole concentration of nitrate in sea water	$mmol/m^3$	Ecological	Yes	GLORYS2V4
nppv	Net primary production of biomass expressed as carbon per unit volume in sea water	$mg/m^3/day$	Ecological	Yes	GLORYS2V4
o2	Mole concentration of dissolved molecular oxygen in sea water	$mmol/m^3$	Ecological	No	GLORYS2V4
ph	Sea water pH reported on total scale	1	Ecological	Not	GLORYS2V4
po4	Mole concentration of phosphate in sea water	$mmol/m^3$	Ecological	Yes	GLORYS2V4
si	Mole concentration of silicate in sea water	$mmol/m^3$	Ecological	Not	GLORYS2V4
spco2	Surface partial pressure of carbon dioxide in sea water	Pa	Ecological	Not	GLORYS2V4

Note: List of environmental variables, which contains abbreviations, full names, units, type, source and indications of whether the variables were included in the final modeling.

TABLE 3 | Summary of selected algorithms.

Name	Abbreviation	Classes	References
Generalized linear models	GLM	Regression	(McCullagh 1984)
Multivariate adaptive regression splines	MARS	Regression	(Friedman 1991)
Classification tree analysis	CTA	Classification	(Breiman et al. 2017)
Flexible discriminant analysis	FDA	Classification	(Hastie et al. 1994)
Artificial neural networks	ANN	Machine Learning	(Ripley 2007)
Random forests	RF	Machine Learning	(Breiman 2001)
Surface Range Envelop	SRE	Regression	(Busby 1991)

(MARS), Random Forest (RF), and Surface Range Envelope (SRE). These algorithms were chosen for their demonstrated predictive performance, robustness, and methodological diversity, encompassing regression-based, classification-based, and machine learning approaches (Table 3) (Haughey et al. 2021; Srivastava et al. 2019).

Each model was run twice using the bootstrapping method, with 80% of the presence-absence data used for training and 20% for testing. True skill statistic (TSS) and relative operating characteristic (ROC) were then used as filters to retain only those models with good performance (TSS ≥ 0.7 and ROC ≥ 0.9) for the final ensemble modeling. The importance of explanatory variables was calculated using the 10 permutation runs randomization procedure in BioMod2 (Thuiller et al. 2009).

The model was used to predict the Habitat Suitability Index (HSI) for PBD in the Taiwan Strait and surrounding regions based on environmental parameters. The HSI ranges from 0 to 1, with values above 0.3 generally indicating suitable habitats and values above 0.7 indicating highly suitable habitats. All data processing and analysis in this study were conducted using Matlab and R, with the biomod2 package in R playing a crucial role in constructing the ensemble models.

3 | Results

3.1 | Marked Dolphin Number

During the 4-year study, a total of 15 boat-based surveys of IPBD were completed, covering 2246.36 km and accumulating over 102 h of observation. IPBD were detected in more than half of the surveys (8 trips), collecting more than 20,000 photographs of IPBD. The dolphins encountered were identified as *Tursiops aduncus* (i.e., IPBD) based on distinct abdominal spotting (Figure 2). The dolphin groups were generally large, ranging from 5 to 100 individuals; most individuals lacked distinct identification features, and high-quality identification photos taken per encounter rarely exceeded two per marked individual. Consequently, the photographic identification coverage of groups was low, capturing only 15%–70% of the estimated group size. A total of 205 marked dolphins were recorded, with the discovery curve (Figure 3a) showing a rising trend in newly identified individuals, and only 7 individuals were resighted at different years (Figure 3b).

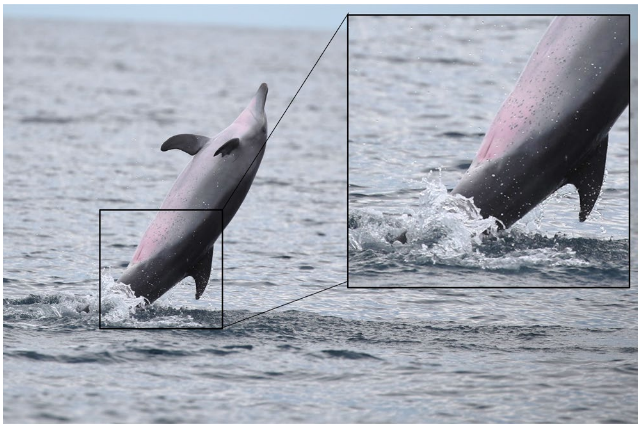

FIGURE 2 | The Indo-Pacific bottlenose dolphin in the Taiwan Strait, showing special ventral spots around the genital area of the species. Photo credit: Fuxing Wu (the corresponding author of this paper).

3.2 | Habitat

IPBD's distribution was pre-modeled using 7 different algorithms, all with identical parameters. The results of candidate models indicated that SRE performed poorly, while the remaining algorithms performed well (Figure 4). Poorly performing algorithms were excluded from the ensemble. The final model demonstrated strong predictive performance (ROC = 0.977, TSS = 0.964), with the TSS in particular exceeding that of all individual SDMs, making it well-suited for assessing habitat suitability of IPBD.

Eight environmental variables (Table 2) were retained for SDM. The final model identified offshore distance (0.63) and adg_655 (0.10) as the two most influential variables driving the distribution of IPBD. Areas more than 17 km offshore with adg_655 values below 0.003 were identified as potential habitats for IPBD (Figure 5). According to the results, under current environmental conditions, the potential habitat of IPBD is estimated to cover 45.97% of the Taiwan Strait and surrounding regions. Notably, areas of high habitat suitability (HIS > 0.7) form a continuous distribution throughout the Taiwan Strait (Figure 6), suggesting that this region may be identified as a distributional hotspot of this species.

4 | Discussion

4.1 | Current Condition of IPBD

The population of IPBD in Chinese waters is promising, with the number of identified individuals comparable to some key IPBD habitats, such as 136–179 individuals in Zanzibar,

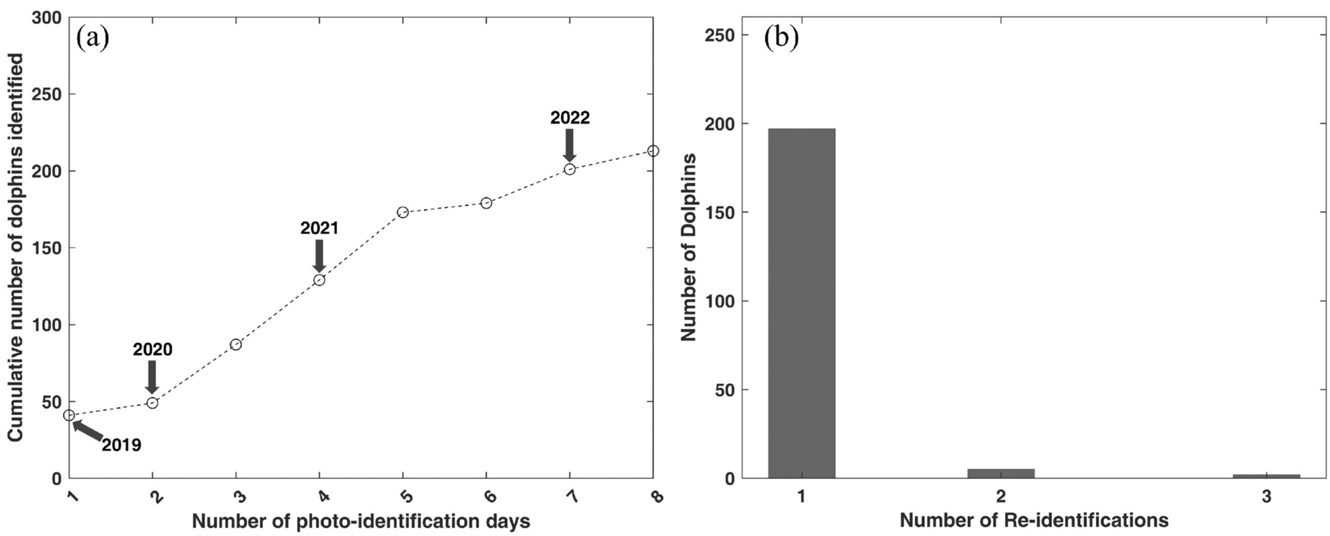

FIGURE 3 | 2019–2022 IPBD survey statistics: (a) indicates the sighting frequency distribution of IPBD, the arrows suggests the survey year; (b) indicates the cumulative curve of identified individuals of IPBD.

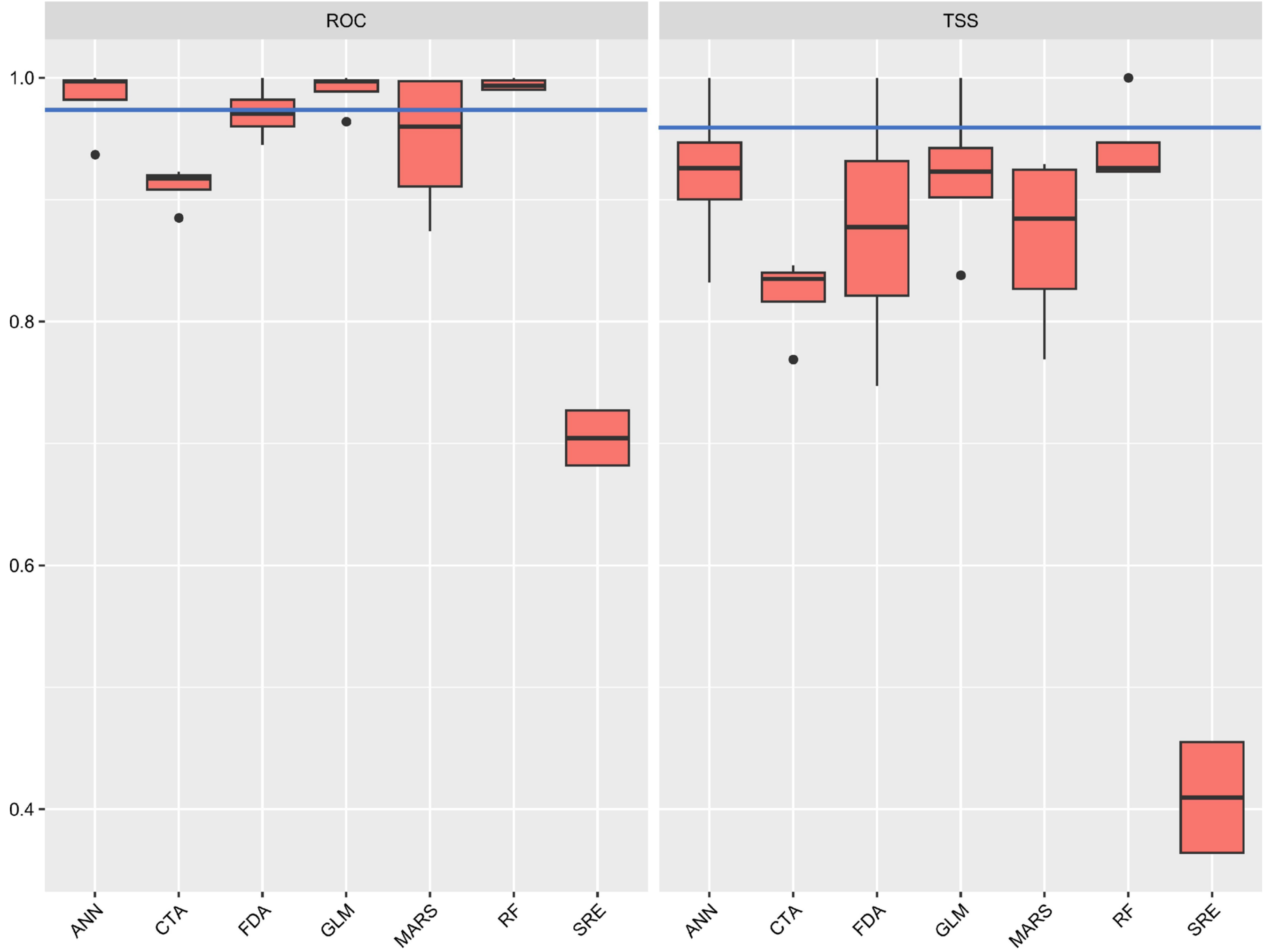

FIGURE 4 | Boxplot of candidate models performance. The blue line indicates the performance of the ensemble model.

Tanzania (Stensland et al. 2006), and 218 in western Kyushu, Japan (Shirakihara et al. 2002). Despite our 4-year marine survey, the increasing (non-asymptotic) discovery curve (Figure 2) indicates that our field efforts were insufficient to identify all or most of the individuals using the area. Unlike closed IPBD populations in estuaries and bays (Cribb et al. 2013; Haughey et al. 2021; Mansur et al. 2012), the bottlenose dolphin population in our survey area is open, allowing individuals to freely leave and enter. This led to the continued observation of new individuals throughout the study period. The large number of identified individuals, the low resighting rate (3.41%), and the large proportion of individuals seen only once (96.59%) suggest that the dolphins observed in this area are part of a much larger, widely distributed population. This pattern is similar to the IPBD populations along the South African coast (Christiansen et al. 2010; Reisinger and Karczmarski 2010). Larger survey efforts over a longer period and across a broader spatial scale may eventually result in an asymptotic discovery curve, but such research may need to continue for several more years. Even then, many dolphins lack distinct identification features, which could make it impossible for the discovery curve to fully reach an asymptote.

4.2 | Potential Drivers of Coastal Dolphin Distribution

The ensemble model results suggest that the distribution of IPBD in Chinese waters is mainly driven by offshore distance and water turbidity (i.e., adg_655): dolphins are rarely found within 10 km of the shore, and areas with high turbidity are unsuitable for their survival. Overall, the East China Sea is potential habitats for IPBD, with high-probability occurrence areas overlapping with the Taiwan Strait. Previous reports indicate that the majority of recorded dolphin strandings and bycatch incidents in East China Sea waters occur in the Taiwan Strait, aligning with the findings of this study (Wang et al. 2000). However, despite extensive survey efforts across the Taiwan Strait, detections of IPBD were limited to the NPAW, resulting in a relatively small number of informative samples. Models based on small sample sizes have been reported to carry significant risks, including reduced reliability in identifying key environmental variables that influence distribution patterns and generating inaccurate estimates of species response curves (Moudrý et al. 2024). This limitation also constrains the capacity to conduct more in-depth exploratory analyses. For instance, the small sample size necessitated

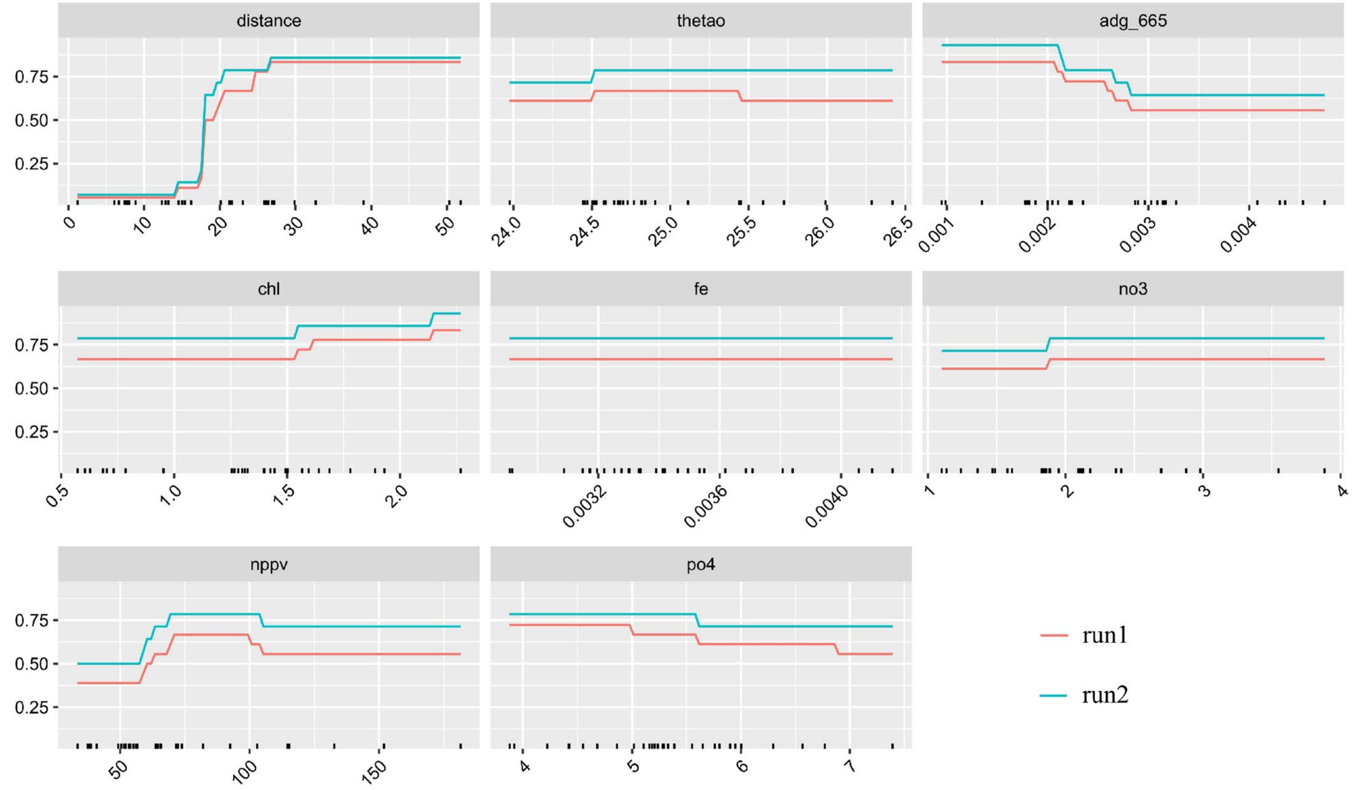

FIGURE 5 | Response curves of environmental factors for IPBD in the ensemble model.

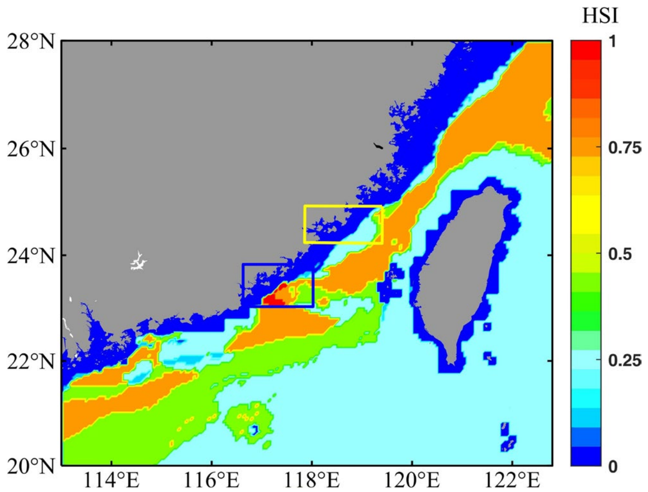

FIGURE 6 | Potential suitable habitat for IPBD in the Taiwan Strait and surrounding regions. Rectangular boxes highlight the long-term monitoring areas: NPAW is shown in blue, and the Quanzhou, Xiamen, and Zhangzhou waters are shown in yellow.

the aggregation of seasonal data across multiple years, which makes it difficult to capture interannual variation in species distribution. Moreover, the model does not incorporate data on individual-level characteristics (e.g., sex and age) or behavioral factors that may influence IPBD distribution. In future work, we plan to conduct targeted field surveys in areas predicted to exhibit high habitat suitability (Figure 6) to identify additional IPBD habitats. Increasing the frequency of surveys and collecting more comprehensive ecological and demographic data are also prioritized in future research efforts.

Prey availability is a key factor influencing dolphin distribution and habitat use (Heithaus and Dill 2006; Wirsing et al. 2008). The Taiwan Strait is significantly influenced by local ocean currents, where the northward warm, saline current meets the southward cold, freshwater flow (Ding 1992). This convergence leads to ample sunlight and abundant nutrients, such as nitrates and phosphates, in the upper water layers, which support photosynthesis and promote phytoplankton growth, enhancing regional productivity (Chu et al. 2005; Jian et al. 2015). These oceanographic processes may affect the aggregation or distribution of key prey species for IPBD, thereby influencing dolphin distribution patterns.

Additionally, space and resource competition may influence habitat use. Habitat overlap among cetaceans in coastal areas is common. For example, in a large-scale SDM study by Hanf (2015), the coastal waters off the northwest coast of Western Australia were identified as highly suitable overlapping habitats for Australian humpback dolphins (*Sousa sahulensis*) and IPDB. In Bangladesh's SoNG region, Bryde's whales (*B. brydei/edeni*), IPBD, spinner dolphins (*Stenella longirostris*), and pantropical spotted dolphins (*Stenella attenuata*) are often observed together (Mansur et al. 2012). During our marine surveys, Indo-Pacific humpback dolphins (*Sousa chinensis*) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) were also observed (Wu, personal observation).[1] Based on their distribution patterns relative to the coastline—Indo-Pacific humpback dolphins being closest to shore, followed by Indo-Pacific finless porpoises, and IPBD the farthest—it is possible that spatial and resource competition may limit the distribution of IPDB in our study area. However, definitive conclusions cannot be drawn, as the phenomenon of mixed dolphin groups and interspecies interactions is a complex and ongoing research topic that is beyond the scope of our study.

FIGURE 7 | Photos of some dolphin dorsal fins reveal noticeable wounds.

4.3 | Conservation and Management

The Taiwan Strait is home to a significant population of IPBD. Recently, the International Union for Conservation of Nature (IUCN) has re-listed the IPBD as a Near Threatened species (Braulik et al. 2019): interactions with fisheries pose a threat to the long-term survival of this population, similar to the challenges faced by Ganges river dolphins (*Platanista gangetica gangetica*) in Bangladesh (Smith et al. 2001) and IPBD in Australia (Bejder et al. 2012). The overlap between fishing operations and dolphin habitats significantly increases the risk of injury to dolphins. In this study, several dolphins identified through photos showed scars or wounds—such as notches on the trailing edge or tip of their dorsal fins—that may be related to entanglement with fishing gear (Figure 7). While direct entanglement was not observed, dolphins were frequently seen feeding near gillnets, which are likely responsible for many of the injuries these animals sustain.

Estimating bycatch in gillnet fisheries is highly challenging. Given that the Indo-Pacific bottlenose dolphin population may be among the largest in the eastern Indian Ocean and western Pacific, further research and targeted conservation efforts are essential. Future studies should include onboard observations to gather reliable data on the nature and extent of gillnet-related mortality and conduct more detailed analyses of scars and injuries visible on dolphins (Peddemors 1999; Reisinger and Karczmarski 2010). These research efforts should also be expanded to larger marine areas, especially in highly suitable habitats predicted by the ensemble model, to ensure that the conservation needs of the entire population are adequately addressed.

Author Contributions

Fuxing Wu: conceptualization, data curation, funding acquisition, investigation, project administration, resources, software, supervision, validation, visualization, writing – review and editing. **Fanyi Meng:** data curation, methodology, formal analysis, writing – original draft, writing – review and editing. **Ruiqiang Zheng:** data curation, formal analysis, investigation, writing – review and editing. **Yupeng Li:** writing – review and editing, formal analysis. **Yuli Wei:** writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

[1] The corresponding author of this paper.

References

Beaumont, L. J., E. Graham, D. E. Duursma, et al. 2016. “Which Species Distribution Models Are More (Or Less) Likely to Project Broad-Scale, Climate-Induced Shifts in Species Ranges?” *Ecological Modelling* 342: 135–146. https://doi.org/10.1016/j.ecolmodel.2016.10.004.

Bejder, L., A. Hodgson, N. Loneragan, and S. Allen. 2012. “Coastal Dolphins in North-Western Australia: The Need for Re-Evaluation of Species Listings and Short-Comings in the Environmental Impact Assessment Process.” *Pacific Conservation Biology* 18: 22–25.

Braulik, G., A. Natoli, J. J. Kiszka, G. J. Parra, S. Plön, and B. D. Smith. 2019. *Tursiops aduncus. The International Union for the Conservation of Nature*. IUCN.

Breiman, L. 2001. “Random Forests.” *Machine Learning* 45: 5–32.

Breiman, L., J. Friedman, R. A. Olshen, and C. J. Stone. 2017. *Classification and Regression Trees*. Routledge.

Breiner, F. T., A. Guisan, A. Bergamini, and M. P. Nobis. 2015. “Overcoming Limitations of Modelling Rare Species by Using Ensembles of Small Models.” *Methods in Ecology and Evolution* 6: 1210–1218.

Busby, J. R. 1991. “BIOCLIM—A Bioclimate Analysis and Prediction System.”

Christiansen, F., D. Lusseau, E. Stensland, and P. Berggren. 2010. “Effects of Tourist Boats on the Behaviour of Indo-Pacific Bottlenose Dolphins Off the South Coast of Zanzibar.” *Endangered Species Research* 11: 91–99. https://doi.org/10.3354/esr00265.

Chu, P., C. Yuchun, and A. Kuninaka. 2005. “Seasonal Variability of the Yellow Sea/East China Sea Surface Fluxes and Thermohaline Structure.” *Advances in Atmospheric Sciences* 22: 1–20.

Cianfrani, C., O. Broennimann, A. Loy, and A. Guisan. 2018. “More Than Range Exposure: Global Otter Vulnerability to Climate Change.” *Biological Conservation* 221: 103–113.

CMEMS. 2023. “Global Ocean Physics Reanalysis.” https://doi.org/10.48670/moi-00021.

Cockcroft, V. G., A. C. D. Kock, D. A. Lord, and G. J. B. Ross. 1989. “Organochlorines in Bottlenose Dolphins *Tursiops truncatus* From the East Coast of South Africa.” *South African Journal of Marine Science* 8, no. 1: 207–217. https://doi.org/10.2989/02577618909504562.

Cockcroft, V. G., and G. J. B. Ross. 1990. “15—Food and Feeding of the Indian Ocean Bottlenose Dolphin Off Southern Natal, South Africa.” In *The Bottlenose Dolphin*, edited by S. Leatherwood and R. R. Reeves, 295–308. Academic Press. https://doi.org/10.1016/B978-0-12-440280-5.50019-6.

Connor, R. C., M. Sakai, T. Morisaka, and S. J. Allen. 2019. “The Indo-Pacific Bottlenose Dolphin (*Tursiops aduncus*).” In *Ethology and Behavioral Ecology of Odontocetes*, edited by B. Würsig, 345–368. Springer International Publishing. https://doi.org/10.1007/978-3-030-16663-2_16.

Cribb, N., C. Miller, and L. Seuront. 2013. “Indo-Pacific Bottlenose Dolphin (*Tursiops aduncus*) Habitat Preference in a Heterogeneous, Urban, Coastal Environment.” *Aquatic Biosystems* 9: 1–9. https://doi.org/10.1186/2046-9063-9-3.

Dai, Y., F. Meng, F. Wu, et al. 2025. “Predicting the Potential Distribution of Major Marine Mammals in the Cosmonaut Sea.” *Frontiers in Marine Science* 12. https://doi.org/10.3389/fmars.2025.1529913.

Ding, Q. 1992. “Analysis and Forecast of Storm Surges at Shantou Port.” *Marine Bulletin* 1: 18–22.

El-Gabbas, A., I. Van Opzeeland, E. Burkhardt, and O. Boebel. 2021. “Dynamic Species Distribution Models in the Marine Realm: Predicting Year-Round Habitat Suitability of Baleen Whales in the Southern Ocean.” *Frontiers in Marine Science* 8. https://doi.org/10.3389/fmars.2021.802276.

Friedman, J. H. 1991. “Multivariate Adaptive Regression Splines.” *Annals of Statistics* 19: 1–67. https://doi.org/10.1214/aos/1176347963.

Fury, C. A., and P. L. Harrison. 2008. “Abundance, Site Fidelity and Range Patterns of Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) in Two Australian Subtropical Estuaries.” *Marine and Freshwater Research* 59: 1015–1027. https://doi.org/10.1071/MF08109.

Fury, C. A., K. E. Ruckstuhl, and P. L. Harrison. 2013. “Spatial and Social Sexual Segregation Patterns in Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*).” *PLoS One* 8: e52987. https://doi.org/10.1371/journal.pone.0052987.

Hanf, D. 2015. “Species Distribution Modelling of Western Pilbara Inshore Dolphins.” PhD thesis, Murdoch University Dubai.

Hao, T., J. Elith, G. Guillera-Arroita, and J. J. Lahoz-Monfort. 2019. “A Review of Evidence About Use and Performance of Species Distribution Modelling Ensembles Like BIOMOD.” *Diversity and Distributions* 25: 839–852. https://doi.org/10.1111/ddi.12892.

Hao, T., J. Elith, J. J. Lahoz-Monfort, and G. Guillera-Arroita. 2020. “Testing Whether Ensemble Modelling Is Advantageous for Maximising Predictive Performance of Species Distribution Models.” *Ecography* 43: 549–558.

Hastie, T., R. Tibshirani, and A. Buja. 1994. “Flexible Discriminant Analysis by Optimal Scoring.” *Journal of the American Statistical Association* 89: 1255–1270.

Haughey, R., T. N. Hunt, D. Hanf, C. Passadore, R. Baring, and G. J. Parra. 2021. “Distribution and Habitat Preferences of Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) Inhabiting Coastal Waters With Mixed Levels of Protection.” *Frontiers in Marine Science* 8. https://doi.org/10.3389/fmars.2021.617518.

Heithaus, M. R., and L. M. Dill. 2006. “Does Tiger Shark Predation Risk Influence Foraging Habitat Use by Bottlenose Dolphins at Multiple Spatial Scales?” *Oikos* 114: 257–264. https://doi.org/10.1111/j.2006.0030-1299.14443.x.

Hunt, B., E. Pakhomov, and B. Trotsenko. 2007. “The Macrozooplankton of the Cosmonaut Sea, East Antarctica (30 E–60 E), 1987–1990.” *Deep Sea Research, Part I: Oceanographic Research Papers* 54: 1042–1069.

Jian, C., Z. Yu, X. Zhaoli, and C. Jiajie. 2015. “Comparison of the Community Structure of Zooplankton Between Minjiang River Estuary and Jiaojiang River Estuary During Summer.” *Marine Science Journal* 37: 111–119.

John, Y. W., and S. C. Yang. 2009. “Indo-Pacific Bottlenose Dolphin: *Tursiops aduncus*.” In *Encyclopedia of Marine Mammals*, edited by W. F. Perrin, B. Würsig, and J. G. M. Thewissen, Second ed., 602–608. Academic Press. https://doi.org/10.1016/B978-0-12-373553-9.00141-3.

Kindt, R. 2018. “Ensemble Species Distribution Modelling With Transformed Suitability Values.” *Environmental Modelling & Software* 100: 136–145.

Kogi, K., T. Hishii, A. Imamura, T. Iwatani, and K. M. Dudzinski. 2004. “Demographic Parameters of Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) Around Mikura Island, Japan.” *Marine Mammal Science* 20: 510–526. https://doi.org/10.1111/j.1748-7692.2004.tb01176.x.

Li, X., and Y. Wang. 2013. “Applying Various Algorithms for Species Distribution Modelling.” *Integrative Zoology* 8: 124–135. https://doi.org/10.1111/1749-4877.12000.

Lin, J., W. Huang, and C. Ke. 2012. “Analysis of Tropical Cyclone Characteristics Along the Coast of Shantou.” *Marine Environmental Science* 31: 225–228.

Mansur, R. M., S. Strindberg, and B. D. Smith. 2012. “Mark-Resight Abundance and Survival Estimation of Indo-Pacific Bottlenose Dolphins, *Tursiops aduncus*, in the Swatch-of-No-Ground, Bangladesh.” *Marine Mammal Science* 28: 561–578. https://doi.org/10.1111/j.1748-7692.2011.00520.x.

Marcer, A., L. Sáez, R. Molowny-Horas, X. Pons, and J. Pino. 2013. "Using Species Distribution Modelling to Disentangle Realised Versus Potential Distributions for Rare Species Conservation." *Biological Conservation* 166: 221–230.

McCullagh, P. 1984. "Generalized Linear Models." *European Journal of Operational Research* 16: 285–292. https://doi.org/10.1016/0377-2217(84)90282-0.

Möller, L. M., L. B. Beheregaray, S. J. Allen, and R. G. Harcourt. 2006. "Association Patterns and Kinship in Female Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) of Southeastern Australia." *Behavioral Ecology and Sociobiology* 61: 109–117. https://doi.org/10.1007/s00265-006-0241-x.

Moudrý, V., M. Bazzichetto, R. Remelgado, et al. 2024. "Optimising Occurrence Data in Species Distribution Models: Sample Size, Positional Uncertainty, and Sampling Bias Matter." *Ecography* 2024: e07294. https://doi.org/10.1111/ecog.07294.

Natoli, A., V. M. Peddemors, and A. R. Hoelzel. 2008. "Population Structure of Bottlenose Dolphins (*Tursiops aduncus*) Impacted by Bycatch Along the East Coast of South Africa." *Conservation Genetics* 9: 627–636. https://doi.org/10.1007/s10592-007-9379-y.

Peddemors, V. M. 1999. "Delphinids of Southern Africa: A Review of Their Distribution, Status and Life History." *Journal of Cetacean Research and Management* 1: 157–165. https://doi.org/10.47536/jcrm.v1i2.463.

Reisinger, R. R., and L. Karczmarski. 2010. "Population Size Estimate of Indo-Pacific Bottlenose Dolphins in the Algoa Bay Region, South Africa." *Marine Mammal Science* 26: 86–97. https://doi.org/10.1111/j.1748-7692.2009.00324.x.

Ripley, B. D. 2007. *Pattern Recognition and Neural Networks*. Cambridge university Press.

Sathyendranath, S., T. Jackson, C. Brockmann, et al. 2021. *ESA Ocean Colour Climate Change Initiative (Ocean_Colour_Cci): Version 5.0 Data*. NERC EDS Centre for Environmental Data Analysis. https://doi.org/10.5285/1dbe7a109c0244aaad713e078fd3059a.

Shirakihara, M., K. Shirakihara, J. Tomonaga, and M. Takatsuki. 2002. "A Resident Population of Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) in Amakusa, Western Kyushu, Japan." *Marine Mammal Science* 18: 30–41.

Smith, B. D., B. Ahmed, M. E. Ali, and G. Braulik. 2001. "Status of the Ganges River Dolphin or Shushuk *Platanista gangetica* in Kaptai Lake and the Southern Rivers of Bangladesh." *Oryx* 35: 61–72.

Srivastava, V., V. Lafond, and V. C. Griess. 2019. "Species Distribution Models (SDM): Applications, Benefits and Challenges in Invasive Species Management." *CABI Reviews*, ahead of print, April 24, 1–13. https://doi.org/10.1079/PAVSNNR201914020.

Stensland, E., and P. Berggren. 2007. "Behavioural Changes in Female Indo-Pacific Bottlenose Dolphins in Response to Boat-Based Tourism." *Marine Ecology Progress Series* 332: 225–234. https://doi.org/10.3354/meps332225.

Stensland, E., I. Carlén, A. Särnblad, A. Bignert, and P. Berggren. 2006. "Population Size, Distribution, and Behavior of Indo-Pacific Bottlenose (*Tursiops aduncus*) and Humpback (*Sousa chinensis*) Dolphins Off the South Coast of Zanzibar." *Marine Mammal Science* 22: 667–682.

Thuiller, W., B. Lafourcade, R. Engler, and M. B. Araújo. 2009. "BIOMOD—A Platform for Ensemble Forecasting of Species Distributions." *Ecography* 32: 369–373. https://doi.org/10.1111/j.1600-0587.2008.05742.x.

Tiongson, A. J. C., and L. Karczmarski. 2016. "The Indo-Pacific Bottlenose Dolphin (*Tursiops aduncus*) in Tañon Strait, Central Philippines." *Marine Biodiversity Records* 9: 85. https://doi.org/10.1186/s41200-016-0088-4.

Wang, J. Y., L.-S. Chou, and B. N. White. 1999. "Mitochondrial DNA Analysis of Sympatric Morphotypes of Bottlenose Dolphins (Genus: *Tursiops*) in Chinese Waters." *Molecular Ecology* 8: 1603–1612. https://doi.org/10.1046/j.1365-294x.1999.00741.x.

Wang, J. Y., L.-S. Chou, and B. N. White. 2000. "Osteological Differences Between Two Sympatric Forms of Bottlenose Dolphins (*Genus tursiops*) in Chinese Waters." *Journal of Zoology* 252: 147–162. https://doi.org/10.1111/j.1469-7998.2000.tb00611.x.

Wirsing, A. J., M. R. Heithaus, A. Frid, and L. M. Dill. 2008. "Seascapes of Fear: Evaluating Sublethal Predator Effects Experienced and Generated by Marine Mammals." *Marine Mammal Science* 24: 1–15. https://doi.org/10.1111/j.1748-7692.2007.00167.x.

Yang, G., K. Zhou, H. Katou, and T. Miyashita. 1997. "Preliminary Study on the Population Size and Distribution of Bottlenose Dolphins in the East China Sea." *Journal of Mammalogy* 4: 2–8. https://doi.org/10.16829/j.slxb.1997.04.001.

Zhao, X., F. Yang, N. Guo, X. Li, and P. Song. 2009. "Analysis of the Impact of Hydrometeorological and Seawater Physicochemical Factors on the February 2007 Red Tide Event in Shantou." *Marine Forecasting* 26: 43–51.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.