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Suitable habitat predition for the Indo-Pacific Humpback Dolphin in Guangdong, China

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Abstract. Two world's largest Indo-Pacific humpback dolphin (*Sousa chinensis*) populations are both in Guangdong province, China, but its suitable habitat there has not been evaluated. We used MaxEnt to predict the suitable habitat of humpback dolphins in Guangdong based on environmental variables and sighting data. A total of 5,545.9 km² of suitable habitat (probability ≥0.5) was estimated to be available for humpback dolphins, mainly occurring in waters of the Pearl River estuary (the Pearl River Estuary and west, Hengqin Island-Chuanshan Islands-Mausoleum Island, approximately 3,637.6 km²), waters near Zhanjiang (Leizhou Bay, Zhanjiang Port, and Jianjiang Estuary, approximately 1,852.7 km²), and those near Chaozhou-Shantou (waters near Guang'ao Bay and Nan'ao Island, approximately 55.6 km²). Currently, only 8.89% of the suitable habitat for Indo-Pacific humpback dolphins is under protection. Therefore, we propose extending the range of current nature reserves and establishing new nature reserves in the suitable habitat area.

Key words: chlorophyll a, habitat prediction, MaxEnt, *Sousa chinensis*, suitable habitat.

Indo-Pacific humpback dolphin (*Sousa chinensis*) is widely distributed in coastal and inshore waters of the Indian and western Pacific oceans (Jefferson & Karczmarski 2001). The humpback dolphins mainly occur in south-eastern coastal waters from the Yangtze River Estuary to Beibu Gulf, China (Jefferson 2000, Jefferson & Karczmarski 2001, Jefferson & Hung 2004, Wang et al. 2004, Wang & Han 2007, Zhou et al. 2007). The world's largest and second largest populations reside, respectively, in waters of the Pearl River Estuary (PRE) (Chen et al. 2010, Jefferson and Smith 2016) and waters of Zhanjiang (Xu et al. 2015) in the Guangdong Province, China.

Previous studies showed that humpback dolphins were frequently active in gulfs, mangroves, seagrass meadows, muddy estuaries and coastal shallow waters (Wang & Han 1996, Corkeron et al. 1997, Jefferson 2000, Jefferson & Karczmarski 2001). However, these animals may also enter rivers; e.g., a humpback dolphin was found in the Yangtze River (Zhou & Gao 1997). Up to now, the relationship between distribution and environmental variables, such as chlorophyll a and sea surface temperature, has not been well understood, and suitable habitat of humpback dolphins in Guangdong is unknown.

Because of their coastal distribution, humpback dolphins are susceptible to human activities, such as targeted fishing and by-catch, ship impacts, underwater blasting, water pollution, etc. (Jefferson 2000, Liu & Huang 2000). It was recorded that the aquatic environment is exposed to the amount of environmental pollutants that have the potential to create oxidative stress in aquatic organisms (Gürkan 2020). Understanding the distribution of suitable habitat would further contribute to an effort to draft policy aimed at protecting this species.

Here, we used MaxEnt and ArcGIS to predict the suitable habitat of humpback dolphins in the waters of Guangdong Province, and we provide suggestions related to existing humpback dolphin protection policy.

Study area. Guangdong Province is located in the southeast of the Chinese mainland, which has a tropical and subtropical climate. The average annual temperature is approximately 21.5 °C, and annual rainfall is 1,500–2,000 mm. More than 365.3 billion m^3 y^{-1} of fresh water from the Pearl River, Hanjiang River, Rongjiang River, Jianjiang River and others are injected into the sea annually.

Three populations of humpback dolphins are present in Guangdong province. It is believed that the largest population resides in the waters of the Pearl River estuary (PRE) and consists of 2,637 individuals (Chen et al. 2010, Jefferson & Smith 2016). The world's second largest population of humpback dolphins is distributed in the waters of Zhanjiang, and it is composed of approximately 1,485 individuals (Xu et al. 2015). There are less than 30 humpback dolphins in Chaoshan waters (Ping Li, pers. comm., 2019). Currently, there are four marine reserves in Guangdong Province to protect marine wildlife: The Pearl River Estuary Chinese White Dolphin National Nature Reserve (460 km²), Jiangmen Chinese White Dolphin Provincial Nature Reserve (107.48 km²), Leizhou Bay Chinese White Dolphin Reserve (20.58 km²) and Nanpeng Islands Marine Ecological Protection Area (356.79 km²).

Sighting Data and Environmental Data. Location data from a total of 413 dolphin sightings in Guangdong Province between 2007 and 2009 were extracted from published references (Hung & Jefferson 2004, Jefferson & Hung 2004, Zhang 2009, Wu 2010, Chen et al. 2011, Wu et al. 2013, Li et al. 2017). Occurrence data are often biased due to differences in sampling intensity (Phillips et al. 2009). To minimize spatial omission, we adopted spatial filtering to mitigate bias. To do so, we made models using the randomly partitioned approach; i.e., occurrence data were randomly selected, one record per grid (Rodriguez-Castaneda et al. 2012). As a result, 181 records remained for further study.

Marine environmental variables, including Chlorophyll a, Bathymetry, and Sea Surface Temperature, on spatial resolutions of 0.05° x 0.05°, 0.03° x 0.03° and 0.05° x 0.05°, respectively, were downloaded from the Asia-Pacific Data-Research Center website (http://apdrc.soest.hawaii.edu/data/data.php) and the NOAA (http://pifsc-oceanwatch.irc.noaa.gov/erddap/griddap/index.html l=?page=1&itemaPerPage=1000); The Distance to Coast data were obtained from ArcGIS 10.4. The pair-wise correlation analysis of four environment variables was implemented, using R package to reduce multicollinearity of environmental layers (Cheng et al. 2015). Correlation coefficients were calculated to estimate correlation variables, where Pearson's | r | > 0.75 independent variables were retained for modeling (Kramer-Schadt et al. 2013). The correlation between Sea Surface Temperature and Chlorophyll a was the highest and positive, where Pearson's | r | reached 0.91. To reduce prediction error, the Sea Surface Temperature was removed. Finally, three variables (Chlorophyll a, Bathymetry and Distance to Coast) were used for predicting suitable habitat.

Maximum Entropy Model. MaxEnt software version 3.4.1 (Phillips

& Schapire 2004) was used to build maximum entropy models and to predict the probabilistic distribution of humpback dolphins. The software could also identify which environmental variables correlated better with the species distribution as well as areas of potential occurrence. We adopted an R package (ENMeval) to adjust MaxEnt model parameters (regularization multiplier, RM) (feature combination, FC) about the level of model complexity and to reduce factors which might affect the prediction results (Elith et al. 2011). The regularization multiplier was set to change from 0.5 to 4.0, increasing by 0.5 each time; six feature combinations were tested, namely, L, LQ, H, LQH, LQHP and LQHPT (where L was linear, Q was quadratic, H was hinge, P was product, and T was threshold). Finally, model performance was evaluated according to Akaike information criterion (AICc) (Akaike 1973), the difference (AUC diff) between training AUC and testing AUC values (Warren & Seifert 2011), and the 10% training omission rate, OR 10 (Pearson et al. 2010).

To assess the relative importance of the candidate environmental variables within each MaxEnt model, we conducted jackknife tests. Results were assessed based on the area under the curve (AUC) values (area under receiver operating characteristic (ROC) curve) calculated for test data. In general, in the interpretation of the model results on species distribution, the AUC value was considered to be unreliable under 0.60, poorly reliable between 0.60-0.90 (Hanley & Mcneil 1982), and highly reliable between 0.90-1.0. In some cases, high AUC value might be caused by overfitting. Here, the OR 10 value was used to measure the degree of model overfitting, where a value greater than 0.1 indicated that the model was overfitted (Muscarella et al. 2014). Raster data files were reclassified upon loading the MaxEnt data into ArcGIS 10. 4. The potential distribution area of Indo-Pacific humpback dolphins was divided into two classes with the suitability index P: P <0.5 was unsuitable, and P >0.5 was suitable habitat.

The AUC values of both training and test data were above 0.9 (Fig. 1), suggesting that the results were reliable. For the threshold dependent tests, p-values of binomial tests for all thresholds evaluated were <0.01, indicating that the model predicted test localities significantly better than random. The OR 10 was approximately 0.0002, indicating that the model was not overfitted.

Table 1. The pair-wise correlation of the three environment variables.

	Distance to coast	Chlorophyll a	Bathymetry
Distance to coast	1.00		
Chlorophyll a	0.24	1.00	
Bathymetry	-0.38	-0.30	1.00

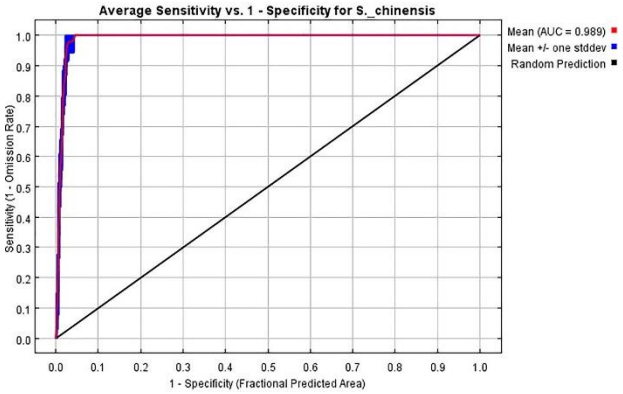

Figure 1. The receiver operating characteristic (ROC) curve with the area under the curve (AUC) values for training and test data.

The response curve (Fig. 2) showed the quantitative relationship between environmental variables and the probability of occurrence (also known as habitat suitability). The humpback dolphins were sensitive to chlorophyll a ranging from 4.4–8.2 mg / m^3 (Fig. 2A), and the most suitable concentration for dolphins to survive was above 5.7 mg / m^3.

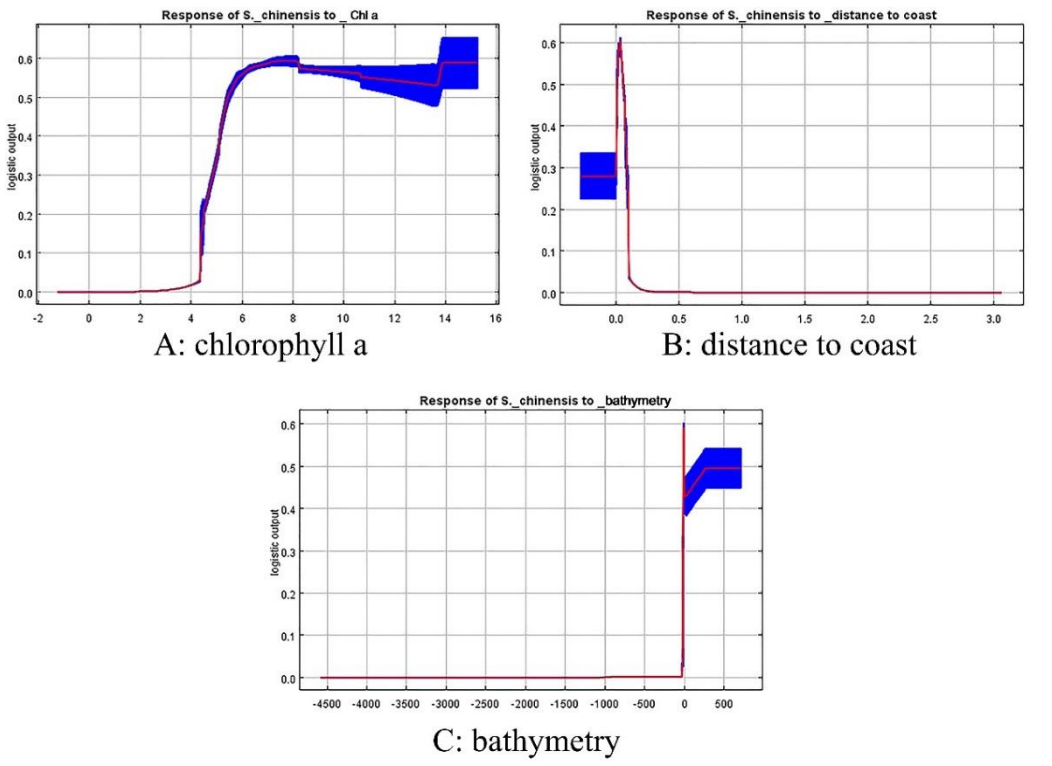

Figure 2. Response curves of environmental variables for the Indo-Pacific humpback dolphin. (A: chlorophyll a; B: distance to coast; C: bathymetry).

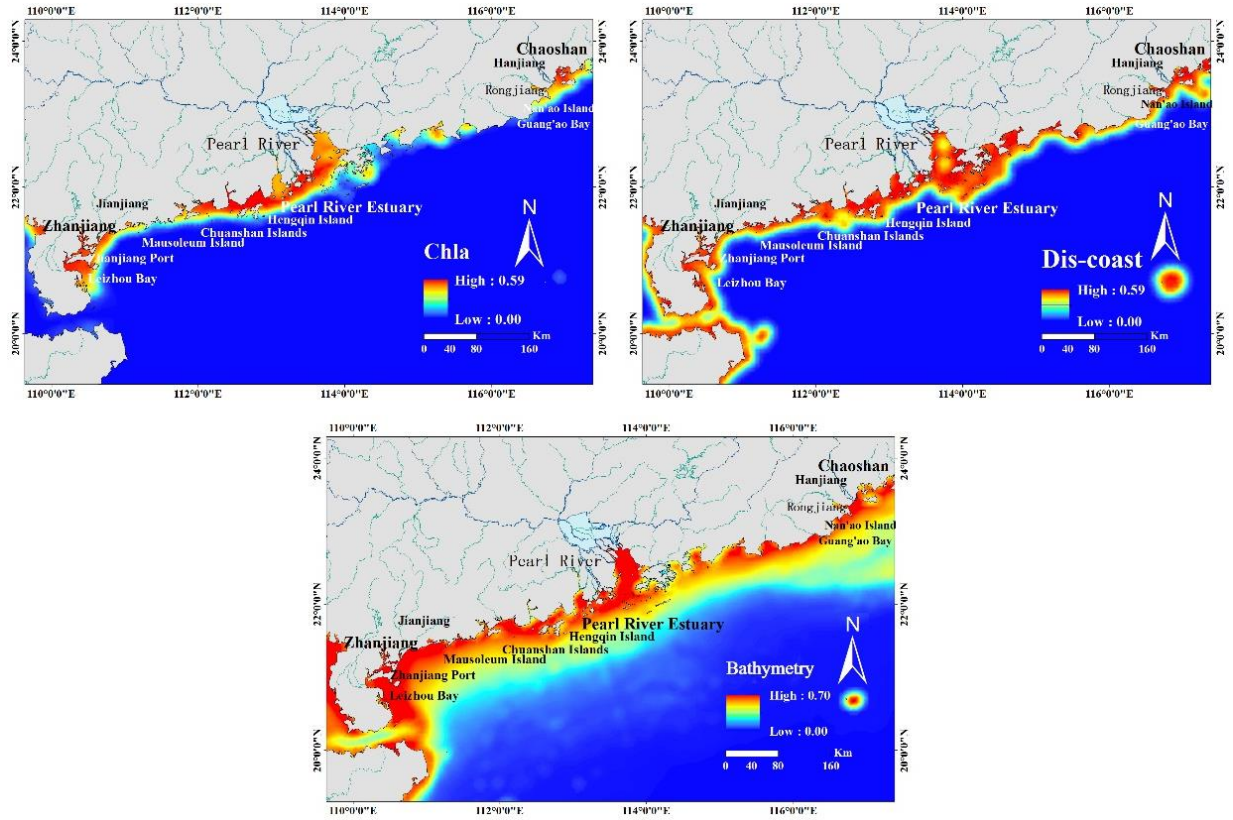

Figure 3. Single variable suitability for potential habitat of *S. chinensis* in Guangdong Province (A: chlorophyll a; B: distance to coast; D: bathymetry).

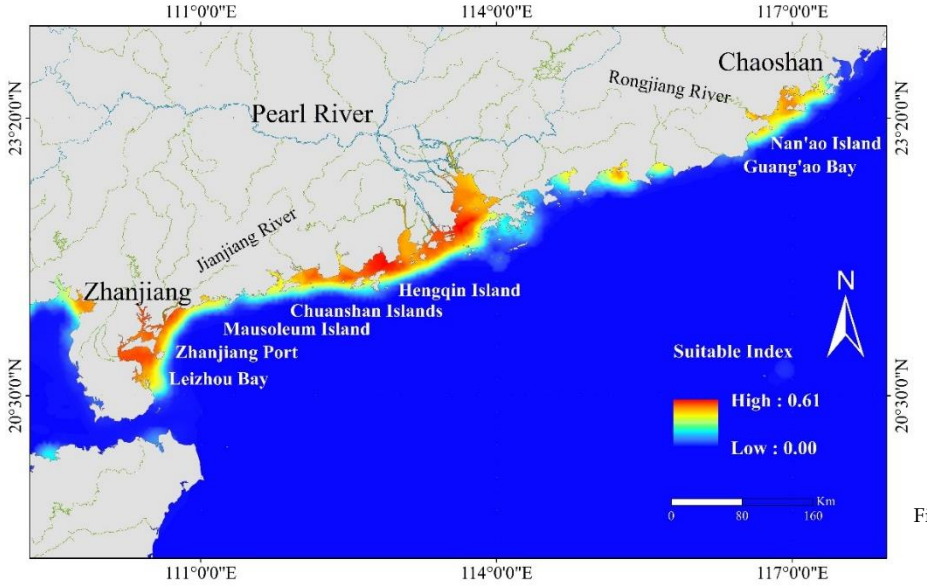

Figure 4. The predicted suitable habitat for *S. chinensis* in Guangdong Province, China.

The suitable offshore distance for dolphins to live was less than 20 km (Fig. 2B). Suitable bathymetry for humpback dolphins was less than 250 metres (Fig. 2C).

The suitable habitat was predicted by each environmental variable (Fig. 3). The jackknife test showed that chlorophyll a had the highest contribution rate of 95.2%, with other variables contributing less than 3%, and the contribution of the bathymetry data was negligible. The suitable habitat for Indo-Pacific humpback dolphins was 5,545.9 km² in total, mainly including Zhanjiang waters, Pearl River estuary waters, and Chanshan waters (Fig. 4). In Zhanjiang, dolphins generally inhabited 1,852.7 km² of suitable area in Leizhou Bay, Zhanjiang Port, Jianjiang River Estuary and their adjacent waters. In the Pearl River Estuary and west, dolphins also had a wide range of suitable habitat from Hengqin Island through the Chuanshan Islands to the waters near Hailing Island (approximately 3,637.6 km²). In Chaoshan waters, dolphins were found in the vicinity of Guang'ao Bay and Nan'ao Island, and the suitable area was approximately 55.6 km².

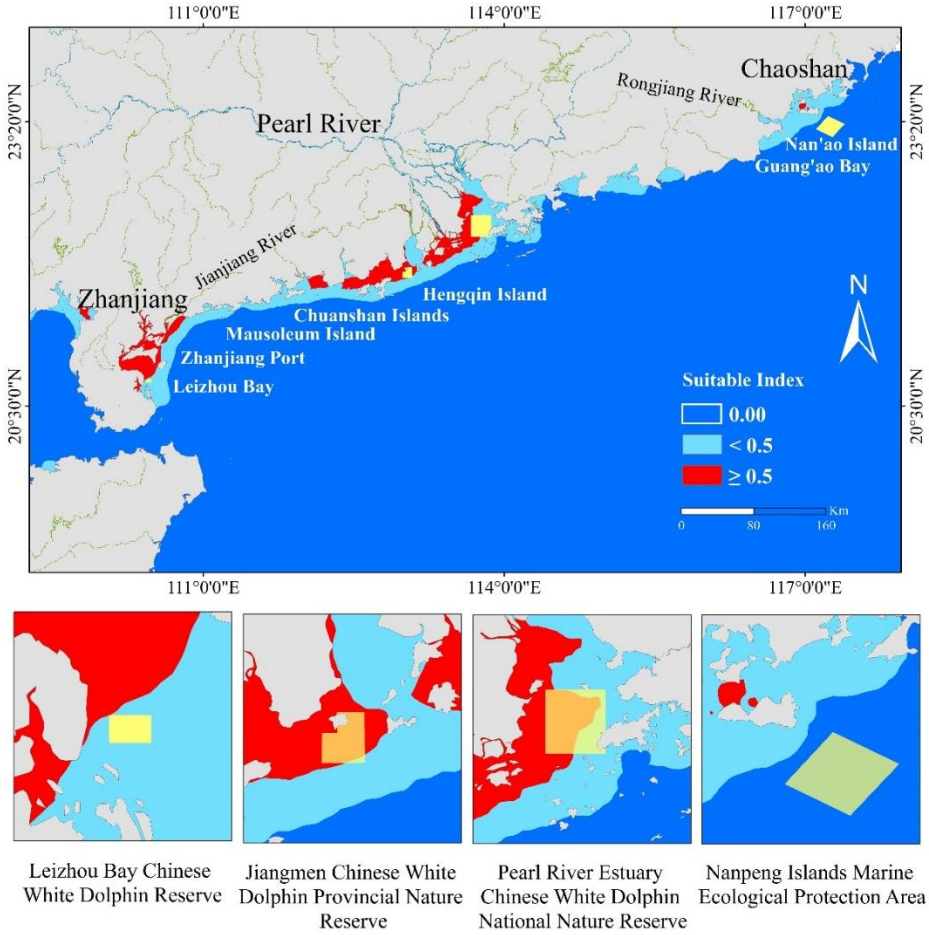

Figure 5. The overlap of four nature reserves and habitats suitable for Indo-Pacific humpback dolphins in Guangdong Province, China.

Chlorophyll a was the most important environmental variable in the present study. The concentration of chlorophyll a in seawater was an indicator of the existing amount of phytoplankton, and its distribution reflects the abundance and variation of phytoplankton in water. The fishery resources became richer following the increasing levels of chlorophyll a, and fishery resources are related to potential prey availability for dolphins; thus, chlorophyll a became the most important factor (Liu et al. 2017). As such, neither bathymetry nor sea surface temperature were important factors. The reason these factors were not as important as chlorophyll a might be that in the coastal area of the study region, these factors were all within the suitable range; e.g., coastal water bathymetry was less than 40 m.

A previous study mentioned that the high productivity of estuary areas might account for the humpback dolphins' occurrence (Parra et al. 2004). Our study supported this opinion. The results showed that Indo-Pacific humpback dolphins live mainly in three major river estuaries of Guangdong Province.

However, four reserves in Guangdong only covered 493.29 km^2 of suitable habitat compared to the 5,545.9 km^2 of suitable habitat predicted for humpback dolphins in Guangdong (Fig. 5). In other words, only 8.89% area of suitable habitat for Indo-Pacific humpback dolphins is protected, while 91.11% suitable habitat is not under protection.

In conclusion, there is evidence that a large area of suitable habitat of Indo-Pacific humpback dolphins is distributed in Guangdong province widely. However, over 90% of the suitable habitat is not under protection, so we recommend extending the range of current nature reserves and establishing new nature reserves in the suitable habitat area.

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