# Population estimate and distribution pattern of Indian Ocean humpback dolphin (Sousa plumbea) in an industrialised bay, northwestern Persian Gulf

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# Population estimate and distribution pattern of Indian Ocean humpback dolphin (*Sousa plumbea*) in an industrialised bay, northwestern Persian Gulf

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ABSTRACT

Monitoring and assessing marine biodiversity relies upon adequate and accurate knowledge of population and distribution patterns of ecologically important species. Cetaceans are recognised both as functionally important and as flagship species and have been the target of monitoring and conservation programs. The habitat specialist Indian Ocean humpback dolphin (*Sousa plumbea*) is the second most common cetacean in the Persian Gulf. Mousa Bay in the northwestern Persian Gulf is an important, but highly industrialised habitat for this species. We developed a systematic and comprehensive distance sampling survey carried out from 2014 to 2016 to estimate abundance and population density of humpback dolphin in this bay. To evaluate distribution pattern of the species, eight environmental variables were measured and employed in a zero-inflated generalised additive model (ZINB GAM). With an estimated abundance of 92 animals (64–131, 95% CI) and density of 0.123 animal/km$^2$ (0.086–0.176, 95% CI), our results revealed Mousa Bay as one of the largest population of humpback dolphin in northern latitudes of its global range. Based on ZINB GAM findings, distance to coastlines, depth, EC, and chlorophyll *a* concentration significantly influence the distribution of the species. Our results highlighted that physiographic parameters and resource availability are the most important motivators of the species distribution in shallow nearshore waters. Biotic (e.g. water quality) factors due to strongly being affected by the variability of time and space ranked after physiographic variables. The high tendency of humpback dolphins to enter in highly developed foreshore of Mousa Bay raise the need for conservation-oriented studies to inform conservation planning. This study provides a basis for monitoring humpback dolphin and assessing ecosystem health of northern Persian Gulf.

## 1. Introduction

Despite the importance of ocean-marine ecosystems, the quality of these natural habitats are rapidly declining particularly due to habitat destruction, over-exploitation, introduction of alien species, water pollution and climatic fluctuations (Pompa et al., 2011; Worm et al., 2006). Additionally, close to 60% of the world's human population is settled at a range of 100 km from shorelines (Pompa et al., 2011). Anthropogenic disturbances in these areas have led to the fact that of the 89 cetacean species, 22% are assigned to threatened (i.e. CR, EN, VU) or near threatened (NT) categories and the conservation status of 50% of them is data deficient (DD) due to the insufficient data of their population trend and geographic distribution (IUCN, 2017). Consequently, planning monitoring programs is indispensable for filling conservation gaps and developing management strategies for marine mammals. Nevertheless, despite successful conservation activities and improved population status of some of the marine mammals in recent decades (e.g. whales), those occurring in coastal areas or inland waters (mainly dolphins and porpoises), have constantly been facing threats from human activities (Lotze et al., 2011; Pompa et al., 2011). Ships and boats traffic, habitat destruction, and entanglement in fishing gears are among the most serious threats to marine mammals in these areas (Komoroske and Lewison, 2015).

Cetaceans are recognised as functionally important species by the EU Marine Strategy Framework Directive (Azzellino et al., 2014). They are also considered as flagship (Hoyt, 2012), keystone (Bănaru et al., 2013), and umbrella (di Sciara and Agardy, 2016) species and hence are the target of conservation efforts.

The Persian Gulf is a relatively small, shallow and semi-enclosed marginal sea of the Indian Ocean bordered by Iran and the Arabian

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**Fig. 1.** Location of Mousa Bay in the northeast of the Persian Gulf, where distance sampling efforts were implemented to estimate abundance of humpback dolphins.

Peninsula. This area harbours diverse marine and coastal habitats and a great diversity of plant and animal species adapted to its unique condition of extreme salinity and high temperature (Hume et al., 2013). The Persian Gulf is the world's largest source of crude oil and gas through which about 60% of the world's sea transport of crude oil passes (Reynolds, 1993) making it one of the most impacted ocean areas in the world. The main anthropogenic pressures to the Persian Gulf's environment includes oil and waste contamination, high maritime traffic, overfishing, rapid coastal development and industrialisation, sedimentation and dredging, introducing nonindigenous organisms through ships' ballast water discharge, and destruction of habitats (Bayani, 2016). During the Gulf War in early 1991, an estimated four to eight million barrels of crude oil were directly released into the Persian Gulf made it the largest oil spill in history.

At least 98 marine mammals have been identified from the Persian Gulf (Owfi et al., 2016), though, most of them are vagrant or seasonal visitors. Persian Gulf is also known as the most important stronghold for dugongs (*Dugong dugon*) in western half of their range outside the Australia, and is home to resident populations of Indo-pacific bottlenose dolphins (*Tursiops aduncus*) and Indian Ocean humpback dolphins (*Sousa plumbea*; hereafter called humpback dolphins) all year round (Owfi et al., 2016; Preen, 2004).

Humpback dolphins are obligate shallow-water species usually found within a narrow strip of nearshore waters and estuarine areas from South Africa northward around the rim of the Indian Ocean to the Arabian Peninsula from the Red Sea into the Persian Gulf and east to Pakistan and the southwestern coast of India. The geographic distribution of the species is discontinuous across most of the range, with probably discrete local subpopulations (Braulik et al., 2015). Preference of *S. plumbea* to disperse within coastal areas with high anthropogenic footprints and ongoing environmental degradation is further fragmenting the aggregate population of the species making it exceedingly vulnerable. *Sousa chinensis* and *S. plumbea*, formerly considered as two morphological forms of a single species (*S. chinensis*) and were assessed together by IUCN as Near Threatened. However, based on the last assessment on the status of *S. plumbea*, the species meets the IUCN Red List requirements for Endangered category (Braulik et al., 2017).

Humpback dolphin is one of the most common marine mammal species seen in coastal areas and shallow waters of Persian Gulf (Preen, 2004). Both humpback dolphins and fishermen of the gulf concentrate in nearshore or estuarine areas, where large schools of fishes with high density are available. Although human attitudes toward humpback dolphin in Mousa Bay has not been assessed negative (Khatibzadeh, 2017), they have been killed intentionally or accidentally as a result of human fishing activities. On the other hand, increasing water pollution as a result of industrial development in coastal areas of the Persian Gulf has been threatening marine biodiversity particularly in semi-enclosed basins, where are important biodiversity and economic areas. Biodiversity conservation in such important areas has been hampered by the scarcity of information on the abundance and habitat suitability of representative target species.

Knowledge of cetacean abundance and distribution is a prerequisite to inform conservation planning of marine ecosystems. Hence, monitoring cetacean populations is of global importance for marine ecosystem conservation (Parsons et al., 2015). Albeit, several studies have been conducted on the abundance and spatial ecology of humpback dolphin from South China Sea (Chen et al., 2010; Xu et al., 2015) to Goa Gulf in India (Sutaria and Jefferson, 2004) and eastern coast of Africa and South Africa (Guissamulo and Cockcroft, 2004; Karczmarski, 2000; Meyler et al., 2011; Stensland et al., 2006), little is known about the ecology, abundance and distribution pattern of the species in the Persian Gulf. We only found two publications on the distribution and population estimation of the Indian Ocean humpback dolphin in the southern coast of the Persian Gulf; Preen (2004) and (Díaz López et al., 2017).

In the current study, we developed a systematic and comprehensive field survey to estimate abundance and evaluate distribution pattern of humpback dolphin in Mousa Bay, a semi-enclosed harbour in the northwestern Persian Gulf. Extensive commercial and industrial activities, including two commercial international ports and a petrochemical special economic zone, threaten the survival of the species in this area. Information on the abundance and distribution of this threatened species is required for planning biodiversity conservation programs in this area. We used standardised line transect surveys covering the whole study area in order to (i) determine abundance and density of humpback dolphins and (ii) explore distribution pattern and environmental variables influencing the species distribution. This study provides a baseline for monitoring and conservation management of humpback dolphin as an ecologically important species in Mousa Bay, Persian Gulf.

## 2. Material and methods

### 2.1. Survey design

Mousa Bay with numerous watercourses is the northern most coastal bay in the Persian Gulf (Fig. 1), located at 30°02′–30°30′N and 48°51′–49°17′E and km$^2$. Water salinity in the Persian Gulf ranges from 40% to 70%, water surface temperature increases up to 36 °C in summer and the annual mean temperature is 24 °C (Bayani, 2016). With an average depth of 20–50 m, reaching to 73 m in some points, Mousa Bay is home to many seabirds and a spawning area for many fish species. The high depth and width of this region allows for commercial sailing ending to two harbours of Mahshahr Port and Imam Khomeini Port at the north of the bay with the highest record of loading and unloading among all Iranian ports. The existence of these ports and a petrochemical special economic zone has caused an over-crowded traffic of oil-tanker and container ships through Mousa Bay. These dense maritime activities and accelerated industrialisation together with placement of the coastal cities of Mahshahr and Sarbandar have resulted in extreme disturbances to natural habitats of the area.

Humpback dolphins sighting data were collected during December 2014 to February 2016 using systematic line-transect methods (Buckland et al., 2001). During the surveys, we followed a boat-based survey along zig-zag transect lines following Strindberg and Buckland (2004). In order to specify the boundary of the study area and design the sampling protocol we compiled marine charts from Ports and Maritimes Organization (PMO), georeferenced them in ArcGIS, and initially determined the extent of the study area. We then validated this boundary, regarding water depth allowing for boat movement, during a pilot onboard survey. Overall, a total of 709 km$^2$ of the Mousa Bay, including the main harbour and its complex channels was delimited and used to design the sampling effort (Fig. 2).

We used the designed zig-zag routes to ensure even sampling probabilities across the study area while maximizing on-effort time for seeking animals. For each effort-day, just one line transect was surveyed to ensure that their sightings would not interfere and the surveys were started from one side and ended to the other side of the bay.

All surveys were run from a 23-foot inboard-engine fishing boat, speed was kept at 20 km/h in calm weather with wind speed slower than 7-knots. A team of three observers continuously scanned in the front and sides of the boat with the naked eye while on effort. When dolphin groups were detected during on-effort searching, the perpendicular distance of the group to the transect line was visually estimated and waypoints were recorded into a handheld GPS unit at the sighting location. The survey team had previously practiced to accurately estimate the distances of floating objects in certain locations. The boat then left the transect route and approached the dolphin group to record the group position using the GPS unit. We also collected additional data of the species and number of animals in the group, approximate age composition (adult or calf), and their reaction to the boat. In the majority of cases, the dolphin groups were calm and it was easily possible to find their initial location. We then returned to the point where the sighting was made along the transect route and continued transect effort. Having the position of dolphin groups and the transect routes, the perpendicular distances were calculated afterward using the NEAR function in ArcGIS 10.4 (ESRI, 2016). The two sets of collected distances obtained by visual estimation and GPS matched closely, but we used distances collected by the latter method for analysis. We did not used trigonometry as using GPS for estimating distances provides more accurate results than trigonometry (Marques et al., 2006).

To explore spatial patterns of humpback dolphin's distribution we statistically assessed the response of the species to physical and biological parameters of the bay. To do this, we first implemented a grid network of 2 × 2 km all over the study area using Hawth Tools extension in ArcGIS. We then measured eight environmental variables of surface water including salinity, pH, EC, temperature, density of cyanobacteria, density of Chlorophyll *a*, turbidity, and sea depth at the sighting points of the dolphins and the center point of each 2 × 2 km cell. Surface water temperature, cyanobacteria, Chlorophyll *a* and sea depth were measured in the field using portable equipment and for other variables we took samples and measured them in the laboratory. For the variable distance to coastline we measured Euclidean distance of central point of each cell from the boundary of the study area using ArcGIS Spatial Analyst Tools.

### 2.2. Data analysis

The on-effort observations of humpback dolphin groups made from the line transects (Fig. 2) were used for the distance sampling analysis. Density of humpback dolphin groups within the area surveyed was estimated as $\widehat{D}_s = \frac{nf(0)}{2L}$, where $L$ indicates the aggregate length of the transects, $n$ is the number of groups observed, and $f(0)$ is the probability density function of observed perpendicular distances evaluated at zero distance from the line. Density of groups $\widehat{D}_s$ was multiplied by the estimated expected group size $\widehat{E}(S)$ to obtain density of individuals $\widehat{D}$, and this estimate was multiplied by the total area of the Mousa Bay to obtain the corresponding abundance estimate of dolphins $\widehat{N}$. In order to model the detection function, various combinations of key functions and adjustment terms were considered (e.g., uniform + cosine or simple polynomial, half-normal + cosine or simple polynomial, hazard rate + cosine, or hermite polynomial). Goodness of fit test was used to detect violations of assumptions. Akaike's Information Criterion adjusted for small sample size (AICc) was used to identify the final model. We used *Distance* package (Miller, 2015) in R v. 3.3.2 environment (R Core Team, 2016) to estimate density and abundance of the distance sampling efforts in the surveyed area.

Generalised additive models (GAM) were used to assess response of the species to the gradient of the environmental variables in the study area. GAM is a non-parametric version of linear regression models that copes with the non-normal distribution of the response variable (Hastie and Tibshirani, 2004). GAM model follows:

$$g(E(Y)) = LP = \widehat{\beta}_0 + \sum_{j=1}^{P} f_j(X_j) + \varepsilon$$

Where $g$ is a link function relating the expected value of response variable $Y$, $\beta_0$ is the intercept and $f_j$ is a non-parametric function of the predictor $X_j$. In additive models, to achieve the best prediction of the dependent variable values, an unspecified (non-parametric) function is estimated for each predictor. Generally, the smoother functions are scatterplots that implement weighted averages in specific regions of the fitted regression estimation (Guisan et al., 2002). To fit GAM model, the total number of individuals seen during distance sampling efforts in each 2 × 2 km grid was used as the response variable and environmental variables, measured at the central point of each cell, were treated as explanatory variables.

Generating the 2 × 2 km grid network and assigning dolphin

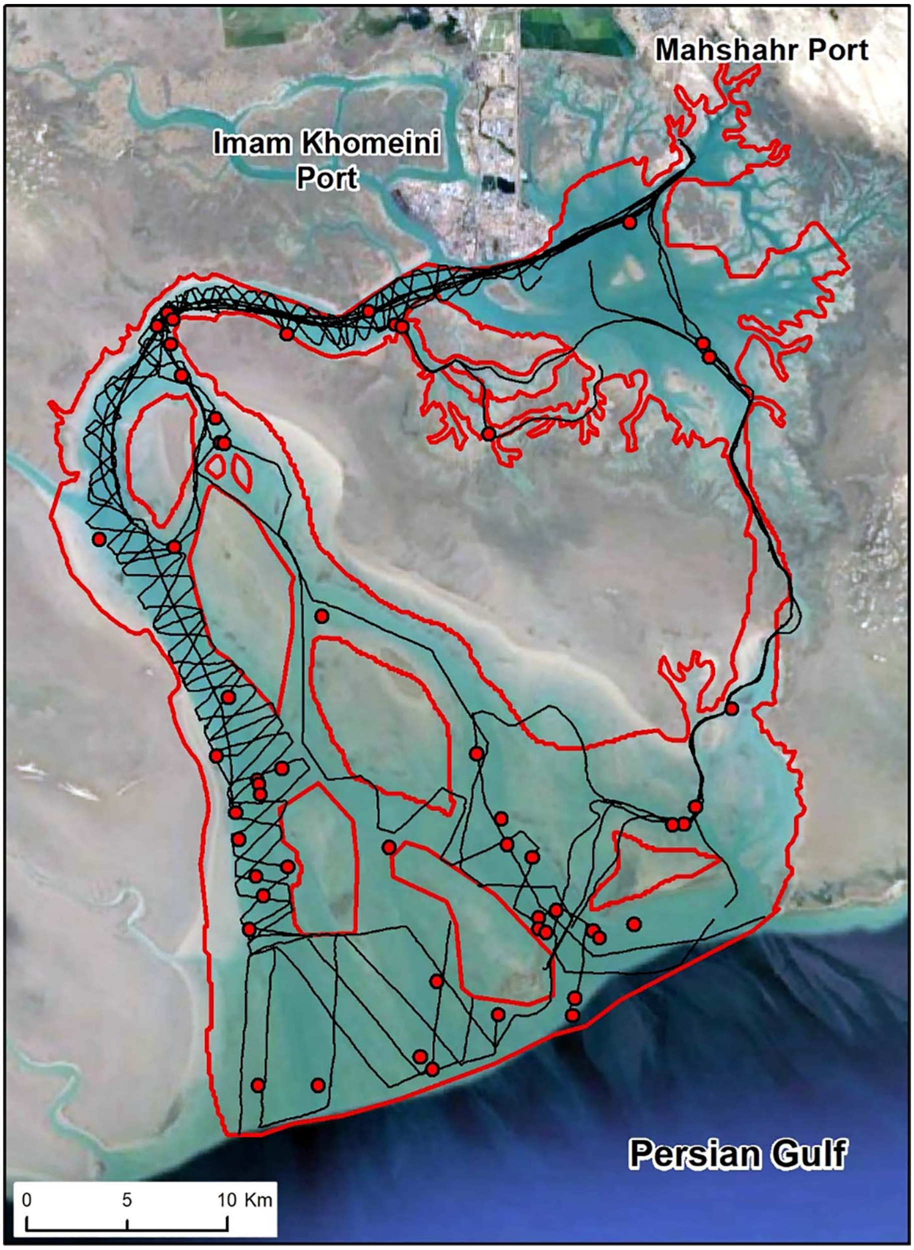


**Fig. 2.** On-effort sightings of humpback dolphin surveys in Mousa Bay, Persian Gulf. Black lines, red lines and red points respectively represent the line transects, the designed boundary of the study area and location of the group sightings. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

numbers to each cell resulted in 304 cells with animal-count ranging from 0 to 15 for each. We used zero-inflated models which are designed to model zero–heavy count data, due to the fact that these zeros might include a mixture of true and false absences (Zuur et al., 2012). Zero-inflated Poisson and negative binomial (ZIP and ZINB) GAM models have recently been developed in R environment and represent a possible solution to cope with the inherent large number of zero observations of marine mammals surveys and fisheries researches (Minami et al., 2007; Yee, 2010). We fitted ZIP and ZINB GAM models and selected the latter based on its better performance according to log-likelihood test. Models were fitted using VGAM package (Yee, 2017) in R environment. Before data analysis, we checked the pairwise correlation between variables showing high correlation coefficient between cyanobacteria and turbidity ($r = 0.76$), EC and salinity ($r = 0.71$), and EC and pH ($r = 0.75$). We removed turbidity, salinity, and pH and finally used EC, temperature, density of cyanobacteria, density of Chlorophyll *a*, depth and distance to the coastal edge to fit GAM model.

## 3. Results

During sampling efforts from September 2014 to January 2016, 44 line transects with an average length of 28.93 km were surveyed over a total size of 709 $km^2$ of the study area. Overall, 1273 km linear transect were surveyed through which 75 humpback dolphin groups were observed. The encounter rate was 0.058 group/km and mean group size was 2.71 dolphin per group ranging from 1 to 15 animals. Among detection function models we selected half-normal model with cosine adjustment terms due to its lowest AICc value compared to hazard-rate and uniform models, however, all three models showed an acceptable goodness-of-fit (Table 1).

In the final models, data were grouped into eight equal-spaced intervals with right truncation at 800 m (Fig. 3). Total abundance and density of humpback dolphins in Mousa Bay were respectively estimated as 92.11 and 0.123 individual/$km^2$ (Table 2).

The final ZINB GAM model explained 50.6% of the deviance. We

**Table 1**
Results of detection function model selection based on line transect surveys of humpback dolphin in the Persian Gulf.

| Model | AICc | ΔAIC | *p*-value | SE |
|---|---|---|---|---|
| Half-Normal | 864.75 | 0.00 | 0.338 | 0.038 |
| Uniform | 865.87 | 1.12 | 0.403 | 0.038 |
| Hazard-Rate | 866.55 | 1.80 | 0.352 | 0.045 |

found a significant effect of smooth functions of distance to coast ($p < 0.001$), depth, EC, and chlorophyll *a* ($p < 0.01$) on the spatial distribution of humpback dolphin groups (Table 3).

Response curve of explanatory variables based on the ZINB GAM model revealed that the highest density of humpback dolphins occurs in areas with distance range of 1 – 2 km from the coast in that the probability of occurrence decreases with increasing distance from the edge (Fig. 4). Moreover, response curves indicated that the highest density is seen in areas with water depth of 30 m, lowest EC values and highest density of chlorophyll *a* (Fig. 4).

**Table 2**
Estimates of abundance and density of humpback dolphins in Mousa Bay with their corresponding standard error (SE), percent coefficient of variation (%CV) and 95% confidence intervals (95% CI).

| | Estimate | SE | CV (%) | 95% CI |
|---|---|---|---|---|
| Abundance | 92.11 | 16.72 | 18 | 64.3–131.8 |
| Density (number/km$^2$) | 0.123 | 0.023 | 18 | 0.086–0.176 |

**Table 3**
Results of the ZINB GAM model for humpback dolphin count data in relation to explanatory variables in Mousa Bay, Persian Gulf.

| Variable | Df Npar | Chi.sq | *p*-value |
|---|---|---|---|
| s(Coast_dis) | 4.91 | 25.81 | 0.0003 |
| s(Depth) | 3.85 | 18.50 | 0.002 |
| s(EC) | 3.28 | 17.77 | 0.003 |
| s(Chlorophyll) | 2.91 | 14.15 | 0.021 |
| s(Temperature) | 1.00 | 2.72 | 0.083 |
| s(Cyanobacteria) | 1.00 | 0.14 | 0.704 |

## 4. Discussion

Coastal areas, estuaries and riverine habitats have been severely modified by human-caused disturbances. Information on the ecology of indicator marine species can assist in planning biodiversity conservation programs in such disturbed ecologically important areas. Spatially explicit estimations of the population and distribution patterns of marine mammal species serve as an ecological indicator for assessing negative comebacks of industrialised developments (Azzellino et al., 2014; Carlucci et al., 2016). More importantly, this information plays a key role in conservation programs and management activities. The importance of these data for updating the state of marine mammals in Red List of threatened species has also been emphasised by IUCN (Braulik et al., 2015).

Designing marine transects and boat-effort sightings has been recommended as the most applicable method for population estimation of marine mammals (Buckland et al., 2001) and widely been used in related researches (Becker et al., 2014; Gomez-Salazar et al., 2012; Hines et al., 2015; Zerbini et al., 2007). In this study, we used marine transects to estimate abundance and density of humpback dolphin in Mousa Bay in the northwestern Persian Gulf. As a minimum number of 60 sightings is recommended for accurate estimation of detection functions (Buckland et al., 2001), our results, incorporating 87 sightings, is thought to be a robust estimation of abundance and density of humpback dolphin in this bay.

We estimated an abundance and density of 92 animals (95% CI, 64–131) and 0.123 animal/km$^2$ (95% CI, 0.086–0.176) in Mousa Bay. Compared to other estimations on the abundance and density of the species, our result reveals Mousa Bay as an important habitat among other global ranges of the species. For example, our estimate is comparable with those of the species in Xiamen in the south of China (Chen et al., 2008), western coast of Taiwan (Wang et al., 2007) and eastern coast of Mozambique (Guissamulo and Cockcroft, 2004) with abundance of 86, 99 and 105 animals, respectively (Table 4). Comparing species abundance over all global ranges highlights small populations of humpback dolphins in many of its natural habitats. For instance, large populations of *S. chinensis* have only been estimated for the Pearl River Estuary and Zhanjiang Bay in southern China (Chen et al., 2010; Xu et al., 2015), and largest populations of *S. plumbea* humpback dolphins are seen in Goa Bay in western coast of India (Sutaria and Jefferson, 2004) and coasts of Emirate of Abu Dhabi (UAE) in southern Persian Gulf (Díaz López et al., 2017). Mousa Bay thus embraces one of the

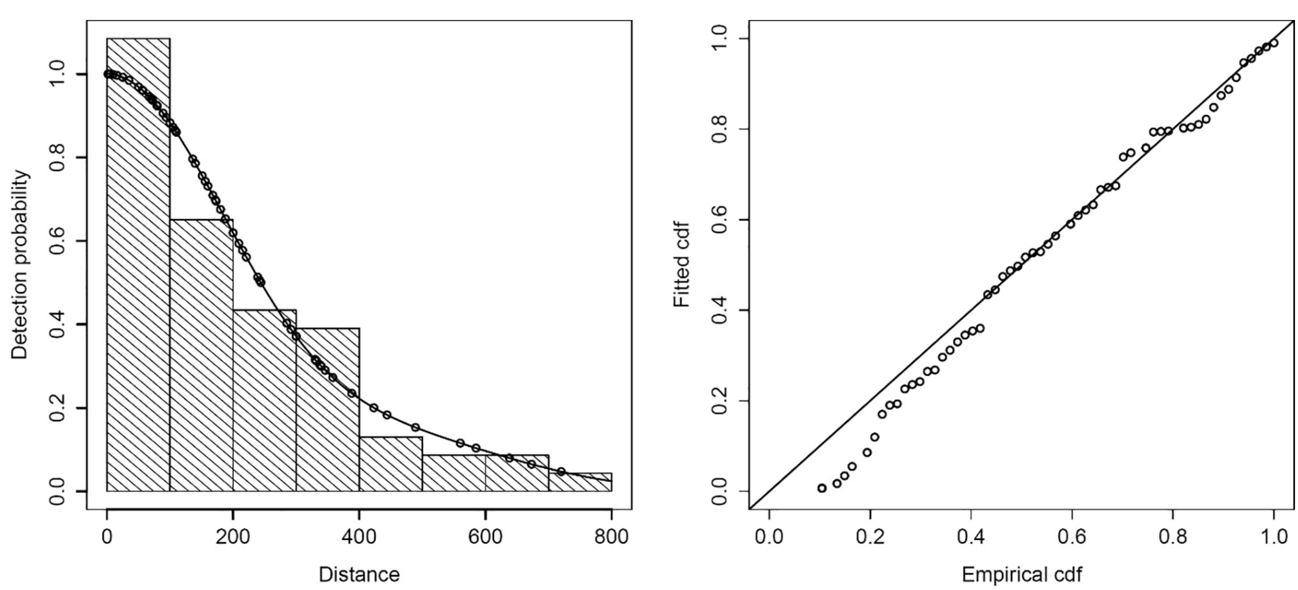


**Fig. 3.** Detection function curve (a) and Q-Q plot of the goodness-of-fit test (b) of the half-normal model fitted to the detected perpendicular distances of humpback dolphin groups in Mousa Bay, Persian Gulf.

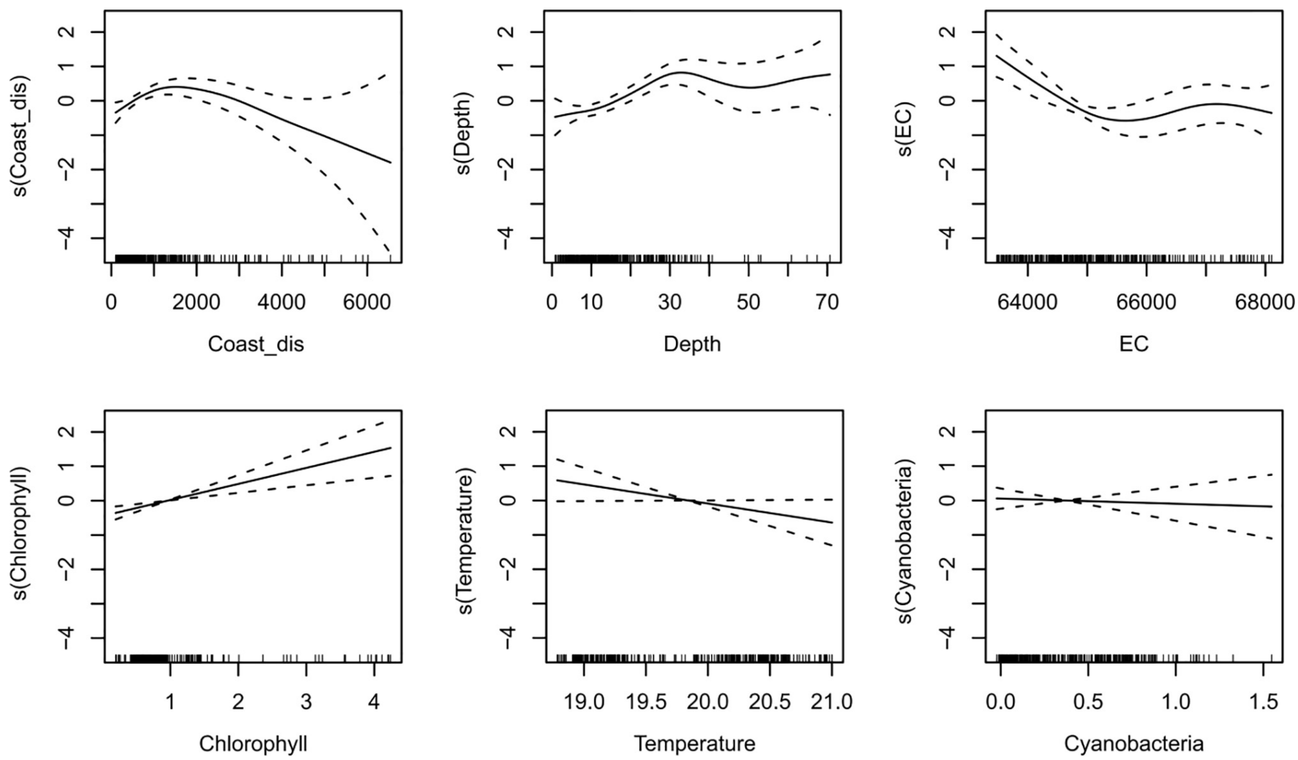


**Fig. 4.** Predicted smooth splines of ZINB GAM model for humpback dolphin count data in relation to explanatory variables: depth (meter), distance to coastal edge (Coast_dis, meter), density of chlorophyll *a*, density of cyanobacteria, EC (µS/Cm) and water surface temperature (°C) in Mousa Bay, Persian Gulf. Dashed lines represent 5% confidence intervals.

largest populations of *S. plumbea* in northern latitudes of the species' global range.

Having estimated the population size of Indian humpback dolphin in Mousa Bay, this study initiated a monitoring program for assessing demographic changes of the species in the area.

Using ZINB GAM in this study allowed incorporating flexible and none-parametric presence-environment relationships of humpback dolphin. Among the environmental variables used, distance from the coast, depth, EC, and Chlorophyll *a* turned out to significantly influence the distribution of humpback dolphin groups. As demonstrated by response curves, the probability of sighting dolphin groups is highest in waters adjacent to the coastal edge, but with keeping a specific distance of about 1–2 km from the coastline. This pattern reveals a balance between preference of the species to spread in shallow waters in one hand, and avoidance of the threats caused by anthropogenic disturbances near the coastlines in another hand. Shallow zones provide dolphins with a high abundance and diversity of prey and higher feasibility of catching them (Braulik et al., 2015; Chen et al., 2010). This pattern of dolphins' habitat preference in coastal habitats has also been documented in other studies (Correia et al., 2015; Marini et al., 2015; Moura et al., 2012).

Moreover, high amount of ship traffic in Mousa Bay as a heavily commercial and industrialised area makes the depth as an important parameter influencing humpback dolphin's distribution. Humpback

**Table 4**
Global literature review of the humpback dolphin population estimation. Density values are calculated as individual/km$^2$.

| Study area | Abundance (density) | Period of study | Source |
|---|---|---|---|
| *Sousa chinensis* | | | |
| Pearl River Estuary, southern China | 2552 (1.36) | 2005–2008 | (Chen et al., 2010) |
| Zhanjiang Bay, southern China | 1485 (0.99) | 2005–2012 | (Xu et al., 2015) |
| Donsak, Surat Thani, Thailand | 160 (NA) | 2011–2013 | (Jutapruet et al., 2015) |
| Beibu Bay, southern China | 153 (0.22) | 2003–2004 | (Chen et al., 2009) |
| Western coast of Taiwan | 99 (0.19) | 2002–2004 | (Wang et al., 2007) |
| Xiamen waters, southern China | 86 (0.12) | 2004–2008 | (Chen et al., 2008) |
| Khanom Bay, Tamarat, Thailand | 49 (0.67) | 2008–2009 | (Jaroensutasinee et al., 2011) |
| *Sousa plumbea* | | | |
| Goa Bay, western coast of India | 842 (3.40) | 2002 | (Sutaria and Jefferson, 2004) |
| Coastlines of UAE, southern Persian Gulf | 701 (0.59) | 2017 | (Díaz López et al., 2017) |
| Algoa Bay, Eastern Cape, South Africa | 466 (NA) | 1991–1992 | (Karczmarski et al., 1999) |
| Maputo Bay, eastern Mozambique | 105 (0.47) | 1995–1997 | (Guissamulo and Cockcroft, 2004) |
| Shimoni Archipelago, eastern Kenya | 104 (NA) | 2006 | (Meyler et al., 2011) |
| **Mousa Bay, northwestern Persian Gulf** | **92 (0.12)** | **2014–2016** | **This study** |
| Kachchh Bay, northwestern India | 78 (0.27) | 2002 | (Sutaria and Jefferson, 2004) |
| Richards Bay, South Africa | 74 (1.13) | 1998 | (Keith et al., 2002) |
| South coast of Zanzibar, Tanzania | 64 (2.46) | 1999–2002 | (Stensland et al., 2006) |
| Saudi Arabia, Bahrain, Qatar | 16 groups | Summer 1986 | (Preen, 2004) |
| United Arab Emirates | 13 groups | Summer 1986 | (Preen, 2004) |
| United Arab Emirates | 2 groups | Summer 1999 | (Preen, 2004) |

dolphin in the southern Persian Gulf is mainly restricted to areas with < 10 m depth (Preen, 2004). Although, this pattern of dispersing in shallow waters is known as the primary habitat preference of the species (Braulik et al., 2015; Chen et al., 2008; Jutapruet et al., 2015; Preen, 2004), it seems that high volume of ship traffic in Mousa Bay has enforced humpback dolphins to use deeper areas as shown in response curves. Suitable depth and bathymetry forms are key factors determining the possibility of diving for marine mammals, which is crucial in humanised areas with high volume of traffic (Braulik et al., 2015; Ng and Leung, 2003). Importance of depth and bathymetric configurations has widely been reflected as an influential parameter for dolphins' distribution in coastal areas (Becker et al., 2014; Cañadas et al., 2002; Carlucci et al., 2016; Marini et al., 2015). Among biotic explanatory variables, the concentration of chlorophyll *a* was positively correlated with the group size of humpback dolphins. Chlorophyll concentration may not be a direct determinant of dolphins' distributions, acts as a renowned indicator for other biological factors such as productivity and prey availability (Cañadas and Hammond, 2008; Ware and Thomson, 2005). The positive association of dolphin's distribution with regions of high chlorophyll concentration found in this study is supported by findings of similar researches (Cañadas and Hammond, 2008; Correia et al., 2015; Moura et al., 2012). Nevertheless, although EC and density of chlorophyll *a* have been recognised as the most important qualitative variables influencing humpback dolphins in waters of Mousa Bay, caution is advised when inferring the distribution patterns of cetacean based on water quality variables. These parameters show a temporal variability, due in part to the oceanographic dynamics which, in turn, influence waters productivity (Heithaus and Dill, 2002; Moura et al., 2012). Whereas the importance of static variables (e.g. physiographic parameters) for cetacean distribution is evident, the habitat dynamics and parameters variability should be considered, especially in coastal habitats that dynamic processes highly influence the productivity and resource availability for cetaceans (Heithaus and Dill, 2002; Hooker et al., 2011). For future studies, we suggest exploring cetacean occurrence-environment relationships with data of a higher temporal resolution and inferring conclusions using environmental extremes and/or averaged over time and space.

Overall, two physiographic variables, including proximity to coastlines and depth proved to be the most important factors influencing the distribution of humpback dolphin groups in Mousa Bay. Our findings are in agreement with other explorations on habitat selection of dolphin species in coastal zones (Azzellino et al., 2012; Becker et al., 2014; Cañadas et al., 2002; Carlucci et al., 2016). These abiotic factors might force direct or indirect influences on the species by providing escaping deep water terrain, particularly in areas with high ship traffic, facilitating social interactions, and or affecting biotic factors such as prey availability.

## 5. Conclusion

Humpback dolphins have been decreasing in numbers due to the increase in human activities across their distribution ranges. Distributed in shallow nearshore waters of Mousa Bay with the high volume of anthropogenic developments, makes Indian humpback dolphin a suitable ecological indicator for future assessments of this ecosystem's health. This is the first published conservation-oriented study on cetacean in the northern Persian Gulf, which serves as an initial step for a monitoring program in this highly industrialised bay.

Distribution of humpback dolphin in Mousa Bay, similar to other cetaceans in coastal areas, is influenced by both environmental suitability and anthropogenic pressures. Although results of this study have evidenced Mousa Bay as an important area among other discrete habitats of the species, industrialised developments and commercial activities in this area threats the survival of the species. Law making and law enforcement for alleviating threats and establishment of an appropriate network of protected areas in the northern Persian Gulf, where the impacts of human activities can be minimised is required for long-term survival of this species.

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