ORIGINAL ARTICLE

Abundance estimation, group dynamics, and residence patterns of Indian Ocean humpback dolphin (*Sousa plumbea*) in the Dayer-Nakhiloo Marine National Park, Northern Persian Gulf, Iran

Nazanin Mohsenian[1] · Séverine Methion[2] · Hamed Moshiri[1] · Shadi Karbalaei Hassan[1] · Shaghayegh Afkhami[1] · Mohammad Amin Tollab[3] · Mahmod Sadeh[4] · Gill T. Braulik[5] · Bruno Díaz López[2]

Abstract

The Persian Gulf is positioned in the heart of the Middle East as one of the most critical water bodies. Indian Ocean humpback dolphins (*Sousa plumbea*) are distributed in nearshore waters and are therefore highly vulnerable to a variety of anthropogenic pressures. To our knowledge, there is a little information and data available about habitat use and abundance of this endangered species in Iranian waters. In the present study, baseline data about population size and site fidelity of Indian Ocean humpback dolphins in the Dayer-Nakhiloo Marine National Park in Northern Persian Gulf, Iran, has been explored for the first time. From March 2014 to December 2018, 127 boat-based surveys and 6436 km of survey effort were conducted. Overall, 127 groups of humpback dolphins were observed on 62% of the surveys. Humpback dolphin group size ranged from 1 to 14 individuals (mean $5.8 \pm SE\ 0.3$). Abundance estimates were calculated and fitted with open population models. Thirty (95% CI 22–38) humpback dolphins were estimated to inhabit the study area. There was a lack of seasonality in the occurrence of humpback dolphins and strong site fidelity within the Dayer-Nakhiloo Marine National Park. Most of the identified individuals used the study zone regularly (79.5%), while a smaller number were present less often. The results of this study provide important baseline information about humpback dolphin ecology in an area subject to significant anthropogenic pressures which can help to take effective conservation and management measures.

Keywords Indian Ocean humpback dolphin · Persian Gulf · The Gulf · *Sousa plumbea* · Abundance · Photo-identification · Conservation · Site fidelity · Residence

---

This article is part of the Topical Collection on Road Ecology
Guest Editor: Marcello D'Amico

✉ Nazanin Mohsenian
Mohsenian@plan4land.org

Séverine Methion
severine@thebdri.com

Hamed Moshiri
Moshiri@plan4land.org

Shadi Karbalaei Hassan
Shadikarbalaei@gmail.com

Shaghayegh Afkhami
afkhami.shaghayegh@gmail.com

Mohammad Amin Tollab
amin.tollab@yahoo.com

Mahmod Sadeh
m_sadeh@bpciran.com

Gill T. Braulik
gillbraulik@gmail.com

Bruno Díaz López
bruno@thebdri.com

[1] Plan for the Land Society, Kish Island, Hormozgan, Iran

[2] Bottlenose Dolphin Research Institute (BDRI), Av. Beiramar 192, O Grove, CP. 36980, Spain

[3] Marine Environment Bureau, Bushehr Provincial Office of the Department of Environment, Bushehr, Iran

[4] Department of Health, Safety, and Environment, Nouri Petrochemical Company, Asaluyeh, Iran

[5] Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews, Fife, UK

🙋 Springer

Introduction

Coastal marine ecosystems are broadly at risk due to human activities (Boesch et al. 2001). Humpback dolphin (Sousa spp.) are distributed in onshore waters and are therefore vulnerable to a combination of anthropogenic pressures such as fisheries (Read et al. 2006; Slooten et al. 2013), pollution (Würsig and Gailey 2002), habitat change (Lotze et al. 2006), aquaculture (Würsig and Gailey 2002; Díaz López, 2012; Methion and Díaz López 2019, 2020), global warming (Simmonds and Isaac 2007), and underwater noise (Wang et al. 2004; Ross et al. 2010; Dungan et al. 2012). These threats appear to be increasing as human populations grow and develop (Wang et al. 2012; Bouveroux et al. 2017).

Marine mammal site fidelity and abundance estimations can provide significant information for the development of conservation and management programs (Akkaya et al. 2019; Díaz López 2012; Xu et al. 2012; Passador et al. 2017). Photo-identification has been applied to study site fidelity and abundance of different species of dolphins such as Indian Ocean humpback dolphins (*Sousa plumbea*) (Díaz López et al. 2018), Indo-Pacific humpback dolphins (*Sousa chinensis*) (Xu et al. 2012), Australian humpback dolphins (*Sousa sahulensis*) (Parra et al. 2006), common bottlenose dolphins (*Tursiops truncatus*) (Díaz López 2012; Methion and Díaz López 2019), Spinner dolphins (*Stenella longirostris*) (Marten and Psarakos 1999), and Rough-toothed dolphin (*Steno bredaenensis*) (Baird et al. 2008).

The genus *Sousa* contains four species of dolphins: the Atlantic humpback dolphin (*S. teuszii*), the Indian Ocean humpback dolphin (*S. plumbea*), the Indo-Pacific humpback dolphin (*S. chinensis*), and the Australian humpback dolphin (*S. sahulensis*). All four of these species are classified as threatened on the IUCN Red List (Jefferson and Curry 2015), and the Indian Ocean humpback dolphin was recently up-listed as endangered (Braulik et al. 2015, 2017). The latter is present along coastlines from South Africa to India and Sri Lanka, as well as in the Red Sea, the Gulf of Suez, the Arabian Sea, and the Persian Gulf (Baldwin et al. 2004; Mendez et al. 2013; Jefferson and Curry 2015; Braulik et al. 2015; Díaz López et al. 2018). The Indian Ocean humpback dolphin is found in shallow waters, usually less than 25 m deep and close to the shore (Braulik et al. 2015). Although these dolphins do not experience large-scale migration, some individuals were recorded traveling up to 500 km along the shore (Vermeulen et al. 2017). This species typically occurs in populations of a few hundred individuals (Braulik et al. 2015), although a larger population has recently been reported off the coast of Abu Dhabi, UAE (Díaz López et al. 2018).

About one-third of the world's oil is extracted in the Persian Gulf region and is exported through the Strait of Hormuz the Persian Gulf crossed every day with an average of 3000 vessels (e.g., including oil tankers, ships, and fishing boats) (Sheppard et al. 2010; Fatima and Jamshed 2015). This region has been recognized as one of the busiest shipping lanes in the world (Kolahi et al. 2014). Several species of cetaceans can be found in the Persian Gulf, including the Indian Ocean humpback dolphin (hereafter refer as humpback dolphin) (Baldwin et al. 2004; Preen 2004; Díaz López et al. 2018). This species likely occurs along the entire coastline of the Persian Gulf, including the coast of Saudi Arabia, Kuwait, Qatar, UAE, Bahrain, and Iraq as well as Iran, and also extends into western Pakistan on the Arabian Sea (Baldwin et al. 2004; Braulik et al. 2010; Owfi et al. 2016; Díaz López et al. 2018).

There is little information about humpback dolphins in Iranian waters (Braulik et al. 2015). Most of the records of this species have been documented around Hara Protected Area on Qeshm Island in the Hormozgan province (Braulik et al. 2010). Only one study carried out in Musa Bay in the Khuzestan province in 2018 estimated the population size of humpback dolphins inhabiting these waters (92 animals (64–131, 95% CI)) (Hemami et al. 2018). Few records exist for this species from two other regions such as the Khuran Strait International Wetland and Deltas of Rud-e-Shur, Rud-e-Shirin, and Rud-e-Minab International Wetland in the Hormozgan province (Mohsenian et al. 2018b), in the Dayer-Nakhiloo Marine National Park and Mond Protected Area in the Bushehr province (Keijl and Van Der Have 2002; Nawas and Moazzam khan 2013; Braulik et al. 2015; Mohsenian et al. 2014; Mohsenian et al. 2018a) (Fig. 1). The presence of humpback dolphins has been confirmed, but have not yet been studied, in the Gwadar Bay (Persian Khalij-e Gavāter) in the Sistan and Baluchestan province, near the border with Pakistan (Kiani and Van Waerbeek 2015).

The present study was carried out in the Dayer-Nakhiloo Marine National Park (DNMNP), and Mond Protected Area (MPA) in the Bushehr province, southern Iran. The objective of this study was to collect baseline data, as well as to estimate population size and site fidelity, of Indian Ocean humpback dolphins in this region. Such information is crucial to make future recommendations to take effective actions for conservation and management measures in this highly impacted area.

Materials and methods

Study area

The Persian Gulf is located in the subtropics and is an extreme marine environment with dramatic changes in water salinity (ranging from 37 to 40 psu) (Pous and Carton 2004) and sea surface water temperatures (ranging from 16 °C in

Fig. 1 Location of the *Sousa plumbea* in northern of the Persian Gulf and Gulf of Oman, Iran. Position number 1 corresponds to the study area (Dayer-Nakhiloo Marine National Park and Mond Protected Area)

winter to 36 °C in summer) (Bauman et al. 2013). The average depth is 35 m, and the maximum depth is 90 m; however, large portions of the Persian Gulf are very shallow (Pous and Carton 2004).

The study site was the Dayer-Nakhiloo Marine National Park (27° 52′ N, 51° 29′ E, 20,436 ha) located at the Mond River Delta in Bushehr province (North Persian Gulf) (Fig. 1), southern Iran. The coastal area of Bushehr province is exposed to different types of human activities. It is one of the most important regions of the Persian Gulf for the establishment of oil and gas industries (e.g., extraction and processing) and the most well-known fishing grounds for shrimp (*Penaeus semisulcatus*) bottom trawling in the Persian Gulf. The Mond River Delta has been protected since 1976 with the creation of the Mond Protected Area (MPA). This protected area covers 53,227 hectares (Mehrabian et al. 2009). In 2008, the National Park was established in the eastern part of the MPA, the Dayer-Nakhiloo Marine National Park (DNMNP), due to the unique wildlife present, compared to other areas of the Mond River Delta. The DNMNP covers 20,434 hectares and contains shallow coastal waters with a variety of marine habitats, including mangroves sandy beaches, and mudflats. Fishing activities such as gillnets, fishing traps (locally named "Gargoor"), hooks, bottom trawlers, and lines can be found both inside and outside of the DNMNP (Paighambari et al. 2011).

The DNMNP is an important habitat for breeding sea birds such as terns (i.e., *Sterna bengalensis*, *Sterna bergii*, *Onychoprion anaethetus*), crab plover (*Dromas ardeola*), Western reef heron (*Egretta gularis*) (Mostafavi et al. 2008),

and hawksbill sea turtle (*Eretmochelys inbricata*) rookeries (Razaghian et al. 2019).

Data collection

Boat surveys were carried out along the DNMNP coastline from March 2014 to December 2018 (Fig. 2). The study area was monitored four times per month during daylight hours. From March 2014 to February 2017, non-systematic visual surveys were carried out, while from March 2017 to December 2018, line transects were conducted. Two sampling seasons were specified following Díaz López et al. (2018): cold season (from October to March) and warm season (from April to September).

Surveys were carried out on days with visibility of more than 1 km and Beaufort wind force state ≤ 4. The survey vessel was a fiberglass fishing boat 7 m in length with a single 60 horsepower motor. Survey speed was maintained at 10–12 km/h. Each survey lasted 5 to 7 h, and three observers searched for dolphins while standing at the front side of the boat, each observing a different angle with binoculars (Nikon 7 × 50). A handheld GPS (Garmin 64S) was used to record the survey track and the location of dolphin sightings. On each survey, the date, local time, speed of the boat, trip distance, wind force according to the Beaufort scale, glare from the sun, and swell were also recorded. When dolphins were sighted, the boat slowly maneuvered towards the group in order to take photographs using a Canon 60D camera and 100–400 mm telephoto lens. A group of humpback dolphins was defined as one or more dolphins observed in a

Fig. 2 Sighting and track survey in the study area
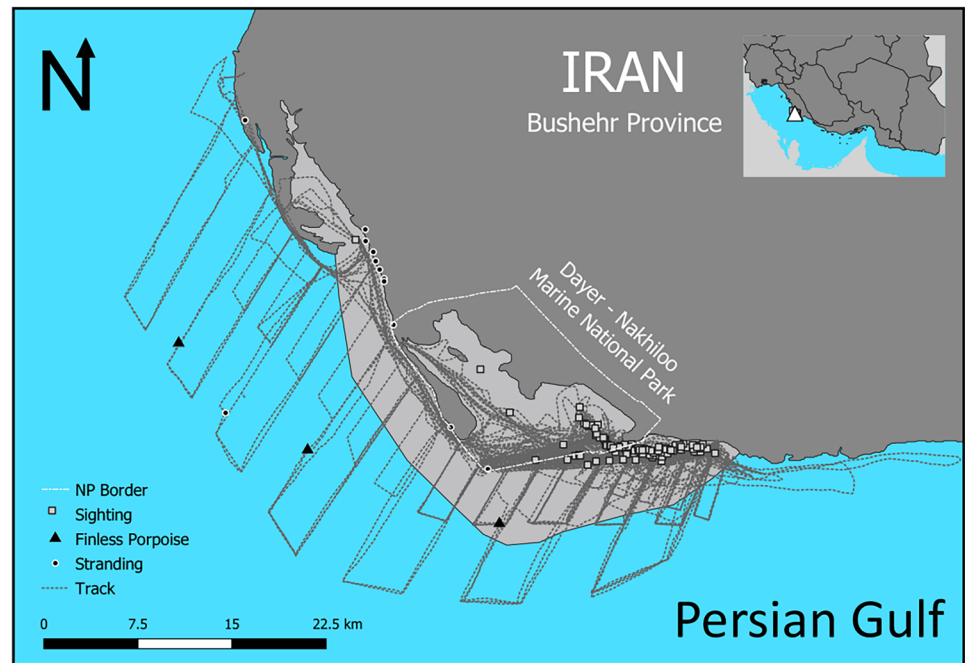
200 m area. Attempts were made to obtain photographs of every humpback dolphin within the group, including both the left and right sides of the dorsal fin for each individual observed. On each sighting, the date, time, GPS location, group size, number of adults and calves, movement direction, and behavior were documented. Behavior was categorized as traveling, feeding, resting/milling, socializing, and undetermined. After finishing the boat survey, photographs and GPS data were downloaded and survey and sighting data were reviewed and entered into Excel sheets.

Photo-identification analysis

Photo-identification is a non-invasive mark-recapture technique extensively used to distinguish individual dolphins (Würsig and Jefferson 1990). Humpback dolphins can be recognized from the pigmentation and mark patterns present on their dorsal fin and hump (Corkeron et al. 1997).

Selection and analysis of the photographs to identify humpback dolphins were done following the steps described by Díaz López et al. (2018) (Table 1). Following this, only photographs with good and excellent quality conditions were used for further analysis. Furthermore, a distinctiveness score was given to every identified individual. A distinctiveness score of zero was assigned to unmarked individuals (i.e., no notches, temporary marks only). A distinctiveness score of one was assigned to marked individuals (e.g., pigmentation patterns and single or several large notches in the dorsal fin).

Only those individuals with a level of distinction one were classified in a photo-identification catalog. The catalog, with excellent and good photographs of both sides of the dorsal fin, was created based on a detailed review of the photographs and was updated regularly during the study.

Table 1 Photo selection process to identify humpback dolphins (based on Díaz López et al. 2018)

A. Photographs were scored from 1 to 50 based on five criteria		B. Based on summed score from part A pooled into four quality groups	
Criteria	Scored	Criteria	Score
1. Position of the dorsal fin in relation to the photographer (i.e., best when perpendicular)	From 1 to 10 (1 low and 10 high)	Excellent	45–50
2. Size of the dorsal fin within the photograph		Good	36–44
3. Amount of dorsal fin visible		Average	25–35
4. Lighting		Poor	< 25
5. Focus			

Abundance estimation

Abundance estimates were calculated and fitted with five population models, using POPAN in SOCPROG 2.8 (Whitehead 2009): (1) Schnabel, which supposes a closed population and size of humpback dolphin population is estimated by maximum likelihood. (2) Mortality, which supposes an open population of constant size, where mortality (which may contain permanent emigration) is balanced by birth (which may contain immigration). (3) Mortality + trend, which supposes an open population increasing or decreasing at a constant rate. (4) Reimmigration, which supposes that a population member moves from (emigration rate) and into (reimmigration rate) the study area (Whitehead 2001). (5) Reimmigration and mortality, which is the model mortality + trend with the exception that mortality is balanced by birth.

Following Díaz López et al. (2018), the sampling period was set by survey season (cold and warm seasons) to obtain appropriate sample sizes and achieve uniform coverage of the study area. Model selection was based on the lowest Akaike's Information Criterion (Akaike 1973; AIC, Whitehead 2009).

The total abundance was calculated using estimates generated from each model and divided by the percentage of marked humpback dolphins (θ) within the population. The percentage of marked humpback (θ) within the population was estimated based on the number of individuals marked divided by the total number of individuals observed in each group, averaging the results of all observed groups (Silva et al. 2009).

The 95% confidence interval of the abundance estimation was calculated using the "Delta method" (Seber 1982).

Some basic assumptions need to be fulfilled in order to obtain unbiased estimates through the use of mark-recapture models. (1) Identified humpback dolphins are always recognized. (2) Identified humpback dolphins have the same probability of being photographed on any sampling occasion. (3) Photo-identified humpback dolphins are representative of the population being estimated.

Body marks and pigmentation

During the photographs review and selection, photographs depicting individuals with potential human-caused injuries were placed in a separate file. The body marks include those from fisheries-related injuries and collision with vessels (Slooten et al. 2013; Díaz López et al. 2018).

Furthermore, we reviewed all the individuals identified and classified them into four arbitrary categories according to the individual level of pigmentation: (1) white spotted body with more than ¼ of the dorsal fin depigmented white;

(2) lightly white speckled body and dorsal fin; (3) grey body, grey dorsal fin, and no spots; and (4) grey body, no spots, and less than ¼ depigmented area on top of the dorsal fin. Juvenile dolphins were sighted during the survey and their proportion was taken into consideration in the total abundance estimate. Juveniles lack obvious notches compared to adults, so they were included in the "unmarked" category, which includes both adults and juveniles. This allowed the calculation of the proportion of marked and unmarked individuals within the study population. Total abundance was calculated taking into consideration both marked and unmarked dolphins inhabiting this region. Continuation of the survey work in Iran and following this population over time will allow for age-related differences in coloration to be better understood in the future, and whether the age-related coloration changes that are shown by *S. chinensis* are also shown by *S. plumbea* in Iran (Guo et al. 2020).

Results

Between March 2014 and December 2018, 127 daily photo-identification surveys were conducted within the study area (920 km^2). On average, 8.9 ± 0.8 days per season were spent at sea, totaling 6436 km of survey effort. Overall, 127 groups of humpback dolphins were observed on 79 days at sea (62% of the total number of days). During the study period, there were 3 encounters with Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) and eleven stranded records of cetaceans (one Humpback dolphin, seven Finless porpoises, one Bryde's whale *Balaenoptera brydei*, one Common dolphin *Delphinus capensis*, and one unidentified dolphin). Humpback dolphins were observed every month and season surveyed, and their occurrence did not show any variation among warm and cold seasons (Mann–Whitney test, $P > 0.05$) (Table 2). The observed behaviors during the study included surface feeding, foraging, floating and resting movements, playing with seaweed, socializing movements with body contact, vertical and side leaps, prolonged body contact with vertical leaps, and lobtailing.

Group size and group composition

Overall, 127 groups of humpback dolphins were studied during the study period. Group size ranged from 1 to 14 individuals (mean $5.8 \pm$ SE 0.3; Table 3). The average number of marked individuals within each group was $0.72 \pm$ SE 0.03. Most of the observed humpback dolphins were adults (94%), and the remaining 6% were categorized as calves.

Group size shows a clear relationship to the presence of dependent calves in the group (Spearman rho = 0.56, $P < 0.01$). Groups composed entirely of adults were smaller than groups including dependent calves (Mann–Whitney test, $P < 0.01$,

Table 2 Details of the observation effort and the number of sightings of Indian Ocean humpback dolphins between 2014 and 2018. Distribution of the survey effort in days (D), kilometers (km), hours (h), and the number of humpback dolphin encounters (S). Sightings per unit of effort, *SPUE1* sightings per day, *SPUE2* sightings per km. *SE* standard error

	D	km	h	S	Mean SPUE1 ± SE	Mean SPUE2 ± SE
Cold season	56	2533	147	59	0.33 ± 0.04	0.03 ± 0.004
Warm season	71	3903	161	68	0.30 ± 0.06	0.03 ± 0.004
Total	127	6436	308	127	0.32 ± 0.04	0.03 ± 0.003

$\text{mean}_{\text{with\_calves}} = 6.8 \pm \text{SE } 0.5$, $n = 42$; $\text{mean}_{\text{no\_calves}} = 3.9 \pm \text{SE } 0.3$, $n = 85$). Group size and the number of calves did not change significantly among cold and warm seasons (Mann–Whitney test, $P > 0.05$).

Photo-identification catalog and abundance estimates

Overall, 39 adult humpback dolphins were photo-identified during 97 encounters and included in the identification catalog. The mean number of individual humpback dolphins identified per sampling period (season) was $15.7 \pm \text{SE } 1.6$. The discovery curve of photographic captures of new permanently marked individuals ($N = 39$) showed an influx and potentially an outflux of humpback dolphins during the eleven research seasons, confirming an open population. (Fig. 3).

Based on the lowest AIC value, the "Reimmigration model" (4) was selected as the most appropriate for the studied population (Table 4). Abundance estimates reported a population size of 22 (95% CI 16–27) marked individuals. Based on the ratio of marked humpback dolphins, which was 72% of the total number of individuals, we estimated 30 (95% CI 22–38) humpback dolphins inhabiting the study area.

Site fidelity

The average number of recaptures per individual humpback dolphin was 11.2 ± 2 SE (from 1–40 times, $N = 447$), with eight individuals identified only once throughout the study period and 31 humpback dolphins (79.5%) identified several times. This shows that most of the identified individuals used the study zone regularly, while a smaller number were present less often. Likewise, most humpback dolphins identified were sighted frequently across seasons (mean seasonal occurrence rate $= 4.3 \pm 0.5$ SE recaptures per season). Overall, 29 of the identified dolphins (72.5%) were identified in more than one calendar year (average $= 2.7 \pm 0.3$ SE). Following Díaz López (2012), individual humpback dolphins were classified into three different categories based on their seasonal occurrence rates (Fig. 4):

1. Regular visitors: humpback dolphins seen regularly in the study area (seasonal occurrence rates ≥ 0.5). This category contained 16 identified humpback dolphins, accounting for 41% of the total 39 identified dolphins.
2. Frequent visitors: humpback dolphins with seasonal occurrence rates between 0.25 and 0.5. This category contained six identified humpback dolphins, accounting for 15% of the total 39 identified individuals.
3. Sporadic visitors: humpback dolphins rarely seen in the study area, with seasonal occurrence rates ≤ 0.25. This category contained 17 humpback dolphins, accounting for 44% of the total of 39 identified individuals.
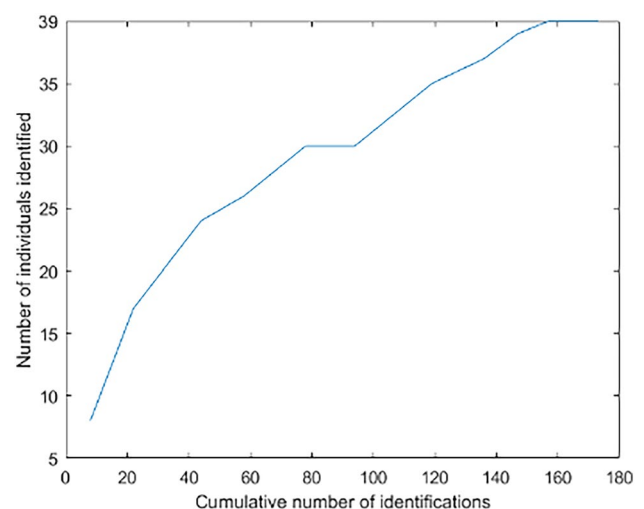
Fig. 3 Discovery curve of photographic captures of new permanently marked individuals ($N = 39$) across the 11 seasons of research

Table 3 Humpback dolphin group sizes (mean ± SE) observed during the study, including all age classes

	Group	Adults	Calves	No
Cold season	6.03 ± 0.49	5.71 ± 0.46	0.32 ± 0.06	59
Warm season	5.44 ± 0.45	5.08 ± 0.41	0.37 ± 0.07	68
Total	5.83 ± 0.34	5.18 ± 0.30	0.34 ± 0.04	127

Table 4 Abundance estimates of humpback dolphins in the Dayer-Nakhiloo Marine National Park between 2014 and 2018

Model	Marked humpback dolphins							Model selection			Total population		
	n	95% CI*	m±s.e	T±s.e	e	r	Nc	sp	Log likehood	AIC	Ø	Nt	95% CI
Schnabel	34.3	30.8–38.9					39	11	−183.56	369.12	0.72	48	42–54
Mortality	25.4	25–26.8	0.097±0.02				39	11	−138.27	280.54	0.72	35.3	35–37.2
Mortality + trend	25.2	24.7–26.7	0.093±0.03	0.02±0.03			39	11	−137.68	281.35	0.72	35	34.2–37
Reimmigration	21.73	15.9–27.6			0.13±0.03	0.04±0.03	39	11	−132	270	0.72	30.2	22–38.3
Reimmigration + mortality	21	16–27	0		0.11±0.04	0.01±0.07	39	11	−132	273.5	0.72	29.2	22.2–37.5

n estimated population size, *CI* confidence interval, *bootstrapped (*n*=500) *SOCPROG* Model results, *n.a.* not available, *m* estimated mortality rate, *T* estimated trend, *e* estimated emigration rate, *r* estimated reimmigration rate, *Nc* number of animals captured, *s.e.* standard error, *s.p.* number of sampling periods, *Ø* ratio of marked to total animals documented, *Nt* estimate of total population size after correcting for proportion of identifiable individuals, *AIC* Akaike Information Criterion

Body marks and pigmentation

Out of 35 humpback dolphins with pictures of their body, six individuals (17.1%) exhibited scars potentially due to interaction with human activities, such as fishing line cuts or propeller cuts (Fig. 5).

In total, thirteen individuals exhibited white spotted body with more than ¼ of the dorsal fin depigmented white; thirteen individuals exhibited grey body, no spots, and less than ¼ depigmented area on top of the dorsal fin; eight individuals exhibited lightly white speckled body and dorsal fin; and five individuals exhibited grey body, grey dorsal fin, and no spots (Fig. 6).

Discussion

In the current study, we used closed and open population models to calculate abundance estimates of *S. plumbea* in the Dayer-Nakhiloo Marine National Park over five consecutive years. Additionally, we explored for the first time in Iranian waters *S. plumbea* site fidelity, group dynamics, and indirectly the degree of interaction with human activities.

During the study period, the mark-recapture analysis yielded an open population estimate of 30 individuals (ranging between 22 and 38). The abundance estimate reported in this study is lower than observed in other areas (e.g., 92 humpback dolphins in the Musa Bay, Iran (Hemami et al. 2018); 701 humpback dolphins in Abu Dhabi, UAE (Díaz López et al. 2018); 36 individuals in Miani Hor, Pakistan (Kiani and Van Waerebeek 2015); 105 individuals in Maputo Bay, Mozambique (Guissamulo and Cockcroft 2004); 60 humpback dolphins in Bazaruto Archipelago, Mozambique (Guissamulo and Cockcroft 1997); 65 individuals off Zanzibar (Stensland et al. 2006); 450 humpback dolphins in the Algoa Bay region, South Africa (Karczmarski et al. 1999); 170–244 in KwaZulu–Natal coast, South Africa (Atkins et al. 2004)). Our estimation of the density of humpback dolphins in this study area (0.147 individuals per km^2; 95% CI, 0.108–0.235) is comparable with those of the species in Musa Bay in northern Iran (0.123 individuals per km2; 95% CI, 0.086–0.176).

From a conservation planning and management perspective, it is important to know to which area an abundance estimate applies, and whether there is any emigration-immigration from adjacent areas. The results of this study show a lack of seasonality in the occurrence of humpback dolphins and strong site fidelity by some individuals within the Dayer-Nakhiloo Marine National Park. However, the study area appears to be only a part of a larger home range for the studied population. This observation is reinforced by the 44% of individuals seen sporadically and the emigration and reimmigration values observed in the study. On a regional scale, our results indicate
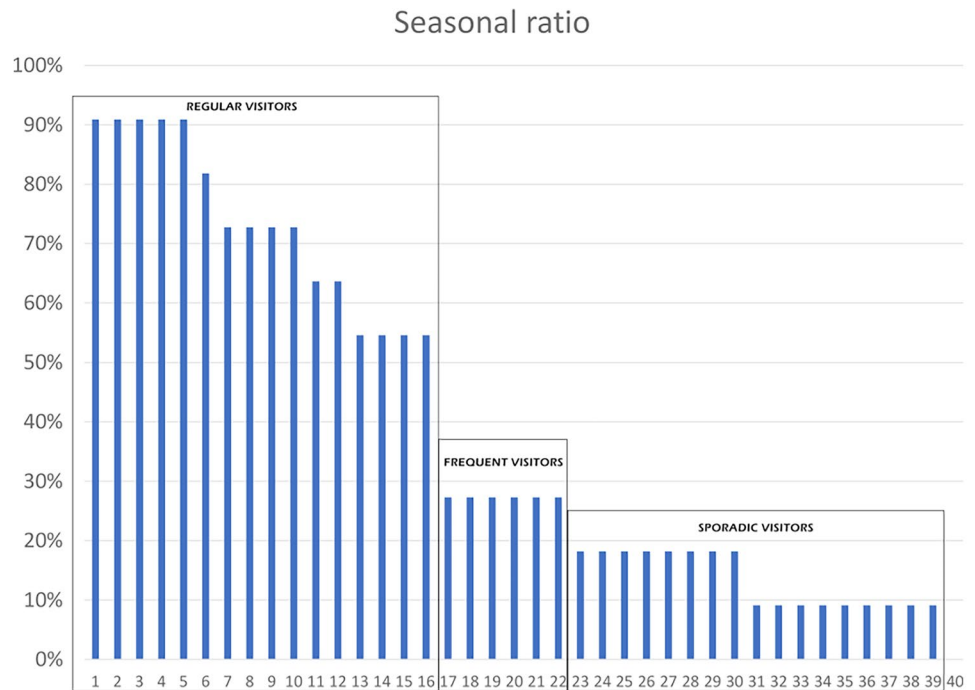
that the Dayer-Nakhiloo Marine National Park is only a small part of the distribution of humpback dolphins in Iranian waters, highlighting the need for further studies monitoring a more extensive area along the Iranian coastline. Increasing sampling effort (with a broader geographical coverage of the distribution) should result in higher capture probabilities, reduced heterogeneity, and improved accuracy of abundance estimation and individual ranging patterns. A previous study carried out in an area of 350 km along the coast in the Persian Gulf has shown that individual humpback dolphins can move more than 100 km along the coast. With this in mind, it would be ideal to be able to carry out an estimate of the population of the southern coast of Iran on a larger spatial scale. This would allow a comprehensive assessment of the abundance of this threatened species in the region. The mean group size ($5.8 \pm$ SE 0.3) of humpback dolphins in the Dayer-Nakhiloo Marine National Park during the study period was similar to the results of other

studies in the Persian Gulf (Abu Dhabi waters, 6.1 ± 0.8, Díaz López et al. 2018), and larger than the groups observed in Musa Bay (2.7 individuals) (Hemami et al. 2018). During this study, in addition to the humpback dolphin, the finless porpoise (*Neophocoena phocaenoides*) was also observed in the study area. The presence of these two species in the same coastal area is remarkably similar to those observations carried out for humpback dolphins and finless porpoises co-occurring in Abu Dhabi waters (Díaz López et al. 2018) and off Hong Kong waters (Jefferson 2000).

Humpback dolphins in our study area show considerable pink spotting as well as pink on the dorsal fin, whereas in other parts of the southern range animals are all uniform grey. Repetition of the morphological analysis conducted here may allow useful comparisons with populations elsewhere that may highlight morphological differences within the species. The type and prevalence of healing patterns
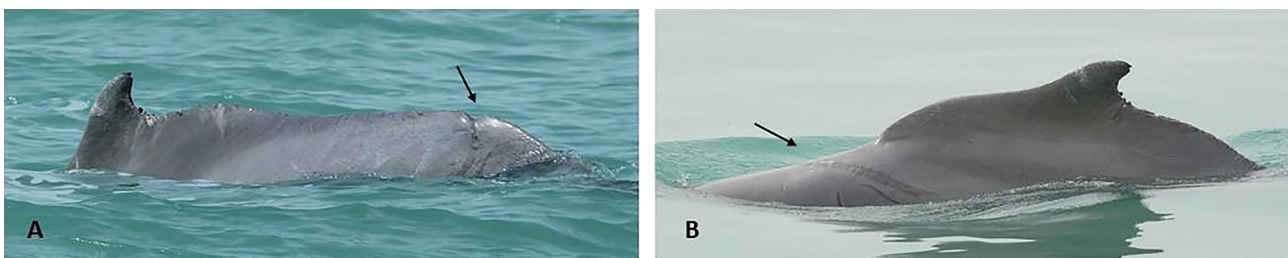
Fig. 5 Pictures **A** and **B** show human-induced impacts, **A** as a potential cut produced by a propeller and **B** as potentially due to interaction with fishing gear (line or net)

Fig. 6 Examples (left and right side of an individual) for each category of catalog: 1, grey body and dorsal fin without spots; 2, lightly white speckled body and dorsal fin; 3, grey body and a very small (less than ¼) depigmented area on the top of the dorsal fin, and no spots; and 4, white spotted body with more than ¼ of the dorsal fin depigmented white

observed in the body of the individuals, present in 17% of the identified humpback dolphins, are similar to those observed in other populations studied in the Persian Gulf (13% in Abu Dhabi waters, Díaz López, et al. 2018) and confirm the existence of injuries caused by anthropogenic activities.

The available information suggests that the *S. plumbea* population of the Dayer-Nakhiloo Marine National Park (IMMA 2019) is small, with some individuals showing a high site fidelity, making the population particularly vulnerable to anthropogenic impacts and justifies the need for developing effective long-term monitoring and conservation programs. Major threats and disturbances to these animals are likely to be incidental captures in fisheries, boat strikes due to vessel traffic. In Iran, humpback dolphins are protected by a series of laws and regulations under the approval of the supreme council of the environment (Environmental Protection and Improvement Act and Wildlife hunting law) (Legal and Parliamentary Affairs Office 2001). Further studies in the region are needed to provide a greater understanding of the movement and distribution of the species along the northern part of the Persian Gulf. It may be possible to combine interviews with local fishing communities, monitoring fish landing sites, and documentation of fishing efforts to conduct a spatial bycatch risk assessment and document fisheries mortality. Public awareness of marine megafauna bycatch within fishing communities and management authorities is essential to improve knowledge of the marine environment and the threats faced by coastal megafauna species in the region. Training programs and capacity building in the region are also needed to contribute to the conservation activities.

Author contribution Hamed Moshiri, Nazanin Mohsenian, Shadi Karbalaei Hasan, and Shaghayegh Afkhami collected the data during the study. Bruno Díaz López analyzed the data with input from Nazanin Mohsenian and Séverine Methion. Nazanin Mohsenian wrote the manuscript with significant input from Bruno Díaz López, Séverine Methion, and Gill T. Braulik. All authors (Hamed Moshiri, Nazanin Mohsenian, Shadi Karbalaei Hasan, Shaghayegh Afkhami, Mohammad Amin Tollab, Mahmod Sadeh, Bruno Díaz López, Séverine Methion, and Gill T. Braulik) conceived and designed the study. All authors contributed critically to the manuscript and gave final approval for publication.

References

Akaike H (1973) Maximum likelihood identification of Gaussian autoregressive moving average models. Biometrika 60:255–265

Akkaya BA, Öztürk B, Amaha Öztürk A (2019) Encounter rate, residency pattern and site fidelity of bottlenose dolphins (Tursiops truncatus) within the Istanbul Strait, Turkey. J Mar Biol Assoc UK 99:1009–1016. https://doi.org/10.1017/S0025315418000577

Atkins S, Pillay N, Paddemors VM (2004) Spatial distribution of Indo-Pacific humpback dolphins (*Souse chinensis*) at Richard's Bay, South Africa: environmental influences and behavioral patterns. Aquat Mamm 30:84–93

Baldwin RM, Collins T, Van Waerebeek K, Minton G (2004) The Indo-Pacific humpback dolphin of the Arabian Region: a status review. Aquat Mamm 30(1):111–124. https://doi.org/10.1578/AM.30.1.2004.111

Baird RW, Webster DL, Mahaffy SD, McSweeney DJ, Schorr GS, Ligon AD (2008) Site fidelity and association patterns in a deep-water dolphin: rough-toothed dolphins (*Steno bredanensis*) in the Hawaiian Archipelago. Mar Mamm Sci 24(3):535–553. https://doi.org/10.1111/j.1748-7692.2008.00201.x

Bauman AG, Pratchett MS, Baird AH, Riegl B, Heron SF, Feary DA (2013) Variation in the size structure of corals is related to environmental extremes in the Persian Gulf. Marine Environ Res 84:43e50. https://doi.org/10.1016/j.marenvres.2012.11.007

Boesch D, Burreson E, Dennison W, Houde E, Kemp M, Kennedy V, Newell R, Paynter K, Orth RJ, Ulanowicz R, Peterson C (2001) Factors in the decline of coastal ecosystems. Science 293(5535):1589c

Bouveroux T, Melly B, McGregor G, Plön S (2017) Another dolphin in peril? Photo-identification, occurrence, and distribution of the endangered Indian Ocean humpback dolphin (Sousa plumbea) in Algoa Bay. Aquatic Conserv: Mar Freshw Ecosyst 2018:1–10. https://doi.org/10.1002/aqc.2877

Braulik GT, Ranjbar S, Owfi F, Aminrad T, Dakhteh SMH, Kamrani E, Mohsenizadeh F (2010) Marine mammal records from Iran. J Cetacean Res Manage 11(1):49–63

Braulik GT, Findlay K, Cerchio S, Baldwin R (2015) Assessment of the conservation status of the Indian Ocean humpback dolphin (*Sousa plumbea*) using the IUCN Red List Criteria. Adv Mar Biol 72:119–141. https://doi.org/10.1016/bs.amb.2015.08.004

Braulik GT, Findlay K, Cerchio S, Baldwin R, Perrin W (2017) *Sousa plumbea*. The IUCN Red List of Threatened Species. e. T82031633 A82031644

Corkeron PJ, Morissette NM, Porter LJ, Marsh H (1997) Distribution and status of humpback dolphins, Sousa chinensis, in Australian waters. Asian Marine Biology 14:49–59

Díaz López B (2012) Bottlenose dolphins and aquaculture: interaction and site fidelity on the northeastern coast of Sardinia (Italy). Mar Biol 159:2161–2172. https://doi.org/10.1007/S00227-012-2002-X

Díaz López B, Grandcourt E, Methion S, Das H, Bugla I, Al Hameli M, Al Hameri H, Abdulla M, Al Blooshi A, Al Dhaheri S (2018) The distribution, abundance and group dynamics of Indian Ocean humpback dolphins (Sousa plumbea) in the Emirate of Abu Dhabi (UAE). J Mar Biol Assoc UK 98(5):1119–1127. https://doi.org/10.1017/S0025315417001205

Dungan SZ, Riehl KN, Wee A, Wang JY (2012) A review of the impacts of anthropogenic activities on the critically endangered eastern Taiwan Strait Indo-Pacific humpback dolphins. JMATE 4:3–9

Fatima Q, Jamshed A (2015) The political and economic significance of Indian ocean: an analysis. Res J South Asian Stud 30(2):73–89

Guissamulo A, Cockcroft VG (1997) Dolphin and dugong occurrence and distribution and fisheries interactions in Maputo and Bazaruto Bays, Mozambique. International Whaling Commission Scientific Committee Report SC/49/SM24

Guissamulo A, Cockcroft VG (2004) Ecology and population estimates of Indo-Pacific humpback dolphins (*Sousa chinensis*) in Maputo Bay, Mozambique. Aquat Mamm 30:94–102

Guo L, Lin W, Zeng Ch, Luo D, Wu Y (2020) Investigating the age composition of Indo-Pacific humpback dolphins in the Pearl River Estuary based on their pigmentation pattern. Marine Biol. https://doi.org/10.1007/s00227-020-3650-x. https://www.researchgate.net/publication/339664955_

Hemami MR, Ahmadi M, SadeghSaba M, Moosavi MH (2018) Population estimate and distribution pattern of Indian Ocean humpback dolphin (*Sousa plumbea*) in an industrialised bay, northwestern Persian Gulf. Ecol Indicators 89:631–638

IMMA (2019) Important marine mammal area regional workshop report for the Western Indian Ocean and Arabian Seas. https://www.marinemammalhabitat.org/download/final-imma-nwindian-ocean-arabian-seas-workshop-report/ or https://www.marinemammalhabitat.org/portfolio-item/nakhiloo-coastal-waters/

Jefferson TA, Curry BE (2015) Humpback dolphins: a brief introduction to the genus Sousa. Adv Mar Biol 72:1–16

Jefferson T (2000) Population biology of the Indo-pacific humpback dolphin in Hong Kong waters. Wildlife Monogr 144:65

Karczmarski L, Winter PED, Cockcroft VG, McLachlan A (1999) Population analyses of Indo-Pacific humpback dolphins Sousa chinensis in Algoa Bay, Eastern Cape, South Africa. Marine Mammals Sci 15:1115–1123

Keijl GO, Van Der Have TM (2002) Observations on marine mammals in southern Iran, January 2000. Zoology in the Middle East 26:37–40

Kiani MSh, Van Waerebeek K (2015) A review of the Status of the Indian Ocean humpback dolphin (*Sousa Plumbea*) in Pakistan. Adv Mar Biol 72:201–228. https://doi.org/10.1016/bs.amb.2015.09.002

Kolahi M, Sakai T, Moriya K, Makhdoum MF (2014) Challenges to the future development of Iran's protected areas system. Environ Manage 50(4):750–765. https://doi.org/10.1007/s00267-012-9895-5 (Epub 2012 Jul 14)

Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH, Jackson JB (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312(5781):1806–1809. https://doi.org/10.1126/SCIENCE.1128035

Legal and Parliamentary Affairs Office (2001) Laws and regulations to protect the environment of Iran. Dept Environ Publication 2 (In Farsi)

Marten K, Psarakos S (1999) Long-term site fidelity and possible long-term associations of wild spinner dolphins (*Stenella longirostris*) seen off Oahu. Hawaii Marine Mammal Science 15:1329–1336

Mehrabian A, Naqinezhad A, Salman Mahiny A, Mostafavi H, Liaghati H, Kouchekzadeh M (2009) Vegetation mapping of the Mond Protected Area of Bushehr Province (South-west Iran). https://doi.org/10.1111/j.1744-7909.2008.00712.x

Mendez M, Jefferson TA, Kolokotronis SO, Krützen M, Parra GJ, Collins T, Minton G, Baldwin R, Berggren P, Särnblad A, Amir OA, Peddemors VM, Karczmarski L, Guissamulo A, Smith B, Sutaria D, Amato G, Rosenbaum HC (2013) Integrating multiple lines of evidence to better understand the evolutionary divergence of humpback dolphins along their entire distribution range: a new dolphin species in Australian waters? Mol Ecol 22:5936–5948

Methion S, Díaz López B (2020) Individual foraging variation drives social organization in bottlenose dolphins. Behav Ecol 31(1):97–106. https://doi.org/10.1093/beheco/arz160

Methion S, Díaz López B (2019) Natural and anthropogenic drivers of foraging behaviour in bottlenose dolphins: influence of shellfish aquaculture. Aquat Conserv Mar Freshwat Ecosyst 29(6):927–937. https://doi.org/10.1002/aqc.3116

Mohsenian N, Moshiri H, Sedighi Savad Kouhi O, Norbakhsh Sh, Heidary Sh, Sharifi SK, Braulik GT (2014) The first long-beaked common dolphin mass stranding in Iranian waters. Marine Biodivers Rec 7(e64):2014

Mohsenian N, Moshiri H, Afkhami Sh, Baradari H, Karbalaee Hasan Sh, Khavari F (2018a) Conservation of Indian Ocean humpback dolphin, *Sousa plumbea* in Dayer-Nakhiloo Marine National Park and Mond Protected Area. Second report, Plan for the Land Society, Kish Island, Iran, Bushehr province (In Farsi)

Mohsenian N, Moshiri H, Afkhami S, Tina P (2018b) Observation report of Indian Ocean humpback dolphin, Sousa plumbea in the Khuran Strait International Wetland and Deltas of Rud-e-Shur, Rud-e-Shirin and Rude-e-Minab International Wetland, Hormozgan province to compare with humpback dolphin population in the Dayer-Nakhiloo Marine National Park and Mond Protected Area First report, Plan for the Land Society, Kish Island, Iran Bushehr Province (In Farsi)

Mostafavi H et al (2008) Biodiversity of Mond Protected Area (Persian book). Shahid Beheshti University, Department of Environment, Bushehr province (In Farsi)

Nawas R, Moazzam khan M (2013) Conservation of Cetaceans in North Arabian Sea, along the Balochistan Coast. Final Rep

Owfi F, Braulik GT, Rabbaniha M (2016) Species diversity and distribution pattern of marine mammals of the Persian Gulf and gulf of Oman - Iranian waters. Iran J Fish Sci 15(2):927–944

Paighambari SY, Daliri M (2011) The by-catch composition of shrimp trawl fisheries in Bushehr coastal waters, the northern Persian Gulf. J Persian Gulf 3(7):27–36

Parra GJ, Corkerona PJ, Marsha H (2006) Population sizes, site fidelity and residence patterns of Australian snubfin and Indo-Pacific humpback dolphins: implications for conservation. Biol Conserv 129:167–180. https://doi.org/10.1016/j.biocon.2005.10.031

Passadore C, Moller L, Diaz-Aguirre F, Parra GJ (2017) High site fidelity and restricted ranging patterns in southern Australian bottlenose dolphins. Ecol Evol. https://doi.org/10.1002/ece3.3674

Pous SP, Carton X (2004) Hydrology and circulation in the strait of Hormuz and the Gulf of Oman-Results the GOGP99 Experiment: Strait of Hormuz. J Geophys Res 109:C12037. https://doi.org/10.1029/2003JC002145

Preen A (2004) Distribution, abundance and conservation status of dugongs and dolphins in the southern and western Arabian Gulf. Biol Cons 118(2):205–218

Razaghian H, Shams-Esfandabad B, Askari Hesni M, Vafaei Shoushtari R, Toranjzar H, Miller J (2019) Distribution patterns of epibiotic barnacles on the Hawksbill turtle, *Eretmochelys imbricate*, nesting in Iran. Reg Stud Mar Sci 27:100527. https://doi.org/10.1016/j.rsma.2019.100527

Read AJ, Drinker P, Northridge S (2006) Bycatch of marine mammals in U.S. and global fisheries. Cons Bio 20:163–169

Ross PS, Dungan SZ, Hung SK, Jefferson TA, Mac Farquhar C, Perrin WF, Riehl KN, Slooten E, Tsai J, Wang JY (2010) Averting the baiji syndrome: conserving habitat for critically endangered dolphins in eastern Taiwan Strait. Aquat Cons: Mar Freshwat Ecosyst 20:685–694. https://doi.org/10.1002/aqc.1141

Seber GAF (1982) The estimation of animal abundance and related parameters. Macmillan Publishing Co., New York, NY

Sheppard CH, Al-Husiani M, Al-Jamali F, Al-Yamani BR, Bishop J, Benzoni F, Dutrieux E, Dulvy NK, Durvasula SRV, Jones DA, Loughland R, Medio D, Nithyanandan M, Pilling GM, Polikarpov I, Price ARG, Purkis S, Rieg B, Saburova M, Samimi Namin K, Taylor O, Wilson S, Zainal Kh (2010) The Gulf: a young sea in decline. Mar Pollut Bull 60(2010):13–38

Silva MA, Magalh͂aes S, Prieto R, Santos RS, Hammond PS (2009) Estimating survival and abundance in a bottlenose dolphin population taking into account transience and temporary emigration. Mar Ecol Prog Ser 392:263–276

Simmonds MP, Isaac SJ (2007) The impacts of climate change on marine mammals: early signs of significant problems. Oryx 41(01):19–26. https://doi.org/10.1017/S0030605307001524

Slooten E, Wang JY, Dungan SZ, Forney KA, Hung SK, Jefferson TA, Riehl KN, Rojas-Bracho L, Ross PS, Wee A, Winkler R, Ch YS (2013) Chen Ch A (2013) Impact of fisheries on the critically endangered humpback dolphin *Souse chinensis* population in the eastern Taiwan strait. Endang Species Res 22:99–114

Stensland E, Carlen I, Sarnblad A, Bignert A, Berggren P (2006) Population size, distribution, and behavior of Indo-Pacific bottlenose (Tursiops aduncus) and humpback (Sousa chinensis) dolphins off the South Coast of Zanzibar. Marine Mammals Science 22:667–682

Vermeulen E, Bouveroux T, Plön S, Atkins S, Chivell W, Cockcroft V, Conry D, Gennari E, Hörbst S, James BS, Kirkman S, Penry G, Pistorius P, Thornton M, Vargas-Fonseca O, Elwen S (2017) Indian ocean humpback dolphin (souse plumbea) movement pattern along the South African coast Aquatic Conservation Marine and Freshwater Ecosystem. https://doi.org/10.1002/aqc.2836

Wang JY, Hung SK, Yang SC (2004) Records of Indo-Pacific humpback dolphins, *Sousa chinensis* (Osbeck, 1765), from the waters of western Taiwan. Aquat Mamm 30:187–194. https://doi.org/10.1578/AM.30.1.2004.189

Wang JY, Yang SC, Fruet PF, Daura-Jorge FG, Secchi ER (2012) Mark-recapture analysis of critically endangered Eastern Taiwan Strait population of Indo-Pacific humpback dolphin (*Sousa chinensis*): implication for conservation. Bull Mar Sci 88(4):885–902. https://doi.org/10.5343/bms.2010.1097

Whitehead H (2001) Analysis of animal movement using opportunistic individual identifications: application to sperm whales. Ecology 82:1417–1432

Whitehead H (2009) SOCPROG programs: analyzing animal social structures. Behav Ecol Sociobiol 63:765–778

Würsig B, Gailey GA (2002) Marine mammals and aquaculture: conflicts and potential resolutions. In: Stickney RR, McVay JP (eds) Responsible marine aquaculture. CAP International Press, New York, 45–59

Würsig B, Jefferson TA (1990) Methods of photo-identification for small cetaceans. In: P. S. Hammond, S. A. Mizroch, & G. P. Donovan (eds.) Individual recognition of cetaceans: use of photo-identification and other techniques to estimate population parameters. Int Whaling Comm Special 12:43–52. Cambridge, England

Xu X, Zhang Zh, Ma L, Li P, Yang G, Zhou K (2012) Site fidelity and association patterns of indo-pacific humpback dolphins off the east coast of Zhanjiang, China. Acta Theriol 57:99–109. https://doi.org/10.1007/s13364-011-0058-5