Visual Health Assessment and Evaluation of Anthropogenic Threats to Arabian Sea Humpback Whales in Oman

G. Minton[1], M.F. Van Bressem[2], A. Willson[3], T. Collins[4], S. Al Harthi[5], M. Sarrouf Willson[5], R. Baldwin[6], M. Leslie[7] and K. Van Waerebeek[2]

Contact e-mail: gianna.minton@gmail.com

ABSTRACT

The sub-population of humpback whales inhabiting the Arabian Sea is a small and genetically distinct population that remains in low latitudes year-round. Designated as Endangered on the IUCN Red list of Threatened Species, the sub-population faces a number of threats throughout its range, including entanglement in fishing gear, ship strikes, disease and habitat degradation. Research conducted primarily off the coast of Sultanate of Oman over the past 20 years has contributed to understanding the population's distribution, abundance, and conservation status. However, information on the population's health and specific threats is limited. This study examines all available images of Arabian Sea humpback whales obtained between 2000 and 2018 for evidence of disease, predation, epizoites, ectoparasites, and human-induced scars and wounds. Tattoo skin disease-like lesions were detected in 41% of 93 whales, with a roughly equal distribution between males and females. Prevalence of the disease was significantly higher in 2012–2018 (51.7%) than in 2000–2011 (27.6%). Killer whale tooth rakes were detected on the ventral surface of the tail flukes of 12% (95% CI 4.5–18%) of 77 individuals. Roughly two thirds (66.6%: 95% CI 52–80%) of the 42 individuals represented by good quality photographs of the caudal peduncle region at the fluke insertion bore scarring patterns consistent with entanglement in fishing gear. At least two individuals showed severe injuries or deformations likely caused by interactions with fishing gear. Six individuals had injuries consistent with vessel strikes. Documented entanglement events from Oman and Pakistan involved large-mesh nylon gillnets, known to be used extensively throughout the Arabian Sea. These findings indicate an urgent need to design effective measures for the management and mitigation of threats, and to continue monitoring Arabian Sea humpback whales, with an emphasis on methods that allow continued and expanded assessment of health, body condition, and anthropogenic interactions.

KEYWORDS: HUMPBACK WHALES; ARABIAN SEA; DISEASE; POXVIRUS; EPIZOITES; CYAMIDS; GILLNETS; FISHERIES; PHOTO-ID; SATELLITE TAGGING

[1] Megaptera Marine Conservation, Netherlands.
[2] Cetacean Conservation Medicine Group, Peruvian Centre for Cetacean Research, Museo de Delfines, Lima 20, Peru.
[3] Future Seas Global, PO Box 286, PC 116, Mina Al Fahal, Sultanate of Oman.
[4] Wildlife Conservation Society, 2300 Southern Blvd, Bronx, NY 10460-1099, USA.
[5] Environment Society of Oman, PO Box 3955, PC 112, Ruwi, Sultanate of Oman.
[6] Five Oceans Environmental Services, PO Box 660, PC 131, Ruwi, Sultanate of Oman.
[7] Biology Department, Swarthmore College, 500 College Ave., Swarthmore PA, 19081 USA.

INTRODUCTION

Humpback whales in the Arabian Sea comprise the only known population that does not undertake the long-range latitudinal seasonal migrations typical of the species. High primary productivity associated with seasonal upwelling ensures that Arabian Sea humpback whales (ASHW) can find abundant prey as well as the tropical conditions associated with mating, calving and nursing (Reeves *et al*., 1991; Mikhalev, 1997; Papastavrou and Van Waerebeek, 1997; Minton *et al*., 2011). Illegal Soviet whaling in the mid-1960's resulted in the killing of 242 humpback whales off the coasts of Oman, Pakistan and India, and scientists on board the vessels estimated that they had taken 60% of the whales in the population (Mikhalev, 1997). Of the likely range countries for this sub-population, dedicated vessel-based surveys have, until recently, been limited to the coastal waters of Oman. Research conducted between 2000 and 2011 confirmed that the population is genetically distinct and isolated (Pomilla and Amaral *et al*., 2014), and that fewer than 100 individuals are likely to remain in Omani waters (Minton *et al*., 2011), factors that contributed to an Endangered IUCN Red List status (Minton *et al*., 2008). Opportunistic sightings, recording of humpback whale song, and reports from fisheries crew-based observers in recent years have also shown that humpback whales are present off the coasts of India and Pakistan, and in the Arabian/Persian Gulf (Mahanty *et al*., 2015; Dakhteh *et al*., 2017; Moazzam and Nawaz, 2017; Madhusudhana *et al*., 2018; Sutaria, 2018).

While much has been learned about the distribution, habitat use, genetics and conservation status of ASHW off the coast of Oman in recent years (e.g. Minton *et al*., 2011; Pomilla *et al*., 2014; Willson *et al*., 2017), little is known about the population's health or general body condition, and quantifiable anthropogenic threats to the population's future survival have rarely been assessed in a systematic manner. Data collected on board Soviet whaling vessels in the 1960s provided some insight into the biology and health of this population, confirming a Northern Hemisphere breeding cycle, and detecting various pathologies, including a heightened prevalence of liver disease (Mikhalev, 2000). Field observations and photographic evidence obtained during dedicated cetacean surveys between 2000 and 2011 indicated that this population exhibited a high prevalence of lesions, conservatively identified as tattoo skin disease-like (TSD-L) as their poxvirus aetiology had not yet been studied (Van Bressem *et al*., 2014a). Examinations of photographs obtained between 2000 and 2004 indicated that 30–40% of the whales assessed bore scars consistent with fisheries entanglement (Minton *et al*., 2011).

Increasing concern about the conservation status and future prospects for this Endangered population suggests that a thorough assessment of natural and anthropogenic threats to the population is necessary. Visual health assessments using high resolution images of free-ranging cetaceans have proven to be an effective means to assess general health and body condition (Pettis *et al*. 2004, Van Bressem *et al*., 2014a) and occurrence and prevalence of barnacles (Kane *et al*., 2008). This methodology is also an effective means to examine the rate of anthropogenic scarring in cetacean populations, particularly those caused by vessel strikes (Moore *et al*., 2013; Hill *et al*., 2017, Bradford *et al*. 2009), interaction with fishing gear (Robbins and Mattila, 2000; Neilson *et al*., 2009; Knowlton *et al*., 2012; Robbins, 2012; Basran *et al*., 2019), satellite tag insertion (Andrews *et al*. 2019, Mizroch *et al*., 2010; Robbins *et al*., 2013; Robbins *et al*., 2016), as well as predatory attempts by killer whales (Mehta, 2004; Naessig and Lanyon, 2004; Steiger *et al*., 2008; Capella *et al*., 2018).

In this study the authors undertook a detailed and systematic examination of all the photographs obtained during 17 years of vessel-based humpback whale research as well as during opportunistic encounters off the coast of Oman, in an effort to quantify the prevalence of cutaneous diseases, predation, and anthropogenic injuries as well as to examine the presence of epizoites and ectoparasites.

METHODS

Photographs and individual identification

All of the photographs taken during both dedicated cetacean surveys and opportunistic sightings of humpback whales off the coast of Oman between 2000 and 2018 were compiled for detailed examination by GM and MFB. Most photographs were taken from vessel-based survey platforms, usually a 6.5m long rigid-hulled inflatable boat. A few photographs were obtained from larger vessels, and a very small number of underwater images were provided by dive operators. While photographs taken in 2000 and February 2001 were on print or slide film, all those taken from October 2001 onward were taken with digital SLR cameras and stored as high-resolution jpgs or raw Canon CRW images. Images were all attributable to known individuals in the Oman Humpback Whale Photo-identification Catalogue[8] and were assigned a quality score (based on resolution, glare and angle of the photo showing the most relevant body part [Friday *et al.,* 2008]). Age classes were assigned whenever possible based on estimated size of the individual, with animals less than 50% of the length of accompanying fully grown whales considered 'calves of the year'. Sex was determined either following genetic analysis of biopsy or sloughed skin samples, or through the presence of a calf (female) or confirmed singing (male).

Assessment was always conducted on the highest resolution image available. GM and MFB examined every image, separated copies of those that contained any evidence of skin disease, injuries, and epizoites, so that they could be examined by the other co-authors, particularly in dubious cases. Photographs were assessed and scored using the protocols and methods developed in previous studies wherever possible (see more detail and references for each type of scarring/disease below).

Tattoo Skin Disease-like lesions

All images from the photo-identification catalogue were examined for the presence of cutaneous lesions consistent with TSD-L (Van Bressem *et al*., 2014a). Whales were only included in the epidemiological analysis if at least one image of average or high quality (Friday *et al.*, 2008) of one flank was available. The TSD-L lesions were identified based on their typical appearance, i.e. irregular or rounded light grey cutaneous marks often showing a contrasting outline. Other skin marks that resembled this condition but lacked characteristic features, were considered dubious and the whales were classified negative. Estimated lesion size (LS) in comparison to body parts, especially the dorsal fin, was classified according to its widest diameter, as small (LS < 50mm), medium-sized (50mm < LS < 100mm), large (100mm < LS < 200mm) or very large (LS > 200mm). The topography, the number of lesions and the percentage of the visible body surface affected were also investigated. The minimal duration of the disease was evaluated in whales that were re-sighted within the study period. We further evaluated the influence of sex on prevalence. Statistical significance of differences in prevalence between two study periods (2000–2011 and 2012–2018) was tested with a McNemar Chi-Square Test ($\alpha = 0.05$).

Epizoites and ectoparasites

The presence of sessile whale barnacles was noted wherever they occurred on the whales' bodies. However, only good quality photographs of the whole ventral surface of tail flukes were used to estimate prevalence of barnacles or barnacle scarring in our sample to facilitate comparison with other populations represented in photo-identification catalogues. Flukes were assigned prevalence scores based on the percentage of the ventral surface covered either by live barnacles or characteristic round pigmented barnacle scars (typically black against white or white against black): (1) < 10% of the fluke is covered by barnacles or their scars; (2) 10–30% coverage; (3) 31–50% coverage; and (4) > 50% marked by barnacles or barnacle scars. The occurrence of stalked goose barnacles (*Conchoderma auritum*) was opportunistically recorded. Finally, the presence and body distribution of whale lice (*Cyamidae*) were recorded, and prevalence calculated.

Predation attempts

All visible portions of whales' bodies were examined for evidence of attempted killer whale (*Orcinus orca*), shark, or cookie cutter shark (*Isistius* spp.) predation. Killer whale tooth marks were defined as a set of three or more parallel, linear scars approximately equidistant from each other (*sensu* Mehta *et al*., 2007). To ensure consistency and minimise bias within our own dataset and to provide a comparable estimate, only good quality photographs portraying the entire ventral surface of the tail flukes were used to calculate prevalence of visible evidence of killer whale predation attempts (Naessig and Lanyon, 2004; Mehta *et al*., 2007; Steiger *et al*., 2008; Capella *et al*., 2018). Following Capella *et al.* (2018), rake marks were categorised by the intensity of the visible scarring:

[8] Curated by GM, with data ownership and oversight by the Environment Society of Oman on behalf of the Government of Oman.

(1) no killer whale scarring; (2) a single set of rake marks or rake marks affecting < 10% of one lobe; (3) at least one set of rake marks per lobe or rake marks covering up to 50% of one lobe; and (4) numerous marks covering more than half the fluke or with missing sections on the fluke tips or trailing edges. We added a category for damage (e.g. semi-circular amputations on the trailing edge of tail flukes) that seemed most likely to be caused by killer whale predation, even if tooth rakes were not present (P). The analysis included other signs of predation on any whale body part visible in the photographic dataset. Bites by cookie cutter sharks were defined as single or numerous, oval-shaped scars and fresh crater-like wounds (Dwyer and Visser, 2011; Bertulli *et al*., 2012).

Entanglement scarring

All photographs were examined for evidence of scars or wounds consistent with interaction with fishing gear, irrespective of the portion of the body depicted or the quality of the photograph. All images that depicted linear scars (wrapping, see S3 in Table 1) such as those typically associated with rope or net abrasion as described by various authors (Robbins and Mattila, 2001, 2004; Neilson *et al*., 2009; Robbins, 2012; Basran *et al*., 2019) were highlighted and flagged for inspection by at least two of the authors. Images were assigned a score for the likelihood that the visible scarring was caused by entanglement using the system developed by Robbins and Mattila (2001) (Table 1).

Table 1

Definitions of scarring and entanglement codes (Robbins and Mattila, 2001).

Summary of scar codes	
Code	**Scar code description**
S0	No visible marks.
S1	Non-linear marks or apparently randomly oriented linear marks.
S2	Linear marks or wide areas lacking pigmentation that did not appear to wrap around the feature (tail flukes, caudal peduncle or dorsal fin).
S3	Linear or wide scars which appeared to wrap around the feature.
S4	At least one visible linear notch or indentation (generally on the dorsal or ventral peduncle).
S5	Extensive tissue damage and deformation of the feature.
Summary of individual entanglement status codes	
Code	**Description**
U	**Unknown**: photographs not sufficient for analysis.
E0	**No evidence of entanglement** (no marks present).
E1	**Unlikely**: Marks were observed but did not suggest a previous entanglement. Scar codes did not generally exceed S2 in any documented region.
E2	**Possible**: Entanglement-like elements were present, but there was no consistent pattern. At least one region was generally assigned a scar code of S3 or higher.
E3	**Likely**: Marks appeared to be entanglement-related and minor tissue damage was evident. At least two regions were generally assigned scar codes of S3 or higher.
E4	**Likely with severe damage**: Marks appeared to be entanglement-related and major tissue damage was evident. At least two regions were assigned scar codes of S3 or higher. At least one region was coded as S5.

Photographs were further filtered to include a subset of those that clearly depicted the caudal peduncle and the leading edge of the fluke insertion, determined in conjunction with the head/mouth and flippers, to be the body parts most likely involved in entanglement (Robbins and Mattila, 2001, 2004; Johnson *et al*., 2005). Only this subset of images was used to calculate prevalence of entanglement scarring in the population.

Following Robbins and Mattila (2001), the minimum percentage of individuals with injuries likely caused by entanglement was then estimated by dividing the number of individuals with a score of at least E3 by the total number of individuals with adequate coverage. A maximum frequency of individuals with high-probability injuries was calculated by dividing the sum of individuals with an E2 scarring code (i.e., possible) and higher by the total number of individuals represented in the analysis. The 95% confidence interval (CI) of percentages was calculated based on the standard error (CI = p ± 1.96*(√(p*(100 – p)/n)), where p = the percentage of individuals with a particular entanglement status and *n* = the total number of animals examined.

Additionally, photographs and video from five documented disentanglement events off the coasts of Oman and Pakistan were examined to gain insight into the type and configuration of gear implicated in entanglements in the Arabian Sea, and the body parts that were affected.

Vessel strike

Vessel strike is defined as a forceful impact between any part of a boat and a live whale resulting in death or physical trauma (Van Waerebeek *et al*., 2007; Cates *et al*., 2017). All images were searched for possible signs of injury induced by vessel hull strike or boat propellers using methods developed in other studies (e.g. Van Waerebeek *et al.,* 2007; Hill *et al*., 2017). Due to the very small number of detected cases, and the different areas of the body where such injuries could be acquired, findings are reported in a descriptive manner.

Wound healing at tagging sites

Photographs of whales that were fitted with satellite tags in 2014–2017 and re-sighted afterwards were examined carefully for evidence of swelling, skin loss, tissue extrusion, fluid exudate, depression, changes in pigmentation and whale lice infestation at the site of tag implantation, as described by Andrews *et al.* (2019). The scoring system from that study was used to characterise the severity of these conditions, with 1 being the least severe and 3 the most serious.

Overall body condition

Photographs were assessed for any gross evidence of abnormal body condition. Prominence of the ribs and presence of a concavity in the occipital and cervical region, some distance behind the blowholes were considered an indication of emaciation or poor body condition (Pettis *et al*., 2004; Clegg *et al*., 2015).

RESULTS

Over 33,000 photographs were analysed, and just over 2,000 of them were extracted and assessed in detail for evidence of disease, parasites and epizoites, predation and anthropogenic scarring. Generally, the quality and resolution of photographs increased over time, as cameras became more sophisticated and photographers more experienced. Images collected from 2011 onward were both of higher resolution and depicted a wider range of body parts than those collected prior to 2006.

Images represented a maximum of 115 individuals sighted between 2000 and 2017. Of these, 80 were represented by both tail fluke and dorsal fin images. However, in some cases individuals were represented only by one feature or the other, introducing the possibility of double representation of individuals for which dorsal fin images could not be linked to fluke images. Although all photographs of the photo-identified whales were examined, the total number of individuals included in each type of analysis varied based on the quality and availability of images of different features (Table 2). With the exception of two calves, all other individuals were considered adults.

Table 2

A summary of the criteria used to filter photographs and resulting sample sizes used for each category of analysis of skin disease, ectoparasites, attempted killer whale predation and entanglement scarring of humpback whales off the coast of Oman.

Analysis and criteria for filtering photographs	Number of individuals
TSD-L: average or better quality dorsal fin and flank photographs	93
Barnacle assessment: average or better quality tail fluke photographs	85
Killer whale toothrakes: good or better quality tail fluke photographs	77
Entanglement scarring: good or better quality photographs of the caudal peduncle region focusing on the fluke insertion	42

Tattoo Skin Disease-like lesions

Of the 93 individuals (36 males, 26 females, 31 of unknown sex) for which suitable photographs were available, 38 (41%, 95% CI 31–51%) had TSD-L lesions, including 15 males and 11 females. The two calves in the sample were negative. Lesion size fluctuated between small and very large, while their coverage varied between less than 10% to over 50% of the visible body surface (Fig. 1). The tattoo-like marks persisted over 2 to 14 years in 10 whales for which photographs were available to compare lesions between multiple sightings, with the proportion of lesions to the visible body surface increasing over time in six of them, but not in the other four. TSD-L lesions prevalence was similar in the 36 males (41.7%, 95% CI 25.6–58%) and 26 females (42.3%, 95% CI 23–61%), allowing sexes to be grouped for further analysis. To examine whether prevalence levels varied over time, we divided the study period into two subperiods: 2000–2011 and 2012–2018. This analysis was only possible for 29 whales that were represented by suitable photographs in both subperiods. Prevalence of the disease was significantly higher (McNemar test, df = 1, 1– tail p = 0.02275) in 2012–2018 (51.7%, 95% CI 33.5–70%) than in 2000–2011 (27.6%, 95% CI 11–44%).

Epizoites and ectoparasites

Of the 85 whales that were evaluated for sessile whale barnacle (*Coronula diadema*) presence and/or scarring on their tail flukes, four (4.5%, 95% CI 0.7–8.8%) had no barnacles or scarring at all, one (1.2%) had barnacles and/or scars covering 10–30% of the ventral surface of its flukes, and 79 (93%, 95% CI 87–98%) had barnacles covering less than 10% of the ventral surface of their flukes, with most of these being concentrated only on the fluke tips. Barnacles were sometimes observed in images of other body parts, including more commonly on the throat or flippers, and more rarely on the flanks or dorsum near the head. Stalked goose barnacles were detected on the tail flukes of nine whales (10.6%, 95% CI 0–29%), attached to *C. diadema*.

Because whale lice were rarely seen on dorsal fins or tail flukes, the areas most often represented in the photographic dataset, a systematic assessment could not be carried out, and prevalence levels should be considered as minimum. Of 63 whales with photographs of a suitable resolution, minimum prevalence of whale lice infestation was 27% (*n* = 17) during all sighting years. The cyamids were generally seen in one to four patches on the flank, back and tailstock. In adult male OM10-001 a minimum of 14 whale lice had colonised the skin close to the blowholes. Whale lice were occasionally seen in association with lesions.

Predation attempts– killer whales and sharks

Scarring consistent with killer whale tooth rakes was sometimes detected on the flanks and pectoral fins. However, as parallel scars on the flanks were difficult to distinguish from parallel curved or linear scars that could result from conspecific aggression, following the protocol of other studies, we focused on tail flukes as a more reliable measure of rates of non-lethal killer whale scarring. Of the 77 whales included in this analysis, nine (12%, 95% CI, 4.5–18% – including 6 males and 2 females) showed unequivocal killer whale tooth rakes on one or both lobes of their flukes. Large, semi-circular partial amputations of the fluke trailing edge, consistent with killer whale or shark bites, were seen in six additional individuals (8%, 95% CI, 1.8–13%) that did not bear tooth rakes (Fig. 2). In all cases where scarring was detected, it was fully healed and was likely to have occurred well before the photographs were taken. Fresh killer whale or shark injuries were not detected during the study period. Typical cookie-cutter shark wounds and scars were not observed on the visible body surface of any whale.

Entanglement scarring

During an initial assessment using good quality tail fluke and dorsal fin photographs of 79 whales, 33 individuals were deemed to bear scarring consistent with entanglement. A further four whales were photographed with fishing gear attached to dorsal fins or flukes at some point during their life. This analysis, based only on the photographs typically available in a catalogue for individual identification, yielded an entanglement scarring prevalence of 46.8% (95% CI 38–60%) for the whole study period.

A separate analysis of 42 individuals represented by good quality photographs of the fluke insertion on the caudal peduncle yielded a minimum prevalence rate of 66.6% (95% CI 52–80; Table 3) based on the proportion

Fig. 1. Typical tattoo skin disease-like (TSD-L) lesions with an irregular, rounded form, and a contrasting outline in humpback whales from Omani waters: (A). Small to large TSD-L lesions on the back and flank of adult male OM15-002 in November 2015; (B) Small to very large TSD-L lesions covering an estimated 60% of the back and flank of adult male OM02-019 in November 2015; (C) Numerous small to large TSD-L lesions on the tailstock of adult OM17-007 (unknown sex).

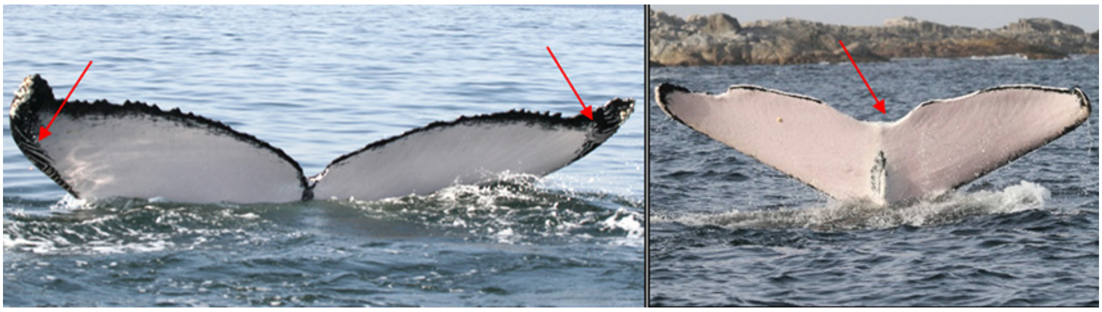

Fig. 2. Individuals OM00-009 (right) bearing signs of non-lethal killer whale or shark predation without characteristic killer whale tooth rakes, and OM14-013 (left), showing characteristic tooth rakes on the tips of both the left and right lobes of the tail flukes, as well as barnacle colonisation on the tips of both lobes in a pattern common for the humpback whales off the coast of Oman examined for this study.

Table 3

Results of entanglement scarring analysis conducted on a subset of 42 humpback whales represented by good quality photographs of the caudal peduncle region, following Robbins *et al.* (2001).

Entanglement status code	Number of individuals	Incidence (95% CI)
E1 – Unlikely/no evidence	6	14.3%
E2 – Possible/uncertain	8	19.0%
E3 – Likely	24	57.1%
E4 – Likely with severe damage	4	9.5%
Minimum entanglement estimate (E3/E4 combined)	28	66.6% (52–80)
Maximum entanglement estimate (E2–E4 or Definite)	36	85.6% (75–92)

of individuals with entanglement codes of E3 (likely) or E4 (likely with severe damage). The maximum entanglement rate that included animals with entanglement status codes of E2–E4 was 85.6% (95% CI 75–92%; Table 3). Minimum scarring rates were slightly higher for males (75%, n = 20) than for females (64%, n = 14). However, this difference was not statistically significant (Fisher's Exact Test p = 0.382).

Due to the small overall sample size, and the general lack of good quality photographs of each individual's caudal peduncle region in consecutive years, it was not possible to estimate rates of entanglement scar acquisition over time. However, four whales were encountered with fishing gear on them at some point during their sighting history, and eight individuals had open/unhealed wounds that were consistent with wrapping or abrasion from fishing gear. These included the only two calves in the dataset that were represented by fair quality photographs: both of which bore clear linear scars and open wounds consistent with wrapping from fishing gear. Both were photographed in shallow water in close proximity to active fishing gear, including anchored gill nets and traps with lines to buoys at the surface.

At least two individuals suffered severe permanent damage likely caused by fisheries entanglements: adult male OM11-010 was missing the entire left lobe of its tail flukes as well as a significant portion of its dorsal fin (Fig. 3a, b). Scarring on the remaining right lobe of the flukes was symmetric to the line of amputation on the left lobe, indicating that severe constriction by fishing line/net led to necrosis and amputation of the left fluke. Scarring on the flank under the damaged dorsal fin indicates that this was also caused by constriction from fishing gear. OM11-010 was first observed in 2011, at which time the fluke and dorsal injuries had completely healed and formed scar tissue. The whale was observed again by divers off the coast of India in December 2019. Whale lice and TSD-L were not detected on this individual, but barnacles were present in the area of healed tissue around the fluke amputation.

Adult female OM03-004 suffered a severe deformity of the lumbar spine with abdominal organs apparently bulging on the right sides (Fig. 3c, d). Though a prolonged constriction by fishing gear around the peduncle posterior to the dorsal fin may have caused these anomalies, entanglement scarring at the caudal peduncle

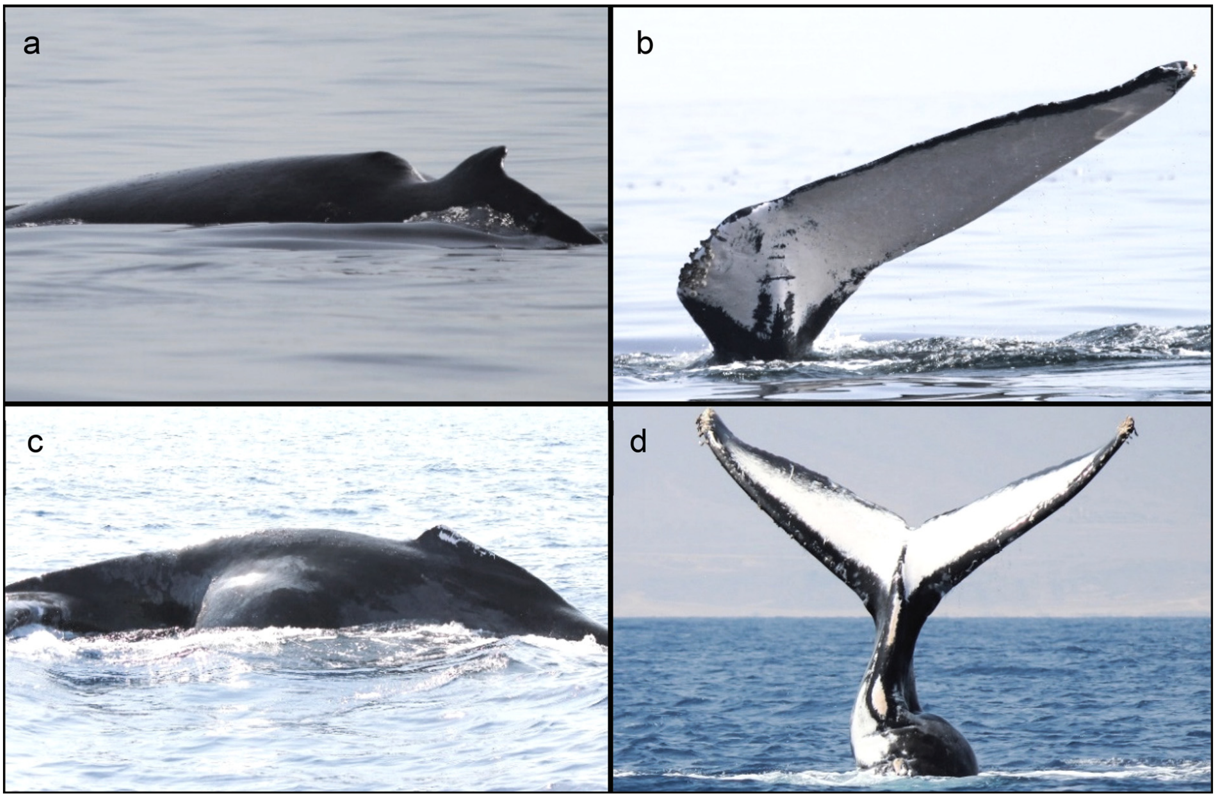

Fig. 3: Humpback whales with severe mutilations believed to be caused by fisheries entanglement: OM11-010 (a, b) and OM03-004 (c, d) although, a congenital deformity in the latter cannot be excluded.

seems of relatively low severity and not proportionate to the scale of the deformity. The advanced lumbar/caudal scoliosis (Fig. 3c,d) may either be congenital or traumatic in origin, or some combination of both. Despite the severe deformities, OM03-004 has been observed in multiple years between 2003 and 2016, and in one year with a calf, so appears to be thriving. She had TSD-L lesions in 2003 and 2015, with the cutaneous lesions covering 5 to 20% of her visible body during both periods. Whale lice were present in 2003, 2004, 2014 and 2015 close to the right bulge.

Documented entanglement events in the Arabian Sea

Photographs and video from five live humpback whale entanglement events that occurred between 1999 and 2017 were examined, including four from Omani waters, and one from Pakistan (Table 4). While thicker nylon nets with a large mesh size designed to tangle tuna and other large predatory fishes were involved in most of the events, cotton mesh entanglement occurred in 1999. Only one incident in 2017 involved a medium-sized mesh net made of clear nylon monofilament.

Entanglements usually involved multiple body parts, including the head, dorsal fin, pectoral fins and tailstock, but the healing of the resulting injuries could not be assessed based on the available information. Most nets used Styrofoam surface floats that would have caused additional drag when the whale was swimming, and at least four of the 10 incidents also mention heavy stone, cement or metal anchors or weights that caused the line to cut deeper into the whales' flesh and required greater effort for the whale to continue surfacing.

Six additional incidents of live entanglement of humpback whales were recorded from Oman between 1990 and 1998, five of which resulted in successful disentanglements (Minton, 2004). Each of the six documented entanglement events involved bottom set gillnets. Photographs and videos (not available for re-analysis in this study, but examined by GM in 2004) show the head, dorsal fin, pectoral fins and tailstock to be the regions entangled, but the resulting injuries could not be assessed. In at least two of the six documented cases, specific mention is made of anchors and heavy concrete weights, which kept the whales in place and caused ropes and net to cut into the skin and blubber of the entrapped animals (Minton, 2004a).

Table 4

Documented humpback whale entanglements in Oman and Pakistan between 1999 and 2020.

Date	Location	Type of gear	Body parts where gear is present/ wrapped	Outcomes
5 April 1999	Muscat, Oman	Large mesh cotton gillnet with green nylon lead ropes and multiple Styrofoam and plastic floats.	Draped over back and hooked behind dorsal fin and around caudal peduncle. Rope visible over dorsal fin and back behind dorsal fin.	Successfully disentangled (RB present).
29 Feb. 2000	Duqm, Oman	Large mesh green nylon gillnet with braided lead rope and heavy anchors in shallow sandy bay.	Gear wrapped over tail stock and pectoral fins. Heavy concrete weights holding whale in place.	Successfully disentangled (GM and TC present).
16 Aug. 2006	Azaiba, Oman	Large mesh green nylon gillnet with braided lead rope and heavy anchors in shallow open coast.	Gear is under the water and appears to be on head/mouth. The dorsal fin and back are free of gear.	Successfully disentangled (RB present).
12 Dec. 2016	Indus Canyon, 140km south of Karachi	Large mesh green nylon gillnet with braided nylon lead rope and multiple white Styrofoam floats.	Gear is visible over entire back visible above water – from just behind the blowhole to the caudal peduncle.	Successfully disentangled (reported on social media by WWF Pakistan).
13 Nov. 2017	100km offshore Muscat, Oman	Medium-sized mesh white/transparent nylon monofilament net with green braided lead rope and multiple Styrofoam floats.	Net completely wrapped around head, back, dorsal fin flippers and tail.	Documented by sport fishermen who at least partially disentangled the animal and shared video via social media.

Vessel strike

Two individuals, both of unknown sex, had injuries consistent with severe blunt trauma, most likely caused by vessel hull strikes. Whale OM02-009 showed a deep broad scar behind the head, and adult OM17-010 had a deep, healed injury on the back and dorsal fin (Fig. 4). Four additional individuals bore characteristic signs of small propeller scars. At least two of these (male OM00-009 and female OM15-006) also showed evidence of entanglement. Prevalence of propeller scars and/or vessel hull strike in 96 whales was 4% (95% CI 0.2–8%) and 2.1% (95% CI 0–5%), respectively.

Wound healing at tagging sites

Of the 20 tag deployments that were attempted between 2014 and 2017, 19 made contact with whales, and 15 were classified as successful, having transmitted for longer than one day. Eleven animals were successfully instrumented once, two (OM01-006 and OM02-019) were successfully instrumented twice, two were successfully instrumented once and unsuccessfully instrumented once, and two animals unsuccessfully tagged once (Willson *et al*., 2015, 2016a and 2018).

Tissue responses were assessed in eight individuals (6 males, 1 female, one of unknown sex) that were re-sighted in periods ranging from a few days to 32 months after tagging. Observed responses included depression at the tag site (n = 4), change in pigmentation (n = 2), swelling (n = 3) and tissue loss (n = 2), all scored as a category 'one' following Andrews *et al.* 2019 (Table 5). There was no evidence of infection in any whale.

Overall body condition

None of the individuals examined in this study showed any evidence of emaciation. One of the two calves represented in the photographic dataset (OM12-004) appeared in sub-optimal condition with its visible body area covered by light grey cutaneous marks and entanglement injuries. However, image quality was poor, and the calf was never re-sighted, preventing further assessment.

DISCUSSION

Tattoo Skin Disease-like lesions

Prevalence of TSD-L lesions was very high (41%) in 93 humpback whales photographed off the coast of Oman in 2000–2018. As observed in most cetacean species, prevalence was similar in males and females (Van Bressem

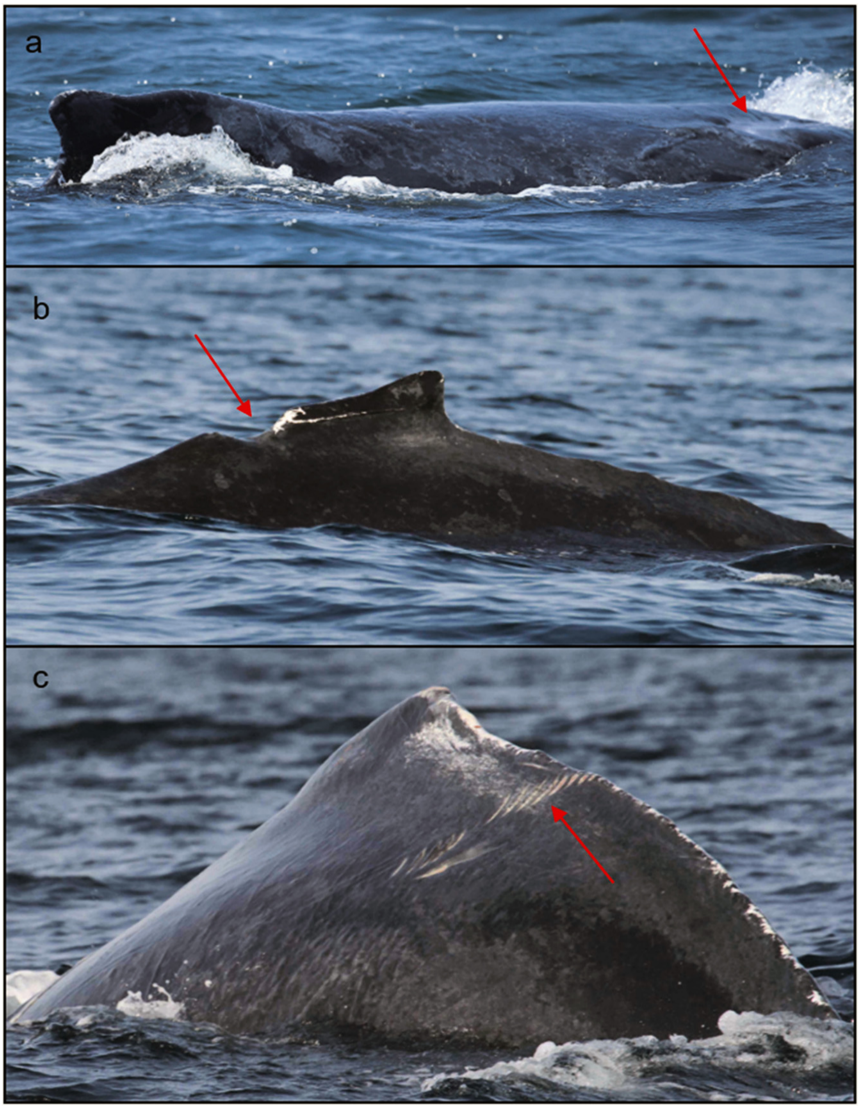

Fig. 4. Evidence of vessel injury in humpback whales in Oman: (A) OM02-009 in May 2015 (unknown sex); (B) OM17-010 in November 2017 (unknown sex); and (C) OM00-009 in March 2017 (male).

et al., 2009). It significantly increased over time in 29 whales that could be evaluated in both the periods between 2000 and 2011 (27.6%) and between 2012 and 2018 (51.7%). Though this may be due in part to improved image quality and quantity for each individual from 2011 onwards, a significant rise in TSD-L prevalence had already been observed in this population from 2000 through 2011 (Van Bressem *et al.,* 2014a). Similarly, the percentage visible body surface affected by TSD-L lesions also tended to grow over time in at least six of the 10 whales with sufficient resight history.

The high prevalence of TSD-L dermatopathy, the presence of very large lesions, the high proportion of affected visible body surface together with a protracted period of infection in some whales suggest that their immune system was not able to clear the disease. Environmental stressors such as fishing gear entanglement and pollution have repeatedly been shown to lower cetacean immune response, to increase the risk of infection, and to alter the epidemiological pattern of tattoo skin disease (Hall *et al.,* 2006; Reif *et al.*, 2009; Van Bressem *et al.*, 2009a, 2018; Rolland *et al.* 2012, 2017, 2019). During the present study, at least 67% of the whales had entanglement lesions that likely caused long-lasting suffering and stress. The threefold increase in vessel traffic documented in the Arabian Sea between 2004 and 2014 (Willson *et al.,* 2016b) may also result in increased levels of stress hormones, as described in right whales from the North Atlantic (Rolland *et al*., 2012). Thus, anthropogenic stress may have played a role in the high prevalence of TSD-L in humpback whales from Oman.

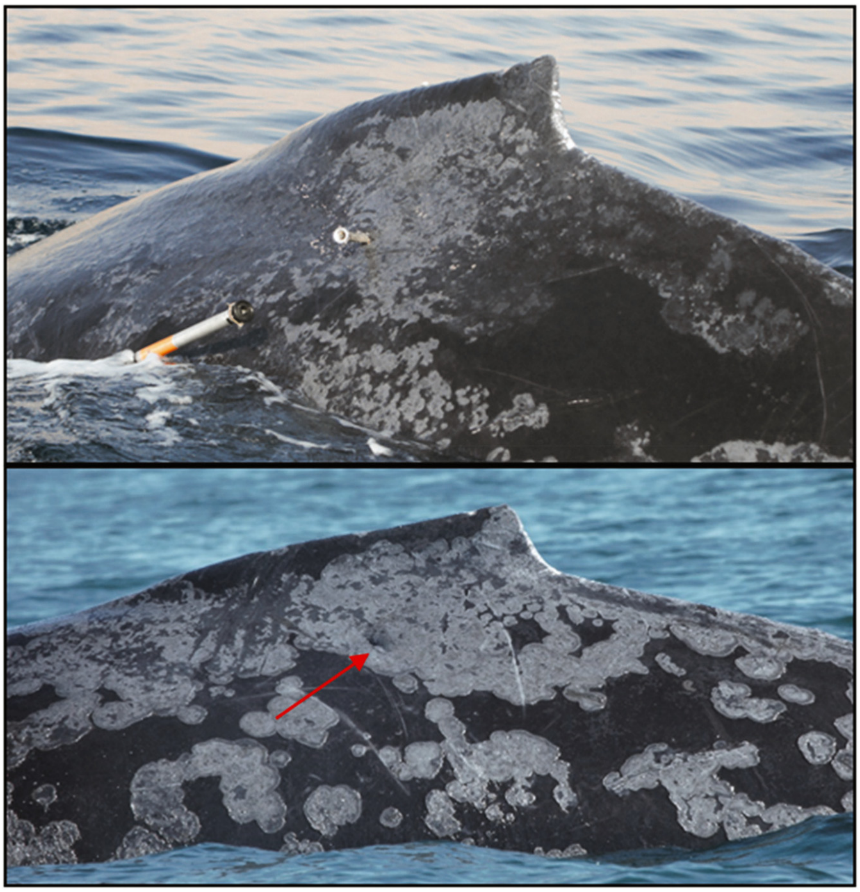

Fig. 5. *In situ* tag in humpback whale OM02-19 in March 2015 (above), and scar in November 2015 showing a depression (arrow) of similar size to the tag (below). The whale is also covered by skin lesions.

Epizoites and ectoparasites

The coverage of sessile whale barnacle infestation on the ventral surfaces of tail flukes in Oman appears to be low compared with that of Southern Hemisphere humpback whale populations. The authors of this study have collectively worked with humpback whale populations in Angola, South Africa, Kenya, Madagascar, Mayotte, Benin, Gabon, and the southeast Pacific and have observed a more extensive coverage of barnacle scarring in a higher proportion of whales in all these locations. However, we could not find any published studies with quantifiable rates of barnacle coverage from the Southern Hemisphere or anywhere else in the world. Environmental factors regulating barnacle colonisation on humpback whales may be related to temperature, salinity or water flow (e.g. Carrillo *et al.,* 2015).

The stalked goose barnacles occurred at a low to medium level in 10.6% of the 85 whales. Whale lice infestation was limited to small aggregations in some animals and did not suggest reduced swimming speed or poor health, as observed in the North Atlantic right whale (Pettis *et al*., 2004; Moore *et al*., 2006).

Killer whale scarring

The 12% rate observed in this study is similar to those reported for humpback whales on low-latitude breeding grounds and high-latitude breeding grounds where rates ranged from a minimum of 6% to a maximum of 26% (Mehta *et al.*, 2007; Steiger *et al.*, 2008; Capella *et al.,* 2018).

Results of killer whale scarring studies in humpback and other baleen whales conducted by Mehta *et al.* (2007) and Capella *et al.* (2018) indicate that killer whale attacks occur mostly on calves, near breeding sites and during the first migration to feeding areas. Killer whale sightings off the coast of Oman are relatively rare (Minton *et al*., 2010; 5OES and ESO, 2021), and are thought to represent transient populations that range throughout the

Table 5

Evaluation of healing of tag insertion sites for those humpback whales that were instrumented with satellite tags off the coast of Oman. Scoring of tag site condition follows Andrews *et al.* (2019). Note that two individuals, OM01-006, and OM02-019 were successfully tagged in two separate years, but that there was no re-sight data after the second tagging of OM01-006.

ID	Sex	Est. length (m)	Age category	Tag date	Tag side	Tag penetration (%)	Tag scar observation date	Number of days elapsed	Tag scar code & condition
OM00-003	Male	11–13	Adult	28/02/2014	Right	75	30/11/2015	640	Depression (1) Swelling (1)
OM01-006	Male	8–12	Adult	14/03/2015	Right	90	23/11/2017	985	Depression (1) Depigmentation (1)
OM01-006 (second tagging event)	–	–	–	16/11/2017	Left	25	No data		No data
OM02-019	Male	12	Adult	25/02/2014	Right	100	28/02/2015	368	Depression (1)
OM02-019 (second tagging event)	–	–	–	13/03/2015	Left	50	30/11/2015	262	Depression (1)
OM02-020	Male	12	Adult	21/02/2014	Right	20	23–28/02/2014	7	Tissue loss (1) Pigmentation change (1) Possible swelling (1)
OM10-01	Male	Unk	Adult	22/02/2014	Left	60	26/02/2014	4	Swelling (1)
							14/03/2015	385	Depression (1)
OM14-013	Male	Unk	Adult	22/11/2015	Left	90	28/11/2015	6	Tissue extrusion (1) Swelling (1)
OM17-005	Unk	Unk	Adult	16/11/2017	Right	40	25/11/2017	9	Tissue loss (1)
OM02-008	Female	Unk	Adult	21/11/2017	Right	50	22/11/2017	1	Fluid exudate (1)

Northern Indian Ocean (e.g. Mohsenian *et al*., 2019 and unpublished data held by the authors; Anon., 2020). More common in Omani waters, false killer whales (*Pseudorca crassidens*) could also have inflicted some of the predation scars, as aggressive interactions between this species and ASHW have been documented (Baldwin *et al*., 2011) and false killer whales have been documented harassing humpback whales on other breeding grounds (e.g. Weir *et al*., 2013).

Entanglement scarring

This study used a systematic approach to estimate entanglement history from diagnostic injuries at the caudal peduncle and fluke insertion. The results indicate that at least 67% of the 42 whales examined have likely suffered a non-lethal entanglement. However, this estimate is expected to be biased low, most notably because it is a study of live whales and does not include any individuals that died from entanglement before they could be sampled (Robbins and Mattila, 2001).

The estimated minimum entanglement rate in this study is similar to rates detected in other populations. In the Gulf of Maine at least half of the humpback whale population bears entanglement injuries (Robbins and Mattila 2001, 2004; Robbins 2009, 2012), while in Icelandic waters a minimum of 24.8% and a maximum of 50.1% of the whales bore scarring consistent with previous entanglement (Basran *et al*., 2019) and in south eastern Alaska, 52–78% of the individuals exhibited unambiguous entanglements injuries (Neilson *et al*., 2009).

Photographing of the caudal peduncle area during surveys in Oman was inconsistent, as photographers were focusing on obtaining images used for individual recognition (photo-ID) during studies with multiple additional objectives (biopsy sampling, acoustic sampling and satellite tagging). Only 42 of the 77 individuals that are represented by good quality tail fluke photographs in the Oman catalogue are also represented by good quality photographs of the fluke insertion region of the caudal peduncle. As such, small sample size precluded a meaningful quantification of scarring acquisition throughout the research period, particularly because individuals that were re-sighted over time were not consistently represented by photographs of the caudal peduncle at the fluke insertion site to allow comparison between years. However, it should be noted that throughout the 18 years covered in this study only four cases of entanglement were reported to the authors, and open/unhealed wounds were only observed on eight occasions. The latter included two calves with open linear wounds consistent with entanglement.

Juvenile humpback whales seem more likely to interact with fishing gear than adults, possibly because of their inquisitive nature or lack of experience in avoiding them (Neilson *et al*., 2009; Robbins, 2012; Basran *et al*., 2019). It seems possible that non-lethal entanglements off the coast of Oman or in other parts of the ASHW range mainly affect immature individuals. A live-entanglement case off Qeshm Island in the Arabian/Persian Gulf involved a juvenile (estimated at 6–7m length) which was disentangled by local fishermen attempting to recuperate the net (Dakhteh *et al.*, 2017). It also seems likely that the majority of entanglement events are undetected by authorities or researchers at the time they occur, either because the whales shed gear of their own accord, or fishermen disentangle whales from gear without reporting it to the authorities. Some anecdotal evidence obtained through social media supports the latter theory (unpublished photographs held by authors). Alternatively, a number of whales may die without being discovered at sea or through stranding response efforts.

Vessel strike

Non-lethal vessel strikes seem to be rare in Oman waters, with only two cases of severe blunt trauma detected among 96 whales. However, the actual number of events resulting in mortality is likely to be higher than those detected, as reported for other species and populations (Rockwood *et al.* 2020). Small propeller wounds and scars were seen in four additional whales. In two whales that also had clear signs of entanglement, propeller wounds may have been inflicted when fishermen approached and/or attempted to disentangle the whales. In the Persian Gulf, vessel strike rate appears to be high, possibly linked to the very dense shipping traffic. Of seven documented humpback whale records, two were confirmed and three were probable vessel collision cases (Dakhteh *et al.*, 2017).

Wound healing at tagging sites

Wound healing appeared normal at the tagging sites in eight whales and there was no indication of inflammation, implying that this research methodology is safe and effective for use even in this Endangered population but continued monitoring is recommended.

Conservation implications

This study provides further compelling evidence of the direct interactions between fishing gear and humpback whales in the Arabian Sea, likely due to the overlap of ASHW habitat with areas of increasing artisanal fishing activity (Minton 2004, Minton *et al*. 2015, Willson *et al*. 2018, Tiwari *et al*. 2015; Willson *et al*. 2020). Fisheries are expanding rapidly in Oman (Yousuf et al., 2009; Oman National Centre for Statistics and Information, 2020) and other parts of the known ASHW range, increasing the likelihood of entanglement. Entanglement, even when not lethal, may compromise feeding and swimming due to the drag created by gear (van der Hoop *et al*., 2016; van der Hoop *et al*., 2017), and should also be considered a serious health and welfare issue, given the severe injuries, pain and stress sustained by affected individuals (Cassoff *et al*., 2011; Moore and van der Hoop, 2012; Dolman and Moore, 2017; Dolman and Brakes, 2018). North Atlantic right whales with non-lethal entanglement histories were more likely to exhibit poor body condition than those without entanglement histories (Pettis *et al*., 2017). Analysis of corticosteroid levels in the baleen of a bowhead whale documented evidence of adrenal gland activation caused by a severe fishing rope entanglement (Rolland *et al*., 2019). Non-lethal entanglements can also have long-term impacts on a population's fitness. Stress from repeated encirclement and release from tuna purse-seine fisheries is thought to be the main factor contributing to the lack of recovery of eastern tropical

Pacific spinner (*Stenella longirostris*) and spotted (*S. attenuata*) dolphins, despite the fact that recorded mortalities associated with these fisheries have decreased dramatically (Gerrodette and Forcada, 2005).

The ASHW population off the coast of Oman is small, and presumed to have a very low reproductive rate, based on the paucity of observations of calves over the years (Minton *et al*. 2011, and Authors, unpublished data). In other species low reproductive rates may be caused, at least in part, by the stress and potentially depressed fitness related to previous entanglement(s) (Pettis *et al*., 2017; Rolland *et al*., 2019; Christiansen *et al*., 2020). ASHW off the coast of Oman have two documented areas of important habitat: in the Gulf of Masirah and the Hallaniyats Bay (Corkeron *et al*., 2011; Minton *et al*., 2011; Willson *et al*., 2017). Both of these areas are associated with high productivity, and consequently also with relatively high levels of fishing effort (Minton, 2004; Oman Department of Fisheries Statistics, 2020). The types of gears used in these areas include gillnets, usually set overnight by coalitions of artisanal fishing dhows that sometimes set up to 20km of net between multiple vessels, as well as anchored gillnets and bottomset fish/lobster traps with tethered buoys. Both gillnets and bottom set traps (tethered to lines with surface buoys) are the gear types most frequently involved in entanglement of humpback whales and other cetacean species in other parts of the world (Johnson *et al*., 2005; Read *et al*., 2006; Reeves *et al*., 2013).

The ASHW range in the 1960s extended to the coasts of Pakistan and India, and evidence is emerging in recent years that the population persists in these areas (e.g. Mahanty *et al*., 2015; Moazzam and Nawaz, 2017; Sutaria *et al*., 2017; Madhusudhana *et al*., 2018). Gillnet usage is also prevalent off the coasts of India and Pakistan (Yousuf *et al*., 2009; Moazzam and Nawaz, 2014; Kiani and Van Waerebeek, 2015; Sutaria *et al*., 2015; IWC, 2019; Temple *et al*., 2019; Anderson *et al*., 2020). Movement of a satellite tagged whale from Oman to India and back again in 2017/18 (Willson *et al*., 2018), and the confirmation of a photographic match of a whale first observed in Oman and then off the coast of India in 2019 indicate that ASHW are at risk of entanglement on both sides of the Arabian Sea, as well as in the Arabian/Persian Gulf (Dakhteh *et al.*, 2017).

Unfortunately, levels of ASHW mortality associated with entanglement, ship strike, or disease are not possible to estimate based on the evidence available to date. In Oman, only 8 records of humpback whale strandings were recorded between 1985 and 2008 (unpublished data held by the Environment Society of Oman, 2020), of which one was a stranding code 3, and the others were either stranding state 4 or 5 (Geraci and Lounsbury, 2005), and thus too decomposed to determine the cause of death. A recent study of mortality in north Atlantic right whales, a species known to be in decline primarily due to anthropogenic pressures from fishing and shipping, revealed that in 43 cases where a cause of death was determined 88.4% were due to anthropogenic trauma, with 58% caused by entanglement, and 42% from vessel strike (Sharp *et al*., 2019).

Conclusions and recommendations

We recommend that photo-identification research continues off the coast of Oman, and be initiated in other ASHW range states, and that it includes clear protocols for capturing images of the caudal peduncle region to facilitate monitoring of the entanglement status of individual whales over time. We also recommend that future research includes additional means to assess health and body condition, for example through the systematic use of drones and photogrammetry (e.g. Christiansen *et al*., 2016) or fluctuations in adiposity (e.g. Bengston Nash *et al.,* 2017). Such studies could be used to determine whether entanglement status and presence of TSD-L dermatopathy, are associated with changes in body condition. Blow and faecal sampling could also help to detect the presence of stress hormones or pathogens to evaluate health and overall fitness (e.g. Apprill *et al.*, 2017; Pirotta *et al*., 2017).

We also recommend that reporting networks and protocols for stranding and entanglement response are further strengthened in Oman and throughout the region. The relatively high proportion of whales with evidence of fisheries interactions in relation to the low number of documented entanglements indicates that interactions may be observed by fishermen but not reported, thus losing valuable opportunities to better understand the exact locations and types of gears that may need to be targeted for mitigation efforts. Reporting networks through trained fisheries crews are providing valuable information in Pakistan (e.g. Moazzam and Nawaz, 2017), and expanding networks are also yielding valuable information on baleen whale sightings and strandings in India (e.g. Sutaria, 2018).

Future studies in Oman should include sampling of cutaneous lesions to confirm the poxvirus aetiology as well as the accumulation of larger samples of images suitable for the assessment of entanglement scarring and lesions to determine whether there is correlation between the history of the whales' entanglements or other environmental factors, and progression of TSD-L lesions. Furthermore, if future studies are able to draw a more definitive causal link between TSD-L dermatopathy and immune deficiency, we recommend that TSD-L condition prevalence and severity be used as one of a number of indicators to monitor the health, welfare and status of the population.

A comparative study of epizoite colonisation on humpback whale tail flukes in different parts of the Indian Ocean could shed light on the mechanisms regulating barnacle colonisation on humpback whales, which may be related to temperature, salinity or water flow that optimises feeding opportunities for the barnacles (e.g. Carrillo *et al*., 2015). This comparison may also yield a proxy measure that could be used in the absence of genetic data to determine whether an individual whale observed in the Arabian Sea or surrounding waters is more likely to belong to the Arabian Sea population or to be a vagrant from the Southern Hemisphere. This was suspected, for instance, in the case of two humpback whales sighted in the Red Sea in 2016, both of which bore extensive barnacle scarring not typical of ASHW (Notarbartolo di Sciara *et al*., 2017). The detection of Southern Hemisphere humpback whale song by passive acoustic recorders off the coast of Oman in August 2012 (Cerchio *et al*., 2018) suggests that this distinction may be useful and needed as Southern Hemisphere populations expand, and as climate change disrupts normal seasonal patterns of oceanographic productivity and migration (e.g. Avila *et al*., 2019; Tulloch *et al*., 2019). Further passive acoustic monitoring work could help to shed light on the frequency and seasonality of Southern Hemisphere humpback whale occurrence within the Arabian Sea.

Further research is required to better understand the effects of sub-lethal fisheries interactions on ASHW physiology and health, as well as behaviour, such as avoidance of areas where fisheries activities occur (and thus loss of potential feeding opportunities). Future studies should also strive to identify which types of fisheries gear present the highest risk to the population as a first step to understanding whether and how to mitigate risks. Although the entanglement data generated in this study does not lend itself to evaluation of short-term changes in the entanglement rates, it provides a reliable baseline upon which future studies that collect more suitable images for analysis can be compared. More reliable long-term individual entanglement histories, and a larger sample size of images suitable for scarring analysis will allow detection of potential trends in entanglement rates and can be used as one of the indicators to monitor the efficacy of any future fisheries management interventions.

With a population of fewer than 100 individuals off the coast of Oman (Minton *et al.,* 2011), mortality exceeding one individual per year (assuming a recovery factor of 0.5 for humpback whales and Rmax = 0.04) would lead to a continued decline and eventual extirpation of the population. The cumulative impacts of the threats documented here may well lead to either direct or indirect mortality exceeding this sustainable limit. As such, our results indicate that these threats urgently require further investigation and collaboration with the appropriate stakeholders in ASHW range states to design practical mitigation and management strategies and actions.

Finally, it is essential that efforts continue to promote regional collaboration and government stakeholder participation to address the most urgent threats facing this Endangered population of humpback whales. The Convention on Migratory Species (CMS) Concerted Action for Arabian sea humpback whales (CMS, 2017) includes a set of quantifiable Key Ecological Attributes (KEAs) and associated proxy indicators that can be used to guide and monitor the efficacy of local and regional conservation efforts. The images required to continue and expand the visual health assessments presented here are relatively easily collected in combination with other survey methods, essential for monitoring distribution, abundance, behaviour and health of the population (e.g. line transect surveys, photo-identification, biopsy sampling) and should inform future research and conservation management efforts in the region.

ACKNOWLEDGEMENTS

Funding for the analysis represented here was made available through the Scientific Committee of the International Whaling Commission. The authors are grateful to the Ministry of Agriculture, Fisheries and Water Resources (formerly the Ministry of Agriculture and Fisheries Wealth) & the Environment Authority (formerly the Ministry of Environment and Climate Affairs), Oman, for participation of staff in field activities and issuing of permits to conduct field research, sampling and analysis. Thanks are extended to the staff at the Environment Society of Oman (www.eso.org.om) through which the research project is run and the network of volunteers for continued support of the Renaissance Whale and Dolphin Project in Oman. Appreciation is expressed for the staff at Five Oceans Environmental Services LLC working in the background for provision of expertise, time. The Wildlife Conservation Society is thanked for supporting the on-going participation of team members in support of field activities, data analysis and reporting. Sincere thanks are given for the unwavering faith and financial support provided to this project by Renaissance S.A.O.G. The authors thank Jooke Robbins and other members of the IWC Scientific Committee for comments on earlier drafts of this manuscript. We kindly thank Dr Juan Antonio Raga for his help in confirming the barnacle species identifications (*Coronula diadema* and *Conchoderma auritum*). KVW thanks ProDelphinus (Lima, Peru) for financial support of scientific work in 2021–22. Finally, the authors are grateful to Jooke Robbins, Frances Gulland and Frederik Christiansen for their feedback and comments on the protocols developed for this study.

REFERENCES

5OES (Five Oceans Environmental Services) and Environment Society of Oman. 2021. Marine Mammal Atlas of Oman. Rev 1.0. Accessed on 30/11/2021. [Available from: *https://doi.org/10.6084/m9.figshare.13514948.v1*].

Anderson, R.C., Herrera, M., Ilangakoon, A.D., Koya, K.M., Moazzam, M., Mustika, P., Sutaria, L. and Dipani, N. 2020. Cetacean bycatch in Indian Ocean tuna gillnet fisheries. *Endanger. Species Res.* 41: 39–53. [Available at: *https://doi.org/10.3354/esr01008*].

Andrews, R.D., Baird, R.W., Calambokidis, J., Goertz, C.E.C., Gulland, F.M.D., Heide-Jørgensen, M.P., Hooker, S.K., Johnson, M., Mate, B., Mitani, Y., Nowacek, D.P., Owen, K., Quakenbush, L.T., Raverty, S., Robbins, J., Schorr, G.S., Shpak, O.V., Townsend Jr, F.I., Uhart, M., Wells, R.S. and Zerbini, A.N. 2019. Best practice guidelines for cetacean tagging. *J. Cetacean Res. Manage.* 20: 27–66.

Anonymous. 2020. Northern Indian Ocean Killer Whale Alliance. [Available at: *https://niokillerwhales.wixsite.com/niokwa*] Accessed 15 April 2020.

Apprill, A., Miller, C.A., Moore, M.J., Durban, J.W., Fearnbach, H. and Barrett-Lennard, L.G. 2017. Extensive Core Microbiome in Drone-Captured Whale Blow Supports a Framework for Health Monitoring. *Systems* 2(5): e00119-17. [Available at: *https://doi.org/10.1128/mSystems.00119-17*].

Avila, I.C., Dormann, C.F., García, C., Payán, L.F. and Zorrilla, M.X. 2019. Humpback whales extend their stay in a breeding ground in the Tropical Eastern Pacific. *ICES J. Mar. Sci.* [Available at: *https://doi.org/10.1093/icesjms/fsz251*].

Baldwin, R., Collins, T., Minton, G., Wilson, A. and Corkeron, P. 2011. Arabian Sea humpback whales 2011 update: resights, bubble feeding and hotspots. Paper SC/63/SH27 presented to the IWC Scientific Committee, June 2011, Tromsø, Norway. 10pp. [Paper available from the Office of this Journal].

Basran, C.J., Bertulli, C.G., Cecchetti, A., Rasmussen, M.H., Whittaker, M. and Robbins, J. 2019. First estimates of entanglement rate of humpback whales *Megaptera novaeangliae* observed in coastal Icelandic waters. *Endanger. Species Res.* 38: 67–77. [Available at: *https://doi.org/10.3354/ESR00936*].

Bengtson Nash, S., Castrillon, J., Eisenmann, P., Fry, B., Shuker, J.D., Cropp, R.A., Dawson, A., Bignert, A., Bohlin-Nizzetto, P., Waugh, C.A., Polkinghorne, B., Dalle Luche, G. and McLagan, D. 2018. Signals from the south; humpback whales carry messages of Antarctic sea-ice ecosystem variability. *Glob. Change Biol.* 24(4): 1500–10. [Available at: *https://doi.org/10.1111/gcb.14035*].

Bertulli, C.G., Cecchetti, A., Van Bressem, M.F. and van Waerebeek, K. 2012. Skin disorders in common minke whales and white-beaked dolphins off Iceland, a photographic assessment. *J. Mar. Anim. Ecol.* 5(2): 29–40.

Bradford, A.L., Weller, D.W., Ivashchenko, Y.V., Burdin, A.M. and Brownell, R.L., Jr. 2009. Anthropogenic scarring of western gray whales (*Eschrichtius robustus*). *Mar. Mamm. Sci.* 25(1): 161–75. [Available at: *https://doi.org/10.1111/j.1748-7692.2008.00253.x*].

Capella, J.J., Félix, F., Flórez-González, L., Gibbons, J., Haase, B. and Guzman, H.M. 2018. Geographic and temporal patterns of non-lethal attacks on humpback whales by killer whales in the eastern South Pacific and the Antarctic Peninsula. *Endanger. Species Res.* 37: 207–18. [Available at: *https://doi.org/10.3354/esr00924*].

Carrillo, J.M., Overstreet, R.M., Raga, J.A. and Aznar, F.J. 2015. Living on the Edge: Settlement Patterns by the Symbiotic Barnacle *Xenobalanus globicipitis* on Small Cetaceans. *PLoS One* 10(6): e0127367. [Available at: *https://doi.org/10.1371/journal.pone.0127367*].

Cassoff, R.M., Moore, K.M., McLellan, W.A., Barco, S.G., Rotstein, D.S. and Moore, M.J. 2011. Lethal entanglements in baleen whales. *Dis. Aquat. Org.* 96: 175–85. [Available at: *https://doi.org/10.3354/dao02385*].

Cates, K., DeMaster, D., Brownell Jr, R.L., Silber, G., Gende, S., Leaper, R., Ritter, F. and Panigada, S. 2017. Strategic Plan to Mitigate the Impacts of Ship Strikes on Cetacean Populations: 2017–2020, International Whaling Commission, Cambridge, United Kingdom. [Available at: *https://iwc.int/ship-strikes*].

Cerchio, S., Willson, A., Muirhead, C., Al Hathi, S., Baldwin, R., Bonato, M., Collins, T., Di Clemente, J., Dulau, V., Estrade, V., Latha, G., Minton, G. and Willson, M.S. 2018. Geographic variation in song indicates both isolation of Arabian Sea humpback whales and presence of Southern Hemisphere whales off Oman. Paper SC/67b/CMP19 presented to the IWC Scientific Committee, April–May 2018, Bled, Slovenia (unpublished). 31pp. [Paper available from the Office of this Journal].

Christiansen, F., Dawson, S., Durban, J.W., Fearnbach, H., Miller, C.A., Bejder, L., Uhart, M., Sironi, M., Corkeron, P., Rayment, W., Leunissen, E., Haria, E., Ward, R., Warick, H.A., Kerr, I., Lynn, M.S., Pettis, H.M. and Moore, M.J. 2020. Population comparison of right whale body condition reveals poor state of the North Atlantic right whale. *Mar. Ecol. Prog. Ser.* 640: 1–16. [Available at: *https://doi.org/10.3354/meps13299*].

Christiansen, F., Dujon, A.M., Sprogis, K.R., Arnould, J.P.Y. and Bejder, L. 2016. Noninvasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales. *Ecosphere* 7(10). [Available at: *https://doi.org/10.1002/ecs2.1468*].

Christiansen, F., Vivier, F., Charlton, C., Ward, R., Amerson, A., Burnell, S. and Bejder, L. 2018. Maternal body size and condition determine calf growth rates in southern right whales. *Mar. Ecol. Prog. Ser.* 592: 367–281. [Available at: *https://doi.org/10.3354/meps12522*].

Clegg, I.L., Borger-Turner, J.L. and Eskelinen, H.C. 2015. C-Well: The development of a welfare assessment index for captive bottlenose dolphins (*Tursiops truncatus*). *Anim. Welf.* 24(3): 267–82. [Available at: *https://doi.org/10.7120/09627286.24.3.267*].

Convention on Migratory Species. 2017. Concerted Action for humpback whales (*Megaptera novaeangliae*) of the Arabian Sea. Convention on Migratory Species, Manila. [Available at: *https://www.cms.int/en/document/concerted-action-humpback-whales-megaptera-novaeangliae-arabian-sea*].

Corkeron, P.J., Minton, G., Collins, T., Findlay, K., Willson, A. and Baldwin, R. 2011. Spatial models of sparse data to inform cetacean conservation planning: an example from Oman. *Mar. Ecol. Prog. Ser.* 453: 249–61. [Available at: *https://doi.org/10.3354/esr00367*].

Cotton Rockwood, R., Calambokidis, J. and Jahncke, J. 2017. High mortality of blue, humpback and fin whales from vessel collisions on the US west coast suggests population impacts and insufficient protection. Paper SC/67a/HIM05 presented to the IWC Scientific Committee, May 2017, Bled, Slovenia (unpublished). 32pp. [Available at: *https://doi.org/10.1371/journal.pone.0183052*].

Dakhteh, S.M.H., Ranjbar, S., Moazeni, M., Mohsenian, N., Delshab, H., Moshiri, H., Nabavi, S.M.B. and Van Waerebeek, K. 2017. The Persian Gulf is part of the habitual range of the Arabian Sea Humpback whale population. *J. Mar. Biol. Oceanogr.* 6(3): 1–6. [Available at: *https://doi.org/10.4172/2324-8661.1000178*].

Dolman, S.J. and Brakes, P. 2018. Sustainable Fisheries Management and the Welfare of Bycaught and Entangled Cetaceans. *Front. Vet. Sci.* 5(287). [Available at: *https://doi.org/10.3389/fvets.2018.00287*].

Dolman, S.J. and Moore, M.J. 2017. Welfare Implications of Cetacean Bycatch and Entanglements. pp.41–65. *In*: Butterworth, A. (eds). *Marine Mammal Welfare: Human Induced Change in the Marine Environment and its Impacts on Marine Mammal Welfare*. Springer International Publishing.

Dwyer, S.L. and Visser, I.N. 2011. Cookie cutter shark (Isistius sp.) bites on cetaceans, with particular reference to killer whales (orca) (*Orcinus orca*) *Aquat. Mamm.* 37(2): 111–38. [Available at: *https://doi.org/10.1578/AM.37.2.2011.111*].

Friday, N.A., Smith, T.D., Stevick, P.T., Allen, J. and Fernald, T. 2008. Balancing bias and precision in capture-recapture estimates of abundance. *Mar. Mamm. Sci.* 24: 253–75. [Available at: *https://doi.org/10.1111/j.1748-7692.2008.00187.x*].

Geraci, J.R. and Lounsbury, V.J. 2005. *Marine Mammals Ashore: a Field Guide for Strandings*. 2nd ed. National Aquarium in Baltimore, Baltimore, MD. 371pp.

Gerrodette, T. and Forcada, J. 2005. Non-recovery of two spotted and spinner dolphin populations in the eastern tropical Pacific Ocean. *Mar. Ecol. Prog. Ser.* 291: 1–21. [Available at: *https://doi.org/10.3354/meps291001*].

Hayes, S.A., Gardner, S.C., Garrison, L.P., Henry, A.G. and Leandro, L.F. 2018. North Atlantic Right Whales – Evaluating Their Recovery Challenges in 2018, NOAA Technical Memorandum NMFS-NE-247. National Marine Fisheries Service, Woods Hole, Massachusetts. 30.

Hill, A.N., Karniski, C., Robbins, J., Pitchford, T., Todd, S. and Asmutis-Silva, R. 2017. Vessel collision injuries on live humpback whales, *Megaptera novaeangliae*, in the southern Gulf of Maine. *Mar. Mamm. Sci.* 33: 558–73. [Available at: *https://doi.org/10.1111/mms.12386*].

International Whaling Commission. 2019. Report of the IWC Workshop on Bycatch Mitigation Opportunities in the Western Indian Ocean and Arabian Sea, 8–9 May 2019, Nairobi, Kenya. Report for IWC Conservation Committee. [Available at: *https://archive.iwc.int/?r=9612*].

Johnson, A., Salvador, G., Kenney, J., Robbins, J., Kraus, S., Landry, S. and Clapham, P. 2005. Fishing gear involved in entanglements of right and humpback whales. *Mar. Mamm. Sci.* 21(4): 635–45. [Available at: *https://doi.org/10.1111/j.1748-7692.2005.tb01256.x*].

Kenney, R.D. 2018. What if there were no fishing? North Atlantic right whale population trajectories without entanglement mortality. *Endanger. Species Res.* 37: 233–37. [Available at: *https://doi.org/10.3354/esr00926*].

Kiani, M.S. and Van Waerebeek, K. 2015. Chapter Eight – A Review of the Status of the Indian Ocean Humpback Dolphin (*Sousa plumbea*) in Pakistan. pp.201–28. *In*: Curry, B. E. (eds). *Humpback Dolphins (Sousa spp.): Current Status and Conservation, Part 1. Advances in Marine Biology*. Academic Press.

Knowlton, A.R., Hamilton, P.K., Marx, M.K., Pettis, H.M. and Kraus, S.D. 2012. Monitoring North Atlantic right whale *Eubalaena glacialis* entanglement rates: a 30 yr retrospective. *Mar. Ecol. Prog. Ser.* 466: 293. [Available at: *https://doi.org/10.3354/meps09923*].

Madhusudhana, S.K., Chakraborty, B. and Latha, G. 2018. Humpback whale singing activity off the Goan coast in the Eastern Arabian Sea. *Bioacoustics*: 17pp. [Available at: *https://doi.org/10.1080/09524622.2018.1458248*].

Mahanty, M.M., Latha, G. and Thirunavukkarasu, A. 2015. Analysis of humpback whale sounds in shallow waters of the southeastern Arabian Sea: an indication of breeding habitat. *J. Bioscience* 40(2): 407–17. [Available at: *https://doi.org/10.1007/s12038-015-9525-5*].

Mehta, A.V., Allen, J., Constantine, R., Garrigue, C., Jann, B., Jenner, C., Marx, M., Matkin, C., Mattila, D., Minton, G., Mizroch, S., Olavarria, C., Robbins, J., Russell, K., Seton, R., Steiger, G., Víkingsson, G., Wade, P., Witteveen, B. and Clapham, P.J. 2007. Baleen whales are not important as prey for killer whales (*Orcinus orca*) in high latitudes. *Mar. Ecol. Prog. Ser.* 348: 297–307. [Available at: *https://doi.org/10.3354/meps07015*].

Mikhalev, Y.A. 1997. Humpback whales, *Megaptera novaeangliae* in the Arabian Sea. *Mar. Ecol. Prog. Ser.* 149: 13–21. [Available at: *https://www.jstor.org/stable/24857503*].

Mikhalev, Y.A. 2000. Whaling in the Arabian Sea by the whaling fleets *Slava* and *Sovetskaya Ukraina*. pp.141–81. *In*: Yablokov, A.V., Zemsky, V.A. and Tormosov, D.D. (eds). *Soviet Whaling Data (1949–1979)*. Centre for Russian Environmental Policy, Moscow. 408pp.

Minton, G. 2004. Population Ecology and Conservation of Cetaceans in Oman, with particular reference to humpback whales (*Megaptera novaeangliae*), PhD Thesis. University of London, University Marine Biological Station, Millport. 250pp.

Minton, G., Collins, T., Findlay, K. and Baldwin, R. 2010. Cetacean distribution in the coastal waters of the Sultanate of Oman. *J. Cetacean Res. Manage.* 11(3): 301–14.

Minton, G., Collins, T., Findlay, K., Baldwin, R., Ersts, P.J., Rosenbaum, H., Berggren, P. and Baldwin, R.M. 2011. Seasonal distribution, abundance, habitat use and population identity of humpback whales in Oman. *J. Cetacean Res. Manage*: 183–98.

Minton, G., Collins, T., Pomilla, C., Findlay, K., Rosenbaum, H., Baldwin, R. and Brownell, R.L., Jr. 2008. *Megaptera novaeangliae* (Arabian Sea sub-population). eT132835A3464679. *IUCN Red List of Threatened Species*. [*https://doi.org/10.2305/IUCN.UK.2008.RLTS.T132835A3464679.en.* Downloaded on 21 February 2021].

Minton, G., Reeves, R., Collins, T. and Willson, A. 2015. Report on the Arabian Sea Humpback Whale Workshop: Developing a collaborative research and conservation strategy, Dubai, 27-29 January 2015. 50pp. [Available at: *http://www.mmc.gov/wp-content/uploads/Arabian_SeaHumpback_whale_0115.pdf*].

Mizroch, S.A., Tilman, M., Jurasz, S., von Ziegesar, O., Herman, L.M., Pack, A.A., Baker, A.N., Darling, J., Glockner-Ferrari, D.A., Ferrari, M.J., Salden, D.R. and Clapham, P.J. 2010. Long-term survival of humpback whales radio-tagged in Alaska from 1976 through 1978. *Mar. Mamm. Sci.* [Available at: *https://10.1111/j.1748-7692.2010.00391.x*].

Moazzam, M. and Nawaz, R. 2014. By-catch of tuna gillnet fisheries of Pakistan: A serious threat to non-target, endangered and threatened species. *J. Mar. Biol. Assoc. India* 56(1): 85. [Available at: *https://doi.org/10.6024/jmbai.2014.56.1.01750s-13*].

Moazzam, M. and Nawaz, R. 2017. Arabian humpback and baleen whale sightings along the Pakistan coast: information generated through WWF Pakistan's fishing crew observer programme. Paper SC/67a/CMP05 presented to the IWC Scientific Committee, May 2017, Bled, Slovenia (unpublished). 14pp. [Paper available from the Office of this Journal].

Mohsenian, N., Moshiri, H., Tollab, A., Bargahi, H.R., Braulik, G.T., Braulik, G., Gemmell, G.L. and Collins, T. 2019. Confirmed sightings of the Killer Whale, *Orcinus orca*, in Iranian waters (*Mammalia: Cetacea*). *Zool. Middle East* 65(3): 280–82. [Available at: *https://doi.org/10.1080/09397140.2019.1596590*].

Moore, M., Bogomolni, A., Bowman, R., Hamilton, P., Harry, C., Knowlton, A., Landry, S., Rotstein, D.S. and Touhey, K. 2006. Fatally entangled right whales can die extremely slowly. Oceans 06, MTS-IEEE-Boston, Massachusetts, September 18–21, 2006. 3pp.

Moore, M.J. and Van der Hoop, J. 2012. The painful side of trap and fixed net fisheries: chronic entanglement of large whales. *J. Mar. Biol.* 2012: 4pp. [Available at: *https://doi.org/10.1155/2012/230653*].

Moore, M.J., van der Hoop, J., Barco, S.G., Costidis, A.M., Gulland, F.M.D., Jepson, P.D., Moore, K.T., Raverty, S. and McLellan, W.A. 2013. Criteria and case definitions for serious injury and death of pinnipeds and cetaceans caused by anthropogenic trauma. *Dis. Aquat. Org.* 103: 229–64. [Available at: *https://doi.org/10.3354/dao02566*].

Naessig, P.J. and Lanyon, J.M. 2004. Levels and probable origin of predatory scarring on humpback whales (*Megaptera novaeangliae*) in east Australian waters. *Wildl. Res.* 31(2): 163–70. [Available at: *https://doi.org/10.1071/WR03086*].

Neilson, J.L., Straley, J.M., Gabriele, C.M. and Hills, S. 2009. Non-lethal entanglement of humpback whales (*Megaptera novaeangliae*) in fishing gear in northern Southeast Alaska. *J. Biogeogr.* 36: 452–64. [Available at: *https://doi.org/10.1111/j.1365-2699.2007.01820.x*].

Noble, A., Nasser, A.K.V. and Radhakrishnan Nair, P. 1992. On a sei whale, *Balaenoptera borealis* landed at Puthuvypu in Vypeen Island near Cochin. *Mar. Fish. Inf. Serv. Tech. Ed. Sers.* 116: 18.

Notarbartolo di Sciara, G., D., K., Smeenk, C., Rudolph, P., Cesario, A., Costa, M., Elasar, M., Feingold, D., M., F., Goffman, O., Hadar, N., Mebrathu, Y.T. and Scheinin, A. 2017. Cetaceans of the Red Sea. *CMS Technical Series* 33: 1–86.

Oman Department of Statistics. 2013. *Fisheries Statistics 2012: Facts and Figures*. Department of Fisheries Statistics, Muscat.

Oman National Center for Statistics. 2017. Statistical Year Book 45: 447.

Oman National Centre for Statistics and Information. 2020. Statistical Year Book 48: 153–67. [Available at: *bar_statistical_year_book_2020-14_4f5cf07c-02d9-4e13-b7aa-0d6b21912f67.pdf*].

Papastavrou, V. and Van Waerebeek, K. 1997. A note on the occurrence of humpback whales (*Megaptera novaeangliae*) in tropical and subtropical areas: the upwelling link. *Rep. Int. Whaling Commn.* 47: 945–47.

Pettis, H.M., Rolland, R.M., Hamilton, P.K., Brault, S., Knowlton, A.R. and Kraus, S.D. 2004. Visual health assessment of North Atlantic right whales (*Eubalaena glacialis*) using photographs. *Can. J. Zool.* 82: 8–19. [Available at: *https://doi.org/10.1139/z03-207*].

Pettis, H.M., Rolland, R.M., Hamilton, P.K., Knowlton, A.R., Burgess, E.A. and D., K.S. 2017. Body condition changes arising from natural factors and fishing gear entanglements in North Atlantic right whales *Eubalaena glacialis*. *Endanger. Species Res.* 32: 237–49. [Available at: *https://doi.org/10.3354/esr00800*].

Pirotta, V., Smith, A., Ostrowski, M., Russell, D., Jonsen, I.D., Grech, A. and Harcourt, R. 2017. An Economical Custom-Built Drone for Assessing Whale Health. *Front. Mar. Sci.* 4(425). [Available at: *https://doi.org/10.3389/fmars.2017.00425*].

Pomilla, C., Amaral, A.R., Collins, T., Minton, G., Findlay, K., Leslie, M.S., Ponnampalam, L., Baldwin, R. and Rosenbaum, H. 2014. The world's most isolated and distinct whale population? Humpback whales of the Arabian Sea. *PLoS One* 9(12): e114162. [Available at: *https://doi.org/10.1371/journal.pone.0114162*].

R Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Ramos, E.A., Castelblanco-Martínez, D.N., Garcia, J., Rojas Arias, J., Foley, J.R., Audley, K., Van Waerebeek, K. and Van Bressem, M.F. 2018. Lobomycosis-like disease in common bottlenose dolphins *Tursiops truncatus* from Belize and Mexico: bridging the gap between the Americas. *Dis. Aquat. Organ.* 128(1): 1–12. [Available at: *https://doi.org/10.3354/dao03206*].

Read, A.J., Drinker, P. and Northridge, S. 2006. Bycatch of marine mammals in US and global fisheries. *Conserv. Biol.* 20(1): 163–69. [Available at: *https://doi.org/10.1111/j.1523-1739.2006.00338.x*].

Reeves, R.R., Leatherwood, S. and Papastavrou, V. 1991. Possible stock affinities of humpback whales in the northern Indian Ocean. pp.259–69. *In*: Leatherwood, S. and Donovan, G.P. (eds). *Cetaceans and Cetacean Research in the Indian Ocean Sanctuary*. United Nations Environment Programme, Nairobi, Kenya. 287pp.

Reeves, R.R., McClellan, K. and Werner, T.B. 2013. Marine mammal bycatch in gillnet and other entangling net fisheries, 1990 to 2011. *Endanger. Species Res.* 20: 71–97. [Available at: *https://doi.org/10.3354/esr00481*].

Reif, J., Peden-Adams, M.M., Romano, T.A., Rice, C.D., Fair, P.A. and Bossart, G.D. 2009. Immune dysfunction in Atlantic bottlenose dolphins (*Tusiops truncatus*) with lobomycosis. *Med. Mycol. J.* 47(2): 125–35. [Available at: *https://doi.org/10.1080/13693780802178493*].

Robbins, J. 2012. Scar-based inference into Gulf of Maine humpback whale entanglement: 2010. Report to the National Marine Fisheries Service. Order number EA133F09CN0253.

Robbins, J., Andrews-Goff, V., Clapham, P., Double, M., Gales, N., Gulland, F., Kennedy, A., Landry, S., Mattila, D., Sandilands, D., Tackaberry, J. and Zerbini, A.N. 2016. Evaluating Potential Effects of Satellite Tagging in Large Whales: A Case Study with Gulf of Maine Humpback Whales. 100pp. [Available at: *https://www.nopp.org/wp-content/uploads/2014/12/Robbins.EffectsWhaleTagging.2013.pdf*].

Robbins, J. and Mattila, D.K. 2000. Gulf of Maine humpback whale entanglement scar monitoring results 1997–1999, Center for Coastal Studies, Provincetown, MA. 24pp. [Available at: *https://arabianseawhalenetworkdotorg.files.wordpress.com/2015/10/robbins-and-mattila-2000-humpback-whale-entanglements1.pdf*].

Robbins, J. and Mattila, D.K. 2001. Monitoring entanglements of humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine on the basis of caudal peduncle scarring. Paper SC/53/NAH25 presented to the IWC Scientific Committee, July 2001, London (unpublished). 14pp. [Paper available from the Office of this Journal].

Robbins, J. and Mattila, D.K. 2004. Estimating humpback whale (*Megaptera novaeangliae*) entanglement rates on the basis of scars evidence. Report to the National Marine Fisheries Service. 21pp. [Available at: *http://www.nmfs.org*].

Robbins, J., Zerbini, A.N., Gales, N., Gulland, F.M.D., Double, M., Clapham, P.J., Andrews-Goff, V., Kennedy, A.S., Landry, S., Mattila, D.K. and Tackaberry, J. 2013. Satellite tag effectiveness and impacts on large whales: preliminary results of a case study with Gulf of Maine humpback whales. Paper SC/65a/SH05 presented to the IWC Scientific Committee, June 2013, Jeju Island, Republic of Korea (unpublished). 10pp. [Paper available from the Office of this Journal].

Rolland, R.M., Graham, K.M., Stimmelmayr, R., Suydam, R.S. and George, J.C. 2019. Chronic stress from fishing gear entanglement is recorded in baleen from a bowhead whale (*Balaena mysticetus*). *Mar. Mamm. Sci.* 35(4): 1625–42. [Available at: *https://doi.org/10.1111/mms.12596*].

Rolland, R.M., McLellan, W.A., Moore, M.J., Harms, C.A., Burgess, E.A. and Hunt, K.E. 2017. Fecal glucocorticoids and anthropogenic injury and mortality in North Atlantic right whales *Eubalaena glacialis*. *Endanger. Species Res.* 34: 417–29. [Available at: *https://doi.org/10.3354/esr00866*].

Rolland, R.M., Parks, S.E., Hunts, K.E., Castellote, M., Corkeron, P., Nowacek, D.P., Wasser, S.K. and Kraus, S.D. 2012. Evidence that ship noise increases stress in right whales. *Proc. R. Soc. Lond.* 279:2363–68. [Available at: *https://doi.org/10.1098/rspb.2011.2429*].

Sharp, S.M., McLellan, W., Rotstein, D., Costidis, A., Barco, S.G., Durham, K., Pitchford, T., Jackson, K., Daoust, P.-Y., Wimmer, T., Couture, E.L., Bourque, L., Frasier, T., Frasier, B., Fauquier, D., Rowles, T., Hamilton, P.K., Pettis, H. and Moore, M. 2019. Gross and histopathologic diagnoses from North Atlantic right whale *Eubalaena glacialis* mortalities between 2003 and 2018. *Dis. Aquat. Org.* 135(1): 1–31.

Soledade Lemos, L., Burnett, J.D., Chandler, T.E., Sumich, J.L. and Torres, L.G. 2020. Intra- and inter-annual variation in gray whale body condition on a foraging ground. *Ecosphere* 11(4): e03094. [Available at: *https://doi.org/10.1002/ecs2.3094*].

Steiger, G., Calambokidis, J., Straley, J., Herman, L.M., Cerchio, S., Salden, D.R., Urban, J., Jacobsen, K., von Ziegesar, O., Balcomb, K.C., Gabriele, C., Dahlheim, M., Uchida, S., Ford, J., Ladron de Guevara, P., Yamaguchi, M. and Barlow, J. 2008. Geographic variation in killer whale attacks on humpback whales in the North Pacific: implications for predation pressure. *Endanger. Species Res.* 4: 247–56. [Available at: *https://doi.org/10.3354/esr00078*].

Sutaria, D. 2018. Baleen whale reports from the eastern Arabian Sea based on interview surveys and stranding reports – update from India. Paper SC/67b/CMP15 presented to the IWC Scientific Committee, April–May 2018, Bled, Slovenia (unpublished). 5pp. [Paper available from the Office of this Journal].

Sutaria, D., Panicker, D., Jog, K., Sule, M., Muralidharan, R. and Bopardikar, I. 2015. Chapter Nine – Humpback Dolphins (*Genus Sousa*) pp.229–56. *In*: Thomas, A.J. and Barbara, E.C. (eds). *India: An Overview of Status and Conservation Issues. Advances in Marine Biology*. Academic Press.

Sutaria, D., Sule, M., Jog, K., Bopardikar, I., Jamalabad, A. and Panicker, D. 2017. Baleen whale records from India. Paper SC/67a/CMP03rev1 presented to the IWC Scientific Committee, May 2017, Bled, Slovenia (unpublished). 16pp. [Paper available from the Office of this Journal].

Temple, A., Wambiji, N., Poonian, C.N.S., Jiddawi, N., Stead, S., Kiszka, J. and Berggren, P. 2019. Marine megafauna catch in southwestern Indian Ocean small-scale fisheries from landings data. *Biol. Conserv.* 230: 113–21. [Available at: *https://doi.org/10.1016/j.biocon.2018.12.024*].

Tiwari, M., Willson, A., Baldwin, B., Al Kiyumi, A., Al Harthi, S., Bulushi, Witherington, B. and Possardt, E. 2015. Spatial analysis of satellite tracking of female loggerheads Masirah Island Oman; application and utility in evaluating fisheries co-occurrence for the assessment of bycatch. Paper presented at the 35th ISTS Symposium on Sea Turtle Biology and Conservation, Dalaman, Turkey. p.138 (Available at: *http://www.seaturtle.org/PDF/KaskaY_2015a_Bookofabstractsof35thAnnualSymposiu.pdf*).

Tulloch, V.J.D., Plagányi, É.E., Brown, C.J., Matear, R. and Richardson, A.J. 2019. Future recovery of baleen whales is imperiled by climate change. *Glob. Change Biol.* 25: 1263–81. [Available at: *https://doi.org/10.1111/gcb.14573*].

Van Bressem, M.-F., Van Waerebeek, K. and Duignan, P.J. 2018. Epidemiology of tattoo skin disease in captive common bottlenose dolphins (*Tursiops truncatus*): Are males more vulnerable than females? *J. Appl. Anim. Welf. Sci.* 24(4): 305–15. [Available at: *https://doi.org/10.1080/10888705.2017.1421076*].

Van Bressem, M.F., Minton, G., Collins, T., Willson, A., Baldwin, R. and Van Waerebeek, K. 2014a. Tattoo-like skin disease in the endangered subpopulation of the humpback whale, *Megaptera novaeangliae*, in Oman (Cetacea: Balaenopteridae). *Zool. Middle East* 2014: 8pp. [Available at: *http://dx.doi.org/10.1080/09397140.2014.994316*].

Van Bressem, M., Minton, G., Sutaria, D., Kelkar, N., Rodriguez Vargas, L. and Rajamani, L. 2014b. Cutaneous nodules in Irrawaddy dolphins: an emergency disease in vunerable populations. *Dis. Aquat. Org.* 107: 181–9. [Available at: *https://doi.org/10.3354/dao02689*].

Van Bressem, M.F., Shirakihara, M. and Amano, M. 2012. Cutaneous nodular disease in a small population of Indo-Pacific bottlenose dolphins, *Tursiops aduncus*, from Japan. *Mar. Mamm. Sci.* 29(3): 525–32. [Available at: *https://doi.org/10.1111/j.1748-7692.2012.00589.x*].

Van Bressem, M.F., Van Waerebeek, K., Aznar, F.J., Raga, J.A., Jepson, P.D., Duignan, P., Deaville, R., Flach, L., Viddi, F., Baker, J.R., Di Beneditto, A.P., Echegaray, M., Genovo, T., Reyes, J., Felix, F., Gaspar, R., Ramos, R., Peddemors, V., Sanino, G.P. and Siebert, U. 2009. Epidemiological pattern of tattoo skin disease: a potential general health indicator for cetaceans. *Dis. Aquat. Org.* 85: 225–37. [Available at: *https://doi.org/10.3354/dao02080*].

van der Hoop, J.M., Corkeron, P., Henry, A.G., Knowlton, A.R. and Moore, M.J. 2017. Predicting lethal entanglements as a consequence of drag from fishing gear. *Mar. Pollut. Bull.* 115(1–2). [Available at: *https://doi.org/10.1016/j.marpolbul.2016.11.060]*.

van der Hoop, J.M., Corkeron, P., Kenney, J., Landry, S., Morin, D., Smith, J. and Moore, M. 2016. Drag from fishing gear entangling North Atlantic right whales *Mar. Mamm. Sci.* 32(2): 619–42. [Available at: *https://doi.org/10.1111/mms.12292*].

Van Waerebeek, K., Baker, A.N., Félix, F., Gedamke, J., Iñiguez, M., Sanino, P.G., Secchi, E., Sutaria, D., van Helden, A. and Wang, Y. 2007. Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere; an initial assessment. *Lat. Am. J. Aquat. Mamm.* 6(1): 43–69. [Available at: *https://doi.org/10.5597/lajam00109*].

Weir, C., Collins, T., Cross, T., Gill, A., Elwen, S., Unwin, M. and Parnell, R. 2013. False killer whale (*Pseudorca crassidens*) sightings in continental shelf habitat off Gabon and Côte d'Ivoire (Africa). *Mar. Biodivers. Rec.* 6(E65). [Available at: *https://doi.org/10.1017/S1755267213000389*].

Wickham, H. 2011. ggplot2. Wiley Interdisciplinary Reviews. *Comput. Stat.* 3(2): 180–85.

Willson, A., Baldwin, R., Cerchio, S., Childerhouse, S., Collins, T., Findlay, K., Genov, T., Godley, B.J., Al-Harthi, S., Leslie, M., MacDonald, D., Minton, G., Zerbini, A.N. and Witt, M.J. 2018. Update on satellite telemetry studies and first unmanned aerial vehicle assisted health assessment studies of Arabian Sea humpback whales off the coast of Oman. Paper SC/67b/CMP13 presented to the IWC Scientific Committee, April–May 2018, Bled, Slovenia (unpublished). 11pp. [Paper available from the Office of this Journal].

Willson, A., Baldwin, R., Cerchio, S., Collins, T., Findlay, K., Gray, H., Godley, B.J., Al-Harthi, S., Kennedy, A., Minton, G., Sucunza, F., Zerbini, A. and Witt, M.J. 2016a. Research update on satellite tagging studies of the Arabian Sea humpback whales in the Sultanate of Oman. Paper SC/66b/SH28 presented to the IWC Scientific Committee, June 2016, Bled, Slovenia (unpublished). 23pp. [Paper available from the Office of this Journal].

Willson, A., Baldwin, R., Cerchio, S., Collins, T., Findlay, K., Gray, H., Godley, B.J., Al-Harthi, S., Kennedy, A., Minton, G., Zerbini, A. and Witt, M. 2015. Research update of satellite tracking studies of male Arabian Sea humpback whales: Oman. Paper SC/66a/SH22rev1 presented to the IWC Scientific Committee, May 2015, San Diego, CA, USA (unpublished). 13pp. [Paper available from the Office of this Journal].

Willson, A., Baldwin, R., Collins, T., Godley, B., Minton, G., al-Harthi, S., Pikesley, S. and Witt, M. 2017. Preliminary ensemble ecological niche modelling of Arabian Sea humpback whale vessel sightings and satellite telemetry data. Paper SC/67a/CMP15 presented to the IWC Scientific Committee, May 2017, Bled, Slovenia (unpublished). 17pp. [Paper available from the Office of this Journal].

Willson, A., Kowalik, J., Godley, B.J., Baldwin, R., Struck, A., Struck, L., Nawaz, R. and Witt, M.J. 2016b. Priorities for addressing whale and ship co-occurrence off the coast of Oman and the wider North Indian Ocean. Paper SC/66b/HIM10 presented to the IWC Scientific Committee, June 2016, Bled, Slovenia (unpublished). 13pp. [Paper available from the Office of this Journal].

Willson, A., Witherington, B., Baldwin, R., Tiwari, M., Al Sariri, T., Al Kiyumi, A., Al Harthi, S., Willson, M.S., Al Bulushi, A. and Al Farsi, G. 2020. Evaluating the Long-Term Trend and Management of a Globally Important Loggerhead Population Nesting on Masirah Island, Sultanate of Oman. *Front. Mar. Sci.* 7(7): 666. [Available at: *https://doi.org/10.3389/fmars.2020.00666*].

Yousuf, K.S.S.M., Anoop, A.K., Anoop, B., Afsal, V.V., Vivekanandan, E., Kumarran, R.P., Rajagopalan, M., Krishnakumar, P.K. and Jayasankar, P. 2009. Observations on incidental catch of cetaceans in three landing centres along the Indian coast. *Mar. Biodivers. Rec.* 2(e64). [Available at: *https://doi.org/10.1017/S175526720900075X*].