SC/67B/CMP/13 Rev1

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INTERNATIONAL
WHALING COMMISSION

Update on satellite telemetry studies and first unoccupied aerial vehicle assisted health assessment studies of Arabian Sea humpback whales off the coast of Oman.

A. Willson[1,2,3], M. Leslie [4], R. Baldwin[1], S. Cerchio[5], S. Childerhouse[6], T. Collins[7], K. Findlay[8], T. Genov[9,10,11], B. J. Godley[3], S. Al-Harthi[12], D. MacDonald[13] G. Minton[14], A.N. Zerbini[15,16,17, 18], M. J. Witt[2]

[1]*Five Oceans Environmental Services, PO Box 660, PC131, Ruwi, Sultanate of Oman*
[2] *Environment and Sustainability Institute, University of Exeter, Penryn Campus, Cornwall, UK*
[3]*Centre for Ecology and Conservation University of Exeter, Exeter, UK*
[4]*Smithsonian Institution, National Museum of Natural History and National Zoological Park, Washington D.C. USA*
[5] *New England Aquarium, USA*
[6]*Blue Planet Marine, P.O Box 3639, Richmond, Tasman 7050, New Zealand*
[7]*Wildlife Conservation Society, Ocean Giants Program, 2300 Southern Blvd, Bronx, NY 10460-1099, USA*
[8]*Centre for Sustainable Oceans Economy, Cape Peninsula University of Technology, South Africa*
[9] *Morigenos – Slovenian Marine Mammal Society, Piran, Slovenia*
[10]*Department of Biodiversity, Faculty of Mathematics, Natural Sciences and Information Technologies, University of Primorska, Koper, Slovenia*
[11] *Sea Mammal Research Unit, University of St Andrews, Fife, United Kingdom*
[12]*Environment Society of Oman, PO Box 3955, PC 112, Ruwi, Sultanate of Oman*
[13]*Clear Blue Photo, Calgary, Alberta, Canada*
[14]*Megaptera Marine Conservation, Netherlands*
[15]*Marine Mammal Lab, Alaska Fisheries Science Centre, Seattle WA, USA*
[16]*Cascadia Research Collective, Olympia, WA, USA*
[17]*Instituto Aqualie, Rio de Janeiro, Brazil*
[18]*Marine Ecology and Telemetry Research, Seabeck, WA, USA*

ABSTRACT

Four previously documented surveys focusing on satellite tagging Arabian Sea humpback whales (ASHW) have taken place off the coast of Oman since 2014. We present information of the most recent multidisciplinary survey from November 2017 including results of telemetry studies to investigate spatial ecology, photo-identification work to support population estimates and the trial of new methods using Unoccupied Aerial Vehicles (UAV's) in conducting non-invasive health assessments. The findings document the first record of the transoceanic passage of an ASHW within the Arabian Sea and preliminary evidence of regional scale connectivity. Small vessel surveys resulted in 45 hours of effort resulting in a total of 35 sightings and encounters with over 18 identified individual ASHWs. Five tags were successfully deployed, three being attached to whales already identified in the ASHW catalogue (one female and two males) and two whales new to the catalogue (of as yet unknown sex). The recent telemetry work brings the project total to 14 deployed tags. Four whales from the recent tagged group occupied regions previously described as important habitat in the South of Oman including the Gulf of Masirah and Hallaniyats Bay. The tag with the longest tracking duration (n=120 days) documented the passage of an adult female from the Gulf of Masirah across to the west coast of India, south towards to the Gulf of Manar off the southern tip of India and the subsequent return of the whale to the tagging site. Additionally, a hexacopter UAV (drone) was used to acquire digital images of 7 whales to inform investigations into body condition (length-width relationship), tissue scaring and skin disease. UAVs that were flown through respired condensate (blow) resulted in collection of three viable samples collected for micro-biome assessment of the respiratory tract. On a broad geographic scale the tracking data continues to confirm the importance of waters over the continental shelf in southern Oman for ASHW and together with passive acoustic monitoring studies provides new evidence to support previous understanding on the connectivity between humpback whales of the Arabian Sea. The frequency of sightings in the study area, and documented breeding related behaviour during the survey supports existing evidence demonstrating that the Gulf of Masirah is a critical habitat for the ASHW. Effective conservation of this population requires concerted application of threat mitigation, whilst studies continue to support the on-going conservation management requirement to understand the broader spatial ecology of the population.

INTRODUCTION

Reeves *et al.* (1991) and Mikhalev (1997) were the first to hypothesis that the humpback whales found in the Northern Indian Ocean form an isolated, non-migratory, population. Further work conducted in Oman led to the designation of this population as 'Endangered' on the International Union for the Conservation of Nature (IUCN) Red List based on a mark-recapture population estimate of 82 individuals (95% CI 60-111; Minton *et al.* 2008). Recent genetic analysis supports the isolated status of these whales and indicates that they diverged from Southern

Hemisphere populations ~70,000 yrs BP (Pomilla, Amaral *et al*. 2014). The population is demonstrably vulnerable to anthropogenic threats (Baldwin *et al.* 1999, Minton *et al.* 2008; Baldwin *et al.* 2010), with evidence that fishing, commercial vessel traffic and oil and gas exploration and production are increasing within habitats associated with higher whale sighting densities (Corkeron *et al*. 2012; Willson *et al*. 2014).

Boat-based surveys conducted between 2000 and 2012 focused on two main study areas off the coast of Oman, the Gulf of Masirah and the Hallaniyats Bay[1] (Figure 1). Genetic sampling of ASHW along with behavioural cues (e.g. singing or the presence of a calf) observed at these sites indicated a near parity of males and females in the Gulf of Masirah and a male bias in the Hallaniyats Bay (Minton et al 2011, Willson et al 2014). Feeding was observed in both of these areas during February-March surveys in the Hallaniyats Bay and October-November surveys in the Gulf of Masirah. However, limitations to the timing and geographical coverage of previous surveys led the IWC to recommend further investigation of this population, including the use of satellite telemetry techniques (IWC, 2011).

Previous surveys have documented the occurrence of whales with emaciated or 'lean' morphology (Willson et al, 2014). Photographic records have also provided evidence of whale interactions with fishing nets (Minton et al. 2008) and the presence of tattoo-like lesions that are suspected to be caused by poxviruses. A significant increase in prevalence of this condition was noted between 2000 and 2011 (r^2 =0.998), (Van Bressem et al. 2014). A recent review of the research goals required to inform ASHW status assessments identified health indicators as priority metrics to develop long-term datasets for (Baldwin & Collins, 2016). The importance of these assessments have been supported by the ASHW Concerted Action plan (CMS, 2017). To address this objective, Unmanned Aerial Vehicle (UAV) methods were incorporated into the survey on a trial basis to evaluate logistical feasibility for their inclusion within the Oman research programme to gather data on morphology, reproductive status (of females), skin disease, scarring in addition to micro-biome assessment of the respiratory tract through the sampling of whale blow.

The IWC Scientific Committee endorsed the use of satellite telemetry to study humpback whales in the Arabian Sea in 2013 according to a set of preconditions (IWC, SC/65a/ Rep1, Annex H). Research updates on the first three seasons of work have since been delivered to the IWC Scientific Committee and analyses of habitat utilisation were identified as critical for the development of measures to mitigate existing and emerging anthropogenic threats to ASHW (Willson *et al.* 2013, 2014, 2016). Additional efforts in March 2017 failed to result in successful tagging of ASHWs. Here we present a research update from the most recent survey in Oman, including sightings and UAV results and preliminary results from analysis of telemetry data from the satellite tagging project within the context of regional spatial ecology and future research priorities.

METHODS AND MATERIALS

Boat surveys

Boat-based surveys were conducted from a base camp at Ras Sarab in the Gulf of Masirah (Figure 1). The surveys were coincident with the beginning of the breeding season (Mikhalev 1997; Minton *et al.*, 2010; Corkeron *et al.*, 2012) and with the survey timing and area selected according to the success of humpback whale encounters documented in November 2015 (Willson et al. 2016). Observers worked from two 6.5 m rigid hulled inflatables (RHIBs) and searched for whales using paired parallel transects separated by 3-4 kilometers. Survey methods were consistent with previously used protocols (Minton *et al.*, 2010; Corkeron *et al.*, 2012; SC/65a/SH06). Omni-directional dipping hydrophones (High Tech Inc., HTI-96) were employed on both vessels to detect ASHWs and guide research vessels towards singing males.

During tagging work, each vessel had a clearly defined role; one RHIB was dedicated to the application of satellite tags (crewed by tagger, biopsy specialist, cameraman and driver) and the other acted as a support and safety vessel for the overall mission. Each vessel utilised pre-agreed protocols for reducing risk during tag deployment. The UAV team operated from the safety vessel (crewed by two licensed UAV operators and an experienced driver) and were given the clearance to initiate flight protocols once the other vessel had completed tagging, photo-ID and biopsy objectives.

[1] Referred to locally as the *Ghubbat ad Dawm* and previously as *Kuria Muria Bay*

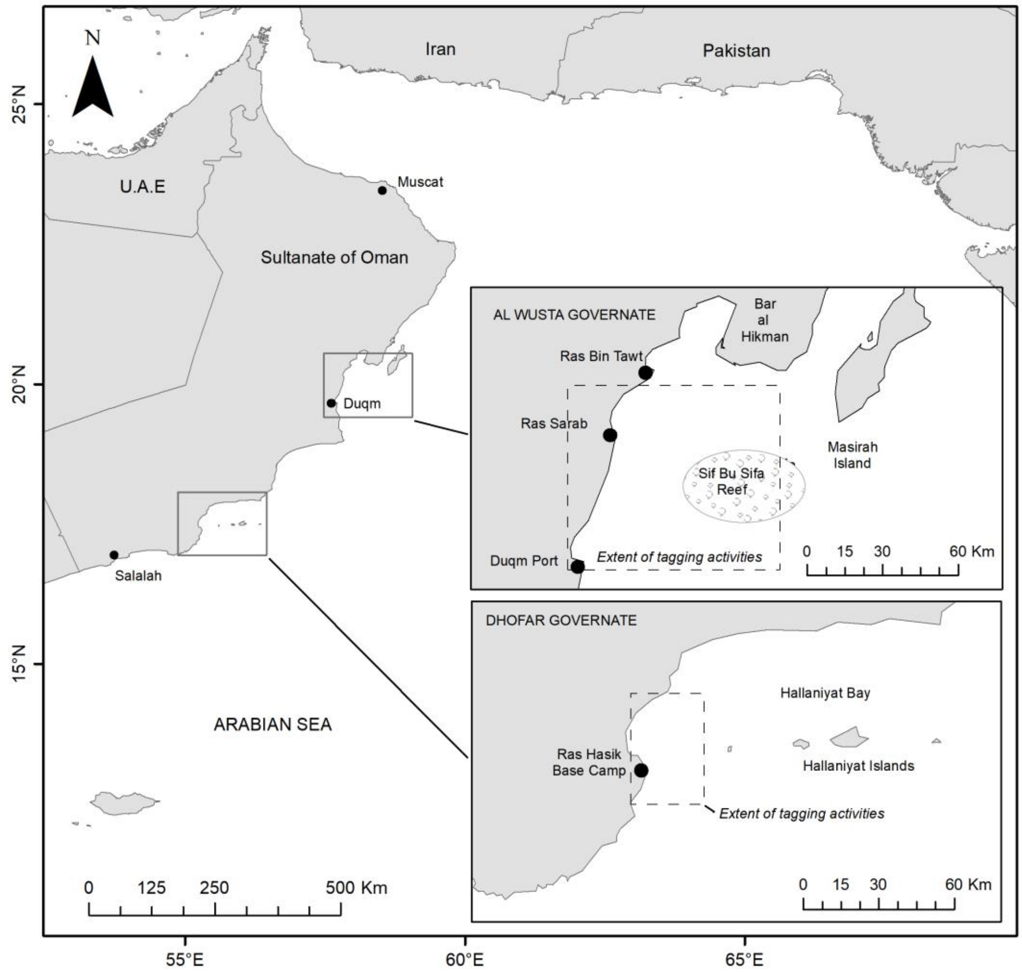

Figure 1. Focal areas of ASHW survey effort, including tagging activities in the Gulf of Masirah (November 2015 and 2017), and Hallaniyat Bay (February/ March 2014, 2015 and 2017).

Satellite tag design and deployment

The Argos satellite platform terminal transmitters used in this study were archival Splash 10 Tags (Wildlife Computers, Redmond, WA, USA). Each transmitter and associated electronic components are contained within an integrated, cylindrical surgical-quality stainless steel housing. The tags are designed to penetrate the epidermis and blubber of the whale and anchor at the variable muscle and the connective tissue matrix underneath the blubber (also known as *fascia*). All external components of the tag were disinfected using ethanol and stored in a sterile box prior to deployment. Tagging and survey activities were carried out under permit from the Oman Ministry of Agriculture and Fisheries Wealth and Ministry of Environment and Climate Affairs.

Once sighted, humpback whales were approached for the collection of identification images (tail flukes and dorsal fins) and other pertinent data. Images were compared *in situ* using an electronic version of the Oman humpback whale photo-ID catalogue (including sighting history, biopsy and sex data - where available). The decision on whether or not to tag encountered whales was subject to a set of evaluation criteria, including the apparent physical gross health (i.e. lack of injury, good nutritional status) and reference of the individual against the humpback whale photo-identification catalogue. Mothers with calves were avoided for tagging purposes. If the animal met with predetermined criteria attempts were made to deploy a satellite tag on the animal, typically during the final surfacing prior to a dive in order to ensure maximum exposure of the area of the body target for tag placement (the dorsum/flank). Tag deployment was carried out from the modified bow of the tagging RHIB at distances of five to eight metres with a pneumatic tag application system (a modified version of the Air Rocket Transmitter system 'ARTS', Heide-Jørgensen *et al.* 2001). A biopsy was collected simultaneously using a crossbow and modified dart (Lambertsen 1987). Video and photographic records were collected throughout the tagging process;

vessels followed tagged whales for a minimum of one hour after each tagging event in order to record behaviour and to further photograph implanted tags. Satellite tagged whales that were resighted on subsequent days were approached for additional photographs to record information on any movement of tag at the site of insertion or local tissue responses (e.g. inflammation, erythema).

Satellite Tag Programming

Satellite tags were configured based on advice from the Marine Mammal Laboratory, (Alaska Fisheries Science Center) and product manufacturers which included reference to methods established by the same team in 2015 (Willson et al, 2016). The configuration accounted for optimisation of battery demands to generate sufficient location data points for spatial modelling of data, meet the power requirements of pressure sensor data transmission and ensure the tags had sufficient endurance to transmit for up to six months. Tag transmissions were duty cycled to coincide with ARGOS satellite overpasses and transmit within four-hour blocks three times per day. Transmissions were restricted to a maximum of 400 within a 24-hour period.

Satellite Tag Data Processing – Best Daily Location

Processing of tag location data into a single *Best Daily Location* (highest spatial accuracy) format was performed to enable preliminary review of whale tracks and future pairing of dive behaviour data and thus provide spatial reference for these data each day. Spatial datasets of humpback whale distribution and movement were generated from location data received from the Argos System. Location data were filtered using R (R Development Core Team 2013). Argos locations with spatial error classes '0' and 'Z' were removed. Locations occurring on land were similarly removed. Implausible locations based on speed and turning angles were removed through the 'sdafilter' from the package 'argosfilter' (Freitas *et al*., 2008). The default parameters of this package were used apart from the speed, which was set to 3.33 $m.s^{-1}$ (12 $km.hr^{-1}$) based on plausible maximum speeds of humpback whales reported by Garrigue et al. (2015). Combined best daily location data and associated track lines for all individuals were plotted using ArcGIS 10.3 (ESRI, Redlands, California, USA).

UAV Deployment and Data Processing

Photogrammetric data collection via unoccupied aerial systems (UAS), and analyses thereof, follow previously developed methods and standards (Durban et al. 2015; Durban et al. 2016). A custom unoccupied hexacopter (APH-22; Aerial Imaging Solutions) was launched from the research vessel to collect high-resolution aerial photographs of surfacing ASHWs from directly overhead. The only deviation from the published method was the use of a laser altimeter (i.e., LIDAR) for more accurate altitude estimation. Using simple geometry, photographs collected at a known altitude (usually >100ft) were used to estimate body size parameters (i.e., girth measured at 60% of total body length, relative to length) indicative of body condition. Plotting of values was done in the *R* programming environment (R Core Team 2011) with the package *ggplot2* (Wickham 2011).

High-resolution images obtained were also used to quantify the level of tattoo-like skin disease (TLSD), body scars, external parasites and injuries key indicators of health (Durban et al. 2015; Durban et al. 2016; Miller et al. 2012; Miller et al. 2011; Van Bressem et al. 2015). Here we only present the quantification of TLSD. From 2-4 photos of the dorsal surface of each individual were used to quantify TLSD. Quantification of pixels for both total dorsal surface and infected dorsal infected were conducted in Photoshop using the Quick Selection Tool and exported as .csv files. Data analysis and plotting were conducted in the *R* programming environment (R Core Team 2011) with the package *ggplot2* (Wickham 2011).

We also collected exhaled respiratory condensate (i.e., blow) to assay the microbial community (i.e. microbiome) in the respiratory tract, using sterile collection techniques and flying the UAV at low altitude (6-9ft) to sample the blow (Apprill et al. 2017). Negative seawater and air samples were collected for controls. All samples were cryopreserved in liquid nitrogen after return of the drone to the vessel and returned to the laboratory in a liquid nitrogen dry shipper.

RESULTS

Survey Effort and Sightings

Vessel surveys conducted between 16^{th} to 30^{th} November 2017 resulted in a total of 10 days at sea and 45 hours of 'on-effort' search time. Within this period, 35 sightings were made of humpback whales with 10 of these sightings made 'on-effort'. Only one sighting was made of another marine mammal species; a Bryde's whale (*Baleanoptera brydei*). Humpback whale song was detected on 31 occasions from 87 acoustic stations (Table 1). Individual ASHWs engaged in song was directly observed on three occasions, and competitive behaviour also documented three times with groups sizes between three and five individuals. A humpback whale mother and calf pair were observed once, and up to three groups encountered included sub-adults. No feeding was observed by humpbacks although the Bryde's whale was likely engaged in foraging behaviour based on surface observations.

Table 1. Summary of vessel survey effort, humpback whale sightings and detections of song using acoustic equipment.

Vessel name	On-effort time (hr)	On-effort distance (km)	Total no. of ASHW sightings	'On-effort' ASHW sightings	No. of acoustic stations	No. of acoustic stations with detection of ASHW song	On-effort sightings rate (sightings hr $^{-1}$)
ESO1	21.2	390	28	6	43	13	0.28
MalA	23.8	338	7	4	44	18	0.17
Total	44.9	728	35	10	87	31	0.22

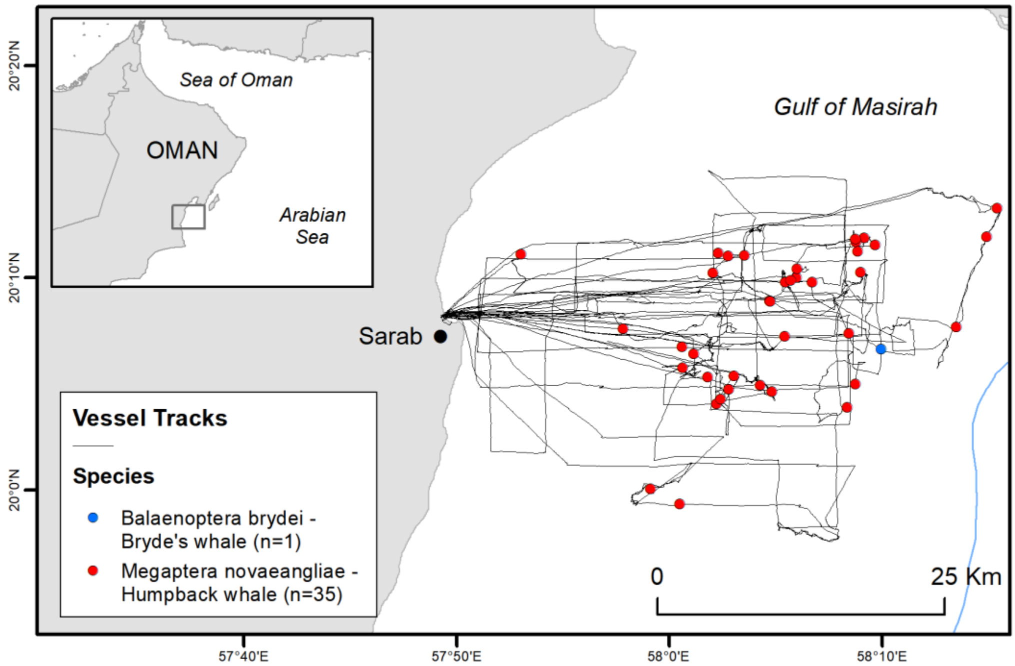

Figure 2. Vessel survey tracks and sighting locations in the Gulf of Masirah, November 2017.

Photo-ID and Genetic Sample Tissue Collection

Photographic data established a total of 42 encounters including within-day matches over the course of the survey. Identification work revealed a minimum of 18 animals were encountered during the survey, with matches from the photo-identification catalogue not yet made for a further seven encounters. Six of the animals encountered appear to be new to the catalogue pending a more rigorous matching of dorsal fin as well as tail fluke photographs. Twelve have been documented from previous surveys. Review of sighting frequency revealed three animals were observed on three separate days during this survey and five were sighted on two separate days. A total of 19 successful biopsies and 2 sloughed skin samples were obtained.

Tagging Activities

From a total of seven tags deployed, five were implanted on whales with subsequent successful transmissions (Table 2). Tags deployed on whales A and G failed to sufficiently implant and fell off soon after deployment. Of the five tags successfully deployments (individuals B, C, D, E and F), two were instrumented on animals not previously identified in the Oman catalogue (individuals B and D) and three animals were known to the catalogue (individuals C, E and F). Until biopsies are processed two of the whales are of unknown sex and two identified as male, with one animal (individual E) confirmed as a female from previous genetics studies. According to the photo identification catalogue this female was previously observed within the same survey area in October and November 2002, 2014 and 2015. This most recent survey brings the total number of ASHWs tagged in Oman to 14, comprised of ten males, two females and two of unknown sex.

Tag transmission periods ranged between 18 and 120 days, providing a cumulative 241 transmission days among the five tagged whales. Tags with the shortest retention times (individuals B, C and F) displaced no further than 100 km from the tagging location with movements ranging no further than the Gulf of Masirah (Figure 3). Whale D traveled south from the survey area to the Hallaniyats Bay immediately after tagging and remained in the area for the rest of the tracking period. The only known female (individual E) remained in the Gulf of Masirah for the first three weeks and thereafter started to move east across the Arabian Sea. Usable location data were absent half way through the crossing with a verified location attained a week later in the third week of December over the continental shelf off the state of Goa in western India. Thereafter, the location data indicated the whale moving southwards to the Gulf of Manar where she arrived on the 1st January and remained until the 1st of February. During this time location data suggested the whale remained within 50 km of the most southerly point of India (adjacent to the town of Kanyakumari) and predominantly within the 50 m isobath. The whale subsequently moved north with locations absent for a 22 day period from the 10th February. Subsequent location data indicated the whale had returned to the general vicinity of the tag deployment region in the Gulf of Masirah within early March accounting for loss of signal during a return journey back to Oman. The tag subsequently transmitted for a further two-week period with the last known location close to the island of Masirah on 18th March.

Table 2. Tag deployment and performance metadata.

Individual Code	PPT ID	Nick Name	Whale Permanent ID Code	Tag Type	Date	Sex	Social Category	Tag Longevity (days)	No of Best Daily Locations
A	171992	Half Moon	OM01-006	Spot6	16/11/2017	M	Single Singer	-	-
B	172006	Dama'a	OM17_XXX	mk10	16/11/2017	U	Single Adult	35	35
C	171999	Zebra	OM01-013	mk10	17/11/2017	M	Single Adult	18	18
D	171996	Nahada	OM17_XXX	mk10	18/11/2017	U	Single Sub-adult	47	30
E	171995	Luban	OM02_008	mk10	21/11/2017	F	Female in competitive group	120	73
F	111868	Shaheen	OM11_011	mk10	25/11/2017	M	Male escort in competitive group	23	23
G	171998	None	OM17_XXX	splash10	27/11/2017	U	Pair	-	-

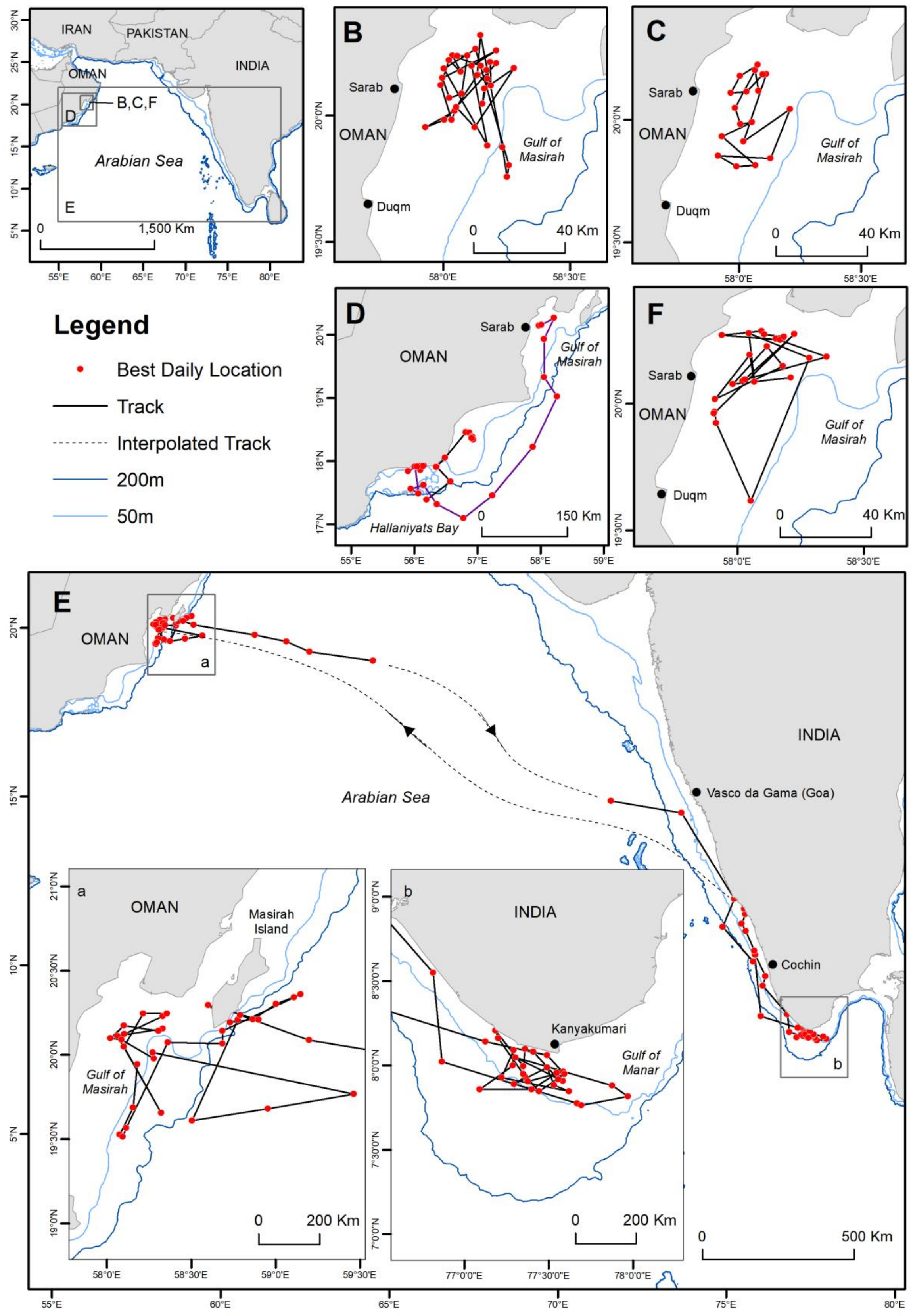

Table 3. Best daily location plots derived from whale telemetry data from animals tagged in the Gulf of Masirah, November 2017.

UAV Field Progress and Preliminary Results

Overall survey information is shown in Table 4. A total of 46 UAS flights (totaling 4.56 hours of flight time) were conducted on six days. Seven whales were measured using photogrammetric techniques. For three of these whales we collected microbiome samples. Body condition measurements are shown in Figure 3. In comparison with the other five ASHWs measured (n=7), body condition measurements for two whales (Mn5 and Mn6) fell along the lower margin of the distribution.

Table 4. Summary information on UAS heath assessment flights over ASHWs.

UAS Survey Days	UAS Flights	UAS Flight Time (hours)	ASHWs Measured	Blow Samples
6	46	4.56	7	3

The quantification of TLSD is shown in Figure 4 (as the mean percent coverage of the dorsal surface taken from several different photos). Measurements ranged from 0.45% to over 75% of total dorsal body surface. Error bars show the standard deviation of measures take from different photographs (numbering 2-4 for each individual). Standard deviation raged from 0.05 to 11.02. Although the parasite load has not been fully quantified yet, our initial qualitative assessment is that the level of ectoparasites is low (<5% on all animals) and consists of almost exclusively barnacles. Additional analyses of these data are forthcoming. Limited evidence of anthropogenic interactions (i.e., net entanglement and/or propeller scars) was observed. Almost all change in dorsal pigmentation could be attributed to skin infections (TLSD) or surface-level abrasions (likely due to contact with conspecifics).

Blow samples were collected from three ASHWs. These samples have been sent to the Aprrill lab at WHOI are awaiting analysis. In addition to these samples negative control samples of seawater and low altitude air samples are also being processed at WHOI.

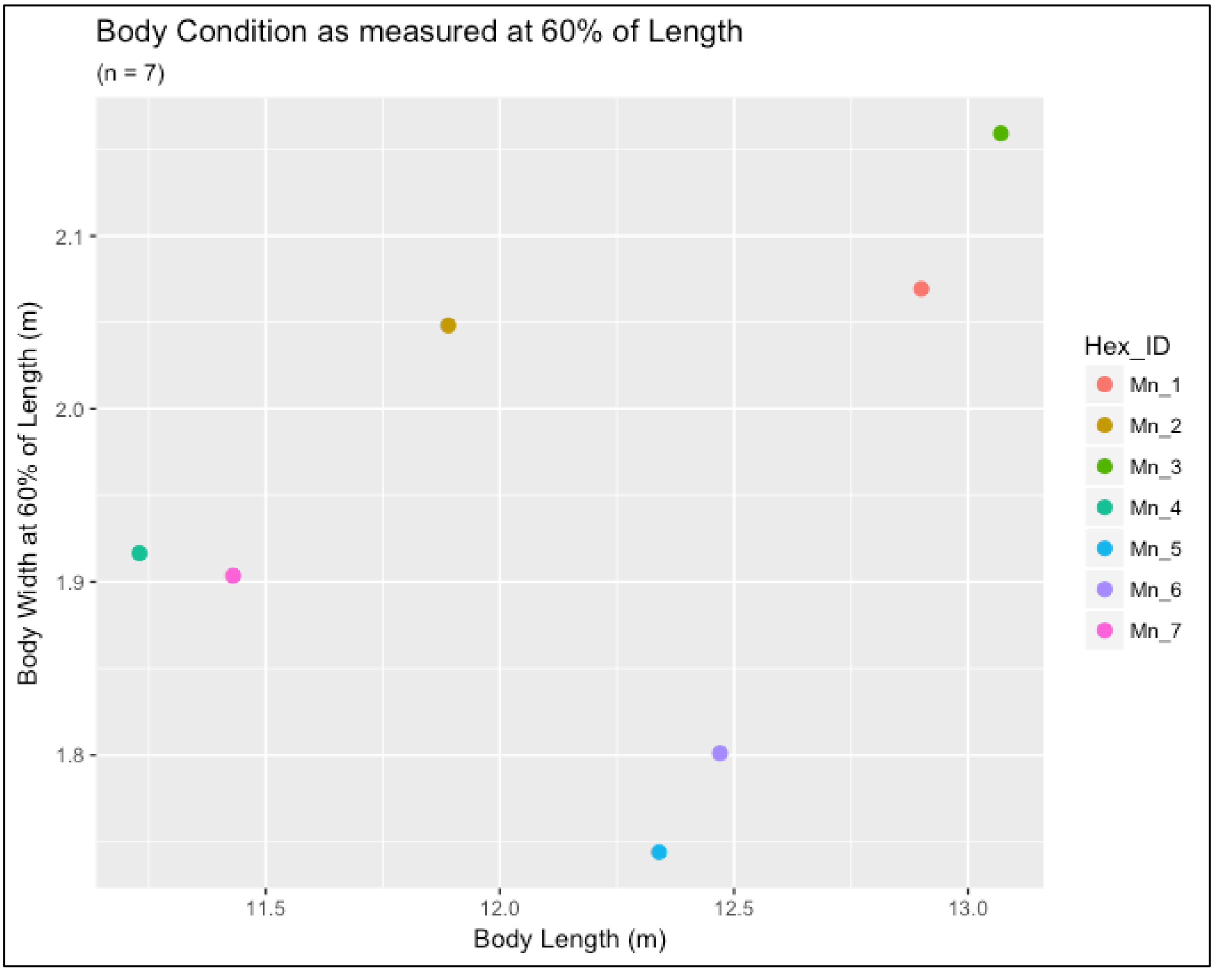

Figure 3. Plot of girth (m) at 60% of body length relative to total body length (m) for each individual ASHW.

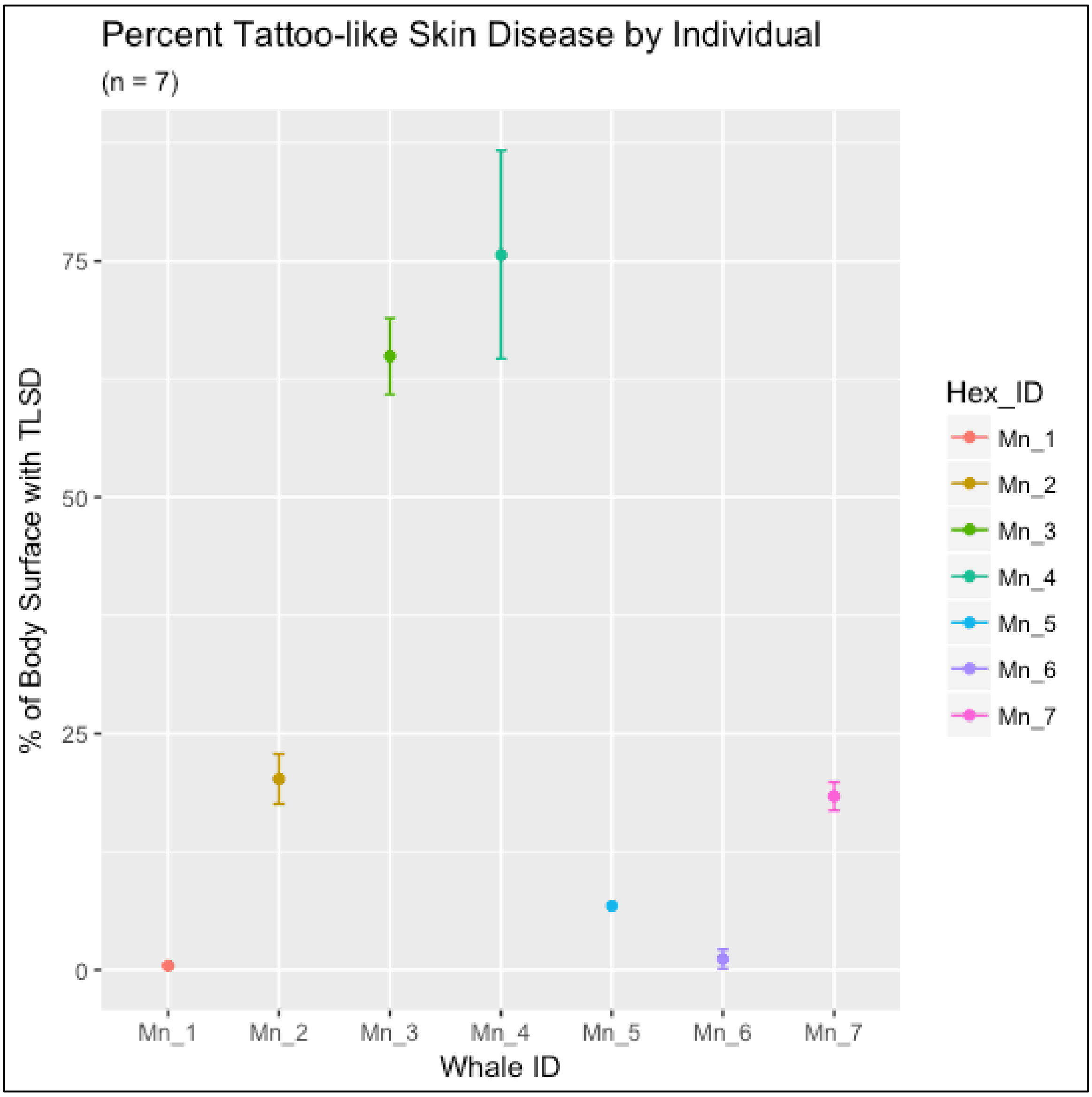

Figure 4 Mean percent of visible dorsal surface covered with TLSD (taken from 2-5 images of each individual). Error bars are standard deviation.

DISCUSSION

Health Assessment Work

The timing extent and application of field effort in the November 2017 survey presented opportunities for the team to meet multiple objectives, including the UAV work. In comparison with the other five ASHWs measured (n=7), body condition measurements for two whales (Mn5 and Mn6) fell along the lower margin of the distribution. These data may indicate slightly reduced body conditions relative to the other ASHW, but comparisons with other populations are needed (and forthcoming). Body condition metrics will be compared among ASHWs in relation to other variables including presence of scars, skin lesions, ectoparasites, and microbiome. These data will also be compared to published literature as well as data in hand from Antarctic Peninsula, eastern north Pacific and western north Atlantic humpback whales.

For the assessment of skin disease the level of infection present in this sample showed high variation. In addition, the level of error in our measurement showed high variation. In general, it appears that the higher the infection rate, the higher the standard deviation of our measurements across different photographs. Although molecular gender determination is still forthcoming, the two ASHWs with the highest levels of TLSD (Mn3 and Mn4) in this sample are thought to be males, as they were escorting (and competing for) a known female. It is important to characterize the type of infection present in ASHW skin. Although we speculate that it is a pox-like virus, histological and genetic characterization are needed to help assess the putative health impacts for this population.

The micro-biome samples are still awaiting analysis at Woods Hole Oceanographic Institution (WHOI). Variation in respiratory microbiome community will be compared between individuals, populations, species, seasons, and body condition (Apprill et al 2017) as well as compared to data on two other humpback populations that appear healthy. Finally, we will compare our data to a custom database of potential pathogens developed in Apprill's lab at WHOI (Gupta 1986; Langille et al. 2013). The prevalence of potential pathogens in the population will allow us to broadly infer exposure levels and overall microbial health of ASHWs.

Although the sample size is limited, the trial of UAV based research methods has validated the feasibility to incorporate health assessment into surveys to produce metrics that are considered essential to tracking the status of the population. Efforts are on-going to secure funding to mobalise further health assessment work in the future.

Spatial Ecology

Previous research efforts have demonstrated the importance of the Gulf of Masirah as important humpback whale habitat through several lines of evidence, including its role as a nursery area of mothers and calves, occurrence of breeding related behavior (competitive groups and song), documentation of feeding and the persistent record of whale movements in the area determined by satellite tracking (Willson et al, 2016; Cerchio et al, 2017). The most recent survey work presented here continues to support this hypothesis with the relative high encounter rate of individuals (n < 18) within the two-week survey period and the documentation of competitive behavior and presence of females with sub-adults. The high re-sighting rate of individuals on 19 occasions within this time indicates that the range of movements of animals at this time of year is limited given the limited spatial extent of the survey. These results are indicative of high site fidelity of animals encountered combined with the evidence that 12 of the whales identified from this survey are known from previous encounters within the Gulf of Masirah within the last 16 years. Identification work from this survey also revealed at least a third of the animals encountered are new to the catalogue which is suggestive that there might be additional individuals within the population that move outside of previously identified important habitats described from the coast of Oman.

Reports on the occurrence of humpback whales across a wider range of the Arabian Sea are well documented in historical and recent records, (Reeves et al, 1991; Mikhalev 1997; Mahnaty et al, 2015; Khan et al, 2017, Dakhteh et al, 2017) but the broader distribution, ecology and connectivity among animals observed within different range states is poorly understood and remained a primary research question of telemetry studies (Willson et al. 2016). Whitehead (1985) reported that based on similarity of song recorded between Oman and Sri Lanka in 1982 and 1983 'animals from both areas must come in acoustic contact with each other at some stage during the year'. However, in the following years no further evidence has provided a link, including the comparison of photo-identification records between the Oman catalogue (collected from dedicated surveys) and photo records (from incidental encounters) elsewhere in the region including Pakistan, India and Sri Lanka. Telemetry data previously reported by this project have revealed that ASHWs instrumented with tags in Oman prior to 2015 (n=9) spent 72% of their time over the continental shelf with 35% of their time within the Gulf of Masirah. Six animals were tracked moving between the Gulf of Masirah and the Hallaniyats Bay, with the maximum southern extent into southern Yemen (Willson et al, 2016). Four of the tags deployed within this last survey concur with these findings, with the tracks again repeating movements within and between these two areas.

The telemetry records reported here from individual 'E' provide the first direct evidence of transoceanic movement of a humpback whale from the population observed off Oman across to the Indian sub-continent with the route trajectory plotted across the central Arabian Sea. The journey of the same whale between Goa and the Gulf Manar has provided further insights into a pathway used along the continental shelf towards the Gulf of Manar where the whale remained in residence within a restricted habitat range for over a month. The movement of the female along this coast supports emerging information on habitat utilization by whales off this coast and is of particular interest in relation to recent song recorded between Cochin and Goa (Mahanty et al, 2015; Madhusudhana et al, 2018) and the first evidence of humpback whale song in the Gulf of Manar (Whitehead 1985). During tag operation, near real time locations were passed by the authors to colleagues in India who followed the route of the female, mobilizing combined fisher-based interview and vessel survey efforts with an objective of gathering additional data about whale occurrence along the coast and identifying potential drivers for habitat use, including prey availability and breeding related behaviour. No humpback whales were observed during vessel surveys, but high catches of small pelagic fish were reported from communities in the Gulf of Manar whom also reported they frequently see and hear whales in an area called the 'Wadge Bank' found in the waters between India and Sri Lanka (Sutaria pers comm). Individual 'E''s presence off the coast of India coincides with the ASHW breeding season, which was established by Soviet Whaling records for ASHWs to peak between December and March (Mikhalev, 1997).

Together these records present a compelling incentive to conduct dedicated surveys in the Gulf of Manar and west coast of India in the near future. The results have significantly extended the documented range of tagged whales and this data will be important to supporting regional ecological niche modeling work previously conducted (Willson et al, 2016) and will make the outputs more robust in supporting regional management efforts. The transoceanic movement also supports proposed work to formalize comparison of acoustic records between Oman and India (Cerchio et al, 2017; Cerchio et al 2018; Madhusudhana et al, 2018) to further understand connectivity between individuals based on cultural transmission of song. The return of this animal back to the Gulf of Masirah indicates the need for regional management measures for the population that takes into account trans-boundary movements and open-ocean crossings as well as their use of localized coastal habitats identified through earlier work in Oman.

CONCLUSION

The findings of telemetry work have revealed new insights into ASHW spatial ecology, particularly when combined with results of passive acoustic monitoring studies. Together these techniques have identified important habitat at local and regional scales as well as their presence through the year. Their contribution towards future research priorities and supporting the conservation management agenda warrants further review. The results are suggestive of as yet undiscovered important habitat elsewhere within the Arabian Sea and research into these elements must continue forwards whilst management and threat mitigation activities are applied to well described habitats in the south of Oman, particularly the Gulf of Masirah and Hallaniayts Bay.

ACKNOWLEDGEMENTS

We are grateful to the Ministry of Agriculture and Fisheries Wealth & 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. Support of Michael Moore and Amy Apprill at Woods Hole Oceanographic Institute in supply of UAV equipment and expertise has been an outstanding contribution in helping the Oman based team to realise new research opportunities. We thank all staff at the Environment Society of Oman (www.eso.org.om) through whom 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 working in the background for provision of expertise, time and patience in dealing with off the clock whale team related demands. The Wildlife Conservation Society is thanked for supporting the on-going participation of team members in support of field activities, data analysis and reporting. The work is also deeply indebted to the technical expertise, resources and patience of the Marine Mammal Laboratory of the Alaska Fisheries Centre and Instituto Aquali without which the tagging work would not have been possible. Finally, sincere thanks are given for the unwavering faith and financial support provided to this project by Rennaisance S.A.O.G since 2011.

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