Research update of satellite tracking studies of male Arabian Sea humpback whales; Oman.

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Abstract

Satellite tags were deployed on three adult male humpback whales (*Megaptera novaeangliae*) encountered off the southern coast of Oman during March 2015. This represents the second year of a telemetry study that began with the tagging of three whales in 2014 and forms part of a broader scientific research programme initiated in 2000 to understand the population biology and spatial ecology of Endangered Arabian Sea humpback whales. Tags were deployed in an area commonly associated with the seasonal presence of singing whales. Resightings of whales tagged in 2014 (*n*=3), supported by photographic evidence of two animals, showed normal healing of epidermal tissue around the tag site over a period of 9 to 11 months. A repeat tagging of one known individual (tagged in 2014) as well as two other known individuals in the Oman photo-ID database provides further evidence for high site fidelity of males to the tagging site as well as the Gulf of Masirah. Habitat utilization inferred from telemetry and vessel survey data have confirmed the urgent need for mitigation measures in high-risk areas and have led to an improved understanding of humpback whale spatial ecology across the wider region.

Introduction

Reeves *et al.* (1991) and Mikhalev (1997) were the first to hypothesise that the humpback whales found in the Northern Indian Ocean formed 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 extremely vulnerable to anthropogenic threats (Baldwin *et al.* 1999, Minton *et al.* 2008; Baldwin *et al.* 2010), with evidence of fishing, commercial vessel activity and hydrocarbon exploration escalating within habitats associated with highest sighting densities (Corkeron *et al*. 2012; Willson *et al*. 2014).

A broad network of individuals and organisations has supported research and conservation management requirements of Arabian Sea Humpback Whales (ASHW) in Oman over the last 15 years. Notable research outputs include; photo-identification and mark-recapture abundance estimates of population size (Minton *et al.* 2008), genetic analysis to define population identity (Pomilla, Amaral *et al*. 2014), spatial ecology through habitat modelling (Corkeron *et al.* 2012) and passive acoustic monitoring (data still undergoing analysis).

Habitat utilisation analysis has been identified as critical for the development of measures to mitigate existing and emerging anthropogenic threats (Willson *et al.* 2013, 2014). The International Whaling Commission Scientific Committee endorsed the use of satellite telemetry for whales in the Arabian Sea in 2013 (IWC, SC/65a/ Rep1, Annex H) and three tags were deployed during February 2014.

Concurrently, proposals were made, and a regional workshop held (in Dubai, January 2015), to develop regional capacity and coordination of work on baleen whales in the Northern Indian Ocean (Minton *et al.*, 2015).

Here we report on a second field season of satellite tagging in Oman, present a comparative review of initial tracking results from 2014 and 2015 and discuss research priorities in the context of addressing identified management and mitigation measures.

Methods

Fieldwork was conducted from a base camp situated at Ra's Hasik (Hallaniyats Bay) on the Dhofar coast (**Figure 1**), between 18th February and 21st of March 2015 (Figure 1), a period coincident with peak breeding (Mikhalev 1997; Minton *et al.*, 2010; Corkeron *et al.*, 2012). Observers aboard two 6.5m rigid hulled inflatables (RHIBs) powered by four-stroke engines searched for whales on a daily basis using paired saw-tooth transects in near-shore waters. Offshore searches were limited, given on-going security (piracy) concerns, but the search method was generally consistent with survey protocols used previously (Minton *et al.*, 2010; Corkeron *et al.*, 2012; SC/65a/SH06). Acoustic stations using an omni-directional dipping hydrophone (High Tech Inc, HTI-96) were also employed to direct searches towards singing whales. Observers on cliff-tops also conveyed sightings to the survey vessels via VHF. Each vessel had a clearly defined role; one vessel 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 utilising recognised protocols for reducing risks during tag deployment.

Tag design and deployment

The tags used in this study were Wildlife Computers (Redmond, WA, USA) SPLASH10/MK10A transmitters contained within implantable cylinder housings. Tags are designed to penetrate into the epidermis and blubber of the whale, typically on either flank just forward of the dorsal fin. They are anchored in the fascia (variable muscle and connective tissue matrix) that underlies the blubber. Tag retention is maintained by two sets of passively deployed barbs that release once the tag is embedded. All external components are made of surgical-quality stainless steel and tags were sterilised 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 initially approached for the collection of identification images (tail flukes and dorsal fins). Images were compared *in situ* with images of previously identified whales from the Oman humpback whale photo-ID catalogue (including sighting history and sex where available). If the animal met with predetermined criteria (see below) 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 dorsal/flank area. 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. Tagged whales resighted on subsequent days were approached for additional photographs in order to record any tag migration or tissue responses.

Sampling design

Two areas previously identified as humpback whale 'hotspots' (Gulf of Masirah and the Hallaniyat Bay) were selected as survey sites, with planned flexibility to shift between locations depending on local weather conditions. A four-week period from the end of February was prioritised given known 'peaks' of whale breeding and relative abundance in focal areas. The decision to tag was made on an opportunistic basis dependent on the individual encountered meeting certain conditions: adult, appearance of good health and demonstration behaviour perceived as conducive to a successful and safe approach. Whales previously tagged in 2014 were to be tagged if prior tag locations appeared to be well healed (see discussion section). Mothers with calves or juveniles were to be avoided.

Data Collection and Processing

Tag programming was modified during 2015 based on realised tag performance in 2014. A primary consideration was the addition of a depth/pressure sensor requiring increased data transmission and associated power demands. Tags were programmed to deliver a maximum of 400 transmissions per day, as this was the maximum achieved in 2014. Transmission periods were programmed to coincide with Argos satellite overpasses, with three periods of four-hour block durations set on a daily schedule from the time of tagging until 31st May. Thereafter the transmission schedule was adjusted to every other day with the objective of capturing movements during the southwest monsoon (May-September) if tag life extended into this period. Humpback whale spatial data during the monsoon is limited as high sea-states preclude small vessel surveys. The pressure sensor was programmed to provide time at depth, depth time-series and depth behavioural log information.

Location data were archived from the Argos data collection system through the intermediary telemetry data management system on seaturtle.org (STAT: Coyne and Godley 2005). Within this system, mapping products were generated through a processing code set to remove all '0' and 'z' class locations and filter speed (>20km/hr), turning angle (25 degrees) and positions over land. The products from this tool were used for initial overview of tracks from each whale.

Subsequent processed datasets for mapping habitat utilisation were generated from location data received from the Argos archived data collection system. Locations were treated using R (R Development Core Team 2013), with a script written to filter '0' and 'Z' Argos location classes, remove duplicate locations and any locations on land. The 'sdafilter' from the package 'argosfilter' (Freitas *et al*., 2008) was also applied within the script and set on default parameters (with a maximum swimming speed of 7.2 $km.hr^{-1}$ (Gales *et al*., 2010), to account for unlikely location points attributed to telemetry errors.

To remove autocorrelation from temporally inconsistent location points in a manner suitable for depicting habitat utilisation, filtered data were also processed to provide an estimate of 'best daily location' (Witt *et al*., 2008). Combined data from all individuals were then plotted and counted with the ArcGIS point count tool to produce maps representing the density of these daily locations within hexagonal cells of 25 km minimum diameter.

To provide a preliminary comparative analysis to satellite tracking habitat utilisation maps, ASHW sightings and effort data from vessel- based surveys conducted between 2001 and 2012 were also processed within ArcGIS. Projections of 'on-effort' sightings data were performed within the same hexagonal grid layer as used for the presented telemetry data. Relative densities were calculated for each hexagon by dividing the number of on-effort sightings by the cumulative length of effort in each cell and accounting for the area of the cell (Corkeron *et al*., 2011).

Results

Tagging

Three males were tagged between the 10th and 14th of March 2015. High sea-states and/or an absence of whales prevented tagging on other dates within the survey period. All tagged whales had been previously identified and catalogued in the Oman Humpback Whale Photo-ID Database. The sex of each individual was confirmed either through prior genetic analysis or behavioural data (Pomilla, Amaral *et al.* 2014). One animal tagged in 2015, OM02-019, was also tagged in 2014 (the opposite flank). All three tags were optimally placed below the dorsal fin with at least ¾ to full implantation.

All whales reacted to tagging with a tail slap and/or quick dive. One whale (OM01-006) that had been singing on the first approach, breached repeatedly within a 20-minute period following tagging before resuming singing. One tag (individual OM01-014) ceased to function after 25 days, while the other two were still providing transmissions at the time of writing (13/05/2015). All have and are continuing to provide pressure sensor data. Complete processing of location and depth data will commence once the remaining two tags cease transmission. Details of tag deployment and performance are presented in Table 1.

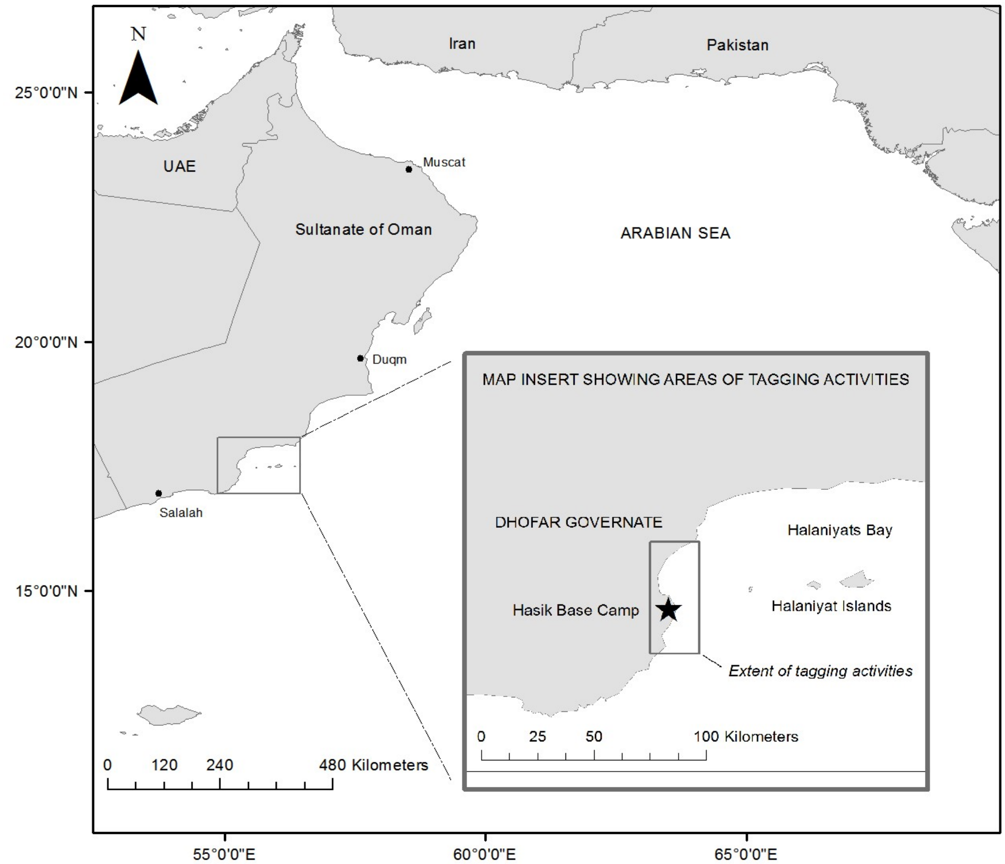


Figure 1 Location of tagging activities from the base camp in Hasik, Southern Oman, (February 2014).

Table 1 Tag deployment and performance metadata of tags deployed in 2015 as reported from 'seaturtle.org' on 13/05/2015.

Tag PTT Number	Tag Date	Whale ID-Code	Current Tag Longevity (Days)	Number of location data points	Number of locations after filtering	Displacement from initial tagging site (km)
87777	10-03-2015	OM01-014	25	330	283	390
81126	13-03-2015	OM02-019	61 - Active	422	393	422
87625	14-03-2015	OM01-006	60 -Active	489	627	489

Track and Dive Descriptions

Location data mapped through 'seaturtle.org' are presented in Figure 2. All three whales spent at least one week in the vicinity of the tagging location before moving north and spending the month of April in the Gulf of Masirah. All three individuals have predominantly spent time in waters shallower than 100m with some movement along the continental slope where maximum dive depths of 240m have been recorded.

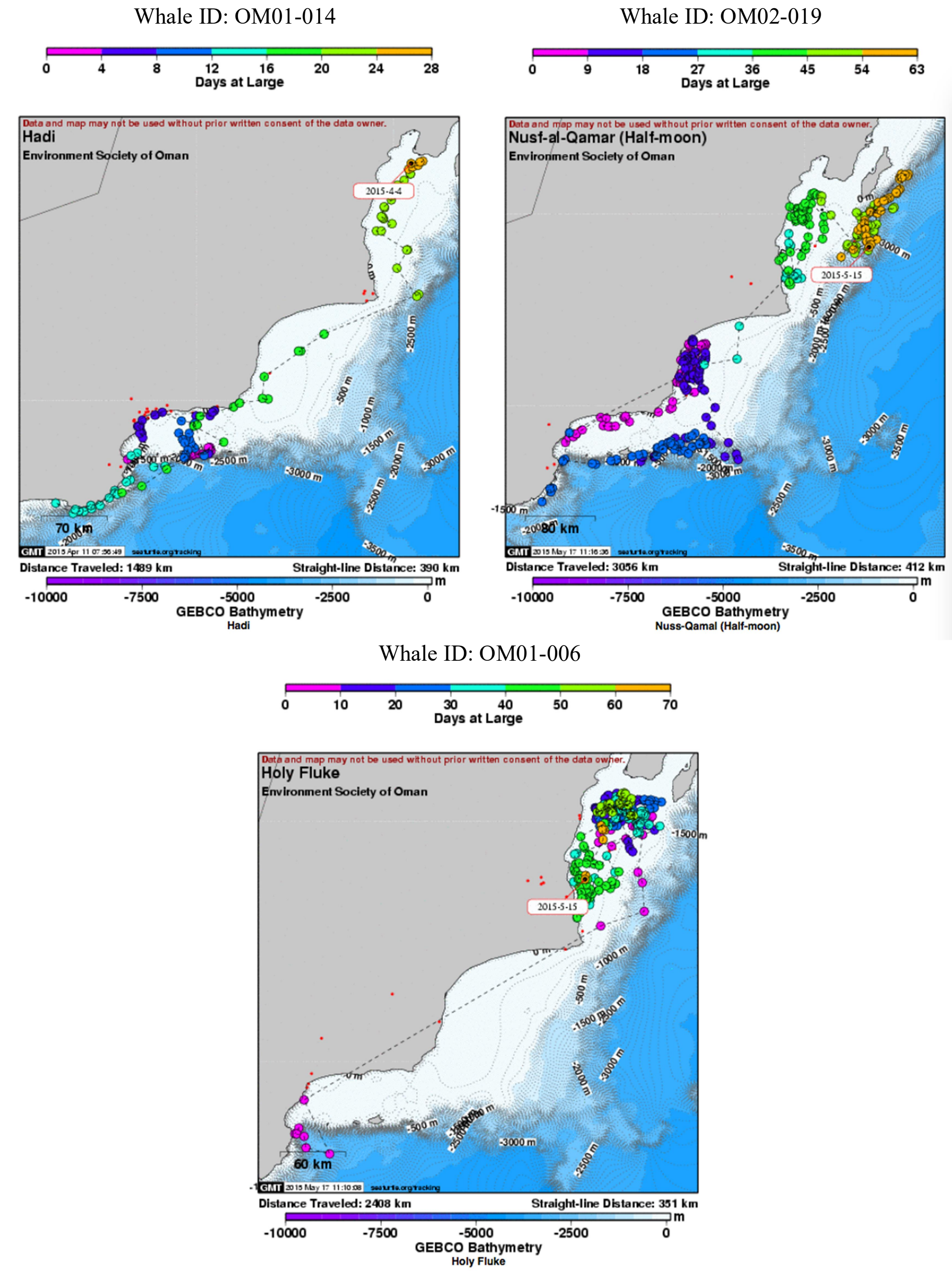


Figure 2 Location and track plots from all three animals as reported from archived data on 'seaturtle.org' as of 13/05/2015.

Discussion

Tag Deployment

Tagging opportunities were restricted by atypically adverse weather, resulting in less than a week of vessel time in the Hasik area over a five-week period. As reported in Willson *et al*., 2014, whales were extremely difficult to approach for tagging[1]. These challenges limited successful deployments to six

[1] Perceptions of the ease of approaching whales for tag application as reported by tagging specialists working with the Oman team; Ygor Geyer (2014) and Amy Kennedy (2015).

tags rather than the anticipated target of 10 tags during the 2-year programme. As such, future work will need to consider a more flexible tagging strategy that allows the survey team to mobilise at short notice to take advantage of suitable weather windows.

2014 Resightings of Tagged Individuals

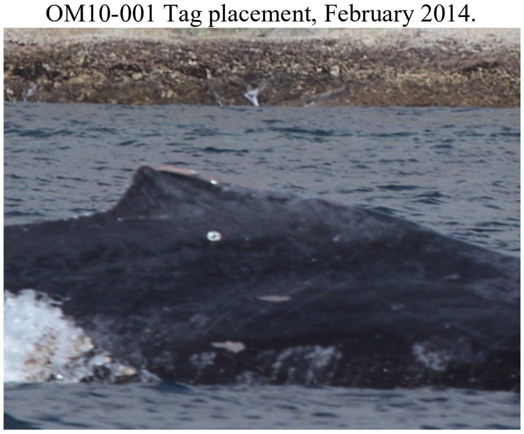
Five humpback whales were previously tagged at the Hasik study site between 9th and 29th February 2014. Two of these tags had sub-optimal placements and provided no data; three tags transmitted for durations between 40 and 54 days (Willson *et al.* 2014).

Resightings of three previously tagged animals were made by MMO observers on seismic surveys conducted in November 2014 and the during the tagging season in 2015 (Table 2). On-board observations and photographs of two individuals (Figure 3) indicate healing of the epidermal tissue layer in the tagged region. Associated depressions suggest that some tissue necrosis, possibly in the dermis, may have occurred following tag rejection. The findings have provided some reassurance that these whales respond to tags in a manner similar to that reported elsewhere (Robbins et al. 2013).

Table 2 Details of whales tagged in 2014 and those resighted in late 2014/ early 2015.

Tag PTT Number	Tag Date	Whale ID Code	Tag Placement	Tag Longevity (Days)	First Re-sighting Date since 2014 survey
121192	21/02/2014	OM02-020	Sub-optimal	1	30/11/14
121193	22/02/2014	OM10-001	Optimal	55	26/2/15
87759	23/02/2014	OM11-002	Sub-optimal	1	Not encountered
87766	25/02/2014	OM02-019	Optimal	41	10/12/2014
121194	28/02/2014	OM00-003	Optimal	42	Not encountered
		Totals		140	

OM10-001 Tag placement, February 2014. OM10-001 Tag scar, February 2015.



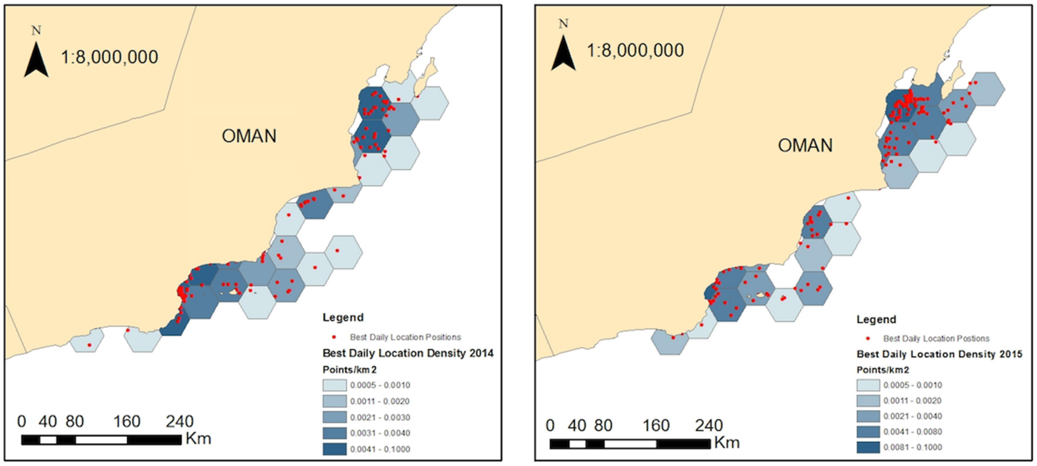
OM02-019 Tag placement, February 2014. OM02-019 Tag scar, February 2015.

Figure 3 Photo records of two individuals tagged in 2014 and resighted in 2015.

Tag Habitat Utilisation Comparisons

Tracks of whales presented in Figure 2 show that tagged animals circulated in the area of the Hallaniyats Bay at least until the end of March. All animals then moved northwards towards the Gulf of Masirah by the beginning of April and remained there into May. These data demonstrate a similar pattern of whale movements presented in 2014 (Willson et al. 2014). It should be noted that whilst this pattern is true for tagged animals, photographs from two third-party sources indicate the presence of at least a few whales in the area of Salalah, ~600 km to the south during May.

Habitat utilisation maps compiled from best daily location points from both tagging survey years are presented for comparison in Figure 4, and show broadly analogous density plots, confirming the importance of the Gulf of Masirah and Hallaniyats Bay as 'hotspots' between February and May, coinciding with the population's breeding season (Mikhalev 1997, 2000). In addition to identified hotspots, plots also identify the shelf break off the Hallaniyat Islands and Gulf of Masirah as regularly frequented areas. From a management perspective the latter two overlap a busy North-South shipping lane running along the coast of Oman between the Gulf of Aden and Straits of Hormuz. Also of note is that none of the tagged animals have left Oman's waters whilst transmitting, although whaling and other data indicate at least a historical presence in waters off Yemen, India, Pakistan and Sri Lanka (Mikhalev 1997, Reeves et al. 1991).



a) All satellite track plots from 2014 **b) All satellite track plots from 2015**

Figure 4 Maps comparing track plots of animals from 2014 (a) and 2015 (b) tagging studies. Hexagonal cell plot minimum radius = 25km.

Habitat utilisation maps generated from satellite tracking also reveal hotspots consistent with those identified from analyses of small vessel survey data (e.g. Minton et al. 2011 and Corkeron et al. 2011). This work is being updated to include data from 2004 to 2012. A preliminary review is presented in Figure 5 where effort corrected sightings from vessel surveys are plotted in the same format as the telemetry data.

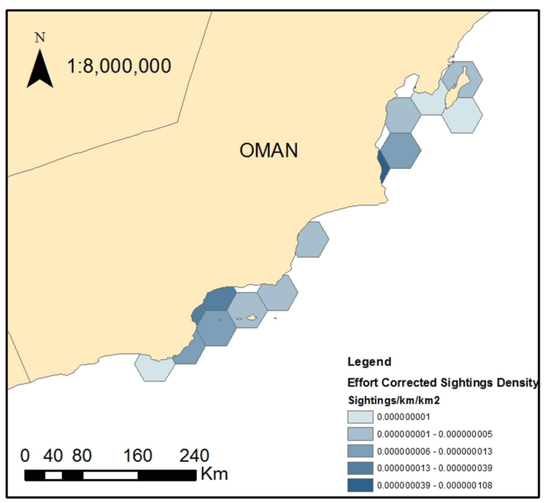


Figure 5 Habitat utilisation map of effort corrected sightings from vessel based line transect surveys conducted between 2001 and 2012. Hexagonal cell plot minimum radius = 25km.

Twenty-eight vessel surveys were conducted between 2001 and 2012, providing 195 sighting records of which 95 have associated effort data to contribute towards habitat utilisation density mapping (Figure 5). In 2014, three tagged animals transmitted positional data over a two-month period and generated 122 location points (best daily locations) used to produce a habitat utilisation map. As such, tagging provides some advantages for improving the understanding of humpback whale spatial ecology in the region. However, our sample is limited, with only five males successfully tagged from the Oman catalogue of 86 possible individuals (26 confirmed males). Sampling efforts to date have also been limited spatially (heavily biased toward Hasik and the Gulf of Masirah) and temporally (February-May). Future tagging efforts should attempt to expand the geographic and temporal scope of tag deployment, and include instrumentation of females when appropriate.

Threats & Vulnerabilities
Industrial development in recognised hotspots, including the Gulf of Masirah and Hallaniyats Bay has previously been reported (Baldwin et al. 2010; Willson *et al.* 2013, 2014). The multi-purpose port and drydock facility at Duqm in the Gulf of Masirah was commissioned for a soft opening in 2013 with new plans unveiled for the additional development of Oman's largest fishing port and an oil tank farm loading facility within 50km of the new port. During a recent 3D-seismic survey in the Gulf of Masirah, in November and December 2014, 68 of the 76 reported baleen whale sightings were confirmed to be humpback whales. Even though measures were taken to limit noise exposure, one humpback whale was involved in a non-fatal strike with leader-cables of the towed seismic array. Further details of port development, seismic surveys and associated mitigation work are provided by *Baldwin et al. (SC66a*).

Five humpback whale mortalities were recorded in Oman between December 2014 and April 2015, (see *Collins et al. this meeting, SC66a)*. The carcasses were too decomposed for any detailed necropsies to be conducted or for cause of death to be determined. This strandings rate is alarming given both the small size of the population and the marked increase in fishing pressure using unattended gillnets within important humpback whale habitat in Oman. Recently published work also indicates the high prevalence of Tattoo-like Skin Disease in Arabian Sea humpback whales, the first confirmed report of a tattoo-like disease in the Balaenopteridae (Van Bressem *et al*. 2014). Examination of 522 humpback whale images collected in Oman between 2000-2006 and 2010-2011 revealed an increased prevalence of the disease over time, with prevalence during the whole study period reaching 21.7% in 60 whales and 16.7% in 36 adults. Genetic work by Pomilla, Amaral *et al.* (2014) shows that the Arabian Sea humpback whale population is highly distinct; estimates of gene flow and divergence times indicate that they have been isolated from southern hemisphere populations for approximately 70,000 years. Genetic diversity values are significantly lower than those obtained for Southern Hemisphere populations and signatures of ancient and recent genetic bottlenecks were identified. Based on these findings the authors suggested that the IUCN Red List status of Arabian Sea humpback whales be elevated to 'Critically Endangered'.

Recommendations

The telemetry data collected to date has been extremely valuable for assessing and confirming areas of overlap between whale distributions and human activities. We recommend additional tagging activities in order to correct for the current bias towards males and the limited temporal scale and geographic range of reported locations. We propose that the next tagging efforts in Oman focus on the October-December period from a base in the Gulf of Masirah. The observed ratio of males to females in this region is at parity (Minton, 2010) and there is a higher rate of discovery of previously unidentified individuals, suggesting both greater use by a greater number of individuals and possible overlap with other under-sampled areas (ESO, unpublished data). To address seasonal weather constraints and add flexibility for tag deployments the capacity of members of the Oman research group should be developed to permit tagging of whales on a more opportunistic basis, for example during other cetacean surveys. Tagging opportunities could also focus on regions or periods that are coincident with known or suspected threats, including seismic surveys.

Given the scale of developments within the Gulf of Masirah, additional advocacy efforts are required to ensure the timely consideration of environmental sensitivities (such as important whale areas) in the early phases of high level strategic planning.

We propose a combined approach to mapping important areas of habitat using vessel surveys, acoustics and tagging datasets in order to most effectively inform management advice related to industry-based threats emerging within the Gulf of Masirah and other areas of high concern identified within the study. Mitigation actions have recently been adopted by companies operating within the Gulf of Masirah. These are based on the evidence gathered by the research group and the broad range of support from across the scientific community for the vulnerability of ASHWs to threats. Assessments of the risk of localized oil spills, ship strikes and noise would further benefit of the management of industries based in these region.

A regional workshop of scientists with data and research interests in ASHW's was held in Dubai in January 2015, (Minton *et al.* 2015). In addition to recommending the formation of an informal network of researchers to optimise data-sharing, collaboration and capacity building, participants also recommended that a habitat modelling exercise using Oman-based data be attempted across the

ASHW's putative range. This approach would include mapping of all known sightings,strandings and identified anthropogenic threats to humpback whales in the Arabian sea. The network will also collaborate on the longer term goal of collecting empirical data from newly initiated and targeted conservation research programmes.

Conclusion

Results of the 2015 tagging survey continue to demonstrate the importance of the Gulf of Masirah as critical habitat for this population, an area where a mosaic of industrial developments has the potential to exert population level impacts on Omani humpback whales. Given their considerable vulnerability, the continuation of this work must be considered a very high priority in order to improve the mitigation of threats to whales. The urgency to conduct research across wider range of the ASHW has been recognized within the regional research community, especially in light of recently catalogued stranding events. Emerging research programmes in new areas throughout the range will require significant financial and technical support to ensure the collection of robust and pertinent data and support evidence-based management interventions.

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